Residential Smart Home Energy Monitoring Pilot

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ABSTRACT

In Spring 2009, a group of 100 volunteers was recruited to participate in Phase One of Cape Light Compact's Residential Smart Home Energy Monitoring Pilot (Pilot). Participants were encouraged to set household energy savings goals and received real-time feedback on their electricity usage and savings via an Internet-based dashboard.

An independent evaluation found that the self-selected participating households reduced their electricity consumption by an average of 9.3% (equivalent to 2.9 kWh per day) compared to two Control Groups. The energy use reductions are relatively high compared to other behavior-based feedback programs, although we believe this finding is reasonable in light of the group of motivated participants and effective program design. The strongest predictor of energy savings among participants was the frequency and nature of interaction with the home energy monitor.

In Fall 2010, qualitative interviews were conducted with a small sample of participants to investigate their continued engagement with the in-home monitoring system and to obtain feedback on what they would like to see in Phase Two of the Pilot. Participants reported that weekly e-mails from Cape Light Compact reporting their electricity use were important motivators to stay engaged. Participants reported using the internet dashboard less frequently, but in a more focused manner. The information used most often includes the comparison of their energy use with "neighbors," the hourly household load graph, and the participant bulletin board.

Recommendations for Phase Two of the Pilot included access to disaggregated energy use information, tailored comparison groups, and ways to get all family members involved in saving energy.

Introduction

Interest in residential energy use feedback and behavior-based programs is undergoing rapid growth. The growth of behavior-based programs can be attributed to two primary factors:

- Recent increases in energy efficiency goals stemming from both local and state policies (Kushler, 2009)
- The advent of the smart meter and new technologies to provide a platform for real-time energy use feedback to consumers (Erhardt-Martinez, et. al., 2010)

As noted by Erhardt-Martinez et. al., it is the use of effective real-time feedback to consumers that is the key to maximizing energy use reductions by households.

Background and Pilot Design

Cape Light Compact, working with the Northeast Energy Efficiency Partnership (NEEP) and GroundedPower[1], designed and implemented a Residential Smart Home Energy Monitoring Pilot (Pilot)

[1] Tendril announced, on October 19, 2010, that it acquired GroundedPower.

in 2009 to evaluate potential energy savings from in-home monitoring systems, gain insight to behavioral aspects of energy use, and inform future residential Smart Grid projects. A group of 100 volunteer households was recruited in Spring 2009 from Cape Cod and Martha's Vineyard. Participants were required to be full-time residents of Cape Cod or Martha's Vineyard, have average monthly household electricity use of at least 600 kWh, and have high-speed Internet access and a modem or wireless router in their home with an available Ethernet port.

A GroundedPower home energy monitoring system was installed in each household at no cost. Participants logged in to the system and viewed their electricity consumption via an Internet-based dashboard displaying real-time demand usage down to the minute. The website provided participants with a variety of details and options, including:

- Savings information (kWh, dollars, and CO_2)
- Monthly usage and totals
- Learn-and-commit-to energy saving actions (each with estimated savings)
- Household energy use distribution (based on detailed survey usage information)
- Energy use comparison against a cohort customer group
- Shared energy tips among participants
- Alerts to potential demand response events

Methodology

Process Evaluation Methods

For Phase One, in-depth interviews were conducted with program implementation staff, and a Computer Assisted Telephone Interview (CATI) survey was conducted with Participant and Control Groups. The CATI surveys were conducted in two waves. The first wave was conducted with two Control Groups in October 2009. Since in-home monitor installations were not completed until October 31, 2009, the participant survey was postponed until February 2010, to allow participants more time and experience with the energy monitors in their households. At the time of the surveys in February, a majority of participants had been active in the Pilot for five to eight months.

Interviews were completed with 66 of the 91 households in the Participant Group, a response rate of 72%. A quasi-experimental design with two Control Groups was employed to evaluate the Pilot:

- Interested Group: 204 households who expressed interest in Pilot participation, completed a screening questionnaire, but were not selected. A total of 96 questionnaires were obtained from this group (46% response rate).
- Blind Group: 400 households selected using a stratified random sampling process to mirror the characteristics of the Participant Group (i.e., geography and monthly kWh usage). A total of 100 completed questionnaires were obtained (25% response rate).

The Interested Group was used to help control for the potential self-selection bias resulting from soliciting volunteers for the Pilot. As described above, the Interested Group had also volunteered for the Pilot and presumably closely mirrored the characteristics of the Participant Group.

In Fall 2010, about 18 months after the Pilot began, follow-up qualitative interviews were conducted with a sample of ten participants to prepare for Phase Two of the Pilot.

Impact Evaluation Methods

A comprehensive energy use analysis was conducted, including an analysis of monthly energy consumption (kWh) across both time (previous year kWh against Pilot year kWh) and across the treatment and both Control Groups. The impact evaluation focused on the following questions:

- Is there a significant difference in electricity usage with in-home energy monitors (1) when compared to households without them, and (2) when compared to a participant's previous year?
- What are the characteristics of households that show a significant reduction in usage?

The eight month time-frame for which the impact data were available made conclusions about persistence tentative, especially if there were seasonal effects that must be accounted for.

Process Evaluation Results

Recruitment and Installation

Participants were recruited with a single short mention in a local newspaper. This single notice yielded 304 prospective participants. Based on eligibility criteria including year-round residency and monthly usage greater than 600 kWh, prospective participants were stratified by town of residence. A total of 100 households were systematically selected for the Participant Group. The remaining 204 households were notified that they were not selected. They formed the Interested Group.

During the installation period, there were a number of electrical box and connectivity issues, as well as cases where elected participants either could not agree upon an installation time, or cancelled scheduled installation appointments several times or more. These installation challenges resulted in a final Participant Group of 91 households.

Customer Survey Findings - Satisfaction

Participants reported high overall levels of satisfaction with the Pilot components (Table 1).

Table 1. Satisfaction with the Pilot Components

	Somewhat Satisfied	Very Satisfied
Actual home installation	8%	89%
Scheduling process for monitor installation	8%	88%
Assistance from Cape Light Compact	31%	63%
Experience using the online monitor	34%	61%
Technical assistance for the online monitor	32%	59%
Training materials available	41%	52%
Breadth of information available through the online monitor	36%	52%
Level of detail available through the online monitor	38%	50%
Actual cost savings to-date	43%	44%

Participants were asked “were you very dissatisfied, somewhat dissatisfied, somewhat satisfied, or very satisfied with [Pilot Component]. A total of 66 participants answered this question.

They were most satisfied with the actual home installation (89% "very satisfied") and the scheduling process for monitor installation (88% "very satisfied"). Two areas with the highest levels of dissatisfaction were the breadth of information available through the online monitor and the level of detail available through the online monitor (12.5% either very dissatisfied or somewhat dissatisfied).

Nearly 90% of participants (n=60) expressed interest in keeping the monitoring system once the Pilot ended. Of the participants who showed an interest in keeping the monitoring system post-Pilot, they indicated an average willingness to pay of $7.57 per month. However, 38% of those who expressed interest in keeping the monitoring system reported that they would not be willing to pay a monthly fee.

Household Monitoring System Use

Nearly half of the participants reported logging on daily or 3-6 times per week to view the dashboard (Table 2). At the other end of the spectrum, 20% of participants reported logging on less than once per week.

Table 2. Frequency of Logging onto the Online Dashboard Website

Frequency of Logging on to View Online Dashboard Website	**Percent Mentioned (n=66)**
Daily	26%
3-6 times per week	21%
1-2 times per week	33%
Less than 1 time per week	20%

Sixty-five percent of participants spent less than five minutes, while another 30% spent 5-10 minutes each time they logged on. Seventy percent of participants reported that they always viewed the house monitor graph when they logged on and slightly over half (52%) of participants always viewed their savings.

Participants rated the energy saving effectiveness of several aspects of the Internet dashboard (Table 3).

Table 3. Participant Rating of the Effectiveness of Online Dashboard Website on Reducing Household Energy Use

Online Dashboard Website Aspects	**Average Effectiveness Rating**
Visibility of real-time energy use (n=63)	8.2
Understanding of household energy use savings (n=65)	7.9
Understanding of household cost savings (n=66)	7.7
Comparison of energy use again set goals (n=65)	6.9
Suggested energy conservation actions (n=66)	6.8
Comparison of your energy use to a Participant Group average (n=66)	6.4
Understanding of household CO2 savings (n=63)	4.9

Participants were asked to rate each aspect of the online monitor, with "0" being not at all effective and "10" being very effective in helping them to reduce household energy use.

Participants rated the visibility of their household's real-time energy use, the understanding of their energy use savings and the understanding of their household electricity cost savings as the most effective aspects of the dashboard in helping them to reduce their household electricity use.

When asked what participants find most useful about the monitoring system, some participants reported turning on a single appliance and watching the real-time household energy use graph to see how it affected their energy use. Based on this type of detective work, participants reported energy saving actions, such as: buying a smaller television to watch "regular" shows and reserving the larger plasma screen unit for "special" shows; cutting the number of loads of laundry by one-half or more; turning computers and electronic equipment off at night; and installing energy-efficient light bulbs throughout the house.

Nearly 90% of participants reported that they had either "definitely" or "probably" reduced their household energy consumption since participating in the Pilot (Table 4).

Table 4. Reduced Household Energy Consumption since Participating in the Pilot

Reduced Household Energy Consumption Since Participating	**Percent (n=66)**
Definitely yes	62%
Probably yes	27%
Probably no	8%
Definitely no	3%

For those participants who said they had either probably or definitely reduced their energy consumption since participating in the Pilot, two-thirds reported that the savings they achieved met their expectations. Other participants, however, reported savings did not meet their expectations, either because they did not have realistic expectations or because they had already adopted many energy-saving measures and did not have a lot of room left for improvement.

Cape Light Compact had anticipated that some participants might be concerned about the security of online energy use data or sharing energy use information with other participants. About one-third of the participants reported they were somewhat or very concerned about the security of online energy use data, and 22% reported the same level of concern about sharing their energy use information with other participants.

Energy Impact Findings

Characteristics of Participating and Control Group Households

Differences in housing characteristics between participants and Control Groups, including age of the house and number of bedrooms, were minimal and did not reach statistical significance at the 0.10 level. The Interested Group tended to have slightly older houses and slightly fewer bedrooms than participants or the Blind Group. Household composition differences between the three groups were also slight. Other differences include:

- Participants and the Interested Group tended to have slightly higher education levels than the Blind Control Group.
- The Blind Group was somewhat more likely to have a minor or young adult living in the household.

- Income levels were similar between the Participant and the Blind Group, though average income of the Interested Group was slightly lower.

These findings support the notion that energy use differences across groups are less likely explained by differences in their housing characteristics and household composition and suggest greater validity for the impact energy analysis results presented later in this section.

Household Energy Use Habits and Tasks

One reason for the surveys of the participant and Control Groups was to examine differences in energy saving habits and tasks. We defined *habits* as actions that recur frequently and *tasks* as recurring less often, such as once every six months or more. Using a series of six habits (such as close the refrigerator door immediately after use, unplug chargers and power off external speakers when not in use, and use task lighting) and 15 tasks (such as plug electronic equipment into switchable power strips, check temperature of refrigerator or freezer, install ENERGY STAR indoor light fixtures, check the refrigerator door seals, and turn off ice maker) paralleling those offered on the energy monitor's online dashboard, we asked the Control Groups if they had undertaken these actions within the past six months. For participants, we asked if they had undertaken these actions since joining the Pilot, which represented about a six month period.

We expected that participants would exhibit higher levels of activity than the Control Groups; however, this was not our finding. Differences in these self-reported habits and tasks between participant and Control Group activities were negligible. The one exception is that participants installed ENERGY STAR indoor light fixtures more often than the Blind Group, though not more often than the Interested Control Group (significant at the 0.10 level).

We know from the energy analysis component of the impact evaluation (detailed below) that participants did indeed exhibit a reduction in kWh that was statistically significant at the 0.10 level, when compared to both Control Groups. There are several potential reasons that self reporting did not show a higher level of participant engagement across the energy-saving habits and tasks. Participants may have taken other effective actions to save energy that are not reflected in the survey items, although when asked about this in an open-ended question, most participants reported the in-home monitoring system had simply made them more aware of their consumption, and that this was important to their overall energy savings.

Another possible explanation for the lack of difference between participant and Control Group activities may be that the survey instrument was not subtle enough to pick up nuances of differences in the way the Participant and Control Groups undertook them or the regularity and intensity with which they undertook them. Still a third possibility is that respondents simply misstated what they had done, either succumbing to the pressure of social desirability or because they did not accurately recall what they had done. In any case, the survey results did not provide strong evidence for what caused the very real differences in consumption.

GroundedPower Login Activity

GroundedPower provided a weekly summary of participants' login activity from the Internet dashboard. The participants' dashboard login activity provided a valuable metric to gauge the level and consistency of Pilot engagement (Figure 1).

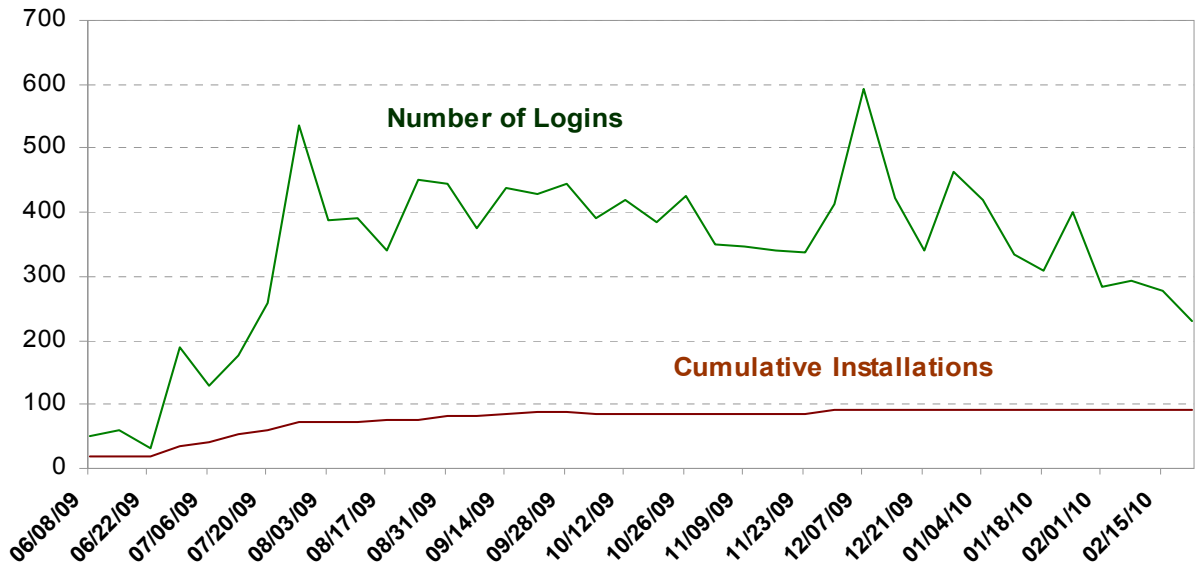

Figure 1. Participant Login Activity

System installations occurred during several months in the summer of 2009, increasing from 19 in June to about 75 in August. From August to December, an additional 16 installations occurred, resulting in 91 total installations. Once a majority of participants were installed, an initial spike in interest occurred in late July, then use remained consistently high (about 400 logins per week) through October. The logins exhibited a more erratic pattern in November through early 2010. It is possible that participant's holiday schedules contribute to these erratic login levels. Overall, the consistency in logins across the first half of the one-year Pilot point to a high level of engagement, with what may be the beginning of a drop-off in early February.

Energy Analysis of the Residential Smart Home Energy Monitoring Pilot

To evaluate the energy impact of the Pilot, we obtained monthly consumption data for the years 2008 and 2009 for the participants and the two Control Groups. We compared consumption during the study period with consumption during the same period in 2008 for all three groups. The study period consisted of the months July to December in 2008 and 2009.

Consumption Differences by Group

Table 5 shows the average daily consumption during the study period for the three groups and for a Blended Control Group that combines the Interested and Blind Groups.

Table 5. Average Daily kWh Consumption during the Study Period, By Group

Group	Number of Households	Pre-Study Consumption	Study Period Consumption	Difference	Percent Change
Participant Group	88	30.11	26.86	3.25	-11%
Interested Group	160	22.70	22.41	0.29	-1%
Blind Group	397	34.05	33.70	0.35	-1%
Blended Control Group	557	30.79	30.46	0.33	-1%

The table also shows the difference in consumption between 2008 and 2009 and the percent change between the two periods. Pilot participants reduced average daily consumption by 3.25 kWh, or about 11% compared to their comparable 2008 consumption. The Control Groups both reduced average daily consumption by less than one kWh, or about one percent.

The blended average consumption for the two groups combined is quite close to the average consumption of the Participant Group, at 30.79.

Figure 2 shows graphically the average change in consumption during the study period for the three groups. The figure also shows 90% confidence intervals around the average.

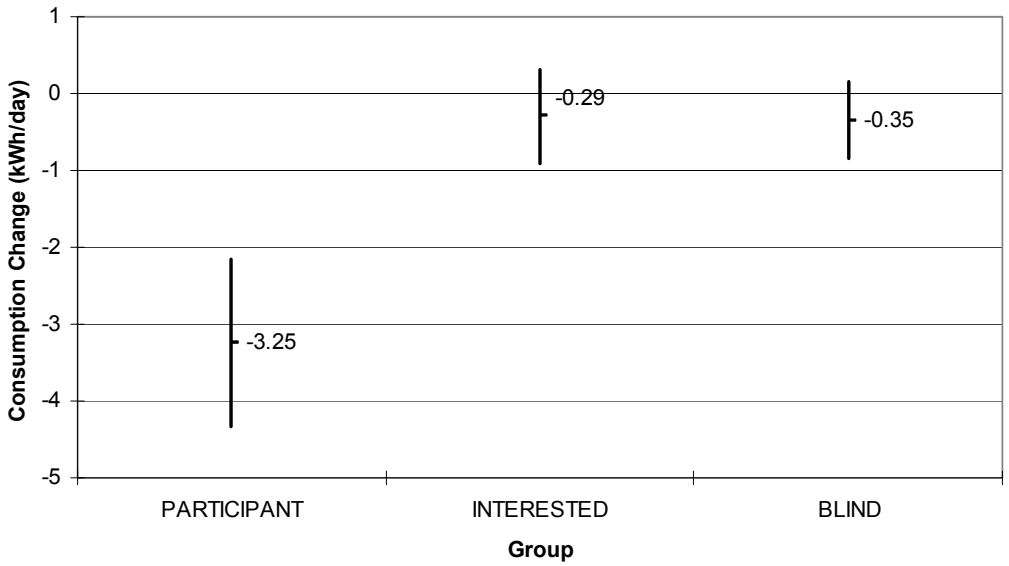

Figure 2. Change in Average Daily kWh Consumption, 2008 to 2009, by Group

The two Control Groups, however, are not clearly distinct from one another. A t-test confirmed that we should reject a null hypothesis that differences in the change in pre-and post-study consumption between participant and Control Groups reflect random sampling error.

The Effect of Weather Differences between 2008 and 2009 on Energy Use Reductions

Analysis of the heating and cooling degree days for the Cape Light Compact service area showed that the 2009 summer was generally cooler than the 2008 summer, with cooling degree days 1-17% lower in 2009 for the four regions in Cape Light Compact's service area. The pattern of differences in heating degree days between 2008 and 2009 is inconsistent, with three of the four regions showing a slight increase in 2009 (1-2%) while the fourth shows a slight decrease of 5%. Both Control Groups reduced consumption slightly between 2008 and 2009, most likely due to the slightly cooler summer in 2009 reducing the demand for energy to power HVAC cooling measures.

If we assume the total change in consumption for participants is composed of two parts, one related to the Pilot and one related to weather, we can use the change in consumption for the Blended Control Group as the amount of change attributable to the weather. If we subtract that average change of 1.1% from the average change for the Participant Group of 10.8%, this yields a 9.7% average reduction in energy consumption due to the Pilot, or an average reduction of 2.9 kWh per day (30.11 kWh x 9.7%).

The Effect of Participation in Other Programs on Energy Use Reductions

To avoid double-counting and to get an accurate estimate of the energy impacts attributable to the Pilot, we also accounted for the effect of participating in other Cape Light Compact programs on the Pilot energy impacts. A total of 41% of the participants and 19% of the two Control Groups reported participating in other Cape Light Compact programs during the study period. To control for the impact of participation in other programs, we calculated the difference in energy use between 2009 and 2008 for those participant and Control Group households who did not participate in any other Cape Light Compact Programs during the study period. This difference in energy use between 2008 and 2009 for the "No Other Program" participants and the "No Other Program" Blended Control Group was very similar and not statistically significant at the 0.10 level from the comparable difference for the full samples of participants and the Blended Control Group. However, the percent reductions in energy use from 2008 to 2009 for the "No Other Program" Participant Group (9.9%) and the "No Other Program" Blended Control Group (0.6%) yielded a difference of 9.3%. This is slightly lower than the 9.7% difference shown above for the full participant and Blended Control Group samples. Even though these differences were not statistically significant at the 0.10 level, we adopted the more conservative finding. As a result, the Pilot energy impact, taking into account differences in weather and participation in other Cape Light Compact Programs, is a 9.3% reduction in energy use for participant households. This is equivalent to an average reduction of 2.9 kWh (31.24 kWh per day x 9.3%).

The Distribution of Pilot Energy Savings

Not all Pilot participants saved energy. Of the 88 households who participated and for whom we have complete data, 23 actually used more energy in 2009 than in 2008. Among households that did reduce energy consumption, there was a fairly wide distribution of savings, with about one-third saving four or more kWh per day, on average (Figure 3).

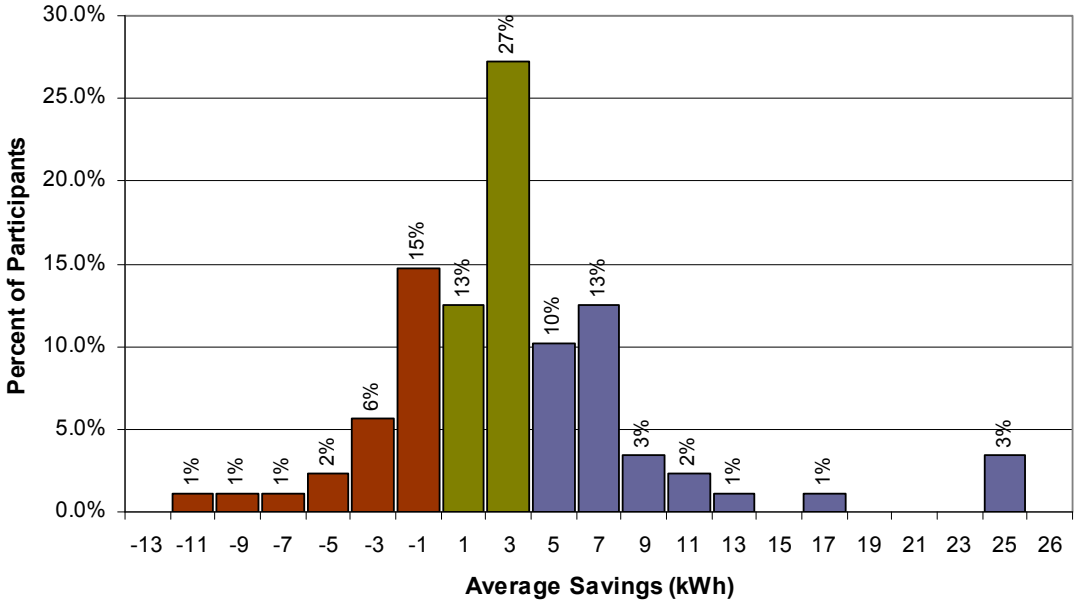

Figure 3. Distribution of Energy Savings for Pilot Participants

Characteristics of the "Large Savers"

In our analysis to identify the factors associated with larger energy savings, we classified the participating households into three groups:

- a "Negative Savers" group that used more energy in 2009 (including those who reduced by 1.3% or less, the weather adjustment)
- a "Small Savers" group that reduced their 2008 consumption by 1.3% to 11.3% (effectively zero to 10% when adjusting for weather differences)
- a "Large Savers" group that reduced their 2008 consumption by more than 11.3%.

We classified participants by percent reduction rather than kWh reduction to control for differences in normal average consumption. We compared reported behaviors, attitudes, and demographics between the three "Savers" groups.

These analyses pointed to differences in using the dashboard as the factor most likely to explain the differences in household energy savings between the Large, Small, and Negative Savers Groups. The Large Savers were more likely to log on daily, spend more time logged on, and to review their house monitor graph, actions, and savings when logging on than the Small and Negative Savers Groups. These differences were statistically significant at the 0.10 level.

We surmise that the higher frequency of reminders about positive habits and behaviors received by the Large Savers from more frequent and involved log ins explains the differences between Large Savers' and other groups' energy use. The greater frequency could be expected to increase the salience of all energy saving actions, whether noted on the site or otherwise, and to increase performance of the activities. This would decrease energy consumption.

Differences in self-reported energy-saving habits and tasks, attitudes about the benefits of energy savings, and demographic characteristics did not provide consistent or compelling evidence to explain the differences between the three groups of "Savers."

In effect, when participants claimed they "always" or "often" undertook habits and tasks, they were closer to the truth—i.e., meaning more actual actions—than Control Group respondents. There may have been a bias in the Control Groups toward over-stating performance of actions simply because they had many fewer reminders that they should do so. The more reminders, the stricter the standard of what constitutes "often" or "always." This hypothesis would also explain why participants who logged on less frequently saved less energy even though they claimed as many actions: they had fewer reminders of how often "often" actually is.

This can only be a partial explanation. Why did different participants log in at different rates? We have to expect that positive reinforcement of the activity would tend to encourage it; lack of reinforcement would tend to extinguish it. In this light, it will be interesting to observe the persistence of login activities and whether a possible drop-off of logins over time presages a decrease in energy savings.

Conclusions from Phase One

The evaluation demonstrates that the Pilot was successful on many fronts, including customer satisfaction and its objectives to save energy. Nearly all participants (90%) wanted to continue access to the dashboard and website, and more than 60% of those who wanted to continue would be willing to pay a monthly fee to do so.

The energy impact analysis showed that participating households decreased net electricity use by 9.3%, compared to the Blended Control Group. The energy impact result for the Pilot is high relative to other behavior-based feedback programs (PA Consulting Group, 2010). We believe this is a reasonable

finding, given the recruit of a self-selected group of customers with a high level of interest and likelihood of active participation in the Pilot. The design of the Pilot also sought to deeply engage participants in the habits and tasks of energy savings. A remaining question is whether this rate of energy savings can be maintained over time.

Because participants were volunteers, self-selection bias is a threat to the internal validity of the Pilot findings. To help control for the potential self-selection bias, an Interested Group was created, comprised of households who volunteered but were not selected for the Pilot. However, while the Participant Group was initially selected randomly, due to selected participant dropouts because of scheduling difficulties or lack of a compatible high-speed interest connection, ultimately the selection process did not strictly adhere to a random sampling process. As a result, it is possible that some pre-Pilot differences between the Participant Group and the Interested Group may account for some of the differences in energy use between the participants and the Blended Control Group.

The distribution of electricity savings among participants indicated that about 47% of participants reduced their consumption by 11.3% or greater (Large Savers), 27% reduced their consumption by 1.3 – 11.3% (Small Savers), and 26% either used more electricity in 2009 or reduced their consumption by less than 1.1% (Negative Savers). The primary factor differentiating the Large Savers from the other two groups was the frequency, length of time, and information sought when logging on to the dashboard.

We were not able to assess the sustainability or persistence of energy savings within the evaluation time period. The recommendations from both the process and impact evaluations, however, suggest several strategies that could assist in both initial energy savings and the sustainability of energy savings over time.

Follow-up Interviews with Customers

In October 2010, about eighteen months after initiation of the Pilot, qualitative interviews were conducted with a sample of ten Pilot participants to investigate their continued engagement with the in-home monitoring system, identify any changes in household energy use and goals and behaviors, obtain feedback and suggestions on changes or features they would like to see in the Pilot.

Continued Engagement with the In-Home Monitoring System

Most of the participants interviewed reported using the Internet dashboard less frequently, but still, in most cases, at least once per week. Many reported they learned what they needed to know about their household and electricity use and didn't need to view the dashboard as frequently as before.

The hourly graph was still the primary piece of information they looked for when they accessed the dashboard. Participants also generally paid attention to the comparison of their household's electricity use to other similar households. For some, it was motivating to see that they were saving energy and doing as well or better than most others.

The weekly e-mails from Cape Light Compact showing their consumption for the week were viewed as an important motivator and reminder to keep track of their household energy use.

Suggested Improvements to the Pilot

The most frequently mentioned suggestions for improvements included:

- Some type of follow-up, perhaps based on the Home Self-Audit, to provide information and specific "how to" advice on additional energy efficiency and energy savings actions that could be implemented
- More detailed and disaggregated end-use information that would enable participants to tie electricity costs directly to specific appliances and end-uses.
- The ability of the in-home monitoring system to work with solar photovoltaic installations or other new technologies that will be available to homeowners.
- Energy use norms tailored to specific types of households, such as households with infants or young children present, households with a home office, and homes of different sizes (square footage) to make "apples to apples" comparisons of energy use.
- Ways to get the whole family involved in paying attention to their energy use behaviors, including children.

Phase Two – Residential Smart Home Energy Monitoring Pilot

Cape Light Compact is proceeding with Phase Two of its Pilot. It has completed the procurement process, hired an implementation vendor and developed a project work-plan. It will employ technology similar to that used in Phase One, with the addition of an in-home display and upgraded dashboard. Cape Light Compact hopes to increase residential participation, as compared to Phase One, and also include a sample of Commercial and Industrial participants. Completion of Phase Two is planned for Fall 2012 and will include a concurrent evaluation including review of savings that may continue from Phase One participants and similar process and impact estimates for Phase Two.

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