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CLEANING UP: AN EFFICIENT APPROACH FOR ESTIMATING SHOWERHEAD SAVINGS

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Cleaning Up: An Efficient Approach for Estimating Showerhead Savings

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H:1. SYNOPSIS

Bonneville Power Administration and Pacific Northwest Laboratory have developed a new and improved algorithm for calculating savings from energy-efficient showerhead retrofit programs.

H:2. ABSTRACT

Determining energy savings resulting from the installation of energy-efficient showerheads has been attempted using a variety of methods. Household-level results from previous methods range from 0 to 2000 kWh of annual savings. The Bonneville Power Administration (Bonneville), through Pacific Northwest Laboratory (PNL), has recently developed a showerhead savings estimation method which we believe is superior to any that have preceded it. This improved method takes into account all major variables that impact savings. The result is a user-friendly algorithm that will benefit any utility attempting to balance its energy resource portfolio.

The PNL energy savings method was developed as a result of two studies. The first study involved sub-metering 85 homes that are geographically dispersed throughout Bonneville's service territory. In each of these homes water heating energy use was recorded for one year prior to and one year after energy-efficient showerheads were installed. Water flow rates were also recorded in the showers of each home before and after replacing the existing showerhead with an energy-efficient showerhead. Other characteristics were also recorded, including water pressure, demographics, and age of home. The second study involved laboratory testing of all of the showerhead brands and models rated at 2.0 and 2.5 gallon per minute (gpm) offered through Bonneville's showerhead program. These tests were performed at 12 different pressure settings.

Within the pages of this paper resides the most comprehensive method for determining energy savings from efficient showerheads to date. Key factors found to have the greatest impact on savings--pre-existing showerhead flow rates, the flow rate of the efficient unit, and the fraction of showerheads replaced in each participant home--are also discussed.

H:3. INTRODUCTION

The Bonneville Power Administration (Bonneville) provides wholesale electric power to over 100 retail distribution utilities in the Pacific Northwest. Faced with growing power demands and limited inexpensive generation resources, Bonneville adopted conservation as a resource alternative in 1980. Efficient showerheads have been a feature in residential conservation programs since 1980 and a focus of the Residential Appliance Efficiency Program since 1992.

This paper describes an evaluation method that relies on in-depth research into the various factors that affect electric energy savings from efficient showerheads. The results were used to design and apply an easy-to-use savings evaluation equation for estimating electric energy savings for both individual utilities and the Bonneville program as a whole. This approach is a departure from Bonneville's traditional program evaluation methods which rely on estimates of average savings per participant multiplied by the number of participants. It takes Bonneville in new directions which anticipate the evaluation requirements of "market driven" conservation program designs that will be critical to Bonneville's future.

H:4. BONNEVILLE'S EFFICIENT SHOWERHEAD PROGRAM

Bonneville has offered a variety of conservation programs since 1980. Its aggressive approach to conservation typically includes full cost reimbursement for the installation of measures expected to be cost effective. Energy-efficient showerheads have been a part of Bonneville's Residential Appliance Efficiency Program since January 1992. The estimated program energy savings for the first 2 years of Bonneville's efficient showerhead program is 21 average megawatts (MWa) from 600,000 participants. (Average megawatts equals megawatt hours divided by 8,760 hours/year.)

H:5. PROGRAM EVALUATION

Household electricity savings from the installation of efficient showerheads were initially estimated using engineering models with assumptions about dwelling and participant characteristics, bathing habits, and manufacturers' showerhead performance estimates. Bonneville's initial assumptions about the performance of efficient showerheads were adequate to design and implement its residential retrofit program. Uncertainties surrounding the savings estimates launched PNL on a process to evaluate the actual cost and effectiveness of the efficient showerhead program and to revise, if necessary, Bonneville's energy resource plans.

To supplement its evaluation, Bonneville initiated several related research studies to collect data on field conditions that affect the performance of energy-efficient showerheads; these included the collection of data on program participation, program penetration, measure penetration, measure persistence, water flow rates, and showerhead energy savings. The program evaluation was initially expected to focus on a reliable estimate of savings per participant, which would be multiplied by the number of participants to estimate program savings.

During the early stages of the evaluation, key elements of the program design dictated radical changes in this initial evaluation approach. The primary driver for those changes was a new "customer-oriented" conservation retrofit program design that gave Bonneville's utilities freedom to design their own efficient showerhead distribution and installation methods for energy-efficient showerhead programs. As a result, over 30 brands and models and over 1,0000,000 showerheads were distributed, using both professional and occupant installation methods.

The sheer variety of showerhead brands and models offered to the utilities complicated the program evaluation because, at the same pounds per square inch (psi), each brand had a different flow rate. Further complicating the program evaluation, each installation approach was expected to result in different participation and retrofit rates. Finally, the different combinations of showerhead brands and distribution methods among utilities required different methods to estimate savings from each participant based on local conditions, program design, and measure options.

The challenge under these diverse program and field conditions was to develop evaluation methods that are non-intrusive, economical, and flexible enough to adapt to the program delivery mechanisms of each utility and provide reliable estimates of program savings. The result of this "customer-oriented" program evaluation design was a program evaluation that more closely resembled the "market segment" designs of utilities other than Bonneville's traditional and relatively inflexible "supply curve" program designs. Although initially unplanned, the efficient showerhead research studies conducted to achieve these program evaluation objectives and the evaluation approach adopted suggest a useful new approach for evaluating efficiency programs. This new approach may be especially useful for programs that include a variety of measures and operating conditions and those that may affect energy use in multiple market segments or utilities.

H:6. A METHOD FOR DETERMINING EFFICIENT SHOWERHEAD ENERGY SAVINGS: LOOK NO FURTHER

Documenting energy saved as a result of the installation of efficient showerheads appears simple. However, there are many programmatic and field condition variables that impact energy savings to varying degrees. Energy savings estimates differ depending on one's perspective or paradigm. Prior to this evaluation design, an engineering model of use and savings based on hydraulics was offered by Seattle City Light and the Seattle Water Department (Okumo and Flory 1991).

The following is an alternative algorithm that focuses on energy use and savings and relies heavily on behavioral factors. This model was used by Bonneville early in its program for program design purposes:

Electricity savings = Shower duration (minutes) * flow rate reduction (gallons/minute) * Hot/cold water ratio * Showers/person/day * Person/household * 365 days * Conversion factor for electricity /gallon of hot water

The initial program evaluation approach assumed that it was necessary to verify the average flow rate reduction through a field study in order to use a classic pre-post energy use analysis to estimate savings. This approach was selected because many of the factors included in the hydraulic and behavioral models would be difficult and expensive to collect from program participants (i.e., inlet water pressure and temperature, persons per household and showers per person).

Bonneville implemented several related research studies to collect data on field conditions that affect the physical performance of energy-efficient showerheads, program participation, program and measure penetration rates, and water flow rates. The primary field study used to collect this data was the Regional End-use Metering Program (REMP) showerhead field study conducted by the Pacific Northwest Laboratory (PNL) (Warwick and Bailey 1993). It was supplemented by other studies by Bonneville and Puget Sound Power and Light (Puget) (Bailey and Warwick 1993). The objective of the REMP study was to first document representative field conditions that affect shower use and resultant energy savings and verify these effects in terms of observed electric energy savings over a 1-year period. The REMP study relied on approximately 150 homes with pre-existing end-use metering of electric water heaters and the analysis of pre- and post-showerhead retrofit sub-metered energy use data. Observed electric energy savings were assumed to provide a better foundation for savings estimates and program evaluation than energy savings based on unverified assumptions.

The REMP field study showed that many of the assumptions underlying Bonneville's initial energy savings estimates were incorrect. The most significant of these concerned pre-retrofit showerhead flow rates. Prior to the REMP study, it was assumed that existing showerheads had flow rates of 5 gallon per minute (gpm). However, the REMP sites averaged only 3.2 gpm. Thus, anticipated savings from showerheads with a 2.5-gpm flow would be much less. Further, it was discovered that the lowest rates of flow were often associated with low water pressure. Low water pressure observations were, in turn, often linked to water supplies tied to domestic wells. Another surprise was that one of the two brands of showerheads used in the study did not perform at its rated flow. This discovery cast doubt on the reliability of manufacturers' flow ratings as a basis for evaluating the program. It also complicated the initial program evaluation approach in that estimated flow rate reductions would have to account for the difference in flow rate for each showerhead model compared to the pre-retrofit flow rate benchmark. In other words, the evaluation needed to explicitly account for savings for each of over 30 models of showerheads under various field conditions.

H:7. A ONE SIZE FITS ALL ALGORITHM

The REMP field study included occupant surveys as well as field measurements. Survey responses were compared to Bonneville's program design assumptions to review the original savings estimation assumptions. A comparison of these assumptions with field data and estimated savings that result from the engineering model used for the program design can be found in Table 1. A comparison of these results shows estimated savings of 400 or 1,200 kWh annually.

[Table 1 goes here]

A pre-post analysis of hot water energy use was conducted after a year of post-retrofit data had been collected from the REMP sites. The results provided an estimate of annual savings from showerheads of 515 kWh. Clearly, the 1,200 kWh savings estimate was too high.

This review led to the development of a showerhead energy savings equation that relies on field study results and readily obtainable program data to produce defensible, reliable estimates of program savings under a wide variety of conditions. This equation can be used to estimate energy savings from efficient showerheads in areas far removed from the Pacific Northwest. A description of this equation and its key parameters follows.

H:7.1. Efficient Showerhead Energy Savings Program Evaluation Algorithm

Energy savings can be expressed in both absolute and relative terms. The focus of this evaluation is on estimates of energy savings in absolute terms (i.e., X kWh savings rather than load reduction from Y to Z). For comparison, previous analyses of the End-Use Load and Consumer Assessment Program (ELCAP) sites by PNL indicated hot water heaters use about 4,200 kWh annually, of which 1,200 kWh is standby heat loss. The total amount of energy available to save from hot water efficiency is about 3,000 kWh. (Hot water energy use for the REMP sites averaged 4,489 kWh for all hot water uses prior to the field study.)

The final form for the energy savings estimation algorithm is

> Showerhead Program savings = REMP Showerhead Savings * Adjustments for utility flows and showerhead efficiencies * Number of participants * Fraction of homes on wells * Retrofit Rates * Persistence

The various parameters, and their source, are described in the following sections.

H:7.2. REMP Showerhead Savings

The energy savings benchmark for the equation is from the REMP results. The REMP savings estimate is 515 kWh annually in the first year. These reflect savings per home rather than per showerhead. As such, they are sensitive to differences across households. Those differences identified as critical to estimating savings compose the balance of the savings equation parameters. Savings deteriorate over time due to several factors including persistence and other factors. Therefore the savings are not constant. Further, the region was in the grip of a seven-year drought that resulted in widespread programs and appeals to conserve water in the 1992 water year (October to September).

REMP continued monitoring of roughly 50 homes that declined to participate in the showerhead field study. (These homes were used as a comparison group). As part of the energy savings analysis, hot water energy use at these sites was reviewed. An analysis of annual water use for the year preceding and during the drought crisis revealed a drought drop in consumption of 153 kWh. Due to the small change in consumption and sample size, the confidence interval for these results was approximately 85%, which is lower than the 90% level normally used. These results were consistent with consumption changes that were observed by several regional water departments. As a result, first-year savings were reduced from 515 kWh to 362 kWh. However, this was a one-time-only adjustment for the program evaluation.

H:7.3. Adjustments for Utility Water Flows and Showerhead Model Efficiencies

The reduction in water flow rate, and hence energy savings, varies locally based on the type of water supply (city versus domestic well), local water pressure, and the flow rates of the stock of existing showerheads. As mentioned earlier, the REMP study results indicated the pre-existing showerhead flow rates are much lower than previously expected. This observation has been confirmed in several other tests of showerhead flow rates conducted by regional utilities. Other than domestic wells, there was no clear correlation of pre-flow rates with other obvious factors, such as dwelling age, among REMP sites. As a result, the evaluation equation assumes the average pre-retrofit flow rate is that of the REMP sites, 3.2 gpm, although local data can be substituted in the energy savings equation if they are available.

The primary determinant of post-retrofit water flow is the retrofit showerhead design flow rate. However, the REMP study results indicated these may vary from the manufacturers' rating due primarily to differences in performance at various water pressures and showerhead design practices. For instance, some manufacturers may design their showerheads not to exceed a specific rate whereas others may design for average performance at that rate.

The REMP study only monitored the typical performance of two showerhead models and of these, one model was used at 22 sites. These results may not be representative of all showerhead brands. As a result, Bonneville conducted performance tests for each of the 30 brands and models of showerheads distributed in its program over a broad range of water pressure settings. The REMP study showerhead performance results were used with a weighted average of REMP post-retrofit water flow rates to project the performance of each specific brand of showerhead at regional average water pressures. This weighting factor was used to adjust expected savings for each showerhead from manufacturers' ratings. A regional average post-flow rate was estimated by weighting the adjusted flow rate results to reflect the penetration rate of each showerhead model in the program. The initial estimate for this value is 2.3 gpm.

The flow rate change was calculated by subtracting this brand-weighted, water pressure adjusted, post-retrofit flow rate (2.3 gpm) from the average pre-flow rate observed in the REMP study (3.2 gpm). The resulting average 0.9-gpm flow rate change was used with the flow rate change observed in the REMP study (1.4 gpm) to develop a ratio of expected program flow rate change to REMP energy savings. This ratio (0.9 gpm/1.4 gpm = 0.643) assumes water and energy use changes are proportional to changes in water flow rates. It also assumes these changes are linear in the range of changes observed in the REMP study. In other words, we assume that changes in flow rates will save an average of roughly 37 kWh per 0.1 gpm change when flow rates are reduced by up to 2 gpm (515 kWh average savings for an average flow rate change of 1.4 gpm yields 36.78 kWh of savings per 0.1 gpm change.) It is not clear that the assumption of a linear relationship is valid for more extreme flow rate reductions. There is weak evidence in the REMP and other data that reductions below 2 gpm may not produce proportionate savings. People may respond simply by taking longer showers to compensate for the reduced water volume.

H:7.4. Number of Participants

The number of program participants is based on utility records. Although a variety of program delivery methods were used, almost all of them included some form of customer registration. These records also categorized each participant by the type of delivery method (e.g., professional installation, self-installation, etc.). This information forms the basis for this parameter. Delivery mechanisms that did not explicitly track participants, such as handing out showerheads at energy fairs, were not credited with any program savings; neither were installations at commercial sites.

During the period covered by this evaluation (1992 and the first three-quarters of 1993), Bonneville utilities distributed showerheads to 600,000 residential customers.

H:7.5. Program and Measure Penetration Rates

Actual measure penetration rates (the fraction of showerheads replaced in each home) are expected to vary based on (1) whether the showerhead is installed by the participant or professionally, and (2) how many showerheads are provided to each site (i.e., one for each shower versus one or two regardless of the number of showers). The REMP study design had a target of 100% replacement. (Due to technical and other barriers, the replacement rate achieved was actually about 90%.) The installation rate of 90% found in the REMP study is expected to be that experienced by utilities using professional installation techniques. Programs that relied on participant installation were credited with an installation rate equal to 50% of the REMP installation rate, and associated energy savings, based on a review of the literature from other programs.

H:7.6. Fraction of Homes on Wells

Low water flow rates were correlated with low water pressure in the REMP study. Low water pressure was, in turn, correlated with sites using domestic wells as a water source. The savings evaluation equation adjusts for low water pressure and reduced savings from lower flow rates based on the fraction of participants on domestic wells compared to the fraction of REMP sites. Coincidentally, this is the same as the regional average, so no adjustment was made for estimating regional savings; nevertheless, the parameter was retained in the equation for sub-regional showerhead savings estimation.

H:7.7. Measure Persistence

How long efficient showerheads stay in place is hotly debated because it has a major impact on expected lifetime savings of the program. There is very little data on the expected life of installed showerheads, and the interpretation of that data is open, due to the entry into the showerhead market of many new products without track records. As a result, measure persistence was broken into two components, first-year retention rates, which are better documented, and "replacement rate," a term meant to capture the time over which almost all of the showerheads in normal use have been replaced.

A variety of factors may cause a showerhead to be replaced before it wears out. These include, but are not limited to, dissatisfaction with performance, leakage, and replacement as a result of remodeling. The probability that a showerhead will be replaced for one of these reasons varies with the age of the existing showerhead, number of years the occupant has been in the home, and so on. These factors are very difficult to sort out. In the end, Bonneville adopted a first-year retention rate of 90% based on REMP study results and assumed a replacement rate of 12 years as a straight line after the first year.

H:8. PRELIMINARY SHOWERHEAD PROGRAM RESULTS

The REMP study was not designed to provide direct estimates of program savings or impacts. Instead it was designed to provide a foundation for developing these estimates using alternative assumptions in an accepted evaluation equation. Estimated program savings using the evaluation equation vary depending on assumptions made about measure persistence and measure life, measure installation rates, and retrofit measure performance. The sources of the assumptions and data for evaluating Bonneville's program are indicated in Table 2.

[Table 2 goes here]

Program impacts can be viewed several ways: as first-year savings, as savings over the projected life of the measures, and as average annual savings over the life of the measure (total lifetime savings divided by measure life). Estimated program savings for the Bonneville program are provided for each of these perspectives in Table 3 using the data and assumptions described previously.

[Table 3 goes here]

The preliminary program results were used to review Bonneville's program design and incentives. The first conclusion reached was that Bonneville's initial savings estimate of 400 kWh per participant was optimistic, especially when the effect of the drought is factored in (see Table 3). The program evaluation equation was used with a variety of alternative program design assumptions to explore alternative designs. One key finding from these analyses was that program showerheads needed to perform at better than 2.5 gpm to justify an incentive (see Table 4). This was partly due to changes in local laws that ended the sale of showerheads over 2.5 gpm. As a result, Bonneville changed its program design specification to 2-gpm showerheads.

[Table 4 goes here]

Another critical finding was that the fraction of showerheads changed in a home, or measure penetration, has a significant effect on program savings. Incomplete replacement of all showerheads is the rule in self-installation programs. As a result, Bonneville also reduced the incentive it provided to utilities that relied on self-installation in its program.

Finally, the evaluation algorithm provided Bonneville with a useful tool for negotiating with utilities under its "power plant" program. This program is similar to conservation bidding in that Bonneville's retail utilities offer to sell conservation savings in their service areas for a negotiated fee. Bonneville has been able to use the evaluation algorithm to help these utilities identify conservation potential in their service areas using data and assumptions that are specific to each service area to generate estimates of savings that are more reliable, consistent with the requirements of the "power plant" contracts. Tools like this are expected to make a significant contribution to the way Bonneville expects to acquire conservation in the future.

H:9. CONCLUSIONS

Bonneville gained several insights from this program evaluation and related research studies that could be applied to conservation programs across the country. The high cost of program evaluations is attracting increasing attention from non-participant ratepayers, regulators, and utility executives. Traditionally, case study approaches have been used to reduce research costs. Case studies are not thought to be sufficiently robust to support generalizations to larger populations. The suitability of large samples for this purpose comes at a high price. The approach described in this paper, which blends in-depth case studies with large samples, directly addresses this problem. However, in-depth case studies can also be expensive. There have been many requests for the results of Bonneville's showerhead research, from utilities here and abroad, from military bases and other institutions, and from plumbing manufacturers. This indicates that well-designed, in-depth case studies of some conservation measures may have national-level benefits which would easily justify their expense. Finding ways to implement appropriate, in-depth, case studies like this should be a major agenda item for evaluation professionals, especially as utility de-regulation erodes the economic foundation conservation has enjoyed in the last decade.

A second finding from this research is that manufacturers' ratings are at best incomplete and at worst misleading. The fact that many showerheads did not perform at their rated flows was an unwelcome surprise. Further, the deviations varied not only depending on water pressure but within samples of the same model. Bonneville's efforts to accurately document flow rates across a range of water pressures will have benefits far beyond its boundaries. This also highlights a need to have independent certification of the performance of conservation measures, particularly those likely to be installed in quantity and in widely varying field conditions. Again, this should be a priority for evaluation professionals.

The final major insight gained by the authors from this research is that field studies are a critical first step in program evaluation. They help identify what the most important savings parameters really are. Engineering models provide extremely useful guides for designing both evaluations and field and case studies; however, assumptions about field conditions are a poor substitute for actual knowledge about those conditions. Usually, information from the field results in significant changes in perspective on which information is important and leads to new approaches to measure and track these parameters.

H:9. REFERENCES

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Table 1. Comparison of Engineering Estimates with Field Data

Factor	Assumption	Field Data
Showerheads Retrofit	100%	90%
Shower Duration	6.5 min	7.4 min
Water Flow Reduction	2.5 gpm	1.4 gpm
Hot/Cold Water Mix Ratio	50% hot	70% hot
Showers/Person/ Day	.77	.95
Person/Home	2.3	2.8
Estimated Savings	400 kWh	1,225 kWh

Table 2. Evaluation Data Sources

Equation Variable	Data Source
Benchmark Savings	REMP
Pre-Retrofit Flow	REMP or utility
Post-Retrofit Flow	flow test
Professional Measure Installation	PNL assumption
Measure Installation	Utility data
Number of Participants	Utility data
Low Water Pressure (well adjust.)	REMP or census data
Retention Rate (year 1)	REMP
Persistence	12-yr life (BPA assumption)

Table 3. Estimation Equation with Program Data and Projected Savings

Parameter	Estimated Savings (Professional Install)	Estimated Savings (Self-Install)	Estimated Savings (Total)
REMP Savings Benchmark	515 kWh first year savings		
Showerhead Flow Rate Adjustment	.643	.643	
Low psi Adjustment	1	1	
Measure Penetration Rate Adjustment	1	.5	
Savings/Participant, First Year	331	166	
Drought Adjustment	-153	-77	
Savings per Participant:			
Net First-Year Savings	178	89	
Lifetime (12-yr) Savings (kWh)	1,539	770	
Annual Average Savings (kWh)	128	64	
Program Savings:			
Participants	347,913	425,550	
Net First-Year Savings (MWa and MWh)	61,928 MWh 7.07 MWa	37,873 MWh 4.32 MWa	99,818 MWh 11.39 MWa
Lifetime (12 yr) Savings	553,471 MWh 63.8 MWa	327,481 MWh 37.38 MWa	862,952 MWh 98.51 MWa
Average Annual Savings	44,623 MWh 5.27 MWA	27,290 MWh 3.12 MWa	71,913 MWh 8.21 MWa
MWa = average megawatts = MWh ÷ 8,760 hours/year			

Table 4. Estimated Per-Participant Savings for 2.0- and 2.5-gpm Showerheads (no drought adjustment)

Estimate	Professional Installation		Self-Installation	
	2.0-gpm Head	2.5-gpm Head	2.0-gpm Head	2.5-gpm Head
First Year Savings	442 kWh	259 kWh	221 kWh	130 kWh
Lifetime Savings	2,250 kWh	1,320 kWh	1,125 kWh	660 kWh
Annual Average Savings	187 kWh	110 kWh	94 kWh	55 kWh

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