Chapter 1: 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 program has been administered by the Virginia Department of Social Services (VDSS)[1] with funds provided by the federal Weatherization Assistance Program in the U.S. Department of Energy (DOE) and supplemented in recent years by state "oil overcharge" funds. Under contract to VDSS, the program is operated by the Virginia Association of Community Action Agencies, Inc. (VACAA), which issues subcontracts to local community action and other agencies (so-called "subgrantees") to implement the program at the local level. VACAA oversees local implementation by establishing installation standards for the energy conservation measures and procedures to be applied, inspecting and monitoring houses completed, and reimbursing local agencies for job completions based on the cost of materials put into the houses.

For many years, VACAA based its installation standards on "Project Retro-Tech", a priority system developed by DOE. Recent advances in weatherization in other states convinced VACAA staff that some of the measures in Virginia's standards may not be as effective as other new measures. In 1988, VACAA began making changes to their standards to reflects some of these advances. However, the agency soon realized that a full evaluation of the program would be necessary to see how these new measures fit Virginia's climate, housing stock, and local weatherization capabilities, and how much they could improve the effectiveness of the program.

In June 1989, the Virginia Association of Community Action Agencies, Inc. (VACAA) contracted the Virginia Center for Coal and Energy Research (VCCER) to conduct an evaluation of the Virginia Weatherization Program. The study ran through December 1990. The main objective of the evaluation was to improve the energy savings and cost-effectiveness of the program by developing a new protocol of energy conservation measures and recommending improvements in administrative procedures.

This final report of the study describes the project and its principal findings and recommendations. The project was conducted by VCCER's John Randolph and Kathy Greely with assistance from Bill Hill (Center for Energy Research, Education Service at Ball State University) and Larry Kinney (Synertech Systems Corp.). Special training of Virginia weatherization crews for purposes of the study was conducted by R.W. Davis and Rudy Leatherman (Corporation for Ohio Appalachian Development), Rana Belshe and Tom Wilson (Residential Energy Conservation Consulting Group (RECCG), and Jim Fitzgerald. In addition to the final report, a *Training and Technical Assistance Manual for Virginia Weatherization* produced by COAD, RECCG, and Larry Kinney, was a product of the evaluation project.

The project included five main components which are discussed in the chapters that follow.

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[1] As of July 1991, administration of the program was transfered to the Department of Housing and Community Development. In discussing our recommendations for the program, however, we will continue to refer to the managing agency as "VACAA," for the sake of simplicity.

- Chapter 2 describes a study to provide information on the energy savings and cost-effectiveness of conservation measures implemented under Virginia weatherization prior to the evaluation. The study used the Princeton Scorekeeping Method (PRISM), a computer model which derives energy savings from utility billing data. In addition to providing important data on the relative effectiveness of measures being implemented under the prior program, this analysis provided a baseline with which to compare savings from new measures tested in the pilot study.

- Chapter 3 examines the savings and cost-effectiveness of various energy conservation measures, based on engineering-economic analysis using Virginia climate and fuel cost data. The technical discussion of individual measures also draws heavily from the literature and evaluations in other states. The analysis served as a first screening of measures to be tested in the pilot study, as well as supporting evidence for our recommendations.

- Chapter 4 presents the heart of the evaluation -- the pilot study. The study was designed to test the energy savings and implementation of selected new weatherization measures in four local Virginia agencies. It observed in the field how effectively some of the new measures used in other states actually perform in Virginia's housing stock and climate, as well as how capable Virginia weatherization crews are to learn and implement the installation of these measures.

- Chapter 5 provides a synthesis of the results of the PRISM study, the engineering analysis, and the pilot study, and based on this synthesis develops a recommended protocol of new energy conservation measures for Virginia weatherization.

- Chapter 6 identifies and discusses administrative issues which may affect the ability of Virginia's weatherization Program to implement effectively the recommended protocol of measures presented in Chapter 5.

- Finally, Chapter 7 provides a summary of findings and recommendations of this evaluation project.

Chapter 2: Effectiveness of the Virginia Weatherization Measures, 1988-89 Contract Year

Introduction

The purpose of this part of the evaluation is to provide information on the savings and cost-effectiveness of conservation measures implemented under the Virginia weatherization program prior to this project. In addition to determining program savings (by building and heating fuel type), this evaluation examines the savings and cost-effectiveness of commonly installed weatherization measures, where possible. This study also looks at the types of homes being served by Virginia weatherization, their energy intensity, the types of measures being implemented across the state, and typical costs associated with weatherization. In addition to providing important data on the relative effectiveness of measures being implemented under the prior program, this analysis provides a baseline with which to compare savings from new measures which were tested in the pilot study (see Chapter 4).

This evaluation was conducted using the Princeton Scorekeeping Method (PRISM), a computer model which derives energy savings from utility billing data (Fels, 1986). Using one year each of pre- and post-retrofit utility bills, PRISM computes energy usage for the periods before and after weatherization, adjusted for changes in weather between the two time frames. PRISM has the advantage of being a widely accepted weather-correction technique that can be applied to utility bills, which are readily available for houses heated with gas or electricity. Therefore, it can provide accurate energy savings results on a large number of houses, without the need for expensive submetering.

This study focuses on energy savings in Virginia gas- and electrically heated homes weatherized between July 1988 and June 1989. Site-built single-family homes, mobile homes, and multifamily dwellings are all included within its scope. The discussion below focuses on the characteristics of the buildings and households in our sample, the types of measures installed and their costs, and the energy savings and cost-effectiveness of the weatherization performed in these homes. Although we tried to calculate savings for all of the gas- and electrically heated homes weatherized during that period (close to 1500 dwellings), reliable energy savings estimates were obtained for only about 200 homes, due to difficulties in obtaining billing data. Appendix A contains more detailed explanations of our methodology (including results for our control group), causes of sample attrition, quality of the energy savings data, and representativeness of the sample.

Building and Household Characteristics

Our final sample of homes with reliable energy savings data consisted of 188 houses. More than half were heated with natural gas (105 houses), while the remainder used electricity for space heating (83 homes). Table 2-1 displays the characteristics of these households, in terms of building type, climate zone, and occupancy. Site-built single-family homes accounted for 60% of the structures we examined. The remaining dwellings were evenly split between mobile homes and multifamily apartment units. All climate zones in the state were well-represented, with the Washington (D.C.), Bristol, and Richmond regions accounting for more than 70% of our sample houses (climate zones are illustrated in Figure A-1, Appendix A). Over 60% of the homes were owner-occupied. The typical home in our sample had two occupants; 44% had at least one elderly occupant, and over one-third housed one or more children.

TABLE 2-1: BUILDING AND HOUSEHOLD CHARACTERISTICS

	Gas Heat (# of dwellings)	Electric Heat (# of dwellings)
Total:	**105**	**83**
Building Type:		
-Site-Built Single Family	91	21
-Mobile Home	0	36
-Multifamily	14	26
Climate Zone[1]:		
-Norfolk VA (3398 HDD)	18	3
-Richmond VA (3914 HDD)	36	2
-Lynchburg VA (4295 HDD)	2	11
-Washington DC (4981 HDD)	19	26
-Roanoke VA (4344 HDD)	23	3
-Bristol TN (4316 HDD)	7	38
Occupancy:		
-Owner-Occupied	70	50
-Renter-Occupied	35	33
-Units with Elderly	60	23
-Units with Children	28	41
-# of Occupants (median)	2	2

[1]Virginia climate zones as defined by the National Oceanic and Atmospheric Administration, based on similarity of weather patterns. Here, these zones are represented by their major climate data collection center and long-term average heating degree-days (base 65° F).

Representation of Weatherization Agencies

During the time these houses were weatherized (mid-1988 to mid-1989), there were 30 local weatherization agencies operating in Virginia. Twenty-one of these organizations are represented in our final sample; however, 70% of the houses were weatherized by just five agencies. This "clustering" of houses by weatherization agency reflects the service areas of utilities which could provide sufficient historical data. State agency staff informed us that these particular agencies represent average to better-than-average weatherization in Virginia. Therefore, the results for these agencies could be slightly better than the state average.

Pre-Retrofit Energy Consumption

We also examined the pre-retrofit energy usage of these households. It is generally thought that homes in milder climates like Virginia's are less energy-intensive than the average U.S. home. We found this not to be the case for our sample. As can be seen in Figure 2-1, the Virginia sample of gas- and electrically heated site-built single-family, multifamily, and mobile homes consumed almost as much energy per dwelling, and even more in some cases, than the U.S. average, despite the fact that the Virginia homes are much smaller than those

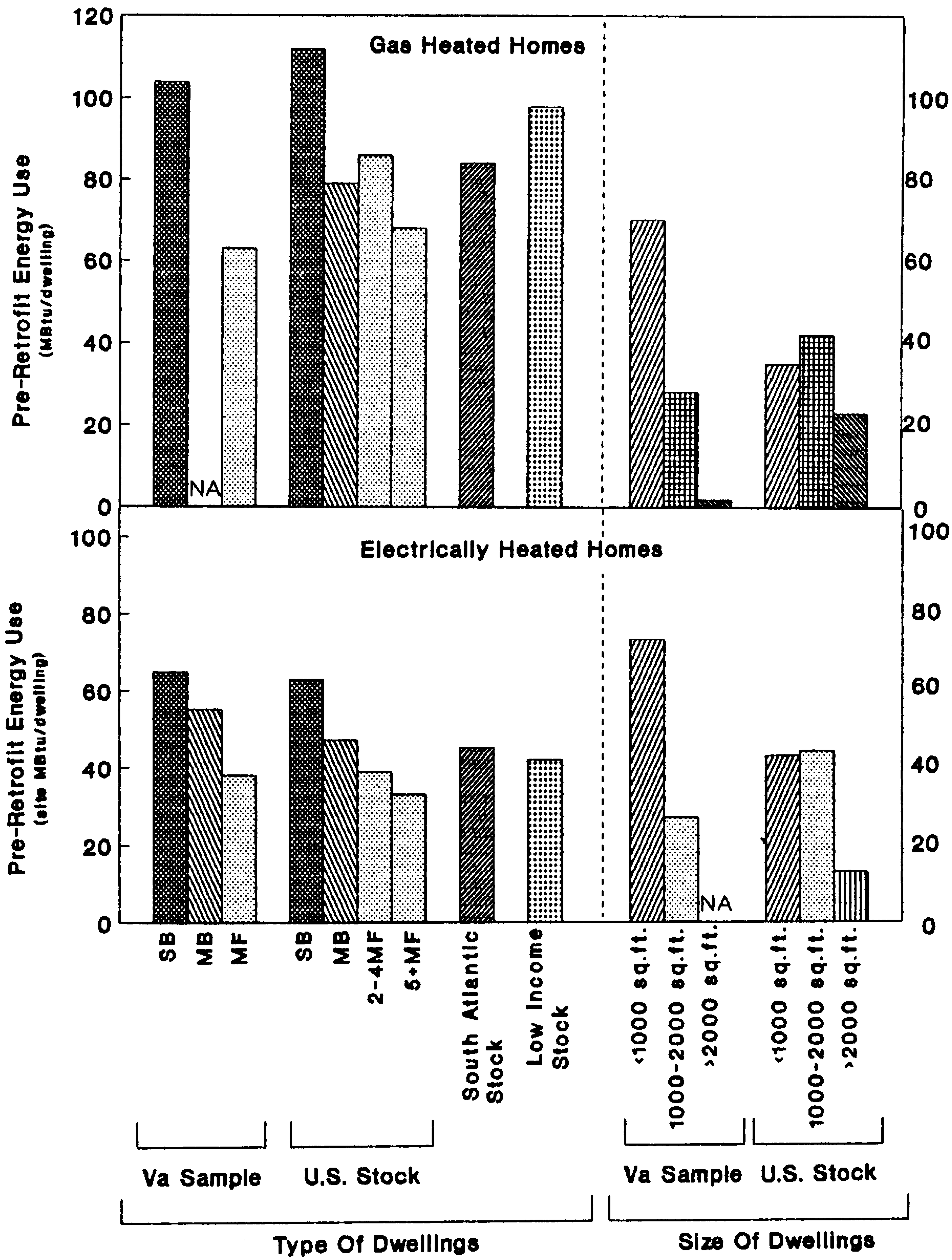

Figure 2-1. Energy usage and size of the final Virginia sample vs. the U.S. stock.
Gas consumption represents all gas end-uses (typically space heat, hot water, and cooking), while electricity use typically includes space heat, hot water, cooking, lights, and appliances. Although the houses in the Virginia sample are much smaller than the U.S. residential stock, energy use by the Virginia homes is as high or higher than that of the U.S. multifamily apartment units. Source: EIA, 1987.

in the U.S. stock.[1] For example, three-quarters of the Virginia sample are smaller than 1000 ft^2, while only one-third of the gas-heated U.S. stock, and 45% of the electrically heated stock, fall into this category. Furthermore, there is anecdotal evidence from the state agency and local crews to suggest that Virginia weatherization homes heated with gas or electricity tend to be in better structural repair, and therefore probably less energy intensive, than weatherized homes heated with oil, wood, and coal. This would imply that energy use in the typical Virginia weatherized home might be even higher than the results from our sample suggest.

Retrofit Measures and Costs

Figure 2-2 illustrates the kinds of conservation measures that were installed in the Virginia homes. Notice that the total number of retrofits is greater than the number of houses, since more than one measure is usually installed in each home. Infiltration reduction (consisting primarily of caulking and weatherstripping) was by far the most popular measure, installed in all of the site-built single-family and multifamily buildings and in more than 90% of the mobile homes. One-quarter of the site-built single-family homes had less than 20 tubes of caulk applied, which we refer to below as "low infiltration" work, while the remainder received from 20 to over 100 tubes, referred to below as "high infiltration" work. (However, even 20 tubes of caulk may in fact be excessive under the advanced air sealing techniques implemented in the pilot study (see Chapter 4).) The majority of multifamily and mobile homes received "low infiltration." Storm windows were the next most popular conservation measure, installed in about half of the site-built single-family and mobile homes. Window and door replacements were also frequently used: primary windows were installed in one-quarter of the site-built single-family homes, 30% of the multifamily units, and 60% of the mobile homes, while one or more doors were replaced in one-third of the site-built single-family houses and two-thirds of the mobile homes. Attic insulation was installed in half of the single-family homes, and attic venting was done not only in these homes but also in many which received no additional attic insulation. Water heater blanket installation varied greatly by building type: water heaters were insulated in one-quarter of the single-family houses, one-third of the mobile homes, and two-thirds of the apartments. Floor insulation (in single-family and mobile homes) and skirting (in mobile homes) were installed in only a few of the dwellings.

The cost of materials was reported for each weatherized house in our sample. Since Virginia reimburses local agencies based on a fixed percentage of materials costs, we calculated total costs (including materials, labor, program support, and administration) as the materials cost multiplied by the median reimbursement rate of the local agencies included in this study (229%), in 1988/89 dollars.[2] Table 2-2 summarizes the total costs for homes in our sample, by building and heating fuel type. The median cost for gas-heated homes was $1573, very close to the federally mandated limit of an average expenditure of $1600 per house. Costs for our small sample of gas-heated apartments were a bit higher ($1819), because primary windows were replaced in most of the dwellings in this group. Costs in electrically heated homes were significantly lower, primarily due to the large number of

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[1] Square footage of weatherized houses is not ordinarily recorded by Virginia weatherization agencies. The state agency derived areas for most of the homes in the final sample either from attic square footage plus Retrotech type (which reveals the number of stories in a home) or from the volume of the house. Therefore, this square footage data is not completely reliable, and we will not rely on it extensively in discussing our results. It does, however, give a general idea of the size of homes in the weatherized sample.

[2] Many program evaluations include only materials and labor costs in cost-effectiveness calculations; however, Virginia did not break out these cost components.

apartments in which only caulking, weatherstripping, and water heater blankets were installed, at the extremely low cost of $75. Even for site-built single-family homes, however, weatherization costs were much lower in electrically heated dwellings; this difference in cost can be attributed to lower levels of infiltration work, attic insulation, and door replacements in the electrically heated houses. Interestingly, weatherization in mobile homes was only slightly less expensive than that in gas-heated site-built houses, and much more costly than that in electrically heated site-built homes, despite the smaller size and lower pre-retrofit energy consumption of mobile homes. This was most likely a result of the high number of window and door replacements in mobile homes.

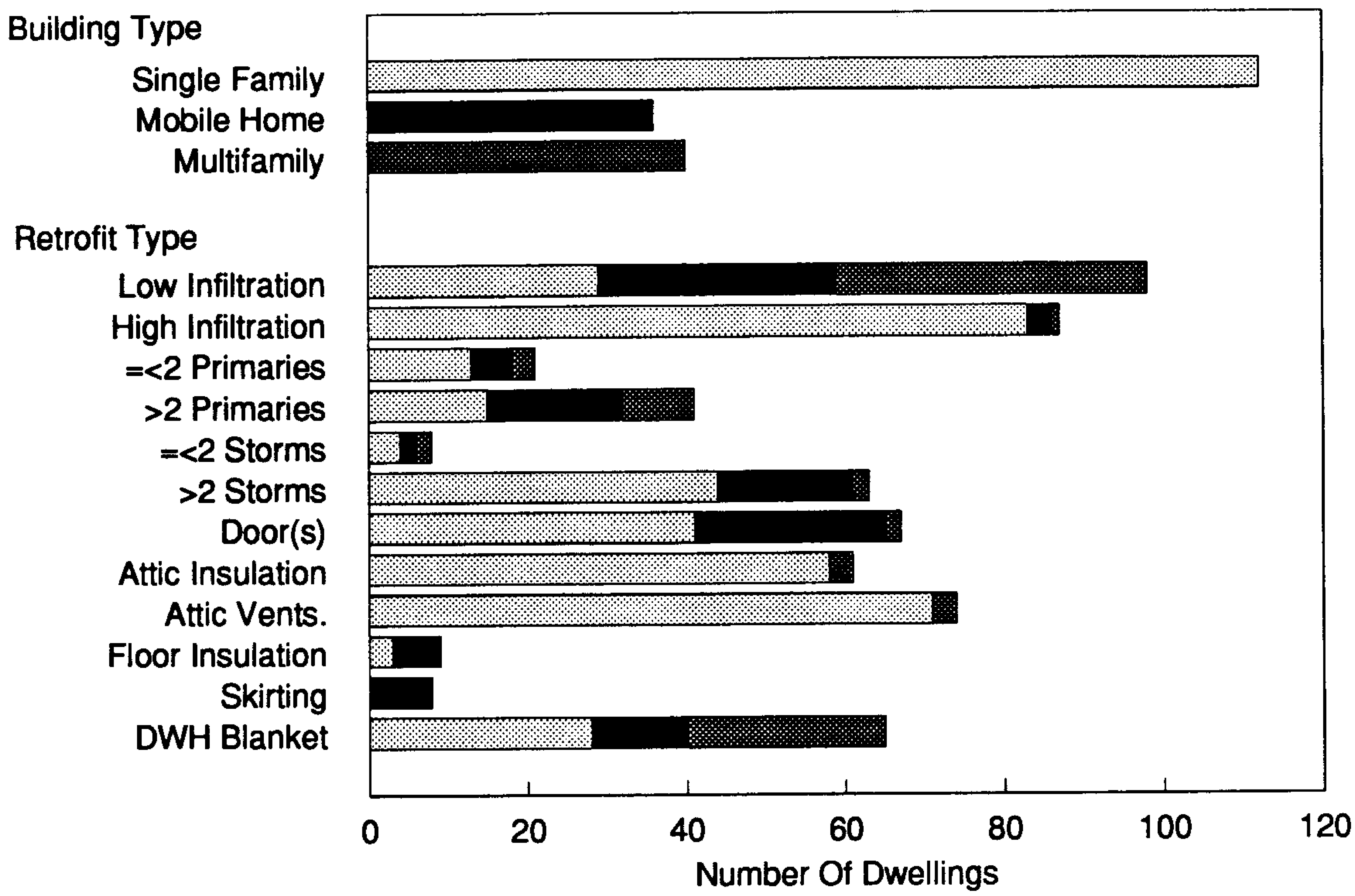

Figure 2-2. Conservation measures installed in weatherized households, by building type.
The number of measures is greater than the number of houses because more than one measure is often installed in each building. "Low Infiltration" refers to homes sealed with less than 20 tubes of caulk, while "High Infiltration" means that over 20 tubes of caulk were used.

Energy Savings and Cost-Effectiveness

Overall Results

Savings from the existing program were rather low: median annual site energy savings were 6.5 MBtu/dwelling for gas-heated homes, or 6% of gas consumption (used for either space heating only, space heat and hot water, or space heat, hot water, and cooking). Savings in electrically heated dwellings amounted to 1.5 site MBtu /dwelling (440 kWh), or 4% of electricity usage (typically space heating, hot water, cooking, lights, and appliances).[3] Table 2-2 and Figure 2-3 summarize savings and cost-effectiveness indicators, by heating fuel and building type. Both absolute and percent savings in site-built single-family homes were slightly higher than for gas- and electrically heated homes in general; savings in apartment units, on the other hand, were very low for those heated with gas (0.5%), and slightly lower than average for those heated with electricity (3%).[4] Median savings in mobile homes were also slightly lower than in site-built single-family homes: 1.7 MBtu (500 kWh), or 3%.[5]

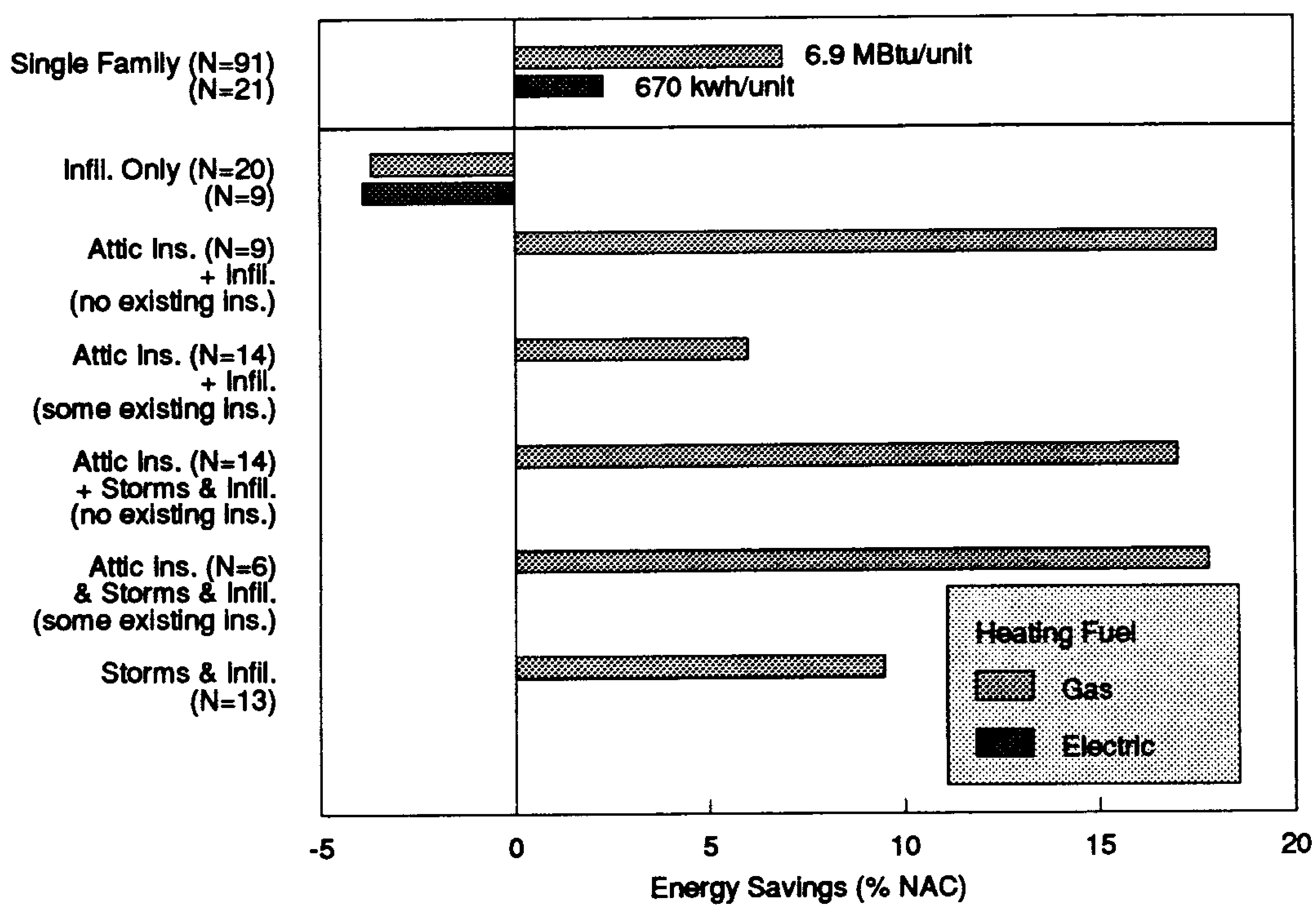

Figure 2-3. Savings by primary retrofit strategy for single-family homes weatherized under the existing program.
Because percent energy savings in gas- and electrically heated homes are for different end uses (space heat, hot water, and/or cooking in gas-heated houses, vs. all end uses in electrically heated homes), we have shown them separately in this figure.

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3 "Site" energy is end use energy; i.e., for electricity 1 kwh = 3412 Btu.

4 Energy savings in multifamily units may be unreliable, due to heat transfer between apartments. In this sample, not all the apartments in a particular building were weatherized; it is possible that unweatherized units received some of the energy-saving benefits of the weatherization work.

5 In the absence of a control group composed of households eligible for weatherization but not yet serviced, we looked at weather-corrected residential consumption trends for some Virginia utilities. Based on this information, we decided to make no adjustments to gross savings attributable to the weatherization program. See Appendix A for more information.

Table 2-2 also shows 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.

The bottom line is that all of these savings are low. In fact, the savings for some of the above categories are not statistically significant; that is, the savings are not statistically differentiable from zero at the 90% confidence level. Only the savings for those categories of homes indicated with an asterisk in Table 2-2 are statistically significant.

In addition to energy savings, we looked at three indicators of the cost-effectiveness of weatherization: the payback time, the cost of conserved energy, and the benefit-cost ratio. When judged solely on energy savings, weatherization in this sample of buildings was not

TABLE 2-2: SUMMARY OF SAVINGS AND COST-EFFECTIVENESS INDICATORS[1]

	All		Site-Built Single Family		Mobile Home	Multifamily	
	Gas	Elec.	Gas	Elec.	Elec.	Gas	Elec.
# of Dwellings	105	83	91	21	36	14	26
Pre-retrofit Energy Use[2] --$\left(\frac{site-MBtu}{dwelling}\right)$	99±8	52±3	104±8	65±8	55±4	63±9	38±5
Energy Savings[2] --$\left(\frac{site-MBtu}{dwelling}\right)$	6.5*±2.0	1.5*±0.8	6.9*±2.2	2.3±2.0	1.7*±1.0	0.3±3.7	1.2±1.5
--(% NAC)	6.0±1.9	3.6±1.5	8.3±2.1	4.1±3.2	3.0±1.9	0.5±7.4	3.1±3.8
--(% Space Heat)	9.4±2.7	5.1±3.0	10.3±3.1	5.1±4.8	9.5±4.8	0.6±9.8	−1.0±8.0
Total Cost --$\left(\frac{\$}{dwelling}\right)$	1573±84	742±152	1489±86	857±252	1289±147	1819±324	75±3
Payback Time[3,4] (years)	34	39	30	21	53	—[5]	5
CCE[3,4] --$\left(\frac{\$}{site-MBtu}\right)$	\$22	\$62	\$17	\$32	\$100	\$870	\$12
Benefit-Cost Ratio[4]	0.26±0.07	0.27±0.19	0.33±0.08	0.50±0.38	0.17±0.17	0.01±0.09	1.50±1.70

[1]Values given are median ± standard error (standard error = interquartile range ÷ $\sqrt{n}$)
[2]Energy use and savings figures are normalized annual consumption (NAC). For gas-heated houses, NAC is space heat, hot water, and/or cooking; for electrically heated houses, NAC is total household consumption Space heat consumption is as derived by PRISM.
[3]Standard errors could not be calculated for these indicators, as several houses had negative savings, and therefore infinite payback times and cost of conserved energy.
[4]See Appendix A for definitions of economic indicators.
[5]The median payback for this group of houses is infinite.
*Savings are statistically significant at the 90% level for these categories.

cost-effective. For both gas- and electrically heated homes, median payback times were extremely long (34 and 39 years, respectively), costs of conserved energy were higher than average Virginia residential energy prices at that time (\$22/MBtu saved for weatherization in gas-heated houses, vs. \$5.65/MBtu for gas in 1988; \$62/MBtu saved for weatherization in electrically heated homes, vs. \$16.70/site MBtu for electricity), and benefit-cost ratios were less than one (0.26 and 0.27 for gas- and electrically heated homes, respectively). When examined by building type, only weatherization in electrically heated apartments appears to be cost-effective. However, the energy savings in these dwellings were very small and not statistically significant; the apparent cost-effectiveness stems from the fact that very little money was spent (only $75/apartment, spent on caulk, weatherstripping, and water heater blankets).

Houses with High Savings

It is always instructive to examine houses with particularly high or low savings. Savings of 10% or more were achieved in 35% of the weatherized sample (42% of gas-heated homes and 25% of those with electric heat).[6] High savings occurred more often in gas-heated site-built single-family homes than in any other building type. We found that houses with attic insulation (either alone or in combination with other weatherization measures) are disproportionately represented among the "high savers". In fact, more than half of the "high savers" were weatherized with attic insulation (alone or in combination with other measures), while only 1/5 of the homes with savings below 10% received attic insulation. Homes with infiltration reduction **alone** accounted for only 15% of the high savers, but for half of the homes with low savings.

Houses with Increased Energy Usage

Energy use in 31% of our sample *increased* following weatherization. Since we do not have any information on changes in the building or household after weatherization, it is impossible to attribute the increased energy usage to changes in the number of occupants, building or appliance additions, or failure of the retrofit. Relatively more of the multifamily and electrically heated site-built single-family dwellings, and proportionately fewer of the gas-heated site-built single-family and mobile homes, displayed increased consumption. Homes weatherized with infiltration reduction work only, or primary window replacements plus infiltration work, are more heavily represented among the buildings with increased usage than in the sample at large.

The Relationship between Savings and Pre-Retrofit Consumption

Evaluations of many residential retrofit programs have observed a strong correlation between energy savings and pre-retrofit consumption (Synertech, 1987; Schlegel and Pigg, 1990; Hill, 1990; Shen, et al., 1990). That is, energy savings are typically larger in homes with high pre-retrofit usage. Some weatherization programs, interested in maximizing the total energy savings they achieve, even screen clients to focus their efforts on high-consumption households. To see if this relationship holds true for our sample of homes, we looked at energy savings vs. pre-retrofit usage for gas- and electrically heated homes (Figure 2-4). We found little correlation between savings and pre-retrofit usage (for site-built gas-heated homes, $R^2=0.02$; for site-built electrically heated homes, $R^2=0.26$; for mobile homes, $R^2=0.00$); energy savings varied widely at all levels of pre-retrofit consumption. This correlation between savings and pre-retrofit use was better for homes weatherized in the pilot study (see Chapter 4).

[6] Of course, 10% savings are not extraordinarily high. In our pilot study, for example, *average* savings were over 20% of space heat usage (see Chapter 4).

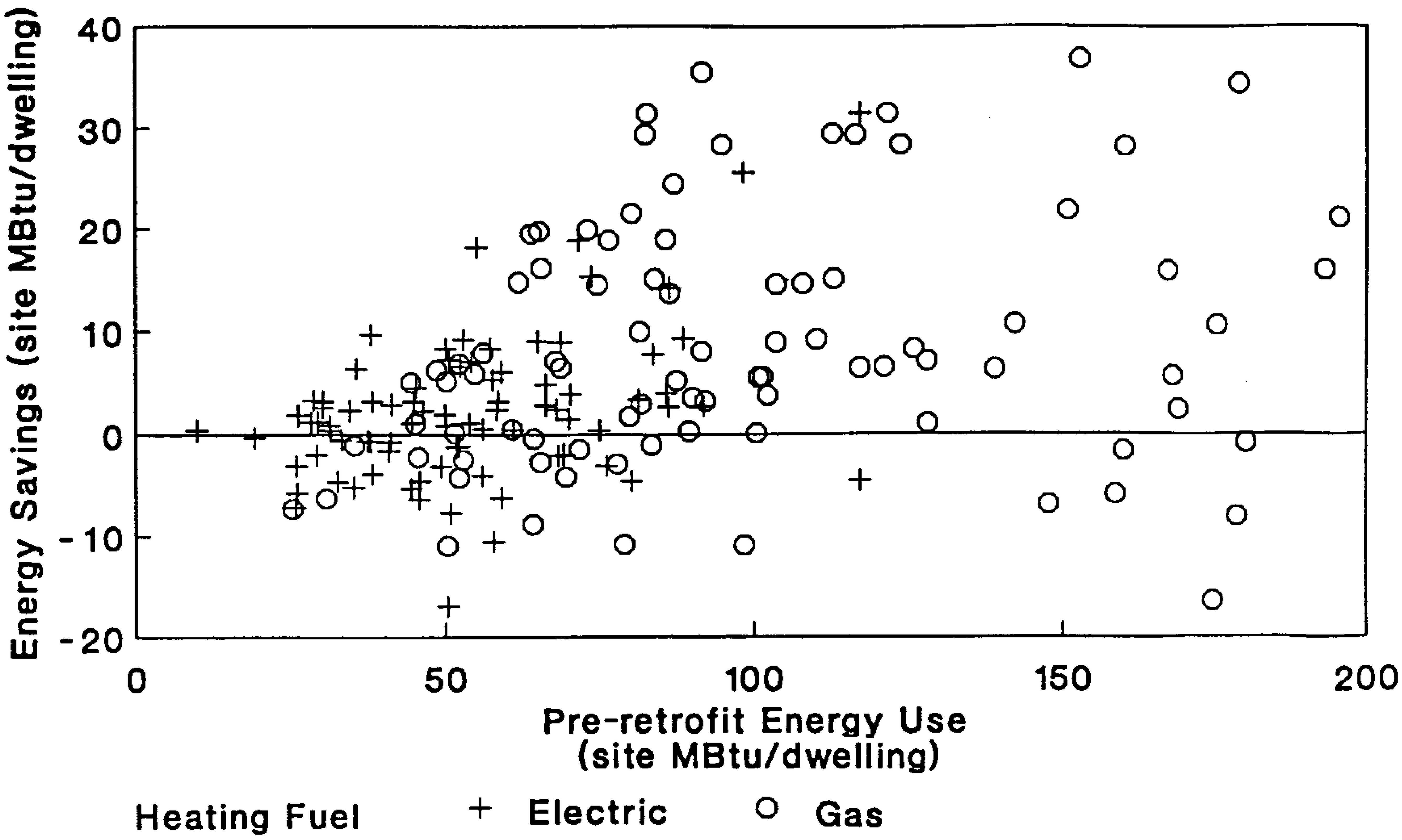

Figure 2-4. Energy savings vs. pre-retrofit energy usage, for gas- and electrically heated homes.
Surprisingly, there was little correlation between savings and consumption prior to weatherization. Eighteen houses lie outside the boundaries of this plot.

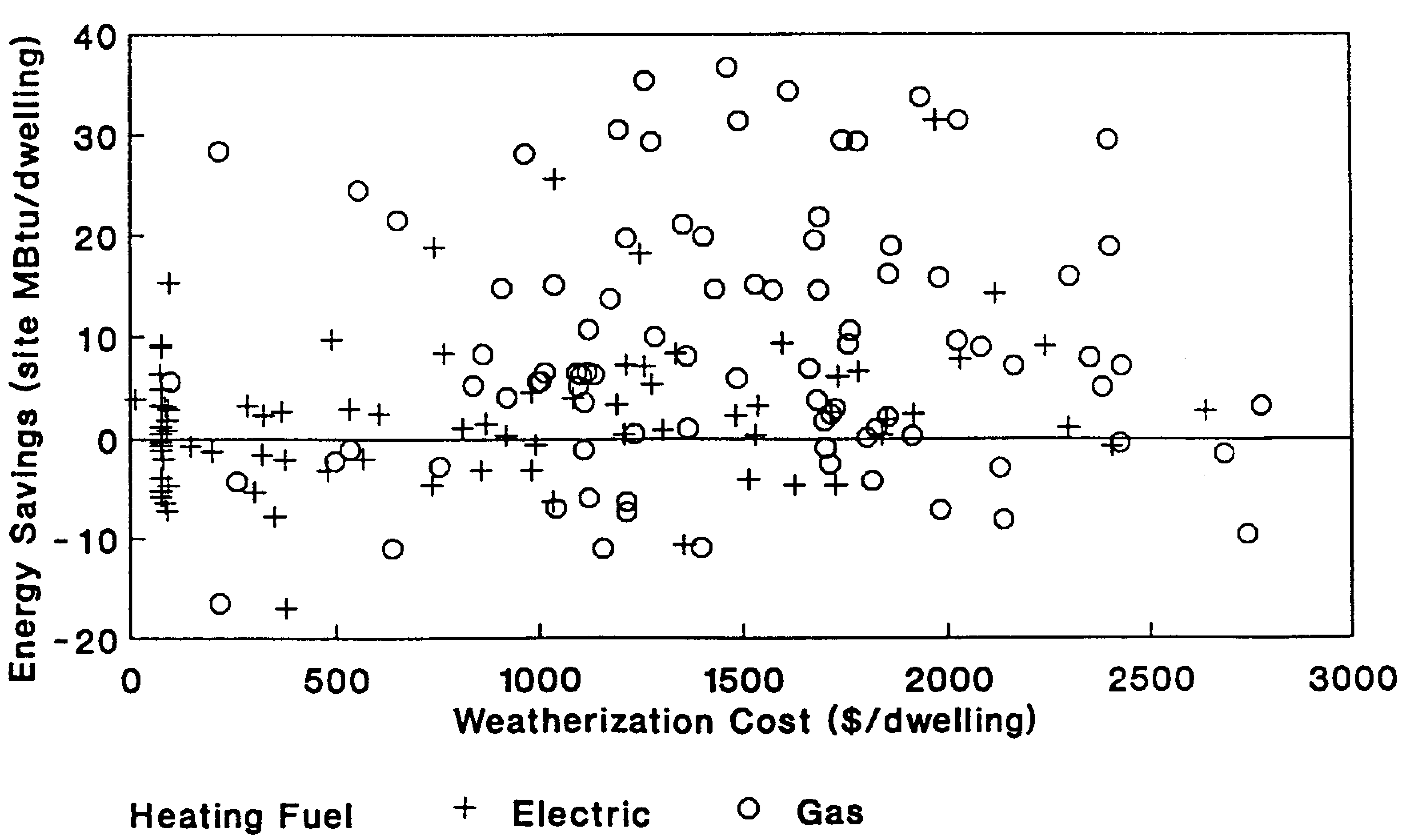

Figure 2-5. Energy savings vs. total weatherization cost, for gas- and electrically heated homes.
Savings show little correlation with the amount spent on weatherization. Fourteen houses lie outside the boundaries of this plot.

The Relationship between Savings and Weatherization Cost

There is a belief that spending more money on weatherization will result in larger savings. We investigated this relationship in Figure 2-5. We found no correlation between energy savings and total weatherization cost, for both gas- and electrically heated homes ($R^2 = 0.00$ and 0.04, respectively). We attribute this lack of relationship between energy savings and weatherization costs to large investments in ineffective weatherization strategies (see "Savings by Retrofit Strategy," below).

Savings by Retrofit Strategy

In addition to looking at program-wide energy savings, we were also interested in determining savings attributable to specific conservation measures installed by the weatherization program. Since more than one conservation measure was installed in almost every building, it is impossible to attribute energy savings to specific retrofits; however, we were able to categorize the houses by the combination of weatherization techniques which were implemented. Table 2-3 summarizes energy savings, costs, and cost-effectiveness for seven commonly installed "packages" of measures, for building types and heating fuels which are well-represented in our final sample of houses.[7] Figure 2-3 graphically displays energy savings for site-built single-family houses. 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 1 or 2 windows, and/or door replacement. Houses were assigned to a "window" category if more than 2 primary or storm windows were installed. (In defining these categories, we ignored the effects of hot water wraps and attic venting, as these measures were so pervasive there was no clear way to separate out their effects.)

None of these groups of retrofits appears to be a clear-cut success, as judged by the cost-effectiveness indicators:

- Median energy use in site-built single-family homes which received only infiltration work **increased** slightly after weatherization; that is, energy savings were negative.
- 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. (The difference in savings between homes with no existing insulation and those with some insulation (typically R-11) was more pronounced for the "attic insulation and infiltration" category than for the "attic insulation and storms and infiltration" group.) We attribute the surprising lack of cost-effectiveness of packages containing attic insulation to the large amount of money spent on infiltration work in these homes. Attic insulation accounted for only 1/3 of the materials cost for homes in the "attic insulation and infiltration" category, while infiltration measures were responsible for more than 40% of the costs. Insulation and storm windows accounted for about half of the materials costs in the "insulation/storms/infiltration" category; another 25% of weatherization costs in these houses was attributable to infiltration reduction.

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7 Because we question the reliability of the data on multifamily units (the energy savings may be inaccurate due to heat transfer between apartments; almost all of the units were weatherized by one agency), we have eliminated them from this discussion.

TABLE 2-3: SAVINGS AND COST-EFFECTIVENESS BY RETROFIT PACKAGE[1]

Retrofit Strategy	Heating Fuel[2]	Building Type[3]	# of Dwellings	Energy Savings[4] ($\frac{site - MBtu}{dwelling}$)	Energy Savings[4] (%)	Total Cost ($/dwelling)	PaybackTime [5,6] (years)	CCE[5,6] ($/site MBtu)	Benefit-Cost Ratio[6]
Infiltration Only	G	SB	20	−2.5 ±3.4	−3.7 ±2.9	1120 ±273	--	--	−0.14 ±0.16
Infiltration Only	E	SB	9	−2.1 ±1.9	−3.9 ±3.3	350 ±128	--	--	−0.65 ±0.51
Attic Insulation & Infil									
-All	G	SB	23	10.6* ±3.4	8.8 ±3.2	1353 ±120	20 ±9	9.90 ±4.30	0.57 ±0.16
-No Existing Insul.	G	SB	9	16.1* ±4.1	18.0 ±5.9	1353 ±120	12 ±5	6.10 ±2.50	0.98 ±0.25
-Some Exist. Insul.	G	SB	14	6.7* ±3.6	6.0 ±3.6	1310 ±190	30	14.30	0.39 ±0.17
Att.Insul.&Storms&Infil									
-All	G	SB	20	17.4* ±5.5	17.0 ±3.5	1704 ±120	17 ±5	10.80 ±3.20	0.53 ±0.14
-No Existing Insul.	G	SB	14	22.6* ±8.3	17.0 ±5.0	1720 ±140	16 ±7	9.90 ±4.20	0.62 ±0.19
-Some Exist. Insul.	G	SB	6	16.8 ±11.5	17.8 ±8.2	1571 ±280	17	10.80	0.53 ±0.37
Primes&Storms&Infil.	E	MB	12	1.8* ±1.0	3.3 ±2.7	1756 ±180	76	117.20	0.15 ±0.11
Storms & Infil.	G	SB	13	6.9 ±6.0	9.5 ±4.4	1663 ±256	27 ±20	17.10	0.33 ±0.17
Skirting & Infil.	E	MB	7	0.4 ±1.9	0.7 ±4.5	1207 ±141	176	416.20	0.04 ±0.23

[1]Figures given are median ± standard error (standard error = interquartile range ÷ $\sqrt{n}$).
[2]G = gas, E = electric space heating
[3]SB = site-built single family, MB = mobile home.
[4]Energy savings figures are savings in normalized annual consumption (NAC). For gas-heated houses, NAC is space heat and hot water and/or cooking; for electrically heated houses, NAC is total household consumption.
[5]Standard errors could not be calculated for these indicators in cases where several houses had negative savings, and therefore infinite payback times and costs of conserved energy. A '--' indicates that the median payback or cost of conserved energy for a group of houses is infinite.
[6]See Appendix A for definitions of economic indicators.
*Savings are statistically significant at the 90% level for these categories.

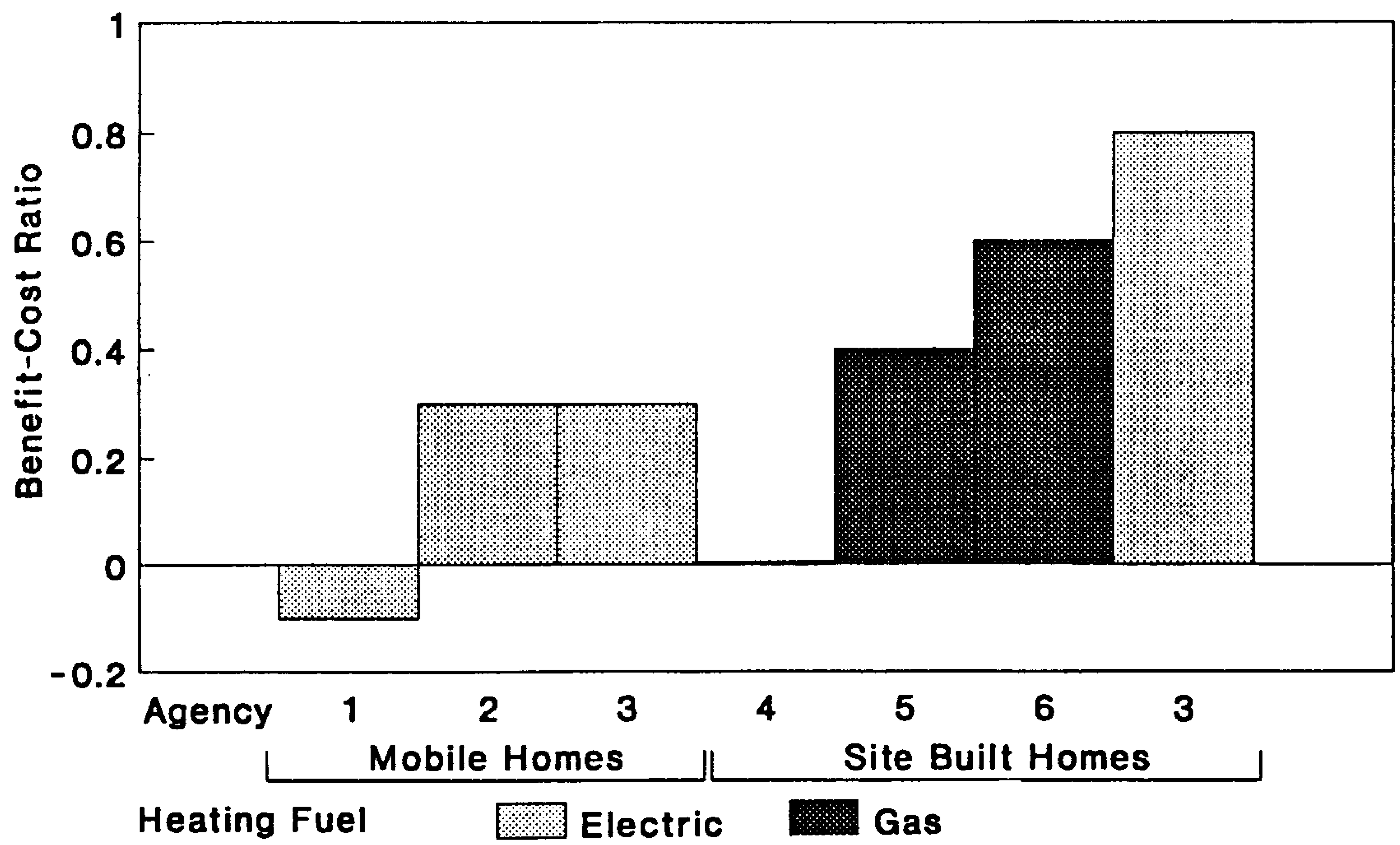

Figure 2-6. Median benefit-cost ratios for 6 local weatherization agencies whose houses were well-represented in the final sample.
There is a wide range in cost-effectiveness of weatherization work by different agencies, even for similar building types. "SB" are site-built single-family homes, and "MB" are mobile homes.

- Primary windows were replaced, plus storm windows were installed on the same windows in 12 mobile homes, again resulting in high weatherization costs ($1800) and low savings (3%).
- Homes in the "storms and infiltration" group typically saved 10%, but the costs were so high that this weatherization was not cost-effective. Costs for the storm windows alone accounted for 60% of the total costs in this category. There was no correlation between the number of storms installed and energy savings.
- Infiltration work and skirting installed in mobile homes typically cost $1200/dwelling and saved no energy.

We attribute the lack of cost-effectiveness of many 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 "storms 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. As the results in Table 2-3 for the "infiltration only" site-built single-family homes show, little energy savings were realized from this type of work. "Infiltration reduction" also included some home repair, using materials such as lumber, roof coating, etc. These measures would not be expected to yield much in the way of energy savings.

Cost-Effectiveness by Local Weatherization Agency

As pointed out in the section on "Building and Household Characteristics," there were 21 local weatherization agencies represented in our final sample. Figure 2-6 illustrates the cost-effectiveness of weatherization done by six of these agencies whose work is well-represented (i.e., at least six houses by each agency in a given building type/heating fuel category). Since we're primarily interested in the range of agency cost-effectiveness, rather than the performance of specific organizations, each agency has been identified by a number only. We've broken down the houses each agency weatherized by building and heating fuel type, since we expected these factors to explain some of the variation in savings by agency. However, there is still a wide range in agency cost-effectiveness within each building and heating fuel type category, as measured by the median benefit-cost ratio. This fact implies that some attention needs to be paid to improving the work of the less cost-effective agencies to ensure that weatherization clients throughout the state are receiving equivalent, and equitable, levels of service.

TABLE 2-4: PERCENT REDUCTION IN BLOWER DOOR READING

	Site-Built Single-Family	Mobile Home
% Reduction, All Measures[1]	39% (N=62)	54% (n=24)

[1]Values given are medians. Results for multifamily homes are not listed here, as we are skeptical about their validity (they were taken simply by pressurizing a single apartment and did not account for air exchange between apartments).

Air Leakage Reduction

Air leakage reduction was one of the major strategies by which weatherization agencies sought to reduce energy consumption in this sample of houses. Infiltration-reduction work and window and door replacements, which comprised the majority of weatherization measures in these homes, are all aimed at reducing air leakage sites.

Table 2-4 shows the percent reduction in air leakage for each building type. Note that blower door readings were only available for about half of the single-family homes, and two-thirds of the mobile homes (readings for the remaining homes were either not taken at all, or taken at different pressures before and after weatherization). Reductions in air change rates were fairly high, at 39% for single-family homes and 54% for mobile homes. However, as mentioned earlier, much of this infiltration reduction was accomplished by sealing leaks in the neutral-pressure plane, and would not be expected to contribute to significant energy savings.

Energy Intensity

Table 2-5 presents information on the pre- and post-retrofit energy consumption and energy intensity of homes in our final sample. By referring back to Figure 2-1, it can be seen that post-retrofit energy consumption is still fairly high compared to usage in relevant sectors of the U.S. stock. Energy intensity is a way of comparing the energy use of different size houses located in different climate zones. By dividing the annual space heating use by the floor area of the house (in square feet) and the annual heating degree-days (base 65° F), we can arrive at a "normalized" measure of space heating in Btu/ft²-DD. A new home built to current energy codes will have an energy intensity of about 10 Btu/ft²-DD, while very well-insulated houses will have energy intensities on the order of 5 Btu/ft²-DD or less. As discussed previously, the space heat fraction derived by PRISM and the square footage data for our final sample are not completely reliable, so we do not wish to place too much emphasis on this way of presenting energy savings. However, since we compute energy intensities for the new weatherization techniques tested in the pilot study (see Chapter 4), we felt it would be useful to present these results as a basis for comparison.

TABLE 2-5: ENERGY INTENSITY OF VIRGINIA SAMPLE[1]

	All		Site-Built Single Family[4]		Mobile Home[4]	Multifamily[4]	
	Gas	Elec.	Gas	Elec.	Elec.	Gas	Elec.
Pre-retrofit[2]							
-- NAC (site-MBtu)	99±8	52±3	104±8	65±8	55±4	63±9	38±5
-- Space Heat ($\frac{site-Btu}{ft^2-DD_{65}}$)	24±2	7±1	24±2	6±1	9±1	--	--
Post-retrofit[2]							
-- NAC (site MBtu)	89±7	51±3	93±9	59±7	53±4	56±11	39±5
-- Space Heat ($\frac{site-Btu}{ft^2-DD_{65}}$)	18±1	7±1	18±1	6±1	8±1	--	--
Savings[2,3]							
-- NAC (site MBtu)	6.5±2.0	1.5±0.8	6.9±2.2	2.3±2.0	1.7±1.0	0.3±3.7	1.2±1.5
-- Space Heat ($\frac{site-Btu}{ft^2-DD_{65}}$)	2.7±0.6	0.3±0.2	2.4±0.6	0.4±0.2	0.3±0.4	--	--

[1]Values given are median ± standard error (standard error = interquartile range ÷ $\sqrt{n}$).
[2]Energy use and savings figures in site MBtu are normalized annual consumption (NAC). For gas-heated houses, NAC is space heat, hot water and/or cooking; for electrically heated houses, NAC is total household consumption. Space heat energy intensities, in site Btu/ft²-DD, are space heating use as derived by PRISM. Space heat energy intensities were not calculated for multifamily units as no square footage information was available.
[3]Median savings do not equal the difference between median pre- and post-retrofit usage, due to the nature of the median as a measure of central tendency.
[4]Square footage data were reported for about half of the single-family and mobile homes; energy intensities were calculated for these homes only.

Representativeness of Virginia Sample

Throughout this chapter, we have looked at the savings and cost-effectiveness of weatherization performed in the 188 homes for which we were able to obtain reliable energy consumption data. How closely does this sample represent "typical" houses served by Virginia's weatherization program during fiscal year 1989? To answer this question, we compared our sample with all houses weatherized that year, in terms of building type, heating fuel, measures installed, and weatherization cost. The details of this analysis are contained in Appendix A. From the comparison, we concluded that overall program results are probably *slightly* better than the results we found for gas-heat houses (savings of 6%, payback time of 34 years), primarily because our analysis was unable to look at homes heated with oil or wood, in which we would expect to see somewhat higher savings.

Comparison with Other Low-Income Weatherization Evaluations

To properly understand the implications of these results for the Virginia weatherization program, we need to place them in the context of the savings and cost-effectiveness of other low-income weatherization programs operating around the country. Figure 4-6 compares these results with other evaluations of standard low-income weatherization programs documented in Lawrence Berkely Laboratory's BECA-B database (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.

Conclusions

This analysis looked at energy savings from 188 gas- and electrically heated homes to determine the effectiveness of measures installed by the Virginia weatherization program during the 1988-89 contract year. Savings and cost-effectiveness are summarized in Table 2-2 and Figure 2-3: savings in gas-heated houses were 6% of pre-retrofit usage (for space heat, and hot water, and/or cooking), while savings in electrically heated homes amounted to 4% of pre-retrofit consumption (for all end uses). By comparing these results with savings from other low-income weatherization program evaluations, we see that results for the Virginia program are among the poorest of all states that have conducted evaluations. Payback times for both gas and electrically heated houses were over 30 years. We found no correlation between energy savings and pre-retrofit consumption, implying that the Virginia weatherization program is not taking full advantage of the greater savings opportunities available in buildings with high energy usage.

When examining savings and cost-effectiveness for various retrofit "packages" (combinations of energy conservation measures typically installed in these homes), we found that houses which received infiltration-reduction work only had virtually no savings. Houses in which attic insulation and infiltration work were installed showed savings of 6 to 18%, but rather long payback times. We attribute the lack of cost-effectiveness of this 1988-89 sample to large expenditures on ineffective weatherization strategies, in particular infiltration reduction in the neutral-pressure plane and primary window replacements. There was also a large variation in cost-effectiveness of weatherization work performed by different local agencies, suggesting that attention needs to be paid to raising the technical competence of the less cost-effective agencies.

Overall, these results indicate that there is considerable room for improvement in Virginia's existing weatherization program. Of course, there are other benefits from weatherization that we were unable to quantify in a study of this type, such as improved occupant comfort and structural integrity. But overall, the Virginia weatherization program has been missing many opportunities for more cost-effective energy conservation and better service to their low-income clients.

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Chapter 3: Analysis of Weatherization Measures

Introduction

In this chapter we examine the savings and cost-effectiveness of various measures tested in other states. Because most of these measures have not yet been used in mild-climate states, we use engineering analysis to look at savings expected from these measures for houses in various parts of Virginia. Then, using Virginia energy price data, we calculate the cost-effectiveness of these measures. These analyses served as the first screening of measures to test in the pilot study. The pilot study (discussed below in Chapter 4) then tested these proposed measures on actual houses in the field. These analyses were also used directly as we developed recommended measures and installation standards (discussed below in Chapter 5).

The first section below discusses some of the principal lessons learned over the last decade from weatherization program evaluations, building science research, and weatherization crews in the field. The next section briefly outlines the methodological approach used in the engineering-economic analyses which were performed to assess the applicability and cost effectiveness of various weatherization measures in Virginia.

The following sections assess the strengths and weaknesses of each of the weatherization measures considered and present the results of the engineeering-economic analyses. For each we first describe how the measure saves energy, and briefly describe installation details essential to its success. This discussion is based on both published literature and communication with the "network" of researchers and practitioners in the weatherization and building science fields across the U.S. and Canada. We then describe the energy savings which we would expect to be realized across the Commonwealth and assess the cost effectiveness for various combinations of climate, heating system efficiencies, fuel costs, and installed costs. The final section reviews other measures not amenable to engineering calculations.

The Revolution in Low-Income Weatherization

In the last decade, and especially in recent years, great strides have been made in advancing the "state of the art" of weatherization. Interestingly, many of the advances have come, not from the research labs or academe, but from the "front lines", the crews in the field, and one of the principal "change agents" has been program evaluation. When state weatherization programs began careful evaluations of the energy savings being realized from weatherization, the shock was almost palpable. Rather than savings of 20% to 40% which they had expected to find based on engineering estimates, evaluators found savings on the order of 10%. Once they got over the shock, these state programs began to look in earnest to discover where those expected savings had gone. Using diagnostic tools such as blower doors and infrared cameras, these programs found what worked and what didn't and, in the process, learned a lot about how buildings work.

Below, we summarize some of the principal findings of the last decade. Rather than presenting this in the form of a detailed "academic" literature review, we instead present these findings in a form most conducive to the task at hand -- improving the Virginia Weatherization program. The reader is referred to Appendix C of the Progress Report for this project (Randolph and Greely 1990a) for an annotated review of the literature and other states' activities. At the end of this report, bibliographic references that contributed to this overview are presented. Specific references cited herein are listed at the end of this chapter.

Some of the Lessons Learned

Actual (measured) savings are less than engineering estimates. Why? First, buildings didn't behave in quite the same way as the theoretical models predicted they would. Second, often the models lost something in the translation to the field level. For example, percentage savings are not additive; 5% savings from this measure plus 10% from another usually do not add up to 15%.

Houses are systems. Residential energy use is a result of interactions between the building's thermal envelope, the heating system and the occupants. Moreover, there is a high degree of "interconnectedness" among the components of the building envelope (e.g., attic, walls, basement) which interact in ways we didn't fully understand before. In order to achieve energy savings, this interconnectedness of the house as a system has to be understood and dealt with.

Attention to detail in installing insulation is important. This is probably one of the more far-reaching findings of the last decade, affecting not only weatherization, but new construction as well. Insulation is traditionally thought of as a low-skilled, minimum wage job. The feeling was that all you needed to do was throw some insulation at it, and if you didn't get complete coverage or missed some spots, no big deal. Researchers have found that this is simply not true. First of all, a small amount of missed insulation can seriously degrade the overall R-value of insulation. Moreover, it's not just missed insulation that hurts you, but poorly installed insulation as well. Back in the early 70s, Princeton researchers in the ground-breaking Twin Rivers study (Socolow 1978) discovered how "convective loops" could work to "bypass" insulation, losing heat in amounts far out of proportion to their areal extent. In the years since, we have learned that these convective loops can in fact be set up in very small places, such as gaps and "gathers" in insulation caused by improper installation. Moreover, very large amounts of heat could be lost through small "misses" or "bypasses" in the insulation if these misses served to connect large inside surfaces with cold outside surfaces (e.g., a "miss" in sidewall insulation in the joist space between the first and second floors which connects to a porch). The infrared camera has been instrumental in advancing the state of our knowledge in this area.

Many of the "traditional" weatherization measures aren't cost effective. Evaluations of measured savings in weatherization programs across the U.S. (but primarily in the northern states) found that many of the measures which had made up the brunt of weatherization in its early years simply were not producing large enough energy savings to justify their cost. These measures, discussed in more detail below, include routine caulking and weatherstripping, replacement windows and storm windows.

Caulking and weatherstripping in the neutral pressure plane doesn't produce much in the way of savings. In the late 70s and early 80s it was "common knowledge" that a few hours spent with a caulk gun was one of the most cost-effective things you could do -- low cost and big savings. Or so we thought. We first learned it was better to caulk the interior of a house than the exterior. So we all brought our caulk guns in from the cold and started caulking everything that didn't move in clients' living rooms. As noted above in Chapter 2, Virginia Weatherization crews were still very much in this mode in the 1988-89 contract year, frequently emptying over 20, and sometimes more than 100, tubes of caulk per house. While the caulk on the interior stood a better chance of lasting than did the caulk on the exterior, we still weren't sealing the right leaks. It turns out that the leaks of importance are those in the attic and those in the basement/crawlspace. The reasons for this are discussed in more detail in the section on "Advanced Air Sealing" below.

The potential savings in heating system repairs may be larger than previously imagined. But, these savings are not to be found where we thought. There have been remarkable advancements made in this area in the last decade. Early heating system work was directed primarily at increasing the steady-state efficiencies of gas- and oil-fired furnaces by cleaning, tuning, de-rating nozzles and retrofitting burners. While these generally resulted in some savings, this was not where the big savings were to be found. Major potentials for energy savings showed up when researchers and crews alike started looking at duct losses. Not only did we find leaking ducts, but ducts which weren't connected and were dumping heated air into basements and crawlspaces. The magnitude of the problem was discovered by the routine use of the blower door by crews in the field; mobile homes were found to be particularly at risk for leaking, poorly fitted or disconnected ducts.

Heating systems in low-income housing often pose significant health and safety risks. It turns out that a weatherization agency that neglects the heating system is not only passing up potentially large savings, but may, more importantly, be putting its clients' lives in danger. As increasing numbers of weatherization agencies across the country were trained and began looking carefully at heating systems, they discovered more and more cases of improper and illegal installations, poor maintenance and other problems which could potentially result in property loss, adverse health effects or death. The health effects were of particular concern in that weatherization agencies which tightened houses against air infiltration without checking the heating systems for safety could exacerbate existing problems with dire consequences to the clients. Some of the problems discovered were cracked heat exchangers, improperly installed or broken flue pipes or chimneys, and missing or undersized return air ducts. Moreover, they discovered more and more cases of furnaces which backdrafted, spilling their deadly combustion gases into the indoor air supply.

Weatherization quality improves with increased crew involvement. Perhaps one of the more exciting lessons from recent years was that weatherization crews, if given the opportunity, could not only master the new technical skills required, but actually enjoyed the new responsibilities and challenges. Feedback from a number of evaluations suggests that while there may be some initial reluctance on the part of crews to learn new tricks, once they get over that hurdle, they take to the new measures with very positive results in terms of process and product: the esprit de corps of the crews improves as does the quality of the weatherization work being done in clients' homes. Weatherization crews, like workers anywhere, like to know that they are accomplishing something, rather than just going through the motions.

Training and technical assistance requirements for crews are increasingly important. As we learned more and more about how houses worked as systems, and found that the old weatherization strategies were not producing cost-effective savings, it became apparent that old ideas of crew training would not suffice. It also became increasingly clear that there was a growing conflict between the legacy of the early years of the weatherization program, when job training was seen as a major objective of the program, and operating an effective weatherization program. It is not at all obvious that a cost-effective weatherization program can be run by hiring minimum wage personnel, providing them with some minimal level of training, and then having them move on to "something better" after a few years. The levels of training (and concomitant costs) required will make it increasingly important that program personnel be retained for the long term.

An ongoing evaluation program, that gets feedback to the crews in a timely manner, can be very effective in improving weatherization. Weatherization programs which have maintained ongoing evaluations of both energy savings and costs have made the largest improvement in the energy savings achieved and the quality of the weatherization "product" being delivered. Ongoing evaluations provide new information on what works and what doesn't, continuing to move programs up both the learning curve and the savings curve. It forces a hard look at not just what produces savings, but what produces cost-effective savings. It is a very useful part of crew training, providing feedback to individual crews on what they are doing that produces cost-effective savings and what they are doing that does not.

Extrapolating These Lessons to Virginia

So, you ask, why not just apply these above lessons to Virginia's program? Why do we need another study? Why not just take the best measures and get on with it? The answer is that you have to be careful in making wholesale imports of what worked in one part of the country and applying it to another. We learned this lesson the hard way in the mid-70s when plans for solar-heated houses designed for northern climates, were imported and built in Virginia and similar milder climates; suffice it to say that the designs lost much in the translation.

First of all, something which is cost-effective in a northern climate is not necessarily going to be cost-effective in Virginia's milder climate. Since savings are directly proportional to the severity of the winters (as measured by the number of heating degree-days), a weatherization measure just barely cost-effective in, say, Minnesota, will not be cost-effective in Virginia. Moreover, something that works in a cold climate might not work, or worse, might cause problems in a warmer climate.

Besides differences in climate, you need to also consider differences in the heating fuels (both the mix of fuels used and the costs). Cost effectiveness is very sensitive to the value of the fuel being saved. Something which is cost-effective in, say, the Northeast where home heating oil predominates and where electricity costs 10 cents or more per kwh, may not be cost-effective in Virginia with its lower-priced natural gas, electricity, coal and wood.

Finally, the differences in housing type and quality are factors which need to be considered. Weatherization measures appropriate for the well-built, fairly tight houses of the upper Midwest, for example, may not be appropriate for Virginia's housing stock. While available data are poor, anecdotal evidence suggests that Virginia's low-income housing includes a wide range of housing types and conditions, including some really poor quality housing and a large proportion of mobile homes in various states of disrepair.

Engineering-Economic Analyses

Heat loss analysis

In the past, engineering estimates tended to badly overstate actual savings. This was due in part to problems with the models themselves (or to poor calibration of the models for this low-income housing stock) and in part to the improper application of these models. In the past 10 years we have gotten better at estimating savings, as the models have been fine-tuned to reflect actual (measured) savings. Still, some measures lend themselves to engineering analysis more so than others. For example, the analysis of savings from insulation installed in an attic or sidewall is relatively straightforward, with relatively few assumptions required; we can be reasonably sure of the accuracy of the savings estimates. Savings from reductions in infiltration, on the other hand, can be predicted with much less accuracy.

The approach used to estimate energy savings herein is the ASHRAE (1989) modified degree-day method (MDD) in which annual savings are a function of the annual heating degree-days (HDD). There are more sophisticated models, but this model's level of accuracy is 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, simply do not warrant more detailed models. One important attribute of this MDD method is its simplicity and the fact that all the assumptions are clearly laid out for all to see (and change as warranted), as opposed to "black box" computer models which tend to hide the underlying assumptions.

In the MDD method, savings (in BTU/ft^2-yr), are given by the equation:

$$\text{Energy savings} = C_D * 24 * (U_{Before} - U_{After}) * \text{HDD}$$

where:

U_{Before} and U_{After} are simply the U-values (reciprocals of the R-values) of the building component (attic, walls, windows) before and after,

HDD is the total annual heating degree-days (base 65°F), and

C_D is the "empirical correction factor" in ASHRAE's MDD method which adjusts for the errors inherent in the method. (Basically, it corrects for the fact that the heat required to keep the house at 70°F will be less than that predicted by the (base 65°F) degree-days). All of the analyses below assume a C_D of 0.65.

For most of the measures it is not necessary to make any assumptions regarding the type or size of the house; both savings and costs can be calculated on a "per square foot basis." Only in the case of infiltration is it necessary to make assumptions regarding the house dimensions. In these cases we use the Project Retrotech "A" house, a ranch house of approximately 1250 square feet as described in Virginia's Home Weatherization Job Book (Virginia Weatherization Program 1980), and assume a certain percent reduction in an initial air exchange rate of 1.5 ACH.

Economic Analysis

In any economic analysis, the first question you need to ask is, "Whose perspective should the analysis reflect?". Lacking any clear guidance from DOE on this, we have adopted the perspective of the individual weatherization client. Thus, we do not take into account any societal benefits such as those accruing from reduced dependence on foreign oil, decreased production of acid rain precursors or global warming gases, etc. The benefits considered are only those accruing to the individual homeowner or tenant.

Moreover, the benefits considered are only those resulting from savings in energy. This is an important point. While it is common knowledge that the weatherization program produces many benefits besides energy savings, such as increased thermal comfort, increased health and safety, home improvement, and job training (of the weatherization crew members), only savings in energy are considered in the analyses below.

The discount rate and economic lifetimes assumed are the same as those used in the PRISM analysis described above in Chapter 2. The discount rate of 7% is equivalent to a nominal rate of 12% with inflation running at 5%. Lifetimes of the various measures are those used in the BECA database at Lawrence Berkeley Laboratory: 25 years for insulation, 20 years for replacement windows, 15 years for storm windows and 10 years for infiltration measures.[1] We assume a 0% fuel escalation rate; that is, we assume that the cost of heating fuels will not increase any faster than the general rate of inflation (quite possibly a conservative assumption).

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[1] S.B. Cohen, LBL, personal communication, 1990.

As was the case with the PRISM analysis, three indicators of cost effectiveness are computed: simple payback time (SPT), benefit cost ratio (BCR), and cost of conserved energy (CCE). (The reader is referred to Appendix A for a description of each of these and how each is computed.) While the SPT is the most widely reported, it is not the indicator of choice. It is a good first-cut indicator, but it is crude in that it does not take into account either the cost of money (i.e., the discounting of future energy savings) or the economic lifetimes of the different measures. While all three indicators are reported below, the criterion used below to determine whether something is or is not cost-effective is the BCR. A measure is cost-effective if it has a BCR of one or more -- that is, if the annual energy savings are greater than the annualized costs of that measure.[2]

In Virginia we are dealing with a wide range of winter temperatures, yielding a mild 3000 HDD or so heating degree-days in the Tidewater area to more than 5000 HDD in the mountains. The colder the winter, the larger the savings. A weatherization measure which is cost-effective in the mountains may not be cost-effective on the coast. In the analyses below the cost-effectiveness of each measure is computed for three HDD values, representing average values for the Coastal areas of Virginia (3400 HDD), the Piedmont (4200 HDD) and the Mountains (5000 HDD).

A home's heating fuel and heating system also directly affect energy savings, and Virginia has a wide range of fuel types and fuel prices. The more expensive the fuel being used to heat the home, the greater the value of the savings achieved by **not** consuming it. Similarly, the less efficient the heating system, the greater the savings from having this heating system run less as a result of conservation measures. Heating fuels used in Virginia homes include electricity, natural gas, oil, kerosene, LPG, coal and wood. The value of the energy saved is a function of the price paid for the energy and the efficiency with which this energy is converted into heat. Electricity, a very high quality energy source, costs much more per million BTU (MBTU) of heat delivered than does natural gas or oil or other directly-combusted fossil fuels. However, at the point of use, electricity can be used more efficiently. Table 3-1 shows the range of values of energy which can be saved by weatherization, depending on the fuel type and cost and the heating system efficiency.[3] The energy prices used in this table are from the Energy Information Administration (1989a,b,c) and represent average values for Virginia; because of the large difference in rates between the two main electric utilities in Virginia, energy costs are shown for both.

As shown in this table, the value of a MBTU of energy saved in Virginia can vary significantly, from a low of about $7/MBTU for a house heated with a high-efficiency (condensing) gas furnace, to a high of about $26/MBTU for a home in Virginia Power's service area heated with a forced air "electric furnace" such as those often found in mobile homes. The value of energy saved in houses heated with wood or coal obtained by the occupants at little or no cost could actually be lower than $7/MBTU. However, this cost does not reflect the true value of these indigenous fuels; their apparent cost does not take into account the labor and the inconvenience involved in both the gathering and burning of these fuels. Therefore, we have valued wood and coal at the cost of oil, its most likely replacement if households could afford it.

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[2] Using a discount rate of 7%, a measure with an economic lifetime of 25 years would need to have a simple payback time (SPT) of 11.7 years or less to be cost-effective; a measure with an economic lifetime of 15 years would need a SPT of 9.1 years to be cost-effective, while one with a lifetime of 10 years would require a SPT of 7 years.

[3] Overall heating system efficiencies take into account steady-state efficiencies, standby losses, and duct/pipe losses and are our best estimates based on values given in the literature. One very good reference on this is a Northwest Power Planning Council (1988) study which summarizes the results of 17 other studies which used both measured and model data.

TABLE 3-1 VALUE OF ENERGY SAVED ($/MBTU)

Natural Gas and Oil Heating Systems			
Furnace Efficiency	Overall Efficiency	Gas @ $.60/therm	Oil @ $.90/gal
70% AFUE	45%	$13	$14
80% AFUE	55%	$11	$12
95% AFUE	80%	$7	$8

Electric Heating Systems			
Type of Heating System	Overall Efficiency	APCO @ $.056/kWh	Va Power @ $.072/kWh
Forced Air	80%	$21	$26
Baseboard	100%	$16	$21
Heat Pump	180%	$9	$12

All Other Heating Systems
(Wood, Coal, LPG, Propane, Kerosene)

While actual costs of these fuels may be very low (approaching zero for wood and coal in some areas), this cost does not reflect the true value of the energy; most of these Wx clients would be using more expensive fuels if they were available and affordable. Therefore, these fuels are all valued at the cost of oil.

Weighted Average Value of Energy Saved		
	Percent*	$/MBTU
Natural Gas	19%	$11
Oil	34%	$12
Electric	16%	$21
All Other	31%	$12
Weighted Ave. Cost of Energy =		$13

* Approximate breakdown by fuel type of houses weatherized by VACAA in 1987-1988.

These two variables, climate and value of energy saved, affect the savings side of the benefit-cost equation; on the other side is the installed cost of the measure. While costs of measures are usually easy to determine, that is not the case here because Virginia weatherization does not document the labor costs of measures installed. The estimates of annual energy savings, for all their shortcomings, are in many cases better determined than is the cost side of the equation. Cost data were obtained from the following sources: actual Virginia weatherization cost data where available (from Home Weatherization Worksheets -- HWWs)[4], quotes from Virginia vendors, other private sector contractors, other states' weatherization programs, and the Center for Energy and the Urban Environment (1990) whose "Operation Insulation" report is a good source of cost data for various types of insulation work.

The "Average" Low-Income Home in Virginia

In an ideal world one would determine cost-effectiveness, and hence what measures to install, on a house-by-house basis, taking into account the climate, the type of heating system, the cost of the fuel, and an agency's actual costs. In the real world of political, institutional and pragmatic constraints, such an approach is not feasible. It is politically and administratively preferable to make generalized decisions on the cost effectiveness of individual ECMs for the Commonwealth as a whole and then apply standards and protocols uniformly across the state. To do this requires that we somehow take into consideration the wide range of values for the above variables and come up with an "average Virginia low-income home".

The average climate for this home could be considered to be the 4200 HDD figure used for the Piedmont, conveniently half-way between the HDD values of the mountains and the coast. The average costs are our "best estimates" of actual installed costs for Virginia weatherization agencies. Obtaining an average value of energy saved is a bit more convoluted, as one has to account for not only the range of fuel costs and efficiencies, but also the relative proportions of each in Virginia's stock of low-income housing. To do this we computed a weighted average value based on Virginia fuel costs, estimated heating system efficiencies, and data from VACAA on the number of houses [weatherized in 1988-89] with each of the different heating systems. This weighted-sum-of-averages approach, shown at the bottom of Table 3-1, yields a value of $13 per MBTU as a good average figure to use for the value of energy saved as result of Virginia weatherization efforts.

The Cost-Effectiveness Tables

The calculated cost-effectiveness indicators for each measure are presented in each of the sections below in the form of matrix which is intended to "bound the analysis." Each table shows cost-effectiveness under 27 different combinations of the three variables -- three climate zones, three values of energy savings, and three installed costs. The three climate zones are represented by the three HDD values given above. The three values of energy savings used are $11/MBTU (corresponding to an 80% AFUE gas furnace), $23/MBTU (corresponding to an "electric furnace" using electricity at a rate between APCO's and Virginia Power's) and $13/MBTU (the weighted average energy savings value discussed above). Our intent here is to present as much information as possible, but in a way which is still useful

[4] Unfortunately, the cost data which were available were not of very good quality. A lot of information is collected on the HWWs, but not in a form that makes it usable for this sort of analysis. While the material costs are usually fairly well documented, the labor costs are not. Since this is the least well-determined part of the cost effectiveness calculations at present, we strongly recommend that efforts be made to more clearly assess these installed costs as the program moves ahead with the recommendations from this evaluation.

to the reader. (These matrices have also been designed so that they can be quickly and easily modified to make use of new data as it becomes available.)

Attic Insulation

Overview

Attic insulation has been one of the mainstays of the weatherization program since the beginning and, unlike many of the other early weatherization techniques, one that has proven to be cost-effective. The reason for this is very simple: Warm air rises, so the largest temperature differential, and hence the largest heat loss, is at the ceiling. Combine this large heat loss with the fact that ceilings/attics can usually be insulated relatively inexpensively and you have all the ingredients for a very cost-effective measure.

While attics can be insulated with fiberglass batts, it is easier and less expensive to blow the attic with cellulose or fiberglass. The economic analyses below assume blown cellulose.

Heat loss analysis

While energy savings are due primarily to a decrease in conductive heat losses across the ceiling, blown cellulose has also been shown to result in some sealing of air leakage sites and, hence, energy savings resulting from a reduction in air changes per hour (ACH). The analyses below, however, do not assume any savings from reduced infiltration, but include only those resulting from an increase in R-value.

The heat loss calculation here is straightforward; the only new assumption necessary concerns the initial R-value of the uninsulated attic. A ceiling with no insulation will have an R-value of less than R-2; however, the roof and the air space between ceiling and roof combine to add additional R-value, with the exact value depending on roof slope and amount of ventilation. The analyses below assume an initial R-value of 4; as it turns out, this is not a critical assumption.

Economic Analysis

The installed costs here are especially difficult to deal with in that the cost will vary with the amount of insulation installed. In all cases we have assumed that the maximum insulation installed will be R-30[5]; however, the amount installed will depend on how much insulation is there to begin with. The total cost of adding attic insulation can be considered to be comprised of two costs, a fixed cost and a variable cost. The former says it costs some fixed amount just to show up with the truck and the blower and get set up and into the attic; the latter reflects the material and labor costs which we assume vary linearly with the amount of insulation installed. The range of these fixed and variable costs used for this analysis represent our best estimates based on a mixture of actual Virginia weatherization costs and private sector quotes.

Table 3-2 presents a summary of the cost effectiveness of attic insulation installed in an uninsulated attic in Virginia. This matrix (and similar ones for other measures discussed below) gives the simple payback time (SPT) and benefit cost ratio (BCR) for the 27 different

5 This is the level of insulation decided upon by VACAA; it corresponds to the level recommended by DOE for Virginia for homes heated with oil, natural gas and heat pumps. The DOE-recommended level for homes in Virginia with electric resistance heating is R-38.

TABLE 3-2 ATTIC INSULATION ECONOMICS -- FROM R-4 (UNINSULATED) TO R-30

Region		Incremental Costs Of Insulation: Fixed +	Incremental	= Total	CCE	Value of Energy Saved: 11 ($/MBTU) SPT	B/C	Y/N	13 ($/MBTU) SPT	B/C	Y/N	23 ($/MBTU) SPT	B/C	Y/N
		($/ft2)	($/ft2-R)	($/ft2)	($/MBTU)									
Coast	Low	$0.05	$0.010	0.30	$2.24	2.4	4.9	YES	2.0	5.8	YES	1.1	10.3	YES
3400	Ave	$0.10	$0.012	0.40	$2.99	3.2	3.7	YES	2.7	4.4	YES	1.5	7.7	YES
HDD	High	$0.15	$0.014	0.50	$3.74	4.0	2.9	YES	3.4	3.5	YES	1.9	6.1	YES
Piedmont	Low	$0.05	$0.010	0.30	$1.81	1.9	6.1	YES	1.6	7.2	YES	0.9	12.7	YES
4200	Ave	$0.10	$0.012	0.40	$2.42	2.6	4.5	YES	2.2	5.4	YES	1.2	9.5	YES
HDD	High	$0.15	$0.014	0.50	$3.03	3.2	3.6	YES	2.7	4.3	YES	1.5	7.6	YES
Mountains	Low	$0.05	$0.010	0.30	$1.52	1.6	7.2	YES	1.4	8.5	YES	0.8	15.1	YES
5000	Ave	$0.10	$0.012	0.40	$2.03	2.2	5.4	YES	1.8	6.4	YES	1.0	11.3	YES
HDD	High	$0.15	$0.014	0.50	$2.54	2.7	4.3	YES	2.3	5.1	YES	1.3	9.0	YES

ASSUMPTIONS:

Interest rate	12%	R-value of uninsulated attic is 4
Inflation rate	5%	Add R-30 insulation
Discount rate	7%	Assumes no savings due to reduced infiltration
Economic lifetime	25 yrs	Cd = 0.65
Initial R-value	4	
Finished R-Value	30	
Change in R-Value	26	
Change in U-Value	0.217	

combinations of climate, value of energy saved and installed cost discussed above. The "Yes/No" column indicates whether the measure is cost-effective based on the BCR. As discussed above, a measure is cost-effective if it has a BCR greater than or equal to one.

The results here are clear cut: adding insulation to an attic which has none is cost-effective in every case. Even under the "worst case scenario" of mild climate (3400 HDD), inexpensive energy being conserved ($11/MBTU), and high installed cost ($0.50 per square foot), the attic insulation has a BCR of 2.9. That is, it returns $2.9 for every $1 invested. Under the "best case scenario" -- a house in the mountains with electric resistance heating and a low installed insulation cost of $0.30 per square foot -- the BCR is 15.1. The simple payback time (SPT) (again, a less accurate indicator) shows that this insulation will pay for itself in anywhere from less than a year to 4 years.

Table 3-2 also gives the cost of conserved energy (CCE). Note that this indicator is not dependent on either the cost of the heating fuel or the heating system efficiency; in essence, it gives the "purchase price" for the BTUs being conserved. If this CCE is less expensive that the cost of energy used to heat the house, then the investment is cost-effective. Table 3-2 shows that, under the worst case scenario of mild climate and high installed cost, the CCE is $3.74/MBTU. This tells us is that insulation installed in an uninsulated attic will be cost-effective no matter what heating system the house has, since, as noted in the discussion above, the least expensive source of heat (natural gas burned in a high efficiency furnace) costs $7 per MBTU; the CCE in all cases is decidedly lower.

What Level of Insulation is Enough?

The above demonstrates that installing attic insulation when there is none is definitely cost-effective. What if there is some attic insulation already? The law of diminishing returns applies here: the first inch of insulation saves a lot, and each additional inch saves a little less. At what point is it no longer cost-effective to add additional insulation? It should be apparent from Table 3-2 that there is not going to be one single answer to this question; the level of insulation that is cost-effective will depend not only on how much is there already, but on all the variables discussed above as well. Table 3-3 asks whether it is cost-effective to add insulation to an attic which already has R-11 in place. The results show that it is cost-effective under almost all cases, the one exception being a house near the coast, heated with natural gas or oil with a reasonably efficient furnace, and high installed insulation costs.

Table 3-4 asks whether it is cost-effective to add insulation to an attic already insulated to R-19. The results here suggest that for most gas and oil furnaces this will not be cost-effective, unless the additional insulation can be installed at our lowest assumed cost. With electric resistance heating at $23/MBTU, however, this additional insulation will be cost-effective in almost all cases. What's the bottom line here? Although the cost-effectiveness of adding attic insulation varies, for political and administrative reasons it is useful to have a single decision criterion for when to add more. If Virginia must have a single criterion for a yes/no decision on additional insulation, R-19 is probably as good as any. For "average" costs, climate and value of energy saved, it is not cost-effective to add insulation if the attic is insulated to R-19 already. It is important to note, however, that this analysis no longer holds if you have the insulation and blower on site for something else (sidewalls or an uninsulated section of attic). If you're set up to blow insulation anyway, it will almost always be cost-effective to bring all the attic insulation up to R-30.

Installation Concerns

Seal before you blow. The section immediately below discusses the importance of careful air-sealing in attics. Suffice it to say at this juncture that blowing insulation in an attic without first attending to bypasses and air leakage sites is bad practice. While cellulose insulation

TABLE 3-3 ATTIC INSULTATION ECONOMICS -- FROM R-11 TO R-30

Region		Incremental Costs Of Insulation			CCE	Value of Energy Saved								
		Fixed +	Incremental	= Total		11 ($/MBTU)			13 ($/MBTU)			23 ($/MBTU)		
		($/ft2)	($/ft2-R)	($/ft2)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$0.05	$0.010	0.23	$6.53	6.9	1.7	YES	5.9	2.0	YES	3.3	3.5	YES
3400	Ave	$0.10	$0.012	0.32	$8.97	9.5	1.2	YES	8.0	1.4	YES	4.5	2.6	YES
HDD	High	$0.15	$0.014	0.41	$11.42	12.1	1.0	NO	10.2	1.1	YES	5.8	2.0	YES
Piedmont	Low	$0.05	$0.010	0.23	$5.29	5.6	2.1	YES	4.7	2.5	YES	2.7	4.4	YES
4200	Ave	$0.10	$0.012	0.32	$7.26	7.7	1.5	YES	6.5	1.8	YES	3.7	3.2	YES
HDD	High	$0.15	$0.014	0.41	$9.25	9.8	1.2	YES	8.3	1.4	YES	4.7	2.5	YES
Mountains	Low	$0.05	$0.010	0.23	$4.44	4.7	2.5	YES	4.0	2.9	YES	2.2	5.2	YES
5000	Ave	$0.10	$0.012	0.32	$6.10	6.5	1.8	YES	5.5	2.1	YES	3.1	3.8	YES
HDD	High	$0.15	$0.014	0.41	$7.77	8.2	1.4	YES	7.0	1.7	YES	3.9	3.0	YES

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	25 yrs
Initial R-value	11
Finished R-Value	30
Change in R-Value	19
Change in U-Value	0.058

Existing attic insulation is R-11
Add enough insulation to bring attic to R-30
Assumes no savings as a result of reduced infiltration
Cd = 0.65

TABLE 3-4 ATTIC INSULATION ECONOMICS -- FROM R-19 TO R-30

		Incremental Costs Of Insulation				Value of Energy Saved								
Region		Fixed +	Incremental	= Total	CCE	11 ($/MBTU)			13 ($/MBTU)			23 ($/MBTU)		
		($/ft2)	($/ft2-R)	($/ft2)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$0.05	$0.010	0.16	$13.04	13.8	0.8	NO	11.7	1.0	NO	6.6	1.8	YES
3400	Ave	$0.10	$0.012	0.23	$19.03	20.2	0.6	NO	17.1	0.7	NO	9.6	1.2	YES
HDD	High	$0.15	$0.014	0.30	$25.02	26.5	0.4	NO	22.4	0.5	NO	12.7	0.9	NO
Piedmont	Low	$0.05	$0.010	0.16	$10.56	11.2	1.0	YES	9.5	1.2	YES	5.4	2.2	YES
4200	Ave	$0.10	$0.012	0.23	$15.40	16.3	0.7	NO	13.8	0.8	NO	7.8	1.5	YES
HDD	High	$0.15	$0.014	0.30	$20.26	21.5	0.5	NO	18.2	0.6	NO	10.3	1.1	YES
Mountains	Low	$0.05	$0.010	0.16	$8.87	9.4	1.2	YES	8.0	1.5	YES	4.5	2.6	YES
5000	Ave	$0.10	$0.012	0.23	$12.94	13.7	0.9	NO	11.6	1.0	YES	6.6	1.8	YES
HDD	High	$0.15	$0.014	0.30	$17.02	18.0	0.6	NO	15.3	0.8	NO	8.6	1.4	YES

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	25 yrs
Initial R-value	19
Finished R-Value	30
Change in R-Value	11
Change in U-Value	0.019

Existing attic insulation is R-19
Add enough insulation to bring attic to R-30
Assumes no savings due to reduced infiltration
Cd = 0.65

may seal some of the leaks to some extent, the proper protocol is to air-seal before blowing; if weatherization is to achieve its full potential savings, it is crucial that this opportunity not be missed. If the attic already has some insulation, use it as a diagnostic tool; air leakage sites will very often be marked by dirty insulation.

A complete and careful installation is important. Voids or missed areas seriously degrade the quality of the insulation and reduce savings. Table B.1 in Appendix B shows that insulation "misses" or "voids" comprising only 5% of the total attic area can reduce by nearly 50% the overall average R-value of an attic insulated to R-30. This is a simplistic analysis which takes into account only the effect the voids have on the average R-value; it does not account for interactions and bypasses. It makes a strong argument for blowing insulation; it's much easier to snake a hose into hard-to-reach attic spaces than it is to get in there with blankets or batts. Inspectors should insist on 100% insulation coverage, and that includes attic scuttle (access) doors.

To vent or not to vent? This is one of the more controversial questions in the weatherization field today. It is probably not necessary in most cases and can certainly increase heat loss and negatively impact savings if the ceiling is leaky. The bottom line, however, is that DOE standards still require it. Our bottom line is this: If you don't insulate the attic, by all means don't vent it (unless there is an obvious moisture problem; and even then you would be wise to look elsewhere for the solution); if you do vent, do careful attic air sealing first.

Advanced Air Sealing

Overview

Air sealing or infiltration reduction in the past was primarily restricted to caulking and weatherstripping doors and windows, as well as general repairs included in the Project Retrotech book under the rubric of "General Waste Heat" reduction. In Virginia in recent years, replacement windows have also been justified on the basis of infiltration reduction. Unfortunately, these air sealing measures have not resulted in the energy savings intended. As noted above in the Introduction to this chapter, we have learned a lot about infiltration in the last decade, much of it as a result of the use of blower doors and infrared cameras and scanners. To its credit, Virginia was one of the first states to require that all its subgrantees use blower doors in air sealing. Unfortunately, a blower door does not, in itself, guarantee good air sealing; in fact, a blower door incorrectly used may result in large additional expenditures of materials and labor with very little to show in the way of savings. The PRISM results discussed above in Chapter 2 suggest that this may in fact have been the case in Virginia, where many houses received a lot of caulking with no appreciable energy savings to show for it.

How can this be? How is it possible to seal air leaks as identified with the blower door, show measured reduction in the air changes per hour at 50 pascals (ACH_{50}), and still not realize energy savings? To answer this question we need to discuss the basics of air movement in a house. For infiltration to occur you need two things, a hole and a driving force. The blower door is very good for identifying the holes; what it doesn't tell you is which of these holes are important. The driving force is a difference in pressure. The pressure difference that we used to concern ourselves with was that resulting from wind blowing against the side of a house. And, sure enough, this wind-driven pressure can result in air leaking in the windward side and leaking out the leeward side. So far so good. Unfortunately, this wind-generated pressure difference is usually not the principal cause of infiltration in a house. As dramatic as it appears when the wind blows the curtains near a leaky, unweatherstripped window, the fact is, the wind just doesn't blow all that much, especially in an urban or suburban area.

The driving force which we need to be concerned with is one that, though less noticeable than the wind, works more or less continuously. This driving force is the pressure difference caused by the "stack effect." Air heated in the house by the expenditure of energy naturally rises, resulting in a slight positive pressure in the upper part of the house and a slight negative pressure near the bottom. If there are holes in the ceiling, this warm air leaks out (exfiltrates) through the attic or roof and is replaced by cold air which leaks in (infiltrates) around the bottom of the house (through the basement/crawlspace cracks and around sill plates, rim joists, etc). The windows and doors where we used to spend so much time and dollars caulking and weatherstripping are located in what is called the "neutral pressure plane," the area in the house which is subject to neither the positive pressure at the top of the house nor the negative pressure at the bottom of the house. The "bottom line" here is that we need to take our caulk guns out of the comfort of the living rooms and get up into the attic and down into the basement and seal the leaks there. These are not always the most pleasant places to work, but that's where the savings are to be found.

The first thing we should do is look for the "big leaks." Quite often a house with large air leakage (as measured by the blower door) will have some big holes, and sometimes these are not immediately obvious (such as above dropped ceilings). Weatherization crews need to be trained in how to look for these big leaks. It's not work which can be done "by the book"; it's work which rewards careful thinking and detective work. One other important place to look for leaks, and one even more important than holes in the attic and crawlspace, is the ductwork. Since it is heated air that is leaking out of these, whether it be supply or return air, it is especially important to find and seal these duct leaks. Lots of good work has been done in this area in the last few years. The Air Sealing portion of the *Training and Technical Assistance Manual* accompanying this report describes in considerable detail both what to look for and how to seal important leaks.

Heat Loss Analysis

Heat lost through infiltration is extremely difficult to quantify. Even if we have good blower door readings before and after weatherization, we cannot predict the energy savings with any reasonable degree of confidence. There are two reasons for this: First of all, it is difficult to extrapolate from air leakage measured at pressure (typically 50 pascals, indicated ACH_{50}) to air leakage under "natural conditions." While there are both rules of thumb and sophisticated models for doing this, none really is terribly reliable. Second, the blower door doesn't tell us where the leaks are, and as discussed above, all leaks are not created equal. Consider a 30% reduction in ACH_{50} as measured by the blower door. If this reduction is a result of sealing holes in the neutral pressure plane, it is much less likely to show up as lower energy consumption than is a similar reduction which is the result of sealing holes in the attic or crawlspace.

For these reasons, any estimates we provide regarding energy savings from infiltration reduction will, of necessity, be very approximate. The purpose in doing any cost-effectiveness calculations at all is so that we can see how air sealing compares with the other measures under consideration. A number of assumptions are necessary in order to make these calculations: First, we assume a fairly "leaky" Retrotech "A" house with a volume of 10,000 ft^3 and a "natural" infiltration rate of 1.5 ACH. We assume that this initial pre-weatherization infiltration is reduced by 30%. This reduction rate is supported by evaluations studies done in weatherization programs in the upper Midwest, most notably by Minnesota's *M-200* program which achieved an average reduction of 36% on 120 houses (Shen *et al.* 1990). The initial ACH of 1.5 is higher than that measured in more northern states, but anecdotal evidence suggests that houses in more southern climates such as Virginia's are leakier to begin with.[6]

Economic Analysis

While the above assumptions necessary for the heat loss analysis are crude, the assumptions regarding costs may be even worse. One problem is that cost data from past Virginia weatherization work is not valid in that most of it was not the type of air sealing we're talking about here. Even if that were not the case, there would still be a problem because costs vary widely: If you find and seal one big hole you can achieve significant infiltration reduction at a very low cost; conversely, it is possible to spend a lot of hours and achieve little reduction in ACH. Another complication arises from the fact that significant air sealing can be achieved by insulating the sidewalls using the "hard blowing" technique discussed in the section below. While infiltration reduction as a result of blowing sidewalls with cellulose is well documented and, in fact one of the main reasons for using this approach, we have elected below not to count these savings in the economic analysis of that measure, but instead include them here under air sealing.

For all these reasons, the costs used in this analysis are little more than educated guesses.[7] The results of this admittedly approximate analysis are given in Table 3-5. What this table tells us is that if we can reduce infiltration by 30% in an average size house for $300 or less it will be cost-effective no matter where the house or what the fuel type. At a cost of $500, however, this 30% reduction in infiltration will be cost-effective only in the mountains with natural gas or oil, or anywhere in the Commonwealth if the house has electric resistance heating.

How sensitive is this analysis to the assumption regarding the size of the house? More specifically, would this same reduction be cost-effective in a mobile home? Table 3-6 presents the results of this analysis. Since it is reasonable to assume that it would cost less to achieve the same percentage reduction in ACH in a home of a smaller volume, we have used a different range of costs in this table, namely, $100, $175 and $250. As this table shows, if this air sealing can be done for $175 it will be cost-effective for all cases except $11/MBTU heating costs along the coast.

It is apparent from the above analyses that cost-effectiveness is very sensitive to costs. Recognizing this fact, at least two programs -- Minnesota's *M-200* Program (Nelson and Dutt 1988) and one developed by the Wisconsin Energy Conservation Corporation (WECC 1988) -- have developed procedures whereby the amount of air sealing done is explicitly driven by the cost of obtaining it. These programs have developed specific criteria for deciding whether each increment of infiltration reduction achieved is cost-effective. For example, in the *M-200* program, the criterion used was that, "...air sealing is no longer cost-effective when it costs more than about $40 in labor and materials to achieve a 100 cfm_{50} air flow reduction" (Shen *et al.* 1990, p. 8). Table 3-7 presents the results of similar analysis done for

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[6] While the infiltration data for the *M-200* program (Shen *et al.* 1990) is given in cfm_{50} it is possible, using assumptions regarding house volume (10,000 ft^3 seems reasonable given the average floor area of 1346 ft^2) and the relationship between ACH_{50} and ACH under normal conditions (20:1), to arrive at before and after infiltration rates in ACH. Using these assumptions, the before-weatherization ACH for this 120 house sample was 0.8 and the after-weatherization ACH was 0.5.

[7] The *M-200* program (Shen *et al.* 1990, p.13) provides one useful data point here: Thirty-two percent of the 128 houses in their sample received "...some caulking, weatherstripping, and/or repair of windows and sashes (at an average cost of $104)." (However, 70% of the houses in the sample received attic bypass sealing work and 52% received some wall insulation. It is likely that these latter measures were more responsible for the 36% average reduction in infiltration that was achieved.)

TABLE 3-5 AIR SEALING ECONOMICS -- RETROTECH "A" HOUSE

Region	Cost of Air Sealing		CCE	Value of Energy Saved								
				11 ($/MBTU)			13 ($/MBTU)			23 ($/MBTU)		
	Range	($)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$100	$3.31	2.1	3.3	YES	1.8	3.9	YES	1.0	6.9	YES
3400	Ave	$300	$9.94	6.3	1.1	YES	5.4	1.3	YES	3.0	2.3	YES
HDD	High	$500	$16.57	10.6	0.7	NO	9.0	0.8	NO	5.1	1.4	YES
Piedmont	Low	$100	$2.68	1.7	4.1	YES	1.4	4.8	YES	0.8	8.6	YES
4200	Ave	$300	$8.05	5.1	1.4	YES	4.3	1.6	YES	2.5	2.9	YES
HDD	High	$500	$13.41	8.6	0.8	NO	7.2	1.0	NO	4.1	1.7	YES
Mountains	Low	$100	$2.25	1.4	4.9	YES	1.2	5.8	YES	0.7	10.2	YES
5000	Ave	$300	$6.76	4.3	1.6	YES	3.7	1.9	YES	2.1	3.4	YES
HDD	High	$500	$11.27	7.2	1.0	NO	6.1	1.2	YES	3.4	2.0	YES

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	10 yrs
Volume of house	10000 ft3
Initial ACH	1.5
ACH reduction	30%
Cd	0.65

TABLE 3-6 AIR SEALING ECONOMICS -- MOBILE HOMES

Region	Cost of Air Sealing		CCE	Value of Energy Saved								
				11 ($/MBTU)			13 ($/MBTU)			23 ($/MBTU)		
	Range	($)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$100	$6.63	4.2	1.7	YES	3.6	2.0	YES	2.0	3.5	YES
3400	Ave	$175	$11.60	7.4	0.9	NO	6.3	1.1	YES	3.5	2.0	YES
HDD	High	$250	$16.57	10.6	0.7	NO	9.0	0.8	NO	5.1	1.4	YES
Piedmont	Low	$100	$5.37	3.4	2.1	YES	2.9	2.4	YES	1.6	4.3	YES
4200	Ave	$175	$9.39	6.0	1.2	YES	5.1	1.4	YES	2.9	2.4	YES
HDD	High	$250	$13.41	8.6	0.8	NO	7.2	1.0	NO	4.1	1.7	YES
Mountains	Low	$100	$4.51	2.9	2.4	YES	2.4	2.9	YES	1.4	5.1	YES
5000	Ave	$175	$7.89	5.0	1.4	YES	4.3	1.6	YES	2.4	2.9	YES
HDD	High	$250	$11.27	7.2	1.0	NO	6.1	1.2	YES	3.4	2.0	YES

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	10 yrs
Volume of house	5000 ft3
Initial ACH	1.5
ACH reduction	30%
Cd	0.65

TABLE 3-7 SPENDING LIMITS FOR COST EFFECTIVE AIR SEALING

Amount That It Is Cost Effective to Spend Per 100 CFM-50 of Infiltration Reduction			
	Value of Energy Saved		
Region	11 ($/MBTU)	13 ($/MBTU)	23 ($/MBTU)
Coast 3400 HDD	$22	$26	$46
Piedmont 4200 HDD	$27	$32	$57
Mountains 5000 HDD	$33	$38	$68

ASSUMPTIONS:
Cost effectiveness criterion is BCR greater than or equal to one.
Discount rate = 7%
Economic lifetime = 10 years
Cd = 0.65
CFM @ 50 Pascals = 20 times CFM under "normal" conditions

Virginia. Instead of coming up with "one number" to use all across the Commonwealth, we have, to be consistent with the approach used throughout this chapter, calculated a "cutoff cost" for each of the three climate zones and each of the three values of energy saved. If Virginia were to decide to adopt this sort of approach to cost-effective blower-door assisted air sealing and wanted a single figure, it might want to use the "average" cost of $32. That is, air sealing, in order to be cost effective, would need to achieve 100 cfm_{50} reduction in air flow for each $32 of labor and materials spent.

Air Tightening Concerns

Certainly a primary concern in Virginia and elsewhere is, "How tight is too tight?" At what point do you stop air sealing out of concern for indoor air quality and moisture problems? ASHRAE established a new ventilation standard for acceptable indoor air quality in 1989. The standard for residences is based on a minimum rate of 15 cfm/person and is given as 0.35 ACH/person (ASHRAE 1989). The *M-200* program (Shen *et al.* 1990, p.1) translated this standard into a minimum blower door reading at 50 pascals so crews could guard against making houses too tight. For deciding when to stop air sealing, the minimum air-tightness of a house was set at 1200 cfm_{50} or, in cases when the number of occupants exceeded five, 225 cfm_{50} per occupant. Other states have used similar guidelines.

Sidewall Insulation

This measure is a good example of how the thinking has changed in weatherization over the past decade. Virginia's "Project Retrotech" manual states that, "While sidewalls are rated high on the priority list, Virginia does not include this measure as a requirement. This decision is based on the required skill level needed to accomplish the blowing, man hours required and the payback." (Virginia Weatherization Program, 1980, p. 6). Recent studies in a number of states have found that sidewall insulation is not only eminently "doable", but, if properly installed, one of the most cost-effective conservation measures there is. The payback is actually extremely good.

The key phrase in the above is, "if properly installed." By proper installation we mean something very specific here -- namely, the technique, honed to a fine art in Minnesota by Jim Fitzgerald (1989, 1990), and known variously as the "high density," "single hole, tube-fill," "dense pack" or "hard blowin'" method. In this method one hole is drilled into each stud cavity (from either inside or outside the house[8]) and a vinyl tube connected to the insulation blower is inserted into the hole until it reaches the top (or bottom) of the cavity. By slowly withdrawing the tube as the cavity fills with insulation, the cavity can be completely filled with well-packed insulation at a density of approximately 3.5 lbs/ft^3.

The beauty of the procedure is that, if done properly, not only do you get the benefits of the increased R-value, but you also achieve significant air-sealing benefits as well. In Minnesota's *M-200* Program, in which high density sidewall blowing was a major part of the protocol, an average reduction in air leakage of 36% (as measured by the change in cfm_{50}) was obtained on a sample of 120 houses (Shen *et al.* 1990, p. 23). Similar results are reported by Fitzgerald et al. (1990, pp. 14-15) for a 32 house sample in Minnesota (46% reduction) and a 92 house study in Ohio (38% reduction). In the latter it was estimated that the

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[8] Access to stud cavaties can also sometimes be obtained through the attic or sill plate area.

dense-pack sidewall insulation and attic insulation accounted for over 50% of the measured air leakage reduction.

The air leakage reduction occurs by the action of the (fiendishly clever) cellulose fibers which are capable of not only seeking out the smallest of cracks, but sealing them as well. Often, sufficient air sealing is obtained by sidewall blowing and attic bypass sealing alone, so that no further (traditional) air sealing by caulking and weatherstripping is required.

This high density method of sidewall insulation addresses two of the complaints which have given blown sidewall insulation a bad reputation over the years. One complaint is that the insulation settles over time, resulting in an uninsulated space at the top of each stud cavity. This settling did, in fact, occur all too frequently, as can be verified on numerous houses by use of an infrared camera. This problem was a result, not of the two-hole method, per se, but rather occurred as a result of the insulation being installed at too low a density, something which is much less likely to happen with the single tube method of blowing. The second complaint concerns voids or "missed stud cavities." As noted above in the section on attic insulation, voids and "misses" in insulation can result in serious reductions in average R-values. This problem also is a result, not of any method per se, but of poor installation practice. While the high density, single tube method cannot rule out poor workmanship, it does it make it more difficult to do a poor job. The usual reason for voids or "misses" is simply improper probing for obstructions in the stud cavities. While "good practice" mandates the probing of each and every stud cavity when using the two-hole method, in actual practice this is seldom done. With the single hole, tube fill method each cavity gets probed as part of the process.

High density sidewall insulation is not without its "downside". It does require a certain amount of practice to achieve the optimal density of the packed insulation. Fitzgerald notes that at densities of less than 3.5 lbs/ft^3 they still see some air flow (using the infrared camera in conjunction with the blower door), and at densities of over 4 lbs/ft^3 they have blown out walls. It is important to check for water-damaged or otherwise weakened plaster or gypboard walls before blowing, as these walls can easily fail under the pressures necessary to achieve this desired density, and filling a client's bedroom with cellulose is not good public relations. Articles by Fitzgerald et al. (1989, 1990) and Jones (1989) as well as the Sidewall Insulation section of the *Training and Technical Assistance Manual* accompanying this report present much useful "how to" information on this single tube method, but there is no substitute for "hands on" training. While the required "learning curve" may appear daunting, it is a skill readily achievable by weatherization crews, as attested to by the many such crews now installing this measure with excellent results in a number of states.

Heat Loss Analysis

As noted above, the energy savings from high density sidewall blowing result from two mechanisms -- 1) the reduction in heat loss across the wall due to the higher R-value, and 2) reduced infiltration from the air sealing effects of the insulation. In the analysis below we have ignored the latter, and and report only savings due to increased R-value. There are two reasons for this: First, we wish to reduce the chance of these results being misinterpreted by the double counting of savings benefits. A second reason is that it is not necessary to include these infiltration savings. As will be demonstrated below, sidewall insulation is cost-effective in Virginia for all combinations of climate, installed cost and fuel value, even without accounting for these air sealing benefits.

The savings resulting from the increased R-value of the wall are relatively straightforward to calculate. As was the case with attic insulation, we need to make some assumptions regarding initial R-value and the R-value per inch of high density insulation. Unlike attics, the amount installed will be well determined; it's simply the depth of the stud cavity, and below we assume either 3.5 or 4 inches. Tables B.2 and B.3 in Appendix B show how the overall R-value of a wall is calculated, with and without insulation. Table B.2 assumes a wall in an older house with full dimension two-by-fours and three-quarter inch wood siding, while Table B.3 gives the results for more recent construction. In the analysis below we have used the former, older construction. For these analyses we assume cellulose blown to a density of 3.5 pounds per square foot, which yields an R-value of approximately 3.4 per inch. These assumptions result in an increase in the average R-value of the wall from R-3.8 to R-12.9.

Economic Analysis

The above increase in R-value will result in annual savings ranging from $0.11/ft^2 (for $11/MBTU fuel costs on the coast) to $0.33/ft^2 (for electric resistance heating in the mountains). On a typical house (e.g., one the size of the Retrotech "A" house) this translates into savings ranging from about $120 to $370 per year.

The cost side of the equation is quite well determined for this measure. Unlike the case with attic insulation, with sidewalls you are always installing essentially the same amount of insulation per square foot. The only uncertainty here is the labor costs which will depend in large part on how difficult it is to drill and repair holes in the home's walls. A good source of cost data for sidewall insulation is the manual prepared by the Center for Energy and the Urban Environment (1990) which provides costs for both interior and exterior filling, and for various types of siding. Their quoted costs range from $.70/ft^2 for wood siding to $1.05/ft^2 for stucco. Other costs were obtained from other state Weatherization programs and private sector contractors. The range of costs used in the analysis below are $.60, $.80 and $1.00 per square foot.

As shown in Table 3-8, sidewall insulation is cost-effective in Virginia under all conditions. The cost of conserved energy (CCE) varies from $3.56 to $8.72 per MBTU, less expensive than almost all fuel and heating system combinations. Even under the "worst case scenario" of a house on the coast with a reasonably efficient gas furnace ($11/MBTU) and insulation installed at $1.00/ft^2, the BCR is 1.3 to 1 and it pays for itself (SPT) in 9.2 years. At the other end of the spectrum, a house in the mountains with electric resistance heating and installed costs of $.60/ft^2, the BCR is 6.5 and the insulation pays for itself in 1.8 years.

Again, benefits from reduced air leakage are not included in the above; these savings are solely due to the increase in the wall's R-value. The results of an analysis which did consider the benefits of reduced air leakage are included in Table B-4 in Appendix B. The results given in that table include savings from a 30% reduction in infiltration, as well as the R-value savings. With these additional infiltration reduction benefits, the BCR ranges from 1.8 to 9.0, with SPTs ranging from 1.3 to 6.6 years.

Storm Windows

Overview

The use of storm windows as an energy conservation measure dates to the earliest days of the weatherization program, when it was one of **the** measures to install. It seemed logical, and the arguments went like this: First, windows represent the "thermal weak link" in any

TABLE 3-8 SIDEWALL INSULATION ECONOMICS

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

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	25
Initial R-value	3.8
Finished R-Value	12.9
Change in R-Value	9.1
Change in U-Value	0.186

Cd = 0.65

Assumes no savings due to air sealing.

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

and the arguments went like this: First, windows represent the "thermal weak link" in any house; adding storm windows increases the R-value from R-1 to R-2 , cutting the heat loss for this component in half. Second, storms can be used to effectively seal leaky primary windows against air leakage. Third, storms can increase the mean radiant temperature of the inside of the primary, resulting in increased thermal comfort. And finally, storm windows are relatively inexpensive, can be installed quickly, and help to increase the value of a home. While there is, indeed, some truth in all of the above statements, the bottom line is that in Virginia they are generally not cost-effective.

Let's consider the above arguments one-by-one: First, while windows are the thermal weak link of a house in terms of R-value, these windows typically don't account for much more than 10 to 15 percent of total wall area, and much less of total house surface area. Moreover, while an old style wood storm **will** more than double the R-value of a single-pane primary, an aluminum storm increases it only to about R-1.67, 25% less than a wood storm.

Using storm windows to seal against air leakage is not a good idea for two reasons: First, as discussed above, it turns out that these air leakage sites in the "neutral pressure plane" are not all that important in terms of energy savings. Second, because of moisture concerns, you don't want to use the storm as the air barrier. You want the primary window to be the barrier against air, and hence moisture, exfiltration. If the primary is leaky, the warm moist air will be able to leak into the space between the primary and storm, condense on the cold surface of the storm, and ultimately result in water damage to the sill and other window and wall components. Therefore, storm windows cannot be recommended as a measure for infiltration reduction.

The third argument, that storm windows can increase thermal comfort, does have merit. A person sitting in line of sight of a single-pane window can feel quite cold, even when the air temperature of the room is 70°F or above. Why? Because the warm body "sees" the cold interior surface of the window and radiates heat to it. By putting a storm on that window, the mean radiant temperature (MRT) of the inside of the primary is increased; thus, less heat will be radiated to it, and the person sitting in front of it will feel more comfortable. Some have argued (see, for example, Wilson and Belshe, 1988) that this increase in MRT will translate into energy savings, though we are aware of no studies which have documented this and none are assumed in the calculations herein. Regardless, the thermal comfort improvement is real.[9]

The final argument, that storms are relatively inexpensive and, therefore, cost-effective is dealt with in the Economic Analysis section below. It turns out that, while they are relatively inexpensive (compared to replacement windows) the savings are also quite modest.

Heat Loss Analysis

The analysis of the energy savings which will result from the installation of storm windows is straightforward. In this analysis we assume that the existing primary window is single-pane, wood sash with an R-value of 1.01, and the storm window being installed is an aluminum "triple track" with an overall R-value of 1.67. All energy savings are due to the increase in R-value alone. As discussed above, it is not appropriate to use storms as an air leakage reduction measure.

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[9] One approach here, as suggested by Wilson and Belshe (1988), might be to install storm window or, better yet, moveable insulation, on only the windows in those rooms where the clients spend most of their sedentary time, such as the living room/family room, and ignore the windows in rooms where thermal comfort concerns are not so important.

Energy savings, as usual, will vary with the value of the heat being saved and the number of degree-days. In Virginia, storm windows will save anywhere from $.23/ft^2 for a house on the coast heated with gas or oil at $11/MBTU, to $0.70/ft^2 for a house in the mountains with electric resistance heating at $23/MBTU.

Economic Analysis

As usual, the cost side of the equation is the least well determined. Virginia weatherization program data for FY 1988-89 taken from HWWs, yield material costs of $5 to $7 per ft^2; using an average reimbursement rate of 125% results in total installed costs of $11 to $16 per ft^2. However, one could argue that using this reimbursement rate to account for labor costs grossly inflates the cost for this measure, in that actual installation costs are actually much lower. Private sector quotes for aluminum triple track storms come in at $7 to $10 per ft^2. The installed costs of $4, $6 and $8 per ft^2 used in Table 3-9 are, if anything, perhaps a bit optimistic (i.e., low).

As shown in Table 3-9, even with these somewhat optimistic costs, storm windows are not cost-effective in most of the Commonwealth. The cost of conserved energy (CCE) ranges from about $14/MBTU to $42/MBTU, and simple payback times (SPTs) range from 5.7 years under the most favorable conditions (mountains and electric heat) to 35 years under the least favorable (coast and relatively efficient gas or oil furnace). Storm windows are cost-effective only with electric resistance heating, and then only at the low end of the installed costs.

The bottom line here is that storm windows are not cost-effective in most cases in Virginia. However, this analysis does not consider the non- quantifiable benefits of increased thermal comfort. While storms cannot be justified on the basis of energy savings, it may be appropriate to install them in certain selected rooms of a client's home in order to increase thermal comfort.

Replacement Windows

Overview

Replacement windows have been a very popular measure in the Virginia Weatherization Program over the years, and were still being installed in many homes in the most recent fiscal year. There are a number of reasons for the popularity of this measure: Clients like them because they improve the "look" and value of their home. Window manufacturers like them for obvious reasons. Crews like them because it's a "cleaner" job than installing insulation, and it requires skills which are readily transferable to the private sector. Finally, the weatherization agencies (subgrantees) in Virginia like them because, under the current reimbursement scheme, they can make money on them; current reimbursement policies favor measures, such as windows, with high materials costs and low labor costs. The only "downside" to replacement windows is they don't save much energy, which, when coupled with their high installed cost, results in really dismal cost-effectiveness, any way you measure it.

Numerous studies have documented the small savings and poor cost-effectiveness of replacement windows. A recent study of a low- and moderate-income energy conservation

TABLE 3-9 STORM WINDOW ECONOMICS

Region	Installed Costs		CCE	Value of Energy Saved								
				11 $/MBTU			13 $/MBTU			23 $/MBTU		
	Range	($/ft2)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$4.00	$21.16	17.5	0.5	NO	14.8	0.6	NO	8.4	1.1	YES
3400	Ave	$6.00	$31.74	26.3	0.3	NO	22.2	0.4	NO	12.6	0.7	NO
HDD	High	$8.00	$42.32	35.0	0.3	NO	29.7	0.3	NO	16.8	0.5	NO
Piedmont	Low	$4.00	$17.13	14.2	0.6	NO	12.0	0.8	NO	6.8	1.3	YES
4200	Ave	$6.00	$25.70	21.3	0.4	NO	18.0	0.5	NO	10.2	0.9	NO
HDD	High	$8.00	$34.26	28.4	0.3	NO	24.0	0.4	NO	13.6	0.7	NO
Mountains	Low	$4.00	$14.39	11.9	0.8	NO	10.1	0.9	NO	5.7	1.6	YES
5000	Ave	$6.00	$21.58	17.9	0.5	NO	15.1	0.6	NO	8.5	1.1	YES
HDD	High	$8.00	$28.78	23.8	0.4	NO	20.2	0.5	NO	11.4	0.8	NO

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	15
Initial R-value	1.01
Finished R-Value	1.67
Change in R-Value	0.7
Change in U-Value	0.391

Cd = 0.65

Assumes no savings due to reduced infiltration.

Assumes aluminum storms installed over single pane wood primaries, both approximately 80% glass.

program in Indiana (Hill 1991) found no significant savings (average savings of only 1.4%) in a sample of 41 houses which installed replacement windows.

In recent years the Virginia program has justified replacement windows on the basis of infiltration reduction. As discussed above, it is now well understood that the leaks around windows, because they are in the neutral pressure plane, do not contribute significantly to infiltration. Thus, whether one seals these leaks with caulking and weatherstripping or by the installation of replacement windows, the air sealing benefits are going to be the same – insignificant. Even if large savings from infiltration reduction could be obtained, the measure would still not be cost-effective because of the very high costs involved. (Table B-5 in Appendix B documents this.)

Heat Loss Analysis

The assumptions here are very similar to those described above for storm windows. The assumptions used are designed to make replacement windows look as good as possible: The replacement window were assumed to be wood or vinyl with a half-inch air space between the panes of glass, resulting in an overall R-value of 2.15. The windows being replaced were assumed to be the same as those for the storm window case -- single-pane, wood sash. Using these assumptions, annual savings range from a low of $.31/ft^2 (for $11/MBTU and 3400 HDD) to $.94/ft^2 (for $23/MBTU and 5000 HDD).

No savings due to decreased infiltration are assumed for two reasons. First, as discussed at length above, these savings from air leakage control in the neutral pressure are most likely insignificant. Second, as will be shown below, it is a moot point; that is, no amount of air sealing benefits are going to make replacement windows cost-effective.

Economic Analysis

As usual, the cost data are the least well determined part of the benefit-cost equation. Cost data obtained from 1988-89 HWWs suggest material costs on the order of $9/ft^2; using a 125% reimbursement rate to determine labor costs results in total costs of about $20/ft^2. However, as noted above in the discussion of storm windows, this reimbursement rate probably overestimates actual labor costs. Private sector cost quotes result in a figure of about $15/ft^2 for replacement windows. The figures used in Table 3-10 are $9, $14 and $19 per ft^2.

As clearly shown in Table 3-10, replacement windows are not cost-effective in Virginia except under the most favorable of circumstances -- namely, electric resistance heating in the mountains at an installed cost of $9/ft^2 or lower. The cost of conserved energy (CCE) for replacement windows ranges from about $21/MBTU to $64/MBTU, and simple payback times range from about 10 years to over 60. It should be apparent from these numbers that replacement windows simply do not produce cost-effective energy savings.

Summary of Engineering-Economic Analyses

Table 3-11 summarizes the results of the analyses for the five energy conservation measures discussed above. Annual savings, cost, simple payback time (SPT), benefit-cost ratio (BCR) and cost of conserved energy (CCE) are given for each of the measures. The savings given are those for the weighted average of fuel costs, $13/MBTU, as derived in Table 3-1, and for

TABLE 3-10 REPLACEMENT WINDOW ECONOMICS

Region	Installed Costs		CCE	Value of Energy Saved								
				11 $/MBTU			13 $/MBTU			23 $/MBTU		
	Range	($/ft2)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$9.00	$30.51	29.4	0.4	NO	24.9	0.4	NO	14.1	0.8	NO
3400	Ave	$14.00	$47.46	45.7	0.2	NO	38.7	0.3	NO	21.9	0.5	NO
HDD	High	$19.00	$64.41	62.0	0.2	NO	52.5	0.2	NO	29.7	0.4	NO
Piedmont	Low	$9.00	$24.70	23.8	0.4	NO	20.1	0.5	NO	11.4	0.9	NO
4200	Ave	$14.00	$38.42	37.0	0.3	NO	31.3	0.3	NO	17.7	0.6	NO
HDD	High	$19.00	$52.14	50.2	0.2	NO	42.5	0.2	NO	24.0	0.4	NO
Mountains	Low	$9.00	$20.75	20.0	0.5	NO	16.9	0.6	NO	9.6	1.1	YES
5000	Ave	$14.00	$32.27	31.1	0.3	NO	26.3	0.4	NO	14.9	0.7	NO
HDD	High	$19.00	$43.80	42.2	0.3	NO	35.7	0.3	NO	20.2	0.5	NO

ASSUMPTIONS:

Interest rate	12%
Inflation rate	5%
Discount rate	7%
Economic lifetime	20
Initial R-value	1.01
Finished R-Value	2.15
Change in R-Value	1.1
Change in U-Value	0.525

Cd = 0.65

Assumes no savings due to reduced infiltration.

Assumes old windows are single pane, wood sash, 80% glass; new windows are double pane with 1/2 inch air space, wood or vinyl, 80% glass.

TABLE 3-11 RELATIVE COST EFFECTIVENESS OF WEATHERIZATION MEASURES

Wx Measure	Measure-Specific Assumptions	Savings ($/yr)	Cost ($)	SPT (yrs)	BCR	CCE ($/MBTU)
Attic Insulation	R-4 to R-30 No inf. savings Cost = $0.40/ft2 Area = 1250 ft2 Lifetime = 25 years	$230	$500	2.2	5.4	$2.40
Sidewall Insulation	No inf. savings Cost = $0.80/ft2 Area = 1100 ft2 Lifetime = 25 yrs	$173	$880	5.1	2.3	$5.70
Advanced Air Sealing	30% reduction in initial ACH of 1.5 Volume = 10,000 ft3 Lifetime = 10 yrs	$69	$300	4.3	1.6	$8.10
Storm Windows	No inf. savings Cost = $6/ft2 Area = 100 ft2 Lifetime = 15 yrs	$33	$600	18	0.5	$26.00
Replacement Windows	No inf. savings Cost = $14/ft2 Area = 100 ft2 Lifetime = 20 yrs	$45	$1,400	31	0.3	$38.20

Assumptions for all measures:
- Real discount rate = 7%
- Value of energy saved = $13/MBTU
- Heating degree days = 4200
- "Average" installed costs
- Cd = 0.65

the "median climate" of 4200 HDD. The cost figures are the average costs from the analyses above. The measures are listed in order of cost-effectiveness by CCE.

When assessed in this light -- i.e., average costs and savings for the Commonwealth -- the results are quite clear. The first three measures -- attic insulation, advanced air sealing, and sidewall insulation -- are all cost-effective in Virginia. Storm windows and replacement windows are not.

Table 3-12 shows the expected savings when these three cost-effective measures are installed in a house similar to the RetroTech "A" house. The "before" house is completely uninsulated, with a infiltration rate of 1.5 ACH. The "after" case shows the effects of insulating the attic to R-30, blowing the sidewalls, and sealing enough air leaks to reduce the ACH by 30%. Note that work in other states, discussed above, suggests that this 30% reduction in infiltration could quite often be realized by the sidewall blowing alone.

The house before weatherization loses 50% of its heat through the uninsulated attic and sidewalls. Insulating just these two components cuts the heat loss by almost 40% and saves over $400 per year. The 30% reduction in air leakage, whether achieved by sidewall blowing or additional air sealing work, results in another 7% savings on the annual heating bill, bringing the total annual energy savings to about 45%. Assuming that these measures are installed for about $1500, the simple payback time (SPT) is 3.2 years and the cost of conserved energy comes out to about $3.50/MBTU.

The above, of course, assumes a totally uninsulated house. Savings on houses with some insulation, or with less air leaks, will not be quite this impressive. However, anecdotal evidence suggests that Virginia has a fair number of houses which fit this example. It appears (somewhat ironically perhaps in light of the Project RetroTech book) that sidewall insulation may in fact be extremely well suited to Virginia, precisely because of the nature of the low-income housing stock. Houses with no sidewall insulation which were "loosely" constructed to begin with are those which will yield the largest benefits from high density sidewall blowing.

Other Measures Less Amenable to Economic Analysis

There are some measures which simply are not as amenable to the above sorts of engineering-economic analyses. In some cases, the retrofit measure is too difficult to model, in others the engineering analysis would appear to be straightforward, but field results have not matched estimates that well. Therefore, no assessment of cost effectiveness is presented for these measures. Instead, we briefly present the current state of knowledge for each.

Heating Systems

There are two reasons for including heating systems in weatherization procedures -- 1) to improve their efficiency and save energy, and 2) out of concern for the heating system's impact on the health and safety of the occupants. The latter is of course the more critical. States which have begun addressing heating systems are finding that the health and safety concerns are indeed very real, with numerous houses failing basic safety inspections, and many of the heating systems presenting potentially life-threatening situations. The safety problem becomes especially serious as weatherization crews become better at sealing air leaks and reducing infiltration/ventilation. A good example of the sorts of deadly serious

TABLE 3-12 SAVINGS FROM ATTIC & SIDEWALL INSULATION AND ADVANCED AIR SEALING FOR AN EXAMPLE (RETROTECH "A") HOUSE

		Before			After			Savings	
Component	Area	R-Value	$/yr	%	R-Value	$/yr	%	MBTU/yr	$/yr
Attic	1250	4	$266	26	30	$35	6	18	$231
Walls	1110	4	$249	24	13	$73	13	13	$176
Windows	180	1	$152	15	1	$152	27	--	--
Doors	42	3	$12	1	3	$12	2	--	--
Floor	1250	4	$133	13	4	$133	23	--	--
Infiltration		ACH=1.5	$230	22	ACH= 1	$161	28	5	$69
			$1,042			$566		36	$476

Assumptions:
4200 HDD
70% AFUE natural gas furnace ($13/MBTU effective heating cost)
Only measures installed are attic and sidewall insulation, and advanced air sealing, together yielding a 30% reduction in ACH.

serious safety problems we need to be looking for is provided in an article by that name written for *Energy Exchange* (Hill, 1989). The energy savings from heating system work are less well-defined. First of all, there is a wide range of heating systems out there, and many different approaches to "improving them." Early work emphasized steady-state efficiency (SSE) improvements, such as by tuning, replacing burners, etc. Savings from "clean and tunes" appear to vary widely, from zero to 8%, due to two factors: widely varying initial conditions of the heating systems, and differing definitions of what actually comprises a "clean and tune" (Witte and Kushler, 1985, 1987; Warner and Claridge, 1986; Macriss, et al., 1984). Oil burner replacements with flame retention-head burners show more promise, with savings in the neighborhood of 10 to 20% (Hopkins, 1988; Berry and Witte, 1988). Other approaches, such as the installation of vent dampers, and intermittent ignition devices, were aimed at reducing stand-by losses. Vent damper savings appear extremely variable and highly dependent on the degree of off-cycle losses and the thermal communication between the furnace room and the living area. The studies in which their use has been investigated reveal little to no savings, on average (Berry and Witte, 1988; Wisconsin Energy Conservation Corporation, 1984; Witte and Kushler, 1987). High-efficiency furnace replacements are the only gas furnace "retrofit" with clear-cut savings (ranging from 15 to 35%) at this point in time (McBride, et al., 1988; Hall, 1988; Hewitt, et al., 1986; Ternes, et al., 1987; Macriss, et al., 1984). They are costly, but in many cases are cost-effective.

More recent work has focused on the whole system, and especially the ducts. Cummings, et al. (1990) found huge losses from leaky ducts. Losses from leaky or missing ducts have been found to be an especially serious problem in mobile homes, as discussed below.

Water Heating

Water heaters are typically the second highest energy user in a house after space heating. Furthermore, the potential savings are significant (though here also actual measured savings have generally not been as large as engineering models predicted.) It is difficult to accurately estimate energy savings because of the number of variables which affect how much energy is used to heat water in a home -- the amount of hot water use, the pattern of the use, inlet temperatures, where the tank is located, the length of plumbing runs, tank and pipe insulation, etc. The costs are small and measured savings in a number of programs which have installed water heater jackets or wraps suggest that the savings can be significant and cost-effective (Brown et al. 1987; Lucas 1986). Low-flow showerheads are also a common component of many other weatherization programs (e.g., Massachusetts, Wisconsin, New York).

Water heater wraps are currently a part of the Virginia Weatherization program and we would urge that they remain so. Procedures used to call for insulating the hot water pipe for a distance of at least 4 feet from the tank. This protocol should be expanded to include the cold water pipe as well. Infrared cameras (or a hand placed on the pipe) clearly show that the cold water pipe is equally effective at drawing heat out of the tank and dissipating it into the air.

Basements and Crawlspaces

It is extremely difficult to accurately model heat loss through basements and crawlspaces. Many factors affect this heat loss, including: Is the basement heated or not? How much of the wall is exposed to ambient air temperatures and how much is beneath the ground surface? What is the soil type and how moist is it? Are the heating system and duct runs in the basement/crawlspace? While we can't accurately estimate savings, we can offer these bits of accumulated wisdom. If the heating system and duct runs are in the basement don't insulate the floor above it; most of these losses will become heat gains to the floor above. If it's a crawlspace you might consider insulating the perimeter. For either basement or crawlspace you will of course want to seal the air leaks around the perimeter (as per the discussion under Advanced Air Sealing above), paying special attention to the cracks between sill plates, rim joists, and floor. Mobile homes are a special case (as discussed below) where insulating the floor via the belly board appears to be quite cost effective.

Mobile Homes

Mobile home weatherization in Virginia has traditionally resembled that done in site-built single-family housing, concentrating on such measures as caulking and weatherstripping and window and door replacements. However, our study of Virginia's 1988-89 weatherization program confirmed that these measures result in low savings for mobile homes (see Chapter 2). Indoor air quality is even more of a concern that in site-built homes, given the small volume of air involved and the high incidence of unsafe heating systems. Recent research has tried to find ways to produce energy savings and deal with safety concerns in this segment of the housing stock. Blower-door-directed air sealing, duct repairs, blown insulation of belly boards, and interior storm panels are the most often mentioned cost-effective measures (Judkoff, 1991; Judkoff, et al., 1990; Knight, 1989).

"How tight is too tight" takes on special significance because of the small volumes of air involved. And this becomes an extremely serious potential problem with wood and coal stoves in a mobile home.

Multifamily Housing

We did not address multifamily housing in this evaluation project. However, it is important to note that it, like mobile homes, has its own unique problems and cannot be weatherized as if it were a detached site built house. This is an especially important point as we saw in Chapter 2 that there were some agencies in Virginia that were weatherizing large numbers of units in multifamily complexes, applying the same measures -- primarily caulking, weatherstripping and water heater wraps -- as they would in single family detached housing. Unfortunately, these measures installed in a multifamily complex of attached units have little chance of saving significant amounts of energy. Air leaks identified by a blower door may be completely irrelevant, as the air leaking in may well be heated air from the neighbor next door. Bypasses are both different and potentially more significant than in single family detached housing. Water heaters are frequently located in utility closets which are typically within the heated envelope. While wrapping these water heaters may cut down on the air-conditioning load, it will have no effect on winter heating energy use, because the heat being "lost" from the water heater helps to heat the unit.

The largest savings in multifamily are usually to be found in improvements to the heating system. But here also, we are often talking about very different sorts of heating systems than those typically found in single family detached housing (Goldman, Greely, and Harris, 1988). In sum, there is great potential for cost-effective energy savings in multifamily housing, and Virginia would be well advised to deal with this at some point in the near future. While the selection of methods most appropriate for weatherizing this stock of housing is outside the scope of this research, suffice it to say that the methods and procedures discussed herein should not be assumed to be applicable to large multifamily units.

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Chapter 4: Testing New Weatherization Measures: The Pilot Study

Introduction

The heart of the Virginia weatherization evaluation project was the pilot study, designed to evaluate the energy savings and implementation of selected new weatherization measures in four local weatherization agencies. The study observed in the field how effectively some of the new measures used in other states perform in Virginia's housing stock and climate, as well as how capable Virginia weatherization crews are of learning to install these measures. This information contributed significantly to the overall recommendations of this project.

The study involved several steps, including:

1. the selection of pilot agencies and pilot homes,
2. installation of furnace elapsed-time meters to measure energy use before and after weatherization,
3. selection of new measures to be installed and development of installation standards for these measures,
4. training of pilot agency crews on the new measures and installation of measures in pilot homes, and
5. follow-up interviews with local coordinators, crews and clients.

Delays in the start of the project, and especially in final selection of pilot agencies, placed severe time constraints on the study. One adverse effect of these delays was the reduced number of dwelling units that could be included in the pilot, although this was also affected by the (non-pilot related) contractual production requirements of the involved agencies. However, the study did succeed in implementing the numerous tasks included in the pilot study design. The following sections briefly describe those activities, then present the quantitative results and discuss their implications for the program's effectiveness.

Pilot Study Procedures

The pilot study followed a design developed in late summer 1989. This section describes the study procedures and how they were implemented.

Measuring Energy Savings: The Use of Furnace Elapsed-Time Meters

An essential part of the pilot study was to measure the change in a house's energy consumption resulting from the weatherization work. While there are various means to measure consumption,[1] the use of furnace elapsed timers was selected because it is simple and inexpensive and, given the right weather conditions, can be employed in a relatively short period of time (12 to 20 weeks). It involves wiring elapsed time meters in parallel with the solenoid valve (in the case of a gas furnace) or the motor which drives both fan and oil pump (in the case of an oil burner). The meters record the run-time of the furnace which, when multiplied by the furnace's firing rate (in Btu/hr), gives energy consumption for a measurement period (usually a week). The procedure calls for obtaining timer readings and computing consumption weekly. Dividing this consumption by the heating degree-days for this period and the house floor area (in square feet), gives a measure of the house's energy intensity (Btu per sq. ft. per degree-day). By comparing the energy intensities for those weeks after the weatherization work to those before, the energy savings can be obtained. (See Appendix C.1 for a more complete discussion and a copy of the logging sheet used to record readings and compute energy intensities.)

Larry Kinney of Synertech Systems, Inc., provided the meters and; in September 1989, trained pilot agency personnel to install them and perform the necessary paperwork. A brochure (see Appendix C.2) was provided to clients to explain the program and the procedures. Agency personnel made weekly calls to clients to obtain the meter readings and performed the calculations. They provided VCCER with copies of the logging sheets for each house on a weekly basis. Overall, this system worked very well, although we 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 meters.

Selection of Pilot Study Agencies and Houses

Four local agencies participated in the pilot study: Community Energy Conservation Program (CECP) of Charlottesville; PEOPLE, Inc. of Abingdon; Rappahannock-Rapidan Community Services Center (Rapp-Rap) of Culpeper; and Total Action Against Poverty (TAP) of Roanoke. Selection of these agencies was based on getting a mix of large and small, urban and rural agencies and a diverse housing stock, as well as on agencies' willingness to participate. Despite some initial difficulties, including bringing two agencies in very late (mid-September), a lower number of units than anticipated, and a fire which destroyed TAP's offices in December,[2] most of the agencies participated in all aspects of the pilot to the extent possible.

Selection criteria used for pilot study houses included: (a) use of gas, oil or electricity in a thermostatically controlled space heating system; (b) no reported use of secondary heating fuels; (c) expectation of the client to remain living in the house for the course of the study; and (d) willingness of the client to report the meter readings over the telephone each week from October through April.

The original goal, laid out in the pilot study design, was to test the new procedures on 120 houses. However, due to time delays, the constraining selection criteria, and the production capabilities of participating agencies, 61 houses were ultimately selected.

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1 Including use of fuel bills (which is time-intensive, generally requiring 12 months of pre- and 12 months of post-retrofit data) or extensive instrumentation (which may require only a winter week in time, but can be prohibitively expensive).

2 The effects of the TAP fire were mitigated by our requiring copies of all paperwork on the pilot houses including furnace timer sheets; we had these in hand when the fire occurred. Although work was completed on these houses, it was delayed, and in many cases, this left little time for post-weatherization, cold weather monitoring of furnace run time.

Table 4-1 gives a breakdown of the pilot houses by agency, building type, floor area, and occupant characteristics. Two of the 61 houses were eliminated during the course of the study due to lack of client participation or excessive use of secondary fuel.

TABLE 4-1: PILOT STUDY AGENCIES AND HOUSES

	ALL	CECP	PEOPLE	RAP-RAP	TAP
Total Units	61	15[1]	10[2]	15	21
No. of Usable Units	59	14	9	15	21
# Units (Avg. Ft^2)					
- Site Built	43 (1166)	2 (1164)	6 (1303)	14 (981)	21 (1251)
- Mobile Homes	16 (668)	12 (664)	3 (617)	1 (871)	0 (-)
Avg. # of Occupants	2.7	2.4	1.6	3.3	2.8
% Owner-Occupied	80%	79%	89%	93%	67%

[1]Includes one site-built, oil-heat home later lost because client refused continued participation.
[2]Includes one site-built, oil-heat home later lost due to extensive use of secondary heating source.

Selection of Energy Conservation Measures To Be Included in Pilot Study

The process for selecting measures to be tested in the pilot study involved: (a) surveying the literature, especially other states' programs and evaluations; (b) assessing the experience and capabilities of local agencies, and (c) performing some preliminary engineering calculations and other analyses to assess the suitability of candidate measures to Virginia's housing stock and climate (see Chapter 3). Although this work identified a range of candidate measures, it was decided to test only a few in the pilot study because of two constraints: first, the questionable capability of the agencies to implement a long list of new measures all at once, and second, the ability to assess the effects of specific measures. As a result, the following new measures were selected for the pilot:

- high-density, blown wall insulation,
- advanced air sealing techniques,
- heating system inspections, and
- furnace cleaning and tuning.

With a few exceptions, most of the measures in the existing VACAA installation standards were retained.

Installation Standards

Installation standards were developed for the measures to be applied to the pilot study units. The full standards are given in Appendix C.3. In summary, they emphasize the new measures listed above, and retain certain of the current VACAA requirements, while downplaying others. For example, traditional interior caulking methods (e.g., caulking all baseboards, window and door frames, etc.) were de-emphasized in favor of advanced air sealing methods concentrating on heating system duct leaks and on large leaks and bypasses in the basement/crawl space and attic areas. In addition, window replacements were eliminated for the purpose of air leakage reduction; primaries could only be replaced if the window was so deteriorated that it could not be cost-effectively repaired. High-density, blown wall insulation and attic insulation were required for all appropriate site-built houses as defined in the standards. In mobile homes, traditional caulking was again de-emphasized in favor of advanced air-sealing techniques, belly-board insulation was required where possible, and window replacements were eliminated in all but the most extreme cases.

Training Sessions

Three trainings were held in conjunction with the pilot study. In September 1989, Larry Kinney of Synertech Systems, Inc., spent one day at each of the pilot agencies demonstrating *furnace elapsed-time meter installation* and data collection methods. This training went well, and the agencies were subsequently able to install meters, record readings, and tabulate results without major problems.

The second training session, on *heating system inspections and clean-and-tune techniques*, was held in November by R.W. Davis and Rudy Leatherman of the Corporation for Ohio Appalachian Development (COAD), Ohio. CECP hosted this training, which consisted of two days of classroom work, one day of field work at CECP, and one day of field work at each of the other pilot agencies. This training was attended by one or two people from each pilot agency. CECP and Rapp-Rap received some additional training in performing furnace clean-and-tunes as part of their day of field work, although only Rapp-Rap felt comfortable with carrying out clean-and-tunes after this instruction.

The classroom portion of this training went well, although some weatherization staff felt that too much information was covered in the short time period. (For additional reactions of weatherization staff to all of the training sessions, see "Weatherization Staff Reactions", below.) However, the day of field work at CECP presented some problems, which stemmed mainly from the trainers not visiting the homes before the day of the training (e.g., one homeowner refused to let them work on his furnace, another home had a brand-new furnace). The field work at the other agencies proceeded without similar difficulties. Availability of inspection equipment caused a few problems at the training (but more problems later in the process--see "Heating System Work", below). At the training, it became apparent that the computerized inspection equipment (at $2500 per inspection kit) is vastly superior to the older chemical kits (at about $700 each for refurbishing the components VACAA already had; purchasing all new equipment for these kits would have come to about $1200). For the inspections, it was possible to make-do with the chemical kits, but the large number of tests needed to perform a clean-and-tune made use of the older equipment extremely time-consuming. Fortunately, VACAA was able to borrow a computerized inspection kit for use by the agency doing the clean-and-tunes.

From observations at the trainings as well as follow-up interviews with the weatherization staff, it is clear that the training was too short. At least another day of field work would have been helpful in familiarizing the inspectors with their tasks. In addition, it became clear that some follow-up training, a month or so after the initial training session, is required. Agency personnel had many questions about unusual situations they encountered in the field, which some follow-up training would help to resolve.

The third training, hosted by TAP in December, covered *high-density wall insulation and advanced air-sealing techniques*. The trainers were Rana Belshe and Tom Wilson of Residential Energy Conservation Consulting Group, Wisconsin, and Jim Fitzgerald of Fitzgerald Contracting, Minneapolis. This training was more widely attended, with two or three people from each agency (usually coordinators, estimators, and/or crew chiefs) and several crews from TAP present. One day was spent in the classroom, outlining principles of air movement and heat loss and techniques for wall insulation, then two days were spent in the field at TAP, practicing air-sealing methods and learning to insulate walls from both inside and outside the house. An additional day of field work was spent at each pilot agency. Despite snowstorms and cold weather, this training went very well. The only problem was that the agencies' blowers, which worked adequately for loose-fill attic insulation, did not work so well for high-density wall insulation. Difficulties included lack of feed gates for controlling insulation flow, malfunctioning remote controls, and poor blower seals. Repairing blowers took several weeks, in some cases cutting into the time planned for weatherization of pilot study homes (and thereby shortening the amount of post-weatherization energy consumption data available).

Because one of the trainers (Jim Fitzgerald) was available to return for a second visit, a day of "follow-up training" was scheduled at TAP in February 1990 after some of the pilot houses had been weatherized. By using an infrared camera and quizzing the crew chief on his decision-making process, the trainer ascertained that the TAP crews were doing a good job of achieving a high-density insulation pack in the areas that they insulated (achieving the proper density is key to the success of this method), but were missing a few key bypasses (e.g., areas above windows, kneewalls). We conclude that the length of the initial training was fine, but that a follow-up session, to help crews fine-tune their skills after having had a chance to practice a bit, is very important in achieving optimum savings from these measures. An infrared camera is an invaluable tool for this training.

Weatherization Work and Documentation

Armed with this training and the installation standards, the four pilot agencies set out to perform the necessary work on the pilot houses.

In addition to installing the measures described in the standards, pilot agencies were required to take blower door readings before and after specific sets of measures were installed, and to record the number of person-hours required for installation of each measure. A series of forms provided to the agencies (including a logging sheet, an air leakage and bypass report and a heating system inspection report) were completed by agency personnel and submitted as documentation of the work performed (these forms are included in Appendix C.4).

Treatment of the pilot study homes took place in two steps. Heating system inspections were done from late November through February. Clean-and-tunes, done only by Rapp-Rap, took place at the same time. The homes were weatherized from mid-December 1989 through the beginning of March 1990. In some agencies, heating system inspections were done prior to the weatherization measures; in others the heating system work was done while crews were installing the remaining measures.

Inspections of 48[3] of the 59 pilot study homes were carried out between late April and mid-May, with each house visited by a VACAA field representative and at least one member of the VCCER project team. Following an inspection report form, reviewing the agency documentation for the house, and using a blower door, the inspectors examined the installation quality and tried to identify areas missed and other factors that might affect energy consumption. At the time of inspection, the clients were interviewed to ascertain their energy use behavior (e.g., thermostat settings, use of supplemental heat) and any changes in the house or heating system that occurred during the winter. This information is extremely important in the analysis of the energy consumption data; data from two mobile homes were

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3 Inspections could not be conducted at 11 houses (3 at CECP, 3 at RAPP-RAP, and 5 at TAP) because the client could not be contacted or was not at home.

disqualified because of a faulty thermostat in one case and modification of the furnace in the other. Clients were also asked about their satisfaction with the weatherization work and perceived changes in the comfort of their homes (see Appendix C.5 for client interview questionnaire and house inspection form.)

Follow-Up Agency Interviews

After the inspections, telephone interviews were conducted with the agency coordinators, pilot house estimators and heating system inspectors; in addition, most crew members who participated in the pilot provided completed questionnaires (see Appendix C.6 for the interview forms). These perceptions of agency personnel were very important in assessing the effectiveness of the training and the ease of implementation of the measures tested, and in identifying specific problems encountered.

Analysis of Results

The data collected from the elapsed-time meter records, the crew logging sheets, and the inspections, as well as the client and agency interviews, provided the basis for analysis of energy savings and cost-effectiveness. Additional labor and warehousing cost information was obtained from the agencies. Numerical data on each house were logged into a computer database and analyzed using dBase and SAS statistical analysis software. Results are presented in the following section.

Pilot Study Results

This section first describes the work that was conducted on the pilot houses then presents the analysis of energy savings, cost-effectiveness, and agency and client reactions.

Heating System Work

Review of other states' programs and the literature indicated that one important new area for Virginia weatherization is heating system improvements. Studies in other states showed that cost-effective energy savings can be achieved through duct sealing, oil burner replacement, and even furnace replacement in some cases. More importantly, inspections of systems revealed that safety problems were prevalent in the heating systems of low-income residents. Moreover, in cases where occupants are exposed to combustion gases or gas leaks, weatherization can make conditions worse by tightening up the house and reducing infiltration/ventilation. It became obvious to VACAA and the evaluation team that Virginia could no longer ignore heating systems in weatherization.

The pilot study aimed to assess two heating system measures believed to be within the capabilities of Virginia weatherization agencies: (a) basic inspections for safety and efficiency, and (b) furnace cleaning and tuning. Specifically, the pilot study addressed the following questions:

- with adequate training, are local weatherization agencies in Virginia capable of performing basic inspections on heating systems?
- with adequate training, are local weatherization agencies in Virginia capable of performing improvements such as furnace cleaning and tuning?
- what level of training is "adequate" for these purposes?
- what are the typical efficiencies and safety conditions of heating systems in Virginia weatherization units--i.e., is there a need for heating system work?
- what are the typical labor requirements for inspections and "clean & tunes"?

- what are the equipment needs for efficient and effective heating system work?

Heating Systems in the Pilot Study

Because of the constraint imposed by the method used to monitor energy consumption in the pilot study (i.e., use of furnace elapsed-time meters), all pilot units had thermostatically controlled natural gas or oil (plus a few electric and propane) furnaces. While this offered the opportunity to examine heating system measures on these devices, the study could not address measures for other systems, such as solid fuel stoves or non-thermostatically controlled oil or gas burners.

Table 4-2 shows the assortment of types of heating fuel and distribution systems in the four pilot agencies. The fuels are almost evenly split between natural gas and oil with only three units using propane or electric heat. Nearly nine in ten of the systems used forced air distribution; the remaining distribution types included floor furnaces, gravity, and boiler systems.

TABLE 4-2: FUEL TYPES AND HEATING SYSTEM IN PILOT UNITS

	Total	Fuel Type				Furnace/Dist. Type*			
	Units	Gas	Oil	Electric	Prop.	FA	FF	G	B
CECP	14	2	10	2	--	14	--	--	--
PEOPLE	9	5	3	--	1	9	--	--	--
RAPP-RAP	15	3	12	--	--	11	4	--	--
TAP	21	17	4	--	--	18	--	2	1
TOTAL	59	27	29	2	1	52	4	2	1

* FA= forced air; FF= floor furnace; G=gravity furnace; B=boiler

Inspections, Safety Problems, and Repairs

Heating system inspections were done on 44 of the 59 pilot units. All four agencies did some inspections, although 95% of the inspections were performed by three of the agencies. The inspections of combustion furnaces and water heaters utilized the Heating System Inspection Report given in Appendix C.4. The form called for basic information on the system, identification of fuel leaks, responses to 21 visual inspection questions, test results on flue gas measurements and steady-state efficiency, and a response for further work required, if any.

Table 4-3 gives the results of the inspections. Safety problems were discovered in 13 (30%) of the 44 units inspected. Problems included unsafe flues, fuel leaks, and miscellaneous others (e.g., a cracked heat exchanger, a bad burner, a faulty gas valve). Non-safety repair needs were cited in 4 other units including cleaning the blower and replacing a nonfunctioning furnace.

TABLE 4-3: HEATING SYSTEM SAFETY AND REPAIR PROBLEMS

	Total Inspections	Units With Safety Problems	Safety Problems Encountered Safety: Bad Flue	Safety: Fuel Leaks	Safety: Other*	Non-safety Repairs
CECP	2	1	1	1	-	1
PEOPLE	9	1	-	-	1	3
RAPP-RAP	14	5	3	-	2	1
TAP	19	6	3	3	1	1
TOTAL	44	13	6	4	4	6

*other safety problems include cracked heat exchanger, bad burner, faulty gas valve.

One potential problem identified early in the study concerned local agencies' ability to respond to heating system problems once they were discovered. The Virginia Department of Social Services agreed to provide fuel emergency funds of up to $700 per unit to hire contractors to fix serious safety problems and set up a response procedure (see DSS Memo included in Appendix C.7). Early in the pilot study, the DSS program was used to replace a non-functioning furnace in one pilot house. However, after the December 1989 cold snap, the DSS emergency fund was depleted and could not support additional furnace repair. After the DSS fund was depleted, VACAA approved use of weatherization funds for material costs of needed repairs which the pilot agencies felt capable of performing themselves.

Local agencies ended up using several means of getting necessary repairs done. As shown in Table 4-4, most were done by the weatherization heating system inspector. In two cases, Virginia Housing and Community Development Emergency repair funds were used. In one case, the landlord paid for the repair. Gas utilities fixed leaks in a number of cases.

TABLE 4-4: HEATING SYSTEM REPAIRS

	Units Needing Repairs	Performed by: Pilot Agency	Housing Rehab	DSS	Utilities	Landlord
CECP	2	1	-	1	-	-
PEOPLE	4	3	-	-	-	1
RAPP-RAP	6	6	-	-	-	-
TAP	6	2	2	-	2	-
TOTAL	18	12	2	1	2	1

Furnace Efficiencies and Effect of Clean and Tune

One agency, Rapp-Rap, went beyond inspections and performed some basic cleaning and turning of furnaces in ten units. Typical measures performed are listed in Table 4-5. As mentioned above, while the inspectors in the other agencies used chemical testing kits to test flue gases, the Rapp-Rap inspector used computerized testing equipment which produced more reliable results in less time.

TABLE 4-5: TYPICAL FURNACE CLEAN & TUNE

- **Clean Heat Exchanger**
- **Adjust Draft**
- **Adjust Combustion Air**
- **Adjust Pump Pressure**

Table 4-6 gives the average values for steady-state efficiency (SSE) for the inspected furnaces. The overall average SSE for 41 units was 75.1%. Gas units ranged from a low of 70 to a high of 85%; the range for oil was 62 to 83%. Six of the inspected oil furnaces (29%) had a SSE below 72%.[4]

TABLE 4-6: STEADY-STATE EFFICIENCIES OF INSPECTED FURNACES

	# Units	Ave. SSE Before	Ave. SSE After	% Change
Inspection:				
Oil	21	74.9%	--	--
Gas/Propane	20	75.9%	--	--
Inspect. + Clean & Tune:				
Oil	10	75.1%	78.5%	+4.8%

The simple cleaning and tuning done by Rapp-Rapp on nine units (one unit had no post SSE test) resulted in an average SSE improvement of 4.8% (difference in efficiency significant at the 5% level). In three of the cases, the SSE increased by more than 6% (in one case by 18%) after the clean and tune.

Weatherization Work

As discussed above under "Selection of Energy Conservation Measures," the weatherization work emphasized in the pilot study included a combination of new methods and existing VACAA measures. For work on mobile homes, the standards implied little more than VACAA's existing requirements. However, not all pilot agencies were fully "up-to-speed" in implementing these requirements. The pilot standards stressed duct and duct register boot sealing, and sealing large holes such as utility penetrations, while downplaying caulking. Likewise, bellyboard floor insulation was required where possible, and window and door replacements were allowed in cases of severe disrepair but de-emphasized. The standards were thus somewhat different from the traditional practices in most of the pilot agencies.

For site-built houses, however, the standards went well beyond both VACAA's requirements and the agencies' practices. The pilot agencies were asked to employ advanced diagnos-

[4] To put these numbers in perspective, many furnace programs call for an oil burner replacement if the SSE is 72% or less.

tics, bypass and air leak sealing, and high-density, blown sidewall insulation. Existing measures such as domestic hot water insulation and attic insulation with venting were also included, but interior caulking and window/door replacements were de-emphasized as air leakage control measures. (See Installation Standards in Appendix C.3.)

Measures Installed

Figure 4-1 and Table 4-7 give data on the measures installed in the pilot houses. All housing units had some air sealing. This ranged from traditional caulking and weatherstripping to application of the advanced diagnostics and large hole sealing techniques that were the subject of the air sealing training.

TABLE 4-7: PERCENT OF PILOT UNITS RECEIVING INDIVIDUAL MEASURES[1]

		TOTAL	CECP	PEOPLE	RAPP-RAP	TAP
# Units	SB	43	2	6	14	21
	MB	16	12	3	1	0
Air Sealing	SB	100%	100%	100%	100%	100%
	MB	100%	100%	100%	100%	100%
Dom. Hot Water	SB	79%	50%	83%	64%	91%
	MB	50%	42%	100%	0%	--
Duct/Boot Sealing	SB	37%	50%	50%	36%	33%
	MB	81%	83%	100%	0%	--
Wall Insulation	SB	40%	50%	100%	14%	38%
Attic Insulation	SB	65%	50%	100%	100%	33%
Attic Venting	SB	79%	50%	100%	93%	67%
Floor Insulation	MB	25%	17%	67%	0%	--
Window Repl. (≥1)	SB	19%	0%	0%	7%	33%
	MB	81%	75%	100%	100%	--
Door Repl. (≥1)	SB	28%	0%	33%	7%	43%
	MB	75%	67%	100%	100%	--

[1]SB = Site-built houses; MB = Mobile homes

As discussed above, the pilot standards posed few new requirements for mobile homes. However, much of that which was new, was not fully implemented by the pilot agencies. While the installation standards called for blown bellyboard floor insulation where applicable, only two bellyboards were blown, both by PEOPLE. CECP installed batt floor insulation in two mobile homes but did not attempt to blow the belly boards in ten other mobile homes.

Although window and door replacements were de-emphasized in the standards, they were still a popular practice in the pilot mobile homes. Thirteen of the 16 pilot mobile homes had an average of 7 window replacements each. Twelve of the 16 had at least one new door installed.

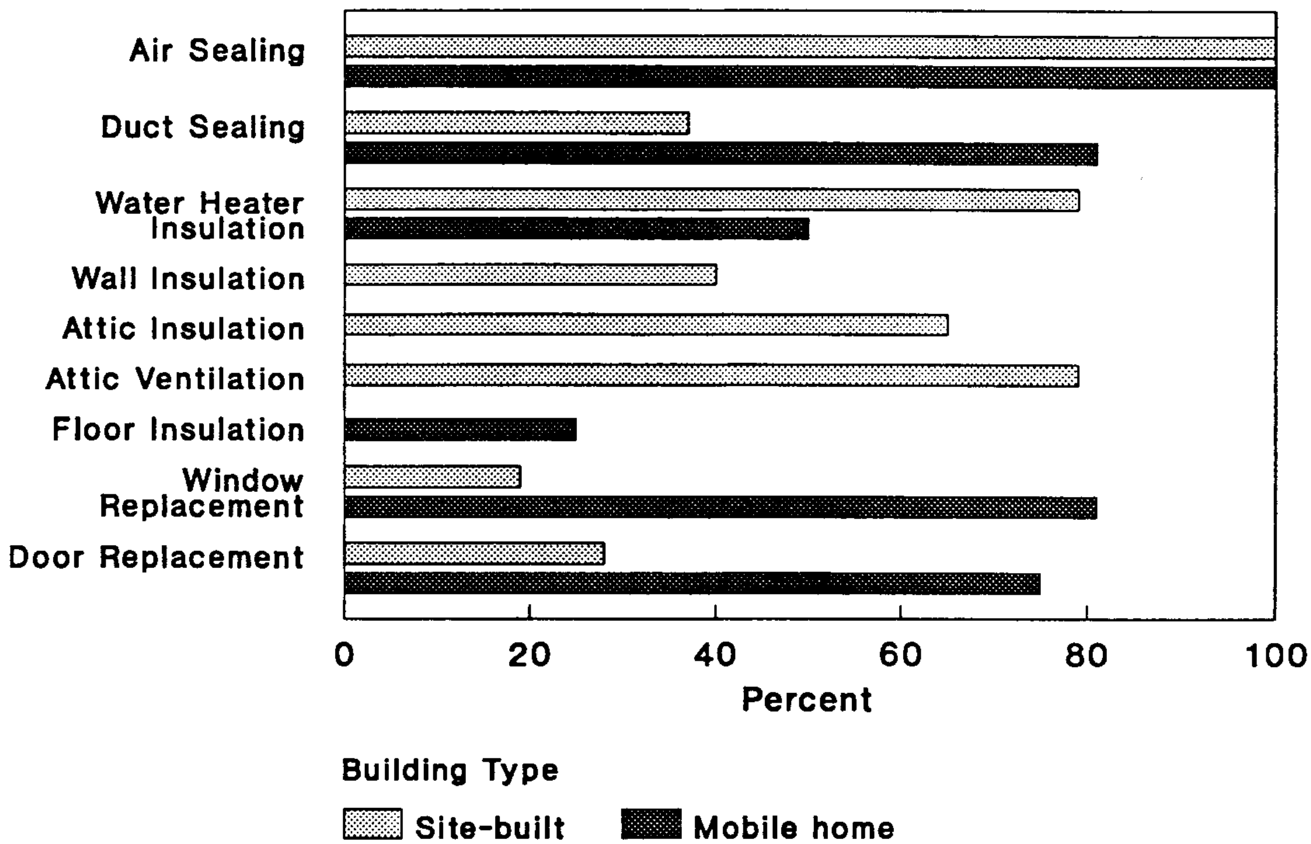

Figure 4-1. Percentage of site-built single-family and mobile homes weatherized in pilot study which received specified measures.

One exception to this general pattern of not fully implementing the new requirements was the emphasis given to duct and duct boot sealing which was applied to 81% of the mobile homes.

While the mobile home work resembled traditional weatherization, the work on site-built houses was quite different. In many houses, air sealing focused on major leaks and by-passes. High-density cellulose was blown into walls of 17 houses (40% of site-built units). Of these, 10 were blown from the outside and 6 were blown from the inside; in one house walls were blown from both inside and outside. Only one-fifth of the site-built houses (8) received windows, and these averaged only two windows each. Twelve of the 43 houses received an average of one door each.

Table 4-7 also shows the variation in measures installed among the pilot agencies. It gives by agency the percentage of applicable units in which the different measures were applied. Of particular note is that PEOPLE blew sidewall insulation in all of its 6 pilot site-built homes; TAP applied wall insulation in 8 of its 21 site-built units. CECP had only 2 site-built homes among its pilot units, and was able to insulate walls in only one of these. Rapp-Rap blew wall insulation in only 2 of its houses, due to two factors: an unexpected number of homes with *existing* wall insulation, and a reluctance to do inside insulation jobs, which would have been required given their predominantly brick housing stock.

Quality of Installation

The utility of weatherization depends not only on the measures installed, but also on the quality of installation. In order to properly interpret the data on energy savings, as well as assess the effectiveness of the training and the capabilities of Virginia local agencies, it is important to evaluate the quality of the work performed in the pilot study. This assessment is largely subjective since it is based on the inspections of 48 of the 59 pilot homes after weatherization was completed; at this stage much of the work is covered up and evaluation can be made only by visual inspection and by use of the blower door. However, some of the TAP houses were also visited with an infrared camera. This offered some valuable insight into the quality of work and demonstrated the camera's utility in monitoring wall insulation and bypass sealing work.

It should be noted at this point that the pilot agencies did not have an easy task in this study. While trying to maintain their contracted production schedule, they were asked to learn and apply several new measures with minimal training and no on-site supervision. The meas-ures themselves, especially building diagnostics and bypass identification, are not easily transferred through conventional training, but rather are learned through experience. The diagnostic approach stressed in the study is quite foreign to most Virginia weatherization personnel. As a result, one should not expect perfect implementation of weatherization measures according to the installation standards. The pilot study should be viewed as a first step. With more training and experience, the quality of installation, as well as the time re-quirements, are likely to improve.

CECP. CECP had a disappointingly low number of site-built houses (2) in the pilot. The lack of site-built units provided little opportunity to demonstrate innovative work. Most work on mobile homes resembled traditional weatherization, with heavy reliance on windows and doors. Sealing of large holes and duct register boots was generally good. Less attention was given to sealing the duct runs, with one exception where the ductwork was exposed (there was no belly board). CECP's reluctance to blow insulation into bellyboard cavities was clear, as it passed up some excellent opportunities, citing low clearance, presence of permanent skirting, and bad working conditions as reasons not to insulate. CECP blew sidewalls from the inside in one site-built house, and the work appeared to be good. The agency has taken the initiative to gain additional experience in wall insulation and bypass sealing in some non-pilot units. CECP did very few heating system inspections; some of their pilot homes were weatherized before the necessary inspection equipment was available.

PEOPLE. PEOPLE did the most careful and complete implementation of new measures of the four agencies and they gained the most experience in wall insulation and bypass sealing. PEOPLE's housing stock of old, large houses was also well-suited to the new measures, as wall, basement, and attic bypasses were quite prevalent. In its careful efforts to implement the measures, however, a great deal of time was spent, and this is likely to affect the cost-effectiveness of its pilot work. The agency did an effective job of blowing sidewall insulation from both inside and outside and in identifying and accessing bypasses. It showed no reluctance to cut into walls or ceilings to access areas needing insulation. PEOPLE demonstrated that Virginia agencies have the capability of understanding and applying advanced diagnostics and sealing techniques. In certain complex houses, some bypasses were missed, but these were generally minor. PEOPLE is continuing with wall insulation and bypass sealing in some of its non-pilot units. In mobile homes, the agency did a very good job of blowing insulation into the floor cavity up through the bellyboard. However, PEOPLE did not adequately address duct sealing in the pilot houses. Upon inspection, leaking ductwork and register boots appeared to be the major remaining sources of heat loss in several houses. PEOPLE did heating system inspections in all their houses, and in addition cleaned several furnace blowers.

RAPP-RAP. Rapp-Rap gained the most experience in heating system work, performing furnace clean-and-tunes on most of its pilot houses. It should be noted that Rapp-Rap volunteered for the additional task of doing clean-and-tunes, and carried them out very well. Perhaps because of the time required for this, the agency installed sidewall insulation in only 2 of its 14 site-built houses, both from the outside. Although some of the houses had existing wall insulation, others appeared to be good candidates for inside blowing of wall insulation. Inspection of several houses was hampered by the unavailability of a blower door. However, there was evidence of good air sealing and bypass sealing work in those houses inspected with use of the blower door. Again, Rapp-Rap is doing additional wall insulation and bypass sealing in its non-pilot homes.

TAP. TAP's involvement in the pilot study was affected by a number of factors, including coming into the study late, its December fire, and a number of complex houses. Despite these problems, the agency had the most pilot houses and the most sidewall insulation jobs of the four agencies. At Fitzgerald's follow-up training session using the infrared camera, TAP's wall insulation blowing was shown to have achieved a solid, high-density pack. However, the follow-up also showed that TAP missed several bypasses which allowed cold air to penetrate interior wall and floor cavities. Likewise, on inspection, many of the jobs were shown to be incomplete: interior partition walls were open to leaky tongue-and-groove floors, exterior walls were not blown, some kneewall and porch roof connection bypasses were missed. While the agency proved it can blow sidewall insulation, it needs additional training and experience in diagnostics of air leakage, bypass and duct leakage problems.

Costs of Weatherization

An important part of the pilot study was to determine the actual costs of implementing specific measures. Since VACAA's current reimbursement system pays local agencies based on material costs multiplied by an agency-specific reimbursement rate, there was no information available on the labor costs associated with different measures. Therefore, information on actual costs was essential for calculating the cost-effectiveness of the pilot work. In addition, cost data were needed in order to assess the viability of specific measures under the current reimbursement system.

On-site cost information came from the pilot study logging sheets that local agency crew supervisors were required to fill out for each job (the logging sheet is in Appendix C.4). Information included the materials cost and labor time by measure. Additional data were supplied by the local agencies on labor wage rates, materials warehousing costs, and program support and administration costs (see Table 4-8).

TABLE 4-8: PILOT AGENCY COSTS INFORMATION*

Crew Wages (including benefits)	**$8.11/hour**
Estimator/heating system inspector wages (including benefits)	**$11.16/hour**
Materials storage & handling (as a percent of purchased material cost)	**9.96%**
Program Support & Administration	**$466/house**

* All figures are averaged over the 4 pilot agencies, weighted by the number of pilot units each agency weatherized. Costs are derived from each agency's Program Planing Document for Fiscal Year 1990 and discussion with agency personnel.

Costs by Measure

Table 4-9 gives the average materials and labor costs by measure for the pilot units by building type. Total on-site costs (sum of materials and labor) and the ratio of labor cost to materials cost is also given. Materials costs include warehousing. It should be noted that pilot labor costs were greater than one would expect under normal conditions for two reasons. First, additional time was required in the pilot to take several intermediate blower door readings during the course of weatherization and to document the work. These blower door readings also slowed the pace of work by requiring that crews not work on different measures simultaneously. This was necessary to determine the infiltration reduction attributable to different measures, but it definitely added to work time. Second, in applying the new measures, crews were "learning by doing." With more experience labor costs would probably decrease.

Figures 4-2 and 4-3 display some of this data graphically. Figure 4-2 gives the average installed costs for measures that averaged less than $50 per house; these included estimation, heating system inspection, duct sealing, and insulating the hot water heater.

Figure 4-3 gives average installed costs for measures that averaged more than $50 per house. These include window and door replacement, mobile home floor insulation, attic insulation and venting, and blown wall insulation. Wall insulation proved to be the most costly measure and the most labor-intensive measure as well. This is shown by the distribution of materials and labor costs in Figure 4-3 and by the ratio of labor-to-materials cost given in Table 4-8 and Figure 4-4. At a labor-to-materials cost ratio of 2.9 to 1, sidewall insulation exceeds all other high-cost measures by nearly five times. In terms of VACAA's reimbursement rate, an agency installing just wall insulation, at the average scale and pace of the pilots, would require a reimbursement rate of 290% to cover just its labor costs. Despite its high cost, wall insulation was shown to be one of the most cost-effective measures for Virginia weatherization in our engineering analysis (see Chapter 3). Therefore, its high cost and labor-intensive nature should definitely **not** be deterrents to its implementation.

It bears repeating that the labor-to-materials cost ratio experienced in the pilots may not be a reasonable approximation of costs of future application of wall insulation. With more experience and training it is believed that labor time will be cut substantially. The experience of the VACAA-run crew in the Shenandoah area (which has been installing wall insulation more quickly than the pilot agencies) supports this notion.

TABLE 4-9: AVERAGE MATERIALS AND LABOR COSTS FOR PILOT UNITS BY MEASURE[1]

Measure	Bldg Type	N	Materials Cost($)	Time(hr)	Labor Cost	Labor Cost to Material Cost	Total On-Site Cost
Estimation	SB MB	43 16	0 ±0 0 ±0	2.4 ±0.2 2.1 ±0.2	27 ±3 24 ±3	-- --	27 ±3 24 ±3
Heating System Inspection	SB MB	38 6	0.4 ±0.1 0 ±0	1.3 ±0.1 1.2 ±0.1	15 ±1 13 ±1	13.0 ±1.8 --	15 ±1 13 ±1
Air Sealing	SB MB	42 10	112 ±13 36 ±13	6.3 ±1.3 2.6 ±0.7	51 ±10 21 ±5	0.5 ±0.1 0.9 ±0.3	163 ±20 57 ±15
Duct Sealing	SB MB	16 13	10 ±2 18 ±4	0.5 ±0.1 3.3 ±0.9	4.0 ±0.5 27 ±8	0.4 ±0.1 2.1 ±0.5	14 ±2 45 ±10
Hot Water Blanket	SB MB	34 8	16 ±0.4 11 ±2	0.5 ±0.1 0.6 ±0.1	4.2 ±0.6 5.1 1.0	0.3 ±0.0 1.0 ±0.8	20 ±1 16 ±2
Wall Insulation	SB	17	262 ±27	82 ±8	666 ±85	2.9 ±0.3	928 ±72
Attic Insulation	SB	28	256 ±18	6.5 ±0.8	53 ±7	0.2 ±0.0	309 ±22
Attic Venting Only	SB	7	84 ±9	1.6 ±0.2	13 ±1.4	0.2 ±0.0	97 ±9
Floor Insulation	MB	4	242 ±41	17 ±6	134 ±50	0.6 ±0.3	376 ±50
Window Replacement	SB MB	3 13	274 ±16 235 ±88	2.3 ±0.8 6.5 ±1.0	19 ±7 53 ±8	0.1 ±0.0 0.2 ±0.0	293 ±14 288 ±46
Door Replacement	SB MB	5 12	160 ±15 158 ±20	4.9 ±1.2 2.4 ±0.4	40 ±10 20 ±4	0.3 ±0.1 0.1 ±0.0	200 ±16 177 ±23

*SB = Site-built house, MB = Mobile home; figures are average per house ± standard error.

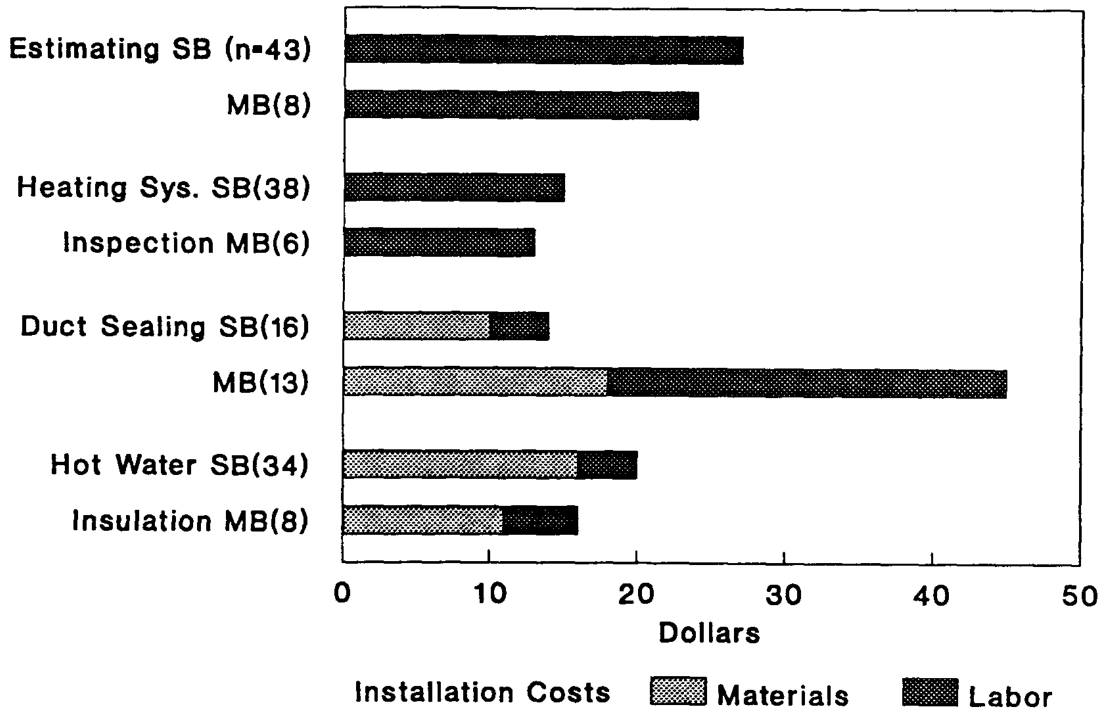

Figure 4-2. Average on-site installation costs (broken down into materials and labor components) of pilot study measures costing less than $50 per unit.

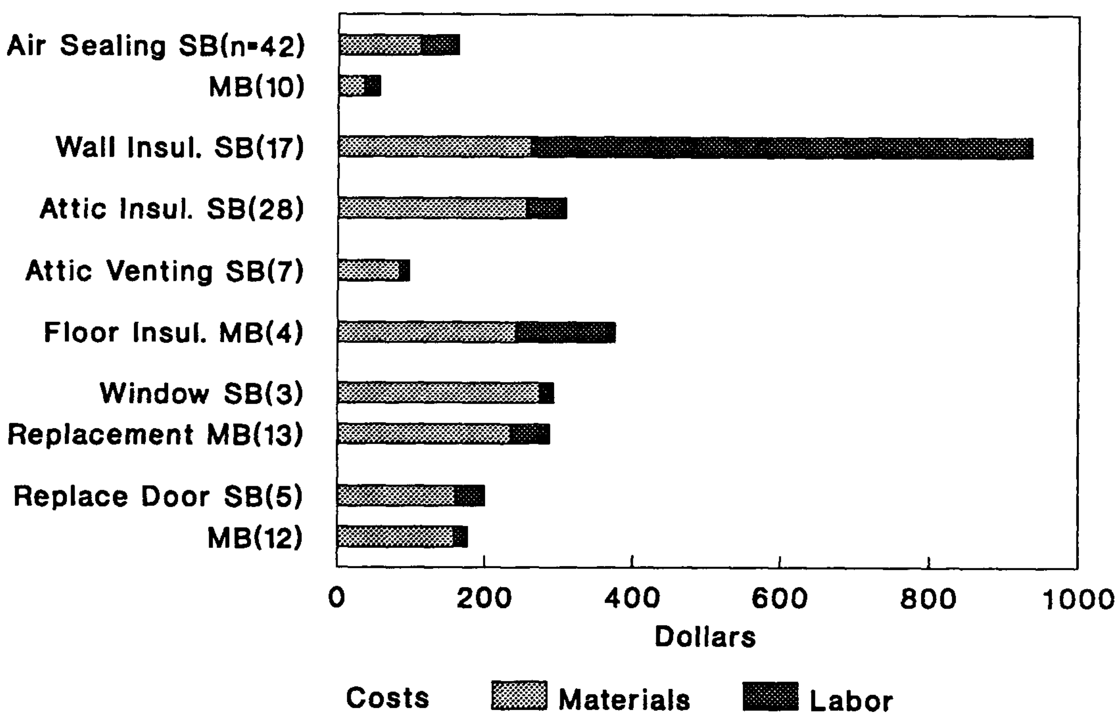

Figure 4-3. Average on-site installation costs (broken down into materials and labor components) of pilot study measures costing between $50 and $1,000 per unit.

TABLE 4-10. WEATHERIZATION COSTS IN PILOT UNITS BY AGENCY[1]

	AVERAGE		CECP		PEOPLE		RAPP-RAP		TAP
	SB	MB	SB	MB	SB	MB	SB	MB	SB
Materials Cost[2] ($)	553 ±47	442 ±68	319 ±68	364 ±70	996 ±132	747 ±127	375 ±39	462	568 ±57
Time (person-hours)	54 ±8	22 ±4	54 ±38	21 ±5	109 ±19	25 ±4	25 ±6	18	57 ±12
Labor Cost[3] ($)	446 ±64	183 ±32	444 ±307	179 ±42	903 ±158	213 ±35	213 ±50	153	471 ±97
On-Site Cost[4] ($)	1000 ±100	626 ±91	763 ±375	543 ±104	1900 ±247	960 ±161	588 ±71	614	1039 ±134
Total Cost[5] including Program Support ($)	1466 ±100	1092 ±91	1229 ±375	1009 ±104	2366 ±247	1426 ±161	1054 ±71	1080	1505 ±134
Cost Based on 250% Reimbursement Rate	1258 ±106	1005 ±154	725 ±155	828 ±159	2265 ±301	1699 ±290	853 ±90	1050	1292 ±129

[1]Average per house, ± standard error; SB = site-built houses, MB = mobile home.
[2]Materials cost includes costs of warehousing.
[3]Based on crew & estimator/heating system inspector wages, averaged across 4 pilot agencies.
[4]Defined as materials costs + on-site labor costs.
[5]Defined as on-site costs plus all off-site wx-related costs per house, averaged across 4 pilot agencies. Program support costs taken from FY90 Planning Documents.

Costs by Agency

Table 4-10 gives average unit costs for the pilot houses by agency and housing type. Figure 4-5 presents this information graphically. Average total on-site costs for site-built houses ranged from $588 for Rapp-Rap to $1900 for PEOPLE; for mobile homes they ranged from $543 for CECP to $960 for PEOPLE. PEOPLE's high unit costs for site-built houses resulted from the labor-intensive wall insulation and bypass sealing applied to all its units.

Total costs, including off-site program support and administration requirements, are also presented. The off-site cost of $466 per unit is an average of the program support and administration costs (not including on-site labor) for the four agencies. Average total costs for all pilot agencies were $1466 for site-built and $1092 for mobile homes. Actual reimbursed costs received by each agency under VACAA's reimbursement system (calculated as material costs multiplied by 250%) are shown for contrast. Note that the reimbursed costs are almost always less than the actual total costs for these weatherization measures.

Energy Savings

The most important results of the pilot study are the data on energy savings accruing from the weatherization measures installed, for these will indicate how effective these measures may be in Virginia. These results must be viewed with the realization that in implementing the new measures, the agencies were "learning by doing." As discussed above, this affected the quality of their work, the time it took, and the costs. From this perspective, the

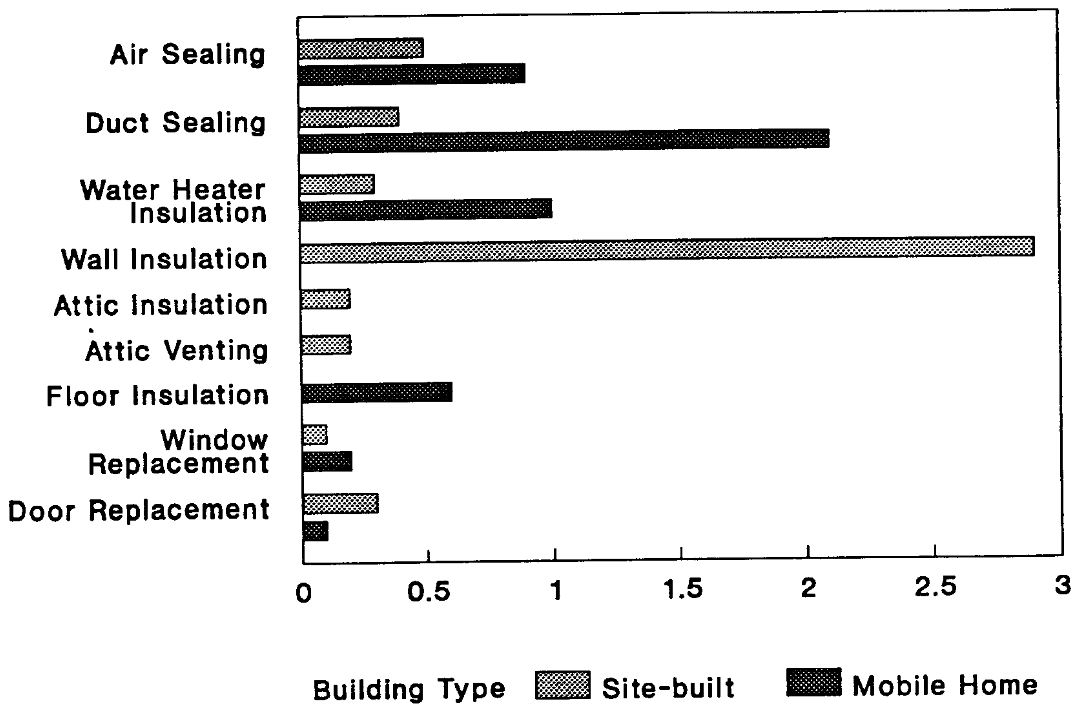

Figure 4-4. Ratio of labor costs to material costs for measures installed in site-built single-family and mobile homes during pilot study.

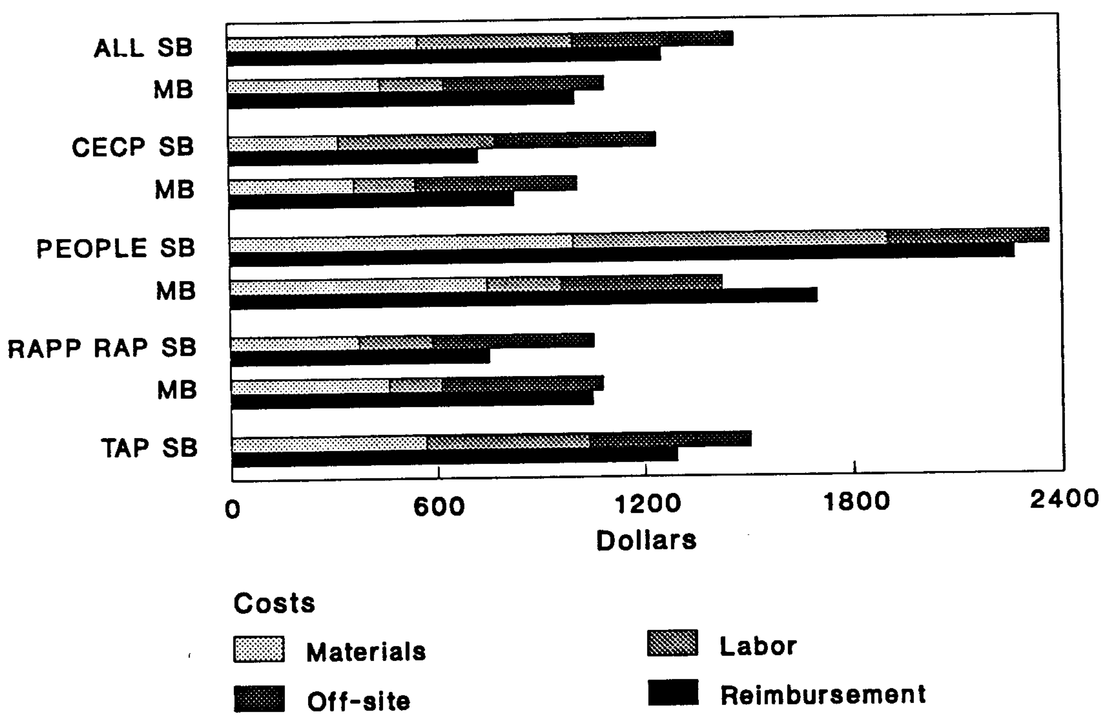

Figure 4-5. Average actual weatherization costs (broken down into materials, labor, and off-site components) and reimbursed costs for site-built single-family (SB) and mobile homes (MB), by local weatherization agency.

energy savings cited here (as well as later estimates of cost-effectiveness) may well be conservative.

Another important issue concerns the reliability of the energy data. While the general approach taken (i.e., use of furnace elapsed-time meters to indicate energy use before and after weatherization) is reliable, its accuracy depends on adequate periods of pre- and post-weatherization data collection and sufficiently cold weather during those periods. This pilot study faced potential problems in both regards. Because of the constrained time period for the study and late entry of two of the agencies, some meters were not installed until early November 1989. Fortunately, cold December weather provided a good period of furnace operation before most of the weatherization took place. (Only one unit that was weatherized in mid-December appears to have questionable pre-weatherization data.)

However, the weatherization work took longer than expected for many units because of the TAP fire and time spent by PEOPLE on each unit. In some cases, work was not completed until early March. The mild winter provided few cold weather periods for steady furnace operation after the weatherization on several units. If anything, the mild post-weatherization weather has made the savings appear **lower** than they truly are, since energy use per degree-days is usually higher during mild periods.

The results below carefully account for these problems. The potential uncertainties posed by having a low number of data points are reflected in the statistical standard errors.[5]

The change in energy consumption resulting from the weatherization was computed from the weather-corrected furnace meter data for each unit in the pilot study. The energy data reflect savings from all work done in each house ("whole job" savings); therefore, it is very difficult to identify the savings accruing from specific conservation measures. However, we will look at the savings from houses in which certain measures (e.g., sidewall insulation/bypasses) were emphasized, as well as incremental blower door readings recorded during the work, to glean as much information as possible about savings from individual measures.

Calculation of Energy Savings

The furnace run-time for each meter reading period (usually weekly) was reported to the pilot agencies by the clients. This run time was multiplied by the furnace's firing rate (measured when the meter was installed) to find the house's Btu consumption for each meter reading period. The space heating energy per square foot per degree-day (Btu/ft^2-DD) was then derived by dividing the energy usage by the house's floor area and the number of heating degree-days (base 65°F) for each period (Equation 4-1). Then, the average Btu/ft^2-DD was calculated for the pre- and post-weatherization period for each house (Equation 4-2). Periods with anomalous data, as revealed in the 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%.[6] The pre- and post-retrofit average heating consumption, absolute and percentage savings (from Equations 4-3 and 4-4), and standard errors for each house are listed in Appendix C.8.

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[5] The standard error is an estimate of the standard deviation of a sample, which is a measure of the distribution of the data around the average value. A small standard deviation means that the data is tightly clustered around the average, while a large standard deviation implies a wide range in data values. The average plus and minus one standard deviation encompasses about 2/3 of the data points.

[6] 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 which had extremely mild weather. This rule typically resulted in the exclusion of 1 or 2 data points for each house.

Eq. 4-1: House weekly energy consumption (Btu/ft^2-HDD) =

$$\frac{\text{Weekly furnace runtime (hr) x furnace firing rate (btu/hr)}}{\text{floor area } (ft^2) \text{ x weekly HDD}}$$

Eq. 4-2: Mean energy consumption (Btu/ft^2-HDD) =

$$\frac{\Sigma \text{ weekly energy consumption } (btu/ft^2 \text{ - HDD})}{\text{Number of Weeks}}$$

Eq. 4-3: Energy savings = Mean pre-wx energy consumption - Mean post-wx energy consumption

Eq. 4-4: $\% \text{ Energy savings} = \frac{\text{Energy savings}}{\text{Mean pre-wx energy consumption}}$

Since the measurement of the firing rate is subject to some error (due to inaccuracies in clocking gas consumption or an oil furnace's actual firing rate differing from its nameplate rating), we have relied on *percent* energy savings, rather than *absolute* savings, wherever possible in the following discussion.

Savings by Building Type and Agency

Table 4-11 presents the average reduction in heating energy consumption experienced in the pilot units after weatherization. Data are given for site-built and mobile homes for all the agencies combined and for each agency. Each subsequent row of the table represents savings of increasing accuracy. The first row, "All Homes," includes all 59 houses weatherized in the pilot study. The next category, "Homes with Consistent Heating Systems," excluded 2 mobile homes with inaccurate metered data (due to a faulty thermostat in one case, and a major furnace repair in the other). "Homes without Supplemental Heating Fuel" excludes houses in which significant use of kerosene, wood, or supplemental electric heaters was noted (despite prior assurances by the clients that they would use no heat sources aside from their furnace over the course of the pilot study). For these homes with supplemental heating, actual energy savings are probably somewhat higher than reported by the furnace meters, since supplemental heat was consistently used more often during the cold December pre-weatherization period than during the milder post-weatherization period.

For homes with consistent heating systems in all four agencies, savings in site-built houses averaged nearly 26% and in mobile homes about 20%. Savings for site-built houses ranged from 7% at CECP to 47% at PEOPLE. Savings for mobile homes ranged from 10% at Rapp-Rap's one unit to nearly 23% at CECP.

To put these energy savings in perspective, recall from Chapter 2 that savings from single-family and mobile homes weatherized in Virginia during 1988 and 1989 were in the neighborhood of 10%. The pilot houses represent a two-fold improvement. 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 4-6). Savings were greater than in all but one of the other demonstration programs documented in the BECA-B database (Cohen et al., 1991).

TABLE 4-11: ENERGY SAVINGS FROM PILOT STUDY WEATHERIZATION[1]

	ALL		CECP		PEOPLE		RAPP-RAP		TAP	
	SB	MH	SB	MH	SB	MH	SB	MH	SB	MH
All Homes - %	$25.8_{\pm 2.9}$ (n=43)	$14.5_{\pm 6.4}$ (n=16)	$7.3_{\pm 14.8}$ (n=2)	$16.7_{\pm 8.2}$ (n=12)	$47.3_{\pm 5.9}$ (n=6)	$8.7_{\pm 10.3}$ (n=3)	$25.8_{\pm 2.7}$ (n=14)	5.1 (n=1)	$21.4_{\pm 4.5}$ (n=21)	- (n=0)
-- Btu/Ft²-DD	$5.7_{\pm 0.7}$	$5.4_{\pm 2.3}$	$1.5_{\pm 2.4}$	$6.6_{\pm 3.0}$	$10.7_{\pm 2.8}$	$1.7_{\pm 2.5}$	$4.7_{\pm 0.6}$	1.0	$5.3_{\pm 1.0}$	
-- MBtu/Unit	$29.2_{\pm 4.8}$	$13.9_{\pm 6.2}$	$3.1_{\pm 9.0}$	$17.3_{\pm 8.0}$	$64.5_{\pm 23.1}$	$3.5_{\pm 6.0}$	$20.8_{\pm 3.2}$	4.0	$27.0_{\pm 5.6}$	
Homes with Consistent Heating Systems - %	$25.8_{\pm 2.9}$ (n=43)	$20.5_{\pm 5.1}$ (n=14)	$7.3_{\pm 14.8}$ (n=2)	$22.6_{\pm 6.2}$ (n=11)	$47.3_{\pm 5.9}$ (n=6)	$16.8_{\pm 11.0}$ (n=2)	$25.8_{\pm 2.7}$ (n=14)	5.1 (n=1)	$21.4_{\pm 4.5}$ (n=21)	- (n=0)
-- Btu/Ft²-DD	$5.7_{\pm 0.7}$	$6.8_{\pm 2.4}$	$1.5_{\pm 2.4}$	$7.9_{\pm 2.9}$	$10.7_{\pm 2.8}$	$3.8_{\pm 2.5}$	$4.7_{\pm 0.6}$	1.0	$5.3_{\pm 1.0}$	
-- MBtu/Unit	$29.2_{\pm 4.8}$	$18.0_{\pm 6.3}$	$3.1_{\pm 9.0}$	$21.0_{\pm 7.8}$	$64.5_{\pm 23.1}$	$8.8_{\pm 4.7}$	$20.8_{\pm 3.2}$	4.0	$27.0_{\pm 5.6}$	
Homes without Supplementary Heating Fuel - %	$27.9_{\pm 3.1}$ (n=34)	$16.9_{\pm 3.9}$ (n=13)	$7.3_{\pm 14.8}$ (n=2)	$18.0_{\pm 4.7}$ (n=10)	$51.6_{\pm 5}$ (n=5)	$16.8_{\pm 11.0}$ (n=2)	$26.3_{\pm 3.6}$ (n=9)	5.1 (n=1)	$24.3_{\pm 4.1}$ (n=18)	- (n=0)
-- Btu/Ft²-DD	$6.2_{\pm 0.8}$	$5.3_{\pm 2.0}$	$1.5_{\pm 2.4}$	$6.0_{\pm 2.5}$	$11.5_{\pm 3.2}$	$3.8_{\pm 2.5}$	$5.2_{\pm 0.7}$	1.0	$5.8_{\pm 1.0}$	
-- MBtu/Unit	$31.6_{\pm 5.5}$	$13.1_{\pm 4.2}$	$3.1_{\pm 9.0}$	$14.8_{\pm 5.4}$	$65.8_{\pm 28.2}$	$8.8_{\pm 4.7}$	$23.3_{\pm 4.5}$	4.0	$29.5_{\pm 5.1}$	

[1]SB = site-built houses, MH = mobile homes. The figures in each category represent average space heating energy savings ± standard error. In parentheses is the number of houses in that category.

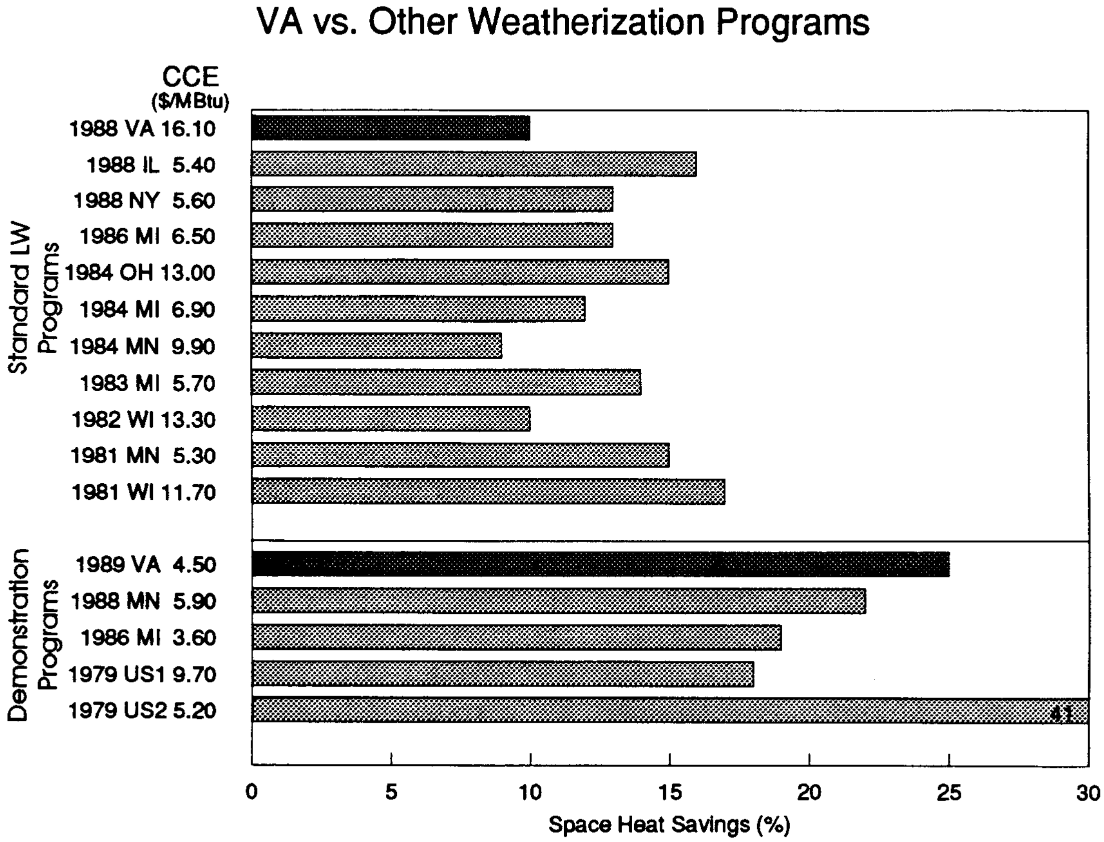

Figure 4-6. Space heat savings and cost of conserved energy for Virginia evaluations compared to other standard and demonstration weatherization programs.
"US1" and "US2" refer to the Community Services Administration study of shell/system measures, respectively. Source: Cohen et al. 1991.

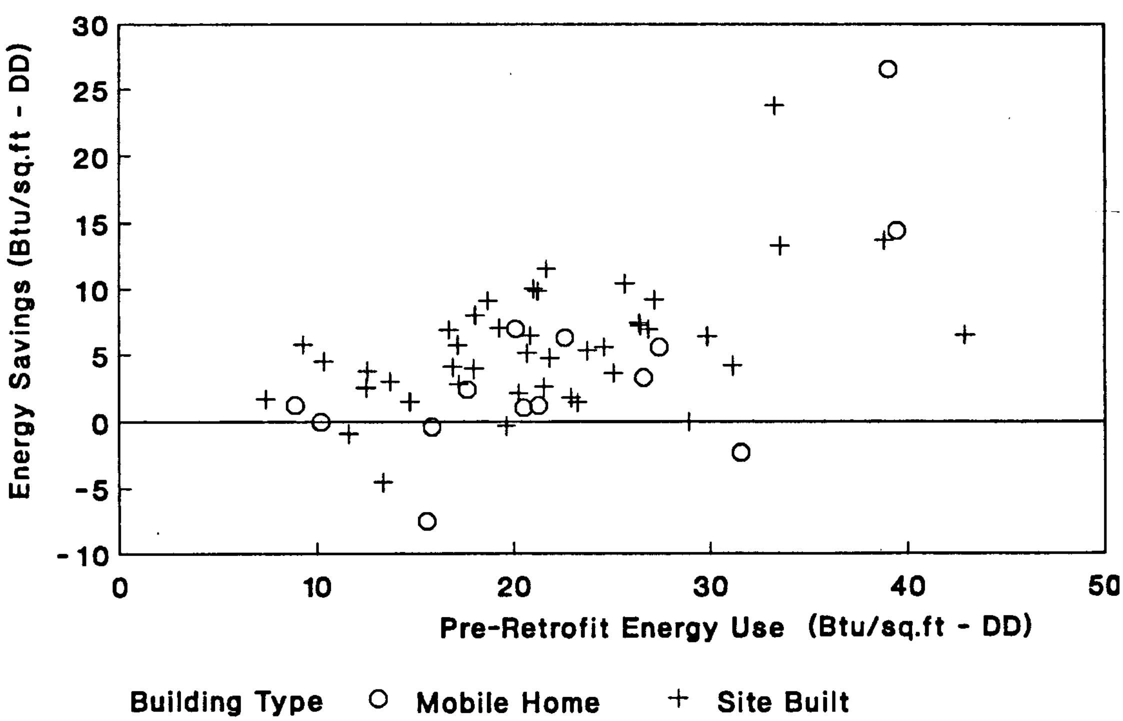

Figure 4-7. Energy savings vs. pre-retrofit consumption for homes weatherized in the pi study.
For site-built homes, R^2 = 0.26, while for mobile homes R^2 = 0.65.

Savings vs. Pre-Retrofit Consumption

We also investigated the correlation between energy savings and pre-retrofit consumption for the pilot study homes. One would expect a strong relationship between these factors, as there are greater opportunities for energy savings in more energy-intensive houses. Other studies have confirmed the presence of this relationship in residential retrofit programs (Synertech, 1987; Schlegel and Pigg, 1990; Hill, 1990; Shen, *et al.* 1990). Figure 4-7 illustrates this relationship for homes weatherized in the pilot study. There was some correlation between savings and pre-retrofit use for site-built homes ($R^2 = 0.26$) and a stronger correlation for mobile homes ($R^2 = 0.65$). The correlation between savings and pre-retrofit use is much greater for the pilot study houses than for the gas-heated homes weatherized in the PRISM study (see Chapter 2). This suggests that the pilot study weatherization was more effective at identifying and correcting the problems of energy-intensive households.

Cost-Effectiveness of Pilot Weatherization

Weatherization aims to save not only energy, but also money. As a public program, it is important to demonstrate that the public investment is cost-effective (i.e., that the energy saved is worth more than the costs incurred to achieve the savings). This section takes the pilot study cost and energy savings data presented above and with certain assumptions, computes the cost-effectiveness of the weatherization in the pilot homes.

There are several measures of cost-effectiveness that can be applied to energy conservation investments. Perhaps the simplest measure, and the most used in weatherization evaluation, is the simple payback time (SPT). This is the period of time it would take to recover the investment costs through the reduction in fuel costs resulting from the energy savings. It is computed by dividing the investment cost by the annual saving.

$$SPT = \frac{\text{Weatherization Cost}}{\text{Annual Energy Savings * Energy Price}}$$

$$\text{Where: Annual Energy Savings} = \frac{\text{Btu saved}}{\text{ft}^2\text{-DD}} \text{ * Floor Area * Annual Degree-Days}$$

Energy Price[7] = \$6.77/1000 ft^3 for natural gas
= \$0.869/gallon for oil
= \$0.0567/kWh for electricity
= \$0.619/gallon for propane

Annual Degree-Days (base 65°F) = 4189 for CECP
= 4688 for PEOPLE
= 4417 FOR RAPP-RAPP
= 4315 for TAP

We computed payback times based on both on-site weatherization costs and total weatherization costs (including program support and administration) as well as based on the current reimbursement system. Averages were computed for each agency by housing type.

[7] These prices are average for residential customers in Virginia during 1988 and 1989 (the most recent prices available at the time of this analysis). (Energy Information Administration, 1990).

Table 4-12 presents the results of these calculations. For all units with consistent heating systems the average SPT for site-built houses is 5.8 years based on on-site costs, 9.7 years based on total costs, and 8.0 years based on reimbursed costs. For mobile homes it is substantially higher: 9.6 years using on-site costs, 17.6 years using total costs, and 15.8 years based on reimbursed costs. Interestingly, PEOPLE, which had the highest per unit total cost of the agencies for site-built houses, has the best payback period. (Other cost-effectiveness indicators for the pilot study homes are discussed later in this chapter.)

One must be cautious when interpreting this data. The on-site and total paybacks are based on the pilot costs including labor. Pilot labor times were greater than one would expect under normal conditions for two reasons. First, additional time was required in the pilot to take several intermediate blower door readings during the course of weatherization and to document the work. These blower door readings also slowed the pace of work by requiring that crews not work on different measures simultaneously. This was necessary to ascertain the infiltration reduction attributable to different measures, but definitely caused the work to take longer than would otherwise have been the case. Second, in applying the new measures, crews were "learning by doing." With more experience, labor time and costs would likely drop.

It is impossible to account precisely for these factors in the data given in Table 4-12. However, it can be said that these SPTs are upper bounds of the paybacks expected for the work tested in the pilots.

Assessment of Energy Savings By Measure

The "whole job" energy savings given above shed little light on the effectiveness of specific measures. This section looks more closely at some of the study data to glean information on individual measures.

Blower Door Readings and Individual Measures

For each pilot job, crews were required to collect blower door readings after specific measures were installed (see logging sheet in Appendix C.4). By comparing the incremental contributions of individual measures to reduction in blower door readings, one can estimate the measures' relative contribution to air leakage control, a major factor in energy savings. It should be noted that air leakage is not the only factor involved in energy savings, as reduction in conductive heat loss through insulation also plays a major role. And there is some question about how accurately blower door readings, with the house pressurized or depressurized, reflect air leakage under ambient conditions.

Table 4-13 gives the percent reduction in blower door readings as a result of weatherization work in the pilot study.[8] It shows the average total percent reduction achieved in the two housing types for each agency and for all pilot units. [The average total reduction was about the same for site-built (34 percent) and mobile homes (33%).] Across the agencies, blower door reductions were comparable with the exception of PEOPLE where the blower door reading dropped by two-thirds (67%) for the three site-built houses with reliable readings. Although the infiltration reduction accomplished by the pilot study measures is slightly lower than that from the existing program, the air sealing in the pilot focused on leaks that were not in the neutral-pressure plane, and which would therefore be expected to lead to relatively greater energy savings.

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[8] We were not able to compare absolute changes in infiltrations rates, as in many homes crews could not achieve the standard pressure of 50 Pascals and were forced to take pre- and post-weatherization blower door readings at a lower pressure.

TABLE 4-12: SIMPLE PAYBACK TIME FOR PILOT STUDY HOMES[1]

		ALL		CECP		PEOPLE		RAPP-RAP		TAP	
		SB	MB	SB	MB	SB	MB	SB	MB	SB	MB
Homes with Consistent Heating Systems	# Units	(39)	(12)	(1)	(9)	(6)	(2)	(14)	(1)	(18)	(0)
	SPT On-Site[2]	5.8 ±0.6	9.6 ±2.5	4.8	5.7 ±1.0	5.9 ±1.0	19.5 ±10.2	5.7 ±0.9	24.6	5.9 ±1.1	--
	SPT Total[3]	9.7 ±1.0	17.6 ±4.1	10.6	11.8 ±2.3	7.5 ±1.2	31.1 ±16.7	10.7 ±1.8	43.2	9.6 ±1.7	--
	SPT Reimb.[4]	8.0 ±0.8	15.8 ±4.6	7.1	8.7 ±1.8	6.9 ±1.1	34.7 ±18.8	8.7 ±1.5	42.0	7.9 ±1.4	--
Homes without Supplementary Heating Fuel	# Units	(31)	(11)	(1)	(8)	(5)	(2)	(9)	(1)	(16)	(0)
	SPT On-Site	5.9 ±0.7	10.2 ±2.7	4.8	6.1 ±1.0	5.6 ±1.2	19.5 ±10.2	5.8 ±1.3	24.6	6.1 ±1.2	--
	SPT Total	9.6 ±1.2	18.9 ±4.3	10.6	12.9 ±2.3	7.2 ±1.5	31.1 ±16.7	10.5 ±2.5	43.2	9.8 ±1.8	--
	SPT Reimb.	8.0 ±1.0	17.0 ±4.9	7.1	9.5 ±1.9	6.6 ±1.3	34.7 ±18.8	8.8 ±2.1	42.0	8.1 ±1.6	--

[1]SB = site-built homes, MB = mobile homes, average ± standard error.
[2]SPT based on material and on-site costs.
[3]SPT based on material and on-site labor costs plus program support costs.
[4]SPT based on material cost multiplied by 250% reimbursement rate.

TABLE 4-13:
AVERAGE PERCENT REDUCTION IN BLOWER DOOR READING BY AGENCY*

	ALL		CECP		PEOPLE		RAPP-RAP		TAP
	SB	MB	SB	MB	SB	MB	SB	MB	SB
% Reduction, All Measures	34% (n=39)	33% (11)	34% (2)	31% (8)	67% (3)	44% (2)	30% (14)	34% (1)	32% (20)

*SB = site-built house, MB = mobile home.

Table 4-14 breaks down the total average reduction in blower door reading by measure. The sums of the reductions of the individual measures do not add up to the total because blower door reductions were not always documented for each measure installed. Substantial contributions to blower door reductions were made by repairs and air sealing in both site-built (22%) and mobile homes (10 percent), duct register boot sealing (11%) and window/door replacement (17%) in mobile homes, and wall/attic insulation in single family homes (10%). The 10% reduction due to wall and attic insulation is not a good reflection of wall insulation's *potential* effect on infiltration, since good blower door readings were not reported for the houses in which wall insulation was applied most effectively (at PEOPLE). Window replacements in mobile homes were responsible for large infiltration reductions because in many cases windows were broken out or completely missing. We would not expect such large infiltration reduction from replacment of windows which were merely leaking but not broken.

TABLE 4-14:
AVE. PERCENT REDUCTION IN BLOWER DOOR READING BY MEASURE*

	All Agencies	
% Reduction	SB	MB
All measures	34% (n=39)	33% (n=11)
Air Sealing &/or Repairs	22% (25)	10% (12)
Duct and Register Sealing	0.4% (9)	11% (10)
Wall &/or Attic Insulation	10% (23)	--
Floor Insulation	--	5% (3)
Window &/or Door Replacement	5% (2)	17% (8)

*SB = site-built house, MB = mobile home.

Savings and Cost-Effectiveness of Weatherized Houses with Wall Insulation

One measure of special interest in this pilot study is high-density, blown sidewall insulation. Table 4-15 gives the energy savings and cost-effectiveness of the 17 pilot houses that received this measure. The percent savings in the wall insulation houses was an exceptional 32%. Since these are "whole job" figures, not all of the savings are attributable to this one measure.

It is interesting to look a little closer at the results. The furnace run-time analysis for two of these houses actually showed an increase in energy use. Both had a very short period of pre- or post-weatherization data collection, and we believe this affected the results. The other 15 houses averaged 39% savings, ranging from 11% to 71%. In one agency, the 6 sidewall jobs achieved an average savings of 47%.

Table 4-15 also gives average costs and cost-effectiveness for the houses receiving sidewall insulation. Despite very high costs, SPTs averaged less than 9 years based on total costs, 7 years based on on-site costs. This compares favorably to the 13 year SPT achieved in the *M-200* study (Shen, *et al.* 1990). As discussed earlier, we expect that the Virginia costs would drop considerably with more training and crew experience.

TABLE 4-15:
SAVINGS & COST-EFFECTIVENESS FOR UNITS WITH SIDEWALL INSULATION[1]

	# JOBS	SAVINGS (%)	ON-SITE COSTS ($)	TOTAL COSTS ($)	SPT ON-SITE (YRS)	SPT TOTAL (YRS)
Sidewall Jobs	17	32 ±6	1682 ±115	2148 ±115	6.9* ±1.0	8.9* ±1.3

[1]Figures given are averages ± standard errors.
*Two of the houses had negative savings and therefore undefined payback times.

Reactions of Weatherization Staff and Clients to Pilot Study

Weatherization Staff Reactions to the Pilot Study

In addition to assessing the savings and cost-effectiveness attributable to the pilot study measures, we were also interested in learning how the weatherization agency staff perceived the pilot study process and reacted to the new measures. We wanted to find out about specific problems they had during the pilot study, and elicit their suggestions for implementing the new measures in other agencies. Separate questionnaires were developed for pilot agency coordinators, those doing estimations or heating system inspections for the pilot houses (who were not always the regular agency estimators), and crew people (questionnaires appear in Appendix C.6). Questionnaires were administered during May and early June of 1990. All four pilot agency coordinators were questioned, either over the phone or in person. All six individuals who served as estimators and/or heating system inspectors were also surveyed, either over the phone, in person, or in writing. Finally, a total of 11 crew members responded to the questionnaire in writing, representing participating crews from all agencies except CECP. (Agency coordinators or estimators were asked to have the crews fill out the questionnaires; CECP was the only agency which did not provide crew responses.) The variety of interview techniques was used to elicit the fullest possible responses, given time constraints on both VCCER personnel and weatherization staff (e.g., crew members are almost always out at job sites, so could not easily be reached on the telephone or for in-person interviews).

Survey questions focused on three main areas: the pilot study training sessions, the process of implementing the pilot study standards, and the future of the pilot study standards. For each topic, we summarize the responses of the pilot agency coordinators, estimators/heating system inspectors, and crew members.

Training Sessions

Two coordinators attended the heating system training, while three were at the sidewall insulation/advanced air sealing session. Both the content and the trainers for the sidewall session were ranked more highly than those of the heating system training (fair to very good, versus poor to good). All thought that the heating system training was insufficient for the work the agencies were being asked to do, and suggested that more time devoted to training in the field was needed. The sidewall training, while more favorably perceived, was still thought by 2 of the 3 coordinators in attendance to be insufficient. Criticisms included lack of the right equipment, too many people in attendance, and most importantly, not enough focus on how to detect and remedy specific types of bypasses.

Of the estimators/heating system inspectors, 5 were at the heating system training and 4 attended the sidewall training. All but one of these attendees thought that both trainings were insufficient. With regards to the heating system training, there was a consensus that the trainers knew what they were talking about, but conducted the training at too high a level for this audience. Some reference was made to personality problems with the trainers. Attendees would have liked to have had the testing equipment they were going to be using at the time of the training, and to have had more small group, in-field training. One suggested that more types of heating systems in the classroom would have been useful to practice on. Another emphasized the need for on-going training, to learn to handle the unexpected situations which will always arise in the field. Attendees at the sidewall training felt that more field work was needed to learn to locate bypasses, and that an infrared camera would have been very useful in detecting the areas they were missing. Equipment problems and bad weather slowed this training.

Only one crew person attended the heating system training, while 8 crew members, mostly from TAP, were at the sidewall training. The crew person at the heating system training thought that more classroom study was needed; all but one of those attending the sidewall training thought that the training was sufficient for the work they were asked to do. Suggestions for improvement included more training on different types of structures, better equipment, and more emphasis on the uses of different tools. A typical comment was "The only trouble I have is finding all the bypasses, it's gotten better as time went on. Doing the work is no problem...".

Implementation of Standards

The coordinators felt that while the sidewall/advanced air sealing measures were definitely effective, they weren't as sure about the heating system work, since they found a number of problems which they couldn't do anything about. Locating the necessary materials did not prove to be a problem for them, but most experienced some difficulties with equipment (getting blowers to work correctly, obtaining the right kind of tubing and reducers, finding long-wearing drill bits, static electricity built up by tubed-in insulation causing shocks to crews on aluminum ladders). Only one coordinator thought that his estimator was having problems with the new measures (specifically, with locating and fixing bypasses), and none thought that the heating system work was a problems for their inspectors, other than the time the heating system work took away from the inspectors' normal duties. Crew complaints, as perceived by the coordinators, focused on the sidewall insulation: the work took too long, the cellulose was very dirty, and "they think it helps, but they don't like it." Coordinators said that client reactions were generally favorable, with some complaints about the weekly phone calls to obtain meter readings, and one client who was bothered about not getting new windows. Other problems mentioned with regard to implementing the pilot study standards were money (both the reimbursement system and lost production time for training sessions and time-consuming weatherization of pilot study homes) and staff time for the heating system work (which took away from the inspectors' usual duties). When asked if they would make any changes to these standards, the coordinators said that they preferred the new standards to their current work (as long as the intermittent blower door readings were eliminated). The forms used in the pilot study were thought to contain too much detail, slowing the work down.

Estimators/heating system inspectors agreed that the new standards were more effective than the traditional measures, but felt some frustration about not being able to do more heating system work. They mentioned the same equipment problems that the coordinators discussed. When asked how the crews were fairing with the new measures, some estimators/inspectors replied that the same people who had trouble with the traditional measures had trouble with the new standards, while others felt that there were more problems with the new work. Specifically, some felt that a little classroom work was needed to impress upon the crews the importance of densely packing wall insulation; without an understanding of why dense-pack is important, the crews would not be vigilant about the quality of work they did. Estimators/inspectors reported that clients were generally pleased, although there was some concern about looking at heating systems and drilling holes in the walls. The main problem clients had was with the repeated visits (for meter installation, estimation, heating system work, weatherization, etc.). When asked if they would want to make any changes to the new standards, one said that belly board insulation should be moved down in priority. Another wanted to see furnace and duct work made the highest priority, followed by bypass sealing, windows/doors, and attic insulation. Other areas mentioned were that more attention should be paid to crawl spaces, and that more extensive heating system work should be allowed. Estimators/inspectors felt that the pilot study forms were helpful in that they provided a system to follow, but that they could be made simpler. Suggestions included a more detailed checklist for bypass sites, and a separate form for inspecting hot water heaters.

Crew persons thought that the new standards were effective, since they made a big difference in the blower door reading. They didn't like working with the cellulose insulation (too dirty, static) and had some problems with the tubing (stopping up, kinks) and reinstalling aluminum siding. When asked if they had any problems with sealing leakage sites or installing wall insulation, they were concerned about not knowing if they caught all the gaps and if they were correctly dealing with unusual construction features (like porches). Accessing crawlspaces to seal leakage sites was also mentioned as a problem. Crews thought that clients were generally pleased. Other problems with the new standards included not having enough experience with finding bypasses. Opinions were divided on whether they'd want to include the new measures in all their work. Some thought the new standards were better, in that they would last longer than the usual measures and eliminated a lot of caulking. Others thought that the new work was too time-consuming and too difficult, given what they were being paid. A few said they could not deal with doing sidewalls every day, and suggested using fiberglass insulation instead (because it is less dirty). The main suggestion for improvement was to have better access to the proper tools and equipment; face masks, protective clothing, and higher pay were also mentioned.

Extending the Pilot Study Standards to All Agency Work

Coordinators had mixed opinions about including the new measures in all their weatherization. Responses ranged from an enthusiastic "yes" (especially for heating system work), to "only if more training were available," to a feeling that the new measures involved so much more time that a revamping of the entire weatherization program would be necessary to include them. When asked if any changes in personnel would be necessary, most felt that it was not a question of the number of staff, but of their skill level. To increase the skills of the weatherization staff, more training and higher pay (to keep the more highly trained individuals from taking other jobs) were thought to be needed. There were not any strong concerns about fitting the new measures into their existing weatherization procedures (e.g., amount of time required for, and spacing of, intake, estimation, weatherization, and inspection); some thought the work would take a little longer, and others thought a little shorter, than their existing procedures. Most coordinators thought that a change in the reimbursement system would be needed (although one thought that if fiberglass was used for wall insulation instead of cellulose, reimbursement would probably work out okay since fiberglass is more expensive).[9] Suggestions for improving the reimbursement system included a flat rate per square foot for wall insulation (including labor and materials), and direct reimbursement of all agency expenses. Other suggestions for improving weatherization focused on training: one coordinator thought that more training is essential for properly motivating the field personnel, and another thought that a statewide training center was needed to ensure the correct implementation of the new measures.

Estimators/heating system inspectors were also questioned about the future of the new standards. All but one definitely wanted to include the new measures, with one mentioning that he had gotten lots of questions from clients on heating system problems before the pilot study. More training was again brought up as the primary change in personnel that was needed; one felt that the crews were not ready to tackle the new measures on their own yet (that is, without the estimator's presence while the work was being done), while another thought that crews needed training to understand the theory behind the new measures. There was some concern that the individuals who acted as heating system inspectors would be asked to continue doing this task in addition to their regular jobs; this was not felt to be feasible. Although they felt that estimations would take a little longer, the respondents did not feel that this would be a problem. Most felt that changes in the reimbursement system would definitely be needed; since heating system inspections would usually have no materials cost, a set charge for heating system inspections was suggested. Higher wages were thought necessary to keep more highly trained crew persons from leaving weatherization agencies. Other suggested changes included adding chimney inspections as part of the heating system work and the need for more training. Comments were also made on general weatherization procedures: estimators in different agencies prescribe different measures and VACAA should make an effort to get all agencies doing the same level of work; that many agencies don't attend VACAA trainings so these trainings should be made mandatory; that VACAA rushes into changes too quickly and should provide agencies with more backup and resources when changes are to be made; and finally, that problems with blower door calibration have been observed (widely differing readings obtained using two recently calibrated doors on the same house on the same day), and so VACAA's air change guidelines should not be so strict.

Client Reactions to Pilot Measures

With only a few exceptions, all clients interviewed were generally pleased with the weatherization performed on their homes. Many clients whose homes received wall insulation noted improved comfort. Notably, there were *not* a greater number of complaints about "messiness" from clients who got wall insulation, as compared to those who did not (weatherization crews were very concerned that clients would object to the mess created during installation of wall insulation). There were a few complaints that all windows were not replaced, creating a mismatched appearance (when 1 or 2 windows in severe disrepair were replaced). Again, it is notable that there were not more complaints about the reduced number of window replacements, given that this was a big concern of weatherization staff.

[9] Fiberglass is not a suitable substitute for cellulose for the purpose of high-density wall insulation, as fiberglass will not pack tightly enough to seal infiltration sites.

Comparing Savings From the 1988-89 Weatherization Program With Pilot Study Results [10]

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 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 4-16 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 earlier, space heat usage for homes weatherized under the existing program was approximated using the PRISM-derived space heat fraction. 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 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.[11] 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).

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[10] Savings and cost-effectiveness results for study presented in this section may not agree exactly with results discussed earlier in this chapter, because averages were used to summarize pilot results presented earlier (because of the small number of houses for some agencies), while medians were used for the pilot results cited in this section.

[11] See Appendix A for a description of how each cost-effectiveness indicator was calculated

TABLE 4-16: SUMMARY OF RESULTS FOR EXISTING VIRGINIA WEATHERIZATION VS. PILOT STUDY[1]

	Existing Program		Pilot Study
	Gas/Oil	Elec.	Gas/Oil
# 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
(% NAC)			
-- Site-Built	8.3	4.1	--
-- Mobile Home	--	3.0	--
(% 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]Values given are medians.
[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 1989/1990 dollars).
[4]Based on 1988 average Virginia residential energy prices of $5.65/MBtu for gas and oil, and $16.61/site MBtu for electricity.
[5]Based on a real discount rate of 7% and measure-specific lifetimes.

Administrative Issues

Administrative issues in general are discussed in Chapter 6. Several of these issues became clear in the pilot study and they are addressed below.

Implications for the Reimbursement System

The reimbursement system is perceived as a problem by local agencies, even with the existing installation standards. The current system, based solely on material costs, makes it difficult for agencies to install labor-intensive measures (like belly board insulation or wall insulation). The data on labor-to-material-cost ratios for various pilot study measures makes this point quite clearly (see Figure 4-4). Agencies are also being given the wrong signal about how to do cost-effective weatherization, because the reimbursement system "rewards" agencies which install high material-cost, low labor-input items like windows. Rather than trying to change agencies' behavior through ever-tighter restrictions on, for example, when windows may be replaced, we think it makes more sense to revise the current reimbursement system and take away the agencies' incentive to install measures that are not cost-effective.

After contacting four states which do wall insulation as part of their weatherization program, and finding that all reimburse based on labor and material-costs, we have concluded that VACAA needs to make some change to acknowledge the different installation times associated with different measures. The expanded definition of material costs is not the full answer. Although such a system would given agencies a bit more leeway in meeting the 60/40 rule, it still gives agencies the incentive to install high material-cost items.

There are many options for altering the reimbursement system. Some states have contractors or local agencies bid on the installed cost of each type of measure. Many just have agencies track and report labor time and material costs. Another alternative would be to have different reimbursement rates for each type of measure. We can more fully develop some of the ideas presented here. We are encouraged that VACAA is exploring new reimbursement system options to test in various agencies during contract year 1991-92.

Equipment Requirements

The advanced techniques tested in the pilot study require increasingly sophisticated and accurate equipment to be fully implemented. For example, most of the pilot agencies carried out their heating system inspections with VACAA's existing inspection kits, but it became clear that the one agency with the computerized heating system inspection kit was able to do a more accurate, thorough job. Several agencies' abilities to install high-density wall insulation were hampered by problems with their insulation blowers (e.g., no feed gates, no remote controls). There were also problems with getting the right kind of tubing and reducers and finding long-wearing drill bits. During weatherization and inspection of the pilot study houses, we noticed a fair number of discrepancies between air change readings taken with different blower doors, even when the doors had been recently calibrated. And finally, our inability to obtain an infrared camera for inspection of wall insulation and bypass sealing work made it difficult to assess the thoroughness of the crews' efforts. These examples illustrate the need for an increased commitment on VACAA's part to helping the agencies gain access to better equipment. In particular, it will be much easier to embark on heating system work if each agency can be given the computerized inspection kit. The purchase of one or more infrared cameras by VACAA, for follow-up training and inspection of wall insulation and bypass sealing jobs, is essential to properly training crews in these techniques.

Areas For Additional Research

Effectiveness of Bellyboard Insulation

As mentioned above, only four mobile homes in the pilot study received floor insulation, and only two of these were insulated with blown-in bellyboard insulation (the other two, with missing bellyboards, were insulated with fiberglass batts). We cannot draw any conclusions about the savings and cost-effectiveness of bellyboard insulation from such a small sample size. Although the literature strongly recommends bellyboard insulation, additional research is needed to measure its effectiveness in Virginia.

Sidewall Insulation and Moisture Problems

Since beginning the pilot study, the question has been raised of whether installing wall insulation might result in moisture problems. There is not yet a clear answer on this issue among specialists around the country. For some construction types (with particular configurations of sheathing and siding), there may be potential problems due to exterior moisture being drawn into the wall cavity and not being able to evaporate (because of the presence of insulation). Practically speaking, however, few problems have been found in the field, although high-density sidewall insulation has not been used very often in mild and semi-humid Virginia-type climates.

Although we do not consider this to be a serious problem, it may be useful to track the pilot study and other weatherization houses with wall insulation to check for moisture problems. The simplest option is to photograph the exterior walls when houses are inspected, and return at periodic intervals (once a year for a few years) to see if any problems develop. A more costly, but more effective option is to revisit the houses and analyze the moisture content of the wood in the walls, repeat this procedure in the future, and note any changes that take place. Unfortunately, this problem was not anticipated when we developed the evaluation project and plans were not made (nor funded) to investigate this issue. However, since it could have major implications for the future of wall insulation in the South, further research on this issue will likely be needed.

Summary and Conclusions

Energy Savings from the Pilot Study

The energy savings measured in the pilot houses, averaged 26% (median of 24%) for the 43 site-built homes, and 20% (median of 17%) for the 14 mobile homes. The 17 houses that received sidewall insulation averaged savings of 32%. To put these savings in perspective, recall from Chapter 2 that space heat savings from comparable houses weatherized in Virginia during 1988 and 1989 were from 5 to 10% (for different building types). The pilot houses represent at least a two-fold improvement. 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, with savings greater than in all but one of the other demonstration programs documented in the BECA-B database (Cohen et al. 1991). These results emphasize that the Virginia pilot savings are a tremendous improvement over previous weatherization in Virginia and are equivalent to some of the most innovative work being done in the weatherization field.

These high savings can probably be attributed in part to the poor condition of Virginia's housing stock. If the pilot houses are typical of Virginia weatherization units (and the agencies indicated that the pilot houses are probably in **better** shape, and therefore **more** energy-efficient, than their average units), then there exists a tremendous opportunity and need for advanced weatherization in Virginia. In addition, even though the pilot savings were substantial, they are likely to improve with more crew training and experience.

Cost-Effectiveness of Weatherization in the Pilot Study

The cost-effectiveness of the weatherization work, as measured by simple payback time, was comparable to other notable pilot studies, such as the *M-200* study (Shen, *et al.*, 1990). Payback times averaged 6 years for site-built houses based on on-site costs, rising to 10 years when program support and administration costs are included. For mobile homes, paybacks averaged 10 years based on on-site costs, and 18 years based on total costs.

A major factor in the long payback times for site-built houses was the higher than expected labor cost component of the pilot study measures. The record-keeping requirements of the pilots, as well as the extra time needed to learn the new techniques, certainly contributed to the high labor costs. After additional experience, and under non-pilot conditions, installation times for the new measures are likely to improve, with a resulting increase in cost-effectiveness.

Mobile home payback times were even longer than those for site-built homes. Window replacement was a costly measure, but was shown to substantially reduce the air change rate in this sample of homes. (It should be noted that many of the mobile home windows that were replaced were either non-functional or completely missing.) Floor insulation also contributed to high weatherization costs. The results from the pilot study on appropriate measures for mobile homes are inconclusive.

Capabilities of Local Agencies

Besides energy savings and cost-effectiveness, an important objective of the pilot study was to assess the capabilities of Virginia local agencies to implement the tested measures. We will distinguish the heating system work from the other weatherization measures, as they have quite different personnel requirements.

Heating System Work

The pilot agencies demonstrated that they can learn to perform both basic safety and operation inspections and furnace clean and tunes. This is especially noteworthy, given the constraints affecting the pilot's heating system initiatives: less-than-ideal field training, problems with obtaining equipment, and lack of resources for dealing with serious safety problems they identified. Despite these problems, the agencies successfully inspected furnaces in 44 units, one agency performed clean and tunes on 10 furnaces, and 17 heating system repairs (primarily related to safety problems) were carried out.

The pilot study provided other useful lessons about prospective heating system work. The most important point is that while weatherization personnel can learn to do inspections and clean and tunes, they need more than a week-long training. To deal with the variety of different heating systems out in the field, a longer training period would be required. The pilots also showed that the amount of time required to do a thorough heating system inspection is roughly equal to that required for estimation. Therefore, this is not a task the estimator could be expected to "squeeze in," along with his other duties, but one which would require a significant amount of time. During the course of the pilot heating system inspections, we found that the extra investment in the computerized inspection equipment is clearly worthwhile, as it makes the inspections faster and more accurate. For agencies to do clean and tunes, the computerized equipment would be a necessity. Finally, we learned that technical and financial back-up will be needed by the agencies if they embark on heating system work. Money to fix the heating system problems will have to be made available to the agencies, through either the weatherization program or some other source, such as the Department of Social Services. Agency personnel will not have the skills to deal with all the problems they might find; some kind of technical back-up, such as a few highly trained technicians which travel from agency to agency, or the ability to hire contractors to fix problems, will be required.

Other Weatherization Measures

The pilot study demonstrated that the agency crews are definitely capable of learning the steps involved in implementing the new measures (e.g., blowing wall insulation to the proper density, sealing bypasses, etc.). However, the estimators and crew chiefs need more experience in learning how to diagnose air leakage and bypass sites, hidden wall intersections in need of insulation, etc. The agencies which most successfully applied the wall insulation and advanced air sealing techniques had personnel who had had previous exposure to these concepts. More field training when the techniques are first introduced, as well as periodic follow-up to ensure that the techniques are thoroughly and correctly applied, will be required. Infrared cameras are a necessity for carrying out thorough follow-up trainings and inspections.

Potential Effectiveness of Virginia Weatherization

The pilot study has shown that substantial energy savings can be achieved in the Virginia low-income housing stock through the use of advanced weatherization techniques like high-density wall insulation and bypass sealing. Heating system safety and efficiency inspections illustrated that many serious safety problems exist in the low-income housing stock; the potential exists for increasing the efficiency of these heating systems, as well as for improving their safety. In addition, the pilot study showed that weatherization agency staff can learn these new techniques in a relatively short amount of time, if proper follow-up training is available.

Pilot savings were over 2 times better that savings from traditional (1988/89) weatherization. If pilot costs are calculated based on the existing reimbursement system, weatherizing the pilot homes was actually cheaper than traditional weatherization. Therefore, we believe that the measures tested in the pilot study have a tremendous potential for saving energy, reducing energy costs, and improving the safety of low-income housing throughout the state of Virginia.

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Chapter 5: Recommended Protocol for Weatherization Measures

The main objective of this evaluation project is to develop recommended changes in the Virginia Weatherization Program's procedures for determining which conservation measures get installed in clients' homes. In this chapter we squarely address that objective by presenting a new protocol and framework for installation standards. The system is based on results from the PRISM study of the 1988-89 program, reported on in Chapter 2, the engineering-economic analysis of weatherization measures in Chapter 3, and especially the pilot study discussed in Chapter 4.

The following discussion focuses on individual measures and summarizes for each the findings from the preceding chapters. These findings are used to recommend selected measures for the new protocol. First, however, to provide points of reference, the current and 1988-89 Virginia standards are summarized below.

Virginia Weatherization Standards 1988-89 and 1990-91

The Virginia Weatherization Program has changed considerably in the past few years as a result of a growing awareness among VACAA staff of new developments in weatherization nationwide. The installation standards for the 1988-89 contract year were revised for 1989-90 and again for 1990-91. In spring 1990, at the mid-point of this evaluation, preliminary findings from the project were used by VACAA in developing the 1990-91 standards. As a result, they incorporate some but not all of our recommendations.

Weatherization Installation Standards, 1988-89

Table 5-1 shows the basic framework of the installation standards for the 1988-89 contract year, which was analyzed by the PRISM study presented in Chapter 2. The actual standards provided considerable installation details for many of the measures (VACAA 1988). Four required measures were included: air leakage reduction (including window and door replacements), water heater insulation, attic insulation, and storm windows. Optional measures included floor insulation, duct insulation, setback thermostat, and crawlspace skirting.

Considerable emphasis was given to air leakage reduction. As reported in the PRISM study, a great deal of effort and materials expense went into caulking around windows and doors and into primary window and door replacement. These standards also included storm windows as a required measure, but this was the last year they were part of the protocol.

The standards did include measures that this evaluation has shown to be effective **if installed properly**. A blower door test was required to assess air leakage. Under air leakage, attention was given to sealing furnace ducts and attic bypasses, although at that time crews lacked experience or detailed training in these measures. Given this lack of training, it is extremely unlikely that bypass sealing was being fully and correctly implemented during the 1988-89 contract year. Attic insulation was a required measure.

TABLE 5-1: 1988/89 INSTALLATION STANDARDS, ALL BUILDING TYPES (subject of PRISM Study)

Required:

1. Reduce Air Leakage
   a. Blower door test
   b. Reduce heat loss (do some of these, as diagnosis indicates)
      1) seal furnace ducts
      2) caulk around window and door frames
      3) repair/replace primary windows as necessary
      4) weatherstrip exterior doors; repair/replace door as necessary
      5) weatherstrip attic hatch
      6) seal attic bypasses
      7) seal/damper direct openings
      8) seal any other openings
   c. Basement: if heated, seal as above; if unheated and uninsulated, seal to provide buffer between heated area and outside
   d. Ensure adequate combustion air.
   e. Seal large exterior cracks to prevent weather damage
2. Water Heater Insulation (electric water heaters only)
   a. Lower thermostat setting
   b. Insulate first 3 feet of hot water line
   c. Install insulation jacket
3. Attic Insulation
   a. Insulate to at least R-19, no more than R-32
   b. Install venting (whether or not insulation added)
   c. Insulate hatch
4. Storm Windows

Optional:

1. Floor Insulation
2. Duct/Pipe Insulation (only if in unheated area)
3. Setback Thermostat
4. Skirting (must vent if installed)

Source: VACAA 1988

Weatherization Installation Standards, 1990-91

Table 5-2 summarizes the installation standards for the 1990-91 contract year. Separate standards were given for single-family houses and mobile homes. As in the 1988-89 standards, air leakage reduction (referred to as "general heat/cool waste") was the top priority. However, caulking and window replacements were clearly deemphasized; replacement windows were relegated to the "optional" category, and were to be applied only when original windows are "deteriorated beyond repair." Storm windows were prohibited. On the other hand, sealing ducts, large openings, and attic bypasses were given top priority. The blower door was to be used not only as a diagnostic tool, but also as a gauge (1) to measure if enough sealing had been done (through the use of "target" blower door readings computed

TABLE 5-2. 1990/91 INSTALLATION STANDARDS

Site-Built, Single-Family Homes

Required:

1. General Heat/Cool Waste
   a. Blower door test
   b. Reduce heat loss (proceed down list until blower door target or minimum ventilation rate (MVR) reached)
      1) seal furnace ducts and registers
      2) seal large openings
      3) seal attic bypasses
      4) install attic insulation, if none existing
      5) if optional sidewall insulation to be installed, do it now
      6) seal sill plate/band joist openings
      7) seal/damper direct openings
      8) glaze and tighten windows
      9) weatherstrip exterior doors, attic hatch
   c. Seal large exterior cracks to prevent weather damage
2. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting
   b. Insulate first 3 feet of hot water line
   c. Install insulation jacket
3. Duct Insulation & Furnace Filters
   a. Supply 6 month's worth of filters
   b. Insulate ducts/pipes if in unheated area
4. Attic Insulation
   a. Insulate to at least R-19, no more than R-32
   b. Install venting (whether or not insulation added)
   c. Insulate hatch

Optional:

1. Sidewall Insulation
2. Water Flow Reducers
3. Floor Insulation
4. Primary Window Replacement (if deteriorated beyond repair)
5. Setback Thermostat

Prohibited:

1. Crawl Space Skirting
2. Storm Windows
3. Foundation Vents

Mobile Homes

Required:

1. General Heat/Cool Waste
   a. Blower door test
   b. Reduce heat loss (proceed down list until blower door target or MVR reached)
      1) seal large openings
      2) seal furnace ducts and registers
      3) insulate floor using blown insulation (unless bellyboard completely missing)
      4) seal/damper direct openings
      5) replace exterior doors if deteriorated beyond repair
      6) replace primaries or storms (not both) if leaky or deteriorated beyond repair
2. Furnace Filters
   a. Supply 6 month's worth of filters
3. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting
   b. Insulate first 3 feet of hot water line
   c. Install insulation jacket
4. Floor Insulation using Fiberglass Batts (if bellyboard completely missing)

Prohibited:

1. Skirting
2. Foundation Vents

Source: VACAA 1990

from house size and pre-weatherization reading) and (2) to guard against over-sealing the house (i.e., dropping below a "minimum ventilation rate").

Duct insulation was elevated to a required measure, while sidewall insulation was included as an optional measure.[1]

For mobile homes, the standards also emphasized sealing ducts and large openings. Replacement doors and windows were allowed, but only "if deteriorated beyond repair." The standards included floor insulation for mobile homes, blown into bellyboard cavities or using batts if bellyboards were missing (VACAA 1990).

Summary of Findings on Energy Conservation Measures

To provide the basis for a new recommended protocol, we review in this section specific energy conservation measures (ECMs), drawing from the three main components of this evaluation study. For each measure, the relevant findings from the PRISM study, the analysis of weatherization measures based on literature review and calculations, and the pilot study are summarized.

The analysis of Chapter 3, especially the engineering/economic calculations, was able to focus on individual measures more than the other studies. However, the calculations are essentially theoretical, based on engineering models and a number of assumptions. Although the PRISM and pilot study results are based on actual weatherization, they provide savings data for "whole" weatherization jobs rather than for individual measures. Efforts were made in both studies to categorize jobs by dominant measures so that as much information as possible on measure-specific savings could be gleaned from the results. Still, the results from all three sources have some limitations in providing actual, measure-specific energy savings and cost-effectiveness data. Taken together, however, the three sources complement one another and provide a comprehensive assessment on which to base a recommended weatherization protocol for Virginia.

Air Leakage Control

Air leakage control has traditionally been, and remains, a mainstay of low-income weatherization. However, the basic approach to air sealing has changed. In most applications the caulking gun has been replaced by the thinking cap; careful diagnostics combined with knowledge of how buildings work is necessary for effective control of air leakage.

From the PRISM Study: The PRISM study offered an assessment of traditional air leakage control. Although crews used a blower door in their work, they lacked sufficient experience and training to use it effectively. Infiltration control focused on sealing leaks in the living space, in the neutral pressure plane, through extensive caulking and weatherstripping of doors, around windows and along baseboards. All units in the PRISM sample had some infiltration control. Although the PRISM results gave changes in energy consumption from the whole job, the units were categorized by dominant measure. The units with "infiltration control only" had few other measures applied. The 29 site-built houses in this category showed an average **increase** in energy use of 4%.

Infiltration rates were reduced by 39% for single-family homes and 54% for mobiles homes in the PRISM sample. However, since much of this infiltration reduction was accomplished

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1 Wall insulation was not a required measure because only the four pilot agencies had been trained to install it. As an optional measure, these agencies could continue to install wall insulation.

by sealing leaks in the neutral-pressure plane, it would not be expected to contribute to significant energy savings.

From the Analysis of Weatherization Measures: Air leakage control does not lend itself to conventional engineering calculations as well as other measures. However, it has been the subject of considerable empirical study that has been well documented. What these studies have shown is that it is important not just to seal leaks, but to seal the leaks that count. These are not the leaks in the living areas for the most part, as these leaks are in the "neutral pressure plane." The important leaks are those in the basements/crawlspaces and attics, those areas in which the air leakage is driven by the "stack effect," and hence are the major source of energy losses. Effective air sealing has evolved into an art involving careful diagnostics, usually using the blower door, to identify large holes, insulation bypasses, subtle convective loops, heating duct and register leaks, as well as crawlspace and attic leaks. With this diagnosis, air sealing can be far more targeted and effective.

Engineering-economic analyses of air sealing required a number of assumptions regarding house size, initial leakiness (in air changes per hour (ACH)), air leakage reduction, and costs. These analyses showed that, for an average size, single-story (Retrotech "A") home anywhere in Virginia, $300 spent on air sealing which results in 30% reduction in ACH will be cost effective. Similarly, about $175 spent achieving the same 30% reduction in ACH in an average size mobile home will be cost effective.

The blower door has emerged as much more a diagnostic tool than a yardstick for achievement. It can be used to detect leaks in critical areas; it can be reversed (i.e., to pressurize the house) to detect leaks in heating ducts. In some programs, it is used to determine when to stop sealing. Most use the door at least to guard against making the house too tight. Others use it to tell crews when they have done enough. In Virginia, for example, a target blower door reading is determined based on the initial reading, and crews must continue sealing until that level is reached. Because the target is not based on the level of work necessary to achieve it, it may lead to too little sealing in some cases, or too much sealing in others. One approach developed by Gary Nelson and Gautum Dutt for the *M-200* program in Minnesota, involves setting a maximum cost value for successive reductions in blower door readings. *M-200* set a maximum cost of $40 for a 100 cfm_{50} reduction in reading. Assuming the most cost-effective sealing is done first, and crews can estimate the time and cost of additional sealing, this can provide a useful quide for when to stop. This approach, using average Virginia climate and fuel cost data, yields a cut-off figure of $32 per 100 cfm_{50}.

Used as a diagnostic tool and to measure incremental reduction, the blower door does not need to give true, absolute values and thus need not be well-calibrated. However, the blower door is an important tool to guard against making the house too tight, and for this, absolute values are necessary. ASHRAE's standard of 15 cfm/person (at ambient pressure) has been used by many programs to establish a minimum blower door reading of about 300 cfm_{50}/person. The *M-200* program, for example, set a minimum level of 1200 cfm_{50} for households with less than 5 persons, and 225 cfm_{50}/person for larger households.

From the Pilot Study: For the pilot study, crews received training on advanced air sealing methods and gave considerable attention to leaks in basements/crawlspaces and attics. They concentrated on big leaks and did far less caulking than was done in the PRISM sample. Window replacements in mobile homes were still a popular measure for infiltration control in the pilot study, but most were done where windows were broken or inoperable.

Although the pilot study gave "whole job" energy savings rather than savings for individual measures, we tried to gather information that would shed some light on the relative improvements from different measures. Crews took blower door readings after each major measure was installed to assess its effect. The total average blower door reduction for all units was 34%. For site-built houses, most of the reduction came from advanced air sealing and wall insulation, while for mobile homes most came from window replacements and duct sealing. This infiltration reduction was actually slightly lower than that from the PRISM study.

Air sealing in the houses in the PRISM sample was primarily in the neutral pressure plane; since these leaks do not contribute significantly to energy losses, reducing these leaks shouldn't be expected to result in savings. The same percent reduction attained by sealing leaks in the attics or crawlspace/basement would be expected to produce larger energy savings, and this is indeed borne out by the results of the pilot study.

Lessons for Protocol: Advanced diagnostics and air sealing techniques are essential measures for effective weatherization and can lead to far greater energy savings than traditional air leakage control. In the protocol, emphasis should be placed on large holes, leaks in attics and crawlspaces/basements, heating ducts and register boots (especially in mobile homes), insulation bypasses and convective loops. Caulking around windows and doors and other areas in the living space sould be eliminated, except when needed to eliminate drafts for occupant comfort. The blower door is a critical tool for diagnostics and for guarding against tightening houses below minimum ventilation requirements. Target blower door readings should not be used to determine when enough air sealing has been done, unless they are related to cost per increment of reduction in the reading. Virginia may wish to explore further the use of this approach.

Attic Insulation

Attic insulation is also a traditional measure in Virginia weatherization, as it has been in most low-income weatherization programs since early on.

From the PRISM Study: Although on average the PRISM sample of weatherization work produced low energy savings and were not cost-effective, the most effective jobs were those which included attic insulation. Weatherization of houses having no existing insulation produced average energy savings of about 18%. However, these jobs were still not cost-effective due to the large amount of money spent on infiltration work. For example, for 46 jobs in the "attic insulation and infiltration control" category, attic insulation accounted for only 1/3 of the materials cost. Therfore, the lack of cost-effectiveness of these jobs should not be attributed to attic insulation. The PRISM study found that attic venting was being done even in cases in which no insulation was added.

From the Analysis of Weatherization Measures: Engineering-economic calculations clearly showed that adding attic insulation to an attic which has none is always cost-effective; in fact, it is about the most cost-effective measure that was analyzed. Because of diminishing returns, adding insulation to an already insulated attic is less effective, but in nearly all cases it pays to add insulation if existing levels are less than R-19.

The analysis also stressed the importance of sealing attic leaks and bypasses before blowing in insulation and that a complete job is critical. It showed that missing 5% of the attic area can result in a 50% reduction in the overall attic R-value. Concerning the issue of venting, the analysis concluded that if you don't insulate the attic, don't vent it (unless there is an obvious moisture problem; and even then you would be wise to look elsewhere for a solution); if you do vent, do careful attic air sealing first.

From the Pilot Study: Attic insulation was installed in 65% of the site-built houses in the pilot study, and these houses averaged energy savings of more than 25%. However, because these jobs included a range of other measures, it is impossible to know how much the attic insulation contributed to the savings.

Lessons for the Protocol: Attic insulation is one of the most effective energy conservation measures to be included in a weatherization program. In Virginia, it is cost-effective to add insulation to a value of R-30 in attics with existing levels below R-19. Before blowing in insulation, attention must first be given to sealing attic leaks and bypasses. Attic venting should be done only if insulation is added, and then only after attic sealing.

Wall Insulation

Prior to this evaluation project, wall insulation was not included as a required or optional measure for Virginia weatherization. Because it has been shown to be effective in other states, wall insulation was given special attention in this study.

From the Analysis of Weatherization Measures: Experience in northern states has demonstrated the effectiveness of high-density blown sidewall insulation not only to increase the R-value of the building envelope, but also to seal leaks and hard-to-get-to bypasses. Studies have shown average reductions in blower door readings of 35% and more from wall insulation. The key to effective wall insulation is proper installation, which requires good training and experience.

Engineering-economic calculations indicate that wall insulation is a cost-effective measure for Virginia even under the most conservative assumptions (i.e., low cost fuel, high cost installation, low heating degree-days, and no air sealing benefits).

From the Pilot Study: Wall insulation was included among the priority measures in the pilot study and proved to be highly effective. In the 17 houses that received wall insulation (along with other measures), energy savings averaged 32%. In one agency, the 6 sidewall jobs achieved an average savings of 47%.

Agency crews received abbreviated training on the measure; most of their learning occurred "on the job." Post-weatherization inspection showed that while the crews appeared capable of getting a good dense pack of insulation where they installed it, they often missed important areas and bypasses. In addition, some crews took several days to complete jobs which added considerably to costs. Still, savings and cost-effectiveness demonstrated in the pilot study were comparable to some of the most innovative work being done in weatherization today (e.g., *M-200*). The most likely reason for this is that Virginia's housing stock, built for a milder climate, probably has both greater infiltration and lower initial sidewall R-values. Both of these factors contribute to poor initial energy performance, but also to high savings potential from weatherization. We would expect as crews gain experience in sidewall insulation, that these already impressive savings might increase even further.

Lessons for the Protocol: Based on the technical analysis and the pilot study, one of the strongest recommendations of this evaluation is the inclusion of high-density blown wall insulation as a high priority measure for Virginia weatherization.

Floor Insulation

Floor insulation has long been an optional measure for Virginia weatherization. In 1989-90, it became a required measure for mobile homes.

From the Analysis of Weatherization Measures: Floor insulation in site-built houses is somewhat difficult to analyze by engineering calculations because of the variability of conditions in basements and crawlspaces and the complexities of downward heat transfer. Instead of focusing on the floor, per se, crews should do a careful job of sealing the perimeter -- i.e. big holes and cracks in the foundation walls, and cracks between the sill plates and rim joists, and the floor above.

For mobile homes, empirical research in colder climates has shown that blowing insulation between the floor and the bellyboard (if none exists) is one of the most effective weatherization measures.

From the Pilot Study: Although bellyboard insulation was included as a high-priority measure in the pilot study installation standards, only two of 16 mobile homes received the measure; batt floor insulation was installed in two others. Unfortunately, the energy consumption results from the two bellyboard jobs were invalid, and both batt insulation jobs had poor installation and lacked full coverage. Thus, the pilot study could shed little light on the effectiveness of floor insulation in mobile homes.

Lessons for the Protocol: Although this evaluation provides little new information on the effectiveness of floor insulation, other studies provide sufficient support for including the measure as a priority for mobile homes. For site-built houses, situations where floor insulation will be warranted are likely to be rare. Emphasis should instead be placed on careful sealing of the perimeter of the crawlspace/basement, with special attention given to cracks around the rim joists and other intersections of floor framing members and the foundation wall.

Window Replacements

Window replacements have been a traditional weatherization measure, embraced by clients and local agencies alike. Clients like the immediate improvement in the appearance of the house; local agencies like the high materials-to-labor cost ratio which provides them substantial earnings under the materials-based reimbursement system. However, these factors say nothing about energy savings and cost-effectiveness.

From the PRISM Study: Primary window replacements were included as principal measures in the weatherization of twelve mobile homes that were part of the PRISM sample. The mobile homes saved little energy (3%), but the costs drove average payback time out of sight (76 years).

From the Analysis of Weatherization Measures: Many state programs no longer include replacement primary windows as a priority measure in weatherization. The engineering-economic calculations showed why. Under only the most extreme assumptions (i.e. electric resistance heat in the mountains and a low installed cost of $9/ft^2), does the measure come close to being cost-effective. Under our best-guess assumptions on installed price and fuel costs, simple payback time (SPT) on replacement windows ranged from 26 years in the mountains to 39 years on the coast.

From the Pilot Study: The installation standards for the pilot study allowed the installation of replacement primaries, but only when existing windows were damaged or deteriorated "beyond repair." Still, probably as a result of habit or reimbursement need, agencies installed more than one window in 19% of the site-built houses and in 81% of the mobile homes. Only for the mobile homes was there any evidence that these measures saved energy. Window replacements (together with door replacements) reduced blower door readings by an average of 17% in mobile homes. In many cases, the original windows were malfunctioning or broken jalousy-type windows.

Lessons for the Protocol: Over-reliance on window replacements was one cause of the poor cost-effectiveness of the Virginia weatherization program in past years. This became clear in the PRISM study. Engineering-economic calculations further documented the general lack of energy savings and cost-effectiveness of this measure. However, there may be certain situations where window replacements may be warranted -- or example, when windows frames are broken out or damaged beyond repair. Also, in mobile homes, malfunctioning windows may be a significant source of heat loss if they cannot close, and inexpensive replacement slider windows can be cost-effective.

But these applications should be the exceptions rather than the rule. Because of their overall poor energy performance, high cost, and cost-ineffectiveness, replacement primaries should be allowed only in extreme situations.

Storm Windows

Storm windows have also been a traditional and popular weatherization measure in Virginia. Until 1988-89, they were included as a priority measure. In 1989-90, they were relegated to an option, and in 1990-91 they were prohibited.

From the PRISM Study: Storm windows (along with infiltration control) were included in 13 site-built house of the PRISM sample. While these jobs showed an average energy savings of almost 10%, they were not cost-effective due to high costs; SPT averaged 27 years.

From the Analysis of Weatherization Measures: The engineering-economic calculations indicated that in general, storm windows are not cost-effective in Virginia. Only in cases of high fuel cost (electric resistance heat) and low installed cost ($\$4/ft^2$), could they be shown to be cost-effective throughout the state.

Storm windows should not be used for infiltration control because when they are installed outside leaky primaries, they can exacerbate window condensation and moisture damage to sills. However, storm windows may provide an improvement in client thermal comfort by increasing the mean radiant temperature of the inside window. This may be important for windows where clients spend most of their sedentary time. Thermal curtains or other moveable insulation may solve this problem better than storms. Some northern states have included "insider" storm windows among their measures for mobile homes.

From the Pilot Study: No storm windows were installed in the pilot study.

Lessons for the Protocol: Like replacement primary windows, storm windows have traditionally been a popular measure in Virginia weatherization, yet one reason for the program's limited energy cost-effectiveness. Because they are not cost-effective throughout the state under normal conditions, they should not be part of a statewide protocol.

Heating System Work

Except for duct sealing, heating system work has not been part of the Virginia weatherization program. The program conducted three pilot projects in 1986 and 1987 to assess oil furnace cleaning and tuning and burner replacements, but the results did not give clear guidance to the program on how to address heating systems. This question provided a major focus of this evaluation.

From the PRISM study: Since heating system work was not part of the 1989-90 program, the PRISM study provided no useful information on this measure.

From the Analysis of Weatherization Measures: There are two reasons for including heating system work in weatherization procedures: 1) to improve their efficiency and save energy, and 2) to correct any impacts the heating system may have on the health and safety of the occupant. The safety problem becomes especially serious as weatherization crews become better at sealing air leaks and reducing infiltration (and ventilation).

Energy savings are less well-defined. From other studies, savings from cleaning and tuning appear to vary widely, from zero to 8%, because of varying initial conditions and differing definitions of a "clean and tune". Replacement of oil burners with a flame-retention head type shows more promise, with savings from 10% to 20% depending on initial conditions. The only gas furnace retrofit with clear-cut savings (15% to 35%) is replacement with a new high-efficency furnace. The above measures involve progressively higher costs, but they can all be cost-effective in certain situations.

From the Pilot Study: Despite abbreviated training, the pilot agencies demonstrated that they can learn to perform both basic safety and operation inspections and furnace clean and tunes. They successfully inspected furnaces in 44 units and one agency performed clean and tunes on ten furnaces. Safety problems were detected in 30% of the inspected furnaces and needed repairs were done by the crews, the gas utility (in the case of leaks), the landlord, or a contractor with money from weatherization, local housing rehab funds, or the Department of Social Services fuel emergency fund.

The clean and tunes resulted in a small improvement in steady-state efficiency, but considering the small sample, and unresolved questions as to the persistence of the efficiency increase, the results were not sufficient for us to conclude that cleaning and tuning furnaces would lead to substantial energy savings in Virginia.

Lessons for the Protocol: Because of safety concerns and the evidence of safety problems, heating system safety inspections and problem remediation must become part of Virginia weatherization. This must include not only oil and gas furnaces, but also the variety of wood and coal stoves and other heating devices used in Virginia. The pilot study showed that Virginia local agencies can be trained to perform inspections and minor repairs, and that a mechanism must be established to solve heating system problems.

Neither the pilot study, nor other evaluations, provide clear or consistent evidence that furnace cleaning and tuning results in cost-effective energy savings. Additional study may be needed before this measure is included in the protocol.

Heating system work should focus not just on the furnace, but on the entire system from the thermostat to the delivery system. Significant savings can be achieved from sealing ducts and register boots (see following section). Although automatic setback thermostats can also help clients save fuel costs, we did not specifically address this measure in the evaluation.

After gaining experience in safety inspections and repairs in all agencies, the program should assess statewide application of other heating system work to improve furnace operating efficiency, such as adjustment of controls, clean-and-tunes, burner replacements, and others.

Sealing and Insulating Heating System Ducts and Registers

Sealing of forced-air heating system ducts has been included under air leakage control in Virginia's installation standards since 1988-89.

From the PRISM Study: Even though duct sealing was part of the installation standards in 1988-89, we were unable to identify if the measure was used in any of in the weatherization jobs represented by the PRISM sample.

From the Analysis of Weatherization Measures: Duct and register sealing and insulation is not amenable to engineering-economic calculations, but empirical studies in both cold and mild climates have shown that leaking ducts and registers can be a major source of energy loss. Ducts are especially important as leaks can discharge heated supply or return air into unheated spaces. The blower door can be used effectively to detect leaks around registers (by depressurizing the house) and in ducts (by pressurizing the house). Insulating metal ducts may also be an effective conservation measure if they run through open or unheated crawlspaces.

From the Pilot Study: It is impossible to determine the effect of duct and register sealing on energy savings in the pilot study, but in the mobile homes this measure reduced blower door readings by an average of 11%. Most of the work focused on register sealing. However, in two of the homes which had high energy savings, duct sealing was among the measures installed. Average total cost for duct and register sealing in the mobile homes was only $45 per job. Duct sealing was done in about one-third of the site-built houses at an average cost of $15.

Lessons for the Protocol: Due to their relatively low costs and large potential energy savings, sealing heating system ducts and register boots may be among the most cost-effective measures in weatherization. In certain cases, duct insulation can also achieve significant savings. This is well-documented in the literature and supported by some information from the pilot study. These measures should be given priority in a new protocol, either as part of the heating system or air sealing procedures.

Water Heater Insulation

Water heater insulation has long been included in Virginia's priority system. Direct measurement of energy savings and cost-effectiveness of this measure was not included in either the PRISM or pilot studies.

From the Analysis of Weatherization Measures: Costs associated with water heater insulation are small and measured savings in other programs suggest that energy savings can be significant and cost-effective. Procedures should include insulating both hot and cold water pipes for a distance of 3-4 feet from the heater. In addition, in other weatherization programs, low-flow shower heads are often used to save hot water energy.

Lessons for the Protocol: Insulation of both electric and gas water heaters should be retained as a priority measure in the protocol for Virginia weatherization. Low-flow shower heads will save energy if clients continue to use them once installed. Virginia should consider them as a future measure.

Using Energy Use Data in Job Estimation

To improve the overall effectiveness of weatherization programs, some states have used pre-weatherization energy consumption data to assist in job prioritization and estimation.

From the PRISM Study: The PRISM study sample showed little correlation between pre-weatherization energy use and post-retrofit savings. We believe that this lack of correlation resulted from the nature of the measures employed; i.e., that the program failed to take full advantage of the savings opportunities in houses with high energy consumption.

From the Analysis of Weatherization Measures: Some studies have shown a strong correlation between pre-retrofit consumption and ultimate savings. They suggest that by focusing on high energy-use dwellings, programs can save more energy and be more cost-effective. Energy use data can be used to prioritize jobs (i.e., high energy-using units are weatherized first). However, such a prioritizing system is not equitable, tends to reward those who don't conserve energy, and is difficult to implement with existing criteria favoring the elderly and handicapped.

Alternatively, energy use data can be used in estimation to determine the level of investment warranted: more work and time is justified for houses with high consumption, while less expense should be put into those with lower consumption.

From the Pilot Study: The relationship between pre-weatherization consumption and savings was stronger in the pilot study than in the PRISM study, especially for mobile homes. This suggests that the pilot study weatherization was more effective at identifying and correcting the problems of energy-intensive households.

Lessons for the Protocol: Because of equity concerns, we do not recommend using pre-retrofit energy consumption data to prioritize units for weatherization. While the information can be very useful to guide estimation and determine investment levels, we do not recommend its use at this time for two reasons. First, although there was a correlation between pre-retrofit use and savings in the pilot study, it was not terribly strong ($R^2 = 0.26$ for site-built, $R^2 = 0.65$ for mobile homes); additional study is needed. Second, this approach could be effectively used only for houses heated by an easily measureable fuel (gas, oil, propane or electricity); 30% of Virginia weatherization houses are heated by other fuels. And third, agencies have limits in their capability to learn and to implement effectively new measures and procedures; this evaluation will likely lead to major changes which may already push those limits. The use of energy use data for estimation should be considered at a later time.

A Recommended Weatherization Protocol for Virginia

Based on the preceding discussion, Table 5-3 presents a framework for a new protocol for the Virginia weatherization program. The measures included in the protocol should not be performed in a traditional step-by-step priority system, but rather as a package of measures to be installed in all housing units where applicable. Their application in specific units would be determined by diagnostics, especially during estimation but also during installation.

The measures include those demonstrated by the discussion above and the preceding chapters to produce cost-effective energy savings and to ensure client safety. In this latter category is heating system inspection. The inspection should review, at a minimum, the following: the integrity of the fuel and electrical supply lines; the combustion system (including air intake, draft, flue and vent system, flue gas carbon monoxide, and heat exchanger integrity); clearance from walls; and safety controls. Simple efficiency improvements, such as cleaning blower fans and providing a six month supply of furnace filters, should be done during the inspection. Important efficiency improvements to air distribution systems (sealing leaks in the plenum, ducts, and register boots) can be done in conjunction with the safety inspection or the air sealing work. (For more detailed information on procedures for heating system inspections, see the *Training and Technical Assistance Manual for Virginia Weatherization* accompanying this report.)

For site-built, single-family homes, the major energy conservation measures include large leak and bypass sealing, sidewall and attic insulation, and water heater insulation. (For more detailed information on procedures for advanced air sealing and wall insulation, see the *Training and Technical Assistance Manual for Virginia Weatherization* accompanying this report.)

During air sealing, the blower door should be run periodically to make sure readings do not fall below a minimum ventilation rate (MVR). The MVR should be based on the ASHRAE standard. With regard to sidewall insulation, we recommend that it be installed even if the blower door reading is at the MVR level. We believe that if the house is already that tight, there is probably little leakage through the walls and insulation should not exacerbate the problem. This premise can be easily tested in the field as these situations arise.

After the major measures are completed, caulking and weatherstripping are warranted only if needed for client comfort and then, only if the blower door reading is still above the minimum ventilation rate. Window replacements are considered "repairs," and as such, are warranted only if the existing window or door is inoperable or deteriorated beyond repair.

The protocol is similar for mobile homes, with the exception that floor insulation is included as a priority measure and attic and wall insulation are not included. Obviously, air leakage sites in a mobile home will differ from those in site-built single-family structures; training will need to focus on these building types individually.

Based on the results of this evaluation, VACAA revised its installation standards and hopes to begin training local agencies on the protocol in Spring 1991 and to start implementing the new standards before the end of the contract year. For more information on the installation standards, see *Virginia Weatherization Program Installation Standards* (VACAA 1991).

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TABLE 5-3. RECOMMENDED FRAMEWORK FOR INSTALLATION STANDARDS

Site-Built, Single-Family Homes

1. Heating System Inspection
   a. Inspect heating system for safety problems
   b. Perform simple repairs, improvements
2. Heating System Ducts and Registers
   a. Seal leaks in forced air plenum, ducts and register boots
   b. Insulate ducts/pipes if in unheated area, as needed
3. Large Leak & Bypass Sealing
   a. Blower door test (record pre-weatherization reading; use as diagnostic tool to find major leaks in attic, basement/crawlspace, and ducts; guard against dropping below the minimum ventilation rate (MVR))
   b. Major air sealing (if above MVR)
      1) seal large openings
      2) seal attic and basement/crawl space bypasses.
      3) seal other major bypasses; use blown cellulose insulation as needed
4. Sidewall Insulation; use high-density, blown cellulose
5. Attic Insulation
   a. If existing insulation is $<$ R-19, add insulation to R-30
   b. If existing insulation is $\geq$ R-19, do not add additional insulation
   c. Install venting (only if insulation added)
   d. Insulate hatch
6. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting, as needed
   b. Insulate first 3 feet of hot and cold water lines
   c. Install insulation jacket
7. Caulking & Weatherstripping
   a. Install ONLY IF needed for client comfort AND still above MVR
8. Weatherization Repairs
   a. Replace windows or doors if inoperable or deteriorated beyond repair
   b. Perform any other repairs necessary to protect weatherization work

Mobile Homes

1. Heating System Inspection
   a. Inspect heating system for safety problems
   b. Perform simple repairs, improvements
2. Heating System Ducts and Registers
   a. Seal leaks in forced air plenum, ducts and register boots
   b. Insulate ducts/pipes if in unheated area, as needed
3. Large Leak Sealing
   a. Blower door test (as above under site-built homes)
   b. Major air sealing (if above MVR)
      1) seal large openings
4. Floor Insulation (blown between floor and bellyboard or batts if no bellyboard)
5. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting
   b. Insulate first 3 feet of hot and cold water lines
   c. Install insulation jacket
6. Caulking & Weatherstripping
   a. Install ONLY IF needed for client comfort AND still above MVR
7. Weatherization Repairs
   a. Replace windows or doors if inoperable or deteriorated beyond repair
   b. Perform any other repairs necessary to protect weatherization work

Chapter 6: Administrative Issues

Introduction

One objective of this evaluation project is to identify administrative issues which may affect the ability of Virginia's program to implement the recommended protocol of measures described in Chapter 5. Indeed, some of these administrative factors already prevent optimal implementation of the existing standards. Interviews with local agency staff, discussions with VACAA personnel, review of other states' programs, the PRISM study, and especially the pilot study all contributed to the assessment of administrative issues. In this chapter, we discuss the major issues and summarize our recommendations for improving administrative procedures.

The Reimbursement System

The current system of reimbursing costs to local agencies is based solely on the cost of materials installed in weatherized houses. Agencies can recoup their non-materials costs such as labor, warehousing, transport, administration, etc., only through "earnings" based on a percentage of the value of materials installed in clients' homes. This percentage varies among agencies and ranges from 120% to 150%. Adding this percentage to materials costs then gives the maximum total reimbursement rate of 250% of materials cost, and the breakdown conforms to the traditional U.S. DOE weatherization rule of a maximum 60% for "program support" costs and a minimum 40% for materials.

This reimbursement system has a major impact on determining the work performed by local agencies, as they traditionally have selected materials-intensive work (e.g., window and door replacements) which will earn them the most money and enable them to cover their own costs. Table 6-1 compares actual and reimbursed costs for measures installed as part of the pilot study. This table clearly illustrates the substantial monetary incentive for agencies to install replacement windows. Local agencies already perceive the reimbursement system as a barrier which dissuades them from installing labor-intensive measures which are part of the existing standards (such as belly board insulation). Some agencies have even established quota systems for their crews, requiring a certain value of materials installed per person per day. However, the PRISM study, described in Chapter 2, and the analysis of weatherization measures in Chapter 3 clearly showed that most materials-intensive measures (such as window replacements) are largely ineffective at saving energy. Therefore, one major conclusion of this evaluation project is that the current reimbursement system is a contributing factor to the past program's lack of energy savings and cost-effectiveness.

TABLE 6-1:
CURRENT REIMBURSEMENT COMPARED TO ACTUAL ON-SITE COSTS IN PILOT STUDY

Measure	Pilot study Actual Matls Cost	Pilot study Actual On-Site Non-Matls Cost	Pilot study Total Actual On-Site Cost	Reimbursed On-Site Costs: Matls + 77%[1]	Reimbursed Costs Actual Costs[2]
MH-Replacement Windows	$235	$ 53	$288	$416	1.44
SB-Replacement Primaries	$274	$ 19	$293	$485	1.66
SB-Attic Insulation	$256	$ 53	$309	$453	1.46
SB-Wall Insulation	$262	$666	$428	$464	0.50
MH-Duct Sealing	$ 18	$ 27	$ 45	$32	0.71
Heating System Inspection	$0.40	$ 15	$ 15	$0.70	0.05

[1]Assuming 150% reimbursement rate, off-site, average local program support of $466 per job is 73% of materials cost ($640) for $1600 job; 77% of materials cost remains for on-site non-materials cost.
[2]Value greater that 1 offers substantial monetary incentive for agency to employ measure under current reimbursement system. Value less than 1 offers a disincentive and perhaps the inability to employ measure under current system.

The pilot study demonstrated that certain labor-intensive measures, such as advanced air sealing, wall insulation, duct and register boot sealing, and heating system inspections, are very effective weatherization measures for Virginia. However, under the current reimbursement system, agencies would be unable to recoup the costs of these measures (see Table 6-1). Therefore, the new installation standards recommended by this evaluation cannot be implemented under the current reimbursement system.

Rather than trying to change agencies' choice of measures through tighter restrictions and more intensive monitoring, the current reimbursement system must be changed to take away the financial incentive for installing high materials-cost items which are not cost-effective. Options for modifying the system include:

- reimbursement based on actual costs including both labor and materials;
- variable materials-based reimbursement rates for different measures reflecting different labor requirements.

Option (b) could provide a standardized system (so that VACAA would not need to worry about the accuracy of agency reported labor times), but more information and experience would be needed to set the measure-specific reimbursement rates. Option (a) is used by several other states[1] and is recommended for Virginia, at least in the short term. In time, this system could provide the information needed to set variable rates for option (b). It should be noted that an expanded definition of material costs, which has been suggested by VACAA in the past, would not solve the reimbursement problem. Such a system includes certain warehousing, transportation, and labor costs under the definition of materials costs and thus

[1] We talked with weatherization staff in Illinois, Massachusetts, Minnesota, and Wisconsin, all of whom reported using a reimbursement system based on actual labor and material costs. They encountered no problems with crews tallying the labor time required for each job.

would allow agencies to justify higher program support costs associated with labor intensive measures. However, the system still gives agencies the incentive to install high materials-cost items.

Technical Training

Over the past decade, the skills expected of weatherization personnel have changed dramatically. New recommended measures (e.g., advanced air sealing, bypass work, heating system inspection) require a less standardized, more house-specific diagnostic approach to weatherization. Agencies tell us that their estimators feel there is a need for more training on diagnosing and prioritizing the needs of each house. They think that the training they have received thus far has focused on how to install particular measures, but more is needed on how to diagnose a house's problems. The PRISM study revealed vast differences in the cost-effectiveness of work performed by different agencies, confirming the need for more training to improve the caliber of weatherization being implemented across the state. Therefore, adequate technical training, especially for the estimator but also for crew personnel, is essential if the new measures are to be implemented properly. A Training and Technical Assistance Manual developed as part of this evaluation project and accompanying this report is designed both to assist in training and to be used by agency personnel as a reference in the field.

Our experience with trainings for the pilot study showed that, although some classroom training is necessary for learning to install new measures, field training and experience are far more important for building expertise. In addition, the pilot showed that some follow-up training is necessary to answer questions that only arise after crews have worked on a variety of houses on their own. Therefore, a critical component of a training program is follow-up, on-site training either done through special sessions or incorporated into field monitoring (see discussion of "Program Oversight/Monitoring" below). For sidewall insulation and bypass control work, an infrared camera is an essential tool for effective follow-up training and monitoring.

Agency Personnel

The diagnostic requirements of the new measures place added responsibility on the estimators, crew supervisors, and designated heating system inspectors. The additional expertise and training required for these individuals may necessitate changes in personnel hierarchy and pay scales in some local agencies. If heating system work beyond inspections is contemplated (e.g., clean and tunes, heating system retrofits), the amount of training required might prohibit having one "heating system person" at each agency. One alternative would be to have several agencies share a highly skilled heating system person, who would travel from agency to agency taking care of any heating system problems that the local agency inspector has discovered.

Mechanism for Solving Heating System Problems

In the pilot study, heating system problems were identified in 30% of the houses inspected. While weatherization staff can be trained relatively easily to perform heating system inspections, they will not be able to fix all the heating system problems they are likely to find. (Such a level of competence would require many months of training.) A procedure and sources of assistance need to be established to respond to problems when they are identified. In the pilot study, various mechanisms were used: Virginia Department of Social Services fuel emergency funds (up to $700 per unit); local agency housing rehabilitation funds; weatherization funds for repairs weatherization staff could carry out (up to $200 per unit); landlords; and utilities (for gas leaks). One possibility might be for several agencies to share a highly trained heating system repair person (see section on "Agency Personnel" above). Another option is to hire private heating system contractors to implement the repairs. However, some provision would have to be made for inspecting the repairs, as the quality of private contractors' work varies widely.

Equipment

New recommended measures require effective equipment including well-calibrated blower doors, correctly operating insulation blowing machines, and heating system inspection equipment. The pilot study was plagued with difficulties caused by ineffective equipment. Proper care and periodic testing and maintenance of equipment are necessary. Infrared cameras are extremely useful to ensure correct and thorough installation of wall insulation and bypass sealing (and absolutely essential for monitoring of such jobs). For more details, see discussion of "Equipment Requirements" in Chapter 4.

Program Oversight/Monitoring

Currently, field monitoring is the principal mechanism for program oversight. There is an opportunity for improved oversight through central office (i.e., Richmond) analysis of Home Weatherization Worksheets (HWWs) and other job-specific reported information. This analysis could assess, on an agency-by-agency basis, the specific measures installed, costs incurred, and other data that can characterize each local agency's approach to weatherization. We compiled this type of information from HWWs as part of the PRISM study, using simple computer database programs, and VACAA could easily do the same. This assessment, complemented and verified by field monitoring, can be used to recommend improvements to the agency.

Improved reporting forms (such as HWWs and estimation forms) can help this assessment. They can also reduce paperwork (by eliminating the repetition that exists on current forms) and more accurately reflect new priority measures of the program (e.g., current forms still emphasize measurements for replacement windows, rather than featuring checklists for locating important air leakage sites in the attic and basement/crawlspace). Improved forms could also simplify future evaluation efforts (by being more measures-oriented, rather than cost-oriented; by recording a client's utility name and account number, which would greatly simplify retrieval of their energy consumption data; by recording the square footage of the house, which would allow more accurate comparisons of energy usage; and by recording the end-uses the heating fuel is used for). We developed forms for use in the pilot study (see Appendix C.4) which incorporated some of these changes that could be used as a starting point for new standardized forms. Another possibility for VACAA to consider is computerization of forms. Some agencies have already developed their own systems for tracking clients and materials, generating forms, etc. Most agencies we surveyed either use or have access to a computer. It would be worth VACAA's effort to develop a computerized tracking system to which all agencies could have access.

Field monitoring should incorporate follow-up training, emphasize constructive criticism, and be less regulatory (so agencies will be more forthcoming about difficulties they encounter). In interviews with local agency staff, they revealed that monitoring was their most valuable training opportunity. It was preferred over workshops because it dealt with the specific problems encountered by their agency, in their own housing stock.

On-Going Evaluation

The most effective weatherization programs in other states have incorporated on-going evaluation to identify and provide continual program improvements. Similarly, VACAA will need to carry out additional evaluation in the future, to identify how well the improvements recommended in this study are being implemented, to investigate questions not answered by this research (e.g., savings from belly board insulation), and to test new weatherization techniques (e.g., heating system efficiency improvements, using energy consumption data as part of the estimation process). Improved central office oversight can contribute to this effort. Some energy-savings analysis is necessary for effective evaluation. Without it, there is no way of knowing if the program is improving, and what proposed changes are worthwhile. Energy analysis methods used in this project (i.e., use of furnace run-time meters (the program has 120 of these meters) or PRISM analysis of utility bills) are options. Improved reporting forms and the experience gained in the course of this study will serve to simplify future evaluation efforts.

Summary

While this evaluation study has focused on developing recommended energy conservation measures for the Virginia Weatherization Program, the effective implementation of those measures depends on a number of administrative factors, principally local cost reimbursement and crew training. Many of the recommended measures cannot be effectively implemented under the existing reimbursement system based solely on the cost of materials installed. A new system based on actual materials **and** labor costs is recommended. Most of the recommended measures are new for Virginia weatherization crews and require special skills and experience. Centralized workshops, field-level training in individual agencies, and follow-up inspection and review of work are all essential components of a comprehensive training program necessary for effective implementation of the measures.

Other issues including equipment maintenance and program oversight, monitoring, and on-going evaluation must also be addressed if the program is to achieve its full potential effectiveness.

Chapter 7: Summary of Findings and Recommendations

The preceding chapters have described in considerable detail the many aspects of the evaluation of the Virginia Weatherization Program. **The main objective of the evaluation was to improve the energy savings and cost-effectiveness of the program by developing a new protocol of energy conservation measures and recommending improvements in administrative procedures.** Although similar studies have been done in nothern 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).

This chapter summarizes the project, highlighting its major findings and recommendations. The main components of the study included the following. First, an analysis of the energy savings and cost-effectiveness of the existing 1988-89 program provided a baseline against which to compare the test results of new measures. Second, a careful review of the literature and experience of other states' programs, as well as engineering/economic analysis, assessed new energy conservation measures and identified those measures to be tested in a field-level pilot study. Third, new measures were tested in the pilot study involving four Virginia local agencies and 59 houses. Fourth, the pilot study results and engineering analysis served as the basis for a new recommended protocol of measures and installation standards. Finally, an assessment of program administrative procedures identified issues that need to be addressed if the proposed program changes are to be implemented effectively. Each of these study components is summarized separately below.

Effectiveness of 1988-89 Virginia Weatherization Program

To evaluate the energy savings resulting from weatherization, the Princeton Scorekeeping Method (PRISM), a nationally recognized computer program for adjusting energy use data for changes in weather, was used to analyze utility bills of a sample of natural gas and electrically heated homes weatherized in the 1988-89 contract year. Agency information on house characteristics, measures installed, blower door readings, and costs were used with the energy savings data to assess relative effectiveness of individual measures. Although almost 1500 housing units were initially screened for this study, the final PRISM sample shrunk to 188 units because of attrition due to unavailability of complete utility bills and other factors. Fifty-six percent of these units were heated by gas and 44% by electricity; 60% were site-built single family units, 21% were multifamily and 19% mobile homes.

The major findings of the study included the following:

- **Energy savings in these 1988-89 weatherized units averaged about 6% of normalized annual consumption for gas-heated units and 4% for electrically heated units (9% and 5% of space heating use, respectively).** The largest sub-sample, 91 gas-heated, single-family houses averaged 8% savings. Thirty-five percent of the units saved 10% or more, while 31% actually increased their energy usage after weatherization.
- The energy savings of all Virginia units weatherized in this period are probably somewhat higher than these results. This sample of gas- and electrically heated units are

generally thought to be in better condition prior to weatherization than the average oil- or wood-heated units (for which energy use data were unavailable). The savings in these latter units, which constitute almost half of Virginia's weatherized dwellings, are expected to be somewhat higher than the PRISM sample.

- The weatherization cost of the PRISM sample, using labor costs as determined by reimbursement formulae, averaged $1573 (including materials, labor, program support, and administration). Due to the low energy savings, the cost-effectiveness of the work was also low. **The simple payback time (SPT) of the weatherization work in the PRISM sample averaged 34 years for gas-heated units and 39 years for electrically heated units.** The acceptable payback threshold for cost-effective weatherization is generally 8 to 10 years.
- The low savings and cost-effectiveness of these 1988-89 units is attributable to the measures installed. The work was characterized by heavy caulking and weatherstripping (e.g., more than 20 tubes of caulk were installed in 75% of the single family houses), storm window installation (in half of the single family (SF) and mobile homes(MH)), replacement of primary windows (in 25% of SF and 60% of MH) and doors (66% of MH), and attic insulation (in half of the SF).
  - The jobs containing attic insulation, especially those with no existing insulation, came closer to being cost-effective than the others. Most of the units with savings greater than 10% had attic insulation installed. High cost of other measures in these jobs lowered their overall cost-effectiveness.
  - In those SF homes which received only infiltration work, median energy use actually increased after weatherization.
  - SF homes receiving a package of storm windows and infiltration work typically saved 10%, but because costs were high, these jobs were not cost-effective, with SPT averaging 27 years.
- Although we believe the gas- and electrically heated units in this PRISM sample are in better condition than the average Virginia low-income housing stock, the pre-weatherization energy consumption was higher than the national average. This indicates that there may be substantial opportunities for savings in Virginia's housing stock. In the PRISM sample, however, there was no correlation between pre-weatherization energy use and resulting savings, indicating this work did not take full advantage of the opportunities for savings which were present.
- The weatherization work evaluated by the PRISM study showed a wide range of effectiveness among local agencies. This indicates a need for additional training and oversight to improve agency performance across the board, but even more so in some agencies than in others.

Analysis of Energy Conservation Measures

To identify appropriate new measures for Virginia weatherization, the project staff reviewed other states' programs and evaluation studies and relevant conference proceedings and technical literature. In addition, engineering calculations and economic analyses were conducted for selected measures to assess their applicability for Virginia's climate, fuel costs, and housing stock. This information was used to select measures to be field tested in the pilot study and also to support the overall study recommendations.

Major findings from this phase of the study include the following:

- **Experience from leading states during the past few years has shown that a revolution has been occurring in low-income weatherization as a result of advances in building science, improved diagnostic procedures and tools, and state-sponsored evaluation studies.** The revolution can be characterized by the following developments:

- Heating system work has become an essential part of advanced weatherization programs. Many programs have included efficiency improvements through cleaning and tuning, burner replacement, furnace replacement, installation of set-back thermostats, and attention to the distribution system (duct sealing, insulating, balancing). It has become clear, however, that at a bare minimum, weatherization programs must address heating system safety problems since tightening the building shell through weatherization can actually exacerbate the hazardous effects of inadequately vented combustion gases, cracked heat exchangers, and fuel leaks.
- Better understanding of air movement in buildings and improved "house doctoring" diagnostics have enhanced weatherization air sealing methods. Attention has focused on leaks in basements/crawlspaces and attics which contribute to a "stack effect" that increases infiltration losses. Leaks in these areas have been shown to be far more important than those in the living space (such as around windows and doors) that 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. More important to the task, however, is a trained and experienced diagnostician.
- Several northern states have employed blown-in wall insulation as a weatherization measure. Experimentation 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 specific measures for cold climates have been shown to be: blower-door-directed air sealing and duct repair; blown belly board insulation; interior storm window panels; and roof-blown insulation.

- **Engineering calculations with accompanying economic analyses were conducted to assess existing and prospective new measures for cost-effectiveness in Virginia.** Unfortunately, not all measures are amenable to engineering calculations. Analyses were performed for attic insulation, wall insulation, primary window replacements, and storm windows. For each measure, sensitivity analysis was conducted for Virginia's three climatic zones (3400, 4200, and 5000 heating degree-days), three fuel costs (gas, oil, and electric), three assumed installed costs, and different engineering assumptions to see under what conditions the measure is cost-effective and under what conditions it is not.

  The analysis provided the following results:
  - **Adding attic insulation to R-30 is extremely cost-effective** throughout Virginia, except when existing levels exceed R-19.
  - **Sidewall insulation is extremely cost-effective** throughout Virginia, even when little or no infiltration savings are assumed.
  - **Replacement primary windows are not cost-effective** throughout Virginia even under the most favorable assumptions.
  - **Storm windows are not cost-effective** throughout the state; they become cost-effective only under the most favorable assumptions (high degree-days, high energy prices).

Testing New Measures in Virginia: The Pilot Study

The heart of the evaluation was the pilot study which tested new weatherization measures in Virginia homes. It involved existing weatherization crews in four agencies. **The pilot study aimed to measure the energy savings and cost-effectiveness of selected new measures and**

to assess the capabilities of Virginia crews to be trained for and to implement the measures. The weatherization measures implemented in the pilot study included:

- **heating system** safety inspections, furnace cleaning and tuning, and duct and register sealing.
- **advanced air sealing** diagnostics focusing on attics, basements/crawlspaces, large holes and bypasses.
- **sidewall insulation** using high-density blown cellulose.
- **attic insulation** in site-built houses and **bellyboard insulation** in mobile homes.

Some measures from existing VACAA standards, such as water heater wraps and attic insulation were retained, but others, including conventional caulking and window replacements, were specifically deemphasized in the pilot study.

Special installation standards were developed for the pilot study. Crews attended short training sessions on the new measures, then applied them to 59 houses between December 1989 and February 1990. The crews carefully documented their work using logging sheets.

Each pilot house was monitored for energy use for several weeks before and after the weatherization using elapsed-time meters on the furnace. Pre- and post-weatherization energy use data were compared to calculate energy savings, which was combined with materials cost and labor data to compute cost-effectiveness.

At the end of the study, each house was inspected to detect any irregularities; also crews and clients were interviewed to assess their perceptions of the work.

The principal results and findings from the pilot study include the following:

- The weatherization work performed on the pilot units conformed with the special installation standards fairly well for the site-built (SB) houses. Of the 43 SB 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 (MH) retrofits followed the standards in emphasizing duct and register boot sealing (in 81% of the homes). However, agencies did not adequately address the standards in that floor insulation was installed in only 25%, and window and door replacements, which the standards specifically deemphasized, were installed in 81% and 75% of the MH respectively.
- Post-weatherization inspection of the pilot houses, some using an infrared camera, showed that the quality of the work performed was mixed, varying from one agency to another. Less-than-perfect work was expected, given the abbreviated training that the crews received and the fact that they were "learning by doing." Still, agency crews demonstrated that they are capable of learning and applying the new measures.
- **Energy savings resulting from the pilot weatherization averaged 26% for all 43 site-built houses and 15% for all 16 mobile homes.** After eliminating units that had supplemental heat or inconsistent heating systems, both of which reduce the validity of the energy results, average savings were 28% for 34 SB and 17% for 13 MH. Compared with the PRISM study results and other national and state evaluations, these savings are very good (see Figure 7-1). Moreover, considering the circumstances of the pilot study (i.e., abbreviated training, crews "learning by doing," less-than-perfect work quality and compliance with pilot installation standards), it is expected that given time and experience, Virginia crews could achieve even greater energy savings.
- While average energy savings were very good overall, they were especially high for certain measures and for certain agencies. The 17 site-built houses that received wall insulation averaged 32% energy savings. In one agency, the six jobs with wall insulation averaged 47% savings. Air sealing measures reduced infiltration, as measured by blower door readings, an average of 34% for all SB and MH units.

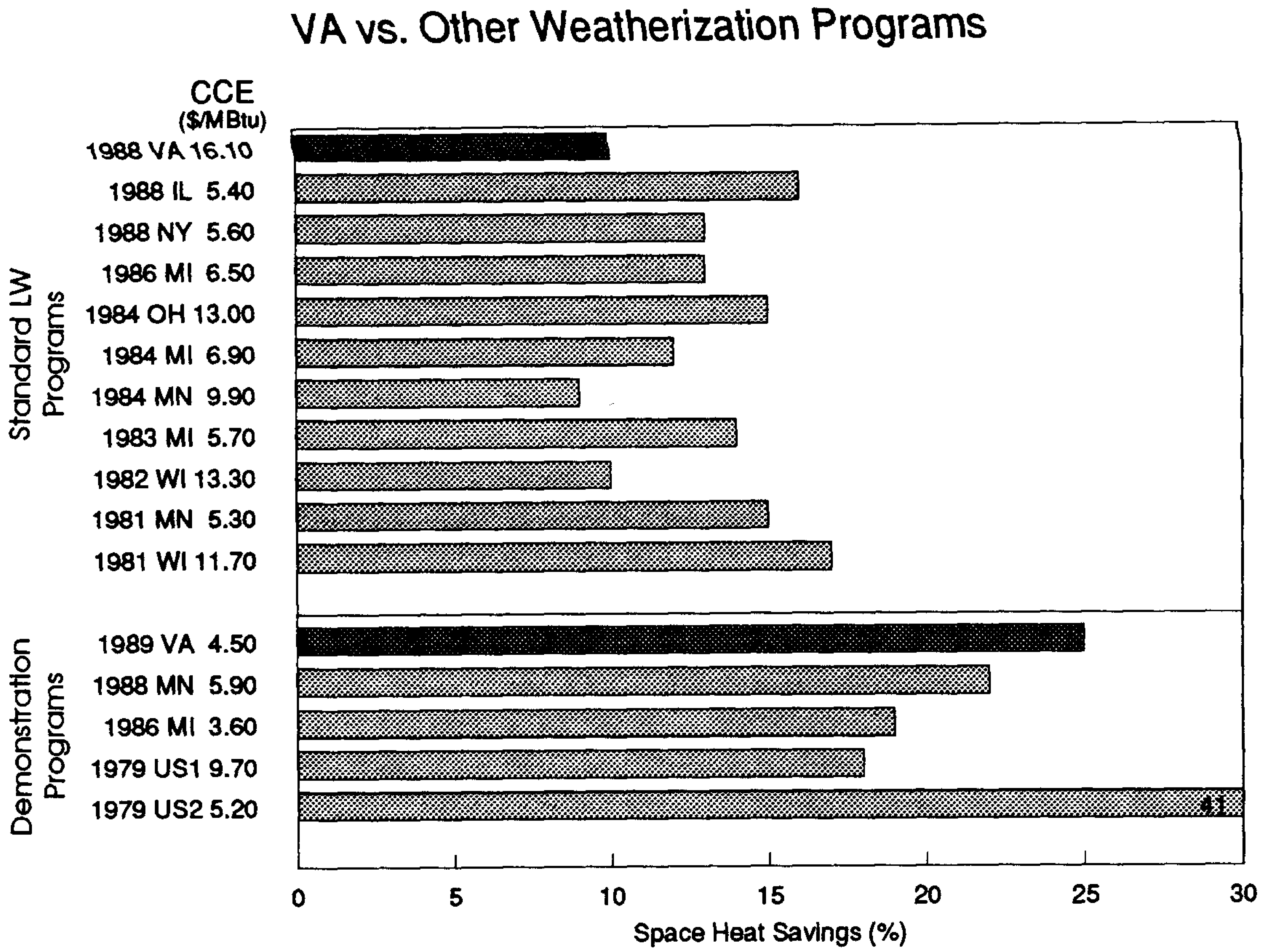

Figure 7-1. Space heat savings and cost of conserved energy for Virginia evaluations compared to other standard and demonstration weatherization programs.
"US1" and "US2" refer to the Community Services Administration study of shell/system measures, respectively. Source: Cohen et al. 1991.

- Cost-effectiveness of the the pilot work was comparable to other notable pilot weatherization studies, such as Minnesota's *M-200* study (see Figure 7-1). **Simple payback times (SPT) based on actual monitored materials and labor costs were 6 years for SB houses and 10 years for MH; when administrative costs are added, SPT rose to 10 and 18 years, respectively.** SPT based on agency reimbursement rates (materials cost + program support (150% of materials cost) = 250% of materials costs) were 8 years for SB houses and 16 years for MH. While these results are much better than those for the PRISM study (SPT = 21-30 years for SB, 53 years for MH). the SB results are about at the acceptable threshold for weatherization SPT (about 8-10 years), and the MB results are well above it. However, there are reasons to believe that under non-pilot conditions and given further experience, local crews can substantially improve the cost-effectiveness of the weatherization measures implemented in the pilot study. The pilot study required additional crew time to record measure-specific labor time data and perform frequent blower door tests, tasks that would not be required under non-pilot conditions. In addition, crews were "learning-by-doing," so labor times were significantly longer than what would be expected after they had more experience. Therefore, the higher than expected SPT resulting from the pilot should not be a source of concern. However, if Virginia follows this study's recommendations and implements the pilot measures statewide, labor time should be monitored to assess the extent to which cost-effectiveness is improved.
- Crews also demonstrated that they are capable of performing heating dystem work, especially safety inspections. Inspectors found safety problems in 30% of the 44 units inspected. The pilot study demonstrated the need for a mechanism to respond to problems once detected. Crews were resourceful in tapping non-weatherization agency funds, Department of Social Services (DSS) emergency funds, utilities, and landlords for needed repairs. One local agency went beyond safety inspections and cleaned and tuned ten furnaces.

- In general, client interviews showed that residents were extremely pleased with the work performed and noticed substantial improvements in levels of thermal comfort.

Recommended Protocol of Weatherization Measures for Virginia

Based on the results of the pilot study and other research for this project, a proposed new protocol of weatherization measures is recommended. The protocol is outlined in Table 7-1. Because of the synergistic and complementary nature of several measures (e.g., bypass sealing and sidewall insulation; air sealing and heating system inspection), they should not be implemented in a traditional step-by-step priority system. Rather, they should be implemented as a package of measures to be installed in all housing units where applicable. The use of specific measures in individual units should be determined by careful diagnostics during both estimation and installation.

Administrative Issues

One objective of this evaluation project is to identify administrative issues which may affect the ability of Virginia's program to implement the recommended priority system. Interviews with local agencies, review of other states' programs, the PRISM study, and especially the pilot study all contributed to the assessment of administrative issues. The major issues and recommendations are highlighted below.

- **The Reimbursement System**

  The current system of reimbursing costs to local agencies is based solely on the cost of materials installed in weatherized houses. Agencies can recoup their non-materials costs such as labor, warehousing, transport, administration, etc., only through "earnings" based on a percentage of the value of materials installed in clients' homes. This percentage varies among agencies and ranges from 120 to 150%.

  The current system has a major impact on determining the work performed by local agencies, as they traditionally have selected materials-intensive work (e.g., window and door replacements) which will earn them the most money. Some agencies have even established quota systems for their crews, requiring a certain value of materials installed per person per day. The PRISM study, as well as engineering calculations, showed that most materials-intensive measures are largely ineffective in saving energy. Therefore, **one major conclusion of this evaluation project is that the current reimbursement system is a contributing factor in the past program's low effectiveness.**

  The pilot study demonstrated that certain labor-intensive measures, such as advanced air sealing, wall insulation, duct and register boot sealing, and heating system inspections are very effective weatherization measures for Virginia. However, under the current reimbursement system, agencies would be unable to recoup the costs of these measures. Therefore, **the new installation standards recommended by this evaluation cannot be implemented under the current reimbursement system.**

  Two options for modifying the system include: (a) reimbursement based on actual costs including both labor and materials; and (b) variable materials-based reimbursement rates for different measures reflecting different labor requirements. Option (b) could provide a standardized system, but more information and experience with the new measures are needed to set measure-specific rates. Option (a) is used by several other states and is recommended for Virginia, at least in the short term. In time, this system could provide the information needed to set variable rates for option (b).

TABLE 7-1. RECOMMENDED FRAMEWORK FOR INSTALLATION STANDARDS

Site-Built, Single-Family Homes

1. Heating System Inspection
   a. Inspect heating system for safety problems
   b. Perform simple repairs, improvements
2. Heating System Ducts and Registers
   a. Seal leaks in forced air plenum, ducts and register boots
   b. Insulate ducts/pipes if in unheated area, as needed
3. Large Leak & Bypass Sealing
   a. Blower door test (record pre-weatherization reading; use as diagnostic tool to find major leaks in attic, basement/crawlspace, and ducts; guard against dropping below the minimum ventilation rate (MVR))
   b. Major air sealing (if above MVR)
      1) seal large openings
      2) seal attic and basement/crawl space bypasses.
      3) seal other major bypasses; use blown cellulose insulation as needed
4. Sidewall Insulation; use high-density, blown cellulose
5. Attic Insulation
   a. If existing insulation is $<$ R-19, add insulation to R-30
   b. If existing insulation is $\geq$ R-19, do not add additional insulation
   c. Install venting (only if insulation added)
   d. Insulate hatch
6. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting, as needed
   b. Insulate first 3 feet of hot and cold water lines
   c. Install insulation jacket
7. Caulking & Weatherstripping
   a. Install ONLY IF needed for client comfort AND still above MVR
8. Weatherization Repairs
   a. Replace windows or doors if inoperable or deteriorated beyond repair
   b. Perform any other repairs necessary to protect weatherization work

Mobile Homes

1. Heating System Inspection
   a. Inspect heating system for safety problems
   b. Perform simple repairs, improvements
2. Heating System Ducts and Registers
   a. Seal leaks in forced air plenum, ducts and register boots
   b. Insulate ducts/pipes if in unheated area, as needed
3. Large Leak Sealing
   a. Blower door test (as above under site-built homes)
   b. Major air sealing (if above MVR)
      1) seal large openings
4. Floor Insulation (blown between floor and bellyboard or batts if no bellyboard
5. Water Heater Insulation (electric and gas water heaters)
   a. Lower thermostat setting
   b. Insulate first 3 feet of hot and cold water lines
   c. Install insulation jacket
6. Caulking & Weatherstripping
   a. Install ONLY IF needed for client comfort AND still above MVR
7. Weatherization Repairs
   a. Replace windows or doors if inoperable or deteriorated beyond repair
   b. Perform any other repairs necessary to protect weatherization work

- **Technical Training**

  New recommended measures (e.g., advanced air sealing, bypass work, heating system inspection) require a less standardized, more house-specific diagnostic approach to weatherization. Adequate technical training is essential if measures are to be implemented properly. A Training and Technical Assistance Manual has been developed as part of this evaluation project both to assist in training and to be used by agency personnel as a reference in the field.

  Field training and experience are far more important for building expertise than "classroom" training. Therefore, a critical component of a training program is follow-up, on-site training either done through special sessions or incorporated into field monitoring.

- **Agency Personnel**

  The diagnostic requirements of the new measures place added responsibility on the estimators, crew supervisors, and heating system inspectors (a position which currently does not exist). The additional expertise and training required for these individuals may necessitate changes in personnel hierarchy and pay scales in some local agencies.

- **Equipment**

  New recommended measures require effective equipment including well-calibrated blower doors, well-operating insulation blowing machines, and heating system inspection equipment. The pilot study was plagued by ineffective equipment. Proper care and periodic testing and maintenance of equipment are necessary. Infrared cameras are very useful to ensure correct and thorough installation of wall insulation.

- **Mechanism for Solving Heating System Problems**

  In the pilot study, heating system problems were identified in 30% of houses inspected. While weatherization staff can be trained relatively easily to perform heating system inspections, they will not be able to fix all the heating system problems they might identify. A procedure and sources of assistance needs to be established to respond to problems when identified. In the pilot study, various mechanisms were used: VDSS fuel emergency funds (up to $700 per unit); local agency housing rehab funds; weatherization funds (up to $200 per unit); landlords; and utilities (for gas leaks).

- **Program Oversight/Monitoring**

  Currently field monitoring is the principal mechanism for program oversight. There is an opportunity for improved oversight through central office (i.e. Richmond) analysis of Home Weatherization Worksheets (HWWs) and other job-specific reported information. This analysis can assess, on an agency-by-agency basis the specific measures installed, costs incurred, and other data that can characterize each local agency's approach to weatherization. This assessment, complemented and verified by field monitoring, can be used to recommend improvements to the agency.

  Improved reporting forms (such as HWWs and estimation forms) can help this assessment. They can also reduce paperwork and more accurately reflect new priority measures of the program (e.g., current forms still emphasize measurements for replacement windows).

  Field monitoring should incorporate follow-up training, emphasize constructive criticism, and be less regulatory.

- **On-going Evaluation**

  The most effective weatherization programs in other states have incorporated on-going evaluation to provide continual program improvements. Improved central office oversight can contribute to this effort. Some energy-savings analysis is necessary for effective evaluation. Energy analysis methods used in this project (i.e., use of furnace run-time meters [the program has 120 of these meters] or PRISM analysis of utility bills) are options.

Progress in Implementing Evaluation Recommendations

VCCER has provided VACAA with the results of this evaluation as they have become available, and VACAA has moved forward to incorporate many of the recommendations. VACAA initiated a program and schedule for local agency training during the spring of 1991. Four agencies were trained during this period. The Virginia Department of Housing and Community Development, which took over management of the program from VACAA in mid-1991, has continued to implement recommendations from this evaluation. Training in the new measures and techniques continues to be carried out; as of late summer 1991 seven of the 27 Virginia local agencies have been trained in sidewall insulation, advanced air sealing, and heating system safety inspections. New standards which closely follow the recommendations of this study were issued for fiscal year 1991-92; as each agency is trained, it is required to implement the new installation standards.

The Department of Housing and Community Development has also made changes in the reimbursement system. Reimbursement based solely on a percentage of materials expenditures has been eliminated. Instead, agencies are now reimbursed for their actual materials, labor, and administrative expenses. However, each agency must still meet DOE's 60/40 program support/materials cost ratio rule, on average for all their jobs. Agencies have been given some flexibility in meeting the 60/40 rule, since the state has allowed an expended definition of materials costs, including such expenses as warehousing as part of the materials costs.

We are pleased to see the Department of Housing and Commmunity Development moving to implement these recommendations, and hope that they continue in their efforts to improve the quality of the Virginia Weatherization Program.

Appendix A: Methodology Used for Evaluation of Existing Weatherization Program

This appendix describes how the evaluation of the existing weatherization program was carried out, including data sources used, how the sample of weatherized homes was selected, analysis methods used, quality of the results, and causes of sample attrition.

Data Sources and Sample Selection

To analyze the energy savings and cost-effectiveness of the existing weatherization program, three main types of information were needed. First, information on the weatherized buildings was collected, including the type of house, weatherization measures installed, cost of weatherization, type of heating fuel, and occupancy characteristics. This data was obtained from the Home Weatherization Worksheets which are filed with the state agency (VACAA) for each completed weatherization job. We selected all weatherization jobs which were completed between July 1988 and June 1989, a period which would give good information on *recent* weatherization activity and still allow collection of sufficient post-retrofit utility consumption data. We also hoped that by selecting this time frame, utilities would have sufficient historical data to cover the necessary pre-retrofit period. Because we were relying on utility billing data to measure energy savings in these houses, only homes with gas or electric space heat, and no reported secondary heating fuel usage, were included in the sample. At this stage, the sample was composed of 1465 weatherized households.

Second, utility billing data for approximately one year before and after the date of weatherization were used to measure the energy savings resulting from the installed measures. After obtaining release forms (giving the client's permission for access to their utility records) signed at the time of weatherization from the local weatherization agencies, we contacted 11 gas and 22 electric utilities to obtain billing records for each weatherization client. Release forms were available for 1328 of the original 1465 households; utilities provided us with billing histories for 797 customers. This process was very time-consuming, as the sheer number of utilities in Virginia, and the ill-defined nature of their service territories, made figuring out which client belonged to which utility no simple matter. Many utilities reported that they had difficulty locating customer records based only on the name and address (we had no account number to give the utility). In addition, only one utility was able to provide billing records in a machine readable format; we were required to enter billing records in our database by hand for all the other utilities.

Third, weather data were needed to adjust the billing data for changes in the severity of winter during the pre- and post-weatherization periods. Daily average temperatures for January 1970 through Many 1990 were obtained from the National Oceanic and Atmospheric Administration (NOAA) for six sites in and around Virginia (Norfolk, Richmond, Lynchburg, Washington DC, Roanoke, and Bristol TN). These cities are the major climate data collection centers for the six Virginia climate zones defined by NOAA (see Figure A-1).

Figure A-1. Virginia climate zones used in this study.
Each zone is represented by its main climatological data collection center, shown in bold type. Source: NOAA, 1989.

Analysis Methods

Energy Consumption

As described in Chapter 2, we used the Princeton Scorekeeping Method (PRISM) to weather-normalize pre- and post-retrofit utility billing records (Fels, 1986). PRISM estimates a weather-normalized annual energy consumption (NAC) by regressing utility bills for the space heating fuel against daily average outdoor temperatures. The NAC represents consumption that would occur in a year with typical weather conditions. The pre-retrofit period consisted of approximately one year before the date of weatherization (anywhere from 6/1/87 to 5/31/89); the post-retrofit period extended from 6/30/88 through 5/31/90. In some cases, a full year of pre- or post-retrofit utility bills was not available; these houses were kept in the analysis as long as the utility data included the peak of winter and at least one summer baseload reading for the pre- and post-retrofit periods. In other cases, more than a year of data was used in the PRISM analysis due to a large number of estimated meter readings. PRISM was run on 349 households; although utility data were available for another 448 houses, there were insufficient readings in either the pre- or post-weatherization period to conduct a PRISM analysis.

The NAC was thus calculated for one year before and one year after weatherization, and the weather-normalized energy savings derived by subtracting the post-retrofit NAC from the pre-retrofit NAC. Energy consumption figures are presented in site MBtu/household (1 MBtu = 1,000,000 Btu).[1] For gas-heated buildings, the end uses included in the NAC could be space heat only, space heat and water heating, or space heat, water heat, and cooking. For electrically heated buildings, the NAC includes total household energy consumption. Therefore, the percent energy savings in gas- and electrically heated homes are *not* directly comparable, as the one figure represents a percentage of space heat or space heat and hot water usage, while the other represents the percentage of *total* household energy usage.

Control Group

We originally planned to construct a control group by collecting consumption data for individuals on waiting lists for weatherization services. Such a control group would allow us to eliminate the effects of non-weatherization influences on energy savings (e.g., fuel price changes, societal pressures to conserve or consume energy, etc.). 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 houses. As an alternative, we looked at weather-corrected residential consumption trends for four electric and gas utilities using aggregate residential sales data (Dunsworth, 1990; Fels and Goldberg, 1986; Reynolds, 1990; Shen et al., 1990).[2] For this purpose, we selected utilities which could provide the necessary information and whose clients were well-represented in our final sample of weatherized houses with reliable energy data.

Table A-1 shows the change in normalized annual consumption (NAC) over the course of the study period (June 1987 through May 1990) for these utilities. Results are presented on both a calendar-year and a heating-season basis, because both time frames were used in analyzing weatherization savings, and changes in consumption appear somewhat different, depending on the period used. For the electric utilities, a slight increase in residential

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1 The following conversion factors were used in calculating energy consumption and savings: 1 therm = 100,000 Btu; 1 ccf = 102,900 Btu; 1 kwh = 3412 Btu.

2 A variant of PRISM was used to weather-correct the aggregate utility consumption.

consumption is apparent for most of the time periods of interest, which would argue for increasing savings attributed to weatherization. The two gas utilities exhibit differing trends: one shows a small decrease in usage, while a larger increase in consumption occurs for the other.

TABLE A-1: RESIDENTIAL CONSUMPTION TRENDS IN VIRGINIA

		June to May[1]			Calendar Year		
		NAC[2]	CV(NAC)	% Change[3]	NAC[2]	CV(NAC)	% Change[3]
Electric Utilities:							
#1	1987	58.4	.02	--	--	--	--
	1988	59.6	.02	+2.1%	58.7	.02	--
	1989	60.8	.02	+2.1%	59.4	.01	+1.2%
#2	1987	48.1	.03	--	--	--	--
	1988	47.9	.02	-0.4%	47.1	.04	--
	1989	49.1	.03	+2.5%	47.8	.02	+1.5%
Gas Utilities:							
#1	1987	105.4	.02	--	--	--	--
	1988	105.0	.02	-0.4%	102.3	.02	--
	1989	104.1	.04	-0.9%	101.6	.03	-0.7%
#2	1987	72.3	.01	--	--	--	--
	1988	74.5	.01	+3.0%*	72.00	.01	--
	1989	--	--	--	73.2	.03	+1.7%

[1]This period includes from June of the specified year until May of the following year.
[2]Normalized Annual Consumption, in site MBtu/dwelling.
[3]Percent change in NAC, relative to previous year.
*Change significant at 90% level.

We decided to make no adjustments to the gross savings attributed to the weatherization program, for two reasons. First, the changes in consumption for our pseudo-control group were very small (less than 3%), and in all but one case, not significant at the 90% level. Second, the aggregate utility data, while giving a general idea of residential usage trends for a few utilities, does not give specific information on consumption for low-income customers eligible for weatherization across the state. This brief investigation of residential consumption trends does reassure us that no *major* changes in household energy use took place over the course of our study period. If anything, the aggregate utility results would argue for increasing weatherization savings by a few percent.

Retrofit Costs

The cost of materials used for each weatherized house was reported on the Home Weatherization Worksheet. At the current time, Virginia reimburses local weatherization agencies based on a fixed percentage of the materials cost. Labor time at each job is not recorded, and no differentiation is made between measures which are quick to install (e.g., windows) and those which are more labor-intensive (e.g., insulation). Therefore, we calculated total retrofit cost as the materials cost multiplied by the median reimbursement rate of the local agencies included in this study (229%), in 1988/89 dollars.

Economic Indicators

We calculated three economic indicators that characterize the cost-effectiveness of the retrofit investment: the simple payback time (SPT), the cost of conserved energy (CCE), and the benefit-cost ratio (BCR). The SPT, while a crude measure in that it neglects both the time value of money and the expected lifetime of the weatherization measures, is useful in that it provides a good "first cut" indication of cost-effectiveness. The SPT represents the number of years required for the value of the energy savings to equal the money invested in the weatherization measures, and is defined as:

$$SPT = TC / (E * P)$$

where:

TC = total cost of retrofit
E = energy savings
P = energy price.

The CCE compares conservation investments to purchases of gas or electricity. It takes into account both the time value of money and the expected lifetimes of the retrofit measures, which the SPT does not. CCE is found by dividing the annualized cost of the retrofit by the annual energy savings. A retrofit is cost-effective if its CCE is less than what the homeowner would pay for fuel or electricity. CCE can be expressed as:

$$CCE = (TC * CRF) / E$$

where:

CRF = capital recovery factor = $d/((1-(1 + d)^{-n})$
d = discount rate
n = expected lifetime of measures.

The BCR tells how much benefit will be received for each dollar invested. Like the CCE, it takes into account both the time value of money and retrofit lifetimes. If the BCR $\geq$ 1, the retrofit is cost-effective. The BCR is calculated as:

$$BCR = (E * P) / (TC * CRF).$$

For this study, all costs are reported in 1988/89 dollars. Average Virginia residential energy prices for 1988 of $5.65/MBtu for gas and $0.057/kWh for electricity are assumed (EIA, 1988 and 1989). A real (constant dollar) discount rate of 7% is used. Retrofit lifetimes were assigned to each house based on the measure category it was assigned to (see Chapter 2 for discussion of measure categories).

Measure Category	**Lifetime (years)**
Infiltration Only	10
Skirting & Infiltration	10
Storms & Infiltration	15
Attic Insulation, Storms, & Infiltration	15
Primary Windows & Infiltration	20
Attic Insulation, Primary Windows, & Infiltration	20
Primary Windows, Storms, & Infiltration	20
Attic Insulation & Infiltration	25

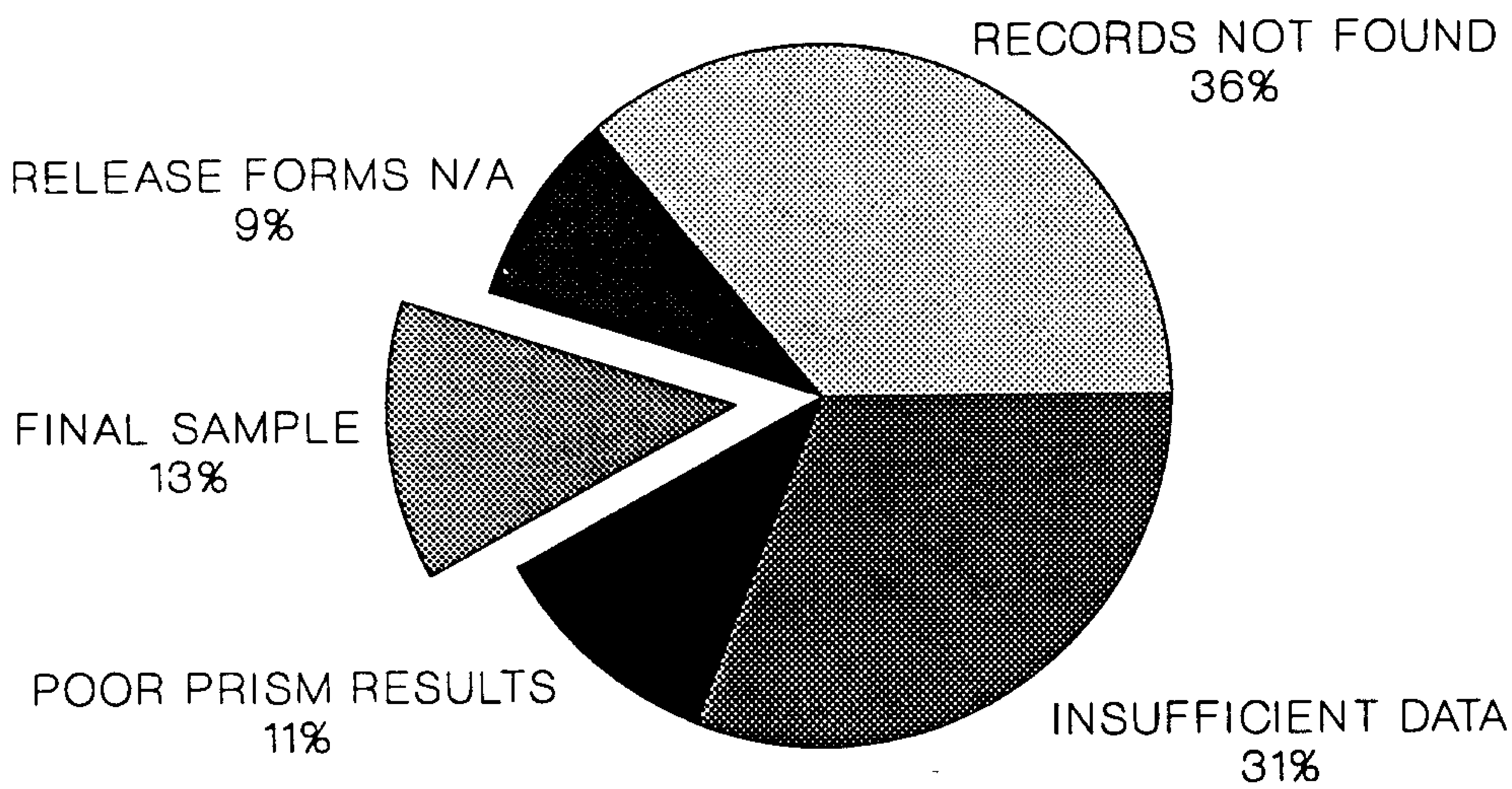
Quality of Energy Data and Results

Examination of the PRISM results revealed that the model poorly fit many houses; that is, the house's energy consumption was not very weather-dependent (as revealed by a low R^2) or its NAC was poorly determined (as shown by the high coefficient of variation of the NAC, or CV(NAC)). A closer look at the billing histories of individual customers showed that some households had "flat" energy consumption year-round; consumption of their supposed heating fuel did not increase in the wintertime. We suspect that these households used a secondary heating fuel (even though all houses with a *reported* secondary heating fuel were not included in the initial sample). In addition, some electrically heated households seemed to be using air conditioners during the summer months (evidenced by a summer consumption peak significantly higher than spring and fall usage). (We did not have any information about whether or not air conditioners were present in houses in our sample, but had hoped they would not be very prevalent in low-income housing.) Other households were poorly fit by PRISM, but examination of their energy usage revealed no recognizable pattern.

Because of these problems, we undertook some "data massage" to obtain reliable savings data on a greater number of houses. We first did a preliminary screen of PRISM results, using the cutoff criteria of CV(NAC) $< 6\%$ and $R^2 > 0.7$ suggested by Fels and Reynolds (1990). We then looked at houses which failed these criteria to see if some of them could be "salvaged" by a more careful examination of the data. Houses suspected of having a secondary heating source were eliminated. We next reran PRISM on houses suspected of having air conditioning use, after first changing those summer months with air conditioning "peaks" to missing values. Then, the reference temperature was fixed at 62°F for houses with poor results (as opposed to allowing PRISM to determine the best reference temperature, as usual). The whole sample was then again run through the "reliability screen" discussed above, using the same CV(NAC) and R^2 criteria. These "fixes" added 15 houses to the final "Good House" sample of 188 homes. The "Bad" houses (N=161) were dropped from the energy savings analysis, as the poor data quality would be expected to bias the results.

Sample Attrition

Out of the original sample of 1465 weatherized houses selected for study, we ended up with reliable energy savings results on only 188 buildings, or 13% of the original sample. As shown in Figure A-2, the inability to match up weatherization clients with utility billing records was the biggest source of attrition. As mentioned above, the release forms signed by the clients contained no indication as to which utility they were serviced by or their account number. Handwritten (and sometimes barely legible) names and addresses were the only clue the utilities had to work with. In some cases, the name of the weatherization client did not match up with the name of any utility customer. Almost as many houses were lost due to an insufficient number of pre- or post-retrofit meter readings for those clients whose billing histories were located. Sometimes, insufficient historical data were available because the utility only kept records for the past year or two; in other cases, the client was connected or disconnected by the utility shortly before or after the weatherization work was carried out. Lastly, almost half of the houses with sufficient pre- and post-retrofit utility data had such poor PRISM results that they were eliminated from the final sample. Although we feared a high rate of attrition, and therefore started our data acquisition efforts with a very large sample, the loss of 87% of our original sample was even worse than we expected (though comparable to results found in some other PRISM studies of low-income households (Blasnik, 1989; Hill, 1990)). See Chapter 2 for a comparison of the representativeness of our initial and final samples.



Original Sample = 1465 Houses

Figure A-2. Sources of sample attrition.
The inability of utilities to match customer records with weatherization clients, and the lack of sufficient historical data to characterize energy use in the pre-retrofit period, were the two biggest reasons that households were dropped from the study sample.

Representativeness of Virginia Sample

In Chapter 2, we have presented information about the savings and cost-effectiveness of the 188 weatherized households for which we were able to obtain reliable energy consumption data. Now we must ask, how well does this sample represent "typical" houses served by Virginia's weatherization program? Concerns about representativeness crop up at two stages in our analysis. First, the use of utility bills to characterize energy consumption required that we restrict our sample to houses with gas or electric space heating; what fraction of all weatherized homes in Virginia use these heating fuels, and how similar is the weatherization done in gas- and electrically heated dwellings to that performed in houses with other heating fuels? Second, we ended up with reliable energy data on less than 15% of the gas- and electrically heated houses weatherized during the period of interest (see section on "Sample Attrition"). How closely does the kind of weatherization done in the final sample resemble that performed in the original group of buildings? The similarity between the three groups (the final sample, all weatherized gas- and electrically heated houses, and all Virginia weatherized homes), in terms of building and fuel type, amount of money spent on weatherization, and types of conservation measures installed, gives us some indication of how closely the savings and cost-effectiveness of the final sample mirror those for Virginia weatherization as a whole.

We were able to obtain information from the state agency on the number of homes weatherized and average material costs, by building type and space heat fuel, for all weatherization done in fiscal year 1989 (July 1988 to June 1989, the period from which our sample was selected). In Tables A-2 and A-3, we compare the number of homes weatherized and the average material costs for all Virginia weatherization during FY 1989 (N=4184) and for our final sample (N=188). The fraction of site-built single-family homes is about the same in both groups, although the final sample overrepresents apartments and underrepresents mobile homes. The ratio of gas- to electrically heated homes is also similar (about 50/50); however, houses heated with oil and wood, comprising almost half of all Virginia weatherization, are the big component missing from our final sample. The next question then becomes, how does weatherization in oil- and wood-heated homes compare to that done in houses heated with gas and electricity?

TABLE A-2: COMPARISON OF SAMPLE WITH ALL UNITS WEATHERIZED: TYPE OF DWELLING

Building Type		Heating Fuel Type					
		Gas	Elec.	Oil	Wood	Other[1]	Total
Site Built Single-Family	-All[2]	14%	9%	16%	11%	13%	61%
	-Sample[3]	48%	11%	--	--	--	60%
Multifamily	-All	3%	4%	<1%	<1%	<1%	8%
	-Sample	7%	14%	--	--	--	21%
Mobile Homes	-All	1%	6%	15%	1%	5%	28%
	-Sample	--	19%	--	--	--	19%
Total	-All	18%	19%	32%	13%	18%	100%
	-Sample	56%	44%	--	--	--	100%

[1]"Other" includes coal, kerosene, propane, & houses using more than one heating fuel.
[2]"All" refers to all homes weatherized in Virginia between July 1988 and June 1989 (4184 dwellings).
[3]"Sample" refers to our sample of 188 gas and electrically heated houses with reliable energy consumption data.

TABLE A-3: COMPARISON OF SAMPLE WITH ALL UNITS WEATHERIZED: MATERIALS COST[1]

Building Type	Heating Fuel Type					
	Gas	Elec.	Oil	Wood	Other[2]	Total
Site-Built -All[3] Single-Family -Sample[4]	$697 $650	$505 $374	$699 --	$858 --	$765 --	$715 $611
Multifamily -All -Sample	$808 $794	$222 $33	$529 --	$699 --	$486 --	$466 $39
Mobile -All Homes -Sample	$602 --	$624 $563	$749 --	$750 --	$742 --	$714 $563
Total -All -Sample	$722 $687	$478 $324	$720 --	$848 --	$748 --	$696 $547

[1]Values listed are averages for "All Weatherization" and medians for the "Final Sample".
[2]"Other" includes coal, kerosene, propane, and houses using more than one heating fuel.
[3]"All" refers to all homes weatherized in Virginia between July 1988 and June 1989 (4184 dwellings).
[4]"Sample" refers to our sample of 188 gas and electrically heated houses with reliable energy consumption data.

Since the state agency does not tabulate information on the kinds of conservation measures installed for each of their weatherization clients, we turned to weatherization costs as an indicator of the level of weatherization activity in the two groups of households. Table A-3 shows the typical material costs for each group, broken down by building and heating fuel type.[3] Weatherization costs were 15 to 20% lower in our final sample compared to costs for all Virginia weatherization, in general and for site-built single-family and mobile homes; costs for multifamily weatherization were drastically lower in the final sample. In gas-heated homes, costs for both groups were in fairly close agreement, while costs for electrically heated homes in the final sample were significantly lower than costs for weatherization as a whole. Costs of weatherizing oil-heated houses were about the same as for gas-heated site-built single-family units; oil-heated multifamily units were weatherized at a lower cost, and oil-heated mobile homes at a higher cost, than their gas-heated counterparts. Weatherization costs for houses with wood heat were significantly higher than costs for gas-heated houses, for all building types but multifamily dwellings. Electrically heated houses were weatherized at a lower cost than houses heated with any other fuel, for all building types except mobile homes.

To summarize, our final sample correctly represents the number of site-built single-family homes, underrepresents mobile homes, and overrepresents apartments, compared to all weatherization in Virginia during the same time period. Judging by material costs, the amount of weatherization work done in our final sample is somewhat lower than in weatherization in general, and the level of weatherization in oil- and wood-heated houses more closely resembles that performed in gas-heated houses than that in electrically heated homes. Furthermore, weatherization staff have reported that gas- and electrically heated houses tend to be in better overall condition that those heated with oil or wood. This would suggest that there are more savings opportunities in the oil- and wood-heat houses, and therefore higher savings are likely.

We know a bit more about the work performed in all Virginia gas- and electrically heated weatherization houses: for these homes, specific weatherization measures and air change rates were tabulated. Virtually all homes in the gas- and electrically heated group and in our final sample had some infiltration-reduction work done. The fraction of site-built single-

[3] As discussed earlier, total weatherization costs are equal to material costs multiplied by a "reimbursement rate" which varies by agency. Here, we are primarily interested in costs as an indicator of the amount of weatherization work performed, and so we will confine our discussion to material costs only.

family homes with attic insulation and venting was about the same for both groups. The proportion of homes with primary window replacements was also equivalent for all building types for the two groups. Fewer site-built single-family and multifamily buildings received storm windows in the final sample; the fraction in mobile homes was equal for both groups. Fewer mobile homes received skirting in the final sample than in gas- and electrically heated homes in general.

We also compared the blower door measurements (in air changes per hour) for homes in the final sample with readings taken in all gas- and electrically heated homes. We found that average pre-weatherization air change rates were slightly (less that 10%) lower for the final sample, across all building types. The reduction in air change rates caused by weatherization were about the same in the initial and final samples. This indicates that houses in our final sample are about as leaky as typical gas- and electrically heated houses served by the Virginia weatherization program, experienced approximately the same level of increased tightness, and that therefore they presented similar opportunities for weatherization savings.[4]

So what does all this say about the representativeness of our results on the energy savings and cost-effectiveness of Virginia weatherization? Savings and cost-effectiveness for all gas- and electrically heated weatherized homes may be slightly higher than the results for our final sample because more storm windows (with savings and paybacks that, although poor, were still better than our average) and less skirting (with worse than average results) were installed in the larger group, and more money was spent on weatherization in the electrically heated homes in the larger sample. Savings for all houses weatherized by Virginia may again be slightly higher than results for gas- and electrically heated homes, since spending in oil- and wood-heated houses is the same or greater than spending in gas-heat houses, and much greater than costs for electrically heated homes. The oil- and wood-heat homes are also thought to be in worse condition, and therefore to have greater opportunities for energy savings. Therefore, we would expect overall program results to be *slightly* better than the results we found for gas-heat houses (savings of 6%, payback time of 34 years).

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4 A previous study had suggested that air change rates and energy savings in houses which meet PRISM criteria are lower than for low-income houses in general. Blasnik found that pre-retrofit blower door readings for low-income households in Philadelphia which met PRISM reliability criteria were 30% lower than air change rates for homes which did not meet the criteria, and that changes in air change rates in the houses which met the criteria averaged twice that of houses which did not (Blasnik, 1989).

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Appendix B: Supplemental Data from Engineering-Economic Calculations

TABLE B-1 EFFECT OF INSULATION VOIDS ON R-VALUE AND HEAT LOSS

Attic/Ceiling with R-30 Insulation					
Component				Between Framing	At Framing
1. Top surface (still air)				0.61	0.61
2. Insulation				30.6	6
3. Nominal 2 in. x 8 in. ceiling joist				—	9.06
4. Half-inch gypsum board				0.45	0.45
5. Bottom surface (still air)				0.61	0.61
Total Thermal Resistance (R)				32.27	16.73
U = 0.90/	32.27	+ 0.10/ 16.73	=	0.034	
Average R-value of attic		29.5			

Assumes 9 inches of blown cellulose at R-3.4 per inch; bringing it to almost 2 inches over ceiling joists.

Attic/Ceiling with R-30 Insulation and 5% Voids							
Component					Between Framing	At Framing	5% Voids
1. Top surface (still air)					0.61	0.61	0.61
2. Insulation					30.6	6	—
3. Nominal 2 in. x 8 in. ceiling joist					—	9.06	—
4. Half-inch gypsum board					0.45	0.45	0.45
5. Bottom surface (still air)					0.61	0.61	0.61
Total Thermal Resistance (R)					32.27	16.73	1.67
U = 0.85/	32.27	+ 0.10/ 16.73	0.05/ 1.670	=			0.0622577
Average R-value of attic		16.1					

Assumes that the 5% voids are between the framing.

Reduction in R-value due to 5% voids = 46%

Increase in U-value, and hence heat loss through attic = 84%

Heat loss through attic is 1.8 times what it would be without any voids.

TABLE B-2 CHANGE IN R-VALUE WITH SIDEWALL INSULATION (OLD CONSTRUCTION)

Uninsulated Wood Frame Wall (2 by 4 Construction)						
Component					Between Framing	At Framing
1. Outside surface (15 mph wind)					0.17	0.17
2. 3/4 inch wood siding					0.94	0.94
3. 2 x 4 stud (actual dimensions)					---	5
4. Non reflective air space					1.01	---
5. 3/4 inch lath and plaster					0.55	0.55
6. Inside surface (still air)					0.68	0.68
Total Thermal Resistance (R)					3.35	7.34
U = 0.8/	3.35	+ 0.2/	7.34	=	0.266	
Average R-value of wall =			3.8			

Same Wall with Blown Cellulose Insulation						
Component					Between Framing	At Framing
1. Outside surface (15 mph wind)					0.17	0.17
2. 3/4 inch wood siding					0.94	0.94
3. 2 x 4 stud (actual dimensions)					---	5
4. High density cellulose insulation *					13.6	---
5. 3/4 inch lath and plaster					0.55	0.55
6. Inside surface (still air)					0.68	0.68
Total Thermal Resistance (R)					15.94	7.34
U = 0.8/	15.94	+ 0.2/	7.34	=	0.077	
Average R-value of wall =			12.9			
* Assumes R-3.4 per inch						

TABLE B-3 CHANGE IN R-VALUE WITH SIDEWALL INSULATION (NEWER CONSTRUCTION)

Uninsulated Wood Frame Wall (2 by 4 Construction)					
Component				Between Framing	At Framing
1. Outside surface (15 mph wind)				0.17	0.17
2. Siding, wood, 1/2 in. x 8 in., lapped				0.81	0.81
3. Nominal 2 in. x 4 in. wood stud				---	4.38
4. Non reflective air space				1.01	---
5. Gypsum wallboard, 1/2 in.				0.45	0.45
6. Inside surface (still air)				0.68	0.68
Total Thermal Resistance (R)				3.12	6.49
U = 0.8/	3.12	+ 0.2/	6.49 =	0.287	
Average R-value of wall =			3.5		

Same Wall with Blown Cellulose Insulation					
Component				Between Framing	At Framing
1. Outside surface (15 mph wind)				0.17	0.17
2. Siding, wood, 1/2 in. x 8 in., lapped				0.81	0.81
3. Nominal 2 in. x 4 in. wood stud				---	4.38
4. High density blown cellulose insulation *				11.9	---
5. Gypsum wallboard, 1/2 in.				0.45	0.45
6. Inside surface (still air)				0.68	0.68
Total Thermal Resistance (R)				14.01	6.49
U = 0.8/	14.01	+ 0.2/	6.49 =	0.088	
Average R-value of wall =			11.4		
* Assumes R-3.4 per inch					

TABLE B-4 SIDEWALL INSULATION ECONOMICS, INCLUDING SAVINGS FROM AIR SEALING

Region	Installed Costs		CCE	Value of Energy Saved								
				11 $/MBTU			13 $/MBTU			23 $/MBTU		
	Range	($)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$0.60	$3.74	4.0	2.9	YES	3.4	3.5	YES	1.9	6.1	YES
3400	Ave	$0.80	$4.99	5.3	2.2	YES	4.5	2.6	YES	2.5	4.6	YES
HDD	High	$1.00	$6.24	6.6	1.8	YES	5.6	2.1	YES	3.2	3.7	YES
Piedmont	Low	$0.60	$3.03	3.2	3.6	YES	2.7	4.3	YES	1.5	7.6	YES
4200	Ave	$0.80	$4.04	4.3	2.7	YES	3.6	3.2	YES	2.0	5.7	YES
HDD	High	$1.00	$5.05	5.4	2.2	YES	4.5	2.6	YES	2.6	4.6	YES
Mountains	Low	$0.60	$2.55	2.7	4.3	YES	2.3	5.1	YES	1.3	9.0	YES
5000	Ave	$0.80	$3.39	3.6	3.2	YES	3.0	3.8	YES	1.7	6.8	YES
HDD	High	$1.00	$4.24	4.5	2.6	YES	3.8	3.1	YES	2.1	5.4	YES

ASSUMPTIONS:

Interest rate	12%	Cd =	0.65
Inflation rate	5%	Volume =	10000
Discount rate	7%	Initial ACH =	1.5
Economic lifetime	25	ACH reduction =	30%
Initial R-value	3.8	Assumes older construction -- full dimension 2 x 4's,	
Finished R-Value	12.9	lath and plaster interior, 3/4 inch wood siding.	
Change in R-Value	9.1		
Change in U-Value	0.186		

TABLE B-5 REPLACEMENT WINDOW ECONOMICS, INCLUDING SAVINGS FROM AIR SEALING

Region	Installed Costs		CCE	Value of Energy Saved								
				11 $/MBTU			13 $/MBTU			23 $/MBTU		
	Range	($)	($/MBTU)	SPT	B/C	Y/N	SPT	B/C	Y/N	SPT	B/C	Y/N
Coast	Low	$9.00	$26.76	25.8	0.4	NO	21.8	0.5	NO	12.3	0.9	NO
3400	Ave	$14.00	$41.62	40.1	0.3	NO	33.9	0.3	NO	19.2	0.6	NO
HDD	High	$19.00	$56.49	54.4	0.2	NO	46.0	0.2	NO	26.0	0.4	NO
Piedmont	Low	$9.00	$21.66	20.9	0.5	NO	17.7	0.6	NO	10.0	1.1	YES
4200	Ave	$14.00	$33.69	32.4	0.3	NO	27.5	0.4	NO	15.5	0.7	NO
HDD	High	$19.00	$45.73	44.0	0.2	NO	37.3	0.3	NO	21.1	0.5	NO
Mountains	Low	$9.00	$18.19	17.5	0.6	NO	14.8	0.7	NO	8.4	1.3	YES
5000	Ave	$14.00	$28.30	27.3	0.4	NO	23.1	0.5	NO	13.0	0.8	NO
HDD	High	$19.00	$38.41	37.0	0.3	NO	31.3	0.3	NO	17.7	0.6	NO

ASSUMPTIONS:

Interest rate	12%	Cd =	0.65
Inflation rate	5%	Volume =	10000
Discount rate	7%	Initial ACH =	1.5
Economic lifetime	20	ACH reduction =	30%
Initial R-value	1.01		
Finished R-Value	2.15		
Change in R-Value	1.1		
Change in U-Value	0.525		

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

Appendix C: Pilot Study Standards and Forms

C.1: Furnace Elapsed-Time Meter Installation Instructions and Logging Sheet

C.2: Project Brochure for Weatherization Clients

C.3: Installation Standards for Pilot Study Homes

C.4: Installation Documentation Forms

C.5: Inspection Form and Client Interview Questionnaire

C.6: Weatherization Staff Interview Questionnaires

C.7: VDSS Memorandum on Heating System Repairs

C.8: Energy Usage and Savings for Pilot Study Homes

Appendix C: Pilot Study Standards and Forms

C.1: Furnace Elapsed-Time Meter Installation Instructions and Logging Sheet

466-5478

VIRGINIA WEATHERIZATION PROGRAM SPECIAL DEMONSTRATION PROJECT

Page 1

Client Number PA-04
Client's Name Margarett Sharret
Address Rt A Box 329 Mendota

Agency People Inc
Firing Rate (Btu/hr) 80,000 FR
House Area (sqft) 887 SF

Tel. (H) 466-9639
(W)
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	109.9	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	1/17/90	
9:50	17	Jan	90	800.2	47	3,760,000	182	20,659.3	23.3
6:45am	24	Jan	90	820.2	20	1,600,000	127	12,598.4	14.2
9:25	31	Jan	90	836.4	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

VIRGINIA WEATHERIZATION PROGRAM SPECIAL DEMONSTRATION PROJECT

Client Number PD-04
Client's Name Margaret Sharret
Address Rt A Box 329, Mendota

Agency People, Inc
Firing Rate (Btu/hr) 80,000 FR
House Area (sqft) 887 SF

Tel. (H) 466-9039
(W)
Best Time to Call

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)
11:00	7	Mar	90	889.9	8.1	648,000	130	4,984.6	5.6
11:05	14	Mar	90	897.4	7.5	600,000	56	10,714.3	12.1
9:35	21	Mar	90	906.3	8.9	712,000	76	9,368.4	10.6

Synertech
Synertech Systems Corporation

SYN TN 89-522
AUGUST 1989

Technical Note

CUMULATIVE ENERGY CONSUMPTION MEASURING SYSTEM

INSTALLATION INSTRUCTIONS

Prepared for

The Virginia Weatherization Program

NOTE TO READERS

Elapsed timers are a very useful and inexpensive way to measure energy conservation achieved by weatherization.

This note consists of three parts: a description of how to install elapsed timers on gas and propane-fired furnaces; a description of how to install elapsed timers on oil-fired furnaces; and a set of instructions that explain how to fill out a one-page data form. A copy of a sample (filled in) data form and a blank form are included as the last two pages. Feel free to photocopy anything you like.

If anyone who reads this can think of clearer ways of putting things, I'd sure like to hear about it. And, if you have any questions that aren't answered very well here, I'll try to deal with them, too. My address and phone number are below.

Larry Kinney

472 South Salina Street / Suite 800 / Syracuse, New York 13202-2401 / (315) 422-3828

recycled paper

TIMER INSTALLATION INSTRUCTIONS FOR NATURAL GAS OR PROPANE FURNACES

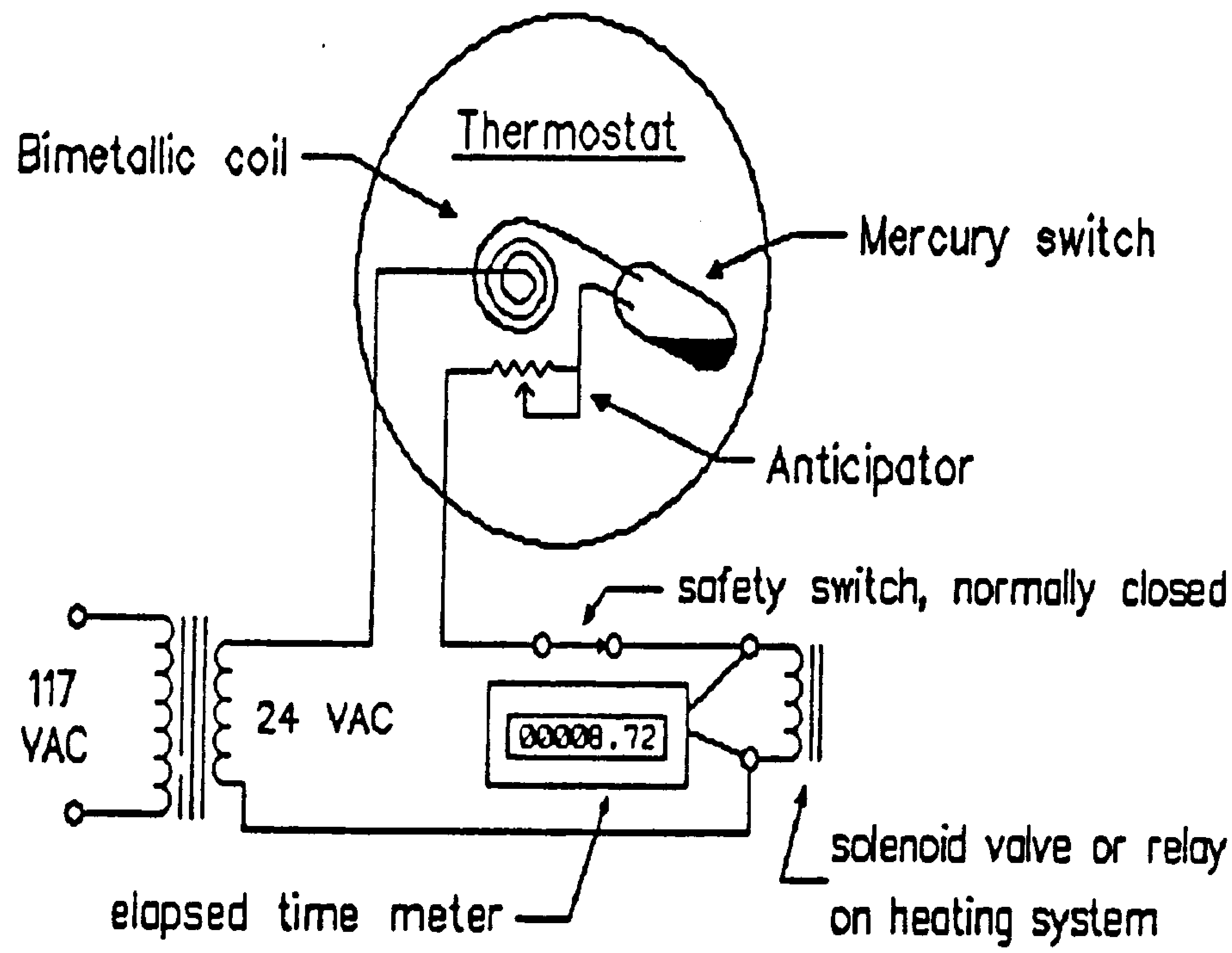
STEP 1. **Explain to the client** exactly what the aim of the energy consumption monitoring system is and what you will install in her dwelling. The brochure should help. Make sure she understands how to read the timer and that nothing bad will happen to the heating system. The aim is to accurately measure energy consumption of the furnace so that when conservation measures are taken it will be possible to calculate energy savings accurately. Show the client the timer you will install and work with her to decide on a convenient location for the timer. The timer should be secured where it will be easy to read, and from where you can easily run a line from the timer to the furnace.

STEP 2. **Fire the furnace** very briefly to make sure that it works. Ask the client what problems she has had with the furnace, and what she plans to do about them.

STEP 3. **Ascertain where to attach timer leads.** Use your multi-meter on the ac volts scale to find the proper screws on the gas solenoid where 24 volts exists when the furnace fires--and where there is no voltage when it doesn't. (The lead going to the thermostat should have 24 volts across it when the furnace is off, but not when it's on.) If 24 Vac cannot be found with your meter, you may have a millivolt system on your hands. To check out this possibility, put your meter on dc volts and find the place on the solenoid where you read 0.5 volts or so when the furnace is on. (You should read about 0.75 volts across the thermostat when the furnace is off.) If you have a 24 Vac system, go to Steps 4-10. If you have a millivolt system, you cannot install the elapsed timer.

STEP 4. **Turn the furnace off.** Turn the thermostat all the way down.

STEP 5. **Place and wire the timer.** Use the new thermostat wire to go between the timer and the furnace. Strip 1/2 inch of insulation from each of the two wires and wrap them carefully around the leads from the timers. Secure them with wire nuts. Secure the timer in a location which is convenient to read, but safe from kids, animals, and stacks of junk. The double-sided tape in the tool case should help secure the timer. **Neatly** staple the wire back toward the furnace, being careful not to put a staple through the wire. Thread the wire into the furnace through a hole which might already be there or through a small one you drill yourself. Take care that the pathway of the wire will never get hot when the furnace is firing. Cut the wire off to the proper length to attach to the furnace and strip the wires. Before attaching the wires, use your ohm meter to make sure the electrical resistance across the wires is the same as the timer itself. (This is a quick check that makes certain that the wires are indeed attached as they should be and that they weren't broken or shorted by the stapling process.)



STEP 6. **Wire the furnace.** Attach the lead from the timer directly across (in parallel with) the gas solenoid. Strip about 3/8 inch of insulation from the timer leads and use the crimping tool to install terminals. Place the terminals under the screws at the solenoid. Tighten carefully, making certain that what used to be attached still is. Dress the lead from the timer away from anything hot, using a turn or two of electrical tape to secure the timer wire to other wires or pipes, if appropriate.

STEP 7. **Verify system operation.** Fire the furnace. Determine that the timer runs when the furnace does--and doesn't when it doesn't. Make sure the client understands what has happened and is able to read the meter.

STEP 8. **Determine firing rate.** For propane furnaces only, read the label on the furnace. Enter this number in the "Firing Rate" portion of the meter log. For natural gas units, use the following procedure. Make sure no other appliance is drawing gas by turning off the stove and lowering the thermostat on the hot water heater. Fire the furnace. Measure the number of seconds it takes for the gas meter to record exactly five cubic feet of consumption. Divide this number of seconds into 18,000,000 to ascertain the firing rate in Btu's per hour of gas. Record this number and reset the client's water heater thermostat.

STEP 9. **Determine heated area.** If you have not already done so, measure the areas of the floors in the heated portion of the dwelling. Enter this information on the meter log. Remaining portions of the meter log should also be filled in at this point, being careful to fill in all headliner information, plus the first five columns of the first data line. (Time, day, month, year, and meter reading.)

STEP 10. **Clean up** the site very carefully and place the note to the client on the furnace. The note should read: **THE FUEL CONSUMPTION OF THIS FURNACE IS BEING MONITORED AS PART OF AN ENERGY CONSERVATION RESEARCH PROJECT. THE ELAPSED TIME METER THAT HAS BEEN INSTALLED DOES NOT AFFECT THE OPERATION OF THE FURNACE. FOR INFORMATION, CALL...**Fill out any remaining paperwork, pack your tools and garbage, tell the client when to expect calls from the agency, and bid her farewell.

WHAT TO DO IF SOMETHING DOESN'T WORK

1. Use your horse sense; figure out what might be wrong

2. Check all of your work with care.

3. Use your multimeter to see what voltages are where. If the elapsed timer is placed across any voltage between 12 and 36 Vac, it will work nicely and accurately record elapsed time. Double- check your wiring work.

4. Call Larry Kinney at Synertech Systems Corporation, telephone (315) 422-3828

TIMER INSTALLATION INSTRUCTIONS FOR OIL-FIRED FURNACES

STEP 1. **Explain to the client** exactly what the aim of the energy consumption monitoring system is and what you will install in her dwelling. The brochure should help. Make sure she understands how to read the timer and that nothing bad will happen to the heating system. The aim is to accurately measure energy consumption of the furnace so that when conservation measures are taken it will be possible to calculate energy savings accurately. Show the client the timer you will install and work with her to decide on a convenient location for the timer. The timer should be secured where it will be easy to read, and from where you can easily run a line from the timer to the furnace.

STEP 2. **Fire the furnace** very briefly to make sure that it works. Ask the client what problems she has had with the furnace, and what she plans to do about them.

STEP 3. **Turn the furnace off.** This should be done by turning off the master switch (in the case of most units) or unplugging it from within the furnace compartment (in the case of many mobile homes.)

STEP 4. **Wire leads to the timer transformer.** Open the main part of the oil burner by loosening the screws holding the transformer and flipping the transformer over on its hinge. Then open the electrical box that is right next to it. There will be a knock out you can use to install the cable from the timer transformer box. Install the cable with care. Then find out where the voltage comes in to the unit and connects to the motor. The leads to the timer transformer are placed in parallel with the leads to the motor. (Thus, when the motor is switched on, the timer will be, too.) Take off the wire nut that goes to one of the leads to the motor and twist all of the wires back together, including one of the wires to the timer transformer. Then install a new (larger) wire nut, checking that all leads are secure and that no bare wires are exposed. Use electrical tape in addition to the wire nut if you need to. Then perform the same operation on the other motor wire. Stow the wires neatly back in the electric box and inspect the job. Finally, replace the top on the electric box.

STEP 5. **Install the transformer box.** Pick a place on a ceiling joist close to the furnace (but not above it) that allows the cable enough slack so that it can be dressed neatly and secured to something sturdy between the burner and the transformer box. Take the lid off the transformer box and mount it using either a pair of wood screws or 10 penny nails. Screw the lid back on the box and use cable clamps, electrical tape, or the equivalent to neatly secure the cable between the burner and the transformer box. For mobile homes, it is usually more convenient to mount the timer transformer within the furnace cabinet. A timer transformer with a shorter cable should be used for these installations; usually three feet is adequate. Pick an out-of-the-way (and out-of-the-heat) place for mounting the transformer. Mount it as above, except use a drill followed by heavy sheet metal screws or self-tapping screws to secure the timer transformer box to the inside of the furnace cabinet.

STEP 6. **Place and wire the timer.** Use the thermostat wire to go between the timer and the transformer box. Strip 1/2 inch of insulation from each of the two wires and wrap them carefully around the leads from the timers. Secure them with wire nuts. Secure the timer in a location that is convenient to read, but safe from kids, animals, and stacks of junk. The double-sided tape in the tool case should help secure the timer. **Neatly** staple the wire back toward the transformer box, being careful not to put a staple through the wire. Cut the wire off to the proper length to attach to the transformer box and strip the wires. Before attaching the wires, use your ohm meter to make sure the electrical resistance across the wires is the same as the timer itself. (This is a quick check that makes certain that the wires are indeed attached as they should be and that they weren't broken or shorted by the stapling process.) Then carefully attach the wires from the timer to the two terminal screws on the timer transformer box.

STEP 7. **Determine firing rate.** Take note of the location of the burner assembly within the fire tube of the burner. Use an open-end wrench to disconnect the fitting from the short pipe between the oil pump and the side of the burner. **Carefully** remove the burner assembly so you can inspect the firing rate that will be found on the side of the nozzle. Placing your thumb over the oil pump end of the assembly will prevent oil from dripping on the floor (or your pants!) Use a rag to clean the side of the nozzle if you can't read the firing rate, but **do not run a rag over the face of the nozzle.** (You might force some dirt into the orifice that could cause misfiring.) Then replace the assembly and reattach the oil line, being sure to (1) orient the assembly exactly where it was before and (2) avoid stripping the threads. The record the firing rate (in Btu's) on the data sheet by multiplying the gallons indicated on the nozzle by 138,000.

STEP 8. **Verify system operation.** Fire the furnace. Carefully examine the oil line to make sure there are no leaks and be sure the system is firing normally, that the flame is normal, and there is no smoke. Be sure that the timer runs when the furnace does--and doesn't when it doesn't.

STEP 9. **Determine heated area.** If you have not already done so, measure the areas of the floors in the heated portion of the dwelling. Enter this information on the meter log. Remaining portions of the meter log should also be filled in at this point, being careful to fill in all headliner information, plus the first five columns of the first data line. (Time, day, month, year, and meter reading.)

STEP 10. **Clean up** the site very carefully and place the note to the client on the furnace. The note should read: **THE FUEL CONSUMPTION OF THIS FURNACE IS BEING MONITORED AS PART OF AN ENERGY CONSERVATION RESEARCH PROJECT. THE ELAPSED TIME METER THAT HAS BEEN INSTALLED DOES NOT AFFECT THE OPERATION OF THE FURNACE. FOR INFORMATION, CALL...**Fill out any remaining paperwork, pack your tools and garbage, tell the client when to expect calls from the agency, and bid her farewell.

* * * * * *

WHAT TO DO IF SOMETHING DOESN'T WORK

1. Use your horse sense; figure out what might be wrong

2. Check all of your work with care.

3. Use your multimeter to see what voltages are where. Double-check your wiring work.

4. Call Larry Kinney at Synertech Systems Corporation, telephone (315) 422-3828.

INSTRUCTIONS FOR FILLING OUT THE ENERGY CONSUMPTION DATA FORM

Header Information

1. Client Number. Use your normal client number to start with. As a suffix, please add a two letter code that signifies your agency and a two digit number that goes from 01 to the number of clients in the demonstration project.

2. Client's Name.

3. Client's Address.

4. Your Agency. Feel free to abbreviate.

5. Firing Rate. This is the firing rate of the furnace in Btu/hr. Note the FR at the end of the line. This code is used to remind you to use the firing rate in the calculation that gives you the number that is entered in column 7.

6. House Area. Record the measured square footage of the area heated by the client's furnace. Note the SF at the end of the line. It is there to remind you to use the heated square footage in the calculation that generates column 10.

7. Page. The present page of the fuel consumption record for this client.

8. Telephone Number. There is space for both home and work numbers. Be sure to indicate which one should be used for regular calls to the client.

9. Best Time to Call. Try for Wednesday morning if possible.

Column Information

1. Time. Enter the time of day that the meter was read using a 24 hour time system. The following conventions hold: nine-fifteen in the morning is 0915 and quarter to four in the afternoon is 1545. To get the afternoon hours add 12 to the "PM" time.

2. Day. The day the reading was taken.

3. Month. The month the reading was taken. Please use the written abbreviations for the months. (Jan, Feb, Mar, etc.)

4. Year. The year the reading was taken. Two digits (eg., 89) are adequate.

5. Meter Reading. The meter reading indicates the cumulative hours of furnace operation. Record the meter reading to the nearest tenth of an hour.

6. Burner On Time This Period. This column records the furnace burner's operation time during the most recent metering period. The present meter reading (C.5) minus the previous meter reading (C.5, but one line up) gives the elapsed time. Record this time to the nearest tenth of an hour.

7. Btu's This Period. This is calculated by multiplying the firing rate (FR) taken from the top of the page times the burner on time this period which comes from column 6. (FR x C.6)

8. Degree Days This Period. Add up the total number of degree days since the client was last called. Include the degree days for the day the client was last called, but <u>not</u> those for this day's call.

9. Btu's Per Degree Day. This is calculated by dividing the Btu's this period (column 7) by the degree days this period (column 8). (C.7/C.8)

10. Btu's per Degree Day per Square Foot. You calculate this by dividing the Btu's per degree day, which comes from column 9, by the square footage of area heated by the furnace (SF). (C.9/SF)

    The calculation for each period needs to be compared with the previous data in this column. If this period's calculation is more than one third greater or smaller than the previous calculation, please call the client back to reconfirm the current reading and ask the client if anything special has happened in the interim. Be sure to write this information down as described below.

Note: Record any problem, detail, or special circumstance affecting the accuracy or completeness of the data on this form right on the form itself! Write all the way across the page, from column 1 to column 10 and use as much space as needed to spell out the problem in detail. Some examples are: client is out-of-town, furnace is broken, ran out of propane, client is unreachable, and client has visiting relatives and is using more rooms than before.

VIRGINIA WEATHERIZATION PROGRAM SPECIAL DEMONSTRATION PROJECT

Page 1

Client Number 89-214 CH08 Agency CHIP Tel. (H) 684-1711

Client's Name E.Z. Sample Firing Rate (Btu/hr) 105,000 FR (Gas) (W)

Address 247 8th St., Charlottsville House Area (sqft) 1,480 SF Best Time to Call Wed a.m.

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)
1430	26	SEPT	89	000.1	INITIAL	INSTALLATION			
0920	9	Oct.	89	25.0	24.9	2,614,500	80	32,681	22.1
1015	11	Oct	89	48.7	23.7	2,488,500	84	29,625	20.0
0930	18	Oct	89	80.6	31.9	3,349,500	117	28,628	19.3
1045	25	Oct	89	108.0	27.4	2,877,000	102	28,206	19.1
1115	1	Nov	89	154.7	46.7	4,903,500	155	31,635	21.4
0830	10	Nov	89	209.6	54.9	5,764,500	192	30,023	20.3
= NO ONE HOME ON WEDNESDAY OR THURSDAY									
0930	15	Nov	89	228.3	18.7	1,963,500	81	24,241	16.4
1020	22	Nov	89	290.9	62.6	6,573,000	194	33,881	22.9
1010	29	Nov	89	359.5	68.6	7,203,000	165	43,655	29.5
= EIGHT GRANDCHILDREN HOME OVER THANKSGIVING									
0930	6	DEC	89	417.3	57.8	6,069,000	205	29,605	20.0
0915	13	DEC	89	480.5	63.2	6,636,000	201	33,015	22.3
= WEATHERIZATION WORK ON DEC. 14 and 15									
1730	15	DEC	89	510.9	30.4	3,192,000	61	52,328	35.4
0930	20	DEC	89	535.5	24.6	2,583,000	118	21,890	14.8
1020	27	DEC	89	594.8	59.3	6,226,500	235	26,496	17.9
0920	3	JAN	90	651.4	56.6	5,943,000	285	20,853	14.1
1015	10	JAN	90	702.8	51.4	5,397,000	264	20,443	13.8
1020	17	JAN	90	757.1	54.3	5,701,500	255	22,359	15.1

C.2: Project Brochure for Weatherization Clients

IMPORTANT INFORMATION FOR PARTICIPANTS IN THE VIRGINIA WEATHERIZATION PROGRAM

SPECIAL DEMONSTRATION PROJECT

What is the best way to make houses more comfortable and lower fuel bills?

Much research on energy conserving techniques has been accomplished over the last ten years to answer this important question, and recent answers are very interesting. By using special tools, it is now possible to examine a dwelling to find out just where it wastes energy. This makes it easier to take energy conservation measures, because the measures can be applied exactly where they do the most good.

Various other tools can be used to verify that a good job has been done.

Most clients will have a meter installed in the fall of 1989. This does not affect the operation of the heating system, but it does allow researchers to tell how much energy a heating system uses so that energy savings can be calculated accurately.

THE BOTTOM LINE

Clients selected to participate in this Special Demonstration Project can not only expect to have excellent work performed on their dwellings, but also contribute to making Virginia's Weatherization Assistance Program one of the most effective energy conservation programs in the nation.

Your local weatherization agency is:

HOME COMFORT

Virginia Association of Community Action Agencies, Inc.

IMPORTANT INFORMATION FOR PARTICIPANTS IN THE VIRGINIA WEATHERIZATION PROGRAM

▲

SPECIAL DEMONSTRATION PROJECT

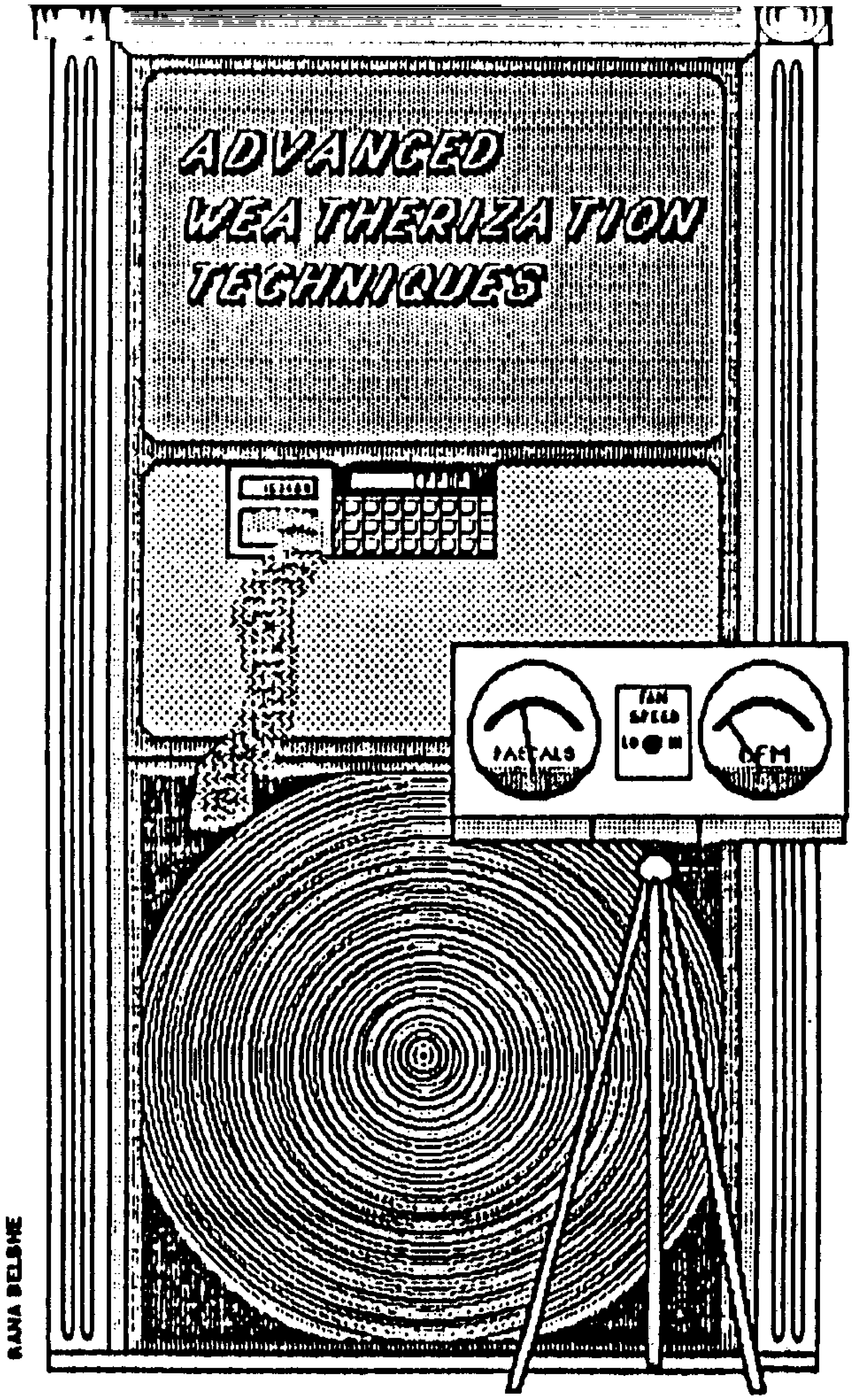
WEATHERIZATION

There is a Weatherization Assistance Program in Virginia whose mission is to make the dwellings of middle and lower income citizens more comfortable and energy efficient. Virginia's weatherization program is one of the oldest--and best--in the Country. Operated for 15 years by the Virginia Association of Community Action Agencies, more than 4,000 dwellings are weatherized each year through 31 local agencies at no cost to occupants.

Depending on the circumstances workers **may**

- Repair windows and doors
- Weather strip and caulk to reduce air leaks
- Insulate attics
- Replace windows
- Raise the energy efficiency of hot water heaters

In the past, this weatherization work was conducted without the benefit of the new tools researchers have found to be useful in making dwellings more energy efficient. However, since the new tools and techniques show strong promise for helping to weatherize dwellings more effectively, a Special Demonstration Project is being conducted over the 1989-90 heating season.



RANA BELSHE

DEMONSTRATION PROJECT

The aim of the demonstration project is to do the best possible job of installing weatherization measures that are fitted to the circumstances of each dwelling. Some houses benefit more by work on heating systems; others by air sealing; and still others by insulation. Accordingly, under the demonstration project, weatherization workers use such tools as a blower door (to measure how air [illegible] infrared scanner (to make sure insulation is installed properly.) Other tools are used to measure and improve heating system performance.

Most important, the energy consumption before and after weatherization is monitored (by a simple elapsed timer on the heating system) to measure actual savings achieved by the conservation work.

Participants in the Special Demonstration Project must be certified for the Weatherization Assistance Program. Further, since it is very important to be able to measure energy savings as accurately as possible, participants in the Special Demonstration Project must

- Live in a one or two-family dwelling
- Have a heating system that uses either oil or natural gas and
- Have lived in the dwelling for the past year and be unlikely to move before the end of 1990.

Finally, participants should be eager to participate in the Demonstration Project, willing to have an elapsed time meter installed on their heating system, and cheerful about reporting (using the telephone) the meter's current reading as often as once a week during the heating season.

C.3: Installation Standards for Pilot Study Homes

Virginia Weatherization Pilot Study: Installation Standards for Pilot Study Homes

Pilot agencies will use the following standards to weatherize pilot study houses. These standards supersede VACAA's FY89-90 standards for the pilot study houses only. Do not weatherize pilot study houses until at least 6 meter readings have been obtained from the furnace timer. Measures are to be done in the order indicated (although subcategories within each step, such as 3a and b, 5a and b, 7a and b, and 9a and b, may be done simultaneously). Blower door readings are to be taken after each set of measures is completed (see logging form for sequence of required blower door readings). As each step of weatherization is completed, indicate number of people who did work and the amount of time each person spent. This information on labor requirements of various weatherization measures is very important to assess the measures' cost-effectiveness.

Rejection of jobs: Virginia Tech, not VACAA, will accept or reject weatherization work on pilot study houses. Houses will NOT be rejected if they go below the minimum ventilation rate (MVR). Houses WILL be rejected if the logging sheet, air leakage report, and heating system inspection form are not completed and submitted, as well as the usual VACAA forms.

Single Family Dwellings

1) Heating system inspection: Perform heating system inspection as outlined on heating system inspection form. Fill out inspection form. Replace furnace filter (if applicable) and inform client of correct filter size and need for monthly replacement of filter during the winter. If safety hazards noted with heating system, contact Dept. of Social Services about correcting problem; if safety hazards noted with domestic hot water system contact Virginia Tech (we will deal with hot water system problems on a case by case basis, as they are not covered by Social Services).

2) Conduct blower door reading. If unable to get a reading at .20 WC, conduct all subsequent readings at both initial pressure and .20 WC. Calculate minimum ventilation rate (MVR) for house as you normally do. If the house is already below the MVR, DO NOT seal major air leaks or insulate the sidewalls, but DO seal bypasses (which do not affect the air change rate) and complete all other applicable measures. You will not be penalized if a house goes below the MVR after installing sidewall insulation or any other measure. For pilot study houses, do not follow closure targets; rather, carry out all applicable steps listed here and then stop, regardless of the final air change rate.

3) Repairs and major air sealing:

   a) Make any necessary repairs to house, such as fixing holes in walls or broken window panes.

   b) Locate and seal bypasses (e.g., chimney and plumbing chases, balloon walls) and MAJOR air leakage sites in attic, basement/crawlspace, and living area (e.g., attic scuttles and stairs, kneewall access doors, rim joists, stairwell/wall/ceiling intersections, utility penetrations). Consult chart provided at training for techniques for sealing various leakage sites. Indicate leakage sites you have sealed on air leakage form.

4) Conduct blower door reading.

5) Furnace ducts and domestic hot water heater:

   a) Check furnace ducts for leaks and seal any openings between ducts and furnace, in duct runs, or where ducts connect to register boots.

   b) Insulate domestic hot water heater according to VACAA standards.

6) Conduct blower door reading.

7) Insulate sidewalls and attic:

   a) If applicable, insulate sidewalls as discussed in training.

   b) If applicable, insulate attic and install attic vents. For attics with existing insulation of LESS THAN R-19, install additional insulation to bring attic up to R-30. If existing insulation is R-19 or greater, do not install any additional insulation. (R-19 is about 6″ of fiberglass batts or cellulose, or 7″ of blown-in fiberglass. R-30 is about 12″ of blown-in fiberglass.) Follow all other VACAA standards regarding installation of attic insulation and attic vents.

8) Conduct blower door reading.

9) Replace windows and doors:

   a) Replace primary windows only when absolutely necessary (e.g., windows do not function or are incapable of holding glass). Windows should NOT be replaced solely for infiltration reduction.

   b) Replace doors only if very deteriorated.

10) Conduct final blower door reading.

11) Record furnace timer reading on logging sheet.

Mobile Homes

1) Heating system inspection: Perform heating system inspection as outlined on heating system inspection form. Fill out inspection form. Replace furnace filter (if applicable) and inform client of correct filter size and need for monthly replacement of filter during the winter. If safety hazards noted with heating system, contact Dept. of Social Services about correcting problem; if safety hazards noted with domestic hot water system contact Virginia Tech (we will deal with hot water system problems on a case by case basis, as they are not covered by Social Services).

2) Conduct blower door reading. If unable to get a reading at .20 WC, conduct subsequent readings at both initial pressure and .20 WC. Calculate minimum ventilation rate (MVR) for house as you normally do. If the house is already below the MVR, DO NOT seal major air leaks, but DO complete all other applicable measures. You will not be penalized if a house goes below the MVR after installing any measures. For pilot study houses, do not follow closure targets; rather, carry out all applicable steps listed here and then stop, regardless of the final air change rate.

3) Repairs and major air sealing:

   a) make any necessary repairs to house, such as fixing holes in walls or broken window panes.

   b) Locate and seal MAJOR air leakage sites (e.g., rim joists, wall/ceiling intersections, utility penetrations). Indicate leakage sites you have sealed on air leakage form.

4) Conduct blower door reading.

5) Furnace ducts and domestic hot water heater:

   a) Check furnace ducts for leaks and seal any openings between ducts and furnace, in duct runs, or where ducts connect to register boots.

   b) Insulate domestic hot water heater according to VACAA standards.

6) Conduct blower door reading.

7) Insulate belly board. On mobile homes with an open cavity between the floor and the belly board, insulate the cavity with "loose-fill" insulation. First, repair any holes in the belly board. Insulation can be inserted in the cavity in two ways: (1) if the rim joists (the boards which tie together the ends of the floor joists) are not load bearing, and constructed of 2x6s, drill through the rim joists and blow in insulation, taking care to drill through the center of the joists; (2) if the rim joists are load bearing, or constructed of 2x4s, cut a hole in the belly board to insert insulation and cover hole when finished. Rim joists are generally load bearing if: (1) the floor joists run the width of the trailer and are on 24″ centers, or (2) perimeter blocking (concrete blocks from the rim joist to the ground) exists or is required in the trailer's set-up manual. Rim joists are usually not load bearing if: (1) the floor joists run the length of the trailer, or (2) the floor joists run the width of the trailer and are on 16″ centers, or (3) perimeter blocking is not required in the trailer's set-up manual. On mobile homes with the belly board completely missing, batt insulation may be installed and then protected with a permanent covering, or the belly board may be replaced and loose-fill insulation may be blown in as described above.

8) Conduct blower door reading.

9) Replace windows and doors:

   a) Replace primary windows only when absolutely necessary (e.g., windows do not function or are incapable of holding glass). Windows should NOT be replaced solely for infiltration reduction.

   b) Replace doors only if very deteriorated.

10) Conduct final blower door reading.

11) Record furnace timer reading on logging sheet.

C.4: Installation Documentation Forms

VIRGINIA WEATHERIZATION PILOT STUDY:
LOGGING SHEET

PILOT AGENCY ______________________ **CLIENT NAME** ______________________

PILOT STUDY NUMBER ______________________ **ADDRESS** ______________________

TASK	DATE	MATERIALS COST	LABOR		BLOWER DOOR READING		
			# PEOPLE	# HOURS/ PERSON	ACH	DIAL SETTING	PRESSURE (WC)
Estimation (attach air leakage report):							
Blower Door Reading							
Minimum Ventilation Rate (MVR)							.20
Other estimation activities (specify)							
TOTAL FOR ESTIMATION							
Heating System (attach inspection report): Inspection & Filter Change							
Repairs (Specify) (circle one: done by pilot agency, DSS, other)							
TOTAL FOR HEATING SYSTEM							
Crew Visit:							
Blower Door Reading							
Repairs (Specify)							
Bypasses & major air leakage sites (attach air leakage report)							

TASK	DATE	MATERIALS COST	LABOR		BLOWER DOOR READING		
			# PEOPLE	# HOURS/ PERSON	ACH	DIAL SETTING	PRESSURE (WC)
Blower Door Reading							
Furnace Duct Sealing							
Domestic Hot Water System							
Blower Door Reading							
Wall Insulation area insulated = ________ sqft. total outside wall area = ________ sqft.							
Attic Insulation & Venting area insulated = ________ sqft. total attic area = ________ sqft.							
Blower Door Reading							
Belly Board Insulation							
Blower Door Reading							
Primary Window Replacement							
Door Replacement							
Blower Door Reading							
Other (Specify)							
Final Blower Door Reading							
TOTAL FOR CREW VISIT							

Furnace timer reading at completion of weatherization = ______________

Any problems with doing this job?

____

____

____

VIRGINIA WEATHERIZATION PILOT STUDY: AIR LEAKAGE AND BYPASS REPORT

Leak/ Bypass Noted	Fixed	
		Bypasses (attic and basement/crawlspace)
___	___	chimney chases
___	___	plumbing chases
___	___	balloon walls
___	___	interior partition wall junctions
___	___	other (specify) ____________________
		____________________
		____________________
		Major Attic Air Leakage Sites
___	___	attic scuttles
___	___	doors to attic stairwells
___	___	fold-up attic stairs
___	___	kneewall access doors
___	___	staircase/wall/attic intersections
___	___	other (specify) ____________________
		____________________
		____________________
		Major Basement/Crawlspace Air Leakage Sites
___	___	utility penetrations (electric, water, sewer)
___	___	sidewall/porch frame intersections
___	___	stairwell/wall intersections
___	___	rim joists
___	___	other (specify) ____________________
		____________________
		____________________
		Major Interior Air Leakage Sites
___	___	utility penetrations (electric, water, sewer)
___	___	split-level intersections
___	___	addition intersections
___	___	other (specify) ____________________
		____________________
		____________________

VIRGINIA WEATHERIZATION PILOT STUDY:
HEATING SYSTEM INSPECTION REPORT

PILOT AGENCY ______________________ **CLIENT NAME** ______________________

PILOT STUDY NUMBER ______________________ **ADDRESS** ______________________

UNIT ID (fill out multiple reports if more than one unit in house)

Type of Unit (circle one):	Gravity Floor Furnace	Boiler Space Heater	Forced-Air Water Heater
Fuel (circle one):	Natural Gas Wood	Propane Coal	Oil Kerosene

Make: ______________________

Model Number: ______________________

Location of Unit: ______________________

Is the unit in a conditioned or unconditioned space? ______________________

____

FUEL LEAKS

*Did you detect any fuel leaks? yes no

If yes, location of leak: ______________________

Did you correct leak? yes no

If no, describe corrective action required: ______________________

____

INSPECTION RESULTS

1.	Is there charred, frayed or missing wiring?	yes	no	
2.	*Is the venting system improper or badly deteriorated or nonexistent?	yes	no	
3.	Are venting clearances insufficient?	yes	no	
4.	*Is there a drafting problem?	yes	no	
5.	*Is the heat exchanger cracked or seriously corroded?	yes	no	NA
6.	Are burners/heat exchanger contaminated with debris?	yes	no	
7.	Are there scorch/burn marks on the unit?	yes	no	
8.	Are there problems regarding switch/limit settings?	yes	no	NA
9.	Is the thermostat malfunctioning?	yes	no	NA
10.	Is the unit leaking?	yes	no	NA
11.	*Is the unit lacking safety controls?	yes	no	NA
12.	Tiles/glass missing, broken or need to be aligned?	yes	no	NA

Continued

INSPECTION RESULTS (continued)			
13. Floor protection needed?	yes	no	NA
14. Is the unit excessively dirty?	yes	no	
15. Air filter size (if applicable):			
16. Combustion chamber size (if applicable):			
17. Chamber condition (if applicable):			
18. Oil filter present (if applicable):	yes	no	NA
19. Rated Input:			
20. Actual Input:			
21. Is there sufficient combustion air for unit?	yes	no	

Explain any "yes" responses in "Inspection Results" by noting nature of problem:

____

____

INITIAL TEST RESULTS

Stack temperature (not for water heaters): __________ °F
Oxygen (O_2) reading (not for water heaters): __________ %
Steady-state efficiency (not for water heaters): __________ %
Carbon monoxide (CO) in flue gases: __________ PPM
*Carbon monoxide (CO) in living area: __________ PPM

NOTE: For further information on inspection and test procedures, consult COAD training materials and NFPA code books on gas and oil appliances and venting requirements (NFPA 31,54, and 211).

FURTHER WORK REQUIRED

Questions regarding serious safety violations are marked with an asterisk (*); such violations include **fuel leaks** (or the lack of **safety controls** for shutting off fuel to the pilot and burner if the pilot goes out) , a **cracked heat exchanger** which allows CO into the living area, other problems which allow CO into the living area (e.g., **venting or drafting problems)** or **no functioning heater** during the winter. Your CO testers are not sensitive enough to detect the presence of CO in concentrations of less than 50 ppm. However, concentrations below 50 ppm can still be hazardous. Therefore, it is very important to look for other signs of CO problems (for example, a cracked heat exchanger, venting or drafting problems), even if your CO test results are okay.

Signs of CO problem in living area (circle one):

CO test reading   Cracked heat exchanger   Venting   Drafting   None

Report serious **heating system safety violations** to the **Department of Social Services** using the enclosed form.

Safety violations involving the **water heater** will not be fixed by the Department of Social Services; contact **Virginia Tech** for further information on repairing serious water heater violations.

Describe safety violations(s) requiring repair: ________________________

____

____

Who will perform repairs (circle one):   Pilot Agency   DSS   Other

C.5: Inspection Form and Client Interview Questionnaire

VIRGINIA WEATHERIZATION PILOT STUDY:
INSPECTION CHECKLIST

Agency: ______________________________ Inspectors: ______________

Pilot Study Number ______________________________ Date: ______________

Client Name: ____

Client Address: ____

Blower Door Reading = __________, dial setting = __________, Pressure = __________
(Note: Use same dial setting and pressure as final reading on logging sheet.)

Repairs:

- Were all repairs noted on the logging sheet correctly and neatly completed?

Repair (specify)	**Correctly Fixed?**	**Neat Workmanship?**
	Yes No	Yes No
	Yes No	Yes No
	Yes No	Yes No

Comments: ____

____

____

- Are there any areas in need of repair not noted on the logging sheet and therefore not fixed?

____

____

____

Bypasses and Major Air Leakage Sites:

- Were all bypasses and leakage sites noted on the logging sheet and Air Leakage/Bypass Report correctly and neatly sealed?

Bypass/Leakage Site (specify)	Correctly Sealed?	Neat Workmanship?
	Yes No	Yes No
	Yes No	Yes No
	Yes No	Yes No
	Yes No	Yes No
	Yes No	Yes No

Comments: ______________________________

____

____

- Are there any bypasses or leakage sites that were **not identified** on the Air Leakage/Bypass Report?

____

____

- Was any air sealing done **in excess** of what was specified in the pilot standards (e.g., around windows, baseboards, or other "typical" locations that are part of statewide weatherization but **not** part of the pilot study)?

____

____

____

Furnace Duct Sealing:

- Were all openings between ducts and furnace, in duct runs, and where ducts connect to register boots sealed with an appropriate material?

____

____

____

Water Heater:

- Type of heater? Electric Gas Oil Cabinet NA
- Is heater wrapped? Yes No
- If wrapped, is R-value of insulation at least R-5? Yes No
- Is thermostat set at 120° (140° for dishwasher)? Yes No
- Are the first 3 feet of hot water line wrapped? Yes No
- Were access panels, pressure relief value, and electrical service cord left uncovered? Yes No
- Overall judgement of water heater: Pass Fail

Comments:

____

____

____

Sidewall Insulation (site-built homes only):

- Were sidewall insulated? Yes No
- If **yes**, were walls completely insulated? Note any missed areas if possible.

  ____

  ____

  ____

- If **yes**, was siding neatly replaced (for outside jobs) or holes neatly patched (for inside jobs)?

  ____

  ____

  ____

- If sidewalls were insulated, note the siding material + **photograph** each side of the house (outside).

  Siding: Wood Aluminum Vinyl Brick Stucco Asbestos Other (specify)

Comments: ______________________________

____

____

____

____

Attic Insulation (site-build homes only):

- Square footage of insulatable attic ______________________________
- Existing R-value __________ Added R-value __________ Total R-value __________
- Uniformly blown? Yes No
- Chimney wrapped? Yes No
- Label in customer folder? Yes No
- Trap door insulated? Yes No
- 3″ clearance around heat-producing devices? Yes No
- Blocking material around attic access? Yes No
- Meets standards? Yes No

Comments:

____

____

____

Attic Venting (site-built homes only):

#	Type	Size	Existing	Installed	NFA/Each	Total NFA/Intake	Total NFA/Exhaust
					Combined Total:		

- Total required intake = ______________ NFA, exhaust = ______________ NFA
- Does venting meet standards? Yes No

Comments: ______________________________

____

____

Belly Board Insulation (mobile homes only):

- Was belly board insulation installed? Yes No

  If **no**, what reason was given?

  Existing insulation   Insufficient clearance   Unsanitary   Other (specify)

  Do you agree with this explanation (VACAA standards say clearance must be ≥ 18″)?

  ____

  ____

  ____

- If insulation was installed, does it meet standards? Yes No
- If insulation was installed, was proper care taken to prevent pipes from freezing? Yes No

Comments: ____

____

____

____

Primary Windows and Doors:

- Number of primary windows replaced = __________

  Windows meet standards? Yes No

- Number of primary doors replaced = ______________________________

  Doors meet standards? Yes No

Comments: ____

____

____

Other:

- Please describe any other work done on the house, and if these additional measures were neatly and correctly installed.

  ____

  ____

  ____

  ____

VIRGINIA WEATHERIZATION PILOT STUDY:

UTILITY RELEASE REQUEST

Name of your gas or oil company: ______________________________

Name of person that bill is sent to: ______________________________

Account number (if known): ______________________________

Name of your electric company: ______________________________

Name of person that bill is sent to: ______________________________

Account number (if known): ______________________________

I hereby give permission to the above named utility companies to release consumption records for my home to the Virginia Center for Coal and Energy Research, for two years prior to and two years after the date noted below. I understand that these records are to be used for research purposes only and my name, address, and other identifying information will not be used.

______________________________ __________

Signature Date

Name: ______________________________

Address: ______________________________

City, State, Zip: ______________________________

(please print)

VIRGINIA WEATHERIZATION PILOT STUDY:
CLIENT QUESTIONNAIRE

HOUSEHOLD INFORMATION

Name: ______________________________

Address: ______________________________

City, State, Zip: ______________________________

Telephone: ______________________________

- When did you move into your home? __________ Month ______ Year
- How many people live in your home? ______________________________
- How many people are usually at home during the day? ______________
- Has the number of people living in your home changed since June 1988? Yes No

  If yes, when and how did the number change? ______________________

- During a typical winter day, do you heat all the rooms in your house? Yes No

  If no, what rooms do you **not** heat? ______________________________

- Have you changed the number of rooms that you heat during the winter of 1988/89 and the winter of 1989/90? Yes No

  If yes, when and how did the number of heated rooms change? ______________

- Was your house vacant for 4 days or more at any time since September 1989? Yes No

  If yes, explain when and for how long the house was vacant:

  ____

FEATURES OF YOUR HOUSE

- Roughly how old is your house? ______________________ years
- Which of the following best describes your house?

  One-story single-family   Two-story single family   Duplex   Trailer   Other (describe)

- Does your house have a basement or crawlspace?

  Full basement   Partial basement   Crawlspace   Other (describe)   None

  If you have a basement, is it heated? Yes No

- What fuel do you use for the following:

	Gas	Oil	Electricity	Other (describe)	None
Main Furnace or Heater	☐	☐	☐		
Hot Water	☐	☐	☐	☐	☐
Cooking	☐		☐	☐	☐
Clothes Dryer	☐		☐	☐	☐
Air Conditioning	☐		☐	☐	☐

- Have the fuels used for any of these purposes changed since June 1988? Yes No

  If yes, when and how did the fuel(s) change? ______________________________

- Does your house have a working fireplace? Yes No

Sept 89 _____	Jan 90 _____
Oct 89 _____	Feb 90 _____
Nov 89 _____	Mar 90 _____
Dec 89 _____	Apr 90 _____

- Many homes supplement their primary heating source (such as a gas or oil heater) with heat from other sources. Have you used any of the following supplemental heat sources?

  Electric Heater Kerosene Heater Wood or Coal Stove Other (describe)

  If yes, please indicate about how many times you used it during the following months:

Sept 89 _____	Jan 90 _____
Oct 89 _____	Feb 90 _____
Nov 89 _____	Mar 90 _____
Dec 89 _____	Apr 90 _____

- Do you have a thermostat in your home? Yes No

  If yes, during a typical winter day, what temperature is the thermostat set on?

  - during the daytime _____
  - during the evening _____
  - when you sleep _____

- Did you change these thermostat settings during the winter of 1989/90? Yes No

  If yes, when and how did you change these settings? ______________________________

- Aside from the weatherization, have you made any major changes to your house since June 1988 (such as building an addition, replacing or repairing your furnace, installing major appliances, replacing the roof, etc.)? If so, what changes were made and when did they take place?

  ____

  ____

  ____

  ____

WEATHERIZATION WORK

How satisfied were you with the weatherization your home received? Please rate each of the issues below from 1 to 5, where "1" means you were totally **dissatisfied** and "5" means you were totally **satisfied**.

▪ the measures that were installed	1	2	3	4	5
▪ quality of the work performed	1	2	3	4	5
▪ length of time to complete the job	1	2	3	4	5
▪ cleanup after the work was completed	1	2	3	4	5
▪ your being informed of what was being done to your home and why	1	2	3	4	5
▪ improving the comfort of your home by reducing draftiness	1	2	3	4	5
▪ reducing your monthly energy bill	1	2	3	4	5
▪ improving the appearance of your home	1	2	3	4	5

- If you were **dissatisfied** with the measures that were installed, what measures would you have preferred?

____

____

____

- How would you rate the overall comfort of the house during the winter months, both **before** and **after** the weatherization work was done?

Before:	1	2	3	4	5
After:	1	2	3	4	5
	cold		pleasant		hot

- Please explain any problems you had with the weatherization work:

____

____

____

____

ENERGY-USING HABITS

- What did you do to save energy **before** the weatherization work was done?

- Did the weatherization workers discuss any things **you** could do to save energy? What changes in your energy-using habits did they suggest?

- Did you make any changes in your energy-using habits **after** the weatherization work was done? What did you do?

- Do you have any other comments about the weatherization work that was done on your house, or ideas about how to improve the weatherization program in Virginia?

C.6: Weatherization Staff Interview Questionnaires

VIRGINIA WEATHERIZATION PILOT STUDY:
COORDINATOR INTERVIEW

Name of person completing interview: ______________________________

Agency: ______________________________

Note: If you did estimations or heating system inspections for any pilot study houses, please complete the "Estimator/Heating System Inspector Interview" also. Some of the questions on the two interviews are repeated; you need answer them on one form only.

PILOT STUDY TRAINING SESSIONS

Did you attend either of the pilot study training(s)? Yes No

If yes, which did you attend? Heating System Sidewall/Air Sealing Both

If yes, please answer the following questions for each training you attended:

		Heating System	Sidewall/Air Sealing	
Were you able to attend the entire training?		Yes No		Yes No
If no, state which portion you attended: ______________________________				
Please rate the **content** of the **classroom** portion of the training on a scale from 1 to 5 (1 = very poor, 2=poor, 3=fair, 4=good, 5=very good)		1 2 3 4 5		1 2 3 4 5
Please rate the **content** of the **field** portion of the training on the same scale		1 2 3 4 5		1 2 3 4 5
Please rate the effectiveness of the **trainers** on the same scale	R.W. Davis	1 2 3 4 5	Rana Belshe	1 2 3 4 5
	Rudy Leatherman	1 2 3 4 5	Tom Wilson	1 2 3 4 5
			Jim Fitzgerald	1 2 3 4 5
Was the training you received sufficient for the work you were asked to do?		Yes No		Yes No

If the training was not sufficient, for which tasks did you feel poorly prepared after the training?

____

____

If similar trainings were held for all state weatherization agencies, what improvements would you suggest to make them more effective?

____

____

____

Do you have any other comments regarding the pilot study trainings?

____

____

____

IMPLEMENTATION OF PILOT STUDY STANDARDS

For the following questions "new measures" refer to *heating system work, sidewall insulation, and/or advanced air sealing techniques* carried out in the pilot study houses.

In your opinion, were the new measures **effective** (at saving energy or identifying heating system safety hazards)? Why or why not?

____

____

____

What problems, if any, did you have obtaining **equipment or materials** required for the new standards?

____

____

Did your **estimator** have any problems with implementing the new standards (e.g., necessary skills, time, etc.)? If so, what?

____

____

____

Did your **heating system inspector** have any problems with implementing the new standard (e.g., necessary skills, time, etc.)? If so, what?

____

____

Did your **crews** have any problems with implementing the new standard? If so, what?

____

____

____

How many crews **worked** on the pilot study houses?

____

Did you have a subcontractor work on any pilot study houses? ____________________

If more than one crew and/or subcontractor worked on the pilot study houses, did you notice any difference in the various crews' or subcontractor's ability to "pick up" on the new techniques? If so, what do you think caused the differences?

Did you receive any comments from the **clients** about the pilot study measures? If so, what?

Did you have any **other problems** with implementing the pilot study standards? If so, what?

Would you make any **changes** to the pilot study standards (if they were being considered for use in all Virginia weatherization)?

What problems, if any, did you have in filling out the pilot study reporting **forms**? Are there any changes you would make to the forms?

FUTURE OF PILOT STUDY STANDARDS

Would you want to include the new measures in all your weatherization work (if the existing standards were changed)? Why or why not?

What changes would be needed in **personnel** to include the new measures in all your weatherization work (e.g., number of estimators or crew people, skills of estimators or crews, etc.)?

Would any changes be needed in your **procedures** for intake, estimation, installation, or inspection (e.g., scheduling of each step, amount of time each step takes, etc.)? What would these changes be?

Would any changes be needed in the **reimbursement system** to make the new measures financially feasible for your agency? What changes would you suggest?

Are there any **other changes** that you think would make it easier to successfully implement the new measures in all your weatherization work?

VIRGINIA WEATHERIZATION PILOT STUDY: ESTIMATOR/HEATING SYSTEM INSPECTOR INTERVIEW

Name of person completing interview: ____________________

Agency: ____________________

Role in pilot study: Estimator Heating System Inspector Both Other (specify)

What is your usual role in your agency? ____________________

Number of pilot houses estimated/inspected:

Did anyone else do estimations or heating system inspections of pilot study houses for your agency?

Yes No

If yes, what is the other person's name? ____________________

PILOT STUDY TRAINING SESSIONS

Which training(s) did you attend? Heating System Sidewall/Air Sealing Both

Please answer the following questions for each training you attended:

		Heating System	**Sidewall/Air Sealing**	
Were you able to attend the entire training?		Yes No		Yes No
If no, state which portion you attended: ____________________				
Please rate the **content** of the **classroom** portion of the training on a scale from 1 to 5 (1=very poor, 2=poor, 3=fair, 4=good, 5=very good)		1 2 3 4 5		1 2 3 4 5
Please rate the **content** of the **field** portion of the training on the same scale		1 2 3 4 5		1 2 3 4 5
Please rate the effectiveness of the **trainers** on the same scale	R.W. Davis	1 2 3 4 5	Rana Belshe	1 2 3 4 5
	Rudy Leatherman	1 2 3 4 5	Tom Wilson	1 2 3 4 5
			Jim Fitzgerald	1 2 3 4 5
Was the training you received sufficient for the work you were asked to do?		Yes No		Yes No

If the training was not sufficient, for which tasks did you feel poorly prepared after the training?

____

____

If similar trainings were held for all state weatherization agencies, what improvements would you suggest to make them more effective?

____

____

____

Do you have any other comments regarding the pilot study trainings?

____

____

____

IMPLEMENTATION OF PILOT STUDY STANDARDS

In the following questions, "new measures" refer to *heating system work, sidewall insulation, and/or advanced air sealing techniques* you did in the pilot houses.

In your opinion, were the new measures **effective** (at saving energy or identifying heating system safety hazards)? Why or why not?

____

____

____

What problems, if any, did you have obtaining or using **equipment or materials** required for the new standard?

____

____

____

Did the **crew** have any problems in correctly carrying out your instructions for sealing air leakage sites or installing sidewall insulation? If so, what?________________________

____

____

Did the **clients** prevent you from carrying out any of the pilot study measures? If so, what measures and why? In your opinion, were they pleased or dissatisfied with the work done to their homes?

____

____

Did you have any **other problems** with implementing the pilot study standards? If so, what? ________

____

____

Would you make any **changes** to the pilot study standards (if they were being considered for use in all Virginia weatherization)? ____

____

____

What problems, if any, did you have with filling out the pilot study report **forms**? Are there any changes you would make to the forms? Were the forms helpful in reminding you of all the necessary steps in identifying air leakage sites, inspecting heating systems, etc.? ____________________

____

____

____

FUTURE OF PILOT STUDY STANDARDS

Would you want to include the new measures in all your weatherization work (if the existing standards were changed? Why or why not?

____

____

What changes would be needed in **personnel** to include the new measures in all your weatherization work (e.g., number of estimators or crew people, skills of estimators or crews, etc.)?

____

____

Would any changes be needed in your **procedures** for intake, estimation, installation, or inspection (e.g., scheduling of each step, amount of time each step takes, etc.)? What would these changes be?

____

____

____

Would any changes be needed in the **reimbursement system** to make the new measures financially feasible for your agency? What changes would you suggest?

____

____

____

Are there any **other changes** that you think would make it easier to successfully implement the new measures in all your weatherization work?

VIRGINIA WEATHERIZATION PILOT STUDY: CREW INTERVIEW

Name of person completing interview: ______________________________

Agency: ______________________________

Number of pilot houses you worked on: ______________________________

PILOT STUDY TRAINING SESSIONS

Did you attend either of the pilot study trainings? Yes No

If yes, which did you attend? Heating System Sidewall/Air Sealing Both

If yes, please answer the following questions for each training you attended:

		Heating System	Sidewall/Air Sealing	
Were you able to attend the entire training?		Yes No		Yes No
If no, state which portion you attended:		______		______
Please rate the **content** of the **classroom** portion of the training on a scale from 1 to 5 (1 = very poor, 2=poor, 3=fair, 4=good, 5=very good)		1 2 3 4 5		1 2 3 4 5
Please rate the **content** of the **field** portion of the training on the same scale		1 2 3 4 5		1 2 3 4 5
Please rate the effectiveness of the **trainers** on the same scale	R.W. Davis	1 2 3 4 5	Rana Belshe	1 2 3 4 5
	Rudy Leatherman	1 2 3 4 5	Tom Wilson	1 2 3 4 5
			Jim Fitzgerald	1 2 3 4 5
Was the training you received sufficient for the work you were asked to do?		Yes No		Yes No

If the training was not sufficient, for which tasks did you feel poorly prepared after the training?

____

____

If similar trainings were held for all state weatherization agencies, what improvements would you suggest to make them more effective?

____

____

____

Do you have any other comments regarding the pilot study trainings?

If you **did not attend the training sessions**, do you feel that the on-the-job training was enough to allow you to do a good job? Or would you have preferred to attend a training session?

INSTALLATION OF PILOT STUDY MEASURES

Please answer the following questions for the *sidewall insulation and/or advanced air sealing techniques* you did in the pilot study houses.

In your opinion, were the new measures **effective** (at saving energy)? Why or why not?

What problems, if any, did you have with using **equipment or materials** required for the new measures?

What problems, if any, did you have with correctly **sealing air leakage sites** or **installing sidewall insulation**?

In your opinion, were the **clients** pleased or dissatisfied with the work done to their homes?

Did you have any **other problems** with installing the pilot study measures? If so, what?

Would you want to include the new measures in all your weatherization work (if the existing standards were changed)? Why or why not?

Do you have any suggestions that you think would make it easier to install the new measures in all weatherization work?

C.7: VDSS Memorandum on Heating System Repairs

BLAIR BUILDING
8007 DISCOVERY DRIVE
RICHMOND, VIRGINIA 23229-8699
(804)662-9204

LARRY D. JACKSON
COMMISSIONER

COMMONWEALTH of VIRGINIA
DEPARTMENT OF SOCIAL SERVICES

November 9, 1989

NOV 10

Mr. Danny Chisom
Virginia Association of Community
Action Agencies, Inc.
Virginia Weatherization Program
520 West Franklin Street, Suite 18
Richmond, VA 23220

Dear Mr. Chisom:

Enclosed please find the memo sent to regionl energy assistance specialists with direct responsibility to agencies participating in the VACAA Weatherization Pilot Program. Also enclosed is a listing of local departments of social services and the telephone number for referrals.

Please instruct your CAAs to ask for the individual responsible for the Energy Assistance Program when contacting the departments with Crisis Assistance referrals. Your clients must complete a Request for Crisis Assistance at the local agency before assistance can be provided. Clients providing verification of their income and resources at the time the request is made will be served expeditiously. Any applicant requesting assistance will be notified of their eligibility within 48 hours of the request.

I appreciate your involving the department in this program. Please feel free to contact me if problems arise or if my assistance is needed in any way (804) 662-9168).

Sincerely,

Laura Shown Wegner
Program Specialist
Energy and Emergency Assistance Unit
Division of Benefit Programs

LSW/ly

Enclosures

cc: Mark Grigsby, Office of Community Services

VSS
PEOPLE HELPING PEOPLE

PEOPLE HELPING PEOPLE

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF SOCIAL SERVICES
MEMORANDUM

NOV 10 198_

DATE: November 9, 1989

TO: Cindy Green, Southwest Regional Office
Alice Retyer, Valley Regional Office
Jay Thomas, Northern Virginia Regional Office
June Ditillo, Roanoke Regional Office

FROM: Laura Wegner, Program Specialist
Energy and Emergency Assistance

SUBJECT: VACAA Weatherization Pilot Program

The Virginia Association of Community Action Agencies, Inc., in conjunction with Virginia Tech is conducting a pilot program aimed at increasing energy efficiency in low-income homes. This program is producing positive results in other areas of the country; however, some problems have been identified. In certain instances, boarderline and high levels of carbon monoxide have been detected in homes. The carbon monoxide levels have been related to malfunctions in the household's primary heating source.

The VACAA agencies will monitor carbon monoxide levels in each home prior to approval for participation in the pilot program. Where problems exist, the household will be advised to contact their Local Department of Social Services to request Crisis Assistance. These requests should be considered emergencies under unsafe heating equipment references in Chapter F, Crisis Assistance. Agencies should take action to repair or replace the equipment as soon as possible, but no later than 48 hours from receiving the request.

A list of VACAA agencies participating in the pilot and the localities they serve is attached. Please advise your agencies of the pilot and the importance of their immediate response to referrals from VACAA agencies.

Thanks for your cooperation. Please call me at 662-9168 or Mark Grigsby 662-9058 if you have questions.

LW/ly

cc: Mark Grigsby, Office of Community Services
Danny Chisom, VACAA Weatherization Program

VACAA Agency	Local Social Services Dept.	Telephone
Community Energy Conservation Program	Albemarle	804-977-6510
	Fluvanna	804-842-8221
	Greene	804-985-5246
	Louisa	703-967-1320
	Highland	703-468-2199
	Nelson	804-263-8334
	Rockingham	703-434-9973
	Staunton	703-885-8911
	Charlottesville	804-971-3400
	Waynesboro	703-942-6646
	Harrisonburg	703-433-2412
People Inc., of Washington County	Washington Co.	703-628-6071
	Bristol	703-669-8117
	Abingdon	703-628-6071
Rappahannock Rapidan Community Service Center	Culpeper	703-825-1251
	Fauquier	703-347-2316
	Orange	703-672-1155
	Madison	703-948-5521
	Rappahannock	703-675-3313
Total Action Against Poverty	Alleghany	703-902-5151
	Craig	703-864-5117
	Botetourt	703-992-8210
	Rockbridge	703-463-7143
	Roanoke	703-387-6267
	Roanoke City	703-981-2422
	Salem	703-387-6267
	Clifton Forge	703-862-4206
	Buena Vista	703-434-9973
	Lexington	703-463-7143
	Covington	703-962-5151

ENERGY ASSISTANCE APPLICATION
COMMONWEALTH OF VIRGINIA
DEPARTMENT OF SOCIAL SERVICES
SUPPLEMENT B
REQUEST FOR CRISIS ASSISTANCE

FOR AGENCY USE ONLY
Local DSS ______
Date Rec'd ______
Date Proc'd by ______
Worker # ______
Case # ______

1. ______
(Applicant Name)
______
(Address)
______
(City, State) (Phone #)

2. I wish to apply for Crisis Assistance for the following reason (s):

(Check all that apply)

A. ☐ My heating stove or furnace is not working. When did it stop working?
______ (Day, month, & year)
Who owns or is responsible for repairs to your heating stove or furnace? ______

B. ☐ My heating stove or furnace is unsafe or dangerous. Explain why you think it isn't working right. ______
______
How long has it been working this way? ______
What do you think is wrong with it. ______
______
Who owns or is responsible for repairs to your heating stove or furnace? ______

C. ☐ My electricity which is needed to run my heating stove or furnace was cut off. When was it cut off?
(Day, month, & year) ______
Whose name is your electric bill in? ______
Who is responsible for paying your electric bill? ______

D. ☐ My electricity which is needed to run my heating stove or furnace will be cut off on
(Day, month, & year) ______
Whose name is your electric bill in? ______
Who is responsible for paying your electric bill? ______

E. ☐ I do not have any heat because I need a deposit to get my heat turned on. How many days have you been without heat? ______
Have you applied for the service? ___ Yes ___ No

F. ☐ Other, explain ______
______
______
______

3. Have you or a member of your household applied for Crisis Assistance before?

_____ Yes _____ No If yes, when? ______________________ where? ______________________

4. Have you or another member of your household applied for Fuel Assistance?

_____ Yes _____ No If yes, answer the following:

a. When and where did you apply for Fuel Assistance? ______________________

b. What is your fuel worker's name? ______________________

c. Has anything in your situation changed since you applied for Fuel Assistance?

_____ Yes _____ No What has changed? ______________________

____

5. Have you contacted any community agencies to help you in meeting your energy crisis?

_____ Yes _____ No If yes, what agency (or agencies)? ______________________

6. If your case is approved, what person or company would you like to provide emergency services to assist you with your energy crisis?

(Name) ______________________

(Address) ______________________

(City/State) ______________________ (Phone) __________

APPLICANT'S CERTIFICATION

I request assistance and certify that the above statements and attachments are true and correct to the best of my knowledge and belief.

I agree to let the Department of Social Services know immediately or the next working day of any changes that occur in my situation.

I understand that neither I nor a member of my household can sell any equipment purchased on my behalf through the program unless I have contacted the local Department of Social Services and received their permission to sell.

I understand that I have the right to file a complaint if I feel I have been discriminated against because of race, color, national origin, religion, sex, age, handicap or religious belief.

I understand that if I give false information, withhold information, or fail to report changes promptly, or on purpose, I may be breaking the law and could be prosecuted for perjury, larceny and/or welfare fraud.

I understand that if I completed, or assisted in completing this form for the applicant and/or aided or abetted the applicant to obtain assistance for which he/she is not eligible that I may be breaking the law and could be prosecuted.

My signature below authorizes the Department of Social Services or other agencies involved in the program to obtain any verifications necessary to establish my eligibility for assistance and to obtain cost and consumption data from my vendor for statistical purposes.

I understand that my signature on this form gives the local Social Service Agency permission to give information in my case record to other organizations from which I have or may request assistance.

______________________ __________
APPLICANT'S SIGNATURE DATE

This application was completed on behalf of the applicant by ______________________ __________
SIGNATURE DATE

C.8: Energy Usage and Savings for Pilot Study Homes

CECP Pilot Houses

(all mobile homes except for # 6 and 13, which are site-built)

	PRE AVG	PRE STD	N	SE	POST AVG	POST STD	N	SE	SAVE	% SAVE	SE(SAV)	80% T	90% T	80% CI	90% CI	80%CI /SAVE	90%CI /SAVE
ce01 wright	17.98	3.06	11	0.92	15.94	2.55	16	0.64	2.04	11	1.12	1.37	1.81	1.54	2.03	0.75	1.00
2 lindsay	61.94	12.60	11	3.80	37.08	4.06	16	1.02	24.86	40	3.93	1.37	1.81	5.39	7.12	0.22	0.29
3 jackson	10.21	2.52	9	0.84	10.22	1.69	17	0.41	-0.01	0	0.93	1.40	1.86	1.31	1.74	############	
5 fitzgerald	15.85	2.05	16	0.51	16.23	2.50	11	0.75	-0.38	-2	0.91	1.37	1.81	1.25	1.65	-3.29	-4.34
sf6 garrison	17.98	3.47	10	1.10	14.01	1.54	12	0.44	3.97	22	1.18	1.38	1.83	1.63	2.17	0.41	0.55
7 keller	39.05	8.44	14	2.26	12.52	3.37	12	0.97	26.53	68	2.46	1.36	1.80	3.34	4.42	0.13	0.17
8 anderson	8.92	1.47	11	0.44	7.69	1.19	12	0.34	1.23	14	0.56	1.37	1.81	0.77	1.01	0.62	0.83
9 shifflett	15.57	4.88	6	1.99	23.08	2.77	15	0.72	-7.51	-48	2.12	1.48	2.02	3.13	4.28	-0.42	-0.57
10 hudgins	17.64	1.97	11	0.59	15.23	2.05	11	0.62	2.41	14	0.86	1.37	1.81	1.17	1.55	0.49	0.64
11 hicks	20.11	3.55	12	1.02	13.14	3.01	13	0.83	6.97	35	1.32	1.36	1.80	1.80	2.38	0.26	0.34
12 owens	27.42	4.55	12	1.31	21.84	3.52	11	1.06	5.58	20	1.69	1.37	1.81	2.31	3.06	0.41	0.55
sf13 noon	11.62	2.23	8	0.79	12.50	1.70	18	0.40	-0.88	-8	0.88	1.42	1.90	1.26	1.68	-1.43	-1.91
14 gibson	39.44	8.97	13	2.49	25.01	3.77	7	1.42	14.43	37	2.87	1.44	1.94	4.13	5.56	0.29	0.39
15 patterson	26.61	4.23	8	1.50	23.31	3.19	14	0.85	3.30	12	1.72	1.42	1.90	2.44	3.27	0.74	0.99
AVERAGE: SF	14.80				13.26				1.55	7							
MB	25.06				18.44				6.62	17							

RAPP-RAPP Pilot Houses

(all site-built except for # 21, which is a mobile home)

	PRE AVG	PRE STD	N	SE	POST AVG	POST STD	N	SE	SAVE	% SAVE	SE(SAV)	80% T	90% T	80% CI	90% CI	80%CI /SAVE	90%CI /SAVE
rr01 roy	17.16	1.64	12	0.47	11.41	2.63	4	1.32	5.75	34	1.40	1.64	2.35	2.29	3.28	0.40	0.57
2 jackson	12.50	2.00	12	0.58	9.94	1.31	5	0.59	2.56	20	0.82	1.53	2.13	1.26	1.75	0.49	0.68
3 williams	17.21	2.60	10	0.82	14.37	2.70	6	1.10	2.84	17	1.38	1.48	2.02	2.04	2.78	0.72	0.98
5 wise	19.28	1.50	11	0.45	12.23	2.05	6	0.84	7.05	37	0.95	1.48	2.02	1.41	1.92	0.20	0.27
6 foster	20.71	1.66	12	0.48	15.56	3.36	4	1.68	5.15	25	1.75	1.64	2.35	2.87	4.11	0.56	0.80
8 simms	29.85	2.75	11	0.83	23.46	3.15	7	1.19	6.39	21	1.45	1.44	1.94	2.09	2.81	0.33	0.44
10 bracey	7.43	0.71	11	0.21	5.72	1.19	6	0.49	1.71	23	0.53	1.48	2.02	0.79	1.07	0.46	0.63
11 snead	12.57	1.46	11	0.44	8.76	2.21	5	0.99	3.81	30	1.08	1.53	2.13	1.66	2.30	0.43	0.60
14 starks	18.05	1.71	11	0.52	10.03	2.16	5	0.97	8.02	44	1.09	1.53	2.13	1.68	2.33	0.21	0.29
15 hawkins	13.73	2.02	13	0.56	10.71	1.55	3	0.89	3.02	22	1.06	1.89	2.92	2.00	3.08	0.66	1.02
16 maddox	16.71	1.95	10	0.62	9.82	0.95	3	0.55	6.89	41	0.83	1.89	2.92	1.56	2.41	0.23	0.35
17 butler	21.86	1.80	11	0.54	17.09	2.59	6	1.06	4.77	22	1.19	1.48	2.02	1.76	2.40	0.37	0.50
19 brumbay	42.89	5.32	11	1.60	36.37	4.77	5	2.13	6.52	15	2.67	1.53	2.13	4.08	5.68	0.63	0.87
20 sharpe	14.73	0.95	8	0.34	13.21	2.40	5	1.07	1.52	10	1.12	1.53	2.13	1.72	2.40	1.13	1.58
mb21 voss	20.52	1.03	5	0.46	19.48	5.54	4	2.77	1.04	5	2.81	1.64	2.35	4.61	6.60	4.43	6.35
AVERAGE: SF	18.91				14.19				4.71	26							
MB	20.52				19.48				1.04	5							

TAP Pilot Houses
(all site-built)

	PRE AVG	PRE STD	PRE N	PRE SE	POST AVG	POST STD	POST N	POST SE	SAVE	% SAVE	SE(SAV)	80% T	90% T	80% CI	90% CI	80%CI /SAVE	90%CI /SAVE
tap01 morgan	20.27	5.82	7	2.20	18.12	1.26	3	0.73	2.15	11	2.32	1.89	2.92	4.38	6.77	2.04	3.15
2 gilbert	19.64	3.15	14	0.84	19.93	2.72	9	0.91	-0.29	-1	1.24	1.40	1.86	1.73	2.30	-5.97	-7.94
3 jefferson	26.44	3.83	5	1.71	19.22	2.85	5	1.27	7.22	27	2.14	1.53	2.13	3.27	4.55	0.45	0.63
a anderson	21.55	4.65	10	1.47	18.94	3.10	9	1.03	2.61	12	1.80	1.40	1.86	2.52	3.34	0.96	1.28
b martin	20.86	2.94	12	0.85	14.40	2.29	9	0.76	6.46	31	1.14	1.40	1.86	1.60	2.12	0.25	0.33
c petty	27.16	9.53	5	4.26	17.96	3.30	12	0.95	9.20	34	4.37	1.53	2.13	6.68	9.30	0.73	1.01
d scott	31.14	6.93	13	1.92	26.92	6.63	7	2.51	4.22	14	3.16	1.44	1.94	4.55	6.13	1.08	1.45
e tennies	26.40	5.95	16	1.49	18.99	4.99	5	2.23	7.41	28	2.68	1.53	2.13	4.10	5.71	0.55	0.77
f f.wilson	16.91	3.10	11	0.93	12.79	3.08	8	1.09	4.12	24	1.44	1.42	1.90	2.04	2.73	0.49	0.66
g mayo	28.92	4.82	16	1.21	28.91	1.22	3	0.70	0.01	0	1.40	1.89	2.92	2.64	4.08	############	
h roberts	25.67	3.23	13	0.90	15.26	2.77	9	0.92	10.41	41	1.29	1.40	1.86	1.80	2.39	0.17	0.23
i w.wilson	21.68	4.36	17	1.06	10.13	3.17	5	1.42	11.55	53	1.77	1.53	2.13	2.71	3.77	0.23	0.33
j saunders	24.60	3.70	11	1.12	19.02	4.12	3	2.38	5.58	23	2.63	1.89	2.92	4.97	7.67	0.89	1.37
k waller	9.32	2.32	7	0.88	3.54	1.04	2	0.74	5.78	62	1.14	3.08	6.31	3.52	7.22	0.61	1.25
l h.jones	22.92	4.64	10	1.47	21.12	2.37	9	0.79	1.80	8	1.67	1.40	1.86	2.33	3.10	1.30	1.72
m buckner	38.81	4.98	11	1.50	25.11		1		13.70	35							
n minnick	13.36	2.49	9	0.83	17.91	11.92	3	6.88	-4.55	-34	6.93	1.89	2.92	13.10	20.24	-2.88	-4.45
o p.jones	23.26	3.86	9	1.29	21.80	2.78	9	0.93	1.46	6	1.59	1.40	1.86	2.22	2.95	1.52	2.02
p robertson	25.09	3.95	11	1.19	21.44	4.83	7	1.83	3.65	15	2.18	1.44	1.94	3.14	4.23	0.86	1.16
q harris	33.54	4.60	8	1.63	20.26	2.27	4	1.14	13.28	40	1.98	1.64	2.35	3.25	4.66	0.24	0.35
r flowers	23.75	6.67	6	2.72	18.42	5.47	5	2.45	5.33	22	3.66	1.53	2.13	5.60	7.80	1.05	1.46
AVERAGE:	23.87				18.58				5.29	21							

PEOPLE Pilot Houses
(all site-built except for # 7, 8, and 12, which are mobile homes)

	PRE AVG	PRE STD	PRE N	PRE SE	POST AVG	POST STD	POST N	POST SE	SAVE	% SAVE	SE(SAV)	80% T	90% T	80% CI	90% CI	80%CI /SAVE	90%CI /SAVE
pd01 bowman	18.70	3.86	17	0.94	9.58	1.00	7	0.38	9.12	49	1.01	1.44	1.94	1.45	1.96	0.16	0.21
2 stallard	10.36	0.78	10	0.25	5.85	0.95	11	0.29	4.51	44	0.38	1.38	1.83	0.52	0.69	0.12	0.15
3 thompson	21.24	1.37	9	0.46	11.40	1.69	6	0.69	9.84	46	0.83	1.48	2.02	1.22	1.67	0.12	0.17
4 sharret	33.29	5.65	10	1.79	9.51	2.88	13	0.80	23.78	71	1.96	1.38	1.83	2.70	3.58	0.11	0.15
mb7 white	22.62	3.41	7	1.29	16.33	2.68	5	1.20	6.29	28	1.76	1.53	2.13	2.69	3.75	0.43	0.60
mb8 atwell	21.28	1.20	4	0.60	20.06	2.82	12	0.81	1.22	6	1.01	1.64	2.35	1.66	2.38	1.36	1.95
10 mcdaniel	26.86	3.75	11	1.13	19.90	3.57	3	2.06	6.96	26	2.35	1.89	2.92	4.44	6.86	0.64	0.99
11 olinger	21.02	3.02	11	0.91	10.99	0.99	6	0.40	10.03	48	1.00	1.48	2.02	1.47	2.01	0.15	0.20
mb12 terry	31.55	2.88	8	1.02	33.87	5.66	8	2.00	-2.32	-7	2.25	1.42	1.90	3.19	4.27	-1.37	-1.84
AVERAGE: SF	21.91				11.21				10.71	47							
MB	25.15				23.42				1.73	9							