Field Study of Energy-Efficient Showerheads

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In August 1991, the Bonneville Power Administration (Bonneville) initiated an energy-efficient showerhead performance assessment project. Approximately 98 homes are participating in this study. All are metered under the Regional End-Use Metering Program (REMP), which is operated by the Pacific Northwest Laboratory (PNL) for Bonneville. Hourly pre- and post-retrofit electrical water heating consumption data will be analyzed using the REMP data archive.

The goal of this study is to identify factors affecting energy savings from retrofit of energy-efficient shower heads which will be used to develop an "algorithm" to credit participants in retrofit programs with savings. This algorithm must be easy to apply, credible, and adoptable to conditions which may vary among utilities in Bonneville's Pacific Northwest service area.

This field data collection project was designed to collect information about site and occupant characteristics that may affect participation and performance. These data are used to verify or modify assumptions used in engineering models to project energy savings. Estimates of measure performance based on comparisons of energy use are not included in this paper because sufficient post-retrofit data is not yet available.

Field data failed to confirm several critical assumptions used to project energy savings. Showerhead water flow rates and anticipated reductions from the retrofit measures were less than expected. Participation in this voluntary study was relatively low considering its risk- and cost-free design. Finally, barriers were encountered that prevented retrofits at some participating sites. The cumulative effect of all factors could reduce projected savings 70% over initial engineering estimates, if 100% participation is assumed.

Introduction

In August 1991, Bonneville initiated the Energy Efficient Showerhead Field Data Collection Project. The objective of the project is to collect field data to verify savings from energy-efficient showerheads. The goal is to develop a verification algorithm that can be used, with local adjustments, to credit participants in conservation programs with energy savings from showerhead retrofits. Payments for energy savings are expected to be on a per-showerhead basis (e.g., x "negagwatts" per showerhead).

Approximately 98 homes are participating in this project, and all are currently end-use metered under an extensive multi-year energy end-use metering program.[2] Hourly pre- and post-retrofit electrical water heating consumption data will be analyzed for the development of the verification algorithm.

Background

Historically, energy efficiency programs have failed to meet initial savings projections. Evaluation results have consistently pointed to erroneous assumptions based on faulty field data as a primary cause of these overestimates. Conservation programs have traditionally begun with "best guess" engineering estimates of savings that have to be revised based on improved program evaluation data. "Pay for performance" conservation acquisition programs are difficult to administer if program performance is measured by program evaluations after the fact.

Utility conservation acquisition programs initially involved active utility participation in their design, implementation, and performance evaluation. As conservation resources become institutionalized as a critical part of utilities' resource plans, the industry is beginning to explore methods to treat conserved energy as a commodity to be traded, just like power purchased from independent power producers. A key characteristic of any commodity is "standardization" in terms of quality and units of measure. Ideally, there would be a "negawatt" meter that could be used to monitor energy savings. In the absence of such a device, utilities are attempting to standardize conservation programs so that the resulting savings are produced in a reliable, predictable manner (e.g., each energy-efficient product sold translates into x kwh saved).

The objective of this project was to avoid the common assumption errors of engineering estimations of savings by collecting detailed field data in advance of program implementation. This paper will present the initial results of these field efforts. Two of the three elements of conservation savings will be discussed: errors in initial estimates of field conditions and barriers to installation of the measures. Preliminary conclusions about measure performance will be drawn. However, the third element, savings results, requires further data collection. Complete savings estimates will not be given in this report, because sufficient data has not been collected (savings estimates will be based on a full year's worth of post-retrofit metered data). Final program design awaits these results. Accordingly, the field study results (e.g., impacts, cost, payback, etc.) are not available.

Energy savings result from reductions in the amount of hot water used to shower, which is a function of water pressure, outlet size (pipe diameter and showerhead orifice size), water temperature, and shower duration. The first two factors, pressure and orifice size, determine the rate of water flow. Duration is dictated by the amount of time it takes to bathe in the shower.

The primary means for reducing water flow in showerheads is to reduce orifice size. Early conservation efforts accomplished this through a restrictor between the showerhead and the inlet water pipe. Modern approaches include redesigned showerheads that restrict the flow in the head itself--restricted throat sizes, fewer and smaller holes in the head, and so on.

The "engineering model" of shower savings assumes standard outlet pressures and sizes and projects savings based on reduced orifice size. The following assumptions are representative of the typical engineering estimates used to benchmark showerhead savings:

- 65 pounds per square inch (psi) water pressure,
- standard 1/2-inch-diameter supply line and shower arm,
- standard showerhead with flow rate of 5 to 6 gallons per minute (gpm),
- shower duration of five minutes.

Energy efficient showerheads have a variety of design flow rates, ranging from 1.2 to 3.5 gpm. If a 2-gpm head is assumed, the savings projected in the standard engineering model would be 5 gpm minus 2 gpm, or 3 gpm (60%). Actual savings will vary if any of these assumptions are inaccurate.

The mechanical factors affecting shower use, pressure, and flow rates are relatively easy to verify in the field. Estimating the affects of showering behavior, especially in reaction to a new showerhead, is more difficult. Both are required to accurately gauge energy savings.

Potential savings is a function of the savings per measure multiplied by the number of measures installed. Overestimates of potential measure installations is another prime source of errors in engineering estimates of energy savings.

There are many causes for less than 100% saturation of measures in both the population and in individual homes. Customer acceptance is one. However, participation does not guarantee complete installation or performance of a measure. If participants have a shower, but rarely use it, little or no savings will be realized from a showerhead retrofit. Similarly, many residential showers can be used for either tub baths or showers through the use of a diverter valve. As a result, showerhead retrofits may not automatically translate into reduced bathing water use. These diverter valves are not totally effective at diverting water flow through the showerhead.

Nonstandard plumbing can also affect participation. Showerheads are typically attached to water supply lines through a "shower arm," a pipe that is bent to direct water flow down toward the bather. Typically, the shower arm and the shower head are installed as a matched set. Generally, the showerhead is attached by means of a standard 1/2 inch iron pipe thread. However, some manufacturers use other methods. Adapter kits are available to match many, but not all, arm designs. Not only do these add time and complexity to the installation, they may present barriers to customer acceptance of retrofit showerheads.

Identification and field documentation of these factors were the focus of this study. Resulting information will be used to review and modify engineering estimates of savings and final program design.

Methodology

An unique sample was used as the basis for this study. All of the participating homes are part of an extensive energy end-use metering program called REMP.[2] These homes have been end-use metered for approximately six years, including direct energy consumption measurements of water heaters.

Participation

All homes in the metering program were eligible for participation in the showerhead field study except for homes with no electric water heater, manufactured homes, and multi-family/apartment dwellings. A total of 150 homes were eligible for participation in the study. These homes are located in Washington, Oregon, Idaho, and Montana.

Initially, 111 participants agreed to be in the project. Of these, 105 homes were actually visited. Seven of these homes were not eligible for retrofit showerheads. For the study, a total of 157 showerheads were installed in 98 homes.

Installation work ran from August 1991 through November 1991. End-Use data collection will be on-going with REMP. One full year of post-retrofit hot water energy end-use data will be used for the algorithm development.

Installation and Characteristics Data Collection

Site-visit protocol were developed specifically for this field study. The following information was collected from each participating home:

- Number, size, age, model number, fuel type, etc., of all hot water heaters in the home
- Number and type of hot water-using devices at each site
- Location (i.e., master bath) and type (shower only, tub/shower combination, etc.) of all showers in the home
- Type of valve fixtures (tub/shower valve, diverter spout, single valve mixer, separate hot and cold valves, etc.) in each shower
- Occupant characteristics and related information
- Frequency of use of each of the showers (infrequent = less than four showers per week, frequent = four or more showers per week)
- Number of energy-efficient showerheads installed
- Household water pressure (measured one time)
- Water flow rates (gpm) at "bath" temperature.

Flow Data Measurements

The primary field measure of potential savings from energy-efficient showerheads is water flow data. Water flow was measured using a Micro Weir developed by Howard Reichsmuth (Manclark 1991). Water flow was measured throughout the installation of the new showerhead, at full flow, in the following sequence:

As found, no changes to existing fixtures, flow through showerhead.

- As found, no changes to existing fixtures, flow through diverter spout, if any.
- Flow rate after showerhead retrofit, flow through showerhead.
- Flow rate after showerhead retrofit, flow through diverter spout, if any.
- Flow rate after showerhead retrofit, flow through showerhead after diverter spout replacement or alteration, if any.
- Flow rate after showerhead retrofit, flow through diverter spout after diverter spout replacement or alteration, if any.
- Occupancy-related information.

Retrofit Showerhead Choice

The specific showerheads used in this study were selected based on previous program experience and customer studies (Katzev 1991). The models selected are used extensively in the Pacific Northwest under other showerhead retrofit programs. While completing installations in 13 homes (22 showerheads) the field technicians noticed a trend of lower-than-expected flow rates before retrofit. We were initially expecting the "before" flow rates to fall between 4 and 5 gpm. Instead, we found that the before flow rates averaged only 3 gpm. The first energy-efficient showerhead model we selected ("Ondine" brand) had a

2.5 gpm design flow rate. This was thought to be too small a change to measure using total water heating energy data. Consequently, a second retrofit showerhead ("ETL" brand), rated at 2.0 gpm, was purchased for use in the study. The remainder of the site visits were completed with this showerhead. The second retrofit head performed at a level of approximately 1.7 gpm. In total, 22 of the first retrofit head were installed in 13 homes. The remaining 85 homes had 135 of the second retrofit heads installed.

Preliminary Findings

Participation Barriers

The first barrier any conservation program confronts is consumer participation. Participation barriers may be confronted at several stages in a program, beginning with recruitment and ending with removal of the installed conservation measure. This study attempted to identify and measure participation barriers at each stage. The results to date are presented in Table 1, "Participation Barriers."

Table 1. Participation Barriers

Population (households)		150
Volunteers		111
Drop-outs		
EESH in place	2	
Changed mind	2	
Aesthetics	1	
Vacant	1	
Drop-out Total	6	
Sites Visited		105
Drop-outs		
EESH in place	1	
Changed mind	1	
Non-electric WH	3	
Non-standard plumbing	2	
Drop-out Total	7	
Participating sites		98

EESH = energy-efficient shower head
WH = water heater

The REMP sample of homes included a total of 150 eligible sites. REMP participants are accustomed to research requests and are normally very cooperative. Attempts were made to recruit each site through telephone solicitations which offered a $40 cash incentive, no-cost replacement of existing showerheads with energy-efficient models, and return of original showerheads at any time. In addition, consumers were informed in advance that the retrofit would be conducted by a professional installer and minor plumbing problems that prevented proper operation of the retrofit showerhead would be repaired.

This was a very customer-oriented offer. Nevertheless, only 74% of the population of potential sites volunteered to participate.

A certain amount of attrition is expected in any voluntary study. This study was no exception. Of the 111 recruited sites, 6 dropped out during the initial site inspection stage. During the site inspection, 8 more sites were dropped from the study. The reasons for this are shown in Table 1. In summary, only 74% of the potentially eligible sites volunteered to participate and 12% of these did not go on to participate in the retrofit project. In other words, only 65% of the eligible population participated in the study and only 88% of those recruited actually had measures installed.

Measure Installation Barriers

Most engineering estimates of savings assume complete installation (e.g., every showerhead in each household is retrofitted). The objective of this research was to identify factors in the field that affect, and may limit, savings from energy-efficient showerheads, including savings per measure and total measure penetration. Both the field data and the research itself revealed potential barriers to complete penetration of energy-efficient showerheads.

This study anticipated that some shower arms would have to be replaced to ensure maximum measure installation. These cases were noted to establish and estimate the potential penetration barriers from this source.

This study also anticipated that many bathrooms would be equipped with tub/shower combinations that divert water flow from a tub spout to the showerhead. The effectiveness of the diverter spout is critical to the achievement of water savings from efficient showerheads. Leakage past the diverter valve undermines the effectiveness of the retrofit showerhead.

The 105 visited sites had a total of 173 showerheads among them. Energy efficient showerheads replaced 139 of these (see Table 2). A total of 108 showers were in tub/shower combinations. Virtually all of these (105) used a diverter in the tub spout to activate the shower. Table 3 presents detailed results for real and potential installation barriers identified in this study. A total of 46 showerheads, or 26%, were not installed due to installation barriers discovered on-site. Another 14 showerheads were installed after potential installation barriers were overcome. These barriers (non-standard shower arms and leaky diverter valves) were overcome through use of professional field staff. These would likely present real barriers in a self-installation program. If they are included in the totals, 34, or 18% of the potential showerheads, would not be retrofit.

Table 2. Installations (105 sites)

Total potential showerheads	173
EESH installed	139
No installation	32

Table 3. Installation Barriers to Showerhead Replacement

Real	Showerheads
EESH in place	2
Changed mind	12
Non-electric water heater	4
Non-standard plumbing	3
Other barriers	2
Missing	9
Potential	
Shower arm	10
Diverter valve	4
Total	46

Another factor that affects measure cost but not savings is "non-productive" measure installation.

Table 4 provides descriptive data on the sites and number of showers: 121 of the showers (or 69%) are used frequently, at least four times per week; 31% of the showers are used infrequently. Retrofitting infrequently used showerheads would produce lower savings (per shower) but at the same cost, reducing cost-effectiveness.

Table 4. Site/Shower Data

Showers per Site	No. of Sites	No. of Showers	No. Used Frequently
1	47	47	39
2	48	96	68
3	10	30	14
Total	**105**	**173**	**121**

Expected Flow Rates Versus Flow Rates Found

The critical estimate of savings from showerhead efficiency programs is the reduction in water use as a result of the retrofit. This is based on two factors, the current rate of flow for the existing showerhead and the flow rate from the retrofit head. The flow from existing heads is widely assumed to be 5 gpm. This rate was cited to Bonneville staff both by utilities interested in showerhead programs and showerhead vendors. However, small-scale studies conducted in the region called this assumption into question (Manclark 1991). Preliminary data from this study indicates a wide range of pre-existing flow rates, but most were significantly below the expected rate of 5 gpm. See Figure 1.

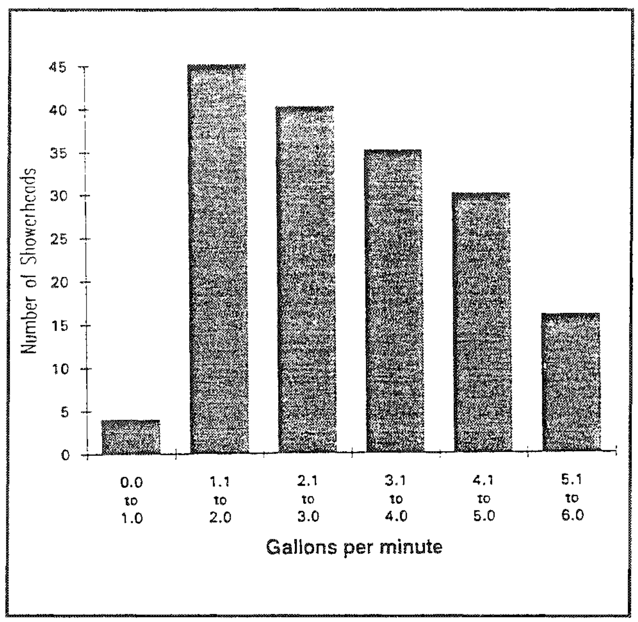

Figure 1. Flow Rates for Preretrofit Showerheads

Flow Rate Versus Pressure

The other factor thought to affect water flow rates in showerheads is water pressure (see Table 5). This study found a wide variation in water pressure, but less correlation between variations in measured household water pressure and the flow rate of existing showerheads than expected.

Table 5. Water Pressure Data

Pressure Class (PSI)	No Well	Well
Less than 45	5	11
45-69	20	1
Greater than 69	26	0
Total	51	12

* Water source data not available for all sites.

It appears that the existing heads either have a greater variation in design flow rates (as should be expected since they include a variety of models) or that fouling occurred in some of the heads presumed to have similar design flow rates; or both may have occurred. Either effect confounds correlations of pre-flow rates with water pressure. When only one model of showerhead is used, the deviations associated with pressure are significantly reduced. This also reflects the fact that modern showerheads are designed to function satisfactorily across a broad range of water pressures (see Table 6).

Additional Characteristics Information

One final assumption tested in this field study is the relative improvement in showerhead flow rates. Expected flow rate reductions are less than initially expected because the pre-retrofit flow rates were less than the 5 gpm initially assumed. Mean pre-retrofit flow rates were 3.1 gpm. However, this value masks a broad variation in flow rates, including flows below the targeted "energy-efficient" flow rate. Consequently, showerhead retrofits, even of energy-efficient varieties, can increase water use in some cases. In this study, 61 showers at 49 sites would realize no savings or see actual increases from a 2.5-gpm showerhead retrofit. Increased flows resulting from the retrofit of energy-efficient showerheads constitute a perverse, programmatic "take back" effect.

Table 7. Showerhead Savings: Assumptions vs. Reality

	Assumed	Field Data
Participation no assumed value given	150	105 (70%)
Measure Penetration (each site)	173	139 (80%)
Pre-flow	5 gpm	3.2 gpm
Post-flow	2.5 gpm	1.7 gpm*
Flow reduction	2.5 gpm	1.5 gpm* (60%)
"Take-back"	0	29%

* lower flow measure than assumed

Conclusions

The objective of this study was to collect field data to identify savings potential from energy-efficient shower-head retrofits. The field data collection effort, by itself, identified significant barriers to the full realization of energy savings from a showerhead retrofit program. These barriers will reduce program potential regardless of how much energy each retrofit showerhead actually saves.

The major sources of savings erosion are compared to expectations in a summary table (Table 7). Only 70% of potential participants volunteered for this study despite its no-cost, no-risk design. Measures were installed at only 80% of these sites. Installed measures achieved only 60% of their targeted water savings. Using field data from this study in place of initial assumptions reduces maximum savings by nearly two-thirds from initial engineering

Table 6. Water Pressure and Flow Rates (ETL sites only, N=80)

	Water Pressure (PSI)	Pre-Flow (gpm)	Post-Flow (gpm)
Mean	60.7	3.09	1.67
Standard Deviation	17.9	1.34	.26

estimates. In addition, field data indicate that measure costs could be 40% higher than they would be if showerheads were not retrofit in little-used showers.

Acknowledgments

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Endnotes

1. The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.
2. The Regional End-Use Metering Program (REMP) is operated by the Pacific Northwest Laboratory for Bonneville. REMP is the follow-on program of the End-Use Load and Consumer Assessment Project (ELCAP).

References

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