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BARAKAT & CHAMBERLIN

- Draft Report -

IMPACT EVALUATION OF THE PACIFICORP/EBCONS MULTIFAMILY PROGRAM

Prepared for:
Margot Everett
Kathi Kazala
PACIFICORP COMPANY

Prepared by:
Jennifer Stout
M. Sami Khawaja, Ph.D.
Mark Hamilton
BARAKAT & CHAMBERLIN, INC.

and

Howard Reichmuth, P.E.

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CONTENTS

Total savings of 996 kWh per monitored site were estimated. An average water savings of 6,169 gallons per year at each site were also realized through the program. Annual kWh savings were disaggregated to fixed flow savings of 103 kWh, flow reduction savings of 640 kWh, and standby savings of 253.

Using two multivariate regression models (kWh and water saving models), the estimated savings were extrapolated to the population of program participants. Had all the participants received all the water heater measures, average savings per participant would have been 1,026 kWh annually. However, while some customers received all measures, others received only water heater wraps, and still others received only showerheads. As a result, program population savings were calculated after making adjustments based on different installation rates of water heater wraps and showerheads. Average adjusted participant savings were estimated to be 840 kWh per year (confidence = 90%, precision = ±24%).

Since the old showerheads were removed by EBCONS as part of the program, persistence was not deemed to be an issue in this program. Furthermore, based on a survey of program participants, less than 2% removed their water heater wraps.

Table E-1 summarizes the program overall findings, and Table E-2 displays the total program savings based on 26,274 electrically heated units in the program.

Table E-1
PROJECTED TOTAL ANNUAL PROGRAM SAVINGS

Average Per Unit Savings (Sample)	996 kWh
Average Per Unit Savings (Population w/all Measures Installed)	1,026 kWh
Average Per Unit Savings (Population w/Actual Installation Distribution)	840 kWh

Table E-2
PROJECTED TOTAL ANNUAL PROGRAM SAVINGS

Electric Energy Savings	Total Annual MWh
Fixed Flow Savings	2,785
Flow Reduction Savings	14,977
Standby Savings	4,310
Total Electric Savings	22,072
Water Savings	**Total Annual Gallons**
Total Water Savings	157,695,834

I. INTRODUCTION

This evaluation assessed savings associated with PacifiCorp's Oregon Multifamily Water Heat Program.

Since the program's inception, 26,274 Oregon customers received conservation measures for their electric water heaters through PacifiCorp's contractor EBCONS. These water heating measures included water tank wraps, pipe insulation, low-flow showerheads, and aerators. The thermostat settings were adjusted to 130° F, as necessary.

Generally, data noise precludes the assessment of small changes in consumption from billing data. Therefore, the measurement and verification approach used detailed metering of a representative sample of multifamily home water heater tanks.

Once data were retrieved from the sites, a multivariate regression model for estimating savings and extrapolating the results to the rest of the program was constructed. This approach conformed to generally recognized methods of statistical inference, as recognized by other utility programs.[1]

Barakat & Chamberlin and Howard Reichmuth conducted sample selection and data analysis. EBCONS staff installed meters and retrieved data.

ANALYTICAL OBJECTIVES

This analysis was designed to quantify the electricity savings resulting from a slate of measures targeted at saving domestic hot water and water heating electricity in multifamily units. The installed measures lowered water heating energy requirements through:

- Tank standby losses and fixed flow end-use loads reduced by lowering water storage temperature.
- Tank standby losses reduced by improving tank and pipe insulation.

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[1]As examples, see California Public Utilities Commission, "Protocols and Procedures for the Verification of Costs, Benefits and Shareholder Earnings from Demand Side Management Programs," November 30, 1993 and National association of Energy Service Companies, "NAESCO Standard for Measurement of Energy Savings for Electric Utility Demand Side Management (DSM) Projects)," October 27, 1992.

- Water heating load reduced by lowering showerhead flow rates.
- Water heating load reduced by lowering the flow rates at kitchen and bath sink outlets.

The objectives of the analysis were:

(1) Quantify total annual electric savings. Disaggregate total savings to individual components of standby, flow reduction, and fixed flow. Consequently, assign these savings to individual measures installed through the program.

(2) Quantify the annual water savings.

The evaluation required the following tasks:

Task 1.	Sample design
Task 2.	Data collection (consisting of three site visits)
Task 3.	Data cleaning and normalization
Task 4.	Estimation of annual savings
Task 5.	Extrapolation of findings to the program

II. SAMPLE DESIGN

To determine the necessary sample size, a probability-based sampling technique was used. The following equation was used:

$$n=\frac{z^2 cv(y)^2}{e^2}$$

where:

n	=	required sample size (number of residences)
z	=	1.282 (for 90% one tail confidence level)
cv(y)	=	coefficient of variation of y, or the standard deviation divided by the mean of consumption reduction
e	=	the required precision level

Assuming a cv of 1.4, based on results from monitoring in Yakima and Utah, and a precision level of 0.20 for a one-tailed, paired observation test, resulted in an estimated sample size of 80. The sample size was set at 100 to protect against equipment failure and data loss.

Sites were selected from Roseburg, Portland, Medford, and Corvallis. Sites were defined as apartment complexes to simplify the data collection process and site visits. The five complexes had a total of 104 units. Table 1 shows the regional distribution of units.

Table 1
MONITORED UNITS BY CITY

City	Units
Roseburg	24
Portland	53
Medford	5
Corvallis	22
Total	104

III. DATA COLLECTION

For this project, EBCONS measured the water heater electrical and water consumption. The electrical consumption was recorded with a small data logger that recorded the cumulative run time while the current was ran through the water heater wire. This run-time measurement was then multiplied by the power draw for the water heater. The power was recorded by actual measurement during the initial site visit. The installation procedure was to run the hot water until the water heater elements turned on, then measure the wattage using a clamp-on ammeter, such as the "Amp-probe."

EBCONS also installed a water flow meter in line with the water heater, so the amount of hot water used could be recorded along with kWh consumption.

EBCONS staff recorded cold water temperatures from a cold water tap. One measurement per building was considered sufficient. EBCONS staff also recorded the hot water delivery temperature for each water heater. This was measured at a hot water tap near to the water heater. Finally, EBCONS staff verified the showerhead and faucet aerator flow rate reductions by measuring each shower pre- and post-retrofit using a "Micro Weir." This measurement confirmed the change in flow.

Two different test periods were conducted. One period of approximately four weeks established the baseline consumption with existing equipment. The second period (also approximately four weeks) established consumption following the installations of low-flow showerheads, faucet aerators, and Water Heater Insulation Kits (WHIKs). This testing required three site visits.

The following section describes the specific site visits.

INITIAL SITE VISIT

On the first site visit, EBCONS installed the water heater data logger and water flow meter. EBCONS also took this opportunity to confirm demographic data, measure water heater wattage, hot and cold water temperatures, and shower flow rates using a "Micro Weir."

MEASURE INSTALLATION VISIT

EBCONS staff visited the site four weeks later to install the low-flow showerheads and WHIKs. Installation included resetting of the water heater thermostat when previous settings exceeded 130° F. EBCONS recorded the time and date when the changeout occured. The installation technician measured cold water temperatures, recorded water flow meter reading and current run time on the data logger, and measured the pre- and post-shower flow-rate, using the "Micro Weir."

FINAL SITE VISIT

After another four weeks, EBCONS revisited the site, retrieved the data loggers, recorded hot and cold water temperatures, recorded water consumption readings and water heater current run times, and removed the equipment. Pressure versus flow tests were conducted at each site on showerhead supply pipes. These tests were designed to support the development of the alternate verification methodology.

DATA COLLECTED

Data were collected at 104 sites to document the hot water and energy use before and after the installation of the energy savings measures. The site data collected were:

- *Demographic and identification data, name, address, occupants, recent change of occupancy, dishwasher use, and clothes washer use.*

- *Hot water use by measuring water flow to and through the tank.* These measurements were made using a water meter installed at the tank's cold water inlet.

- *Measurements of the tank's inlet and outlet water temperatures.* These measurements were made by measuring the full hot and cold only temperatures at outlets nearest the tank after letting the water run for at least a minute.

- *Hot water heater electric measurements, made by attaching a magnetically induced elapsed time meter to the electric wires serving the water heater.* These meters were actuated by the change in magnetic field in wires corresponding to the hot water heater elements' on and off states.

- *Flow rate measurements (with a Micro Weir) on the original and replacement showerheads and faucets.*

- *Pressure versus flow tests on showerheads removed from each site.*

- *Pressure versus flow tests on the showerhead supply pipe at each site.*

Appendix A provides a summary of showerhead data and analysis. Sample site visit forms used to guide data collection are provided in Appendix B.

IV. DATA CLEANING AND NORMALIZATION

Missing or inaccurate data caused by equipment failure were removed from the analysis. Periods of extended vacancy were also removed. To minimize variances in the results, we removed cases deemed to be anomalous using traditional statistical methods as well as common sense.

Initial Sample	**104**
Sites with "normal" occupancy and valid water measurements	**72**
Sites with "normal" occupancy and valid water and electrical measurements	**34**

Data loss varied by the variable of interest. For example, 72 sites had complete demographic and water usage data and no major periods of vacancies. These sites composed the core of this evaluation.

To account for differences in the length of monitoring, consumption data were calculated as an average kWh/day for each site. In doing this, energy consumption (kWh) was first calculated by multiplying the run-time recorded by the data logger by the wattage for each site.

For each site and each measurement period, amounts of standby and variable consumption were estimated using the following equation:

$$kWh/day_{Standby} = kWh/day_{total} - kWh/day_{variable}$$

where:

kWh/day_{total} was the average kWh per day measured at the site during each measurement period. The $kWh/day_{variable}$ was computed as:

$$kWh/day_{variable} = (T_{out} - T_{measured}) * (Gal/day) * \frac{8.33\ BTU/degFgal}{3412\ BTU/kWh}$$

Gal/day was the average water flow through the hot water tank at the site.

To adjust for seasonal changes in incoming water temperatures, the variable component of consumption for each site and each measurement period was adjusted using:

$$kWh/day_{Adjusted} = kWh/day_{Standby} + kWh/day_{variable} * \frac{T_{out} - T_{normal}}{T_{out} - T_{measured}}$$

where:

kWh/day_{adjust}	=	Daily kWh with average annual inlet water temperature.
$kWh/day_{Standby}$	=	Amount of kWh/day consumption due to standby loss from the tank computed using the equation.
$kWh/day_{variable}$	=	Variable amount of consumption.
T_{out}	=	Delivered hot water temperature measured at the site during each measurement period.
T_{normal}	=	Normal average annual cold water temperature.[2]
$T_{measured}$	=	Measured cold water temperature at the site during each measurement period.

The adjustment for temperature applied only to the variable portion of the observed consumption. It was corrected only for the change in the inlet water temperature's difference between hot and cold.

[2]This corresponded to the cold water temperature between 4/25/96 to 5/5/96, or the temperature taken on the first visit.

V. ESTIMATION OF ANNUAL SAVINGS

SUBTASK 1: ESTIMATION OF ANNUAL ELECTRIC SAVINGS

At each site, seasonally adjusted average annual variable savings were calculated as:

$$\Delta kWh/day_{adjusted_{variable}} = kWh_{variable_{pre}} * \frac{T_{out_{pre}} - T_{normal}}{T_{out_{pre}} - T_{measured_{pre}}} - kWh_{variable_{post}} * \frac{T_{out_{post}} - T_{normal}}{T_{out_{post}} - T_{measured_{post}}}$$

Installation of the water heater insulation and temperature reset primarily affected standby losses. Annual savings for insulation measures installed were separated as:

$$\Delta kWh_{insulaton} = (kWh/day_{standby_{pre}} - kWh/day_{standby_{post}}) * 365$$

Similarly, annual savings for water saving measures (mainly for showerheads) were computed by disaggregating the change in variable kWh into fixed flow and flow reduction savings. Daily savings associated with fixed flows were calculated as:

$$\Delta kWh/day_{fixed_{flow}} = FXT*(T_{out_{pre}} - T_{out_{post}}) * Gal/day * \frac{8.33\ BTU/degFgal}{3412\ BTU/kWh}$$

where FXT was the fraction of the hot water tank flow to fixed flows, such as dish and clothes washers. Calculations were based on the assumption that FXT, the fixed flow, was 35% of the pre-flow rate in gallons per day.

Annual savings associated with the flow reduction were calculated as:

$$\Delta kWh_{flow_{reduction}} = (\Delta kWh/day_{variable} - \Delta kWh/day_{fixed_{flow}}) * 365$$

Total annual site savings were calculated by adding these three saving components:

$$\Delta kWh_{total} = \Delta kWh_{insulation} + \Delta kWh_{fixed_{flow}} + \Delta kWh_{flow_{reduction}}$$

SUBTASK 2: WATER SAVINGS

Data from 104 sites were screened for occupancy changes preretrofit to postretrofit. All remaining sites with complete water measurements pre and post were selected as the water flow measurement set (72 sites). Some data reconstruction was necessary to fill missing dates and decimal point errors.

Water flow measurements were made with measurement intervals of 30 to 40 days. These flow measurements were normalized at a gallon per day.

Water flow savings were not normalized for seasonal variability. As previous monitoring did not demonstrate significant seasonality for the amount of hot water consumed (Oregon Department of Energy, "Cost and Performance of Solar and Heat Pump Water Heaters in the Pacific Northwest," June 1987), programmatic results were the mean of estimated annual savings for all sites.

These water flow measurements were made at the tank, and therefore were intermediate water flow measurements, as nonheated water consumption was also reduced. The measurements were consolidated with water inlet and outlet temperature measurements for use in estimating energy savings or water savings.

Calculating corrected changes in water consumption proved quite lengthy and tedious, the as corrections were applied sequentially. Gross flow savings were first corrected for tank outlet temperatures from pre- to postperiod using the equation:

$$\Delta fgal/day_{corrected} = FXT * (1 - \frac{T_{out_{pre}} - T_{measured_{pre}}}{T_{out_{post}} - T_{measured_{post}}}) + f_1 * \frac{T_{out_{pre}} - T_{measured_{pre}}}{T_{out_{post}} - T_{measured_{post}}} - f_2$$

where

FXT	=	Fixed flow fraction assumed to be $.35*f_1$
f_1	=	Preretrofit flow in gal/day
f_2	=	Postretrofit flow in gal/day

The portion of the total corrected change in water use that is attributable to the program was calculated:

$$\Delta f_{fixture} = (\Delta fgal/day_{corrected} * \frac{T_{out_{post}} - T_{measured_{post}}}{T_{fixture} - T_{measured_{post}}}) * 365$$

where T fixture was the water delivery temperature at the fixture (assumed to be 105° F). (This was intended to be the weighted average of the shower and bath water temperatures. This was not measured, but rather assumed to be within the human comfort zone of 100 to 110 degrees.)

Total savings were estimated at 996 kWh per treated site. The program also realized average water savings of 6,169 gallons per year at each site. Annual savings were disaggregated to fixed flow savings of 103 kWh, flow reduction savings of 640 kWh, and standby savings of 253 kWh (Table 2).

Table 2
MONITORED PROGRAM SAVINGS OF THE ANALYSIS SAMPLE

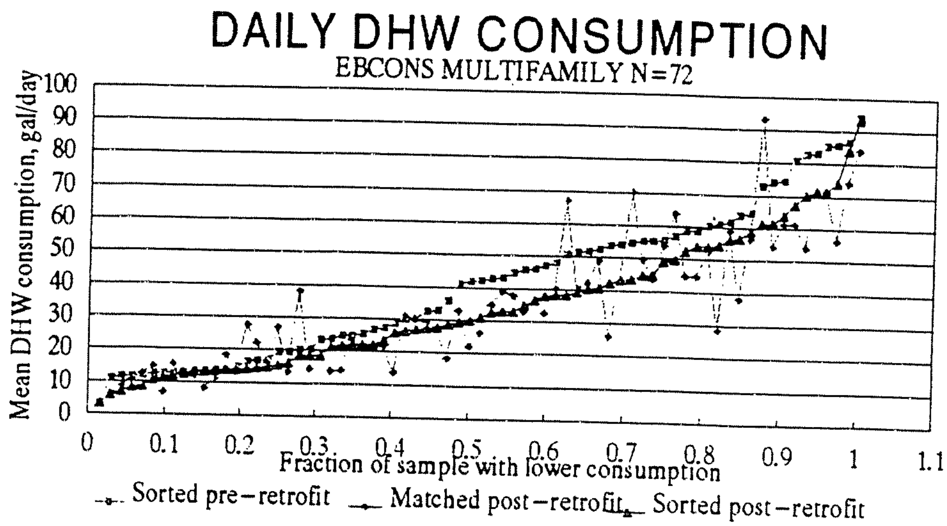
Electric Energy Savings	kWh Per Day	Annual kWh	Percent of Total
Fixed Flow Savings	0.28	103	10.4%
Flow Reduction Savings	1.75	640	64.3%
Standby Savings	0.69	252	25.4%
Total Electric Savings	2.73	996	100%
Water Savings	**Gallons Per Day**	**Annual Gallons**	
Total Water Savings	16.9	6,170	100%

Total savings were partitioned into the standby and flow-related components for the 34 sites with metered electric data.

Program standby savings formed the difference between pre- and postperiod standby electricity consumption. It should be noted that cases of negative standby energy occurred. These were artifacts of measurement errors compounded by the actual inlet temperature being higher than the measured inlet temperature. The effect was caused by the supply pipe detaining a few gallons of water in approximately 100 feet of pipe proximate to a heated space. Even in cases where standby losses were negative, the pre/post difference in the standby loss would show positive savings.

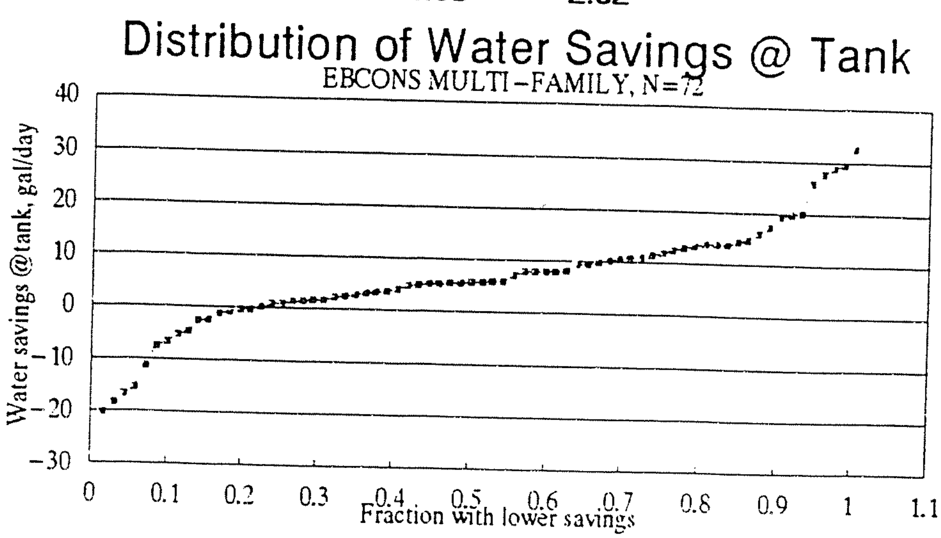
FIGURE 1 – SUMMARY of GROSS WATER MEASUREMENTS

Pre/Post water measurements at the tank were available for 72 sites. These measurements are presented in the distributions below showing the Pre DHW usage and the Post usage at the same site, "matched post". The sorted Pre usage is also compared to the sorted post usage. These distributions show a clear reduction in Pre/Post usage.



The DHW flow savings at the tank are shown in the savings distribution below. The mean Pre and Post usages and savings in gal/day are:

	PRE	POST	SAVINGS
Mean	**40.99**	**34.61**	**6.37**
Std Dev	**23.55**	**20.80**	**10.41**
+/- 90% confidence	**4.57**	**4.03**	**2.02**



The sample's estimated standby savings were 0.69 kWh/day, or 253 kWh/year.

Table 3
STANDBY ELECTRICITY CONSUMPTION

	Pre kWh Per Day	Post kWh Per Day	Savings kWh Per Day
Mean	1.47	0.78	0.69
Standard Deviation	1.66	1.28	1.63

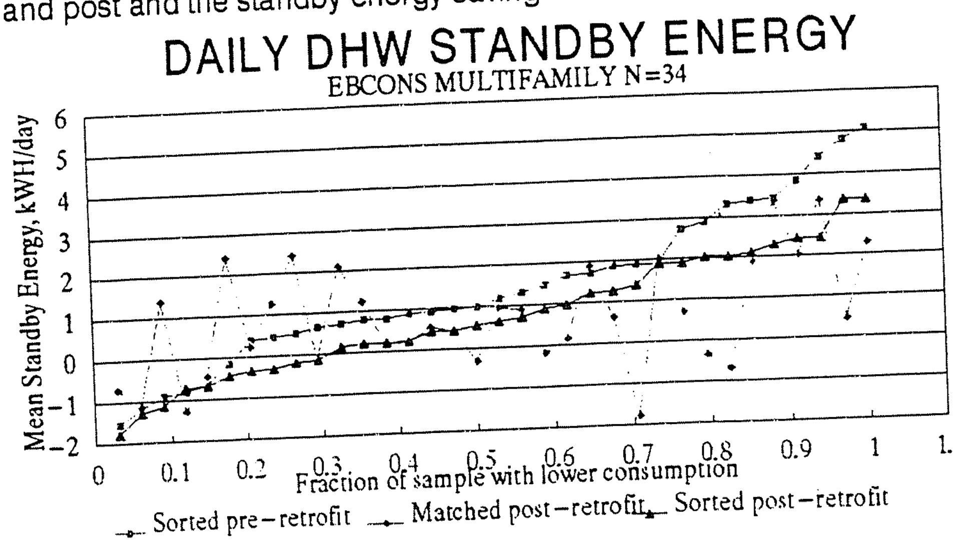
Variable energy savings made up the bulk of program savings. These savings were derived from flow reductions of installed showerheads and aerators and from reduced tank thermostat settings.

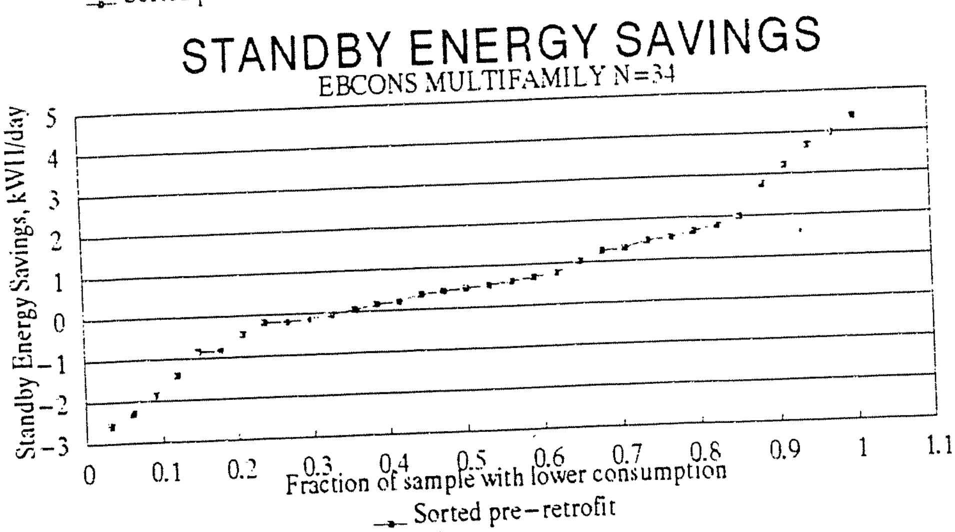
Normalized variable savings were estimated from pre- and postperiod estimates of seasonally adjusted variable electricity consumption. This was calculated for 72 sites that had flow and measurement data available and had not experienced occupancy changes.

Mean variable energy savings measured and corrected for seasonal variation were 2.04 kWh/day for annual savings of 743 kWh.

FIGURE 2 – DHW STANDBY SAVINGS

Pre/Post total electric measurements were available for 34 sites. These totals are disaggregated into separate components for standby energy and for and for kWH/day variable energy by means of associated water flow and inlet outlet temperature measurements. The distributions below show the standby energy pre and post and the standby energy savings.



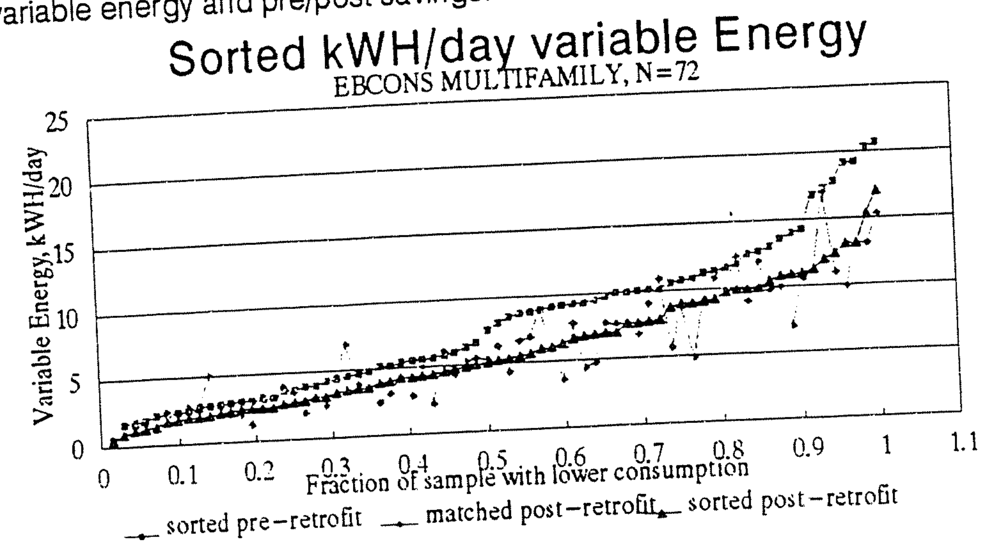


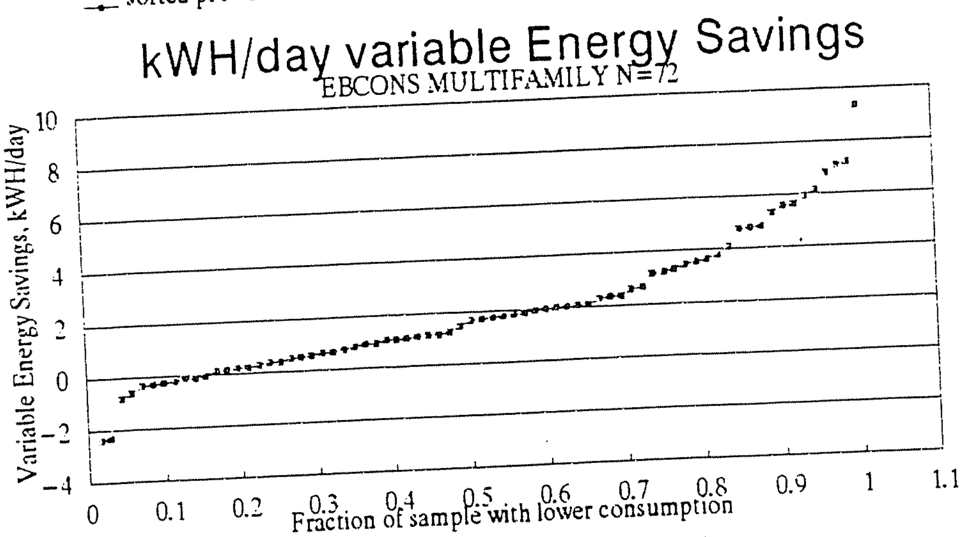
The Standby Energy and the standby energy savings are shown below in kWH/day:

	PRE	POST	SAVINGS
Mean	1.47	0.78	0.69
Std Dev	1.66	1.28	1.63
+/- 90% confidence	0.47	0.36	0.46

FIGURE 3 – kWH/day VARIABLE ENERGY

Pre/Post measurements of kWH/day variable were available for 72 sites. This measurement is based on water flow and temperature measurements. These energy measurements have been corrected for seasonal variations in the temperature of the inlet water. The distributions below show the pre and post kWH/day variable energy and pre/post savings.





The mean kWH/day variable energy and savings are shown below in kWH/day:

	PRE	POST	SAVINGS
Mean	8.08	6.05	2.04
Std Dev	4.98	3.75	2.28
+/- 90% confidence	0.97	0.73	0.64

Table 4
VARIABLE ELECTRICITY CONSUMPTION

	Pre kWh per day	Post kWh per day	Savings kWh per day
Mean	8.08	6.05	2.04
Standard Deviation	4.98	3.75	2.28

Variable savings were disaggregated into two components—fixed flow and reduced flow savings. Fixed flow savings were solely resulted from reducing the hot water temperature to water for end uses other than showerheads and aerator-installed faucets. Reduced flow savings were caused by a reduction of the volume of water used by the household. Both savings could be calculated using the previous cited equations of 35% of the water flow was assumed to be fixed. Fixed flow savings were estimated at 0.28 kWh/day, or 103 kWh annually, and reduced flow savings from installed showerheads and aerators were calculated at 1.75 kWh/day, or 640 kWh annually.

Overall average monitored savings were estimated at 996 kWh annually (the sum of the three energy saving components). The associated precision of this estimate was ±24%. These results are presented in Table 2, above.

Table 5 provides an overall summary of estimated water flow and temperature measurements.

Table 5
WATER SAVINGS SUMMARY

Category	Pre	Post
Gallons Per Minute	4.9	1.9
Outlet Temperature	140	127
Tank Gallons/Day	41	34.6
Tank Savings Gallons/Day		6.4
Fixture Saving Gallons/Day		16.9

VI. EXTRAPOLATION OF FINDINGS TO THE PROGRAM

Multivariate regression models were constructed using energy savings as the dependent variable. Savings results were extrapolated to the multifamily population using collected demographic information.

The model was specified as:

$$\Delta kWh/day = \alpha + \beta_1(Occupant * \Delta Flow) + \beta_2(\Delta Temperature\ Setting) + \varepsilon$$

where the change in the amount of electricity used to produce hot water was assumed to be a function of the number of occupants, the change in water flow of the showerhead, and the reduced temperature setting.

Table 6
REGRESSION: WATER HEATER ELECTRICITY CONSUMPTION
(n=72, adjusted-R^2=0.16)

Variable	Coefficient	t Statistic
Intercept	1.420	3.1
ΔTemperature Setting	0.048	2.1
Occupant#*ΔFlow	0.149	2.6

Inserting overall program averages into the regression resulted in savings of 2.81 kWh per day, or 1,026 kWh/year. These higher-average savings for the program population resulted mainly from the slightly different values for the averages of explanatory variables. A survey of apartments treated by EBCON revealed that occupants averaged 2.31 versus 2 for the regression sample.

As part of this project, laboratory tests were performed on the 104 showerheads replaced. These tests revealed that, under typical water pressure conditions, the average water flow was 4.48 gpm. This was slightly lower than the 4.8 gpm measured on-site for the regression sample. Finally, the average temperature setting reduction for the total metered population was 11.5° F—slightly greater than the 9.8° F measured in the regression sample.

The population's average water savings were estimated in a similar manner.[3] Average water savings of 19 gallons per day (6,939 gallons/ year) were estimated for a participant installing a low-flow showerhead.

As mentioned previously, total energy savings were disaggregated into three components:

(1) Fixed Flow Savings (due to temperature reductions).

(2) Flow Reduction Savings (due to the installation of low-flow showerheads and aerators).

(3) Standby Savings (due to the installation of tank wraps).

Table 7 displays the disaggregation in percentage terms based on the study sample. The population-estimated average savings of 1,026 kWh were broken into savings components using the sample-derived distribution.

Table 7
PROGRAM POPULATION SAVINGS BY TYPE

Electric Energy Savings	Percent of Total	Annual Population kWh Savings
Fixed Flow Savings	10.4%	106
Flow Reduction Savings	64.3%	659
Standby Savings	25.4%	260
Total Electric Savings	100%	1,026
Water Savings		**Annual Gallons**
Total Water Savings	100%	6,939

The population savings per treated units still had to be adjusted for participating customers that did not receive all the program services. Of 26,274 electric water heater treated by the program, only 92.7% had electric water heat and were eligible to receive the water heating measures. The total numbers installing each measure are

[3]A simple regression was estimated where the change in gallons consumed per day was a function of the number of occupants.

shown in Table 8. The distribution of measures was obtained from a survey of approximately 300 EBCONS participants.

PERSISTENCE

As old showerheads were removed when low-flow ones were installed, persistence was not a concern. Water heater tank wraps were only removed in 3 cases (approximately 1.5% of respondents).

Table 8
PROGRAM POPULATION MEASURE INSTALLATION

	Number	Percent of Total
Units Installing Showerhead	22,726	86.5%
Units Installing Water Heater Wrap	16,551	61.5%

Savings were distributed between the two measures by assuming that standby savings were due to the water heater wrap, and flow reduction savings were due to the showerhead.

Total electricity savings were estimated at 22,072 MWh, for average electricity savings of 840 kWh a year in residences with electric water heat. This average savings reflects the actual installation of measures, thus accounting for persistence.

Table 9 provides an overall summary of the electric saving estimates.

Table 9
AVERAGE PER PARTICIPANT SAVINGS

Participant Group	Average Annual Savings Per Participant (kWh)
Study Sample	996
Population (Assuming All Measures Installed)	1,026
Population (Actual Installations)	840

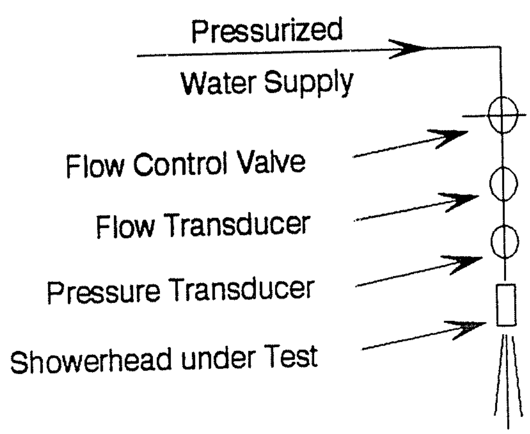
APPENDICES

Appendix A
SUMMARY OF SHOWERHEAD DATA

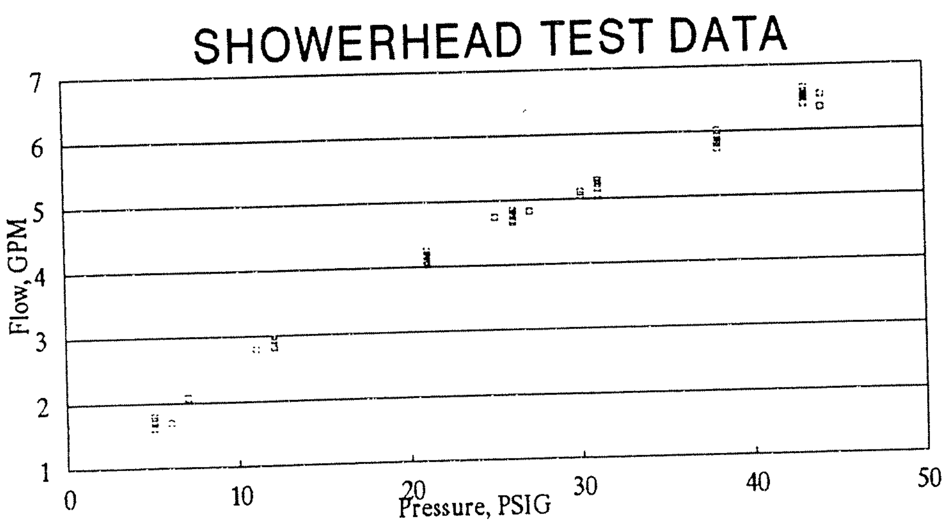
FIGURE 1. – SHOWERHEAD FLOW TEST

Showerheads to be tested are connected to a test apparatus as in the diagram shown below. The test consists of actuating the flow control valve from an initial OFF position through several intermediate positions to a final ON position. The pressure and flow at each valve position are recorded and plotted.

SHOWERHEAD TEST SETUP



The recorded pressure and flow data will generally appear as in the plot illustrated below. Typically several flow measurements are taken at each pressure.



measurements to an estimate of real world showerhead flows. The assumed site conditions have been generalized from measured site conditions observed at 76 sites. The supply pressure test conducted at these sites is described and illustrated in fig 2. Figure 3 shows the assumed "reference supply source" and the site measurements from which it was derived.

The integration of the laboratory test data and the assumed site conditions leads to an equilibrium flow as illustrated in figure 4. This equlibrium flow is the "normalized flow" estimated for each showerhead: the flow that would occur at an average site, ie a site described by "reference supply source". For each showerhead tested, the test results and the estimated normalized flow are presented on a separate page for each showerhead along with specific showerhead identifiaction information.

Each showerhead is tested "as is", and special care is taken not to loosen any scale on the showerhead or to modify any adjustment. The test data for each showerhead has been fitted by a quadratic function to simplify subsequent operations with the test data.

AGGREGATED TEST RESULTS and DISCUSSION of RESULTS

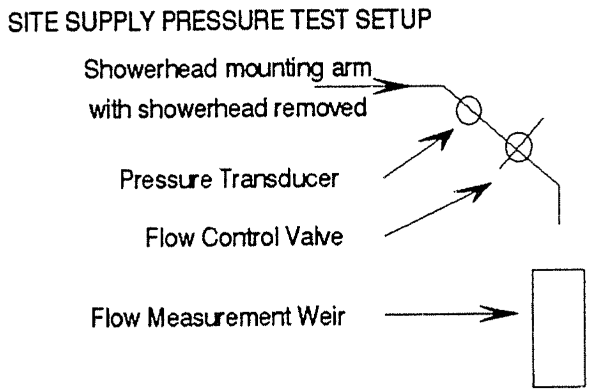
The distribution of individual normalized flow results and some aggregations of these results is shown in figure 5. In figure 5., the normalized flow estimates are also compared to actual showerhead flow measurements taken at the site.

The site flow measurements are presented in a ranked order distribution labelled as "sorted site measurements". The normalized flow estimate corresponding to each of these site measurements is shown labelled as "matched normalized flows". The normalized flows matched the site measurements in only about one half the cases. However, some mismatch between site flows and the normalized flow estimates can be expected because the actual site conditions exhibited a scatter about the "reference supply source" as illustrated in figure 3.

Figure 5. also compares the sorted order distribution of the site measurements to the sorted order distribution of normalized flow estimates. This comparison is reanonably close. The distributions of the site measurements and normalized flow estimates compare favorably even though the normalized flow estimates do not compare well on an individual site by site basis. Based on a sample of 85 sites, the mean site measured flow was 4.90 GPM and the mean normalized flow estimate was 4.49 GPM.

FIGURE 2. – SITE SUPPLY PRESSURE TEST

The site supply vs pressure test employs test apparatus set up as in the diagram shown below. The test consists of actuating the flow control valve from an initial OFF position through several intermediate positions to a final ON position. The pressure and flow corresponding to each valve position are recorded and plotted.



The recorded pressure and flow data will appear as in the plot shown below.

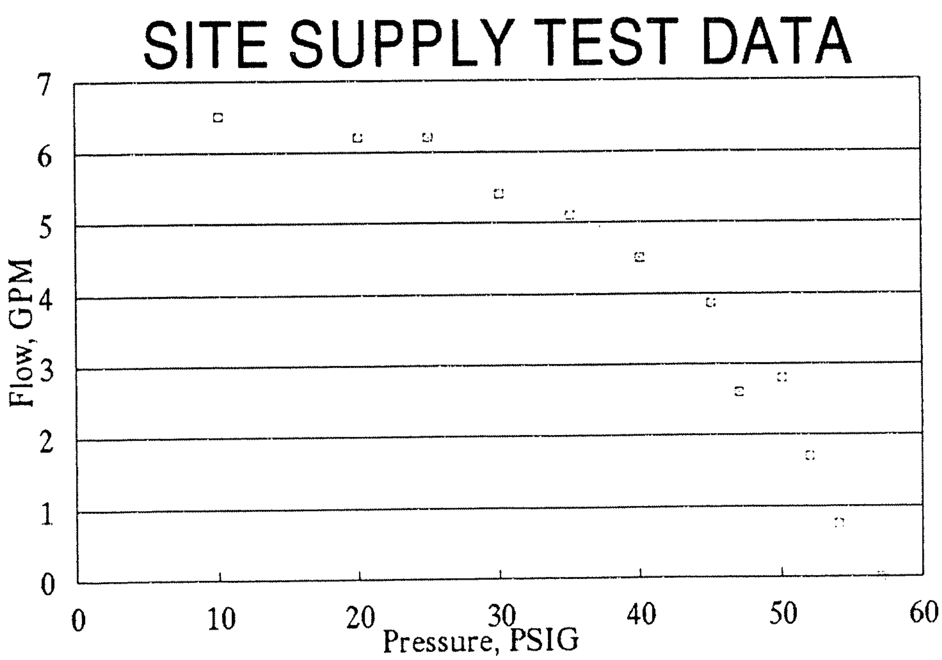
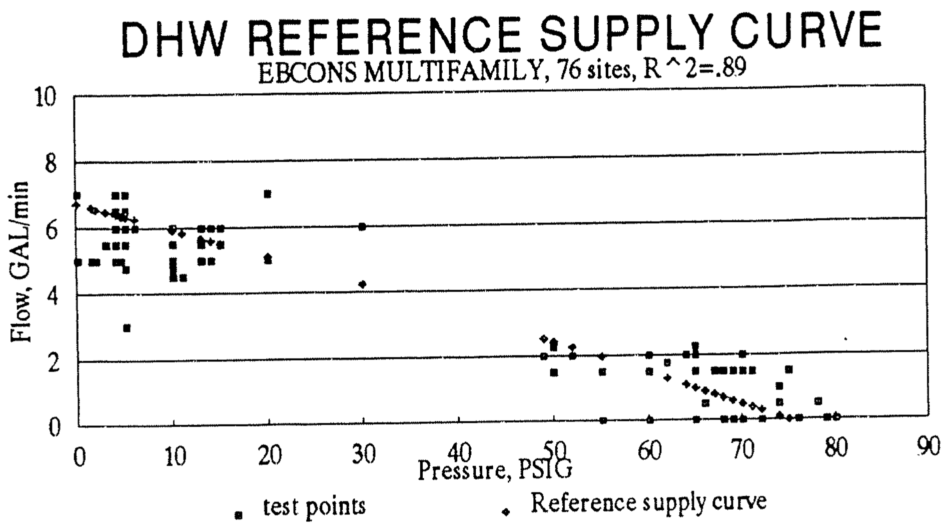


FIGURE 3 – DHW REFERENCE SUPPLY CURVE

Site supply pressure test data were available for 76 sites. The test measurements show a general trend as shown below. A quadratic curve is fitted to the pressure and flow measurements to serve as a "Reference Supply Source" which approximates the site supply pressure for the average site.



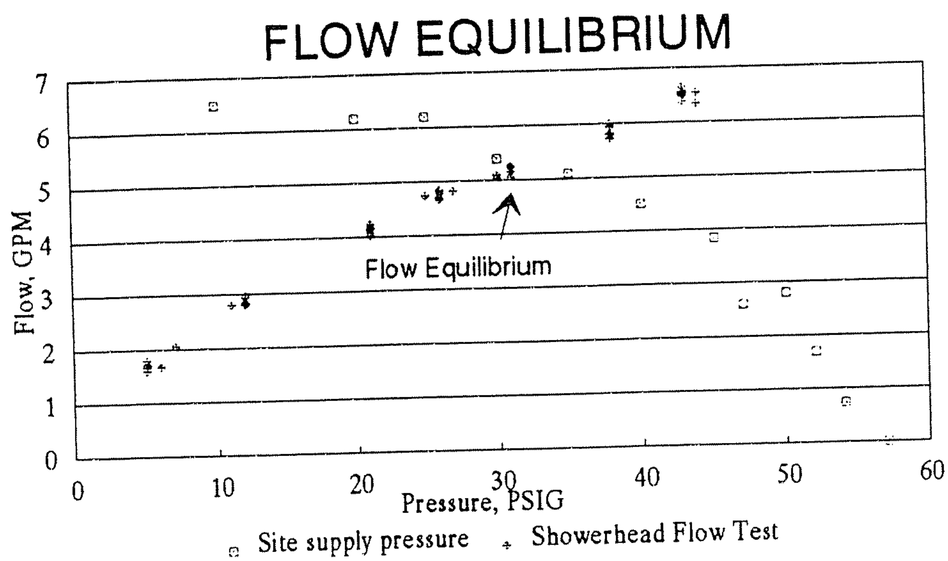
The regression fit is summarized below:

Regression Output:

Constant		6.719211
Std Err of Y Est		0.897384
R Squared		0.894544
No. of Observations		380
Degrees of Freedom		377
X Coefficient(s)	–0.07887	–0.00014
Std Err of Coef.	0.008298	0.000113

FIGURE 4. – FLOW at EQUILIBRIUM

The flow for a specific showerhead at a specific site will be the equilibrium flow which satisfies both the site supply pressure and the showerhead flow pressure. The equlibrium flow conditions are illustrated below as the intersection of the site supply pressure curve and the showerhead flow curve.



At the same site, the equlibrium flows and pressures can differ dramatically for different showerheads. Illustrated below, showerhead #1 has an operating pressure of 30 PSIG while showerhead #2 has an operating pressure of 45 PSIG.

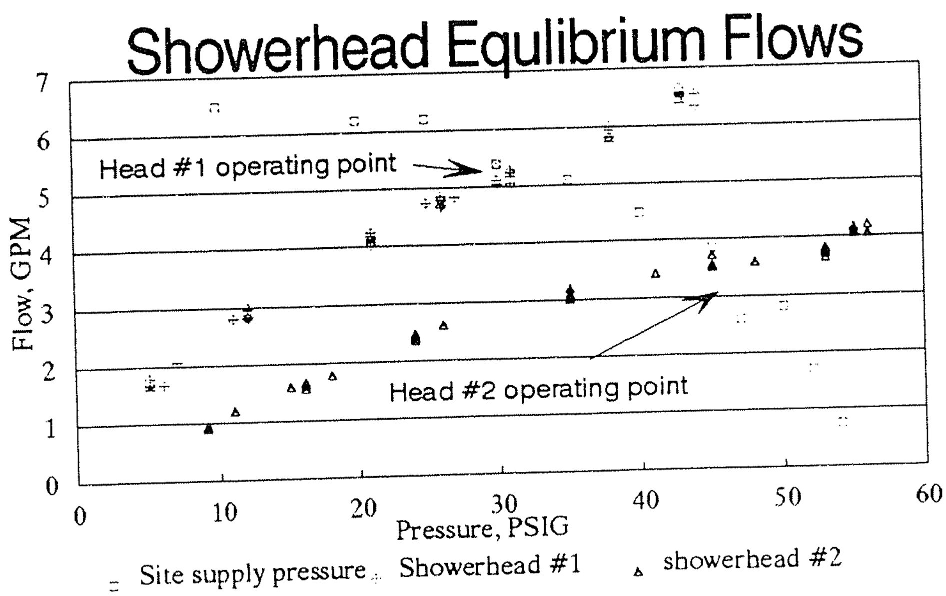
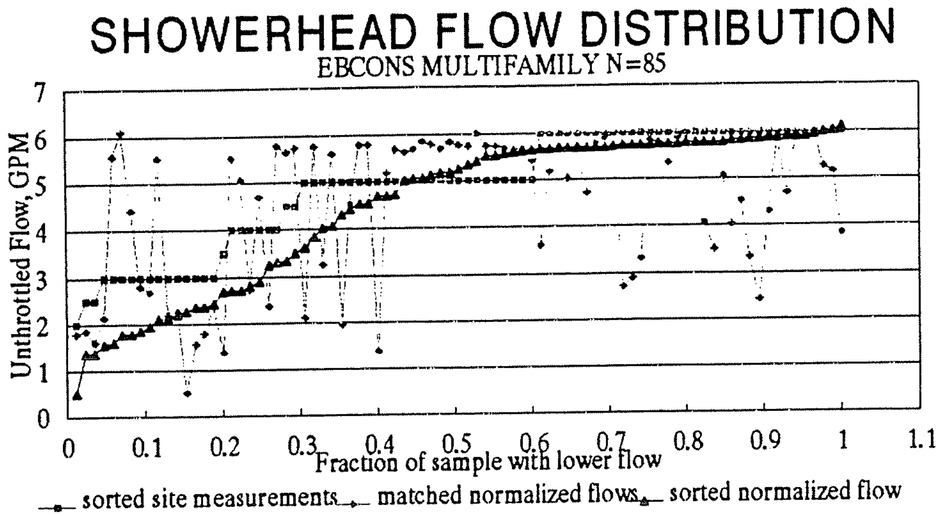


FIGURE 5.– FLOW TEST RESULTS

The "Reference Supply Source" has been used to estimate the equilibrium flow for each of the lab tested showerheads, referred to here as the normalized flow. The distribution of normalized flows approximates the distribution of site–measured flows as shown below. The mean site measured flow was 4.90 gpm, and the mean normalized flow was 4.49 gpm.



The normalized flow test results and the site flow test results are aggregated below in GPM:

	SITE FLOW	NORMALIZED FLOW
Mean	**4.90**	**4.49**
Std Dev	**1.17**	**1.56**
N	85	85

SHOWERHEAD THROTTLING - The site flow measurements to which these lab tests are compared are flow measurements at full flow. The weir flow measurement protocol called for measurements at a ressonable showering temperature but with the valving at full flow. For many of the showerheads tested this full flow could exhaust the stored hot water if several showers were involved in a limited period such as from 6-7 AM. It is probable that in a portion of the high flow cases, the occupants will either turn down the flow or shorten shower duration inorder to avoid a cold shower.

No comprehensive measurements of throttling are available, but the effects of throttling are implicit in studies where the total elapsed flow is measured at the showerhead, or where the showering time is measured. Usually, the overall water and energy savings are less than would be predicted using flow rate data and showering time.

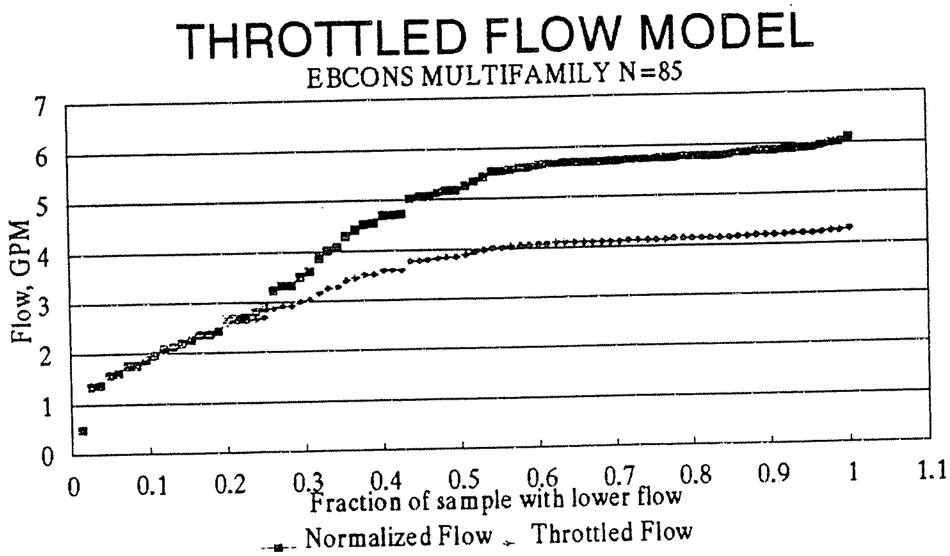
To correct for the effects of throttling of high flow showerheads this laboratory test proceedure employs a simple model which reduces all flow above 2.5 GPM by 50%. While this model is an assumed correction, it is a midrange correction, well within reasonable upper and lower flow bounds. This correction will significantly reduce the mean flows for samples heavily weighted with high flow showerheads. In this sample of 104 showerheads the mean flow was reduced from 4.49 GPM to 3.44 GPM by throttling. Figure 6 gives the throttling model and shows the effect of the throttling model on this distribution of normalized showerhead flows.

FIGURE 6. – THROTTLING MODEL

The high flow showerheads encountered in this study had flows of 5 GPM or higher. There is a clear motive for throttling these high flow heads inorder avoid running out of hot water. The throttling can take the form of a reduction in shower duration or a reduction of shower flow. The distribution of normalized flows can be readily modified to simulate throttling of the high flow heads in the distribution. There is no firm experimental basis for this throttling model, therefore throttling is assumed as follows:

Throttled flow = 2.5 GPM + .5*(normalized flow−2.5)

The distribution of normalized flows with and without throttling is shown below:



AGGREGATE NORMALIZED FLOWS in GPM:

	NORMALIZED FLOW	THROTTLED FLOW
Mean	**4.49**	**3.44**
Std Dev	**1.56**	
+/− 90% confidence	**0.28**	

Appendix B
SITE VISIT FORM FOR DATA COLLECTION

PACIFIC POWER OREGON MULTIFAMILY MONITORING PROJECT

Accnt. #: Auditor signature:

Complex Name: City:

Complex Address:

Owner Name: City: Phone: ( )

Owner Address:

Property Mgmt. Firm Name: City: Phone: ( )

Property Mgmt. Firm Address:

FIRST SITE VISIT: DATE ___/___/___ INFO. CARD LEFT? Y N

Accnt. #: Auditor signature:

On-site Manager Name: Apt. #: City: Phone: ( )

On-site Manager Address:

Tenant Name: Apt. #: City: Phone: ( )

Tenant Address:

Number of Occupants:

Water Heater: Size (gallons): Amps: Nameplate Wattage:

Water Heater Location: Heated Space ☐ Unheated Space ☐

Washing machine in Unit?: Y N

Dishwasher in Unit?: Y N

Water meter serial #:

Datalogger serial #:

Meter readings: Water: Datalogger:

Temperature readings: Hot water: Building cold water:

SECOND SITE VISIT: DATE ___/___/___ INFO. CARD LEFT? Y N

Accnt. #: Auditor signature:

On-site Manager Name: Apt. #: City: Phone: ( )

On-site Manager Address:

Tenant Name:

Same occupants as previous visit? Y N IF NOT: Date new occup. moved in: / / Number of new occup:

Meter readings: Water: Datalogger:

Temperature readings: Hot water (Pre-Setback): Building cold water:

Water pressure reading: PSI:

Water Heater Thermostat Setting: Pre Setback: Post Setback:

NOTE: If water heater replaced between visits, record new size, amp, wattage in comments section.

No. of measures installed: WHIK: Showerheads:

Hot Water Pipe Insul.: ft. Aerators:

CFLs: Ceiling Insul. Y N

MicroWeir serial #: Shower: Faucet:

Water Flow Rates (Full-on):

		Kitchen or Bath		Pre (GPM):	Post (GPM):	Measured?
Fixture #1:	Faucet	K B	Shower:			Y N
Fixture #2:	Faucet	K B	Shower:			Y N
Fixture #3:	Faucet	K B	Shower:			Y N
Fixture #4:	Faucet	K B	Shower:			Y N
Fixture #5:	Faucet	K B	Shower:			Y N

THIRD SITE VISIT: DATE ___/___/___ INFO. CARD LEFT? Y N

Accnt. #: Auditor signature:

On-site Manager Name: Apt. #: City: Phone: ( )

On-site Manager Address:

Tenant Name:

Same occupants as previous visit? Y N IF NOT: Date new occup. moved in: / / Number of new occup:

Meter readings: Water: Datalogger:

Temperature readings: Hot water: Building cold water:

Measures still in place?: Y N IF NO: Which were removed?:

Additional comments:

PACIFIC POWER CONSERVATION AND MONITORING PROGRAM
CUSTOMER INFORMATION CARD

Thank you for participating! Sorry we missed you. Please fill out this postage-paid card and mail it back. ***You will receive a $15.00 incentive at the end of the program for participating.*** This information will be held in strict confidence. Thank you for your help!

How many people in each of the following age groups live here?

4 yrs. or under	_____	35 to 44 yrs.	_____
5 to 12 yrs.	_____	45 to 54 yrs.	_____
13 to 18 yrs.	_____	55 to 64 yrs.	_____
19 to 24 yrs.	_____	65 yrs. & over	_____
25 to 34 yrs.	_____	Total	_____

About how many showers *total* does your household take per week? ______
What is the average shower length? ______ minutes

If you have a washing machine in your unit, about how many loads of wash do you do each week? _____

If you have a dishwasher in your unit, about how many loads of dishes do you do each week? _____

Tenant Name: ____ ***Thank you!***

Accnt. #:__________________ Site Visit #:________ Date Card Left:___/___/___
Complex Name:____