The Net impact of Home Energy Feedback Devices

Brien Sipe, Energy Trust of Oregon, Portland OR
Sarah Castor, Energy Trust of Oregon, Portland OR

ABSTRACT

Recently, much attention has been focused on modifying the way individuals interact with energy consuming products. In order to examine the viability of real-time feedback devices to produce energy savings, Energy Trust of Oregon, Inc. piloted the Blueline PowerCost Monitor. The pilot consisted of two distinct groups: "early adopters," who were given the opportunity to order the monitors online for a nominal fee, and Home Energy Review (HER) participants, who had monitors installed via home energy audits. Both groups combined represent over 350 monitors in the field. The HER sample was based on quotas which were stratified based on the serving Oregon utility, home vintage, and geographic region, while the "early adopter" group was based only on region.

In order to confidently attribute changes in consumption to the presence of the monitors, comparison groups were utilized for both groups to control for secular trends in energy consumption. These comparison groups were obtained via random stratified sampling of the general population of utility customers (for early adopters) and home audit recipients who did not receive a monitor (for the HER participants).

Preliminary findings indicate monitors did not have a significant impact on energy use for either cohort. While substantial reductions in energy use occurred for participants during the study period, the comparison groups experienced equivalent reductions in their consumption as well.

Introduction

Energy Trust of Oregon, Inc. is an independent 501(c)(3) nonprofit organization which manages Oregon's systems benefit charge for the state's investor-owned electric and gas utilities. The agency manages energy efficiency and renewable energy programs that span Residential, Commercial, and Industrial sectors. Currently, the residential program focuses on retrofit and incremental energy conservation measures, and also offers free home audits, called Home Energy Reviews.

Interested in findings stemming from Canadian utility pilots of instantaneous feedback devices, Energy Trust began investigating potential products for a home energy monitor (HEM) pilot. The agency chose the Blueline PowerCost Monitor because a homeowner could install the device themselves. Following product testing, Energy Trust launched a small-scale pilot in January 2008 with installations continuing through August 2008. The pilot tested two delivery mechanisms: self-installations by the customer, and Home Energy Review (HER) installations. In the first method, the monitor was offered for purchase through Energy Trust's website for a discounted price of $29.99; the typical retail price at the time was $150. A total of 164 monitors were sold through the website. The buyers, hereafter referred to as the "early adopters," had to install the monitors themselves. In the second delivery mechanism, the monitors were offered to customers during HERs and were installed by the auditor at no cost. In total, the pilot consisted of 164 "early adopter" households and 201 HER households.

This study details the net impact of the monitor on electricity use for "early adopters" and HER participants. The current analysis is being viewed as an 'interim' impact analysis, given that the average participating site has (at the date of this report) less than a full years' worth of post-installation bills to use in the analysis. A final analysis with at least one full year of post data, and the potential for analysis using a wider variety of estimation techniques is expected in July or August 2009.

Background

Pilot participants were surveyed about their immediate response to the presence of the monitors in their homes, typically within three weeks. A group of randomly selected 2008 audit participants who did not receive the monitors were also surveyed to serve as a comparison group for the HER pilot participants. Both groups were asked about plans they had to install energy conservation measures (ECMs) over the next six months.

Following six months of the monitors being in the field, all those who responded to the initial survey were re-surveyed, and asked if the monitor was still functional and whether they were still using their monitor. Energy Trust program tracking data were also linked to participant information for use in pre-post savings estimates, to account for other ECMs installed through the program.

Table 1: Survey responses – Initial & six month follow-up

	Early adopters	HER	HER-comparison group (2008 audit sites)
Participants	164	201	6,340*
1st survey respondents	133	178	417
2nd survey respondents	93	110	169

*This reflects the 2008 audit total sites not receiving HEMs.

Table 1 details the sample attrition rate for survey takers for the follow-up survey. Significant attrition occurred by the end of six months, with response rates of 57% and 55% for self-installed and HER-installed monitor participants, respectively. The six month surveys gathered a number of key data points about monitor longevity and household use of the monitor. Regression billing estimates of monitor impact on energy consumption took into account all participants, as well as the subset of survey respondents.

Table 2: Self-reported monitor use

	Early Adopters	HER-Installed
Initially did not install/use		
Total Respondents	*128*	*176*
Not using/Did not install	2%	2%
Monitor use after 6 months		
Total Respondents	*109*	*92*
Still using	66%	64%
Monitor not functional	20%	27%
Monitor functional but not in use	14%	8%
Frequency of use at 6 months		
Total Respondents	*73*	*60*
Less than once per day	15%	23%
1-2 times per day	55%	51%
3 or more times per day	29%	26%
Length of time used if discontinued or monitor failed		
Total Respondents	*37*	*30*
1-2 months	32%	33%
3 or more months	68%	67%

Table 2 presents survey responses about monitor use, both initially and at 6 months after installation. In the first survey, "early adopters" were asked if they had installed the monitor and if they looked at the monitor; since HER participants had the monitors installed for them, they were only asked if they looked at the monitor. For both groups, 2% of participants indicated they either did not install the monitor or never used the display.

In the second survey, respondents were asked if they were still using the monitor, and again the about the same proportion of the willing respondents from both groups – almost two thirds – were still using the monitor. About a quarter of respondents reported that the monitor was no longer functional. During the study period, Energy Trust was made aware of product defects which lead to many of the devices failing in the field.[1] In addition to product failure, some participants reported that the monitor was functional but they no longer looked at it.

Of those still using the monitor after six months, more than three quarters of participants indicated they checked the monitor more than two times per day. Among respondents who reported monitor failure or discontinuing use, two thirds were able to use the monitor for three or more months (but less than six). As can be seen in Table 2, there were almost no differences on any point at all between the two groups selected via different methods.

[1] Savings were estimated using a variety of post-period lengths to identify potential savings stemming from monitor use in the short-term, prior to product failure. These model estimates are detailed in the findings section.

Table 3: Initial and six month self-reported reductions in energy usage attributed to monitor use*

Appliance**	EA initial	EA 6 month	HER initial	HER 6 month
Indoor Lighting	74%	56%	74%	71%
Outdoor Lighting	28%	19%	37%	26%
Air conditioning	58%	n/a†	52%	n/a†
Television	22%	20%	25%	23%
Electric cooking range	22%	18%	28%	23%
Electric oven	22%	12%	43%	22%
Computer boxes	37%	39%	27%	33%
Computer monitors	48%	41%	38%	36%
Electric space heating	42%	42%	42%	53%
Electric water heating	40%	18%	37%	30%
Electric clothes dryer	53%	45%	40%	42%
Stereo	15%	15%	24%	9%
Hot tub	6%	6%	33%	27%
Overall	**58%**	**73%**	**71%**	**65%**

***% reporting a large or small reduction in use of a particular appliance.**
****N varies for each appliance depending on the number of respondents indicating they own the appliance.**
† The 6 month survey was administered in fall/winter.

Table 3 highlights the initial, and six month, self-reported changes in usage behavior for a wide variety of household appliances. Percentages reflect the fraction of participants indicating a 'small change' or 'large change' in an appliance they indicated they possessed.

Participants were also asked if they felt reductions were a result of having the home energy monitor. After six months, nearly three quarters of "early adopters" and two thirds of the HER participant group attributed an overall reduction in their energy use to the monitor. The self-reported responses indicate that a majority of participants, even after six months, attribute reductions in their energy use to the information provided by the monitor.

Billing Analysis Methodology

To control for secular trends in energy use over time, the analysis utilized a comparison group for each participant cohort. For the HER-installed monitors, the comparison group was drawn from other households receiving audits in 2008, but not the monitors. The "early adopters" were compared to a random sample of Oregon households who have not participated in any Energy Trust program.

Comparison households were randomly selected to fill strata based on weather zone, and quartiles of pre-period average daily electricity consumption for the participant cohorts.

Monitor impacts were estimated using a variety of model specifications. Primary modeling utilized a simple cross-sectional model for each cohort. In addition savings were estimated using fixed effects specifications to control for site level variations in energy consumption. Controlling for site level variations allowed for the inclusion of ECM installation data to further control for variations in energy consumption unrelated to the monitors.

Electric billing data for all study cohorts were collected for the time period January 2007 to January 2009. For HER-installed monitors, the month of installation is known, and the 'post' period for both participants and non-participants begins the month after the HER. The month of the audit is omitted from regression analysis.

For "early adopters," the shipping date of the monitor is known, rather than the actual date of installation. For this reason, an artificial billing blackout period of two months, the month the unit was shipped and the following month, was used to allow time for delivery of the monitor and installation. For households in the comparison group, a two-month blackout period was randomly assigned; the distribution of blackout periods for the comparison group matches the distribution for the "early adopters."

Table 4: Monitor installation periods

	Beginning of installations	Last installation
HER installed	January 2008	August 2008
Early Adopters	February 2008	June 2008

Table 4 shows the date range of monitor installation for the two groups. HER installed monitors share the same installation date as the audit, while the "early adopter" installation periods are identified by the shipping dates of the monitors.

Standard billing data cleaning steps included:

- Elimination of duplicate readings
- Adding estimated readings to next actual reading
- Dropping reading periods of less than 10 or more than 60 days.

In addition, models were run only with sites which had no account turnover in the study period. This is to reflect the nature of the impacts of the monitor on 'behavior' rather than the housing structure.

Energy Trust utilizes eleven weather stations around Oregon to calculate HDD and CDD based on average daily temperature. Models were estimated using HDD base 60 and CDD base 70.

Models were then estimated based on the full sample of program participants, regardless of survey completion. The rationale for including all program participants, whether or not they answered the survey, is that (1) they were all program participants and had a monitor and (2) we know that the HER monitors were installed, and that the "early adopter" group paid for the monitors, so installation was likely. Self-selection in the response rate would only have to do with refusals, not inability to contact the participants. Further we included all participants, even when survey responses claim to not have installed or even used the monitors, because in any future program offerings there will be some rate of non-installation and discontinuation of use.

Table 5: Participant site attrition

	Early adopters	**HER sites**
Total participating sites	164	201
Sites where utility accounts were found	139	195
Occupancy changes	39	62
Double or halve consumption pre-post	3	25
0 post installation reading days	1	4
Final sites for model estimations	96	104

Table 5 details the attrition of participant sites based on a variety of criteria. By far the largest source of attrition is a change in occupancy in the study period. Given the behavioral nature of the monitors, rather than structural modification of a building with other types of ECMs, it was deemed necessary to eliminate these sites. Attrition resulted in the loss of roughly one third to half of the "early adopter" and HER sites, respectively.

Measure Installation Data from Energy Trust Programs

Table 6: Sites installing ECMs

Measure installed	Early Adopters	HER participants	HER comparison group
Air sealing	1	11	9
Ceiling insulation	1	8	9
Clothes washer	10	-	-
Duct insulation	-	1	3
Duct sealing	-	3	6
Duct testing/sealing	1	8	6
Energy saving kit	3	1	8
Faucet aerators/showerheads	4	75	124
Floor insulation	1	3	6
Fridge recycling	-	-	1
Heat pump	1	2	2
Lighting	12	96	152
Solar PV	-	-	2
Tankless water heater	-	-	2
Wall insulation	1	1	3
Windows	-	2	4

Counts of sites installing ECMs in addition to the monitors during the study period are presented in Table 6; information comes from Energy Trust program tracking systems. While survey respondents were asked what substantial changes they made to their houses during the study period, which may have occurred outside of the Energy Trust programs, those responses have not yet been processed as of the date of this report.

Table 7: Descriptive statistics for participant and comparison group billing data

Group	Sites	Avg. # of readings in post period	Mean kWh/day in pre period	Std. Dev. kWh/day in pre period	Min kWh/day in pre period	Max kWh/day in pre period
Early Adopters	96	6.8	35.4	22.0	3.0	133.9
Comparison group	490	7.0	36.3	19.8	4.4	112.9
HER participants	104	10.4	31.0	18.7	8.0	97.8
HER comparison group	201	6.2	30.1	16.9	8.5	81.3

Descriptive statistics based on the pre-period kWh usage for both the participant and comparison groups are presented in table 7. The "early adopter" comparison group was constructed using sites which have never participated in Energy Trust program, while the HER comparison group was comprised of sites who received audits in 2008 and had no monitor installed.

Pre-period minimum, maximum and quartiles of average daily consumption (kWh/day) were calculated using 2007 data for each pilot cohort. The HER comparison group is significantly smaller than the self-installed comparison group due to the inadequate number of 2008 audit participants to fill strata during sampling. The total comparison group size was restricted to ensure all strata were proportionally represented in the final comparison group.

Models

The net impact of the monitor on household average daily electricity consumption was estimated using the following models:

Early adopter impact models:

(1) $AVGUSE_{it} = \alpha + \beta_1 POST_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{\ it} + \beta_3 INPILOT_i + \beta_4 MONITOR_{it} + \beta_5 HAVEGAS_i + \varepsilon_{it}$

(2) $AVGUSE_{it} = \alpha + \beta_1 POST_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{\ it} + \beta_3 INPILOT_i + \beta_4 MONITOR_{it} + \beta_5 HAVEGAS_i + \gamma_i + \varepsilon i_t$

(3) $AVGUSE_{it} = \alpha + \beta_1 POST_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{\ it} + \beta_3 INPILOT_i + \beta_4 MONITOR_i + \beta_5 HAVEGAS_i + \gamma_i + \beta_j ECM_i + \varepsilon_{it}$

where,

$AVGUSE_{it}$ = average daily kWh usage in period 't'
$POST_{it}$ = dummy variable equal to 1 in the post-installation period
$HDD60_{it}$ = average daily heating degree days in period 't' calculated at reference temperature 60
$CDD70_{it}$ = average daily cooling degree days in period 't' calculated at reference temperature 70
$INPILOT_i$ = dummy variable indicating program participant
$MONITOR_{it}$ = dummy variable representing the effect of the monitor ($POST_{it}$*$INPILOT_i$)
γ_i = individual site fixed effect
ECM_i = vector of dummy variables for ECM installations based on Energy Trust tracking data
ε_{it} = unexplained variation in AVGUSE

All specifications were run as ordinary least squares (OLS). Given the large variance in consumption within the sample, all models were estimated using robust standard errors due to the presence of heteroskedasticity.

Several alternative specifications were examined which utilized interaction terms for the impact of the monitor and weather and allowed an examination of the effect of the monitor on heating and non-heating related energy usage. It was determined that these alternative specifications did not to produce appreciably different or more insightful results than the ones presented and are not reported.

Table 8: Early adopter model summaries:

VARIABLES	Model (1)	Model (2)	Model (3)
	AVGUSE	AVGUSE	AVGUSE
POST	-2.598***	-1.599***	-1.594***
	(0.465)	(0.29)	(0.291)
HDD60	0.969***	1.008***	1.009***
	(0.033)	(0.021)	(0.021)
CDD70	2.844***	1.776***	1.773***
	(0.219)	(0.158)	(0.158)
INPILOT	0.107	-54.301***	-12.195**
	(0.74)	(9.812)	(5.593)
MONITOR	-0.479	0.403	0.544
	(1.157)	(0.614)	(0.617)
HAVEGAS	-12.918***	-41.368***	-41.365***
	(0.398)	(9.733)	(9.734)
Constant	33.731***	58.646***	58.637***
	(0.472)	(9.436)	(9.438)
Observations	12,131	12,131	12,131
R-squared	0.185	0.73	0.73
*** p<0.01, ** p<0.05, * p<0.1			
Robust standard errors in parentheses. Models 2 and 3 include individual site fixed effects (not reported).			

Table 8 presents the results of the model estimates for the "early adopter" participant cohort. The estimated impact of the monitor, represented by MONITOR, is small and not statistically significant in any of the models. Parameter estimates for INPILOT and HAVEGAS vary widely between model 1 and models 2-3 due to the site specific dummy variables (not reported).

For both the "early adopters" and their comparison group, average daily consumption dropped between 1.6 and 2.6 kWh per day in the post installation period, as shown by POST. We hypothesize that this reduction may have been due to rising energy costs in conjunction with the collapse of the stock market representing the onset of the current recession.

These results were strikingly counter-intuitive, given that this participant group was highly motivated, having purchased their quota of monitors in short-order.

Table 9: Monitor estimated impact on early adopters at 3, 6, and 9 months

MONITOR	Early Adopters Model (1)
3 months	-1.179
	(1.941)
6 months	-0.243
	(1.271)
9 months	-0.41
	(1.153)
*** p<0.01, ** p<0.05, * p<0.1	
Robust standard errors in parentheses.	

Given that a number of monitors which failed in the field around the 3 month mark, monitor impacts were estimated over a variety of time horizons. Table 9 shows the impact of the monitor on the energy use of the "early adopter" cohort at 3, 6 and 9 month intervals. While none of the estimated coefficients are statistically different from zero, the point estimates after 6 and 9 months decline relative to the initial 3 month impact.

These findings cast doubt on the hypothesis that monitor failure accounted for the lack of significant savings estimates. It may be that participants attributed energy savings to the monitors when in fact they were being affected by secular trends occurring in the wider economy, i.e., rate increases and increasing economic uncertainty.

HER installed monitor impact models:

(4) $AVGUSE_{it} = \alpha + \beta_1 AUDIT_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{it} + \beta_3 MONITOR_i + \beta_4 HAVEGAS_i + \varepsilon_{it}$

(5) $AVGUSE_{it} = \alpha + \beta_1 AUDIT_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{it} + \beta_3 MONITOR_i + \beta_4 HAVEGAS_i + \gamma_i + \varepsilon i_t$

(6) $AVGUSE_{it} = \alpha + \beta_1 AUDIT_i + \beta_2 HDD60_{it} + \beta_3 CDD70_{it} + \beta_3 MONITOR_i + \beta_4 HAVEGAS_i + \gamma_i + \beta_{j\text{-}} ECM_i + \varepsilon_{it}$

where,

$AVGUSE_{it}$ = average daily kWh usage in period 't'
$POST_{it}$ = dummy variable equal to 1 in the post-installation period
$HDD60_{it}$ = average daily heating degree days in period 't' calculated at reference temperature 60
$CDD70_{it}$ = average daily cooling degree days in period 't' calculated at reference temperature 70
AUDIT = dummy variable representing the HER being conducted at the site in period 't'
and all other variables are defined as for early adopters.
$MONITOR_{it}$ = dummy variable representing the effect of the monitor ($POST_{it}$*$INPILOT_i$)
γ_i = individual site fixed effect
ECM_i = vector of dummy variables for ECM installations based on Energy Trust tracking data
ε_{it} = unexplained variation in AVGUSE

Audit impact models were estimated using the same specifications as the "early adopters" with one important distinction: post periods for the HER group were determined by the audit date. The MONITOR coefficient is interpreted as the monitor-related savings over and above the HER savings. As with the "early adopter" model specifications, a variety of other specifications were examined but not reported on due to their lack of contributory value to the analysis. All models were estimated using robust standard errors due to the presence of heteroskedasticity.

Table 10: HER participant model summaries:

VARIABLES	Model (4)	Model (5)	Model (6)
	AVGUSE	AVGUSE	AVGUSE
HDD60	0.728***	0.762***	0.761***
	(0.028)	(0.019)	(0.019)
CDD70	1.537***	2.056***	2.050***
	(0.28)	(0.203)	(0.204)
AUDIT	-0.538	-0.565	-1.698***
	(0.528)	(0.363)	(0.658)
MONITOR	**-0.767**	**-0.669**	**-0.629**
	(0.677)	**(0.509)**	**(0.513)**
HAVEGAS	-23.591***	-38.071***	-50.756***
	(0.574)	(4.263)	(5.016)
Constant	41.525***	40.298***	53.546***
	(0.601)	(4.141)	(4.918)
Observations	10,499	10,499	10,499
R-squared	0.305	0.755	0.757
*** p<0.01, ** p<0.05, * p<0.1			
Robust standard errors in parentheses. Models 5 and 6 include individual site fixed effects (not reported).			

The estimates from HER models are outlined in Table 10. As with the "early adopter" models, the HER installed monitors did not yield statistically significant reductions in energy consumption during the study period, represented by the MONITOR term. Parameter estimates of the monitors' impact were the expected sign, and stable, across the range of model specifications. These findings contrast with the survey finding that nearly two thirds of HER installed monitor participants felt that they had reduced their overall energy consumption as a direct result of the monitor.

Table 11: Monitor estimated impact on participants at 3, 6, and 9 months

MONITOR	HER installed Model (4)
3 months	-1.567
	(1.12)
6 months	-1.168
	(0.804)
9 months	-0.763
	(0.702)
*** p<0.01, ** p<0.05, * p<0.1	
Robust standard errors in parentheses.	

As with the "early adopter" cohort, the HER participants had a significant number of monitor failures during the study period (about 23%). To evaluate what impacts, if any, occurred in the short run, model (4) was run with 3, 6, and 9 month post periods.. Table 11 presents these results. While none of the coefficients are significant, point estimates of the impact are highest at the three month mark, and generally decline over time**.**

Discussion & Conclusion

In an effort to ascertain the impacts of real-time feedback devices on household behavior, Energy Trust fielded the Blueline PowerCost monitor in 350 homes for over six months. The scope of the present study was to identify the viability of claiming energy savings from these devices across a diverse array of potential program participants. The analysis examined roughly 200 households' utility data to estimate their net impact on household energy usage.

For the "early adopters," the estimated savings from an HEM were not significantly different from zero. Parameter estimates for the effect of the monitor were robust across a variety of specifications. Despite a large majority of participants reporting a reduction in energy use attributable to the monitor during the study period, post-period reduction in electricity use was statistically identical for the participant and comparison groups. This is not the intuitive result expected, given that these participants were eager, self-selected adopters who were fast to order and had to pay a non-trivial amount. If any group should show above average reductions in consumption, this would be the participant group.

HER installed monitors also had no significant effect on household energy consumption. While the sign of the coefficient representing monitor impact was correct, it was not statistically significant.

For both groups, point estimates of energy savings, while never significant, were highest within three months of installation, and declined as the post period was extended to six or nine months. While not significant, these findings seem to indicate that participants may have been taking steps to reduce consumption, which diminished over time. The failure of some units due to a manufacturing defect may have contributed to this attenuation of energy savings.

Several confounding factors were also at play during the study period. Participants, and their comparison groups, saw electric rate increases as well as a declining economy, likely resulting in an overall decrease in energy consumption. Participants may have felt that the monitor was aiding them in reducing their consumption while in reality economic trends were resulting in wide-spread reduction in energy usage among all utility customers.

A follow-up analysis using similar methodology is planned for June 2009, which would utilize twelve or more months of post-installation billing data for each participant. In addition, the one year study will be able to utilize a wider range of analytic techniques to evaluate the robustness of savings estimates, such as analysis of weather-normalized annual consumption, in addition to fixed effects models like those used in this study.

In conclusion, it does not appear that instantaneous feedback devices can be counted on to deliver large savings. While a decline in savings stemming from these devices could be expected over time, results of this study indicate that the monitors to have no appreciable immediate impact as well. Given the level of interest in this technology, and the volume of program pilots currently in the field nationwide, impact results from much larger studies using a variety of delivery methods, with the possibility of analyzing sub-sets of participants, should help inform the applicability of instantaneous feedback devices in the residential market.