The Reliability of Residential Energy Conservation Resources

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This paper focuses on the reliability of residential energy conservation in the Bonneville Power Administration's Residential Weatherization Program (RWP). Three reliability issues are addressed. First, this paper examines the persistence of energy savings over time for each cohort of RWP participants. Second, the paper describes the decline in conservation resources from one RWP cohort to the next. Third, this paper compares patterns in energy savings with changes in the nature of the weatherization program, the participants, and electricity prices.

Bonneville has operated residential weatherization programs for the last ten years and has evaluated seven of those program years. The 1982, 1983, 1985, and 1986 program evaluations include estimates of energy savings for three years following retrofit. The 1988 and the 1989 program evaluations include estimates of energy savings for one and two years after weatherization. In order to increase its understanding of the persistence of energy savings over time, Bonneville revisited the 1983 program to evaluate energy use patterns for six years after weatherization.

Generally, once achieved, savings from residential energy conservation programs tend to persist. Four of the participant cohorts that were followed for three or more postretrofit years demonstrate that net savings in the second year after weatherization are always lower than first-year net savings. However, third-year savings do not always continue to decline. Moreover, six-year savings are only 27 percent below those achieved in the first year after weatherization. Patterns in energy savings over time are correlated with pre-retrofit electricity consumption, program expenditures, and levels of consumer cost-sharing.

Introduction

In many regions of the United States, energy conservation is becoming a resource that can be bought and sold like output from power plants. However, the market value of conservation is distorted by uncertainty concerning its persistence and, hence, its reliability.

Over the past decade, the Bonneville Power Administration (Bonneville) has supported one of the largest residential energy conservation programs in the United States. In addition to providing free on-site home energy audits to its residential consumers, Bonneville has offered financial incentives to encourage the installation of cost-effective energy conservation measures. The underlying assumption of Bonneville's weatherization efforts is that installing retrofit measures will lead to substantial reductions in residential energy use, and that the value of these savings will justify Bonneville, utility, and household costs of implementation.

To ensure proper assessment of its weatherization program activities, Bonneville has sponsored regular program evaluations, beginning with its 1980-81 program and extending most recently to its 1989 program (Goeltz, Hirst, and Trumble 1986; Haeri 1988; Hirst, et al. 1983a; Hirst, White, and Goeltz 1985; Hirst, et al. 1985; Horowitz, Bronfman, and Lerman 1987; Schweitzer, Brown, and White 1989; White and Brown 1990; Brown and White 1992). Altogether, these studies provide unique documentation of the life cycle of a conservation program.

Background

Bonneville launched the Residential Weatherization Pilot Program in 1980 (Bonneville 1980). The residential weatherization effort was initiated in response to the 1980 Pacific Northwest Electric Power Planning and Conservation Act, which greatly expanded Bonneville's responsibilities for energy planning in the Pacific Northwest (U.S. Congress 1980). By improving the energy efficiency of existing electrically heated homes, Bonneville hoped to acquire a significant energy resource to help meet the region's energy needs.

Through evaluations of the Pilot (1980-81) and Interim (1982-83) Programs, Bonneville demonstrated that residential weatherization was a significant energy resource that Bonneville could purchase. Consequently, Bonneville implemented a long-term weatherization program to be operated from 1984 through 1990.

In 1986 Bonneville forecast an unanticipated power surplus, and its overcapacity was projected to extend through the year 2005. The value of operating conservation programs through to the end of the decade was therefore questioned. After a series of public meetings, Bonneville decided to operate the Residential Weatherization Program at a reduced level through FY 1990. Bonneville and the participating utilities developed several options to reduce Bonneville's costs that utilities could implement individually or in combination.

With the exception of the various cost-reduction measures, the long-term RWP as implemented in 1988 and 1989 is similar to the long-term program first implemented in 1984.

Methodology

Each of the program evaluations sponsored by Bonneville has employed a similar research design. A subset of utilities provided information on a sample of participants and nonparticipants, including pre- and post-weatherization electricity consumption, installed measures, and program costs. The utilities vary from one evaluation to the next, but each group is selected to represent the range of Bonneville's climate regions.

Each of the program evaluations has applied a weather-normalization technique called PRISM to the billing records of both participant and comparison households in order to obtain an estimate of electricity use under normal weather conditions (see Fels 1986 for a detailed discussion). The basic assumption of PRISM is that residential energy consumption and outdoor temperature are linearly related. PRISM uses average daily energy consumption and average daily outdoor temperature to fit the following linear model for each housing unit:

$$F_i = a + bH_i(t) + e_i. \qquad (1)$$

where F_i = the average daily consumption (kWh) in time interval i,
a = the fixed amount of daily consumption (baseload),
b = the proportional constant amount of daily consumption (space heating),
H_i = the heating-degree days per day computed to reference temperature t in time interval i,
e_i = the random error term.

Normalized Annual Consumption (NAC) is then calculated as follows:

$$NAC = 365a + bH_o(t), \qquad (2)$$

where $365a$ = the fixed amount of base load electricity consumed by a household in one year,
$H_o(t)$ = the heating-degree days (base t) in a typical year, so that
$bH_o(t)$ = the amount of electricity consumed for space heating,adjusted for long-term outdoor temperatures.

NACs are calculated for each participant and comparison household for pre- and postretrofit years. Gross energy savings (DNAC or change in NAC) are estimated for each household by subtracting NAC of the postretrofit year from NAC of the pre-retrofit year. Thus, a positive value for DNAC indicates a reduction in energy use (i.e., an energy savings).

Average DNACs are calculated for participant and comparison groups. The comparison group average DNACs are then subtracted from the average DNACs for participants. The difference is the average net energy savings per household for the program.

The procedure for developing program-wide average savings for a particular year involves the use of customized weights. The weights are developed for each utility's participant and comparison groups to reflect the relative contribution of each group to the energy saved by all of the participants and nonparticipants in that year. For example, if there are 500 participants in XYZ Program and 50 of those are customers of Utility A, then Utility A participating households receive a weight of 0.10. If there are 100,000 customers eligible for XYZ Program but they are not participating and 6,520 of the eligible, nonparticipants are customers of Utility A, then Utility A nonparticipating/control households receive a weight of 0.0652.

In addition to estimating energy savings, each evaluation has calculated the levelized costs of the program. Cost levelization is a technique that puts costs on a common basis, allowing comparisons across different retrofits, different markets, and different supply options. Consistent with Bonneville procedures, the following equation was used to calculate the levelized costs of the RWP to the Bonneville region:

Levelized costs (mills/kWh) =
[1000 x (first costs)
x (composite multiplier)]
/ [(line loss credit)
x (annual energy savings)] (3)

where composite multiplier = [(financing factor)
x (real levelizing factor)]
/ (nominal discount factor),

annual energy savings = first year net savings.

Two types of first costs are considered: (1) regional costs and (2) Bonneville costs. Regional costs are the weighted average costs of weatherization installation plus administrative costs. Bonneville costs are the weighted average costs of weatherization installation that were covered by Bonneville incentive funds (i.e., excluding utility and consumer contributions) plus administrative costs. Regional levelized costs result from the former, and Bonneville levelized costs result from the latter. The Northwest Power Planning Council (the Council) recommends a regional cost-effectiveness ceiling of 56 mills (real 1990$) per kWh.

Assumptions of the levelized cost calculation are: the weatherization measures deliver savings for 31 years, the nominal discount rate is 3 percent, the inflation rate is 5 percent, the long-term financing rate is 8.35 percent, and the levelizing rate is 3 percent. The annual energy savings are the net savings achieved one year after weatherization. This savings is multiplied by a line loss credit of 1.075, which reflects a 7.5% credit given to conservation programs due to electricity transmission and distribution losses. In order to compare findings across evaluations, dollars are inflated to 1989 values using 1981 through 1989 Consumer Price Indexes for the Seattle, Washington area.

Findings

This section discusses various trends in the implementation and effectiveness of Bonneville's weatherization programs. These trends and other program features are discussed below.

Weatherization Measures

Table 1 provides an historic profile of the installation rates for categories of weatherization measures, dating back to 1982. The statistics indicate a decline in installation rates for setback thermostats, an increased emphasis on storm windows, storm doors, caulking, and weatherstripping, and a fairly steady installation rate for various insulation measures. House tightening measures were limited in the 1982-83 Interim Program to homes that met certain indoor air quality criteria. This limitation did not apply to

Table 1. Installation Rates for Categories of RWP Measures (weighted)

	Percent Installed					
Measures	1982	1983	1985	1986	1988	1989
Insulation						
Outside Wall	16	9	46	34	21	31
Roof/Ceiling	90	80	61	77	78	71
Floor	73	73	39	64	72	66
Heating Ducts	17	15	15	27	18	23
Storm						
Windows	37	46	63	68	62	62
Doors	15	7	15	28	29	22
Infiltration						
Caulking	} 20	} 17	37	38	54	44
Weatherstripping			42	44	52	45
Setback Thermostat	29	14	16	14	5	12

See Brown and White, 1992, for annotated source citations and table notes.

subsequent programs. Although windows and doors have been removed from the list of eligible measures by some of the utilities participating in the 1988 and 1989 programs, the popularity of these measures is indicated by their continued prominence as installed measures.

In both 1988 and 1989, 82% of the audit-recommended measures were installed (Brown and White 1992). This rate is slightly higher than the rates identified by previous evaluations. In 1982 and 1983, 70% of the recommended measures were installed by the Bonneville program (Hirst, et al. 1985); in 1985 the measure installation rate was 78% (Horowitz, Bronfman, and Lerman 1987); and in 1986 it was 83% (White and Brown 1990). The recent increase may reflect the increased use of the Dipstick cost-reduction option, a program implementation option that required the installation of all recommended measures.

Where there is a considerable disparity between rates of recommendation and installation, the non-installed measures tend to result in lower-than-average audit-estimated energy savings and greater-than-average costs per kWh of estimated savings (e.g., clock thermostats, sash-mounted windows, and weatherstripping). In contrast, ceiling, floor, wall, and duct insulation were installed in almost all of the homes where the audit indicated a need, and each of these measures offers significant energy savings at a relatively low cost per energy saved. This pattern has been identified in several RWP evaluations (Schweitzer, Brown, and White 1989; Brown and White 1992).

Weatherization Costs

There has been a discernable reduction in the real resources devoted to the typical weatherization job, particularly since the 1986 RWP (Table 2). Some of this decrease is undoubtedly due to the cost-reduction measures implemented in 1988. The decrease in costs is inconsistent with the general rise in the number of measures installed, per home, in recent years. The implication is that less was spent per measure in 1988-89 than in the 1982-83 program.

The average consumer contribution has increased markedly in recent years (Table 3). In 1988 and 1989 consumers contributed 33% and 39% of the total RWP costs, respectively. In previous years the consumer contribution was less: it was 31% of the total cost of the job in 1986, 27% in 1985, 20% in 1983, and only 6% in 1982. Utilities became significant stakeholders in Bonneville's long-term RWP in 1986, and their financial support continued through 1988 and 1989. The proportionate share of costs provided by utilities has not increased, however, since 1986.

Table 2. Comparisons of Weatherization Costs for Long-Term RWP Participants and Participants in Earlier Bonneville Weatherization Programs

Program	Regional Costs/Unit (nominal $)	Regional Costs/Unit (1989-$)
Pilot (1980-81)	2,630	3,220
Interim (1982-83)	2,100	2,540
Long-Term RWP (1985)	2,280	2,580
Long-Term RWP (1986)	2,790	3,130
Long-Term RWP (1988)	2,130	2,240
Long-Term RWP (1989)	2,370	2,370

See Brown and White, 1992, for annotated source citations and table notes.

Table 3. Weatherization Costs by Source of Contribution (in percentages)

Source	1982	1983	1985	1986	1988	1989
Bonneville	94	80	73	57	59	52
Utility	0	0	0	12	8	9
Consumer	6	20	27	31	33	39

See Brown and White, 1992, for annotated source citations and table notes.

Previous research on demand-side management programs suggests that incentive levels have minimal impact on rates of participation--far less, for example, than the impact of using different types of marketing (Berry 1990). It is possible, however, that requiring a significant consumer cost share would change the mix of participants away from the most capital-constrained households. Additional research in consumer participation decision-making would be useful in helping to segment markets and effectively target the market segments that have the most to gain from residential energy conservation programs.

Pre-retrofit Energy Consumption

Pre-retrofit energy consumption has been shown in numerous studies to be the single greatest predictor of energy savings due to weatherization (Brown and White 1988; Hirst, Goeltz, and Trumble 1989). Recognizing this, many weatherization programs screen applicants to give highest priority to those that are most energy-intensive (Mihlmester et al. 1992).

The RWP does not employ such a screen but "self selection" processes have resulted in two distinct patterns. First, the pre-retrofit NAC of participants and nonparticipants has decreased markedly over the past decade (Table 4). We would therefore also expect to see diminished programmatic energy savings over the same period. Second, since the inception of Bonneville's weatherization program, participants have consumed more electricity prior to weatherization than eligible nonparticipants (Table 4). This finding is consistent with the evaluation results of other residential conservation programs (Hirst et al. 1983b; Goldberg 1986; Brown and White 1988).

This characteristic difference in pre-program electricity consumption between RWP participant and comparison group households has persisted over time. In the Pilot Program (1980-81), participating households included in the evaluation used 29,350 kWh/year in the pre-weatherization year while nonparticipants used 25,410 kWh/year. Thus, participants used 16% more electricity than nonparticipants.

In the 1986 long-term RWP, participants used 24,310 kWh/year (weighted) in the pre-retrofit year while the comparison group households used an average of 22,270 kWh/year (weighted). Thus, participants used 9% more electricity than nonparticipants. In the 1988 RWP, the difference in pre-program electricity consumption between participants and comparison group households was 21%, and in the 1989 RWP, the difference was 16%.

Thus, households throughout the Pacific Northwest appear to have increased their energy efficiency during the 1980's--a trend that is nationwide in character (Carlsmith et al. 1990). The trend in the Pacific Northwest reflects the increasing real cost of electricity (up by 9% between 1981 and 1989) general improvements in energy efficiency housing and appliances, and apparent increased consumer attention to conservation.

Energy Savings

Table 5 shows net savings for participants in the RWP Pilot, Interim, and long-term programs, whose homes were weatherized between 1981 and 1989. For the Pilot Program, the savings presented are for the first three years following weatherization. For 1982 and 1983 participants in the Interim Program, savings estimates are available for three and two years after participation, respectively. For the long-term RWP, the savings experienced by 1985 and 1986 participants are tracked for three post-weatherization years. For 1988 and 1989 participants, savings are estimated for two and one year postretrofit, respectively.

There has been a downward trend over the years in the net savings achieved during the first postretrofit year by successive cohorts of participants, declining from high values of 3,840 kWh in 1981 and 4,200 kWh in 1982-83 to 2,410 kWh in 1988 and 1,830 kWh in 1989. Contrary to this trend, the 1986 group had higher savings than the 1985 group in the first postretrofit year. Recall that average weatherization costs per job were also higher in 1986 than in 1985. The audit-estimated savings for 1986 long-term RWP participants were also greater than for 1985 participants.

Table 4. Pre-retrofit Energy Consumption for RWP Participants and Nonparticipants

Program	Normalized Annual Consumption (NAC) for Participants (kWh/year)	Normalized Annual Consumption (NAC) for Nonparticipants (kWh/year)	Percent Difference
Pilot (1980-82)	29,350	25,410	16
Interim (1982-83)	26,100	24,800	5
Long-Term RWP (1985)	23,900	22,100	8
Long-Term RWP (1986)	24,310	22,270	9
Long-Term RWP (1988)	24,320	20,150	21
Long-Term RWP (1989)	23,400	20,200	16

See Brown and White, 1992, for annotated source citations and table notes.

Table 5. Average Annual Electricity Savings During Postretrofit Years

Program	Net Energy Savings (kWh/year) Year 1	Year 2	Year 3
Pilot (1980-82)	3,840	3,790	3,410
Interim (1982-83)	4,200	3,600	2,500
Long-Term RWP (1985)	2,610	2,565	2,600
Long-Term RWP (1986)	3,060	2,112	2,140
Long-Term RWP (1988)	2,410	2,460	NA
Long-Term RWP (1989)	1,830	NA	NA

NA = not available.
See Brown and White, 1992, for annotated source citations and table notes.

Two of the five cohorts with multiple postretrofit years of consumption data exhibit marked decline in savings over time. For instance, net savings for the Interim Program (1982-83) declined by 40% between the first and third postretrofit years. Similarly, the amount of energy saved by the 1986 group fell by nearly 31% from the first to the third postretrofit year. Net savings by the other cohorts (including 1988) remained relatively constant.

While the causes of inconsistency in conservation over time are still being debated, there is a growing body of empirical evidence documenting the magnitude of conservation decay. Longitudinal evaluations of Seattle City Light's Home Energy Loan Program (HELP) and Utah's Institutional Conservation Program (ICP) are particularly noteworthy.

Sumi and Coates (1988) examined HELP to determine the persistence of energy savings over the 1982-87 period. The analysis was restricted to 1,030 single-family households who had received a loan, performed a home weatherization, and who had lived in the same home for the duration of the study period. A nonparticipant sample of 229 homes was studied for comparison purposes. All energy consumption data were weather-normalized using PRISM. On average it was found that the energy saved by participating households during their first pre-retrofit year declined 5.9% per year, or 27% over the six-year period for each of the six program cohorts (that is, participants weatherized in 1981, 1982,. . . , 1986). There was much less decline in energy savings when each cohort was tracked over time. For instance, annual energy savings in 1982 for 1981 participants was 2,805 kWh. Subsequent years of savings for the same 1981 cohort fluctuated slightly up and down between 1983 (when savings were 2,932 kWh) and 1987 (when savings were 2,759 kWh) (Sumi and Coates 1988). Thus, most of the decline in savings over time was due to the reduced savings associated with each new program cohort. The same is true for the Bonneville programs.

The analysis of Utah's ICP examined forty buildings that were retrofitted in the early 1980's. Energy use for each building was normalized using building area and weather factors, but no comparison group of buildings was studied. It was estimated that the energy savings realized immediately after retrofit were declining at an average rate of 6.9% per year (Utah Energy Office 1989). Without a comparison group, however, the trend toward increased "plug loads" in institutional buildings will appear to diminish savings.

The overall experience with Bonneville's weatherization efforts suggests a conservation decay comparable to the Seattle and Utah programs discussed above. The average decline in first-year net savings for the nine one-year segments represented in Table 5 is 8%.

Each of the RWP evaluations has revealed significant variation in gross energy savings across participating households. For instance, many 1989 program participants (25%) used more energy following weatherization than before weatherization. This finding is common to many other studies of conservation programs.

Nonparticipants also experience changes in consumption. In this case, however, the average comparison household used 124 kWh more during 1989/90 than 1988/89. The standard deviation was high, at 4,030 kWh, and many households experienced substantial savings (42% reduced energy use), even without being weatherized through the RWP.

Household energy savings are difficult to predict using audit estimates. In general, audit-estimated savings are much higher than the savings actually realized. This is frequently found in other conservation programs, as well (Hirst, Goeltz, and Trumble 1989; Nadel and Keating 1991). In this study, average audit-estimated savings (unweighted) were approximately 3,180 kWh (with a standard deviation of 3,250 kWh). Mean (unweighted) gross savings, however, were only 2,150 kWh for the first year after weatherization. Thus, 68% of the estimated savings were realized during the first postretrofit year. On a household-by-household basis, there is little correspondence between audit-estimated and actual gross energy savings.

Levelized Costs

None of the long-term RWP cohorts (1985 through 1989) have been as cost-effective for the region as Bonneville's two earlier weatherization programs. The 1989 program is notably more expensive than previous years of weatherization activities. It is also the first to exceed the Council's 56 mills/kWh limit. However, utility and consumer contributions to the program's costs have also increased over time (Table 3), resulting in Bonneville levelized costs of 36.9 mills/kWh, which are well below the Council's 56 mills/kWh ceiling.

Conclusions

The success of demand-side management (DSM) programs like the long-term RWP is determined in part by (1) the length of time that it takes the conservation action to pay off the cost of its implementation and (2) the continued energy savings due to the conservation action. Keating (1991) explains:

> The planned value of savings to be acquired from these [DSM] programs, and hence the cost-effectiveness, is dependent on the continued impact of the program over the expected life of the program measures. Unless the savings continue from the program intervention, the alternate resources replaced or deferred by the program will be needed, or needed sooner than expected. Without persistence, the DSM resource loses both its reliability and some, or all, of its value. Put simply, *if it isn't there when you need it, it isn't worth much.* [*Italics added.*]

Evaluations of the maturing Bonneville programs indicate that persistence is not a one dimensional or otherwise simple effect of residential weatherization programs.

The persistence of energy savings for each cohort (i.e., each cohort continues to save energy at an approximately stable rate one-, two-, and three years after weatherization) is probably related to the consumer's commitment to the cost-share: the consumer uses energy in ways that support the return on the weatherization investment.

Program costs declined by 26% from 1980 to 1989, although installation rates of energy conservation measures (ecms) increased slightly. Declines in installation rates were observed for roof/ceiling insulation from 90% to 71%, having bottomed in 1985 at 61%; setback thermostats from 29% to 12%, with a low of 5% in 1988. Increases in installation rates were observed for wall insulation from 16% to 31%, having peaked in 1985 at 46%; storm windows from 37% to 62%; storm doors from 15% to 22%, with non-trivial fluctuations in installation rates over time; and caulking and weatherstripping from 20% to 45%. There was virtually no change in the installation rate of floor insulation. Although installation costs declined from 1980 to 1989, the increase from 70% to 82% in the installation rate of recommended measures can be attributed to improved installer's efficiency, reductions in expenditures per measure, redistribution of direct costs to administration and overhead, or combinations of these factors, among others.

The changes in cost-sharing calculations are correlated with energy savings. The proportion of the cost that was Bonneville's declined by more than 44%, while the proportion of the cost that was picked up by the consumer increased almost 5-fold, from 6% to 39%, which translates to an absolute increase of 80%--what consumer would not notice an annual increase in personal commitment of nearly 10%. The Bonneville share decreased by almost 60% while first-year savings across cohorts declined by more than 52%, almost a point for point tradeoff. For every one percentage point increase in consumer absolute cost, energy savings declined by nearly 0.7 point.

This redistribution of weatherization costs could explain the decline in first-year savings for each new cohort. Although previous research on demand-side management programs suggests that **incentive levels have minimal impact on rates of participation**, an increase in cost-share from 6% (or about $195 in 1980) to 39% (or about $925 in 1989) is a **non-trivial change in incentive**, which might attract consumers with different energy goals and dissuade consumers with the largest propensity to save energy and protect their investments.

Moreover, the energy savings pie is not as large as it once was; each new participating cohort uses less energy in the pre-retrofit year than the preceding cohort; households in the Pacific Northwest, in general, are reducing energy consumption. Thus, first-year energy savings across cohorts over time have declined because the best predictor of energy savings is pre-retrofit energy consumption--the larger the pie, the bigger the slice that can be saved.

It appears, then, that there are two faces to persistence. On one side, participating cohorts will continue to save in subsequent years what they saved in the first year after weatherization. On the other side, cost-sharing strategies will help to define the level of each first-year savings.

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Endnote

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