A Reflection of Ourselves…How Households Interact with In-Home Feedback Devices: Results from a Treatment/Control Experiment

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ABSTRACT

There has been widespread interest in the savings potential of in-home direct power feedback displays, with studies showing a wide range of results. This paper presents the results of an assessment of the electricity savings from such a device (BlueLine Innovation's PowerCost Monitor (PCM)), and shows that savings are dependent upon individual household behavior. A telephone survey was conducted to identify several hundred Wisconsin homeowners who expressed an interest in using an in home feedback display. These households were randomly assigned to two groups: (1) a treatment group receiving the PCM (about 150 successful installations) and periodic tip sheets; and, (2) a control group (about 100 homes). Electricity usage histories for the years preceding and following distribution of the PCM were obtained for both groups and statistically analyzed for savings using a unique, non-parametric simulation approach.

Data from three surveys, one pre- and two post-treatment, allows for investigating the presence of statistically significant electricity savings according to a variety of survey responses, including, but not limited to: users who self-identified themselves as frequent observers of the PCM and treatment households that expressed a belief that the PCM was useful in reducing their home energy use. Our results suggest that savings, as one might expect, are largely realized by treatment households that self-identified as frequent viewers/users of the PCM device. Drawing upon both survey responses and the billing analysis, the paper provides insight on maximizing savings in home energy efficiency programs designed for direct power feedback displays.

Introduction

In-home Feedback Displays

Recent concern about global climate change and the emission of greenhouse gases has led to a significant amount of interest in the topic of behavior change as it relates to reducing residential household energy consumption. A focus within this area has been the savings potential which may be achieved by providing homeowners timely feedback on their energy use and its associated costs. The theory behind providing such feedback is simple. Many details concerning domestic energy consumption remain invisible to many households. Providing households timely information about their energy use (and its associated costs) is a necessary condition for enabling them to become more attentive to conservation opportunities (Darby, 2008).

Feedback can be provided to the homeowner in a variety of ways. Some methods use rather low-tech mediums, such as a mailing with an analysis of a household's home energy use relative to similar households in their service area. Other feedback mediums, such as real time in-home power feedback displays, are significantly more high-tech. An in-home power feedback display is thought to offer one of the most direct forms of feedback, providing homeowners with instantaneous knowledge of how much electricity they are using, and how much their use is directly affecting their pocketbook.

General research in the topic of power feedback displays has shown that expected savings for instantaneous feedback are on the order of 5 to 15% (Darby, 2008; Mountain, 2006; Ueno et al., 2005). However, two recent pilot programs specifically testing BlueLine Innovation's PowerCost Monitor (PCM) have delivered mixed results. In addition to the study discussed in this paper, these pilots have shown that savings are more likely to range from 0 to 7% (Norton, 2008; Sipe & Castor, 2009).

The PowerCost Monitor in Wisconsin – A Treatment/Control Experiment

Wisconsin's Focus on Energy retained the Energy Center of Wisconsin to implement a pilot study using the PCM, which effectively ran from the spring of 2008 through the summer of 2009.[1] The study ultimately distributed PCMs free of charge to 218 Wisconsin homes. Households receiving the PCM were also sent three tip sheets with energy saving ideas throughout the course of the study. After the initial screening, study participants were surveyed two additional times; once several months into the study and approximately one year after the PCMs were installed (end of study). The study used a control group of 95 homes as a baseline for estimating treatment group savings. Households in the control group only received the end of study survey.

We conducted a billing analysis of monthly electricity use for the periods (approximately one year each) preceding and following the installation of the PCM. The billing analysis included a total of 307 electric utility accounts. Of these, 212 belonged to homes receiving a PCM and the remaining 95 accounts belonged to the control group. We categorized the 212 treatment group accounts according to the ultimate status of the PCM at the end of the study: still functional (85 units), no longer functional (68 units) and never installed or unknown (59 units). Our primary billing analysis concentrated on the participant homes where we could confirm that the PCM was installed, which included 153 treatment homes, and 95 control homes.

There are several key aspects to the study that parameterize our findings. First, study participants were not required to share in the costs of the PCM. Moreover, treatment homes and control homes were given an additional $25 incentive to participate. Although participants were not required to pay for the PCM, the phone screening process eliminated candidates who did not express a willingness to pay at least $25 for what was only described as an in-home power feedback display (the PCM was not explicitly identified by name during the screening process). No measure of "energy IQ" was used in the phone screening process to gauge a potential participant's level of energy awareness.

Second, study treatment homes were mailed three "tip sheets" throughout the course of the study. The tip sheets provided households a set of ideas for conserving energy within the home. The tip sheets were identical to three tip sheets already in use by Focus on Energy's residential energy efficiency programs. The first tip sheet was sent along with the PCM. The other two tip sheets were mailed in August and December, and included seasonally appropriate

[1] Focus on Energy is a public benefits program that operates many customer-sited renewable energy and demand side management programs within the State of Wisconsin. Visit www.focusonenergy.org for more information.

ideas for saving energy. It is important to note that control homes were not given the tip sheet, thus the overall treatment effect includes both impacts attributable to the tip sheet and impacts attributable to the PCM itself.

One reason Focus on Energy chose the PCM for this study is that it can be installed by homeowners without any additional training or assistance from qualified technicians.[2] The device itself consists of two components: a sensor unit and a power monitor. The sensor is located at the residence's electric meter and is affixed such that an optical reader is aligned with the electric meter's indicator disc. A transponder sends a signal to the power monitor, which is a digital display located inside the residence (the reader is directed to visit http://www.bluelineinnovations.com for photos and additional product specifications). Users may input current retail rates into the PCM in order to view the current cost to power the home. It was important for Focus on Energy to better understand how successful homeowners would be in installing the device without significant assistance/intervention from the program itself. Accordingly, the study did not explicitly offer any assistance to participants regarding technical issues, other than to refer participants to the manufacture's help line.

Finally, a savings threshold of 2 percent was chosen by Focus on Energy as a benchmark to assess whether or not a random selection of homes using the PCM would achieve enough savings to offset the estimated costs for operating a program that would be similar in design to this study. The 2 percent savings threshold was chosen independent of study results.

Findings

Summary of Findings

Overall, we found the savings for participant homes that successfully installed the PCM to be modest (about 1.5% of pre-treatment usage levels), and likely fall within the range of -1.4 to 4.3 percent.[3] We found the probability that the true median savings surpass the 2 percent savings threshold to be 38%. We also examined savings for several key subgroups of the larger treatment group (identified through survey response and pre-treatment usage levels). We found that the probability of exceeding the 2 percent threshold for some of these subgroups was markedly higher than that of the overall treatment group, indicating that more reliable savings may be achieved if suitable participants can be identified *a priori*.

Savings Estimates

We used a non-parametric bootstrap simulation modeling approach to test for electricity savings in homes that successfully installed the PCM.[4] All reported savings are treatment group

[2] From a program administrator's perspective, the PCM is attractive because installation is quite simple and can be completed without any specialized training (i.e. it is not hard-wired into a breaker box which would often necessitate the assistance of a trained technician or electrician).

[3] 90% confidence interval.

[4] In part, our chosen simulation approach is used to assign pseudo-treatment dates to control homes by randomly selecting treatment dates (with replacement) from the treatment group. The bootstrap model derives confidence intervals for the median using a percentile method, following techniques discussed by Efron (Efron, 1993).

savings (at the median), relative to control group savings. We also present a probability (in percentage terms) describing the certainty that savings would exceed the 2 percent savings threshold.

Our modeling approach allowed us to estimate savings for several subgroups taken from within the overall treatment group. The subgroups were identified using responses from the middle- and end-of-study surveys. We focused on questions that provided insight about participant attitudes toward the PCM (as an energy saving device) and the persistence of using the PCM after it was initially installed. In addition to survey responses, we used pre-treatment usage levels to test whether or not this single piece of *a priori* knowledge was helpful in predicting greater amounts of conservation. The five subgroups discussed in this paper are:

- Treatment group homes that successfully installed the PCM device. (*Test 1*)
- Treatment group homes for which the PCM was functional and was consulted (at least) occasionally at the time of the end-of-study survey. (*Test 2*)
- Treatment group homes for which the PCM was consulted (at least) as often at the time of the mid-study survey as when the PCM was initially installed. (*Test 3*)
- Treatment group homes that thought the PCM was useful in saving electricity. (*Test 4*)
- The top three quartiles of treatment group energy users, relative to the top three quartiles of the control group. (*Test 5*)

Test 1: Savings for Participants who Successfully Installed the PCM.

We estimated savings for study participants who self-reported as having successfully installed the PCM device. There were 149 accounts that met this criterion, representing about 70% of the entire treatment group.[5] We compared usage for the 149 treatment accounts against the usage of 91 control homes. We did not find savings for this group to be statistically different from zero. Regardless, the point estimate for net median percentage savings for this group is 1.4%, or about 126 kWh/yr. We found the probability that savings for treatment homes successfully installing the PCM would exceed the 2% savings threshold to be 38%.

Test 2: Savings for Participants who Successfully Installed the PCM, the PCM was both Functional and Consulted (at least) Occasionally at the Time of the End-of-Study Survey.

As several pilot programs have demonstrated, our survey responses indicate that there is significant attrition (from the point of installation to the end of the study) in the number of PCMs remaining functional and/or in how often participants consulted the PCM. We found that out of all PCMs that were installed, 44% were functioning and (at least) being consulted occasionally at the time of the end-of-study survey. We estimated savings for this group to be 3.4%, or 440 kWh/yr. Savings for this subgroup fell within a 90% confidence interval of -0.4% and 6.1%.[6]

[5] The effective sample of treatment homes in Test 1 (N=149) is lower than the number of treatment homes we had billing data for (153) due to discrepancies in the data. We followed several conventional rules for cleaning billing data, including treating for estimated meter readings, insufficient pre/post billing information and extraordinarily short or long meter read periods. Table 1 gives the effective samples sizes after the data were cleaned.
[6] Expressed as a 90% confidence interval.

We found the probability that savings for this group would exceed the 2% savings threshold to be 81%.

Test 3: Savings for Participants who Successfully Installed the PCM and Consulted the PCM (at least) as Often as When Initially Installed.

Test 3 asks whether or not savings are statistically significant when participant interaction with the PCM persists at least several months after the PCM was installed. We found that at the time of the mid-study survey, 41% of participants consulted the PCM at least as often as when the it was initially installed. For these homes, we found savings to be 3.8% relative to the control group, or 416 kWh/yr. The estimate falls within a 90% confidence interval of -0.2% and 6.4%.[7] We found the probability that savings for this subgroup exceed the 2% savings threshold to be 83%. As a comparison test, we evaluated savings for participants who reported consulting the PCM less frequently than when it was initially installed. We estimated savings for this group (55% of respondents) to be 0.1% (within a 90% confidence interval of -2.9% and 3.6%). This comparison test provides another indication that real savings are in fact related to how frequently participants consult the PCM.

Test 4: Savings for Participants who Successfully Installed the PCM and Responded in the Final Survey That They Thought the PCM WAS Helpful in Reducing Their Electricity Consumption.

Test 4 estimates savings for households that thought the PCM was helpful in reducing their electricity consumption, regardless of the status of the device at the end of the study, or whether or not the PCM was consulted more or less frequently than immediately following the initial installation. Approximately 53% of respondents answered that the PCM was indeed helpful in saving electricity (21% said that it was not, and 26% said that they did not know). We estimated savings for participants answering in the affirmative, and found that savings for this group were 5.4%. Moreover, the lower bound of the 90% confidence interval for this estimate was greater than zero (the interval was 2.5% to 8.7%). The probability that savings for this group would exceed the 2% threshold was 96%.

We further subdivided this group by how frequently participants consulted the PCM. The resulting sample size for participants who reported that they thought the PCM was helpful, and who reported consulting the PCM (at the end of the study) at least several times per week, was 22 respondents. We found that savings for this subgroup were 6.4% and fell within a 90% confidence interval of 2.9% and 10.8%; however, such a small sample size may be inappropriate to analyze using our bootstrap estimation methodology. As a comparison, we tested savings for participants that self-identified as infrequent viewers of the PCM (but still thought it was helpful). This subgroup was also relatively small (29 respondents). Savings for this subgroup were 0.8% and fell within the 90% confidence interval of -3.9% of 5.9%. Our results from Test 4 reinforce the notion that savings attributable to the PCM are strongly related to the level of participant engagement. Unfortunately, Test 4 results only pertain to attitudes that study

[7] Note that kWh savings for Test 3 are lower than those estimated for Test 2, even though Test 3 shows higher percentage savings. This is not unexpected when percentage estimates are close in values, as pre-usage levels (used as a basis for calculating percent savings) will vary across subgroups based upon the sample population.

participants revealed *ex post,* and may not be useful to the program designer who is trying to identify a targeted population of program candidates *ex ante.*

Test 5: Do PCM Savings Vary by Pre-Treatment Usage Levels?

Test 4 provides a hint that significant savings may be achieved if a suitable type of participant can be identified *ex ante*. There is at least one participant trait that can be used for targeted marketing: pre-treatment usage levels. Test 5 examines whether or not savings are statistically significant for the treatment group homes that fell within our sample population's top three quartiles of pre-treatment usage (when compared against the top three quartiles of the control group). We found that savings for this subgroup were indeed higher than the overall treatment group at 3.4%, or 360 kWh/year. The savings estimate for this subgroup fell within a 90% confidence interval of -0.3% and 6.3%. We found the probability that savings for the Test 5 subgroup would exceed the 2% savings threshold to be 77%.

Table 1. Summary of Test Results

Test	Savings (%)	Savings (kWh)	P(s>2%)[8]
Test 1. Participants successfully installing the PowerCost Monitor			
[n_{treat}=149, $n_{control}$=91]	1.4 [-1.4, 4.6]	126 [-206, 489]	38%
Test 2. The PowerCost Monitor was functional at the time of the final survey and (at least) consulted occasionally at the time of the final survey.			
[n_{treat}=55, $n_{control}$=91]	3.6 [-0.6, 6.8]	440 [46, 755]	81%
Test 3. The PowerCost Monitor was consulted at least as often as when initially installed at the time of the mid-study survey.			
[n_{treat}=49, $n_{control}$=91]	3.8 [-0.2, 6.4]	416 [-4, 760]	83%
Test 4. Participant stated the PowerCost Monitor was helpful in reducing electricity consumption.			
[n_{treat}=70, $n_{control}$=91]	5.4 [2.5, 8.7]	576 [226, 937]	96%
Test 5. Participant is within the top three quartiles of pre-treatment usage levels.			
[n_{treat}=107, $n_{control}$=64]	3.4 [-0.3, 6.3]	360 [-12, 717]	77%

[8] Where "s" is the percentage savings. Values indicate the probability that percent savings exceed the 2% savings threshold and are expressed as a real number between 0 and 1.

Discussion

Ex Ante Identification of Likely Savers

As we might expect, our findings clearly indicate that savings attributable to the PCM are linked to user behavior and attitudes toward the device. For example, as a group, those participants stating that they hardly ever consulted the device saved nothing, while midpoint savings estimates for more frequent viewers ranged between 3 to 5 percent. The difficulty for the program designer comes with identifying who the frequent viewers will be *ex ante*. If this can be done, the program may be able focus its efforts on targeting such users directly. There may be several avenues of approach to achieve higher likelihoods of success in this regard.

Payment considerations may be important. Although the Focus study participants were required to express some willingness to pay for an in-home direct feedback device in order to be considered for the study, they were not required to share in the cost burden of obtaining the actual device. In fact, study participants were given a cash incentive, in addition to the PCM, in order to participate. It could be that requiring participants to purchase the PCM (even if at a subsidized price) would attract homeowners who were more serious about installing and using the device. Households making a monetary investment in the PCM may feel more obliged to use the device than those that do not.

Targeting more prolific energy users could also be important. Our findings show that savings were negligible for participants described by our sample's lowest quartile of pre-treatment usage levels. Participants in the lowest quartile may already have been electricity "sippers" prior to the study, without much opportunity for additional savings. Lowest quartile users may already be vigilant about turning off lights, appliances and electronics when not in use, or are already conservative in their use of electric resistance heating or air conditioning.

Finally, program designers should consider some social aspects of in-home feedback displays when advising participants and planning a marketing campaign. Some of the more prolific savers in the study (particularly homes with children) reported turning PCM consultations into a game, allowing family members to compete against each other in reducing their usage levels. Competitive behavior may be extended to various community groups, to include churches or other social organizations. Distributing the PCM at events organized by these groups could provide an added benefit to the program administrator: an opportunity to train and provide energy saving tips to participants in a single sitting.

How Participants Thought the PCM Helped Them Save Energy

Open ended responses to the mid- and end-of study surveys provide an indication of how participants used the PCM to save electricity. Participants were asked in both surveys whether or not they thought their electricity use had changed since the PCM was first installed. Responses from both surveys were similar, with participants most often citing that the PCM helped them conserve electricity in the following ways:

- The PCM led to a heightened general awareness of the household's electricity consumption and its associated costs.

- The PCM helped some participants “zero in” and reduce their use of appliances that had a large power signature. Appliances mentioned most frequently by these participants were electric dryers, air conditioners, television sets and electric kitchen appliances (toasters, coffee pots, ranges).
- The PCM prompted participants to pursue changes in home lighting, by either turning off lights when not in use or encouraging a household to transition from incandescent to CFL light bulbs.
- The PCM was a frequent reminder to shut off devices that were drawing power but not being used in other parts of the house. Devices that were commonly mentioned were personal computers and various electronics plugged into power strips.
- The PCM prompted users to experiment with thermostat and appliance settings. Air conditioning, refrigerator/freezers, dehumidifiers and water heaters were the end uses that were mentioned the most frequently.

There were several responses from the mid- and end-of-study surveys where the PCM resulted in interesting changes in behavior. These may be fruitful topics for further research. They are:

- Some families treated the PCM like a video game (e.g. “How low can we go!”).
- Some households mentioned conserving in non-electric end uses such as non-electric space and water heating (e.g. changing setback settings on a thermostat during winter, taking shorter showers, etc.).
- Some households mentioned that the PCM encouraged them to consider switching fuels for certain appliances (e.g. now considering a gas water heater).
- Responses indicate that the PCM induced some amount of load shifting (e.g. shifting laundry from day to night). We did not ask whether or not these homes were billed according to time of use.

Technological Considerations

The PCM offers several technological advantages over other types of direct feedback displays. The PCM is a relatively inexpensive device, retailing for under $125. Even at its low cost, the PCM is informative. It provides near-instantaneous feedback on electricity use, and converts energy use directly into dollars and carbon equivalent emissions. Finally, participants require no assistance from trained technicians to install the device; it can be mounted by homeowners onto an outdoor utility electric meter and does not need to be hard-wired into the home’s electrical system.

Despite being technologically simple, about 40 percent of respondents reported having some form of difficulty when installing the PCM. The most often cited source of difficulty was in aligning the PCM’s sensor to the electric meter’s indicator disc. Overall, 18 percent of the end-of-study survey respondents stated that they did not install the device (about two thirds of these tried, but could not). Designers and administrators should consider these attrition rates when projecting a program’s overall impact. Another disadvantage of the PCM is that because it is not connected to the home’s electrical system, it requires periodic battery replacement. Sixty-seven percent of respondents indicated that they changed batteries at least once during the study period. These participants reported replacing batteries anywhere from less than a month to more than 9 months after the PCM was initially installed. Finally, some types of electric meters may not be compatible with the PCM's sensor technology. Program personnel considering the PCM should conduct a field study to ensure that the PCM is compatible with the electric meters in their local service areas.

We queried participants in the end-of-study survey about what improvements they would suggest to make the PCM more useful. Although most suggestions were related to improving the ease of installation, programming the display and battery replacement (many users wanted a "plug-in" model without batteries), there were several respondents that desired an additional capability or added feature. These were:

- Several participants indicated a need for more refined end use level monitoring.
- Several participants indicated a need for some added data logging capability and/or additional statistical analysis. Some respondents would have liked to have seen average, maximum and minimum daily or weekly energy usage. Several respondents wanted this information to be accessible on their home PC or via the internet.
- Some respondents thought it would be helpful if the PCM had an audible or visual alarm that would activate when they surpassed a pre-programmed power threshold.

Conclusion

As one might expect, in-home feedback devices only save energy when program participants actively consult the device. Our results suggest that the median treatment group home in our study did not achieve savings at the levels often cited from the existing research on the general topic of direct feedback displays. We can state with reasonable certainty that participants who thought the PCM was helpful in reducing household electricity consumption saved a statistically significant amount of energy, although the savings are likely to be below 8 percent – and probably closer to 5 percent at the midpoint.

Open ended responses to our surveys indicate that the PCM is used by households to monitor energy use in a variety of ways, whether as a persistent reminder of household energy use, or as an in-home "energy detective" used to isolate and reduce usage of the most power hungry end uses within the home. Either way, an engaged household offers the best opportunity for success. The difficulty resides in identifying such households *ex ante.* Our results suggest that program designers may find pre-treatment usage levels to be a useful tool for increasing the likelihood of achieving non-negligible savings. However, the size of our sample precludes us from narrowly defining the range of pre-treatment usage that would lead to the greatest savings. Defining this range would be an interesting topic for future research.

Our study only encompasses a single technology, the PCM, which has its own unique set of technical features and attributes. Our study provides evidence that maintaining elevated user consultation rates with the feedback device can improve the probability of achieving savings. Survey responses from our study provide insight about some device attributes that may encourage higher levels of interaction with feedback displays. Some participants stated that they would be interested in using devices that track usage over time (and report back daily or weekly averages and ranges). Other responses indicate that audible or visual alarms may encourage viewers to consult a display when consumption exceeds a certain level. Finally, it may be beneficial to send feedback information to displays that users already consult on a regular basis (their home computer, personal web page, Wi-Fi enabled mobile devices, etc.).

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