Effectiveness of In-Home Feedback Devices in Conjunction with Energy Use Information on Residential Energy Consumption

By

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ABSTRACT

Residential energy consumption accounts for 22% of the total energy use in the United States. The consumer's perception of energy usage and conservation are very inaccurate which is leading to growing number of individuals who try to seek out ways to use energy more wisely. Hence behavioral change in consumers with respect to energy use, by providing energy use feedback may be important in reducing home energy consumption. Real-time energy information feedback delivered via technology along with feedback interventions has been reported to produce up to 20 percent declines in residential energy consumption through past research and pilot studies. There are, however, large differences in the estimates of the effect of these different types of feedback on energy use. As part of the Energize Phoenix Program, (a U.S. Department of Energy funded program), a Dashboard Study was conducted by the Arizona State University to estimate the impact of real-time, home-energy displays in conjunction with other feedback interventions on the residential rate of energy consumption in Phoenix, while also creating awareness and encouragement to households to reduce energy consumption. The research evaluates the effectiveness of these feedback initiatives. In the following six months of field experiment, a selected number of low-income multi-family apartments in Phoenix, were divided in three groups of feedback interventions, where one group received residential energy use related education and information, the second group received the same education as well as was equipped with the in-home feedback device and the third was given the same education, the feedback device and added budgeting information. Results of the experiment at the end of the six months did not lend a consistent support to the results from literature and past pilot studies. The data revealed a statistically insignificant reduction in energy consumption for the experiment group overall and inconsistent results for individual households when compared to a randomly selected control sample. However, as per the participant survey results, the study proved effective to foster awareness among participating residents of their own patterns of residential electricity consumption and understanding of residential energy use related savings.

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Chapter 1

INTRODUCTION

Research Overview

Residential energy use. Residential homes now account for 22 percent of the total primary energy use in the United States according to the Energy Information Administration (EIA) (2010), and 54 percent of consumption in the building sector. Of the total energy consumption in an average household, 50% goes to space heating, 27% to run appliances, 19% to heat water and 4% goes to air conditioning.

Table 1.

Household Site End-Use Consumption & Expenditures in the U.S., Totals and Averages, British Thermal Units (Btu)(Energy Information Administration, 2009)

Average Site Energy Consumption (million Btu per household using the end use)						**Average Energy Expenditures (dollars per household using the end use)**					
Total	Space Heating	Water Heating	Air Condi-tioning	Refrig-erators	Oth er*	Total	Space Heating	Water Heatin g	Air Condi-tioning	Refrig-erators	Oth er*
89.6	38.7	16.0	6.8	4.3	26.7	2,024	593	280	237	153	827
100%	43%	18%	8%	5%	30%	100%	29%	14%	12%	8%	41%

*"Other" includes end uses not shown separately (e.g., cooking appliances, clothes washers, dryers, dishwashers, televisions, computers, small electronic devices, pools, hot tubs, and lighting

The average household spends at least $2000 a year on energy bills with over half going to heating and cooling and almost a third going towards appliance, electronic devices and lighting.

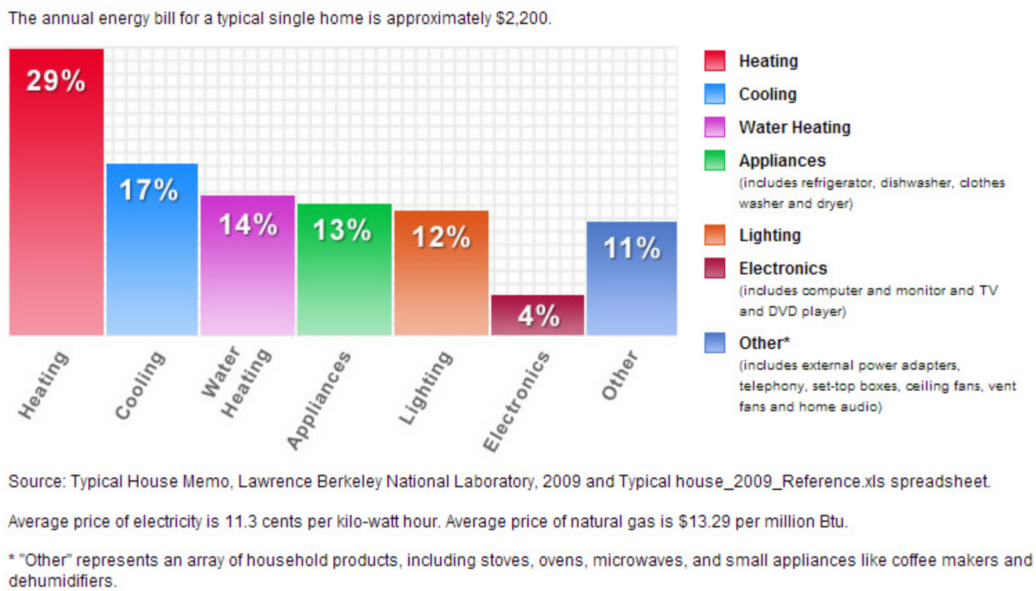


*Figure 1.*Annual Energy bill for a typical home (www.energystar.gov)

The EIA reports that there is a growing trend in electricity use every year through these end uses and engaging energy consumers can influence their usage. If individuals can experiment with energy in their homes or workplaces and see the consequences of their usage through frequent meter reading, improved billing or some sort of dedicated display, control over their consumption is increased. Readily available, easily accessible, real-time information feedback delivered via technology is reported to produce important declines in residential energy consumption (Faruqui et al., 2010; Ehrhardt-Martinez et al., 2010). The conservation effect varies according to circumstances, but participants in feedback trials have typically reduced their energy consumption by up to 10% when given ‘indirect’ feedback and between 5% and 15% when they use ‘direct’ feedback (Darby, 2006). Other estimates of the energy savings from feedback technologies vary widely, from none to as much as 20 percent too. (Faruqui et al., 2010; Ehrhardt-Martinez et al., 2010). Recent studies have shown that real-time feedback can be a powerful stimulant for behavioral change when coupled with other interventions such as competition (Petersen et.al., 2005) and visual displays (Matsukawa, 2004; Petersen et al., 2005; Ueno et al., 2006).

Energize Phoenix Program Background

The Energize Phoenix program is a U.S. Department of Energy (DOE) funded program conducted in partnership with the City of Phoenix, Arizona State University, and Arizona Public Service. The program was funded with a $25 million federal grant from the DOE Better Building Program and the American Recovery and Reinvestment Act (ARRA) with the a goal to save energy, create jobs and transform a diverse array of neighbourhoods along a 10-mile stretch of the light rail line in Phoenix. Figure 2 shows the Energize Phoenix program boundary and the light rail line central to this boundary.

The program's specific goals are to reduce home energy consumption by 30% and commercial energy use by 18% and eliminate carbon emission by as much as 50,000 metric tons per year. In addition to these goals of increasing energy efficiency by transforming infrastructure in the corridor, the project also aims to promote savvy energy consumer practices.

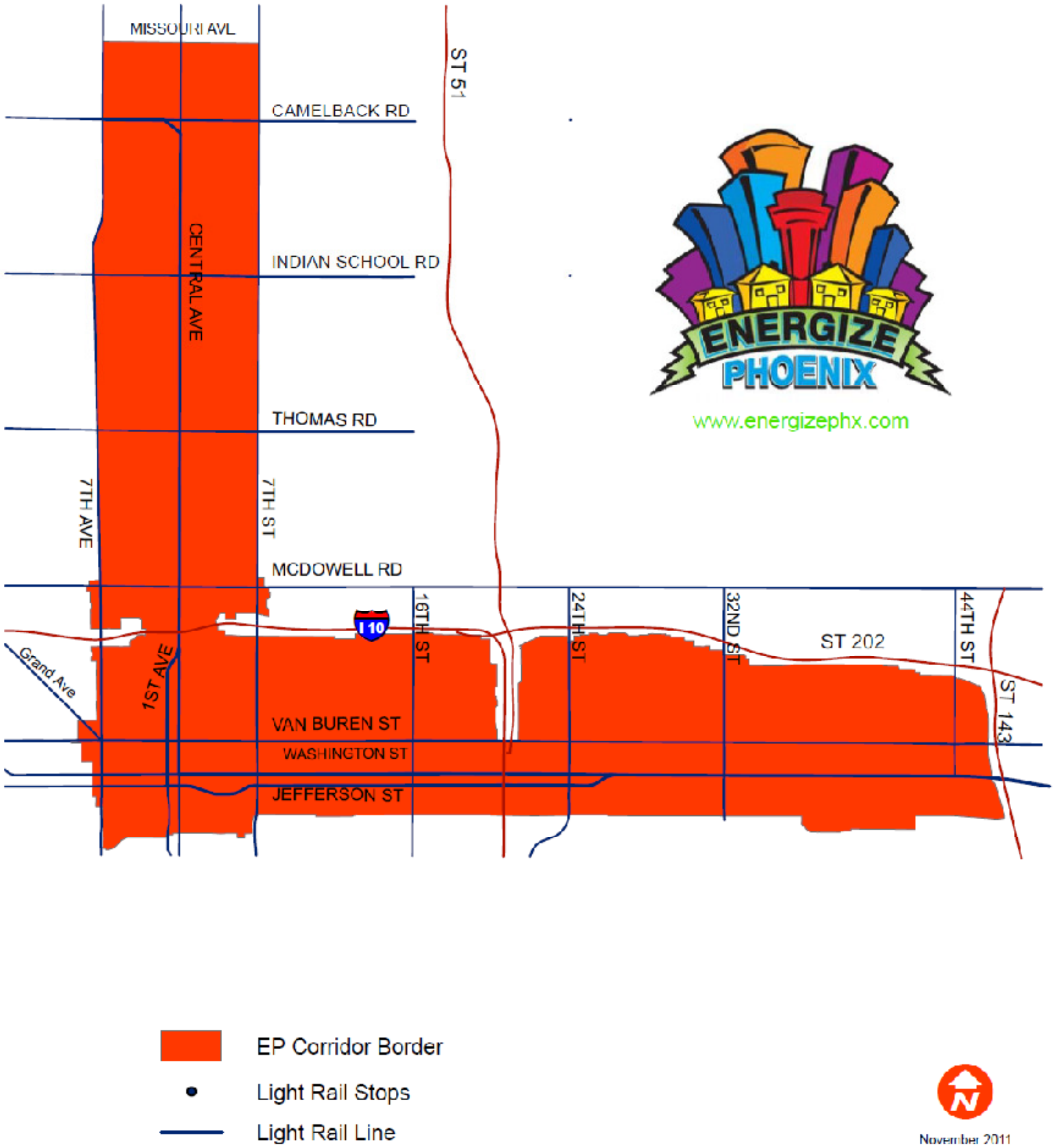


Figure 2. Energize Phoenix Corridor (www.energizephx.com)

Energize Phoenix Dashboard Program

The Energy Dashboard program, a sub-study of the Energize Phoenix program, teams Arizona State University with Phoenix's Neighborhood Services Department to measure the effectiveness of education and feedback strategies in reducing energy waste for Phoenix home renters. This program and study sheds light on an understudied population of energy users through two different interventions:

- An energy dashboard device, installed at no cost, provides renters with real-time feedback about the home's energy usage.
- An energy use awareness assessment and education program that provides renters with information about major appliances and other energy factors, such as window shades, thermostat, and fans.

Problem Statement

According to the EIA (2011), the projected electricity will increase by about 25% over the period 2012 through 2035 in the United States. A variety of demographic and economic factors will drive this trend, especially as they influence residential air conditioning, cooking and the use of consumer electronics and appliances, which EIA suggests will grow 10, 38, and 48%, respectively. These particular end uses are also among those that are likely to be influenced in response to the effective introduction of new feedback programs and technologies.

While the relative importance of electricity consumption in the residential sector continues to grow, so too has the level of interest in engaging energy users in new ways. This renewed attention to the human dimensions of energy consumption has enabled a fresh look at how a more informed understanding and increased levels of awareness and engagement might reshape energy use practices in a positive and cost effective manner. Based on this perspective, there is also a shift toward a 'people-centered' approach to generating greater levels of energy productivity as well as also emphasizing a technology-based approach.

Though real-time information feedback delivered via technology, along with other energy use feedback interventions, has been reported to produce up to 20 percent declines in residential energy consumption through past research and pilot studies, there have been large differences in the estimates of the effect of these different types of feedback on energy use. Therefore, there is further need to evaluate the effectiveness of this technology driven feedback in conjunction with other energy feedback interventions and motivational information which could further enhance reductions in residential energy consumption.

Although several studies have looked at the impact of feedback technology, providing insights into study design, technology features, and characteristics of the people using the feedback devices impact the energy savings estimates, several questions remain. To determine if feedback technologies are cost-effective measures to manage energy demand, it is necessary to assess whether they provide persistent energy savings and how they change consumption profiles. This study, conducted in a metropolitan city, Phoenix, Arizona, investigates whether a simple, commercially available, whole-house electricity monitor, along with education/information sessions as an added intervention, can be effective in impacting residential energy consumption while alsoteaching residential users about their electricity use. Part of this research also examines whether there is a difference in energy use impacts for the participant group equipped with the home-energy display and education and the other participant group treated with only education as an intervention, to better understand the impact of real-time energy use feedback. Ultimately, this field experiment investigates the impact of attitudes and household characteristics on the effectiveness of energy feedback in general, and on the potential success of real-time feedback in a residential setting.

Low-income, multi-family housing groups have been an understudied demographic. The feedback studies done in the past have mostly been conducted for home owners rather than renters. This group which was selected for the study exceeded their monthly dollar allotment for electricity which gives the people of this demographic a purpose and need to look for accurate measures to understand their energy use. Though the initial design of the study started for single family home owners, due to various problems regarding recruitment of this demographic occurred, especially with receiving individual consents from all participants across the light rail corridor, it was decided that project would shift towards a multi-family housing. Most of the multi-family housing renters in the Phoenix light rail boundary were low-income group and hence the program was further compelled to shift to this demographic for the study.

Research Objective

This research aims to estimate the impact of real-time energy feedback through in-home energy display in conjunction with an information and motivational intervention given to the multi-family housing residents. In addition, it investigates the effectiveness of different conditions of feedback interventions given to the residents. To investigate the effectiveness of feedback in conjunction with energy use information, this research has the following objectives in particular:

- To analyze the energy savings/loss between the pre-study and post-study period overall, to see if there were any significant savings due to feedback interventions.
- To analyze and compare each group condition to see if there were any significant differences in energy use. The group conditions were as follows: the first group received only education; the second received the same education and information as well as the In-home energy display device, and the third group which received education, the In-home display device and an added motivational intervention, in this case budgeting information.
- To analyze the effect of orientation and position of the apartment on energy savings/loss due to feedback interventions.
- To analyze range of energy savings for individual participants within each group to understand the impact of a feedback device by itself, a feedback device in conjunction with education, and a feedback device with education and budgeting information.

The selected low-income study residents receive a nominal monthly allotment towards their electric bill, which communicates their monthly electricity use that exceeded the specified allotment amount. The residents are not provided their actual energy usage or their allotment amount on their monthly electricity bills. Most of the residents do not have a clear understanding of their electric energy use and billing.

Based on the deficiencies related to informative billing, this study also aims to;

- Foster awareness among participating residents of their own patterns of residential electricity consumption and understanding of energy use related savings.
- Analyze the participant surveys collected during the study to determine their understanding of their energy consumption and monthly billing.
- Analyze the participant survey results with energy savings or loss to determine a trend or identify an explanation for particular findings in the results.

Potential Contribution

This research is going to measure the effectiveness of different feedback intervention conditions within a study group and compare the results to determine whether the results of technology driven feedback along with education help in energy savings. This will determine the importance of conducting education an important part of feedback driven studies. Additionally it will also explore if the added motivational information effects residents which receive the education as well as the in-home display device.

The research study will also help the low-income multi-family housing understand their energy related consumption and create awareness about energy savings.

Thesis Organization

The thesis is organized as follows based on the objectives of this research,

Chapter 2 reviews behavior and feedback related literature with respect to energy consumption. Different feedback types and their effects on energy savings are described, in addition to other program related variables that also influence energy savings. The intersection of these variables on energy savings is also discussed. Residential feedback technologies prevalent in the residential sector and descriptions of the device technology used for this study is then discussed. Next, selected pilot program and past literature papers were studied to summarize the learning from them.

Chapter 3 explicates the methodology used in this research by first recalling the learning from the literature discussed in the previous chapter, after which an explanation of the low-income multi-family complex selection and the study scope with its limitations are discussed. The description of the selected housing complex related details are then discussed. This chapter then describes the experiment design, the process of the study itself, and the challenges faced due to the specific demographic and feedback device selected. The data collection and an overview of its analysis are also discussed.

Chapter 4 illustrates the detailed analysis of the data results with respect to overall study period data, monthly data and data based on individual residential units. Study results based on participant survey data are also discussed to see its co-relation with the data results. In addition device related data information is also discussed.

Chapter 5 provides conclusions based on the data and survey results, possible explanations for the data results, future work, and recommendations.

Chapter 2

BACKGROUND LITERATURE

This chapter presents literature and references necessary to understand types of energy consumption feedback and their capability, the development of the experiment design, and tools to analyze the energy use impacts of the feedback interventions.

The literature includes references from many fields. In the beginning sections various types of energy use feedbacks and their effectiveness is reviewed through past research and pilot studies. These sections review behavioral related papers indicating the influence of feedback in energy conservation and the energy savings that can be achieved. Next, feedback technologies prevalent in a residential sector are described. Examples of products that already give some consumption feedback are also discussed in this section. The next section gives a description of the in-home feedback device used for the study, The Energy Detective(TED) 5000. Other references about the method used for weather normalizing data before analysis, have been discussed for calculating the feedback impacts on energy consumption.

Behavior Literature

Types of Energy Behavior. To achieve the goal of reducing residential energy consumption, a number of related tasks are essential and the first among those is a well-researched understanding of existing energy and uses, including the types of behavior associated with these different end uses. A second, but related task, involves identifying those behaviors that are most malleable and the types of interventions that are likely to have the largest impact. Another way of understanding existing energy and use patterns is to identify the different types of behaviors that cause them. Figure 2provides a typology of energy behavior as a function of the frequency of the action taken and the economic cost associated with the undertaking of that action. (Ehrhardt-Martinez et. al., 2010).Energy related behavior can be categorized into three different categories as suggested by Ehrhardt, Donelly & Laitner (2010): 1) Energy stocktaking behaviors and lifestyle choices; 2) Habitual behavior; and 3) Consumer behaviors, technology choices or purchasing decisions

Energy stocktaking behaviors and lifestyle choicesare infrequent and low or no cost, for instance, installing compact florescent lamps (CFLs), weather-stripping, or choosing to live in a smaller apartment or house. Habitual behavior must be repeated frequently, for instance, habits associated with appliance use, lighting and electronics usage and the frequency of turning these devices off.Consumer behaviors, technology choices or purchasing decisionsinvolve buying energy-efficient products and appliances. (Laitner et al., 2009a).

Table 2.

Energy Behavior as Function of Frequency and Cost*(Ehrhardt, Donelly & Laitner, 2010)*

	Frequency of Action	
	Infrequent	***Frequent***
Low-cost / no cost	ENERGY STOCKTAKING BEHAVIOR Install CFLs Pull fridge away from wall Inflate tires adequately Install Weather Stripping	HABITUAL BEHAVIORS AND LIFESTYLES Slower Highway Driving Slower Acceleration Air Dry Laundry Turn Off Computer and Other Devices
Higher cost / Investment	CONSUMER BEHAVIOR New EE Windows New EE Appliances Additional Insulation New EE Car New EE AC or Furnace	
These include habits, lifestyles, technology, purchases or investment decisions, technology use and maintenance		

How feedback influences behavior. Different characteristics of feedback influences behavior and in turn the energy savings differently. Three such characteristics are describes below.

Frequency of feedback.When feedback is frequent it is seen to be more effective (Abrahamse et al., 2005;Darby, 2006; Fischer, 2007). Feedback-related energy savings for direct feedback range from 5% to 15% (Darby, 2006).

Whether the feedback is direct or indirect. Savings from Indirect feedback generally ranges from 0% to 10% (Darby, 2006), but it varies depending on the context and the quality of information given to the consumer. In the case of direct feedback through in-home displays, the consumer receives instantaneous information about their smaller end uses. Savings from such motivated participants was reviewed to range from 10-20% (Darby, 2006).

Whether the feedback provides contextual frameworkby which the individual can evaluate his/her performance. According to Abrahamse(2006), when there is a sense of comparison between either a historical consumption and/or between households, there is sense of competition or social pressure. This might play an important role in determining actual energy savings.

Feedback Types

Early classification (Darby, 2000). The most useful means of categorizing different types of feedback is whether it's direct or indirect. According to an early study, Darby (2000) identifies five types of feedback: direct, indirect, inadvertent, utility controlled and energy audits.

Direct feedback. According to Darby, direct feedback is available on demand and includes direct display or in-home monitors as well as interactive feedback through personal computers.

Indirect Feedback. Indirect feedback involves the processing of utility data that is sent out to consumers by the utility company or a third party. Consumers are thought to learn from indirect feedback by reading and reflecting.

Inadvertent feedback. Darby's classifications identify inadvertent feedback as involving a less systematic form of learning associated with the adoption of new energy using equipment and social learning contexts. This type of learning occurs through association.

Utility controlled feedback. A fourth type of feedback, which is utility controlled learning, is not geared toward learning on the part of the consumer, but on the part of the utility.

Finally, the fifth category focuses on energy audits that are identified as type of feedback that provides baseline information as opposed to a source of continuous information.

Recent Classification according to Electric Power Research Institute EPRI (2009). A more recent study (EPRI, 2009) builds on Darby's distinction between direct and indirect forms of feedback, but develops a somewhat different classification scheme. The EPRI classifications are presented in Figure3. While both characterizations recognize the important difference between direct and indirect feedback, the EPRI approach further refines this distinction based on the availability of information provided by particular type of feedback as well as the cost to implement. The feedback types according to EPRI (2009)are described below.

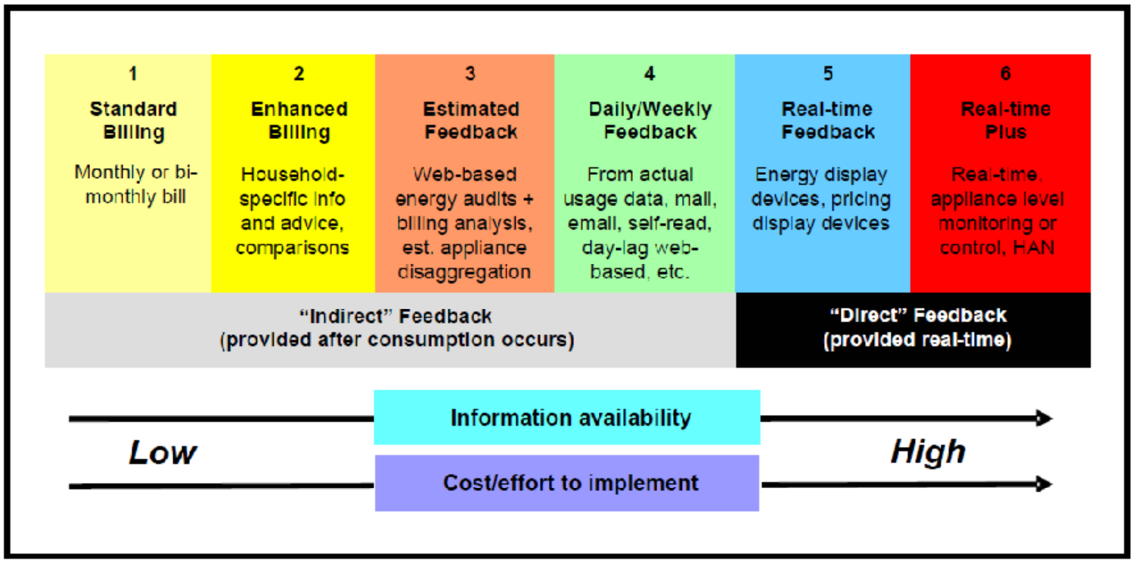


Figure 3.Types of Feedback(EPRI 2009)

Standard billing. An energy bill that displays the monthly kilowatt-hour (kWh) of consumption and the unit rate ($/kWh), the corresponding total cost and other billing charges, as well as the total amount due. This form of feedback generally lacks comparative statistics or any detailed information about the temporal aspects of consumption

Enhanced billing. Provides more detailed information about energy consumption patterns, and often includes comparative statistics, either comparing the most current monthly electricity usage and expenditures together with historical consumption and /or a comparison to other households

Estimated feedback. This approach uses statistical technique to disaggregate the total energy usage based on a customer's household type, appliance information and billing data. The resulting feedback provides a detailed account of electricity use by major appliances and devices. These most commonly take the form of web based "home energy audits" tools, offered by a utility to its customers.

Daily/Weekly feedback. These reports use averaged data in which the individuals read their meter and record the energy usage themselves, as well as studies in which individuals are provided with daily or weekly consumption reports from the utility or research entity.

Real-Time feedback. In home energy display devices that provide real-time or near real-time energy consumption and energy cost data at the aggregate household level

Real-Time plus. In home energy display devices that provide real-time or near real-time energy consumption and energy cost data disaggregated by appliance.

Program Related Variables Influencing Energy Savings

A review of past research was done for 57 studies and the outcomes of these different variables were summarized by Ehrhardt, Donelly and Laitner (2010). Energy savings can be influenced by other program variables as well those mentioned above. This review builds on earlier reviews of feedback-related savings (Darby, 2006; Fisher, 2007;EPRI, 2009). Ehrhardt, Donelly and Laitner (2010), explore the relationships and importance of variables with respect to energy savings. Below are the variables.

Feedback type and energy savings. This section will discuss57 studies reviewed by Ehrhardt, Donelly and Laitner (2010), that fall into five relevant feedback categories, i.e. three that are indirect feedback, (enhanced billing, estimated feedback, daily/weekly feedback) and the two that are direct types of feedback (aggregate real-time feedback and appliance-specific or disaggregated real-time feedback). Based on the summary of those 57 studies, this section will reviews the effect of different feedback types on energy savings.

Enhanced billing. Approximately11 studies out of the total 57 reviewed this feedback type. The savings ranged from 1.2 to 10% across these 11 studies. This feedback type of intervention averaged a 5.2% in energy savings.

*Study example 1.*The reported savings ranged from 2 to 2.5% in various assessments of the enhanced billing program by Sacramento Municipal Utility District (SMUD, April 2008 to 2009)that used social norms to reshape energy consumption behavior. This study was based on the idea that residential energy consumers can benefit from being provided a point of comparison from which they can assess the reasonability of their levels of energy consumption. Comparative information can be provided in the form of historical data or social comparison.

Study example 2. A more complex, multi-component study in Denmark by Nielsen (1993) achieved savings as high as 10% in single-family household and only 1% in apartments. This study provided feedback via enhanced billing and also offered households the opportunity to receive consultation with a utility representative to assess potential means of achieving energy savings.

Study example 3. A study by Staats et al. (2004) combined feedback though enhanced billing with the use of commitment strategies, group interventions and social interaction to assess both short-term and long-term impacts. It was noticed that after seven-month intervention period, the study had achieved 5% energy savings, and two years later, an increased savings of 8% despite the lack of any subsequent intervention, indicating that a well-designed program can result in persistent savings.

Estimated feedback. Three studies published between 2006 and 2007 investigated the use of web-based tools to provide consumers with estimated feedback, which resulted in two of the three studies having savings of 5.1 to 8.5% (Abrahamse et al.,2007;Benders et al., 2006), and the remaining study (Elliot et al., 2006) reported no significant savings.

The purpose of this remaining study (Elliot et al., 2006) was to test if online (and through mail) feedback could be used to increase peak period savings above and beyond the peak rate structure. The study found that participants did have savings, but were not very significant. It was noted that the savings achieved were not limited to peak events, but instead tended to be distributed somewhat evenly across time.

Daily/weekly feedback. A total of 15 studies were involved and reviewed concerning the provision of daily/weekly feedback. The savings represented with this type of feedback ranged from 3.7 to 21%. Energy savings varied greatly from 4% in an early study of the effect of daily cost feedback on residential electricity consumption to 21% in a complex Finish study (Haakana et al., 1997) of 105 district heated, single-family houses. Savings of 10% or more were reported by roughly two-thirds of the studies using this type of feedback and among those the higher level of savings was mostly from combined multiple approaches.

Study example 1. The Finish study (Haakana et al., 1997) provided targeted feedback to households involved in the program, including historical and social comparison. In addition, households were given additional household related energy saving tips.

*Study example 2.*Hayes and Cone (1997)achieved energy savings of 18% by combing a price rebate scheme with the feedback.

*Study example 3.*Brandon and Lewis (1999) achieved 12% savings through a program that included the use of comparative and historical norm.

*Study example 4.*In a California study of nearly 1000 households, Nolan (2008) received savings of 10% through the use of descriptive norms. Results show that normative messaging can be a powerful persuasion lever, but its influence is under detected according to the findings of the study.

*Study Example 5.*Another study by Winett (1982) combined goal setting, commitment, modeling, information and feedback, which resulted in 15% electricity savings on an average among the participants.

Notably, pilots and programs that used daily/weekly feedback mechanisms have typically relied on relatively low-tech means of implementation. Of the studies reviewed, most relied on the use of feedback cards, door hangers and other hand written methods to inform participants of their energy consumption patterns and savings. These strategies have been labor intensive and difficult to scale up. However, more modern, higher-tech applications are possible and could provide the opportunity for significant savings on a large scale without the use of in-home devices, for instance, using web-based technologies to communicate weekly or daily energy use information. The prior studies suggest that this type of feedback maybe especially effective at catalyzing household energy management associated with heating and cooling, water heating and other large energy uses.

Aggregate, real-time feedback. A total of 23 feedback studies were involved in the application of real-time aggregate feedback, which represented 47% of all the feedback studies reviewed. Energy savings associated with real-time aggregate feedback varied widely, but typically fell between 0.5 to 18%. Some of the program methods and their observation used for the studies of this feedback type were as follows

Study Example 1. A study where an energy efficient home was involved, the authors concluded that the savings achieved through feedback were behavioral change and that behavior can result in significant savings (McClelland and Cook, 1979). In-home energy monitors were used in this study.

Study Example 2. A study used an outdoor device that notified participants when the outdoor air temperature fell below a temperature threshold, promoting customers to turn off their air conditioning. This simple feedback resulted energy savings of 15.7%(Seligman et al., 1978).

Study Example 3. A study found that people with favorable attitudes were likely to conserve more energy savings, while senior citizens were likely to conserve less. The study used Blue Line Power cost monitors.

Study Example 4. A study resulted savings as a result of program that combined in-home monitoring devices with a pay-as-you-go program(Pruitt, 2005). The study used SRP M-power monitor in 2600 Arizona households

Study Example 5. In a dorm study, dorms that received weekly feedback in conjunction with competitions revealed a savings of 32% and dorms that received real-time feedback in conjunction with competitions revealed a savings of 55% (Petersen et al., 2006).

Study Example 6. A study that focused on reducing peak demand and participating in the time-of-use pricing structure did not result in any savings, but did contribute to shifting use from peak to off-peak periods. The study's focus on peak load shifting resulted in an overall increase in household energy consumption, i.e. 5%(Sexton et al 1987). A more recent study used both critical peak pricing and peak time rebates, and the peak savings ranged from 17 to 33% across study groups, however total savings were only 0.5%. Feedback applied to peak load shifting tends to result in less overall energy savings.

Disaggregated, real-time feedback. Only 5 studies focused on the provision of disaggregated, real-time feedback out of the 57 reviewed. Except for one study, which did not have any reported savings, the rest reported overall savings of 9 to 18%.

Study Example. One of the studies of real-time, appliance-level feedback in the UK, tested for the effects of both the feedback and energy information when compared to the control group. Households that received the 'Energy Consumption Indicator,' i.e. the feedback, saved more than the control group. Households that received feedback with information had a higher energy savings compared to the households that received information only.

Summary of energy savings comparison by feedback type. A comparison of feedback induced energy savings by type of feedback is provided in Table 3. As shown, median household savings varied from 5.5% for programs that employ enhanced billing strategies to 14% for those that provided real-time feedback disaggregated by energy use. While aggregate, real-time feedback has recently gained much popularity, evidence from the field suggests that this type of feedback tends to generate modest levels of household energy savings. While these differences between feedback types are important, it is equally important to note the significant variation between each of the feedback categories. This variation suggests that while the type of feedback is important, other less prominent variables are also equally important in shaping feedback-related savings. Those other variables are motivational elements and other program design characteristics like study size, study duration and regional context and culture.

Table 3.

Average and median household energy savings by feedback

	Number of Studies		Range of Savings	Average Savings	Median Savings
Type of Feedback	#	%	%	%	%
Estimated Feedback	3	5%	5.1 - 8.5%	6.8%	6.8%
Real time Plus	5	11%	9.0 - 18.0%	13.7%	14.0%
Enhanced Billing	11	19%	1.2 - 10%	5.2%	5.5%
Daily/Weekly	15	26%	3.7 - 21.0%	11%	10.8%
Real Time Aggregate	23	39%	-5.5 - 32.0%	8.6%	6.9%

Motivational elements and energy savings.Many research papers suggest that non-economic factors can provide an important source of motivation for energy savings in a residential sector. Despite the growing recognitions of these factors, only 18 studies of the 57 used non-economic factors in the study design. Four of them used goal setting, two of them used competitions and 14 attempted to apply social norm research.

Goal Setting. One of the types of motivational elements is goal setting. Some project examples are illustrated below.

*Study example 1.*One of the studies (Seligman et al., 1979), which investigated the impact of daily/weekly feedback with goal setting, hypothesized that difficult goal setting was more impactful compared to easy goal setting. The results were that the only group, i.e. the difficult-goal-with-feedback-group revealed significantly lower energy consumption compared to the control group. In addition, the two groups that received feedback saved significantly more energy that the two groups that did not receive feedback

Study Example 2. Another study (Winett et al., 1982) using daily/weekly feedback proposed a15% reduction goal setting by asking the residents to sign a form indicating their commitment towards the goal. The study was successful in generating 17% energy savings.

*Study Example 3.*Van Houwellingen (1989) studied the effects of aggregate, real-time feedback that revealed the benefits of goal setting used in conjunction with the feedback. Households with in-home displays exceeded their energy savings goals. Houses that received monthly feedback fell short of the goal, but reduced their energy consumption, and households that self-monitored had the least energy reductions.

Commitment and competitions. This is another motivational element that can be induced in a feedback program. Only two of the present 57 studies that were reviewed, employed these strategies as part of the overall program design.

Study example. Peterson's (2007) study in Oberlin University, of feedback-induced energy savings in college dormitories, incorporated the competitive element. The competition resulted in 32% electricity savings. A post-intervention survey found that students were highly motivated, holding planning sessions, as well as email-based discussions, to brainstorm ways they could lower their resource use.. It was reported and concluded by the authors that the challenge itself and the social interaction involved in meeting the challenge were maybe more important forms of motivation than the reward offered for the winners of the challenge.

Social norms. The third type of motivational element is using social norms. One quarter of the feedback studies reviewed in Ehrhardt, Donelly, and Laitner (2010) attempted to capture the powerful influences of social norms to help residential energy consumers reduce their energy consumption. Many of these interventions were associated with OPOWER and their collaborations with various utility companies.

OPOWER's approach provides households with monthly Home Energy Reports that include both targeted and contextualized information, i.e. historical energy consumption, semi tailored energy saving tips, and information concerning the energy consumption patterns of other household similar to their own. The third provides the households with social or normative context with which to compare and assess their personal energy use patterns.

Study example 1. OPOWERS's first intervention was in 2008 with the Sacramento Municipal Utility District (SMUD). The SMUD intervention was very large, involving 85,000

California households. Subsequent interventions in Minnesota and Washington also involved large samples. In all three cases, households in the intervention group received normative information in addition to feedback and energy saving tips, making it impossible to separate out the unique contribution of the normative information. However, a comparison of the intervention and control groups revealed savings of 1.1 to 2.5% among households receiving OPOWER's Home Energy Reports.

Study example 2. Another Study by Nolan et al. (2008) reported that the normative messages motivated people to conserve more energy than did the control message or other three messages that contained more traditional types of appeals, which were either to protect the environment, benefit society, or save money. The normative messaging was shown to achieve energy savings of 10%.

Study Example 3. In a similar study by Schultz et al. (2007), households in the treatment group were given handwritten door hangers with information on how much energy they used, as well as descriptive normative messages regarding electricity use and energy saving tips. The second group also received a smiley face to communicate approval or disapproval (the injunctive norm). Households within the first treatment group experienced an overall decline in electricity consumption of 5.7%. However, in the absence of injunctive norms, households that were initially consuming below the average experienced a 7.9% increase in consumption. Notably, however, when the injunctive norm was added to the door hanger, low energy consumers maintained their low levels of consumption.

Sample, size, study duration and persistence of energy savings. These are other program variables where the effectiveness of the energy use feedback is likely to be impacted by and in turn the energy savings.

Sample size. Study size can be can measured in two ways: total number of study participants (i.e., including control group participants) and the number of study participants receiving feedback. Both measures were taken into consideration. Among the 57 studies, most of the studies had between 60 and 600 participants with a median study size of 189 households.

In the case of feedback participants, the vast majority of studies provided feedback to fewer than 700 households. The median number of households receiving feedback was 105.

Study size has important implications for feedback-related energy savings. As shown in Table 3, studies with larger feedback sample sizes (100+ participants) show lower levels of feedback-related energy savings compared to smaller feedback sample size(<100). According to the review by Ehrhardt, Donelly and Laitner (2010), the large sample studies had average savings roughly 6.6% compared to average savings of 11.6% across small-sample studies. Typically, findings of larger studies tend to be more generalizable to the larger population. These are relevant to the efforts aimed at estimating the potential scope of feedback-related energy savings.

Study duration and persistence. Most studies from the 57 studies lasted between two and twelvemonths with a median study duration of six months. A review of the relationship between study duration and feedback related energy savings revealed that average energy savings were higher for shorter studies than for longer studies as shown in Table 3.

While this finding suggests an inverse relationship between study duration and energy savings, there was evidence from 27 studies (Ehrhardt-Martinez et al., 2010) that attempted to measure feedback effect persistence suggest that the feedback-related savings are often persistent.

Research examples of persistence and feedback frequency. According to Darby (2006) and reinforced by several other studies, persistence of savings may rely on the continued provision of feedback. Alcott(2009) found that there was some decay in the energy savings for the households receiving quarterly reports. However, this decay was not found for households receiving more frequent monthly reports. Similarly, in a twelve-month study of the effects of real-time feedback in the Netherlands, van Houwellingen et al. (1989) found that in-home displays were highly successful in reducing energy consumption. However, when the energy monitors were removed from the households following the 12-month intervention period, energy savings did not persist.

In order to resolve this question, it was suggested that future feedback studies should provide feedback over a period of at least 24 months and report on the related savings over several time periods while controlling seasonal variations in the end use demands.

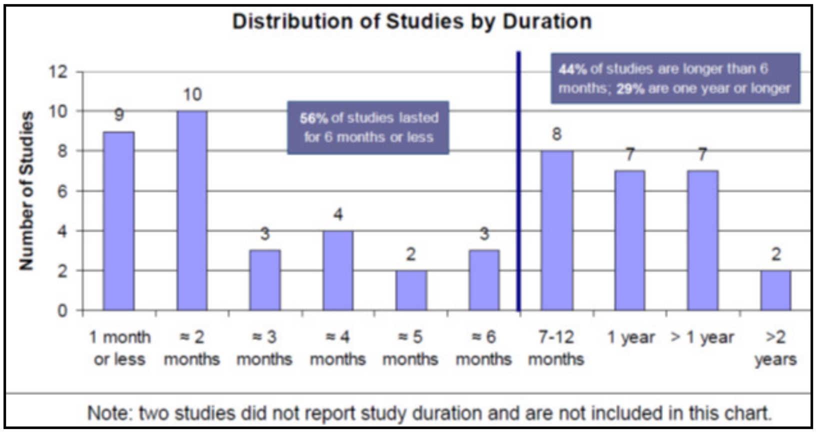


*Figure 4.*Distribution of Studies by Duration, Ehrhardt, Donelly, Laitner (2010)

Intersection of Contextual and Program Variables

This section summarizes the bivariate relationships between energy savings and feedback type, program characteristics, regional context, study size and study duration.

Feedback type. The energy savings vary greatly across the feedback types with more than 10% savings coming from Daily/Weekly and Real Time Plus.

Region. The effects of feedback are also expected to vary by regional context (as shown in Table 3) since social, cultural, political and structural differences associated with these regions are likely to influence feedback-related energy savings.

Era. The older studies performed during the Energy Crises Era, i.e. prior to 1995, achieved higher levels of feedback-related energy saving compared to the newer studies performed during the Climate Change Era.

Size. As pointed out, earlier studies with larger samples (100+) showed lower levels of feedback-related energy savings compared to the smaller sample size studies. These findings are relevant to the efforts aimed at estimating potential feedback-related savings.

Study Duration. As discussed before, energy savings also vary as a function of study duration. Longer studies (>6 months) tend to achieve lower rates of household energy savings when compared with shorter studies (<6 months). The review by Ehrhardt-Martinez, Donelly & Laitner (2010) found that average household energy savings for longer studies were on the order of 7.7% while savings for shorter studies averaged 10.1%. This discrepancy is likely a reflection of study design decisions associated with the shorter studies, which are often performed during summer months when electricity consumption is at its highest.

Table 4.

Intersection of program variable. (Ehrhardt, Donelly and Laitner, 2010)

	Number of Studies		Range of Savings	Average Savings	Median Savings
	#	%			
Type of Feedback					
Enhanced Billing	11	19%	1.2 - 10.0%	5.2%	5.5%
Estimated Feedback	3	5%	5.1 - 8.5%	6.8%	6.8%
Daily/Weekly	15	26%	3.7 - 21.0%	11.0%	10.8%
Real Time Aggregate*	23	40%	-5.5 - 32.0%	8.6%	6.9%
Real Time Plus	5	9%	9.0 - 18.0%	13.7%	14.0%
Region					
United States*	33	58%	-5.5 - 32.0%	8.8%	8.5%
Canada*	9	16%	0.0 - 18.1%	7.3%	6.5%
Europe	13	23%	5.0 - 21.0%	10.0%	8.5%
Other	3	5%	3.7 - 12.0%	8.2%	9.0%
Study Era					
Old—Energy Crisis Era	21	37%	-5.5 - 21.0%	10.3%	11.0%
New—Climate Change Era	36	63%	0.5 - 32.0%	8.2%	6.9%
Study Size					
Small (<100)	28	49%	-5.5 - 32.0%	11.6%	12.0%
Large (100+)	29	51%	0.5 - 12.8%	6.6%	6.0%
Study Duration**					
Shorter (≤ 6 months)	31	57%	0.5 -32.0%	10.1%	9.3%
Longer (> 6 months)	23	43%	-5.5 - 21.0%	7.5%	7.2%
Total	57	100%	-5.5 - 32.0%	9.1%	8.5%

Combined Impact of selected program variables on energy savings. Summaries of energy savings based on study size and duration, feedback type and study size, feedback type and study duration are shown in Table 5, Table 6, and Table 7 below, respectfully.

Table 5.

Energy savings by study size and duration (Ehrhardt, Donelly & Laitner, 2010)

	Small (≤100)			Large (>100)			Total		
	Average Savings	Median Savings	Number of Studies	Average Savings	Median Savings	Number of Studies	Average Savings	Median Savings	Number of Studies
DURATION									
Short (≤6 months)	13.3%	13.0%	18	6.6%	6.0%	13	10.1%	9.3%	31
Long (>6 months)	8.7%	7.2%	9	6.7%	6.3%	14	7.7%	7.4%	23
Total	11.6%	12.0%	27	6.6%	6.0%	27	9.1%	8.5%	54

Table 6.

Energy savings based on feedback type (Ehrhardt, Donelly & Laitner, 2010)

	ERA				STUDY SIZE			
	Energy Crisis (<1995)		Climate Change (1995+)		Small (<100)		Large (100+)	
Type of Feedback	Average Savings	No. of Studies	Average Savings	No. of Studies	Average Savings	No. of Studies	Average Savings	No. of Studies
Enhanced Billing	7.5%	5	3.8%	6	n.a.	1	5.2%	10
Estimated Feedback	n.a.	0	6.8%	3	n.a.	0	6.8%	3
Daily/Weekly	12.1%	10	8.4%	5	12.4%	10	8.7%	5
Real Time Aggregate	7.8%	5	9.2%	18	10.7%	12	6.7%	11
Real Time Plus	12.9%	1	12.0%	4	12.2%	5	n.a.	0
Total	10.3%	21	8.2%	36	11.6%	28	6.4%	29

Table 7.

Savings based on feedback type and study duration (Ehrhardt, Donelly & Laitner, 2010)

	Shorter Studies (≤ 6 months)			Longer Studies (>6 months)		
Feedback Type	**Average Savings**	**Median Savings**	**N**	**Average Savings**	**Median Savings**	**N**
Enhanced Billing	6.0%	6.0%	2	5.1%	5.0%	8
Estimated Feedback	6.8%	6.8%	3	n.a.	n.a.	0
Daily/Weekly Feedback	10.1%	10.3%	13	16.5%	16.5%	2
Real Time Feedback	11.5%	7.7%	9	7.3%	7.0%	12
Real Time Plus	12.2%	12.5%	4	n.a.	n.a.	1
Total	10.4%	9.6%	31	7.5%	7.2%	23

Residential Feedback Technologies

This part of the literature discusses the different residential sector feedback technologies and their potential role in empowering consumers, facilitating new, smarter energy-use behaviors, and reducing residential energy consumption. First, the bigger picture is described, i.e., the smart grid, which further breaks down to different types of feedback and automation technologies, starting with utility feedback approaches, specifically advanced metering systems. The non-utility technology feedback and automation solutions are then explored after which home automation, focusing on do-it-yourself, is discussed.

The Smart Grid is generally the system that delivers electricity to the specific end-use, including electricity, generation, transmission lines and distribution systems. The smart grid can even include smart appliances, feedback displays and other devices operated inside the consumer's home. According to U.S. DOE, definition of smart grid it includes the follow:

- Integrated, open architecture, real time communications for information and control
- Sensor, measurement and interface technologies for monitoring, feedback, time-of-use (TOU) pricing and demand side management
- Advanced components such as superconductive transmission lines, storage, power electronics and diagnostics tool.
- Control and monitoring methods (DOE, 2009)

Inside the residential consumer's home, feedback and automation technologies can be used to involve the consumer in managing their energy use. Ehrhardt-Martinez, Donelly & Laitner (2010) discuss the potential impacts of the feedback and automation technologies and services currently available to the residential consumer on an analogy based on an onion where it is divided into three layers or parts: indirect feedback, direct feedback, and home automation.

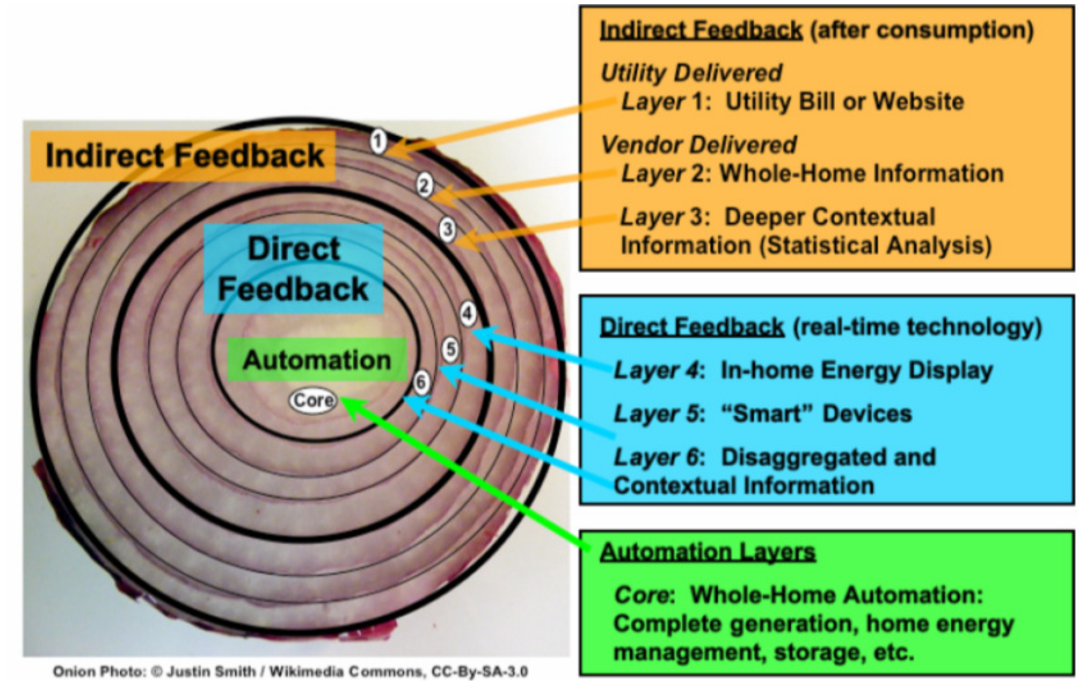


Figure 5. The layers of energy feedback technologies (Ehrhardt-Martinez et. al., 2010)

Indirect feedback is feedback provided after consumption and comprises the outermost three layers of the illustration above (see Figure 5). It includes enhanced billing with specific household information and advice, estimated feedback that uses statistical techniques to estimate total household energy usage based on a customer's household type, appliance information, and billing data, and daily/weekly feedback that uses real-time energy use measures gathered by a utility or third party and presented to the customer via the web, e-mail or mailed reports.

Utility-provided indirect feedback represents the current monthly utility bill, as well as existing and proposed advanced metering installation that provide consumers with limited Indirect feedback. Although it is capable of providing energy feedback and management services to residential consumers, this far, advanced metering systems are being underutilized in almost all cases.

Technology and Cost. An example of utility-provided indirect feedback is Automatic Meter Reading (AMR) technologies that record interval meter data (e.g., hourly, daily, or monthly) of whole-home electricity (or natural gas or water) use and transmits a one way radio (or other network) signal that utilities can access using a drive-by or walk-by meter reading system. There are also newer advanced which use two-way communication between meter and utility, meaning the can remotely read ,meters, as well as provide price and supply condition information to enable the consumer to react. Although it is technically feasible, only in very limited cases do advanced meters provide communication directly to the consumer via short distance wireless, broadband, cell phone, short range radio and home power lines (Frost and Sullivan, 2007).

The total costs of one-way meter varies from $85 to $100 and the installation of two-way advanced meter may cost up-to $120. A total system including the meter and utility communication, controls, computers, software systems as well as installation would cost $150 per household.

Effectiveness. This kind of feedback available to today's households by utilities represents the least-effective form of feedback to the consumer, and does not motivate consumers to reduce energy consumption.

Vendor provided indirect feedback. The next two layers represent the different types of indirect feedback, including aggregate or whole-house feedback as well as appliance and end-use disaggregate feedback (e.g., estimated appliance-specific, historical comparison, social comparisons, etc.). These types of feedback are provided by means of web-based presentations and utilize a variety of data sources including electric utility data and other existing types of data (e.g., assessor parcel maps, home audits, census, etc.). It delivers processed feedback on the consumer's computer, smart phone, iPad, etc. There are numerous service providers that leverage existing data to provide personal and social contextual feedback. Table 11 describes three such companies that provide behavioral-focused indirect feedback to residential energy consumers (after consumption with no automation).

Table 8.

Vendors providing indirect feedback of utility data (Ehrhardt-Martinez, Donelly and Laitner, 2010)

Company	Feedback Technology	Behavior Principles	Maturity
OPOWER	Depending on utility, send monthly or quarterly mailings, and/or provide Web site with newly forming social networks.	Feedback Type: Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO_2, kWh, & $. Behavior Principles: Social Comparisons, Goals, Personal Comparisons, and Action Steps.	Growth Stage
Efficiency 2.0	Social community Website with energy and water consumption feedback.	Feedback Type: Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO_2, CO_2, kWh, $, and other units. Behavior Principles: Social Comparisons, Goals, Competitions, Social Networks, Personal Comparisons, and Action Steps.	Start-Up
Google.org	Google.org PowerMeter on Website, including Google social networks.	Feedback Type: Indirect including: Household information, estimated household and monthly bill, estimated appliance-specific. Behavior Principles: Social Comparisons, Goals, and Personal Comparisons.	Established start-up for the Google PowerMeter

Technology. Indirect Feedback is primarily derived from monthly utility data or in very limited cases more frequent advanced metering interval data. Several vendors use statistical software algorithms to analyze existing data and user inputs to provide deeper knowledge. These vendors mostly communicate feedback to households over the Internet, although several have mobile phones, TV, and other enabling-technology applications. Many indirect feedback vendors can add enabling technology to the solution, such as energy displays and smart appliances.

Feedback and behavior. Web based software vendors provide the following.

Learning by doing. Basic energy consumption and energy cost information, where a person learns by doing. For example, a person first learns the cost of running the air conditioner(through feedback) and then decides to set back the thermostat.

Contextual Information. Some deeper personal and/or social contextual knowledge through the framing of the data. This second type of feedback provides contextual information about energy use patterns of other households so as to provide contextual information about energy use patterns of other households so as to perform relative to other people in similar circumstances. Thus the Web interface enables contextual learning, allowing users to dig deeper into their energy consumption patterns.

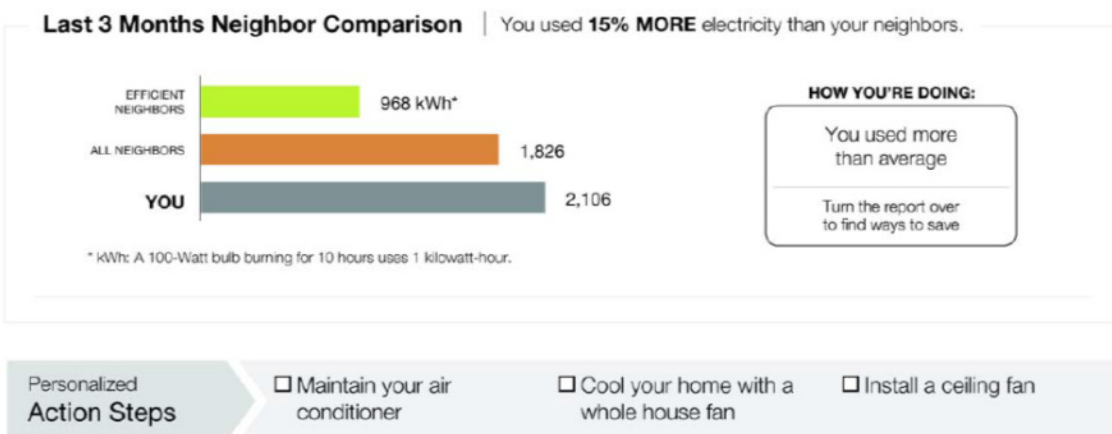
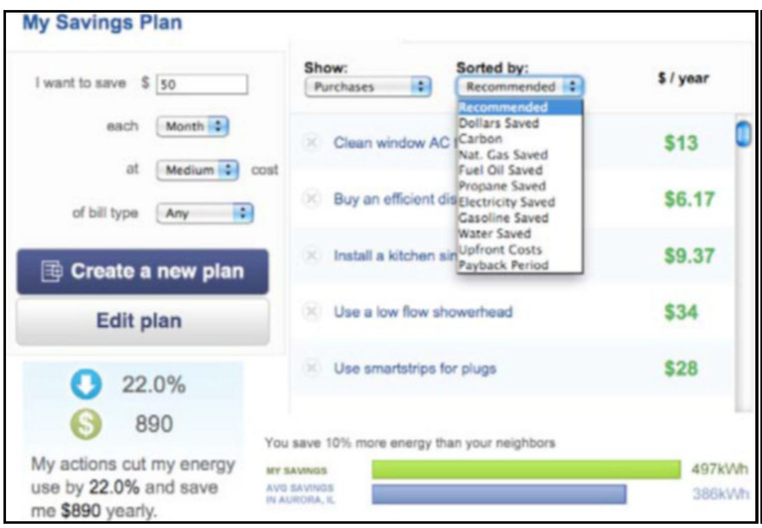


Figure 6. Example feedback: social norms and action steps (Kavazovic, 2009)



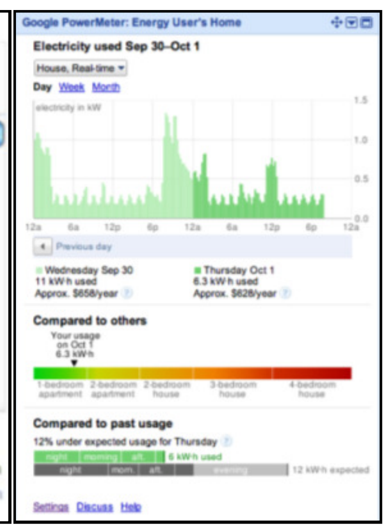


Figure 7. Efficiency 2.0 Savings Plan: information, goal setting and feedback (Ehrhardt-Martinez et al. 2010)

Figure 8. Google.org Power Meter example

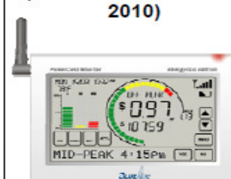
Companies that provide indirect feedback offer evidence that post-consumption feedback can be provided with existing technologies and using existing data. (e.g., Google.org is training the TED 5000 to recognize energy signal patterns and correlate them with appliance-specific usage). These indirect web interface feedback approaches do not require any additional advanced metering hardware. These types of feedback can enable residential consumer to choose which energy-saving actions to take as the scope of behaviors they engage in.

Direct feedback, the middle three layers, provides energy use information at the time of consumption (or shortly after consumption) and include real-time feedback, appliance-specific real-time feedback and simple automation.

Real-time, direct feedback provides a wide range of contextual knowledge to users to learn by doing as well as through the provision of more tailored and socially relevant feedback. In this case, the user receives immediate appliance specific feedback that allows them to learn about energy in an incremental fashion. A few examples of in-home energy displays are shown in Table 9 below.

Table 9.

In-home energy display device examples (Ehrhardt-Martinez, Donelly & Laitner 2010)

	The Energy Detective TED 5000 	Wattson 	PowerCost Monitor (WiFi edition due mid-2010) 	Efergy Elite 
Technology Description	Display, Supportive Software, Mobile Applications	Display, Supportive Software with Holmes and 20TEN Communities	Display, Supportive Software, Mobile Applications	Display
Feedback Mechanisms	Displays real-time kW, $/hr, CO_2; daily kWh and $; billing cycle in kWh, $, peak use, min/max V, and projected cost and demand. Viewable in seconds, minutes, hours, days, months. Alarm: red flashing light, beep.	Displays near real-time usage in W, kW, and estimates bill. 3 to 20 s readings. Glows by usage: blue=low, purple=average, red=high.	Displays near real-time (30 s) kW and $/hr, peak usage in last 24-hrs, counting kWh (reset), appliance measurement feature.	Displays near real-time in kW and $/hr (6, 12, or 18 s readings), hourly, daily, weekly, monthly, and average information. Alarms for high usage.
Consumer Behavior Principles	Feedback Types: Direct including: Household feedback and advice, web-based energy audits, billing analysis, estimated appliance, CO_2, $. Behavior Principles: Social Comparisons, Goals, Personal Comparisons, and Action Steps.		Feedback Types: Direct: Household feed-back, billing analysis, est. appliance, CO_2, $. Behavior Principles: Goals and Personal Comparisons.	Feedback Types: Direct: Household information, billing analysis, Elec., $. Behavior Principles: Goals and Personal Comparisons.
Cost	$239.95 (& up for addl. circuit sensors and/or solar/wind connections)	£99.95 (UK only)	$250	£39.95

Technology. There are numerous energy displays in market that contain some combination of the standard features as shown in Table 9, with most of them being similar to Efergy device. In most cases the data are sent from the home's main circuit panel there they are measured using two to three current clamps that around the home's electricity mains. The Energy Detective (TED 5000) can monitor up to 220 Volt or eight 110 Volt circuits or separate consumer appliances and devices. It is sensitive to as little as one watt of electricity consumption. This means, the device can provide circuit level data, so it is conceivable that one would know how much electricity one is using in the kitchen, family room, bedroom or anywhere else, thereby providing more specific feedback. Communication ranges to the display vary from 30 to 70 meters depending on the home's signal obstructions. Data storage capabilities also vary greatly and are dependent on the number of on-board components. Storage varied as low as 28 days as in case of Wattson and as high as 10 years worth of data like in TED. Other features also vary greatly in terms of display presentation. For example, the Efergy and Wattson provide simple, easy to read displays, while TED 5000 includes web, mobile, and stand-alone display technologies that can coordinate with the complete home generation and automation network.

Feedback and Behavior. The application of consumer behavior principles varies widely by energy display. For instance, some devices display information in ambient ways through colors and alarms and some provide indirect feedback through websites or on digital TV. At a minimum, all feedback devices provide household level information, some billing analysis and estimated usage for some period of time. Most of the stand alone displays show energy consumption while other displays provide information on energy related carbon dioxide emissions, voltage, peak use, and other measures. Additionally energy displays are programmable for various rate structures. In some cases, displays and supplemental web software packages provide additional personal social contextual information, including household baseline energy use information, energy use trends, projections, alarms and goal tracking. Some other displays like Wattson provides social comparison to potentially help consumers gauge their own consumption patterns. Some devices are increasing their product flexibility for instance the WiFi edition of the Power Cost Monitor will have an open platform for certified apartments to build Web and mobile phone applications. The goal is to enable access for the consumer to their data.

As with all other types of feedback, the effectiveness of the energy displays will be highly dependent on the design of the technology and associated application. Consumer engagement will likely vary by the number of behavioral principles incorporated into the design. Future technology assessments based on user experience will be needed to determine actual product effectiveness.

Direct feedback and automation with "smart" devices. The next layers consist of energy efficient and "smart" (automated) appliances that can provide direct, real-time plus feedback and include appliance-specific information as well as automation. Another critical feature of these smart devices is their capability to receive pricing signals and utility load control in some cases. A broad range of feedback, behavior, and automation devices and appliances are available and described in Table 10. Most of these devices can be classifies as do-it-yourself (DIY). It includes sensors (measurement. diagnostics, automation), in-home energy displays, programmable communicating thermostats (i.e., smart thermostats), smart plugs, lights and appliances and utility load control devices.

Table 10.

Automation, settings, user behavior, and cost for "smart" devices (Ehrhardt-Martinez et al., 2010)

Appliance Attributes	Resultant User behavior	Regular Device and Appliance Examples	"Smart" Examples	2010 Cost Range
Low automation Many settings	User required for part of operation. Settings easily altered during operation.	Grill, Stove, Oven, Simple Thermostat, Iron, Vacuum.	Dimmer Light	$10 to $70
Low automation Few settings	User required for operation. Simple automation (turns off when not in use).	PC, TV, Light, Oven hood	Smart Outlets and Lights	$15 to $150
			Smart Power Strips	$25 to $200
High automation Many settings	User not required during operation. Difficult to change settings, causes interruption of operation.	Washing Machine, Dryer, Dishwasher	Smart (two-way) Thermostats	$175 to $250
			Energy Displays	$100 to $250
			Smart Appliances	Near-term Market*
High automation Few settings	User not required during operation. Settings easily altered during operation and rarely need changed.	Coffee Pot, Heater, Air Conditioner, Freezer, Refrigerator, Pool Pump, Water Heater	Utility Load Control Devices	$15 to $150
			Sensors/Networking Chips	$7 to $150

*This is accomplished today using smart outlets and network chips.
Source: Builds upon Wood and Newborough (2007b).

Technology and cost.The data in Table 10 reflects a general behavior framework as developed by Wood and Newborough (2007b). The framework can be used to categorize different appliances by the degree to which their attributes are automated and the complexity of settings. (Wood & Newborough, 2007b)The costs of consumer-purchased enabling technologies vary widely and are related to the complexity of the automation features.

Although, it is still an early adopter market, do-it-yourself and third-party installer home automation devices are expected to grow considerable, especially given its ties to the other home automation market segments. At the core of the illustration in Figure 5, Home Automation represents whole systems that include the highest level of real-time feedback, home automation and sometimes energy generation and storage systems.

Direct feedback and automation using home networks. This sub-section is the inner core of the onion and is a combination of the six outer layers, including indirect and direct feedback, as well as energy-efficient technologies and automation enabling-technologies.

The Energy Detective (TED)

Based on the previous section's discussion about indirect, direct & home automation, the TED device was selected for the present research due to following reasons.

Technological features. The TED device is noted to have a greater level of resolution, detecting changes of as little as 10 watts, while the devices like Power Cost Monitor (PCM) is unlikely to detect changes below 300 watts. The PCM does not have the advantage of wireless portability like TED which transmits data from gateway to the display wirelessly, though TED does requires connection to a wall outlet to receive a signal from the transmitter through the power-line. The TED has been utilized for several pilot programs and has shown a high degree of effectiveness and consumer engagement. It has ability to provide energy feedback through web, mobile and stand-alone display technologies, It has a large internal memory compared to other devices – due to which it can store up to 10 years of data.

The Energy Detective 5000 (TED 5000) is an in-home electricity designed for home owners. This interactive energy management system provides the residents with instant electricity updates, in both kWh and customized dollar amount. Appendix B describes the features of the device that will help in understanding its capabilities with respect to providing real-time feedback to the participants of the study.

Pilot Programs

Four pilot studies using different types of feedback interventions are reviewed in this section. The pilot studies were Hydro-One, Oberlin Homes, Sacramento Municipal Utility District (SMUD)and British Columbia (BC) Hydro. The project year, duration, methodology and outcomes are summarized below for each pilot to compare the effects of different technologies on energy consumption and participant behavior.

Hydro-One. In 2004, Hydro-One provided 500 Power-cost home energy monitors to homes in Ontario, Canada. These homes were monitored for 2.5 years, and demonstrated around 6.5% energy savings. The project had three distinctive objectives,

- To determine whether provision of a real-time feedback device is sufficient to empower residential customers with the information needed to reduce their electricity consumption,
- To establish whether the use of this type of device can help customers save money and assist in promoting a “conservation friendly” culture, and
- To assess whether real-time feedback is effective and to determine, from change in usage data, if behavior of the participants could be quantified as energy savings.

The program methodology, behavioral, and energy savings are summarized in Appendix A, Table 44.

Oberlin homes. This study investigated whether continuous feedback was effective in a residential setting. The study explored the effects of socioeconomic status and household characteristics on conservation practices and energy use consciousness. Ten households were randomly invited from a 60-household survey to receive a digital electricity monitor called The Energy Detective (TED). Surveys, utility bill records, semi-structured interviews with these households, and the effectiveness of the monitor in each household were examined in this study. The program methodology, behavioral and energy savings are summarized in Appendix A, Table 45.

Sacramento Municipal Utility District (SMUD). Indirect feedback in the form of OPOWER's electricity use reports, lowered electricity demand by 2% amongst SMUD customers.

A powerful finding from behavior science is at the core of this program; individuals are motivated much more by their perceptions of what other people do and find acceptable than they are by other factors such as the opportunity to save money or conserve resources, contrary to even their own perceptions of motivation. The program methodology, behavioral and energy savings are summarized in Appendix A, Table 46.

BC Hydro. BC Hydro has found the use of personal commitments, incentives, and online information tools to be an effective means to drive behavior changes. The Canadian utility has enrolled more than 60,000 customers in the first few months of this effort. The program methodology, behavioral and energy savings are summarized in Appendix A, Table 47.

Literature Review Summary and Conclusions

Three research papers were looked into in particular, which are: 1) Sarah Darby's (2006) 'The Effectiveness of Feedback on Energy Consumption. A Review for DEFRA of the Literature on Metering, Billing and Direct Displays', 2) Corinna Fischer's (2008) 'Feedback on Household Electricity Consumption - A Tool for Saving Energy?' and 3)Wokje Abrahamse's (2005) 'A Review of Intervention Studies Aimed at Household Energy Conservation'. These papers have reviewed several other field studies and research several. The conclusions derived from all these are studies are as follows.

- The type of feedback is likely to play an important role in determining the subsequent levels of household energy savings for instance Darby (2006) through her research concludes that direct feedback has a higher potential of resulting in energy savings compared to indirect feedback.
- People would learn and benefit better if feedback is provided in conjunction with advice and information since understanding of consumption related feedback to achieve savings is important. Feedback devices, computerized and interactive tools are found to engage users in energy saving behaviors, though technology alone cannot benefit. Their understanding is important as well.
- Having user-friendly display for instantaneous feedback as part of new meter specification which would not only show historic feedback and expenditure but also display information on tariffs and carbon emissions
- The nature and frequency of feedback, study design, and sample size all create challenges in drawing conclusions. All the three papers have concluded that giving feedback frequently and over a long period improves its effectiveness.
- The ability to give appliance-specific information is helpful.
- Information tends to result in higher knowledge levels, but not necessarily in behavioral changes or energy savings.

- Rewards effectively encouraged energy conservation, but are rather short-lived effects.
- Shortcomings related to either program study design and/or its evaluation need to be addressed before hand. Feedback interventions needs to be studied, planned properly and their effectiveness should be further examined

Lessons Learnt from Literature and Pilot Programs

Sample size. A sufficiently large sample population with adequate segment representation will lead to more robust and flexible analytics. It will allow necessary precision and confidence in drawing conclusions about specific sub-segments of the population.

Control group. Incorporate a control group that is representative of the underlying population (SMUD). A well-designed experiment incorporating representative control and test groups will lay the foundation for definitive comparisons in later analysis. Studies that rely on comparisons to historical performance introduce a significant number of variables for which it may very difficult to control. A robust design with test and control groups will allow for comparison of two equivalent populations that were subject to identical environmental factors

Analysis/Evaluation. All the key variables such as weather, demographic factors and appliance installations or changes in the residence need to be accounted for and controlled in the analysis. (Hydro One).

Feedback monitors. Some learning, observations & possible suggestions related to feedback monitors as per the past research and studies are as below

Technical related issues. There is a possibility of potential technical issues after the installation of the feedback monitors. For example, in the NSTAR pilot of the 33 % customers who had stopped using the PCM 40% indicated the reason being the improper functioning of the PCM. Validating the functionality of new technology can avoid headaches down the road. There is a need to run new technologies through user acceptance tests to identify potential technical issues. Making sure technologies worked as anticipated will avoid any potential for customer satisfaction issues. Running a test pilot could help understand these technical issues before starting the actual study.

Real-time feedback information. An increase in sophistication of real-time feedback technology does not corresponded with an increase in measured energy savings. As seen in the case of the Oberlin homes pilot study the users indicated usability problems with The Energy Detective (TED) device. It is the presence of the information itself, not its presentation in a more salient, graphical format, that causes the behavior change.

Also there is a need to extend the functionality of the in home display device. Software on the device can disable or enable the entertainment functionality based on a user's energy consumption performance. Given that the user also gets the benefit of viewing photos, videos, or listening to audio files, they are more likely to interact with the energy feedback as well

User's compatibility with intervention. Ensure that the solution is well suited to the customer population. Several utilities have run into trouble with customer acceptance of different interventions. Many of the program participants recruited struggled to understand the operation and functionality of the wireless handle monitors. As a result of these user acceptance issues, there has been little impact on behavior change and energy savings.

Feedback related learning. There were various findings and learning related to different types of feedback, its effect on savings, its effectiveness with other program variables and its conjunction with other motivational elements in a program design.

Feedback frequency. More frequent feedback leads to higher savings. An example is the SMUD pilot project where energy savings among monthly report recipients were greater than those among customers receiving the reports quarterly.

Understand effects of different feedback types. Indirect feedback will not match the real-time and (unless coupled with AMI-enabled technology) use-specific feedback that direct feedback devices provide, making it more difficult to see the impact of discrete behavior and individual appliances.

Feedback and other program variables. Though differences between feedback types are important to understand, other less prominent variables like motivational elements and other program design characteristics like study size, study duration and regional context and culture.

Feedback and motivational elements. Higher level of savings were reported by combined multiple approaches in many of the projects reviewed in the literature. The results in the Hydro one pilot study are interpreted as the bare minimum impacts due to absence of incentives and information.

Hybrid of Comparative and Direct Feedback. The novelty of the feedback will wear off particularly in the case of real-time in-home displays that tend to have participants excited and engaged to experiment with their new gadget early on, there is a tendency for participant's interest in feedback to wane over time. A well-designed program can result in persistent savings.

Utilities need to look for ways to remind and motivate their program participants to stay involved. Engaging customers through ongoing messaging and education helps to ensure persistence of savings. In the case of BC Hydro, an electronic newsletter sent by email was shown to drive traffic to the online feedback tool.

Education. Several studies that reported low energy savings concluded that the lower savings were due to lower participant involvement. The Energize Phoenix Dashboard study addresses this issue by designing interactive education sessions with the participants. This interactive educational component of the study aims to address the issue of participant involvement and distinguishes our study from the previous similar programs.

Study follow-up. Administering customer Questionnaires/Follow ups at different stages of the pilot is necessary to capture information on qualitative factors such as ease of use, changes to dwelling characteristics (such as square footage, age of dwelling) or appliances.

Chapter 3

METHODOLOGY

Literature Review

Extensive literature review was accomplished to understand behavior and feedback related influence on energy consumption. This literature review encompassed the following areas of discussion:

Different feedback types were understood along with other program variables that influence feedback and energy savings like motivational elements, study sample size, study duration etc. The intersection of these program variables were also studied through 57 studies reviewed by Ehrhardt-Martinez, Donelly and Laitner (2010). Several sample studies were reviewed and it was concluded that direct feedback along with education or information enhanced energy related savings. In addition it was also concluded that motivational elements along with feedback also enhance feedback induced energy savings. Different technologies prevalent in the residential sector were described and reviewed. Among the different feedback devices studied in this section, The Energy Detective (TED) was chosen due to its technological features and behavioral impact related potentialities. Next, past research papers were also reviewed which mentioned the importance of having resident's education and understanding of feedback technologies.

Pilot Study Review

Large sample population. Pilot studies reviewed in the research had large sample population except for the 'Oberlin Homes' pilot. For robust and flexible analytics it is important to consider a large sample population for the experiment. Therefore one of the considerations for deciding the study site during the site selection phase was to have a large sample population.

Incorporating representative control and test groups. The pilots had incorporated a control and test group for definitive comparisons and for evaluating the intervention's effectiveness. This was helpful in comparing two equivalent populations that were subject to identical environmental factors. Therefore this was another key factor of consideration during the experiment design phase.

Key variables were accounted for and controlled in the analysis. As seen in the pilot studies too, key variables were decided to be accounted for during analysis such as weather, demographics, apartment orientation and location and changes in residence.

Feedback related learning. Following feedback related learning were considered

Feedback frequency. The pilots incorporated frequent feedback practices either in the form of direct or in-direct feedback. Therefore, in this study too feedback frequency in the form of follow-up sessions for participation during the study months was decided.

Feedback and motivational elements. Motivational element in the form of providing a gift basket at the end of study was incorporated.

Education sessions for participant involvement. For better understanding of resident's energy use related information, education session along with feedback device was conducted.

Feedback monitors. Technical issues with the device and user's compatibility with the it need to be studied and accounted for, before the study begins.

Methodology

The initial study was designed and decided for owner-occupied residential homes but they were not able to be used for this dashboard experiment design but to overlap of the EEM funding of the same homes. It was therefore decided that the study would move to rental residential home. There were many challenges faced during this phase such as difficulty in getting landlord approvals from each potential renter participant, no permission of installing TEDs in the APS owned electric meters, inability to install the MTUs of the TEDs in some meters etc. Additionally the study site had to be restrained within the physical boundaries of the Energize Phoenix program. All these reasons had compelled the team to decide on the selection of this low income multi-family housing from the potential group of housing complexes within the boundary of the Energize Phoenix corridor.

Site Selection Criteria for the Study

Arizona State University, the City of Phoenix, and Arizona Public Service conducted the Energize Phoenix Dashboard Study as a sub-study of the Energize Phoenix Program (a Department of Energy funded program). The selection of the dashboard study site had to therefore be along the Energize Phoenix Light Rail Corridor. There were many low-income housing sites to select from within the Energize Phoenix boundary. The following housing site characteristics were considered important determinants for dashboard study site selection.

No recent retrofits. One of the more important determinants of site selection was whether there were any recent retrofits done in the housing units. By removing recent retrofits as a variable, evaluating the effectiveness of the dashboard and education interventions could be more clearly isolated.

The selected site for the study was identified to have no recent major retrofits done as per the information provided by the City of Phoenix's Neighborhood Service Department.

Sample size. For the dashboard study, it was essential to have a good sample size for data analysis as well as to keep in mind the possibility of future participant opt-outs and move-outs during the experiment phase.

The selected site for the study had 145 apartment units, which was a good sample size to consider for the dashboard study.

Individual Metering. For the dashboard study, it was mandatory to have individual metering for each apartment for individual device installation as well as for the dashboard study analysis. This was because the TEDs were to be installed for individual meters for each resident so the effectiveness of the feedback could be identified for individual participants and not as a whole.

The selected dashboard site was individually metered with each apartment sub-panel located on the exterior walls of the units. Figure 9 shows the layout of the sub-panels outside the apartment blocks.

Figure 9. Dashboard selected site electric meter sub-panels close-up

Table 11 gives an overview of some of early determinants for site selection that were available from the information provided by the Neighborhood Service Department.

Table 11.

City of Phoenix low-income housing complexes

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Selected Dashboard Site	Site10
#of Units	38	202	230	102	?	120	69	28	145	112
AC or Evaporative Cooling	AC	Evap	Evap	?	?	AC?	AC	?	AC	AC
Individual Meters	Yes	Yes	Yes	?	?	Yes	?	?	Yes	Yes
Meters Read Monthly	Yes	Yes	Yes	?	?	No	?	?	Yes	No
Additional Notes					Retr-- ofit 2011		New			

High rental turnover and billed energy use. Another criterion was to identify if the apartment units of the housing site had a high rental turnover. It was also important that the residents received a separate billed energy use, i.e., other than their apartment rent.

The selected dashboard site was a multi-family low-income housing complex, where the units varied from a low to a very high rental turnover depending on their apartment type (2, 3, 4 or 5 Bedroom Apartments) and billed electricity amount.

Tenants were given an allowance for the utility energy use without any charge for this energy use. If they go beyond this allotted amount, their rent invoice includes an additional charge for excess utility use. This allowance changes from month to month. There is no rollover if they are under one month and then go over the next month. It was determined that many tenants generally exceed this allowance over the summer. The rates charged per unit of excess energy vary by month or season (i.e., winter vs. summer rates). More detailed information about the apartments and their allowance is mentioned in the 'Monitored Housing Background' section.

Availability of historic & consistent utility data. To determine energy savings during the study months and evaluate effectiveness of the dashboard and education intervention, it was essential to have the pre-study energy consumption data along with the post-study data.

Also, for comparison of consumption data during the pre- and post-study periods, it was important to have a consistent billing period for all apartments of the selected site.

The selected dashboard site had the availability of the monthly kWh consumption data and monthly billed utility charges data recorded for each apartment for both the 2011 and 2012 years. It was available upon request from the Housing Supervisor. The resident's monthly energy consumption and their billed usage was consistently recorded by the Neighborhood Services on the first of every month, for the amount exceeding their allotment.

Compatibility of electric panel with TED device & ease of installing. For the experiment, it was essential to assess the feasibility of dashboard installment before the study began on the study site. It was important that the appointed electrician could install the MTU of the TED device in the sub-meter without touching or mingling with the part of the master meter owned by APS. APS owned meters could not be touched or mingled with for installation purpose since it was decision taken by the utility company. Also, it had to be made sure that the electric panels were not too small to have Dashboard clamp installed properly. Another aspect of consideration was that apartments had to essentially have a single-phase service. TED is suitable for installation on a single 120/240V single-phase 60Hz service and it is not suitable for three-phase service.

For the selected dashboard site, once the City of Phoenix appointed electrician received the request form from Neighborhood Services, he visited each home to assess the feasibility of Dashboard installation. The Electrician did not foresee any issue with installing the MTU of the TED device in the sub-panels for each unit. The layout of the panels was such that, there was one APS master meter and the equipment beyond the APS master meter was owned by the City of Phoenix, including the individual meters for each unit. Therefore, the installation of the MTU in the sub-panel for each unit would not involve APS. Each of the sub-meters and panels are on the exterior of the units and there are no panels inside the units. The apartments were all single-phase service, so there were no issues with the TED device compatibility either.

Scope

The scope of the study is constrained to a low-income, multi-family housing complex in Phoenix, Arizona for the duration of six months from July to December, 2012, as potential benefit of energy-use feedback is expected during the summer months.

Limitations

- The ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) inverse modelling toolkit (IMT) was used to fit regression model for energy consumption for each apartment unit, with temperature as the only independent variable. The three parameter model is used to predict the consumption, i.e., the new baseline during the post-study period, using the corresponding temperature. The savings is calculated by comparing the new baseline with the actual energy consumption values. A downside to this method is that energy consumption for residential buildings depends on a lot of variables. Therefore, assuming energy consumption to be only dependent on temperature is a vast generalization that has been made for calculating the new baseline,

- The study was carried out for a short period of six months from July to December 2012. Therefore, determining the effect of feedback device with other interventions along with limited number of follow-up sessions with the participants was a challenge.
- The sample size of the study group for data analysis after the recruitment, follow-up sessions and data clean-up reduced to 34 participants.

Potential benefits of the study to the residents.

Lack of proper energy feedback. The complex's APS master meter is not smart meter. Also, none of the sub-meters for each units were smart meters. This factor was an important consideration as it would provide the opportunity to the residents to explore the effectiveness of being equipped with real-time feedback and education that would help them understand their energy use patterns.

Apartments exceeding their allotment at the study site. It was also identified by the meter reading data (provided by the housing supervisor) that more than half of the units exceeded their allowance during the summer months at the dashboard site. The table below summarizes the apartments that exceeded their allowance in the 2011 and 2012 years. Since more than half of the apartments exceeded their allowance both years, this was considered a motivating factor for the residents to participate in the study and explore the potential of educating themselves and understanding their energy usage patterns.

Table 12.

Number of apartments exceeding their allowance in 2011 & 2012

Month	Total No. of Apartments in the Complex	Total No. of Apartments considered for analysis after data clean up	No. of Apts. that Exceeded their Allowance in 2011 from the selected 83 apartments	No. of Apts. that Exceeded their Allowance in 2012 from the 83 selected apartments
Jan	145	83	45	41
Feb	145	83	29	28
Mar	145	83	58	43
Apr	145	83	65	68
May	145	83	72	73
Jun	145	83	68	73
Jul	145	83	73	71
Aug	145	83	72	73
Sep	145	83	72	73
Oct	145	83	57	65
Nov	145	83	47	53
Dec	145	83	61	60

Significance

The significance of this study is evaluating the effect of different conditions of feedback interventions within the same study. This study analyzes the effect of feedback, be it in form of education alone, a combined effect of both TED device and education or a combined effect of education, TED device and added budgeting information. It not only compares within the study groups but also with a control sample that received no intervention. It also looks into the effect of orientation and location on energy savings. These research areas may identify the effect of education in comparison with the combined effect of both the education and technology driven feedback. In addition it may also identify the effect of orientation and location of the apartment on feedback driven energy savings.

CHAPTER 4

DATA ANALYSIS AND RESULTS

Description of Study Site

Location. The dashboard study was conducted within the program's light rail boundary in Phoenix, in the metropolitan area of the city. The site name and exact location of this city-owned, low-income multi-family housing is not disclosed in this thesis document to maintain the anonymity of the occupants.

Apartment and panel layout. The complex was built in 1966 and includes 26 buildings with a total of 146 apartments. The apartments are grouped into different blocks as seen in Figure 11 and Figure 12. Typically, there are six apartments to each building block, three in the upper level and 3 in the lower level. There is one master electric meter that APS owns, which feeds each apartment's sub-meter, which are owned by the City of Phoenix. The apartment and meter sub-panel layout is important to understand because the TED device has distance limitations between the MTU installed on the electric meter feed and the display device that is located within the apartment.

Figure 10. Site plan of dashboard study

Figure 11. Apartment blocks consisting three upper and three lower units

Figure 12. Individually metered apartments, sub-panels outside the unit blocks

Other apartment specifications. Other apartment specifications with respect to material, area, allotment, billing and number of apartments going above their allotment are described below.

Material. Each apartment building is made of un-insulated concrete masonry units (CMU) and single-pane, clear glass windows.

Space cooling. As mentioned in the previous section, the units are cooled by AC, not evaporative cooling, which provides greater potential for energy savings for this study.

Apartment Area. Each apartment type area, in square feet, are specified in Table 13. FAM 2 represents two-bedroom apartment. FAM 3 represents three-bedroom type apartment. FAM 4 represents four-bedroom apartment and FAM 5 represents five-bedroom apartment. This nomenclature will be used throughout remainder of the document.

Figure 13. Two-storied block consisting of six units each, un-insulated concrete blocks

Table 13.

Apartment type area in square feet

Apartment Type	Area (Square feet)	No of Units
2 Bedroom (FAM 2)	702 sqft	42 units
3 Bedroom (FAM 3)	869 sqft	89 units
4 Bedroom (FAM 4)	976 sqft	8 units
5 Bedroom (FAM 5)	1256 sqft	6 units

Unit's monthly allotment & billing. The city of Phoenix Housing Department reads the meter manually each month for billing purposes. Depending on the apartment type, the resident is given a fixed allowance every month. The allowance varies month to month with the highest allowance given during August and the lowest during January. The resident pays for the amount exceeding the allotment for that month. Residents are charged 10 cents for every kWh used.

Table 14.

Monthly kilowatt hour allowance for 2011 and 2012 (City of Phoenix Housing Department)

	Jan kWh	Feb kWh	Mar kWh	Apr kWh	May kWh	Jun kWh	Jul kWh	Aug kWh	Sep kWh	Oct kWh	Nov kWh	Dec kWh
FAM 2	221	255	271	291	410	625	696	767	553	410	237	223
FAM 3	229	263	279	316	457	709	793	878	625	457	245	231
FAM 4	239	273	289	343	505	797	894	991	700	505	255	241
FAM 5	249	284	300	372	556	888	999	1110	778	556	265	252

Table 15.

Monthly dollar allowance for 2011 and 2012

	Jan ($)	Feb ($)	Mar ($)	Apr ($)	May ($)	Jun ($)	Jul ($)	Aug ($)	Sep ($)	Oct ($)	Nov ($)	Dec ($)
FAM 2	$22.10	$25.50	$27.10	$29.10	$41.00	$62.50	$69.60	$76.70	$55.30	$41.00	$23.70	$22.30
FAM 3	$22.90	$26.30	$27.90	$31.60	$45.70	$70.90	$79.30	$87.80	$62.50	$45.70	$24.50	$23.10
FAM 4	$23.90	$27.30	$28.90	$34.30	$50.50	$79.70	$89.40	$99.10	$70.00	$50.50	$25.50	$24.10
FAM 5	$24.90	$28.40	$30.00	$37.20	$55.60	$88.80	$99.90	$111.0	$77.80	$55.60	$26.50	$25.20

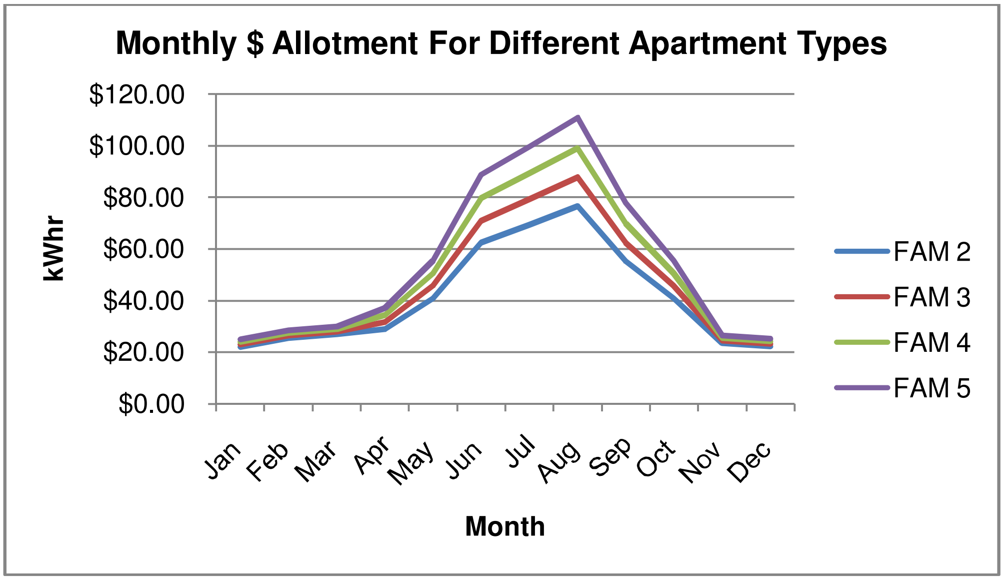


Figure 14. Monthly dollar allotment for different apartment types

Experiment Design - Program Time-Line

The study's entire process, from recruitment until device de-installation,startedMay8, 2012 and endedFebruary15, 2013. TED device installation was still underway during June and July 2012, though most of the apartments had received their device by the beginning of July. For this study analysis, the actual study months were considered from July 2012 until the end of December 2012, i.e., six months.

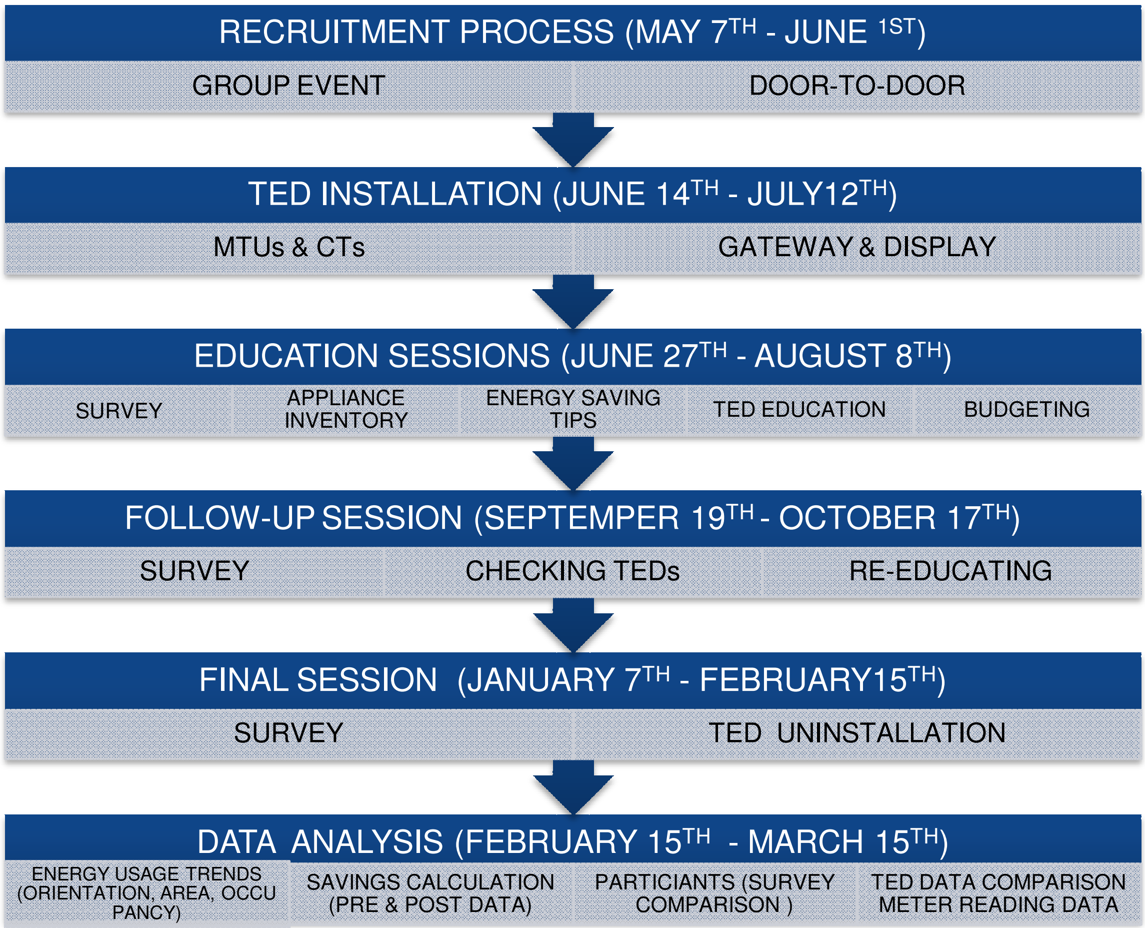


Figure 15. Timeline of the study

Initial design set-up. Before the recruitment phase began, all 145 apartments were considered potential participants. Keeping this sample size in mind, it was decided that the participants would be randomly assigned to one of the three conditions. Participants would not be told at the time of recruitment, about their group condition, i.e., whether or not they would be in the dashboard or education groups. This section describes the conditions of the experimental groups. The study was design such that, out of the recruited residents, one third would be randomly allotted to the groups described below. The rest would be treated as the control group, i.e., the group receiving neither the education nor the TED.

Education-only group (Group 1). Participants in the 'education only' would only receive the education and not the dashboard device. They would receive education about their major energy-use appliances/equipment (kWh), their monthly allowance, energy rates and other energy saving tips that might change energy use/consumption (e.g. window shades, phantom loads, use of CFLs (compact fluorescent lights), Energy Star appliances, thermostat settings, use of fans during mild weather, etc.).

Dashboard plus education group (Group 2). Participants in the dashboard plus education group will complete the waiver to share energy data, the initial survey, and have a dashboard device installed in a visible location in their homes. They will also receive education or training about how to use the device and general energy savings tips. These participants also received education similar to group 1, about their major energy-use appliances/equipment (kWh), their monthly allowance, energy rates and some energy savings tips that might change their energy use/consumption, (e.g., window shades, phantom loads, use of CFLs (compact fluorescent lights), Energy Star appliances, thermostat settings, use of fans during mild weather, etc.)

Dashboard plus education with added tailored information (Group3). Participants in this group received the same interventions as group 2, i.e., the dashboard plus education along with additional tailored information. In congruence with the participants' apartment type (FAM 2, FAM 3, etc.), the residents would receive a budget sheet that would help them compare their daily-billed usage with the kilowatt-hour and dollar usage on one of the screens of the in-home display device. Detailed information about this is explained in the later sections.

Table 16.

Study groups planned as per initial design

Group 1	Group 2	Group 3
Education	Education	Education
No Home Energy Display	Home Energy Display	Home Energy Display + Tailored information
1/3rd of Total Recruited	1/3rd of Total Recruited	1/3rd of Total Recruited

Other aspects of the study design. Informed by the outcomes of the literature previously discussed, the study was designed with the following considerations.

Hybrid of feedbacks types and motivational element. Provision of real-time feedback in the form of a home-energy display, in this case The Energy Detective 5000 (TED) and provision of disaggregated appliance information as well, was decided as forms of feedback to be provided. For understanding the effects of TED, education and tailored information individually, the study was designed such that group 1 had one intervention that is the education, group 2 had two interventions, i.e. TED as well education and group 3 had three interventions, i.e. education, TED and a motivational element i.e. goal setting in the form of budget sheet.

Promoting participant involvement. Education in the form of providing energy saving tips, individual appliance information and training for understanding the TED functionality for the group receiving the in-home display device was planned for this study.

Study duration and time. The duration of the study when the participants would be under the intervention, was designed for at-least 6 months, including the summer months, to benefit the residents during their most potential months of the energy savings.

Feedback frequency & Follow-up sessions.As part of the study, after installation of the In-Home Display, ASU researchers would contact participants four times, i.e. within first two weeks when the installation would take place, 2 weeks to 1 month post-installation during first education sessions, 3 months post-installation, and 6 months post-installation, which is when the study would conclude and the Dashboard would be uninstalled. The follow-up session with the participants after 3 months was decided, to check the functionality of the device as well as take participant inputs related to their understanding of the device (group 2 & 3). During these visits, the residents of all the groups were re-educated by summarizing about energy saving tips that were discussed during the first visit. Questions related to any major appliance work orders, or occupant move-in move-out that would affect to energy usage would also be asked.

Incentive. The participants were promised a gift basket consisting of $75 worth energy-saving products at the end of the study.

Pre-Recruitment Preparations

Before the recruitment procedure began, there were certain tasks to be completed to make sure the recruitment procedure and the study phase were conducted as per study protocols since this experiment involved human subjects.

Preparation of study design draft and sessions related material. Below are the description of all the different materials that were prepared for the study. The materials related to participant sessions were prepared both in Spanish and English languages since residents of various ethnicities resided at the study site

Experiment design draft. The experimental design, i.e. description of group conditions, the study time-line, regarding visits to the occupant homes etc. were developed in conjunction with researchers from the Department of Psychology and the Global Institute of Sustainability. A copy of study approval by the IRB has been attached in Appendix E***.***

Education script. Additionally, for the education sessions, the scripts in both English and Spanish were prepared that described the education content and the order in which each information was to be given to the resident. This script was meant only for the recruiters who were interacting with the residents during the session.

Information flyers. Information flyers consisted of energy savings tips and general individual appliance information as provided by APS (Arizona Public Service) official website. The energy saving tips consisted of measures that might help the resident change their energy use/consumption. For instance window shades, phantom loads, use of CFLs (compact fluorescent lights), Energy Star appliances, thermostat settings, use of fans during mild weather, etc were mentioned in the education tips flyer. A copy of this flyer is provided in 'Education Session Materials' section of Appendix D. This information flyer was prepared for all the three groups.

TED flyer. This flyer consisted of Information and description related to various display screen options the resident could access to. Also general guidance and precautions with respect to the display and gateway workability was also mentioned. A copy of this is provided in the

'Education Session Material' section of the appendix. This flyer was prepared only for group 2 and 3 participants.

Monthly allowance. Most of the residents were not aware of their exact monthly allowance. Therefore, as part of the study design, energy budgeting information was included as one of the interventions to assist residents in understanding the variations in their electricity allowance during summer and winter months. The monthly allowance for each apartment type was requested from and provided by City of Phoenix's Neighborhood Service Department. Additionally, this allowance sheet was also provided to all three groups to help the residents compare this allowance with the display's monthly information screens. Figure 16 shows a copy of the monthly allowance sheet prepared for the participants as per their apartment type.

	FAM2	FAM3	FAM4	FAM5
January	$22.10	$22.90	$23.90	$24.90
February	$25.50	$26.30	$27.30	$28.40
March	$27.10	$27.90	$28.90	$28.40
April	$29.10	$31.60	$34.30	$30.00
May	$41.00	$45.70	$50.50	$55.60
June	$62.50	$70.90	$79.70	$88.80
July	$69.60	$79.30	$89.40	$99.90
August	$76.70	$87.80	$99.10	$111.00
September	$55.30	$62.50	$70.00	$77.80
October	$41.00	$45.70	$50.50	$55.60
November	$23.70	$24.50	$25.50	$26.50
December	$22.30	$23.10	$24.10	$25.20

Figure 16. Allowance sheet given to the participants as per apartment type

Budget sheet. The budget sheet consisted of pre-calculated information related to their daily energy usage for the residents to refer to. The information calculated the approximate billed kilowatt-hour consumption (per day), i.e., after deducting the allowed kilowatt-hours. Depending on exceeded kilowatt-hours (per day), an approximate monthly-billed amount was projected on the sheet. Many such billed amounts were projected starting from $0. This was to help the resident understand, control or use their energy depending on the budget amount they could spend. The budgets were projected as per allowance given to different apartment type. This information was only for the group 3 participants. Figure 30 provides the budget sheets prepared for group 3 participants depending on their apartment type.

Daily kWh Budget

FAM2

	$0.00	$25.00	$50.00	$75.00
June	20.8kWh	29.2	37.5	45.8
July	22.5	30.5	38.6	46.6
August	24.7	32.8	40.9	48.9
September	18.4	26.8	35.1	43.4
October	13.2	21.3	29.4	37.4
November	7.9	16.2	24.6	32.9
December	7.2	15.3	23.3	31.4

These numbers tell you daily kilowatt hours you can use to stay within a budget. This corresponds to the display setting "recent usage".

Daily kWh Budget

FAM3

	$0.00	$25.00	$50.00	$75.00
June	23.6kWh	32.0	39.0	47.1
July	25.6	33.6	41.7	49.8
August	28.3	36.4	44.5	52.5
September	20.8	29.2	36.3	44.4
October	14.7	22.8	30.9	38.9
November	8.2	16.5	24.0	32.1
December	7.5	15.5	23.6	31.6

These numbers tell you daily kilowatt hours you can use to stay within a budget. This corresponds to the display setting "recent usage".

Daily kWh Budget

FAM4

	$0.00	$25.00	$50.00	$75.00
June	26.6kWh	34.9	41.8	49.9
July	28.8	36.9	45.0	53.0
August	32.0	40.0	48.1	56.2
September	23.3	31.7	38.7	46.8
October	16.3	24.4	32.4	40.5
November	8.5	16.8	24.4	32.4
December	7.8	15.8	23.9	32.0

These numbers tell you daily kilowatt hours you can use to stay within a budget. This corresponds to the display setting "recent usage".

Daily kWh Budget FAM5

	$0.00	$25.00	$50.00	$75.00
June	29.6kWh	37.9	44.8	52.8
July	32.2	40.3	48.4	56.4
August	35.8	43.9	51.9	60.0
September	25.9	34.3	41.2	49.3
October	17.9	26.0	34.1	42.1
November	8.8	17.2	24.7	32.7
December	8.1	16.2	24.3	32.3

These numbers tell you daily kilowatt hours you can use to stay within a budget. This corresponds to the display setting "recent usage".

Figure 17. Budget sheets prepared for group 3 participants

Participant Surveys. Participant surveys were prepared, which consisted of information related to the in-home display device, for instance, their understandability with the device, preferred setting of the screen, using budget and allowance sheet with the display, etc.

Approvals from IRB & badging. Since the study involved interaction with human subjects, Arizona State University required Institutional Review Board (IRB) approval to ensure that subjects are treated ethically and that their rights and welfare are adequately protected. See Appendix E.

Background checks. Per ASU's public safety requirement agreement with the City of Phoenix, and because recruiters would be in direct contact with vulnerable populations, each recruiter had to be fingerprinted for a security background check.

Recruitment Procedure

Evening events. Prior to the door-to-door recruitment, a pizza party was organized on the May 7th and 8th of 2012 for the residents at the study location. This event was conducted to invite interested residents to participate in the study. Interested participants filled out a contact information sheet and short survey about their appliance usage during this event.

Door-to-door recruitment. To invite more participants to the study, door-to-door recruitment was conducted from May 8th to June 1st. The residents were asked to fill out a contact information sheet, which included their name, contact information and their possible availability during the week. They were further informed of being contacted again to let them know their group allotment. During this phase, a total of 82 possible participants were recruited.

Random allotment of groups. The interested participants were randomly divided equally into the three groups. The table below categorizes the participants group-wise.

Table 17.

Random allotment of groups

	Group1	Group 2	Group 3	Possible Participants	Control Group	Total Residents
No of Households	26	28	28	82	63	145
Description	Education	Education + TED	Education + TED + Budgeting Information	With Interventions	No Intervention	Sample size

Challenges during recruitment. Challenges related to participant availability during door-to-door recruitment reduced the number of possible participants. Door-to-door recruitment was conducted both during the morning as well as evening hours to get maximum resident availability. Additionally, some of the apartment units were vacant while some residents had not resided in the apartment for a minimum of twelvemonths. This further reduced the number of potential participants.

Device Installation & Education Sessions

Setting up appointments. The possible participants were contacted again through the contact information sheet provided by them at their best possible availability. Phone appointments were made with the group 2 and 3 participants, to inform them about their group allotment and device installation.

Installation & device configuration. The Energy Detectives (TEDs) were installed from June 14th to July 30th, 2012. There were two phases to this installment.

MTUs and CT's Installment. The Neighborhood Service Department(NSD) appointed electrician installed the meter part of the TED component, i.e., the Measuring Transmitting Unit

(MTU) and Current Transformers (CT) in the individual sub-panels of the participating apartment units. The MTU transfers data to gateway, which is the second TED component that is plugged inside the apartment. A brief description about the MTUs and CTs has been given in the TED section of the background literature (see Appendix B).

Display and gateway Installment. This part of the installment involved visiting each participant of group 2 and 3 units whose MTUs had been installed. The gateway and display were installed and configured such that it could receive the information from the MTU. During these two first phases, not all the participants were reached and some others opted out from the study.The information flyer describing the display functions, precautions and guidance related to gateway and display were provided. The 'Education Session Materials' section (see Appendix D) shows the copy of the flyer provided with the instructions for the participants. A brief pictorial description of the general configuration is mentioned in the TED section of the background literature in this report (see Appendix C). There were other specific configurations that were done for the participants of the study.

TED configuration step 1. The gateway and device was first plugged in two different outlets of the apartment. It was made sure with the resident that the gateway would not be unplugged from the outlet chosen, else the data transmission would stop.

TED configuration step 2. The gateway was connected with a personal laptop temporarily using an ethernet cable to access the footprint software. The serial numbers of the MTU and display were noted so they could be used in the footprint software to set up the initial connection between all the three components of the TED.

TED configuration step 3. Once the footprint software recognized the gateway, the footprint software was accessed and inputs related to date, time, location, display screen option, rates, etc. were filled in. For this study, all the display options except the CO2 screen were enabled. An input of $0.10 per kWh of electricity was filled in kWh, which was the amount charged to the residents of that location.

Though TED has features to display feedback online, through the footprint software, it was decided that for this study, the feedback related to only an in-home display device would be tested.

Table 18.

Number of participants left after the TED installation phase

	Group1	Group 2	Group 3	Possible Participants	Control Group	Total Residents
1. No of Households	26	26	28	82	63	145
2. No of Households after TED Installation	26 (No TEDs)	23	17	67	78 (63 + opt outs)	145
Description	Education	Education + TED	Education + TED + Budgeting Information	With Interventions	No Intervention	Sample size

First education/information session. These sessions took place from June 27th to August 8th, 2012. The sessions lasted for about one to one and half hours. Below are the various education and training given to the residents.

Survey. Survey questions about participant age group, occupancy, duration of residency in the present apartment, their understanding of energy usage, etc. were asked.

Appliance Inventory. Residents were asked about the appliances they owned, as well as its frequency of usage. Watts consumed per appliance were measured using a kilowatt meter when in on as well as off mode. The off mode was measured to check for the phantom loads associated with the appliance. Electronic appliances and electronic devices were checked if they were Energy Star rated. Appliance information related to their consumption in measured watts versus the designated watts, measure of phantom loads associated with certain appliances, and Energy Star label were given to the residents through this inventory.

Energy saving tips. Tips related to window shades, phantom loads, use of CFLs (compact fluorescent lights), Energy Star appliances, thermostat settings, use of fans during mild weather, etc. were explained to the residents. A flyer was also left behind for their reference.

TED Education. Once the TED was configured completely in the presence of the resident, training related to reading and understanding the information on the display screen option was explained. The residents were taught how to change the display options and an actual demonstration of the effect of turning lights on and off on the display was conducted. In addition, the residents were cautioned about not unplugging the gateway or plugging it into a power strip as that would result in loss of connection between the gateway and MTU. To check the interaction of the gateway with the MTU and the display, the residents were asked to check if the LED lights on the gateway were constantly blinking. This part of the training was only for group 2 and group 3 participants.

Allowance and budget sheet information. The residents were also taught how to compare their allowance with the TED information on the screen with the help of 'month-to-date' and 'monthly projections' screen options. This was explained to only group 2 and 3 participants. The budgeting sheet information was explained to only group 3 participants. Using this information, the resident could set goals by referring to the 'recent usage' screen option and compare the information on the budget sheet. The information on the budget sheet pre-calculated the approximate billed kWh consumption (per day) i.e. after deducting the allowed kWh given to a resident. Depending on exceeded kWh (per day), an approximate monthly-billed amount was projected on the sheet starting from $0.00 (which meant that the resident was within their allowance). Refer to Figure 30 previously described in the 'Experiment Design' section of the report under the allowance and budgeting information sub-section.

Final number of participants. During this phase, there were more participant opt-outs. The final numbers are as mentioned in Table 19 below.

Table 19.

Number of participants left after the education session phase

	Group1	Group 2	Group 3	Possible Participants	Control Group	Total Residents
1. No of Households	27	27	28	82	63	145
2. No of Households after TED Installation	26 (No TEDs)	23	17	67	78 (63 + opt outs)	145
2. No of Households after Education Session	13	19	13	45	100 (78 + opt outs)	145
Description	Education	Education + TED	Education + TED + Budgeting Information	With Interventions	No Intervention	Sample size

Follow-up session.

A follow-up session was conducted half-way through the study phase, from September 19th until the end of October. During this session, displays of all the group 2 and 3 participants were checked, i.e., if they were working properly. This was followed by a short questionnaire about participant energy use, and their understanding of energy use and savings. Group 2 and 3 participants were questioned about their understanding of the display device and using this device to compare with the allowance sheet. Similarly, group 3 participants were asked about their understanding of the budget sheet information.

The final group of participants after this session is illustrated in Table 23. Though one of the units, after the follow-up session had moved and another opted-out, their data for summer was still recorded and the apartments were under the intervention, therefore their usage would be used for analysis from July to September 2012.

Table 20.

Number of participants left after the follow-up session

	Group1	Group 2	Group 3	Possible Participants	Control Group	Total Residents
1. No of Households	27	27	28	82	63	145
2. No of Households after TED Installation	26 (No TEDs)	23	17	67	78 (63 + opt-outs)	145
3. No of Households After Education Session	13	19	13	45	100 (78 + opts outs)	145
4. No of Households After Follow-Up Session	13	18	12	44	100	145
Description	Education	Education + TED	Education + TED + Budgeting Information	With Interventions	No Intervention	Sample size

Final session & device de-Installation.

This final session was conducted from January 7, 2013 to February 15, 2013. The gateways and TEDs were uninstalled during this phase, followed with a short questionnaire, similar to the questionnaire prepared during the mid follow-up session. The participants were given the gift bags as well, which consisted of smart powers strips, compact fluorescent lights and LED night lights.

Challenges

TED Related Challenges

Technical issues with TED. The electrician had pointed out, during the installation phase, that some apartments at the study site had wiring issues, which would cause issues with transmission of data from MTU to the Gateway in those apartments. It was consequently seen that those gateways frequently lost their interaction with the MTU, and in-turn, caused the screens to not display correct energy-use information. Each time the connection was lost between the gateway and MTU, the number of skips on the stats page would increase compared to what was received. This part of the relationship between the number of skips and the percentage difference between the TED and meter readings is shown in the analysis section of the report.

Resident interaction with the TED. According to the occupant surveys, some of the residents mentioned difficulty in understanding the information on the screen. The follow-up session tried to re-educate those participants. It was also noted that some residents had unplugged their device while one of them had changed the position of the gateway to a power strip. The results of the resident interaction with the TED is discussed in the analysis section, through the results of the participant survey.

Session Challenges

Rescheduling appointments and opt-outs. During the first scheduling of appointments, the resident's contact information was either incorrect or unreachable. Some apartments that were scheduled on phone were not available in person during the appointment and some participants rescheduled the session more than once. There were many opt-outs as well before the first session began. There were some apartments that received the device, but could not receive the information/education session due to their unavailability each time the participant was tried.

Participant's knowledge about their energy bill. Most of the participants were not aware of their allowance and how it varied and worked on a monthly basis. Also, since most of participants had limited or no knowledge about how electricity is measured, they faced difficulty in understanding the relationship between the kilowatt-hour and corresponding dollar amount. During the follow-up sessions, the participants were re-educated to help them summarize what was informed to them.

Difficulty in understanding information/questions. Some of the participants faced difficulty with understanding the survey questions which were based on a scale. This resulted in longer duration of sessions.

Participant concentration. Some of the participants were distracted during the sessions either due to the presence of their kids or because they were busy with their household chores.

Baseline and Post-Study Data Collection

Monthly energy billing data. Monthly energy usage and billed amount was collected from the housing supervisor of the complex at different stages of the study as and when the residents were billed. The data was provided in the form of previous meter reading, present meter reading and the difference for each apartment was calculated between the two to get the units used. One unit of usage was equivalent to one kWh of usage. The residents were billed at the rate of $0.10 per unit of exceeded usage. This calculated usage was the amount the resident exceeded their allowance (depending on their apartment type).

Table 21.

Example of data related to meter reading provided before data analysis

Jul-11			Aug-11		
Previous Reading	**Current Reading**	**Units Used**	**Previous Reading**	**Current Reading**	**Units Used**
72	1197	1125	1197	2471	1274

Apartment-related data. Other apartment data, such as move-in dates, occupancy, apartment area, its orientation & position were also requested, for analysis purpose. Other than the study designed interventions, these additional variables were considered as possible reasons affecting energy consumption of the apartment. A detailed analysis of the effect of these variables has been discussed in the analysis chapter with graph descriptions.

Table 22.

An example of apartment related data provided before data analysis

Unit #	Move-In Date	Block #	Up/ Down	Orient	Location	Occupancy	Apt Type	Area (sq.ft.)
-	11/1/1999	1	U	E/W	N	6	FAM3	869

TED data collection. The TED data was collected after de-installing the gateway and display. Since the gateway contained the stored information, it was possible to download all the data from the group 2 & 3 participants. The monthly, daily, and hourly data were collected along with the stats page, which was extracted for some of the apartments during the de-installation. The monthly data from TED is compared with the meter readings in the analysis chapter to check for the percentage difference.

Challenges with data collected. There were many errors and outliers with the data collected from the meter readings data as well as skipped and missing data from the TED.

Meter reading data issues. The monthly meter readings, which were sent to the team for analysis had many outliers primarily due to the following reasons.

Multiple move-in and move-outs. During 2011 and 2012,there were multiple move-in and move-outs, which caused unexpected energy usage trends in particular months. Those unusual readings were identified with the move-in, move-out dates provided. Through this information, the vacant apartments could also be identified.

Table 23.

Example of data error related to months with move-in or move-out dates

Move-in Date 1	Move-in Date 2	Jan-'12	Feb-'12	Mar-'12	Apr-'12	May-'12	Jun-'12	Jul-'12	Aug-'12	Sep-'12	Oct-'12	Nov-'12	Dec-'12
3/1/2010	**8/1/2012**	181	156	172	338	792	1195	495	0	0	0	4	29

Error due to technical issues with meter. Meter readings for some months, from the data provided, had a very high consumption. whereas the month before it had a very low consumption.

Those meters, in particular had technical issues, due to which it skipped recording some data for a particular month and then recorded the entire consumption of two months in one go, in the month next to it. These errors were identified through close examination of the previous meter readings and the current meter readings. This error trend was identified in some apartments.

Table 24.

Example of data error due to technical issues in meter reading

	Jan-11			Feb-11		
MOVE-IN	**Previous Reading**	**Current Reading**	**Units Used**	**Previous Reading**	**Current Reading**	**Units Used**
12/1/2010	35831	35831	**0**	35831	37293	**1462**

Error due to incorrect manual recording of data. Since these meters are read manually, it was noticed from the data received, that either the previous or present meter readings were recorded incorrect. Those errors were easy to identify, especially when one month had a high energy usage and the other was too low.

Table 25.

Example of data error due to incorrect manual recording of data

	Dec-11			Jan-12		
MOVE-IN	**Previous Reading**	**Current Reading**	**Units Used**	**Previous Reading**	**Current Reading**	**Units Used**
10/01/2010	25471	**26656**	**1185**	**25656**	25792	136

Analysis Approach

Step 1.Pre-analysis data clean-up. This clean-up consisted of two steps.

sub-step 1.In this step, apartments that moved after March 2011 were eliminated from both the control and participant group.

sub step 2. In this step, apartments with data anomalies, in two or more months, were eliminated. Energy consumption was either too low, zero or they were obvious outliers. In addition, in this step, some of the meter readings were modified/corrected due to incorrect meter readings.

Table 26.

Summary table of participants left after each study phase and data clean up

	Group1	**Group 2**	**Group 3**	**Possible Participants**	**Control Group**	**Total Residents**
1. No of Households	27	27	28	82	63	145
2. No of Households after TED Installation	26	23	17	67	78 (63 + opt outs)	145
3. No of Households After Education Session	13	19	13	45	100 (78 + opt outs)	145
4. No of Households After Follow-Up Session	13	18	12	44	100	144
5. No of Households left after data clean-up 1 (Move - in dates)	11	16	10	38	75	113
6. No of Households left after data clean-up 2 (Data anomalies) + Eliminating 4 Bedroom Aprtment	9	15	10	34	49	83
Final List of Households	9	15	10	34	49	83
Description	**Education**	**Education + TED**	**Education + TED + Budgeting Information**	**With Interventions**	**No Intervention**	**Sample size**

Step 2. Predicted energy consumption calculation. In the next step, all the cleaned up monthly energy consumption of 2011 year were regressed using average monthly temperatures of 2011 and corresponding monthly energy consumption. This regression was performed separately for each apartment unit.

ASHRAE IMT, Three Parameter Model Regression. The toolkit used for this regression was ASHRAEs three parameter model regression.

sup-step 1. Plug in monthly energy consumption and its corresponding average monthly temperaturein the ASHRAE IMT Software (2011 kWh monthly consumption & 2011 average monthly temperature) input file, selecting the appropriate model regression, in this case the three parameter cooling model. Run the IMT '.exe' file which calculates the corresponding change point temperature (X_{cp}), the energy consumption at the change point temperature (Y_{cp})and right slope(RS) needed to calculate the baseline equation for 2011.

*sub-step 2.*The values obtained from the toolkit software were plugged in the equation below. The temperature 'T_o' used now is the average monthly temperature of 2012. The X_{cp}, Y_{cp}& RS values are obtained from the 2011 regression model as explained in the previous step.

$$\text{if(To<Xcp) then Predicted Energy (2012)} = Y_{cp}$$

$$\text{if(To >Xcp) then Predicted Energy (2012)} = Y_{cp} + RS(T_o - X_{cp})$$

Table 30 explains the steps involved in calculation of the predicted energy consumption with an apartment example.

Table 27.

Example calculation of predicted energy consumption for 2012 study year

sub-step 1.

	Jan-'11	Feb-'11	Mar-'11	Apr-'11	May-'11	Jun-'11	Jul-'11	Aug-'11	Sep-'11	Oct-'11	Nov-'11	Dec-'11
Monthly kWh	346	283	402	597	1199	1776	1855	2005	1536	667	288	333
Average Temp(F)	51	52	65	71	76	87	92	95	87	74	59	49

Apt No.	N	R^2	AdjR^2	CV-RMSE	Y_{cp}	RS	X_{cp}
X	12	0.973	0.973	12.64%	319.499	57.3838	64.64

sub-step 2.

	Jan-'12	Feb-'12	Mar-'12	Apr-'12	May-'12	Jun-'12	Jul-'12	Aug-'12	Sep-'12	Oct-'12	Nov-'12	Dec-'12
Average Temp(F)	54	56	62	71	81	90	90	92	84	73	62	51

	(N) Jan-'12	(N) Feb-'12	(N) Mar-'12	(N) Apr-'12	(N) May-'12	(N) Jun-'12	(N) Jul-'12	(N) Aug-'12	(N) Sep-'12	(N) Oct-'12	(N) Nov-'12	(N) Dec-'12
Calculated Predicted Monthly kWh	319	319	319	705	1247	1786	1787	1874	1446	816	319	319

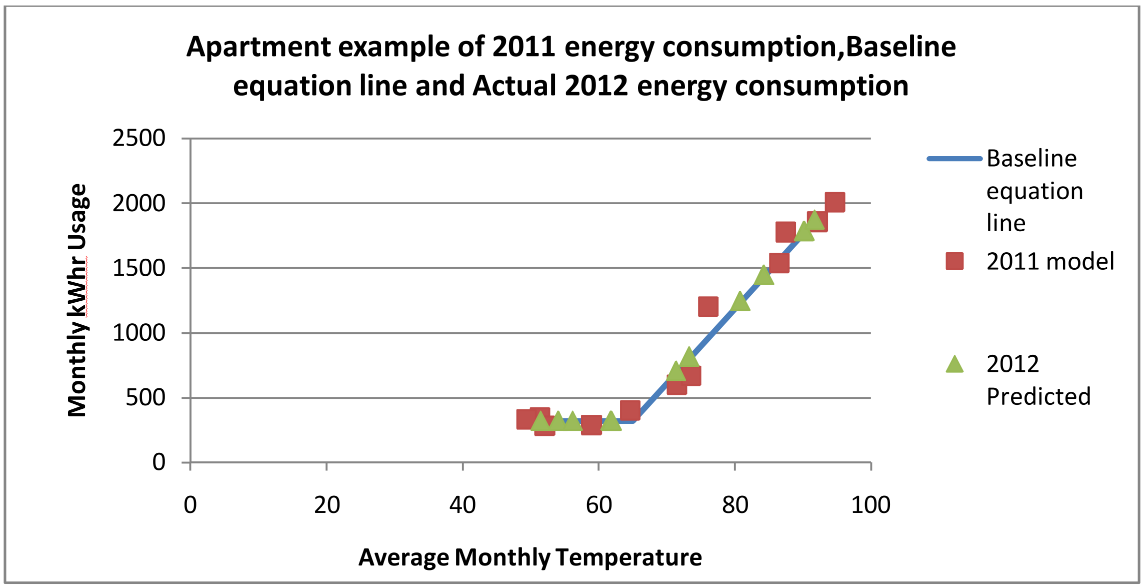


*Figure 18.*Single apartment example of three parameter (cooling) model regression

Step 4.Pre and post-study data difference calculation. The predicted monthly energy consumption, calculated from the previous step is the new baseline data. The energy savings/loss for each apartment is calculated by subtracting measured energy consumption of 2012 from the predicted energy savings. The measured energy consumption is the meter readings available for each apartment.

Table 28.

Example calculation of energy savings or loss using predicted and measured values

	Jan	Feb	(N) Mar	(N) Apr-'12	(N) May-'12	(N) Jun-'12	(N) Jul-'12	(N) Aug-'12	(N) Sep-'12	(N) Oct-'12	(N) Nov-'12	(N) Dec-'12
Calculated Predicted Monthly kWh 2012	319	319	319	705	1247	1786	1787	1874	1446	816	319	319
Measured Monthly kWh 2012	249	258	453	716	1225	2002	1675	1748	1392	701	281	305
(Predicted - Measured)	70	61	-134	-11	22	-216	112	126	54	115	38	14

Step 3. Analysis of pre-study and post-study data. Pre- and post-study data is analyzed between all the groups and the control group. The different levels of savings analysis is conducted as mentioned below.

Overall savings calculations. This energy savings analysis is conducted for all apartments and for the entire period of six months. The second part of this analysis also calculates and analyses savings calculations based on apartments grouped as per their orientation position for instance all the upper level apartments with east-west orientation.

The corresponding savings/loss in the billed dollar amount is also calculated and analyzed.

Monthly savings calculations. This analysis is conducted for all apartments and for different periods within the six months of intervention for instance, before the follow-up session and after the follow-up session. Individual monthly savings analysis is also conducted.

The corresponding savings/loss in the billed dollar amount is also calculated and analyzed.

Step 4. Comparing and evaluating energy savings/loss with participant surveys. In this step, the energy savings determined from pre and post-study data are analyzed with survey results. A general analysis of the survey is also analyzed.

Step 5. Meter Readings & TED Data Comparison. TED and meter reading data are compared to check the accuracy of TED readings.

APPENDIX G table gives the results of the ASHRAE IMT for the 83 apartments with their corresponding X_{cp}, Y_{cp}, RS, RMSE and CV-RMSE values.

Chapter 4

DATA RESULTS AND ANALYSIS

Part 1A- Pre-study and Post-study Energy and Billed Usage Comparison

This part analyzes and compares the overall energy consumption during the pre-study and post-study period, i.e. from July to December months for both the periods. Corresponding to the energy consumption, the billed usage is also compared for the same periods. The difference in energy and billed usage consumption is compared and analyzed across the different groups.

Energy savings comparison. Table 29 shows the energy consumption during the pre- and post-study periods. The energy consumption from the months of July to December for both predicted and measured usage is summed up to get the pre- and post-study period energy consumption respectively. It is seen that group 1 (consisting of 9 households) had a loss of 3009kWh in total, i.e. an increased energy usage during post study period. Group 2 (consisting of 15 households) had a savings of 2667kWh i.e. a decreased energy usage during the post-study period. Group 3 (consisting of 10 households) had a savings of 513kWh, i.e. a decreased energy usage during the post retrofit period. Control group (consisting of 49 households) had a loss of 4634 kWh, i.e. an increased usage during the post study. The corresponding percentages are also shown in Table 29. Group 3 had an insignificant savings of 0.9% during the study period and its savings percentage was less than group 2, which was 3.3%. Group 1, the 'education only group, incurred a higher loss of 6.7% than the control group which was -1.7%.

Table 29.

Energy savings or loss comparison between groups - Pre study and Post study periods

	Group1	Group2	Group 3	Control Group
Predicted Usage Jul to Dec 2012 (kWh) PRE-STUDY PERIOD	44942	80647	58852	270808
Measured Usage July-Dec 2012 (kWh) POST-STUDY PERIOD	47951	77980	58339	275442
July to Dec (% Savings '+' or %Loss '-') PRE STUDY - POST STUDY	-6.7%	3.3%	0.9%	-1.7%
July to Dec (kWh Savings '+' or Loss '-') PRE STUDY - POST STUDY	-3009	2667	513	-4634
Number of Apartments	9	15	10	49

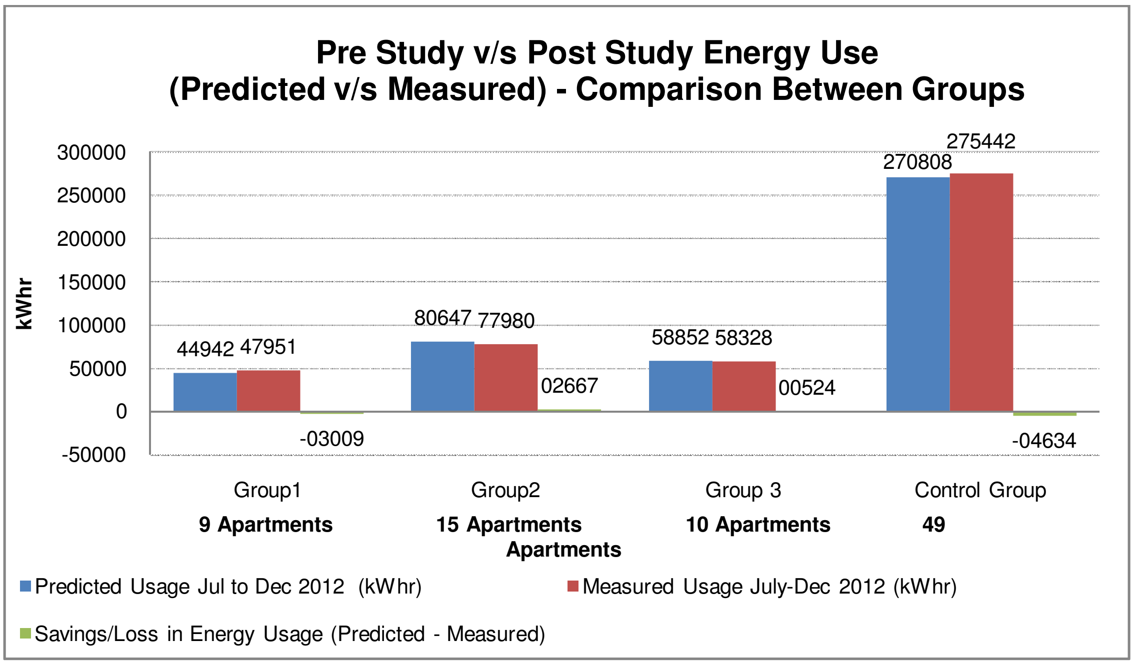


Figure 19.Pre-study versus Post-study energy use - comparison between groups

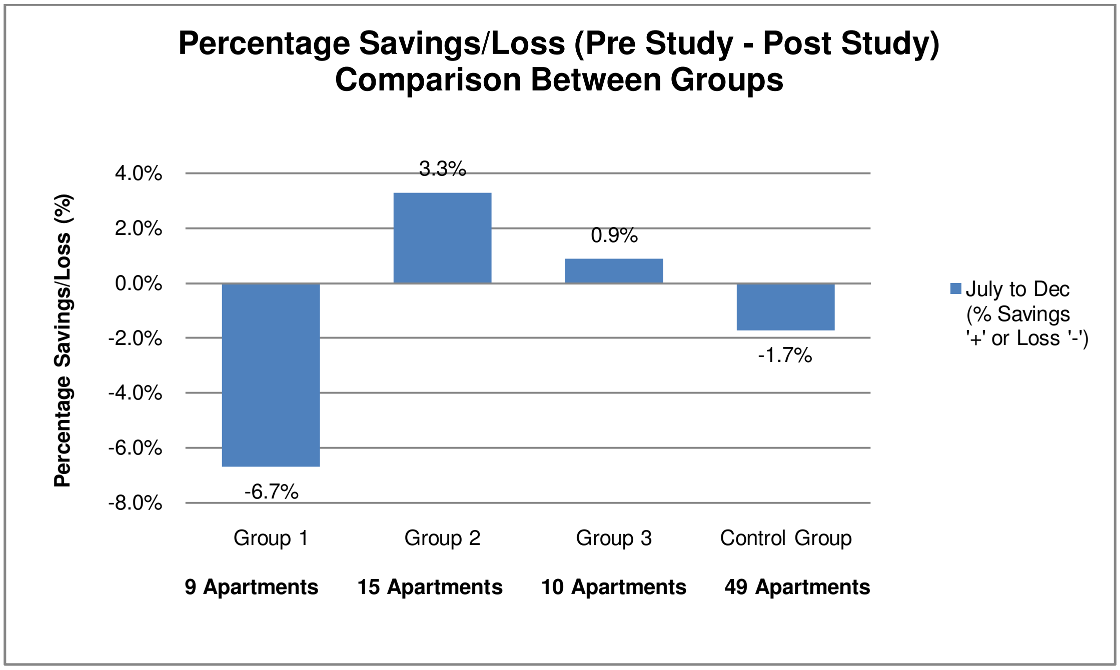


Figure 20. Percentage savings or loss in energy usage(Pre-study – Post-study)

Figure 19 shows energy consumption of different groups during the pre- and post-study period and Figure 20 shows their savings or loss percentage.

Correcting errors due to model uncertainty. The above savings or loss results calculation is corrected for uncertainty. The predicted models for each apartment have their RMSE (Root mean square errors), which have not been taken into consideration in the above results. To consider the uncertainty, the following calculations were conducted as shown in Tables 30 & 31.

Table 30.

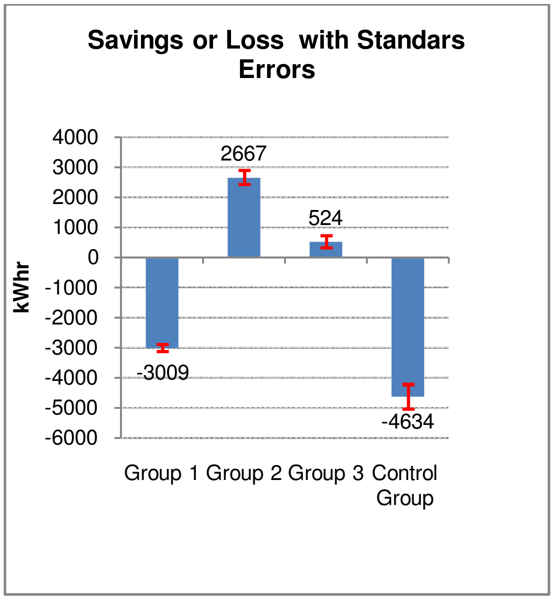
Group 1, 2 & 3 RMSE values taken from the ASHRAE IMT toolkit results for 12 months model

Group1		
Predicted kWh per unit for 6 months (July to December)	**RMSE (12 months model)**	**$RMSE^2$**
4630	102	10448
4104	61	3667
5903	112	12533
4959	91	8232
4396	82	6717
5649	76	5760
5038	58	3331
5411	130	16808
4853	97	9500
Group 2		
Predicted kWh per unit for 6 months (July to December)	**RMSE (12 months model)**	**$RMSE^2$**
4152	110	12070
2481	112	12484
5997	144	20847
4699	94	8891
5150	171	29257
5654	238	56612
5575	158	24984
7080	144	20786
4058	238	56879
6349	140	19731
10431	150	22612
2847	70	4940
4883	84	7073
5516	161	25916
5776	136	18378
Group 3		
Predicted kWh per unit for 6 months (July to December)	**RMSE (12 months model)**	**$RMSE^2$**
3897	164.44	27040
7222	138.08	19067
4681	198.00	39205
6377	102.73	10553
3903	217.43	47276
5375	95.79	9175
6806	123.39	15226
5092	235.34	55387
7208	67.73	4588
8290	157.09	24678

Table 31.

Calculation of uncertainty in energy savings or loss calculation

	Group 1	Group 2	Group 3	Control Group
Predicted	44942	80647	58852	270808
Measured	47951	77980	58328	275442
Predicted-Measured	-3009	2667	524	-4634
Percentage savings or loss without uncertainty correction	-6.7%	3.3%	0.9%	-1.7%
No of Apartments	9	15	10	49
Sum of RMSE^2	76995	341460	252195	1011959
n	6	6	6	6
Total Standard Error = ((Sum of RMSE^2)/n))$^{1/2}$	113.3	238.6	205.0	410.7
Fractional Uncertainty	0.25%	0.30%	0.35%	0.15%
Higher Range	**-6.4%**	**3.6%**	**1.2%**	**-1.6%**
Lower Range	**-6.9%**	**3.0%**	**0.5%**	**-1.9%**



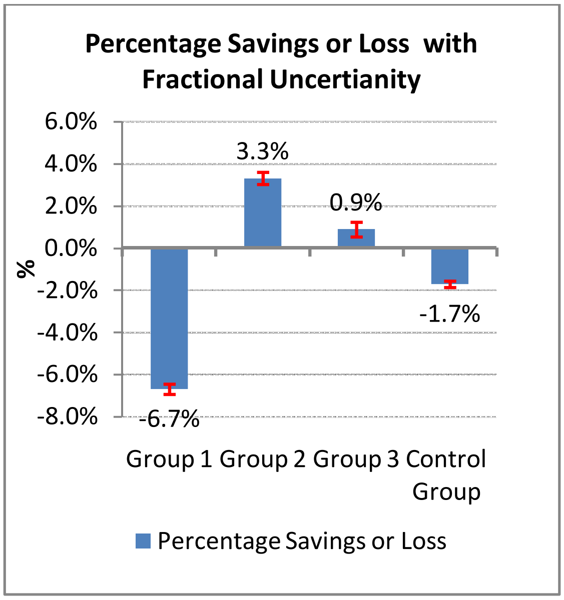


*Figure 21.*Calculation of uncertainty in energy savings or loss calculation

Billed usage savings comparison. Similar to the energy usage, the billed usage is compared between pre- and post-study periods across the groups as shown in Table 32. The billed usage is calculated based on the kilowatt-hours exceeding the allotted kilowatt-hours. The exceeded kilowatt-hours is charged at the rate $0.10 per exceeded kilowatt-hour. Group 1 incurred an increased bill of $301.00 and loss of -18.2%. Group 2 incurred a decreased bill of $285.00 and savings of 8.6%. Group 3 incurred a decreased bill of only $51.00 and a savings of about 2%. The control group incurred an increased bill of $442.00 and loss of 3.8%. Compared to the control group, group 2 and 3 had savings though not very significant. Group 1 overall, due to its increase energy usage during the post-study period, had a higher loss compared to the control group despite the education provided.

Table 32.

Billed usage savings or loss comparison between groups - Pre study and Post study periods

	Group1	Group2	Group 3	Control Group
Predicted Usage Jul to Dec 2012 (kWh) PRE-STUDY PERIOD	$1,652	$3,295	$2,759	$11,729
Measured Usage July-Dec 2012 (kWh) POST-STUDY PERIOD	$1,953	$3,011	$2,708	$12,171
July to Dec (% Savings '+' or %Loss '-') PRE STUDY - POST STUDY	-18.2%	8.6%	1.9%	-3.8%
July to Dec (kWh Savings '+' or Loss '-') PRE STUDY - POST STUDY	-$301	$285	$51	-$442
Number of Apartments	9	15	10	49

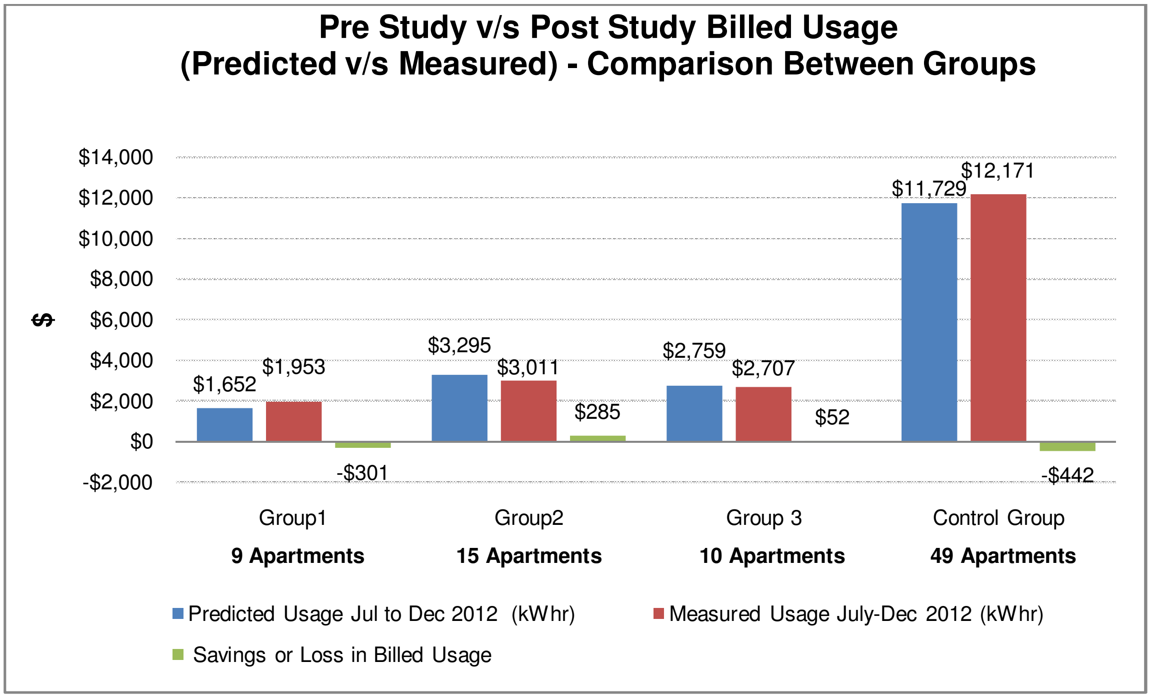


*Figure 22.*Pre-study versus Post-study billed usage - comparison between groups

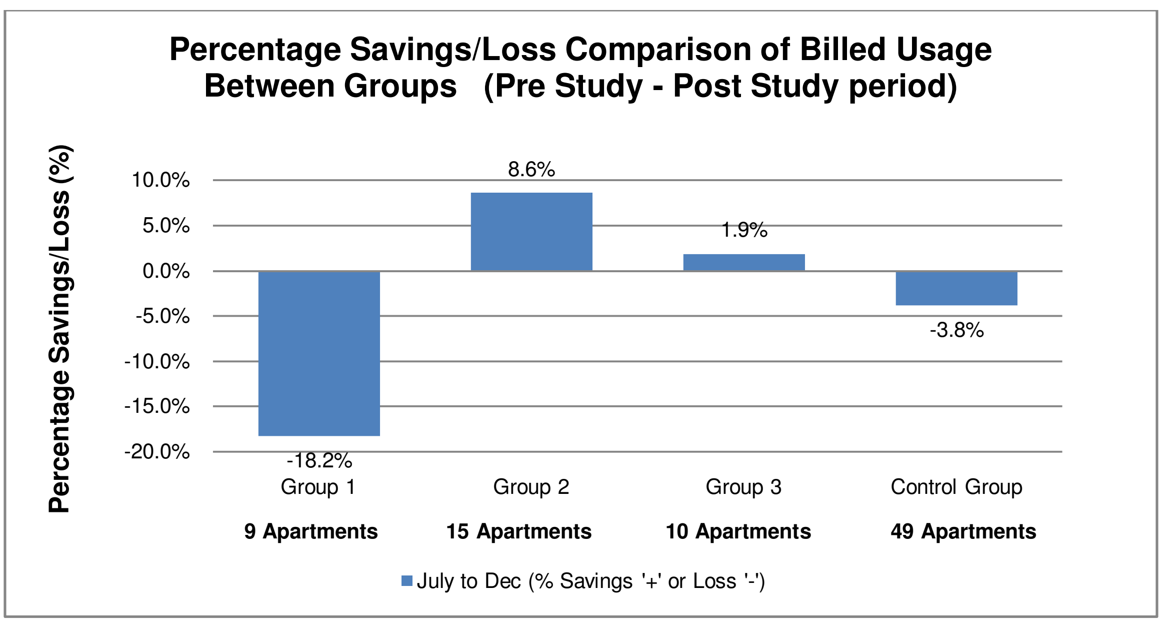


*Figure 23.*Percentage savings or loss in billed usage(Pre-study – Post-study)

Energy usage per unit area comparison. Since the distribution of the sample group consisted of different apartment sizes, energy usage per square foot was calculated and analyzed during the pre- and post-study period across different groups. This was to verify if any vast difference was identified in savings when energy use per unit(i.e. kilowatt-hour per square feet) was considered instead of only energy use (i.e. kilowatt-hours). It is seen that the percentage difference was not much between the two methods. Group 1 had an increased use of 6%, i.e. a loss, group 2 had savings of 3.8%, group 3 had savings of 0.6%, and the control group had loss of 1.9%. Table 33 presents the calculations for the savings and loss percentage. Figure 24 presents the bar plot of the percentages.

Table 33.

Energy per unit area, savings or loss comparison - Pre study and Post study periods

	Group1	Group2	Group 3	Control Group
Predicted Usage Jul to Dec 2012 (kWh) PRE-STUDY PERIOD	55.6	89.3	71.1	327.7
Measured Usage July-Dec 2012 (kWh) POST-STUDY PERIOD	58.9	86.0	70.7	333.8
July to Dec (% Savings '+' or %Loss '-') PRE STUDY - POST STUDY	-6.0%	3.8%	0.6%	-1.9%
July to Dec (kWh Savings '+' or Loss '-') PRE STUDY - POST STUDY	-3.3	3.4	0.4	-6.1
Number of Apartments	9	15	10	49

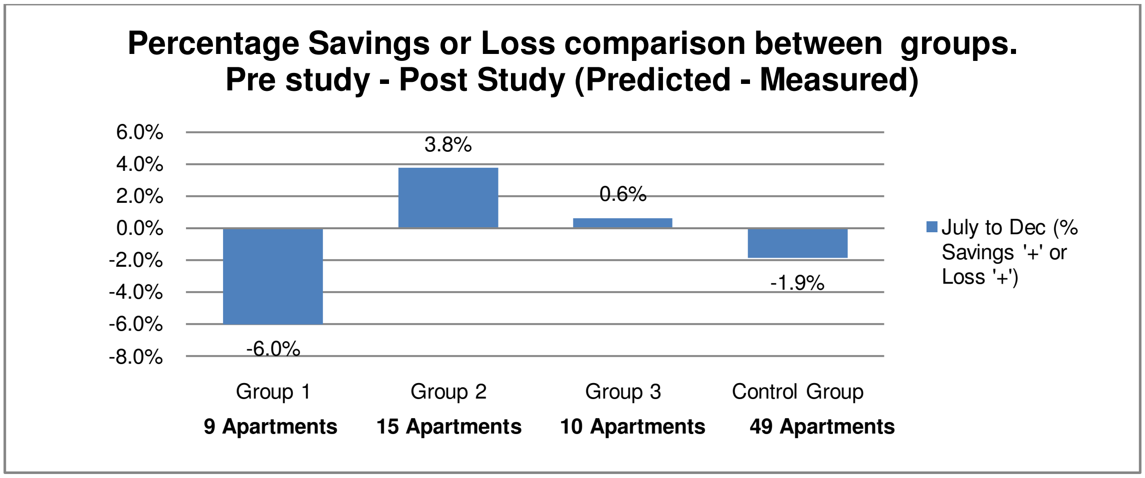


*Figure 24.*Percentage savings or loss in billed usage (Pre-study – Post-study)

Energy savings comparison between upper level and lower level apartments. Average energy use during the pre- and post-study period for upper and lower level apartments across the groups were compared. The study complex consisted of east-west orientation and north-south orientation. There were not enough north-south orientation apartments in all groups to compare orientation of this type. Hence, apartments were grouped in upper level, east-west oriented apartments and lower level, east-west oriented apartments. Table 34 and Figure 25 shows and compares the energy usage and savings during the pre and post study periods across different groups for these two categories of apartment location described above. Figure 26 shows the plot for the savings or loss percentage among the two categories.

Table 34.

Average energy use and savings comparison between Pre-study and Post-study periods among different floor level categories

July to December	Group1	Group2	Group 3	Control Group
DOWN, EW Predicted Average Energy Usage	4717	4754	5738	5397
DOWN, EW Measured Average Energy Usage	5325	4560	5511	5351
UP, EW Predicted Average Energy Usage	5073	6289	6092	5796
UP, EW Measured Average Energy Usage	5329	6100	6353	5963
DOWN, EW (Savings or Loss)kWh,(%)	-608 (-12.9%)	194 (4.1%)	227 (4.0%)	46 (0.8%)
UP, EW (Savings or Loss)kWh, (%)	-256 (-5%)	189 (3.0%)	-261 (- 3.7%)	-167 (-2.9%)
No of Apartments DOWN,EW	2	8	5	22
No of Apartments UP, EW	7	6	3	22
Apartment Type	5 BED (1) 3 BED(3)	2 BED (1) 3 BED (6) 5 BED(1)	2 BED (2) 3 BED (3)	3 BED (15) 2 BED (7)
Apartment Type	2 BED (4) 3 BED (3)	2 BED (1) 3 BED (5)	3 BED (3)	2 BED (8) 3 BED (11) 5 BED (3)

It is seen through the table and plots that apartments in the upper level have a higher average energy usage compared to the average energy usage of apartments in the lower level. Additionally, it is also seen that the savings in the lower level apartments is higher compared to upper level apartments in all the groups except group 1. In the category of apartments that are in the lower level, the percentage savings in both the TED groups, i.e. group 2 and 3 are more or less the same. The intervention of budgeting information in the group 3 participants in this study did not make a difference in the energy savings compared to group 2 participants who did not have the budgeting information.

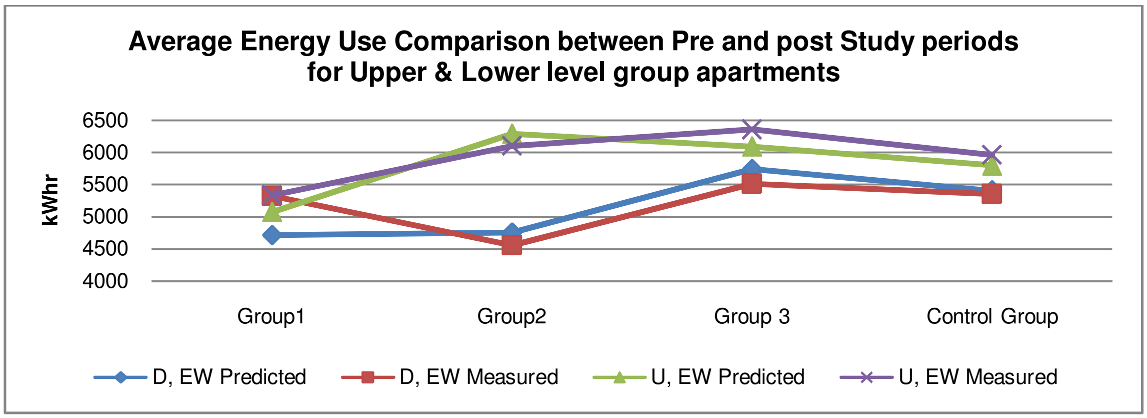


Figure 25. Average energy use comparison upper and lower level apartments with east-west orientation across different groups.

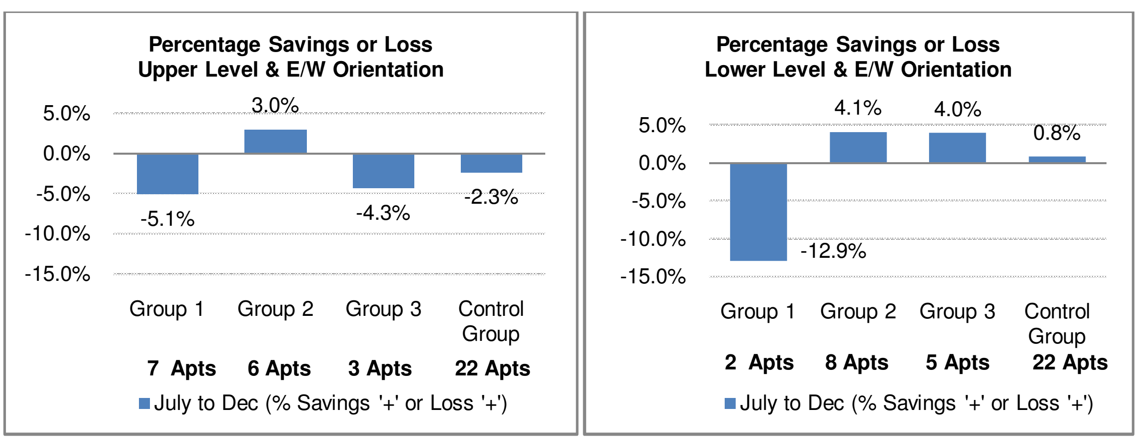
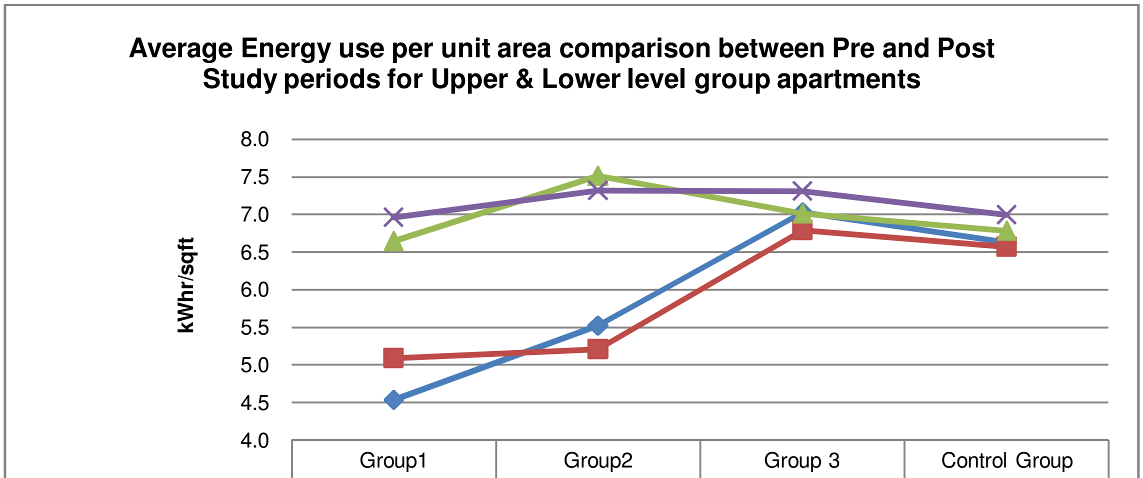


Figure 26. Percentage energy savings comparison between upper and lower level apartments with east-west orientation across different groups.

A similar trend is seen in the average energy use per unit area consumption. The percentage savings also resulted in savings in lower level apartments, for groups 2 and 3 and loss in group 1 apartments. Upper level apartments incurred increased usage that is loss in the post-study period. Except for group 2, all other groups had increased energy consumption. Figure 27 and Figure 28 show the average energy usage and percentage savings across the groups.



	Group1	Group2	Group 3	Control Group
D, EW Pre Study	4.5	5.5	7.0	6.6
D, EW Post Study	5.1	5.2	6.8	6.6
U, EW Pre Study	6.6	7.5	7.0	6.8
U, EW Post Study	7.0	7.3	7.3	7.0

*Figure 27.*Average energy use per unit area comparison - upper and lower level apartments with east-west orientation.

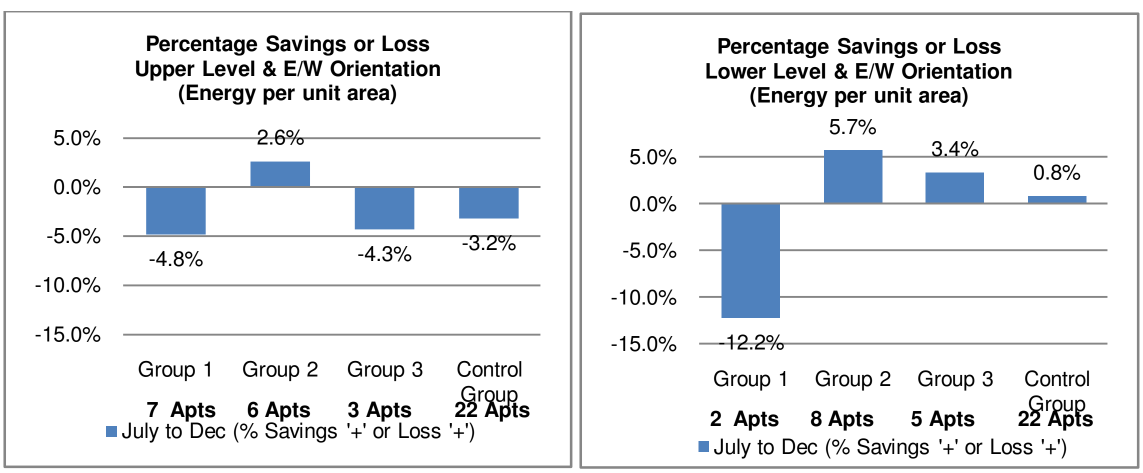


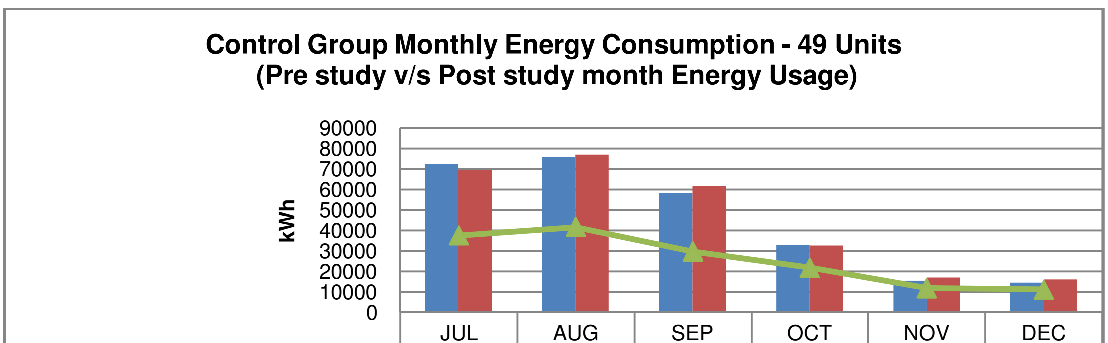
Figure 28. Percentage (energy per unit area) savings comparison between upper and lower level apartments with east-west orientation.

Part 1B- Monthly Energy and Billed Usage Comparison During Pre- and Post-study Period

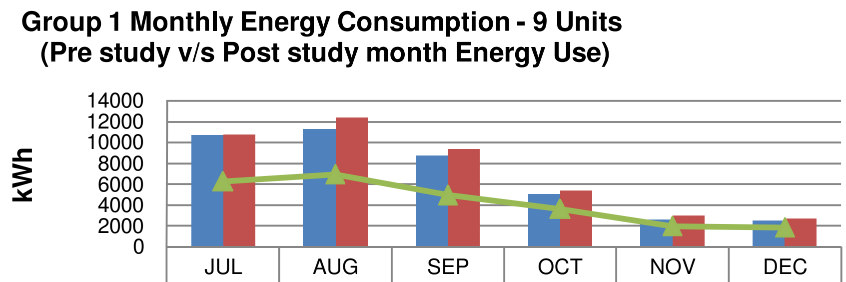
Monthly energy use comparison. Figures 29 shows the monthly energy consumption during the individual pre- and post-study months, comparing an increased or decreased usage during the post study period. Additionally is also seen that overall, all the groups exceed their allotment for all the study months.

The control group resulted in an increased energy usage during all the post-study period months except in July. Group 1 also resulted in an increased energy usage for all the post study months when compared with the pre-study months. Group 2 resulted in a decreased usage in all the post-study months compared to the pre-study months except for the December month, which had an increased usage. Group 3 had an increased energy use during the post-study months of August September and December. The months of July and October had a decreased usage and hence savings. The decreased usage could be particularly because of the interventions or education sessions that took place in July and then October.

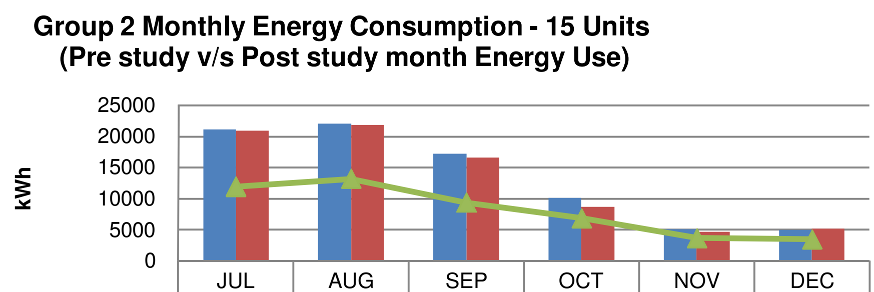
The corresponding energy savings or loss in kilowatt-hour and percentage is shown in Figures 30.



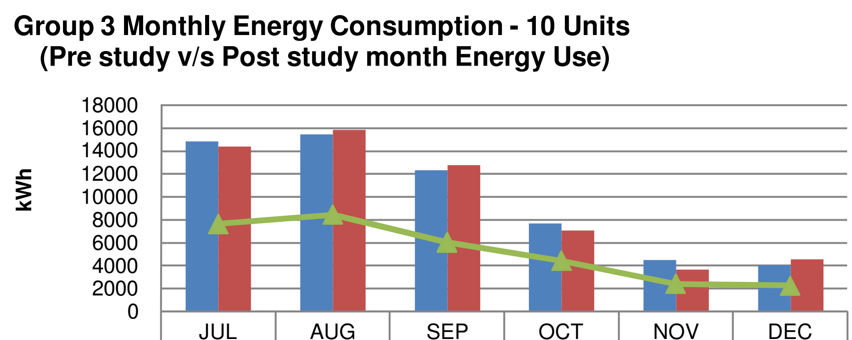
	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Energy Usage	72475	76029	58536	33207	15737	14824
Measured Energy Used 2012	69822	77190	61963	32849	17311	16307
Monthly Energy Allotment	37729	41720	29788	21844	11921	11238



	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Energy Usage	10719	11224	8738	5078	2624	2455
Measured Energy Used 2012	10757	12334	9326	5376	2974	2676
Monthly Energy Allotment	6259	6923	4937	3614	1956	1845

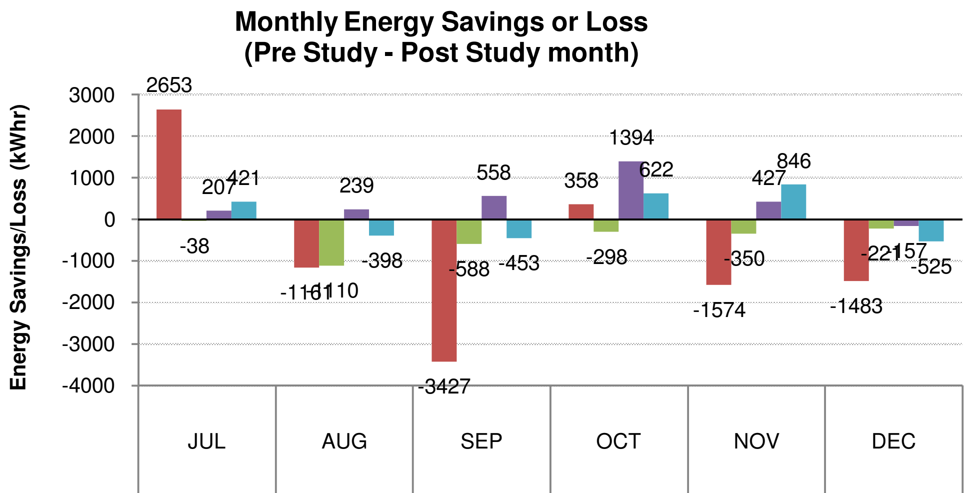


	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Energy Usage	21083	22071	17205	10115	5106	5068
Measured Energy Used 2012	20876	21832	16647	8721	4679	5225
Monthly Energy Allotment	11907	13180	9384	6860	3679	3470

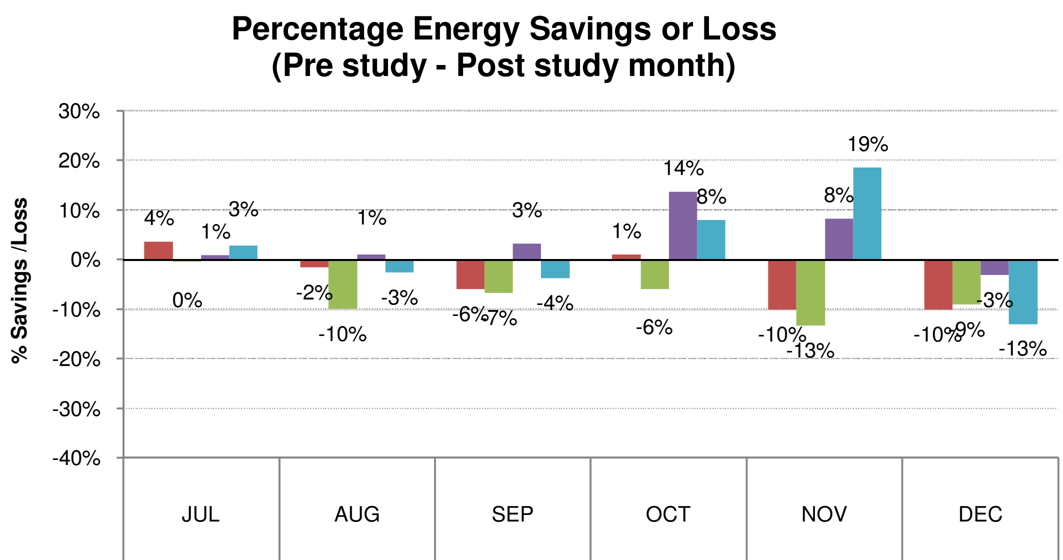


	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Energy Usage	14809	15449	12299	7705	4537	4053
Measured Energy Used 2012	14388	15847	12752	7083	3691	4578
Monthly Energy Allotment	7639	8447	6034	4429	2426	2286

*Figure 29.*Monthly energy use comparison for Control Group, group 1, group 2 and group 3 during Pre- and Post-study months



		JUL	AUG	SEP	OCT	NOV	DEC
10 Apts	Control Group	2653	-1161	-3427	358	-1574	-1483
15 Apts	Group 1	-38	-1110	-588	-298	-350	-221
9 Apts	Group2	207	239	558	1394	427	-157
49 Apts	Group 3	421	-398	-453	622	846	-525



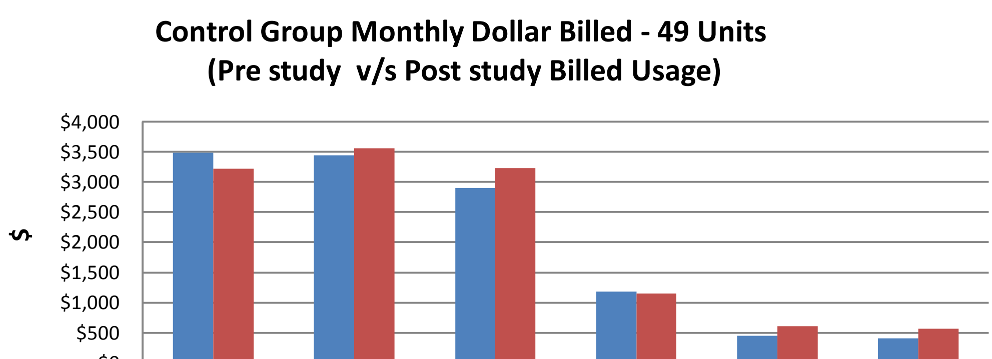
	JUL	AUG	SEP	OCT	NOV	DEC
Control Group	4%	-2%	-6%	1%	-10%	-10%
Group 1	0%	-10%	-7%	-6%	-13%	-9%
Group2	1%	1%	3%	14%	8%	-3%
Group 3	3%	-3%	-4%	8%	19%	-13%

*Figure 30.*Monthly energy usage savings in kilowatt-hours and percentage across different groups.

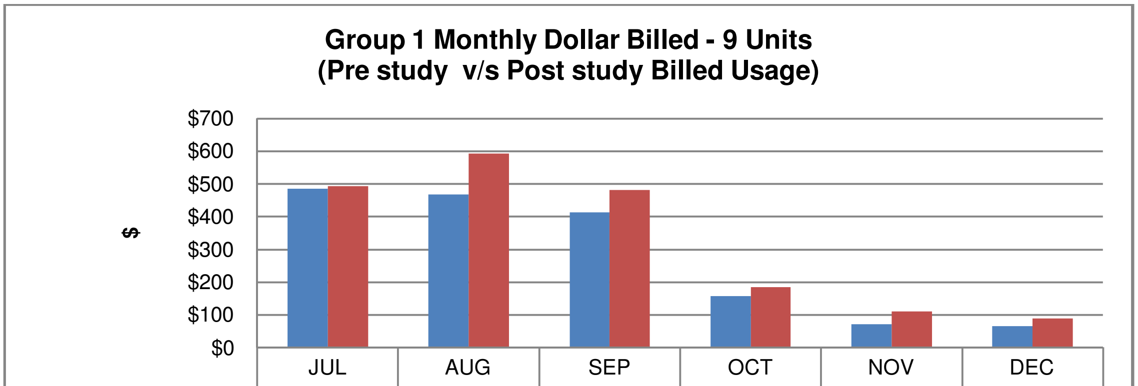
Monthly billed usage comparison. Figure 31 shows the monthly-billed usage during the individual pre-study and post-study months, comparing an increased or decreased billing during the post-study period. Overall, all the groups exceed their allotment for all the study months.

The control group resulted in an increased billed usage during all the post-study period months except in July. The group one also resulted in an increased billed usage for all the post-study months when compared with the pre study months. Group 2 resulted in a decreased billed usage in all the post-study months compared to the pre-study months except for December, which had a higher bill. Group 3 had an increased billed usage during the post-study months of August, September and December. The months of July, October and November had a decreased usage and hence incurred savings in their bill. The decreased usage could be particularly because of the interventions or education sessions that took place in June-July and end of September months.

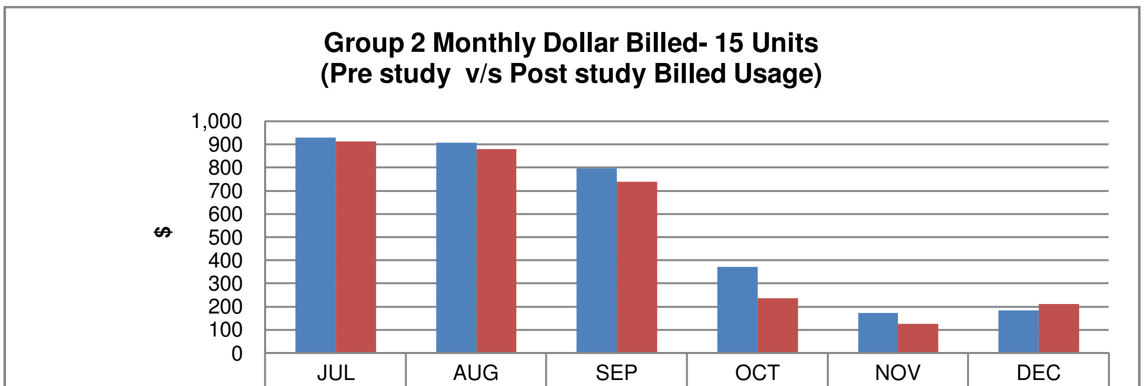
The corresponding savings or loss in dollar amount and percentage is shown in Figure 32.



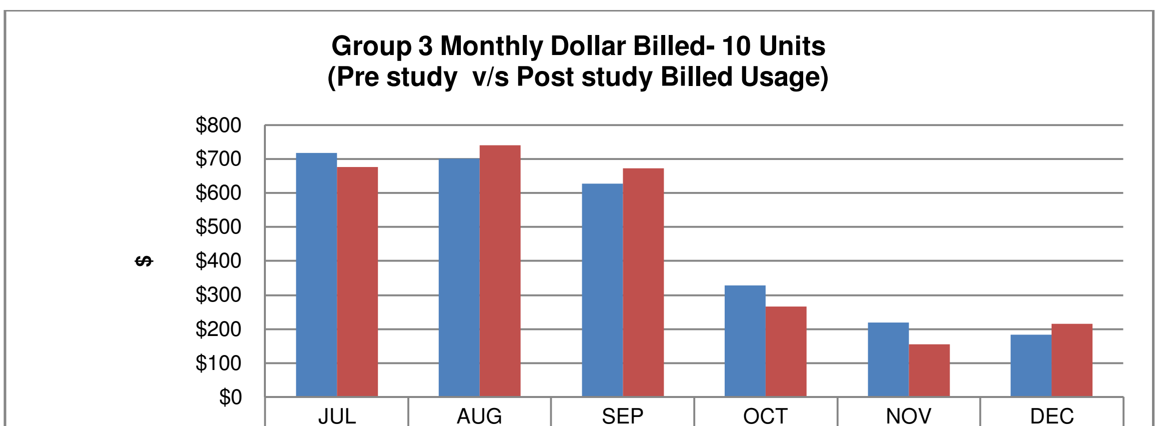
	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Bill 2012	$3,485	$3,441	$2,900	$1,183	$455	$415
Actual Billed 2012	$3,218	$3,558	$3,225	$1,158	$611	$572



	JUL	AUG	SEP	OCT	NOV	DEC
Predicted Bill 2012	$485	$467	$414	$158	$72	$66
Actual Billed 2012	$494	$593	$481	$186	$111	$90

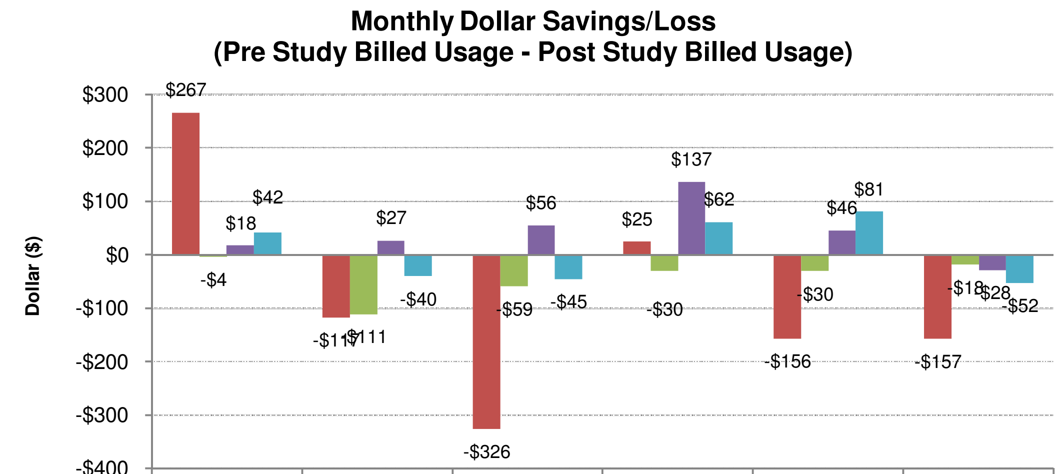


	JUL	AUG	SEP	OCT	NOV	DEC
Predicted $ Usage	929	905	795	371	172	182
Actual $ Used 2012	911	879	739	234	126	210

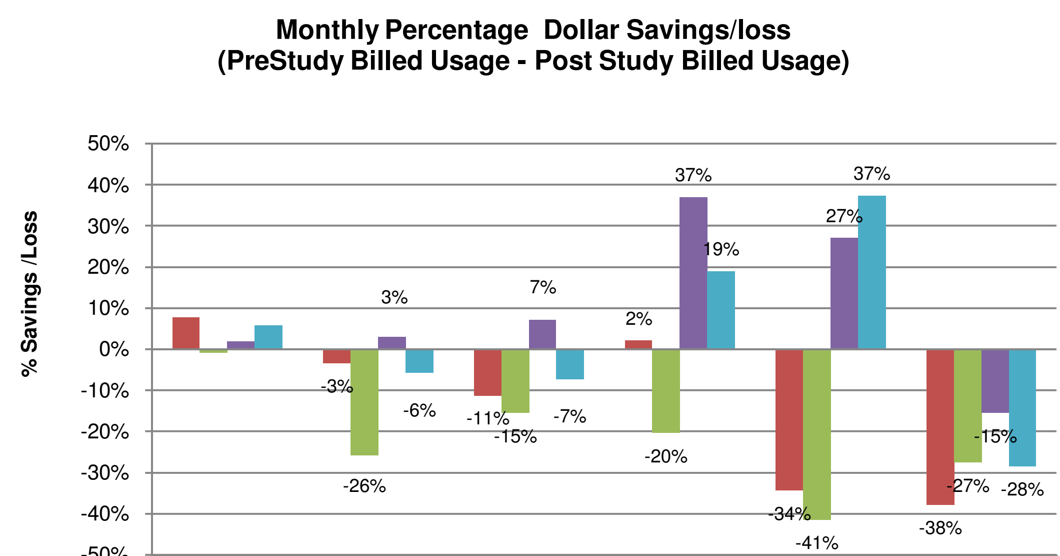


	JUL	AUG	SEP	OCT	NOV	DEC
Predicted $ Usage	$717	$700	$627	$328	$218	$182
Actual $ Used 2012	$675	$740	$672	$266	$155	$214

*Figure 31.*Monthly-billed dollar comparison between pre and post study periods for Control group, group 1, group 2 and group 3.



	JUL	AUG	SEP	OCT	NOV	DEC
Control Group	$267	-$117	-$326	$25	-$156	-$157
Group 1	-$4	-$111	-$59	-$30	-$30	-$18
Group2	$18	$27	$56	$137	$46	-$28
Group 3	$42	-$40	-$45	$62	$81	-$52



	JUL	AUG	SEP	OCT	NOV	DEC
Control Group	8%	-3%	-11%	2%	-34%	-38%
Group 1	-1%	-26%	-15%	-20%	-41%	-27%
Group2	2%	3%	7%	37%	27%	-15%
Group 3	6%	-6%	-7%	19%	37%	-28%

*Figure 32.*Monthly billed usage savings in dollar and percentage across different groups

Part 1C-Individual Apartments Energy and Billed Usage Comparison During Pre and Post-study Period.

Group 1 apartments analysis.

Energy use. Seven out of the total nine apartments had an increased energy usage in the post-study period. The increased energy difference between the pre- and post-energy study period ranged from 134kWh to 948kWh and increased percentage difference varied from 2.4% to 17.5% respectively. Two units that had savings decreased their usage by 59kWh (1.2%) and 249kWh (4.2%). Table 35 shows energy consumption during the pre- and post-study months and the range of saving or loss incurred for the individual apartments. Additionally, Figure 33 plots the energy savings in kilowatt and percentage for individual group 1 apartments.

Billed use. Seven out of the total nine apartments had an increased billed usage in the post study period. The increased billed usage difference between the pre- and post-energy study period ranged from $13.00 to $ 94.00 and increased percentage difference varied from 4.9% to 43.4% respectively. Two units that had savings, had a decreased bill of $ 5.87 (3.6%) and $ 24.89 (8.2%). The trend in billed usage savings did not necessarily coincide with the energy savings. This is because some apartments, although they might show significant energy savings or loss, could still be within their total monthly allotment. Table 35 shows the billed usage during the pre- and post-study months and the range of savings or loss incurred for the individual apartments. Additionally, Figure 34 plots the billed usage savings in dollars and percentage for individual group 1 apartments.

Table 35.

Group 1- Pre and post study data for individual apartments, with energy and billed usage savings

Apt IDs	July to Dec Post-Study kWh	Jul to Dec Pre-Study kWh	Jul-Dec Savings / Loss (kWh)	Jul-Dec Savings / Loss (kWh%)	Jul - Dec Fixed Allotment Given	July to Dec Post-Study Billed ($)	Jul to Dec Pre-Study Billed ($)	Jul-Dec Savings / Loss ($)	Jul-Dec Savings / Loss ($ %)
10	4942	4630	-312	-6.7%	$322.90	$171.30	$140.07	-$31.23	-22.3%
19	4508	4104	-404	-9.8%	$288.60	$162.20	$121.85	-$40.35	-33.1%
35	5654	5903	249	4.2%	$288.60	$276.80	$301.69	$24.89	8.2%
39	5262	4959	-303	-6.1%	$288.60	$237.60	$207.32	-$30.28	-14.6%
43	4798	4396	-402	-9.1%	$322.90	$156.90	$116.68	-$40.22	-34.5%
45	5783	5649	-134	-2.4%	$288.60	$289.70	$276.26	-$13.44	-4.9%
46	5851	5038	-813	-16.1%	$396.00	$189.10	$107.76	-$81.34	-75.5%
67	6359	5411	-948	-17.5%	$322.90	$313.00	$218.21	-$94.79	-43.4%
79	4794	4853	59	1.2%	$322.90	$156.50	$162.37	$5.87	3.6%

Group 2 apartments analysis.

Energy use. Nine out of the total fifteen apartments had an increased energy usage in the post-study period. The increased energy difference or loss between the pre- and post-energy study period ranged from 21kWh to 505kWh and increased percentage difference varied from 0.4% to 17.5% respectively. Apartments that had savings had a decreased usage ranging from 111kWh (2.7%) to 1000kWh (21%). One unit had a decreased usage of 2184kWh, which incurred 20% savings. Table 36 shows energy consumption during the pre- and post-study months and a range of saving or loss incurred for the individual apartments. Additionally, Figure 33 plots the energy savings in kilowatt-hour and percentage for individual group 2 apartments

Billed use. The increased billed usage difference (i.e., loss) between the pre and post energy study period ranged from $2.00 to $46.00 and increased percentage difference varied from 4.9% to 43.4% respectively. Units that had savings, had a decreased bill ranging from $0.00 (0%) to $100(68%). The one unit that had energy savings of 2481kWh incurred a billed savings of $218.00 (30.3%). The trend in billed usage savings did not necessarily coincide with the energy savings. This is because some apartments, though they had a significant energy savings or loss, were still within their total monthly allowance. Table 36 shows the billed usage during the pre- and post-study months and range of saving or loss incurred for the individual apartments.

Table 36

Group 2- Pre and post study data for individual apartments, with energy and billed usage savings

Apt IDs	July to Dec Post-Study kWh	Jul to Dec Pre-Study kWh	Jul-Dec Savings / Loss (kWh)	Jul-Dec Savings / Loss (kWh%)	Jul - Dec Fixed Allotment Given	July to Dec Post-Study Billed ($)	Jul to Dec Pre-Study Billed ($)	Jul-Dec Savings / Loss ($)	Jul-Dec Savings / Loss ($ %)
6	4041	4152	111	2.7%	$322.90	$81.20	$92.28	$11.08	12.0%
7	2280	2481	201	8.1%	$288.60	$0.00	$0.00	$0.00	0.0%
8	6461	5997	-464	-7.7%	$288.60	$357.50	$311.06	-$46.44	-14.9%
18	3699	4699	1000	21.3%	$322.90	$47.00	$147.04	$100.04	68.0%
26	5209	5150	-59	-1.2%	$322.90	$198.00	$192.06	-$5.94	-3.1%
49	5978	5654	-324	-5.7%	$322.90	$274.90	$242.49	-$32.41	-13.4%
50	5776	5575	-201	-3.6%	$322.90	$254.70	$234.60	-$20.10	-8.6%
51	6470	7080	610	8.6%	$396.00	$251.00	$312.04	$61.04	19.6%
53	4087	4058	-29	-0.7%	$322.90	$85.80	$82.89	-$2.91	-3.5%
63	6664	6349	-315	-5.0%	$322.90	$343.50	$312.05	-$31.45	-10.1%
64	8247	10431	2184	20.9%	$322.90	$501.80	$720.18	$218.38	30.3%
69	3352	2847	-505	-17.8%	$322.90	$12.30	$0.00	-$12.30	-
73	4904	4883	-21	-0.4%	$322.90	$167.50	$165.40	-$2.10	-1.3%
75	4669	5516	847	15.4%	$322.90	$144.00	$228.68	$84.68	37.0%
83	6143	5776	-367	-6.4%	$322.90	$291.40	$254.66	-$36.74	-14.4%

Group 3 apartments analysis.

Energy use. Five out of the total ten apartments had an increased energy usage in the post-study period. The increased energy difference or loss between the pre- and post-energy study period ranged from 45kWh to 685kWh and increased percentage difference varied from 1% to 17.6% respectively. Units that had savings had a decreased usage ranging from 152kWh (2.4%) to 1515kWh (21%). Table 37 shows energy consumption during the pre- and post-study months and range of saving or loss incurred for the individual apartments. Additionally, Figure 33 plots the energy savings in kilowatt-hour and percentage for individual group 3 apartments

Billed use. The increased billed usage difference (i.e., loss) between the pre- and post-energy study period ranged from $4.51 to $68.00 and increased percentage difference varied from 2.5% ($4.51) to 67.7%($68.00). Units that had savings had a decreased bill ranging from $15.20 to $151.00.The savings percentage varied from 4.8% ($15.20) to 38% ($151.00). The trend in billed usage savings did not necessarily coincide with the energy savings. This is because some apartments, though had a significant energy savings or loss, were still within their total monthly allowance. Table 37 shows the billed usage during the pre- and post-study months and range of saving or loss incurred for the individual apartments.

Table 37

Group 3- Pre- and post-study data for individual apartments with energy and billed usage savings

Apt IDs	July to Dec Post-Study kWh	Jul to Dec Pre-Study kWh	Jul-Dec Savings / Loss (kWh)	Jul-Dec Savings / Loss (kWh%)	Jul - Dec Fixed Allotment Given	July to Dec Post-Study Billed ($)	Jul to Dec Pre-Study Billed ($)	Jul-Dec Savings / Loss ($)	Jul-Dec Savings / Loss ($ %)
2	4582	3897	-685	-17.6%	$288.60	$169.60	$101.13	-$68.47	-67.7%
5	5707	7222	1515	21.0%	$322.90	$247.80	$399.33	$151.53	37.9%
12	4726	4681	-45	-1.0%	$288.60	$184.00	$179.49	-$4.51	-2.5%
28	6225	6377	152	2.4%	$322.90	$299.60	$314.82	$15.22	4.8%
41	3691	3903	212	5.4%	$288.60	$80.50	$101.70	$21.20	20.8%
48	5603	5375	-228	-4.2%	$322.90	$237.40	$214.65	-$22.75	-10.6%
59	7468	6806	-662	-9.7%	$322.90	$423.90	$357.72	-$66.18	-18.5%
68	5366	5092	-274	-5.4%	$322.90	$213.70	$186.28	-$27.42	-14.7%
71	6999	7208	209	2.9%	$322.90	$377.00	$397.90	$20.90	5.3%
77	7972	8290	318	3.8%	$322.90	$474.30	$506.06	$31.76	6.3%

Control group apartments analysis

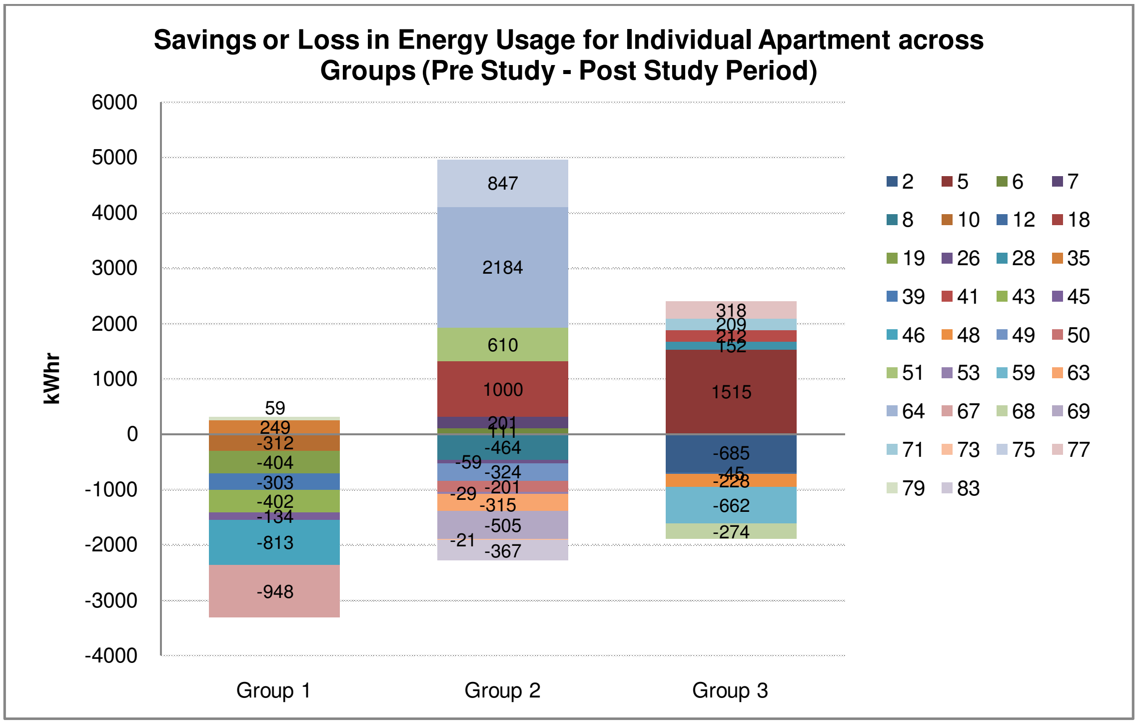
Energy use. Thirty-two out of the total forty-nine apartments had an increased energy usage in the post-study period. The increased energy difference or loss between the pre- and post-energy study period ranged from 55kWh to 1764kWh and increased percentage difference varied from 1.1% (63kWh) to 26.6% (1764kWh). Seventeen units that had savings had a decreased usage ranging from 10kWh (0.2%) to 1633kWh (31%). Table 38 shows energy consumption during the pre- and post-study months and a range of saving or loss incurred for the individual apartments.

Billed use. The increased billed usage difference (i.e., loss) between the pre- and post-energy study period ranged from $0.00 to $176.00. Seventeen units that had savings had a decreased bill ranging from $0.97 to $163.00. The trend in billed usage savings did not necessarily coincide with the energy savings. This is because some apartments, although they had a significant energy savings or loss, were still within their total monthly allowance. Table 38 shows the billed usage during the pre and post study months and range of saving or loss incurred for the individual apartments.

Table 38

Control Group-Pre and post data for individual apartments, with energy and billed usage savings

Apt IDs	July to	Jul to	Jul-Dec		Jul - Dec	July to	Jul to	Jul-Dec	
1	6102	6563	461	7.0%	$322.90	$287.30	$333.44	$46.14	13.8%
3	4017	3613	-404	-11.2%	$288.60	$113.10	$72.66	-$40.44	-55.6%
4	6415	6425	10	0.2%	$322.90	$318.60	$319.57	$0.97	0.3%
9	5117	4925	-192	-3.9%	$322.90	$188.80	$169.64	-$19.16	-11.3%
11	6610	5527	-1083	-19.6%	$288.60	$372.40	$264.14	-$108.26	-41.0%
13	5102	4381	-721	-16.5%	$288.60	$221.60	$149.52	-$72.08	-48.2%
14	3973	3481	-492	-14.1%	$322.90	$74.40	$25.22	-$49.18	-195.0%
15	2378	2161	-217	-10.1%	$288.60	$0.00	$0.00	$0.00	0.0%
16	4286	4939	653	13.2%	$288.60	$140.00	$205.27	$65.27	31.8%
17	6000	5595	-405	-7.2%	$288.60	$311.40	$270.90	-$40.50	-14.9%
20	6219	5504	-715	-13.0%	$322.90	$299.00	$227.53	-$71.47	-31.4%
21	5070	4805	-265	-5.5%	$288.60	$218.40	$191.88	-$26.52	-13.8%
22	6951	6591	-360	-5.5%	$288.60	$406.50	$370.51	-$35.99	-9.7%
23	5885	6116	231	3.8%	$288.60	$299.90	$322.99	$23.09	7.1%
24	3995	3256	-739	-22.7%	$288.60	$110.90	$36.98	-$73.92	-199.9%
25	6709	6354	-355	-5.6%	$322.90	$348.00	$312.55	-$35.45	-11.3%
27	5706	5290	-416	-7.9%	$322.90	$247.70	$206.15	-$41.55	-20.2%
29	7266	6671	-595	-8.9%	$322.90	$403.70	$344.23	-$59.47	-17.3%
30	5185	5369	184	3.4%	$288.60	$229.90	$248.28	$18.38	7.4%
31	5450	6467	1017	15.7%	$322.90	$222.10	$323.80	$101.70	31.4%
32	4832	4617	-215	-4.7%	$322.90	$160.30	$138.81	-$21.49	-15.5%
33	5030	4758	-272	-5.7%	$288.60	$214.40	$187.23	-$27.17	-14.5%
34	5364	5148	-216	-4.2%	$288.60	$247.80	$226.16	-$21.64	-9.6%
36	5126	5397	271	5.0%	$288.60	$224.00	$251.12	$27.12	10.8%
37	3797	3742	-55	-1.5%	$288.60	$91.10	$85.57	-$5.53	-6.5%
38	5273	4967	-306	-6.2%	$322.90	$204.40	$173.78	-$30.62	-17.6%
40	3326	4959	1633	32.9%	$322.90	$9.70	$173.02	$163.32	94.4%
42	6145	5856	-289	-4.9%	$288.60	$325.90	$297.01	-$28.89	-9.7%
44	6010	5920	-90	-1.5%	$322.90	$278.10	$269.11	-$8.99	-3.3%
47	6400	7739	1339	17.3%	$396.00	$244.00	$377.94	$133.94	35.4%
52	8478	6714	-1764	-26.3%	$396.00	$451.80	$275.42	-$176.38	-64.0%
54	9822	9177	-645	-7.0%	$396.00	$586.20	$521.70	-$64.50	-12.4%
55	5261	6047	786	13.0%	$322.90	$203.20	$281.81	$78.61	27.9%
56	5103	5170	67	1.3%	$322.90	$187.40	$194.09	$6.69	3.4%
57	3406	3606	200	5.5%	$322.90	$17.70	$37.71	$20.01	53.1%
58	6104	6435	331	5.1%	$322.90	$287.50	$320.63	$33.13	10.3%
60	5602	5163	-439	-8.5%	$322.90	$237.30	$193.36	-$43.94	-22.7%
61	6526	5868	-658	-11.2%	$322.90	$329.70	$263.92	-$65.78	-24.9%
62	6210	6352	142	2.2%	$322.90	$298.10	$312.30	$14.20	4.5%
65	6643	7489	846	11.3%	$322.90	$341.40	$426.05	$84.65	19.9%
66	5734	5331	-403	-7.6%	$322.90	$250.50	$210.19	-$40.31	-19.2%
70	6672	6491	-181	-2.8%	$288.60	$378.60	$360.50	-$18.10	-5.0%
72	5047	4779	-268	-5.6%	$322.90	$181.80	$154.98	-$26.82	-17.3%
74	5737	5441	-296	-5.4%	$288.60	$285.10	$255.47	-$29.63	-11.6%
76	6744	7284	540	7.4%	$322.90	$351.50	$405.51	$54.01	13.3%
78	6169	5996	-173	-2.9%	$322.90	$294.00	$276.69	-$17.31	-6.3%
80	5344	5236	-108	-2.1%	$322.90	$211.50	$200.70	-$10.80	-5.4%
81	5332	5386	54	1.0%	$322.90	$210.30	$215.66	$5.36	2.5%
82	5769	5706	-63	-1.1%	$322.90	$254.00	$247.65	-$6.35	-2.6%



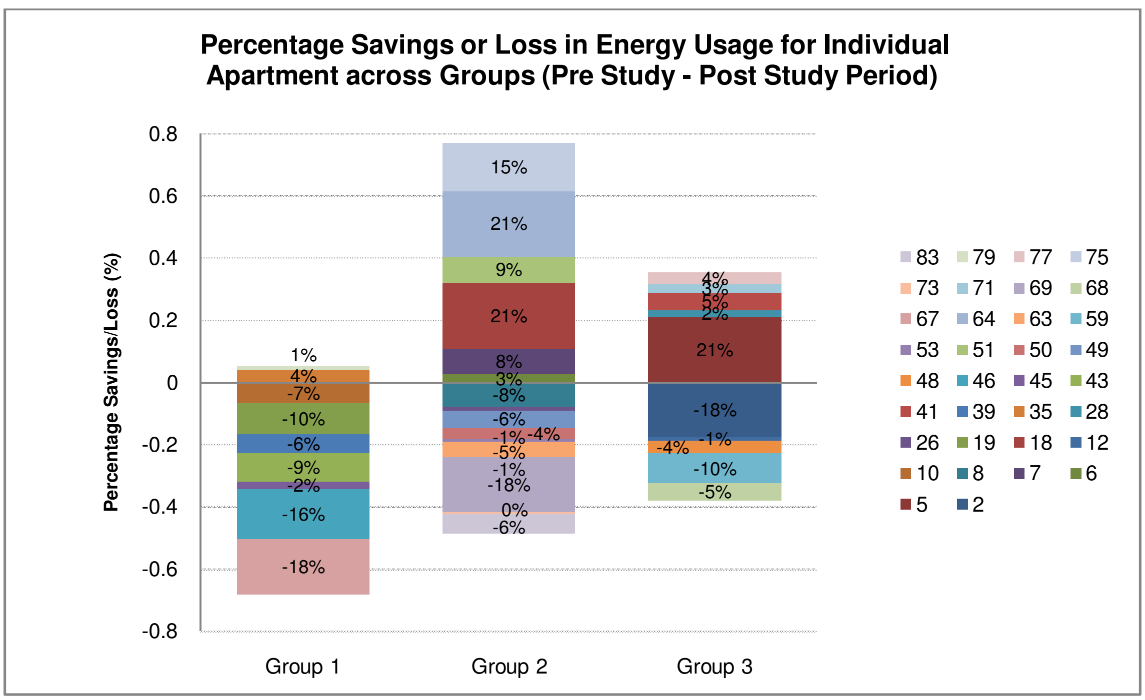
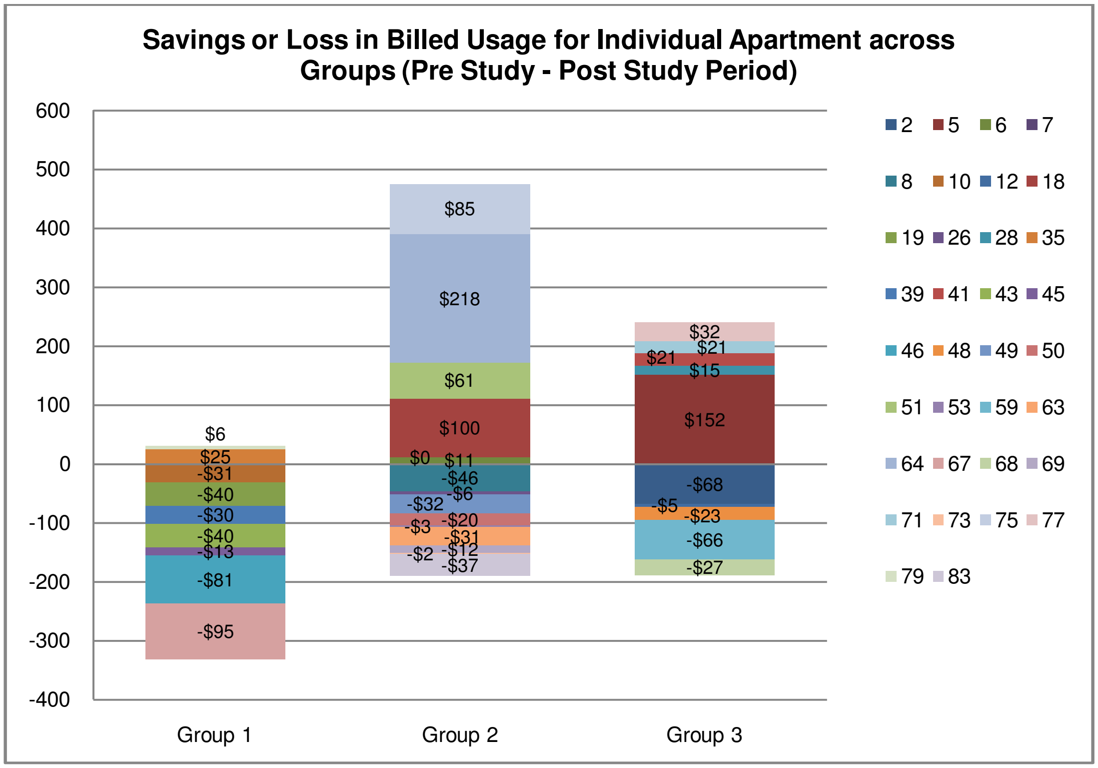


*Figure 33.*Comparison of percentage savings or loss in energy use for individual apartments across groups



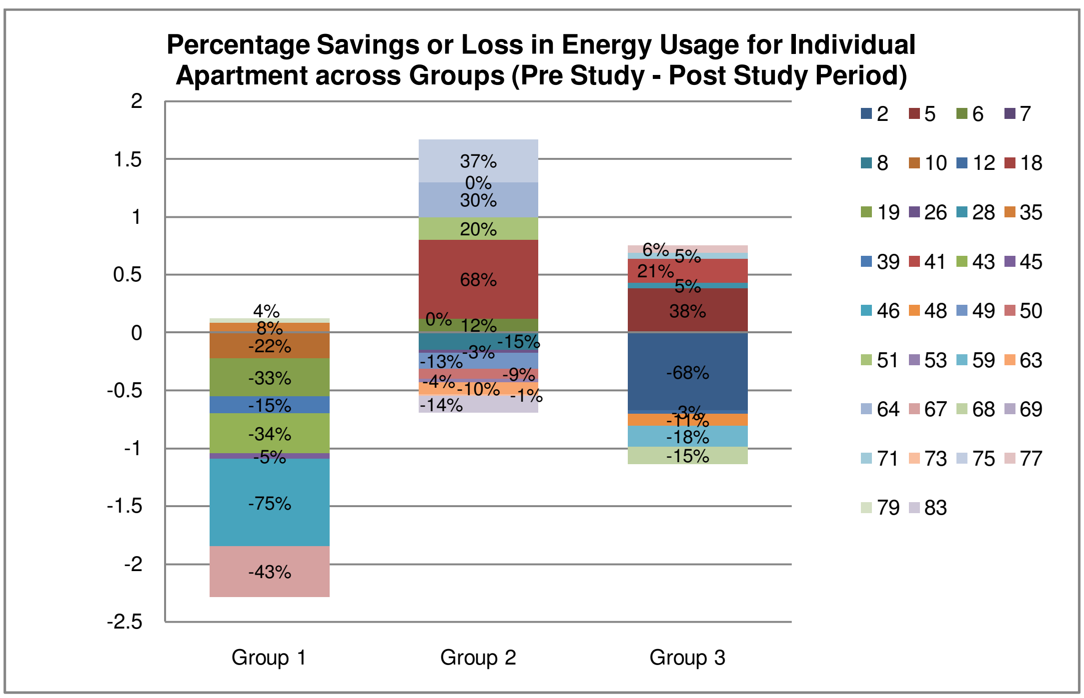
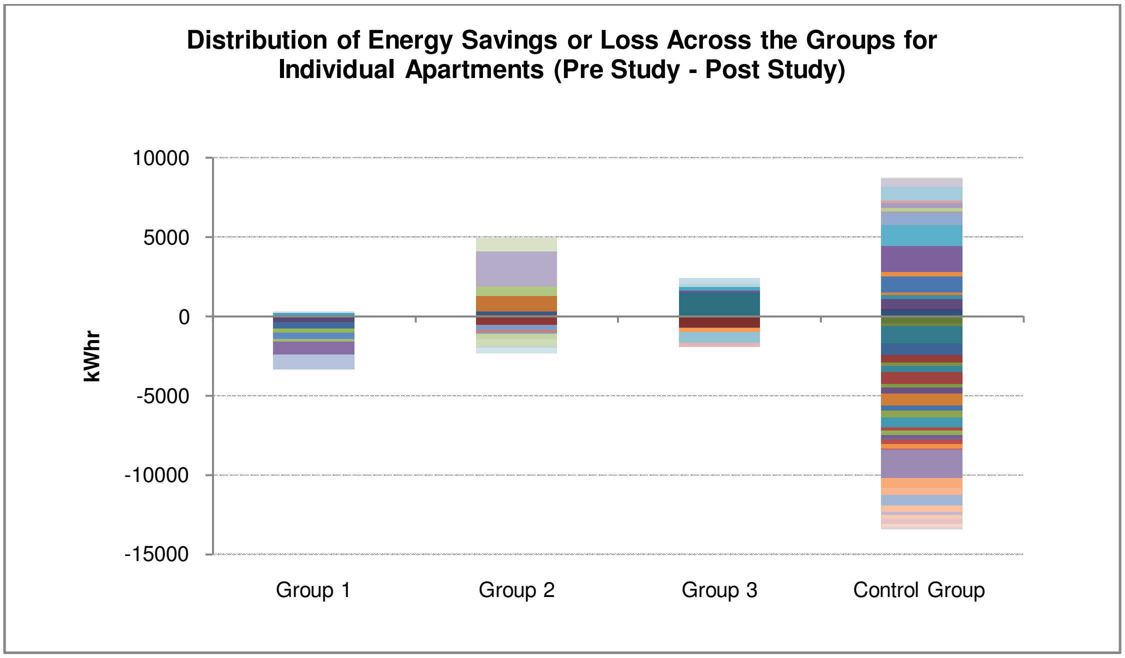


*Figure 34.*Comparison of percentage savings or loss in billed usage for individual apartments across groups



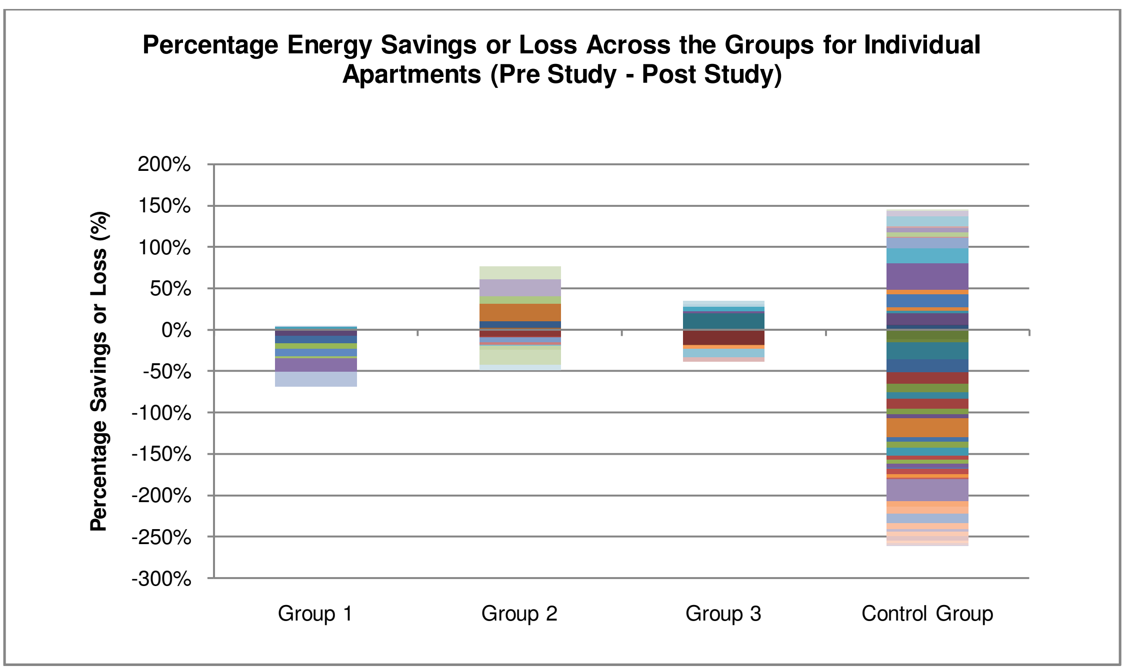


*Figure 35.*Distribution of energy savings or loss and its percentage distribution for individual apartments

Part 2- Study Results Analysis Based on Participant Survey

General participant understanding of energy after the study. According to the participant survey taken at the end of the program, almost all of the 34 participants reported at post-study that they better understood the relationship between their electrical devices' energy usage and how much money they could save by practicing what was suggested to them during education sessions. About 76% of the participants(25 households) felt that they benefitted a lot from the program, whereas 24% of the participants (8 households) felt they benefitted a little. Table 39 shows the individual apartment survey results with their overall energy savings.

Table 39.

Participant Survey-General understanding of household energy

			In comparison to before the study began how well do you understand how much energy your electrical devices use			In comparison to before the study began how well do you understand how much money you can save?			In comparison to before the study began how well do you understand what you can do to save energy?			Do you feel this program has benefitted you		
Group No.	Apt ID	Savings Percentage	Worse than before	Same as before	Better than before	Worse than before	Same as before	Better than before	Worse than before	Same as before	Better than before	Yes, very much	Yes, a little bit	No
1	10	-6.7%			x			x			x	x		
	19	-9.8%			x			x			x	x		
	35	4.2%			x			x			x	x		
	39	-6.1%			x			x			x	x		
	43	-9.1%			x			x			x	x		
	45	-2.4%			x			x			x	x		
	46	-16.1%			x			x			x	x		
	67	-17.5%			x			x			x	x		
	79	1.2%			x			x			x		x	
2	6	2.7%			x			x			x		x	
	7	8.1%	No Survey											
	8	-7.7%			x			x			x		x	
	18	21.3%			x			x			x		x	
	26	-1.2%			x			x			x	x		
	49	-5.7%			x			x			x	x		
	50	-3.6%			x			x			x	x		
	51	8.6%			x			x			x	x		
	53	-0.7%			x			x			x	x		
	63	-5.0%			x			x			x	x		
	64	20.9%			x			x			x	x		
	69	-17.8%			x		x				x	x		
	73	-0.4%			x			x			x	x		
	75	15.4%			x			x			x		x	
	83	-6.4%			x			x			x	x		
3	2	-17.6%			x			x			x	x		
	5	21.0%			x			x			x	x		
	12	-1.0%			x			x			x		x	
	28	2.4%			x			x			x		x	
	41	5.4%			x			x			x	x		
	48	-4.2%			x			x			x	x		
	59	-9.7%			x			x			x		x	
	68	-5.4%			x			x			x	x		
	71	2.9%			x			x			x	x		
	77	3.8%			x			x			x	x		
Number of Group 1, 2 & 3 Apartments			**0**	**0**	**33**	**0**	**1**	**32**	**0**	**0**	**33**	**25**	**8**	**0**
Percentage on Total (33)			**0%**	**0%**	**100%**	**0%**	**3%**	**97%**	**0%**	**0%**	**100%**	**76%**	**24%**	**0%**

Participant interaction with the TED device. This part of the survey questions were asked only to the TED group participants that is group 2 and 3.

Understanding information on display screen. 36% of the participants (i.e., 9 households mentioned that they understood the device very well, whereas 52% of the participants mentioned that they understood the device 'mostly ok'.

Display setting preferred. Regarding display settings, 24% of the participants (i.e..6 households) preferred real-time use setting on the display. 40% of the participants (i.e.,10 households) preferred 'recent usage' setting on the display.28% of the participant (i.e.,7 household) preferred month-to-date setting. There was one household, 'Apt ID' 64,that referred to all three settings during their interaction with the device. This participant also mentioned their 'very good' understanding of the TED device. It was seen that this resident had a savings of 21% in their energy savings, which was the highest savings achieved within this group.

Frequency of looking at the display. Regarding the frequency of looking at the display during the last week of the experiment,32% of the participants (i.e.,8 households) mentioned they did not look at the device at all, 32% of the participants (i.e.,8 households) mentioned that they looked at it 1-3 times in the week, 4% of the participants (i.e.,1 household) mentioned that they looked at the device 4-6 times in the week,16% of the participants (i.e.,4 households) looked at it daily and only one participant looked at the device several times a day.

Comparing participant device interaction survey results with energy savings. Out of the 9 participants who mentioned that they understood the device very well, 6 of them had savings in their energy usage. Out of the 15 participants who mentioned that they interacted with the TED until the last week of the study, 10 of them had savings.

Table 40.

Participant survey-TED device interaction versus percentage savings(group 2 & 3 only)

		% Savings	Understanding information on Display Screen			Display Setting Preferred			Frequency of Looking at the Display in the last week of the experiment				
Group No	Apt ID	July to Dec	Very well	Mostly OK	Not at all	Real Time Use	Recent Usage	Month to Data	0 times	1-3 times	4-6 times	daily	several times a day
2	6	2.7%	x				x			x			
	7	8.1%	No Survey			No Survey			No Survey				
	8	-7.7%											
	18	21.3%	x			x				x			
	26	-1.2%		x			x					x	
	49	-5.7%		x		x				x			
	50	-3.6%		x			x				x		
	51	8.6%	x			x						x	
	53	-0.7%		x				x		x			
	63	-5.0%		x				x				x	
	64	20.9%	x			x	x	x	x				
	69	-17.8%	x					x					x
	73	-0.4%		x				x	x				
	75	15.4%		x			x			x			
	83	-6.4%		x			x		x				
3	2	-17.6%	x					x	x				
	5	21.0%		x			x		x				
	12	-1.0%		x			x		x				
	28	2.4%		x					x				
	41	5.4%	x				x					x	
	48	-4.2%		x				x	x				
	59	-9.7%	x			x				x			
	68	-5.4%		x			x			x			
	71	2.9%		x		x				x			
	77	3.8%	x			x				x			
Number of Group 2 & 3 Apartments			**9**	**13**	**0**	**6**	**10**	**7**	**8**	**8**	**1**	**4**	**1**
Percentage on Total (25)			**36%**	**52%**	**0%**	**24%**	**40%**	**28%**	**32%**	**32%**	**4%**	**16%**	**4%**
Number of Group 2 Apartments			**5**	**7**	**0**	**4**	**6**	**5**	**3**	**5**	**1**	**3**	**1**
Percentage on Group 2 Total (15)			**33%**	**47%**	**0%**	**27%**	**40%**	**33%**	**20%**	**33%**	**7%**	**20%**	**7%**
Number of Group 3 Apartments			**4**	**6**	**0**	**2**	**4**	**2**	**5**	**3**	**0**	**1**	**0**
Percentage on Group 3 Total (10)			**40%**	**60%**	**0%**	**20%**	**40%**	**20%**	**50%**	**30%**	**0%**	**10%**	**0%**

Understanding of and using budgeting information. This part of the survey questions were asked of group 3 participants only. Out of the 10 participants who received the budgeting information, 6 of the participants compared this information with the screen during the last month of the study. Out of the 10 participants, only 5 knew which screen on the display was to be referred to with the budgeting information. Though the screen to refer was 'recent usage', two of the participants mentioned that it was 'month to date.' The overall understanding of the budgeting information was difficult for the residents to understand. Though the participants were re-educated regarding this information during the follow-up session in September, more than half of the participants did not fully understand how to use it.

Table 41.

Participant Survey- Group three's understanding of budget sheet information

Apt ID		Where is the budget sheet kept?						In the last 30 days how often did you look at the budget sheet				Have you used your allotment information (budget sheet) to compare with the display screen		
	Savings %	Displayed near the device	Displayed elsewhere (e.g fridge)	Hidden but accessible (eg in a drawer)	Inaccessible	Unknown	Other ______	Never	1-2 times	3-4 times	5 or more times	No	Yes. What setting helps you do this?	Notes
2	-17.6%		x								x	x		
5	21.0%	x							x			x		
12	-1.0%		x					x				x		
28	2.4%					x		x				x		
41	5.4%						x	x					x	Month to Date
48	-4.2%					x			x			x		
59	-9.7%	x							x				x	Month to Date
68	-5.4%	x							x				x	
71	2.9%	x						x					x	Don't rememb er
77	3.8%	x							x				x	
No. of Apartments		**4**	**2**	**0**	**0**	**2**	**1**	**4**	**4**	**0**	**1**	**5**	**4**	
Percentage from total (10)		**40 %**	**20 %**	**0%**	**0 %**	**20 %**	**10 %**	**40 %**	**40%**	**0%**	**10%**	**50 %**	**40%**	

Energy saving strategies mentioned by participants. All the participants were asked about their general understanding about what would help them save energy in their household. Table 42 gives a summary of the strategies mentioned by each participant. The majority of the participants mentioned disconnecting appliance and electrical devices when not in use, especially to avoid 'phantom' loads. The majority also mentioned turning off lights and the television in order to avoid wasting energy. The next most mentioned strategy was to keep the air conditioner on auto mode or change thermostat setting to avoid excess usage when not needed. Many of them also mentioned buying/using 'energy efficient' appliances like those that were labeled 'Energy Star'.

Table 42.

Participant Survey- Energy Savings or Loss versus Savings strategies mentioned during survey

Group No. & Apt ID		% Savings July to Dec	Energy Saving Strategies as Mentioned by the Participants (Group 2 and 3 only): Follow the advice given during the education session	Having a Display Device helps	Disconnect Appliance/unplug when not in use	Turning off lights/TV when leaving house, be cautious in not wasting	Use AC Consciously eg (Set AC on Auto/Change thermostat Setting, Use less)	Buy Energy Star/Efficient Appliances	Use less devices that use a lot of energy	Not opening doors when AC is on/windows closed	Have Curtains on Windows during Summer
2	6	2.7%				x					
	7	8.1%	No Survey								
	8	-7.7%			x						
	18	21.3%			x	x	x				
	26	-1.2%			x			x			x
	49	-5.7%			x	x	x				
	50	-3.6%			x					x	
	51	8.6%				x					
	53	-0.7%			x			x			x
	63	-5.0%			x	x					
	64	20.9%				x					
	69	-17.8%		x					x		
	73	-0.4%			x						
	75	15.4%			x	x		x			
	83	-6.4%			x	x					
3	2	-17.6%	x					x		x	x
	5	21.0%		x	x						
	12	-1.0%			x	x					
	28	2.4%			x						
	41	5.4%				x					
	48	-4.2%				x	x			x	
	59	-9.7%			x	x					
	68	-5.4%			x	x					
	71	2.9%			x	x	x	x			
	77	3.8%			x	x		x			
Number of Group 2 & 3 Apartments			**1**	**2**	**17**	**15**	**4**	**6**	**1**	**3**	**3**
Percentage on Total (25)			**4%**	**8%**	**68%**	**60%**	**16%**	**24%**	**4%**	**12%**	**12%**

Part 3- TED Device Functionality and Comparison With Meter Readings

TED's functionality during the study period. Table 49. in APPENDIX H summarizes TED's functionality for individual apartments during each study month. Out of the 25 apartments in the group 2 and 3 together, 6 of them had technical issues with their TED, which stopped working. In these apartments, it was seen during the September follow-up session that the gateways had stopped interacting their respective MTUs, resulting in no data transmission. After the follow-up session, most of the TEDs that were checked and re-configured stored correct data for the last three months.

Some of the TEDs had missing days of data in the last month or days of the study. The reason could be that the residents might have unplugged their gateways. Only 11 devices out of the 25 installed had all the months' data from the day they were installed until the end of the study and they were de-installed. See APPENDIX H for summary of TEDs installed and its functionality during the study

Comparison with meter readings. The monthly TED data readings were compared with the meter reading and the results varied from -3.6 % to 6%. According to the TED official website, TED is calibrated at the factory to be accurate to within 2% and might even find that it is generally closer to 1%. The variation in the TED device and meter readings could be due to loss of data transmission or meter readings being read one or two days prior or later to end of the month since these meters are manually read. There were two apartments, which a very high percentage difference as seen in Table 43. This could be due to wiring issues in the meter or technical issues with the device itself. Figure 36 shows the plot of the percentage variations in the TED and meter readings.

Table 43.

TED and meter readings comparison during the study period

TED & METER Readings Comparison

Group Number	Apt ID	Data with No. of Correct & Complete months	TED UNITS (kWh)	METER UNITS (kWh)	Percentage Difference between TED and Meter Readings
2	6	4	1706	2011	-17.9%
2	7			No TED data	
2	8	3	1223	1199	1.9%
2	18	6	773	3699	-378.5%
2	26	5	3970	3830	3.5%
2	49	3	1522	1490	2.1%
2	50	2	727	709	2.5%
2	51	3	1558	1520	2.4%
2	53	6	4178	4087	2.2%
2	63	3	1749	1669	4.6%
2	64	3	2684	2607	2.9%
2	69	6	3517	3352	4.7%
2	73	6	5035	4904	2.6%
2	75	2	2594	2608	-0.5%
2	83	4	3821	3811	0.2%
3	2	2	748	711	5.0%
3	5	6	5857	5707	2.6%
3	12	6	4820	4726	2.0%
3	28	6	6616	6225	5.9%
3	41	5	2896	2802	3.2%
3	48	1	1689	1578	6.6%
3	59	2	3855	3758	2.5%
3	68	6	5665	5366	5.3%
3	71	2	1321	1269	4.0%
3	77	4	6624	6876	-3.8%

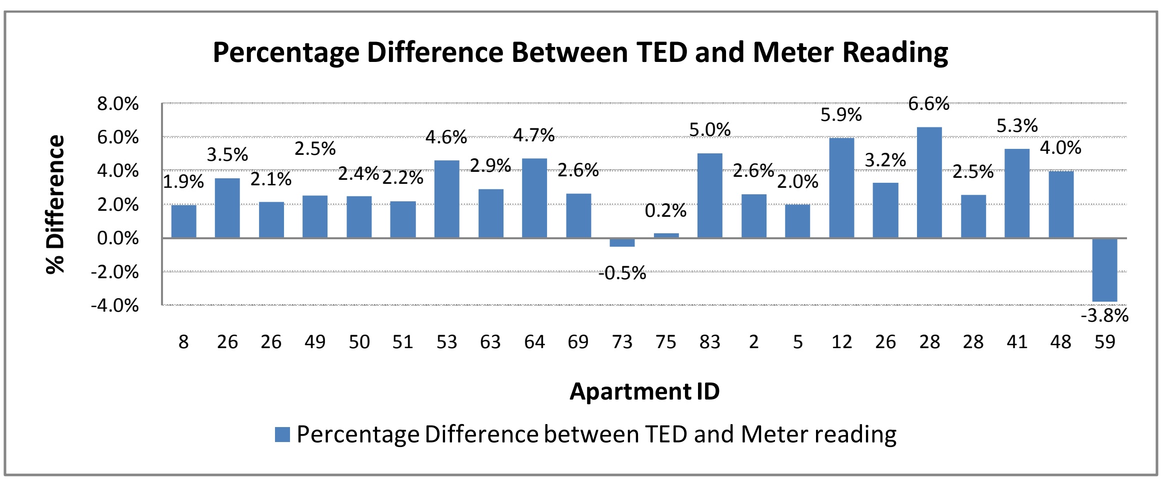


*Figure 36.*Percentage difference between TED and meter readings

TED Data analysis. The TED data was not used for analysis in this research for the overall post study period. This is because as seen in the above description, that only 11 of the 25 TEDs had the complete data. However on an individual case study basis the data of the 11 apartments could be further used to analyze the daily and hourly consumption during the study period.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This research study was carried out to investigate the Effectiveness of In-Home Feedback Devices in Conjunction with Energy Use Information on residential energy consumption. An analysis of the pre-study data versus post-study data was carried out between the various participating groups with different levels of intervention. These groups were compared with each other as well as with a control group. The effect of orientation and position of the apartment on energy savings was also analyzed. In addition, an analysis of the participant survey was also carried out with respect to their understanding of energy usage post study and their interaction with the in-home display device during the study. The above set of studies concludes as follows:

- In the first part of the analysis, which evaluated the overall savings of all the apartments within each group, group 1,which was the 'only education' group, revealed an increased energy usage of 6.7%, which does not support the intended hypothesis. Group 2, which received both the education and the TED device, revealed a savings of 3.5%, which though was not a significant saving as identified through past literature and pilot studies, still resulted in a decreased usage of energy when compared to the control group which had an increased energy usage of 1.7%. Group 3 which received the same education, TED device, and added budgeting information, revealed an insignificant savings of 0.9%, which did not support the past literature study that added motivational element, (in this case the budgeting information) results in an increased. Since this saving was insignificant, it raised a further question about the accuracy of the prediction model used for normalizing the data, and therefore, the random errors that were considered in the total results of each group. The corrected saving still resulted in group 1 having a loss of -6.7% ±

0.25%, group 2 with savings of 3.5% ± 0.30%, group 3 with savings of0.9%± 0.35% and the control group with loss of 1.7% ± 0.15%.

- To further analyze the effect of other variables on energy savings, such as the variations of apartment area within the groups and orientation and floor level location of the apartment, savings were calculated based on grouping the apartments that belonged to the same orientation and location. Also, average energy consumption per unit area was considered in these calculations. It was seen that lower level apartments with east west orientation, revealed a savings of 5.7 % in group 2, and 3.4% in group 3. The upper level apartments revealed a savings of 2.6% in group 2, and a loss of -4.3% . The group 3 showed a similar trend.. The apartments in the upper level apartments could not save as much as the lower level apartments within the same orientation. The upper units revealed an increase of -4.8% in energy usage and the lower apartments revealed an increase of -12.2% which was worse than upper level.
- Monthly savings analysis revealed that group 1had an increased usage all of the post-study months. Group 2 had a decreased usage of energy in all the post-study months. Group 3 had decreased usage in the July, October and November months. The reason for savings in these months could be due to first interventions in taking place June-July month and then the second intervention, i.e., the follow-up sessions taking place September-October months. This states a possibility that these groups of households did not have a long-term effect of the feedback interventions and hence lacked persistence in their savings.
- Individual apartment savings and loss analysis in energy and billed usage showed interesting and inconsistent results overall, as well as within their own groups. Group 1 had only two apartments, which had savings with 1.2% (59kWh) and 4.2%(259kWh). Group 2 savings ranged from 2.7% (111kWh) to 21% (1000kWh). Only one apartment had a very high savings, i.e., about 2184kWh (20%).The group 3

savings ranged from 2.4% (151kWh) to 21% (1515kWh), excluding one apartment which had a high savings of 2184kWh(20% reduction). If the apartment in the group 2 with the high kilowatt-hour savings of 2184kWhwas not considered, then the minimum and maximum range in savings for group 3 would have been higher. The trend in billed usage savings did not necessarily coincide with the energy savings. This is because some apartments, although they had a significant energy savings or loss, were still within their total monthly dollar allowance.

- Though the feedback interventions did not result in significant savings overall, as per the participant survey results, the study proved effective to foster awareness among participating residents of their own patterns of residential electricity consumption and understanding of residential energy use related savings. Survey results with respect to the TED device revealed that 6 out of the 9 participants who mentioned that they understood the device 'very well' had savings. There were also particular results where a participant, who referred to majority of the TED display screen and interacted with it, had a savings of 21% in its energy consumption. Survey results also revealed that 5 out of the 10 participants in group 3 did not understand the budgeting sheet information. Also only few of those 10 participants compared the budget sheet with the TED display device. Thus, the effect of the budgeting information did not result in a big impact with respect to educating or providing added information to the participants.

Possible Explanations for Insignificant Findings.

- **Difficulty in understanding device.** The population that received the feedback and education related to household energy use, had difficulty with understanding the kilowatt hours and their billed dollar relation. It was experienced during the interaction and follow-up sessions with the residents as well as with the survey results, where less than half of the participants understood the device 'very well'. Since the residents had initial difficulties in understanding the readings on the TED display device, many of the participants had to be re-educated during the follow-up session, which took place during the mid-phase of the study i.e. in September.

- **Duration and delay of study.** The program design and implementation had undergone many changes before and during the study. There was a time lag of three years during the selection process of the potential participants. There were many initial IRB approvals of program design and education material, which had to take place before the study began as well as approvals for the follow-up sessions. Researchers entering the households had to be badged as well. All these reasons led to lesser number of study months and thus the duration had to be limited to six months due to the program deadline. There were fewer months to determine the feedback effects. The potential of savings could have been lesser in the later 3 months that is from October to December.
- **Low feedback frequency.** In this study only two sessions could be held with the participants during the six months. Due to the program delay which led to a restricted period of six months study and the unavailability of participants to hold education sessions within the time frame led to a lesser number of follow-up sessions.
- **Benefits of TED not completely utilized.** Low-income group did not have access as a whole to avail the TED footprint software. To reduce the variable and keep the study design simplified, the footprint software screen was not introduced to the participants. The home energy display showed information based on numbers alone with no graphical display of household energy use. This kind of feedback for a population type of this complex would have easily lost interest.
- **Savings persistence**. Savings persistence is an issue in energy feedback studies, as even pointed out it the past studies. The decline in the use of feedback device could result in null savings. As seen in the TED data downloads, some of the apartments had missing days of data. The participant would have probably disconnected the device. Participant surveys also revealed that their interaction with the device had reduced or

they had not interacted at all by the last week of the program. Previous studies have proved and suggested that frequent feedback intervention results in a better savings and is thus an important factor in feedback-induced programs.

Future Works

- **Persistence of savings.** Examine the persistence of savings post study, to see if there was any significant increase or declines in the energy consumption and billed usage during that period. Especially, examine those apartments that were highly motivated and incurred savings during the study period.
- **TED data analysis.** Analyze the daily or hourly data collected by the TED device to identify trends in the energy consumption during the different intervention periods of the study especially for the days after the September month when the first follow-up session was completed.
- **Group 1 results.** Group 1, which was the 'only education' group, though had received the education, experienced an increased use of energy consumption during the study period. Further research as to what reasons could have led to this needs to take place.
- **Group 2 results.** Group 2, which was the TED plus education group revealed a higher savings than Group 3, which was given the same interventions with an added budgeting information. This was an unexpected result and further analysis of data needs to be conducted to identify this result. One of the apartment in group 2 revealed decreased usage of more than 2000kWh. The savings calculation could be performed for all the apartments in group 2 again, eliminating this apartment to see the percentage change in the savings. This result could then be compared to group 3.
- **Regression model.** Energy consumption for residential buildings depends on a lot of variables. Assuming the residential energy consumption at this complex to be only dependent on temperature was a vast generalization that was made in this research. A

regression model taking into consideration other variables as well could determine the savings further accurately.

- **Demographic specific study design and education.** Further study on the modification of education design for the demographics of this complex would be important to understand. It was seen during in the survey results that some of the participants had stopped interacting with the device by the end of the study month. The group 3 participants had difficulty understanding the screen to refer to for comparing their budgeting sheet information. Therefore a more demographic-specific education design is suggested. Study of the effect of savings, depending on the type of demographics, would be an area of further research to understand how one could design the experiment such that maximum benefit is experienced.
- **Disaggregated energy use information.** Using further disaggregated energy use information for the households i.e. providing them with energy feedback related to each of their major appliances. For instance using think-eco type of modlets which provide with such disaggregates information. The effectiveness of this type of feedback initiative would be interesting to analyze.

Recommendations policy makers and utilities

- Policy makers and utility companies should provide all the households with smart meters in case they don't have them, and for those who do, provide them with real-time feedback, which can be of the web-based tool or an in-home feedback monitor.
- Remove barriers to third party providers of feedback technologies and services and encourage partnerships between third-party providers, utilities and governments.
- Have more number of feedback programs that provide mutable, incremental and more flexibility in integrating new automation and feedback technologies in the future. Invest in multiple programs to assess effectiveness of different approaches.

- Address behavior as well as technological means of reducing household energy consumption. Rather than simply promoting in investments in energy efficient products, programs should encourage households to consider engaging in a wide variety of energy savings behavior.
- Implement studies with large sample size, which examine the effectiveness of feedback for more than a year and then examine the persistence of savings over multi-year periods.

ABBREVIATIONS

AC – Air conditioning, Air conditioner,

AMI – Advanced Metering Infrastructure

AMR – Automatic Meter Reading

APS – Arizona Public Service

ARRA – American Recovery and Reinvestment Act

ASHRAE – American Society of Heating, Refrigeration, and Air-conditioning Engineers

ASU – Arizona State University

AZ – Arizona

BTU – British Thermal Unit

BC – British Columbia

CFL – Compact fluorescent lamp

CMU – concrete masonry unit

CT – Current Transformer

DIY – Do-it-yourself

DOE – Department of Energy

EIA – Energy Information Administration

EPRI – Electric Power Research Institute

FAM – Family Type or Bedroom type

GIOS – Global Institute of Sustainability

IMT – Inverse Modeling Toolkit

IRB – Institutional Review Board

kW – kilowatt

kWh – kilowatt-hour

LED – Light emitting diode

MTU – Measuring Transmitting Unit

NSD – Neighborhood Service Department, City of Phoenix

RMSE – root mean square errors

RS – right slope

SMUD – Sacramento Municipal Utility District

TED – The Energy detective

TOU – time of use

TV – television

UK – United Kingdom

US – United States

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APPENDIX A

SUMMARY OF PILOT STUDY RESULTS

Four pilot studies with different feedback interventions have been summarized in the tables below. The project name, duration, sample size, objective, methodology, behavioral response, energy consumption related results and conclusions are summarized for each study.

Table 44.

Summary of Hydro One pilot

Project Name	Year	Duration	Region Covered	Feedback Type	Home Energy Monitor / Mechanism	Sample Size	Overall Savings
Hydro One	June 2004	2.5 Years	Ontario	Real-Time Feedback	Power Cost Monitor (PCM)	500+	6.5%
Objective	• To determine whether provision of a real-time feedback device is sufficient to empower residential customers with the information needed to reduce their electricity consumption. • To establish whether use of such a device can help customers save money and be an aid in promoting a "conservation friendly" culture. • To assess whether real-time feedback is effective and to determine, from change in usage data, if behavior of the participants could be quantified as energy savings.						
Methodology	• 500 Participants received the monitor & 72 were control group. • In order to assess the impact of the real-time monitor on electricity consumption, the electricity (kWh) usage was monitored from the date of initial installation until September, 2005 • The impact of the real-time feedback monitor was quantified by comparing electricity usage (kWh) against the prior year. • Usage data was also collected for all pilot participants prior to the real-time monitor being made available for a period of up to 18 months. • Customer usage was tracked over 2.5 years including the pre-experiment period. • Historical data was adjusted for weather and appliances in order to evaluate energy savings • Study excluded customers that lived in apartments, condominiums, town homes, and row homes or were renters.						
Behavioral Response or Customer Satisfaction	• Behavioral response remained persistent and did not decrease over time during the study period. • 60.5% of the participants felt the monitor made a difference in their homes • 65.1%, planned to continue using the monitor after the pilot was complete. • 39% of participants reported consulting the monitor either daily (24%) or multiple times per day (15%)						
Energy Consumption	• Across the study sample • Aggregate reduction in electricity consumption (kWh) was 6.5% • Households with non-electric space heating : • Aggregate reduction in energy consumption was 8.2%. • House with non-electric water heating and space heating : • Within this sample a reduction of 5.1% was observed • Non electric House with electric water heating : reduction of 16.7% is observed • Households with electric space heating : • Reduction of 1.2% (low impact of real time feedback)						
Conclusion	• Study concludes that separating out feedback from the electric heating load for the rest of the load would be required to encourage saving in this segment. • Suggests that home heating may not be a major opportunity area for behavior change.						

Table 45.

Summary of Oberlin Program pilot

Project Name	Year	Duration	Region Covered	Feedback Type	Home Energy Monitor /Mechanism	Sam ple Size	Overall Savings
Oberlin Homes	Janua ry 2006	3 Months	Oberlin, Ohio	Real-Time Feedback	The Energy Detective (TED)	60	No Significant Savings
Objective	• This study investigates whether continuous feedback is effective in a residential setting, and explores the effects of socioeconomic status and household characteristics on conservation practices and energy use consciousness						
Methodology	• From the initial 60 households, a sub-sample of 5 households from each of the low-income and higher income neighborhoods were invited, on a first-come, first-serve basis, to be part of a pilot study. • Final subsample contained 4 households from the low-income neighborhood, and 6 households from the higher income neighborhood • After the installation of the monitors in their presence, the homeowners could ask questions, and were left with a product manual and savings chart. • Semi-structured interviews were conducted at the residences one and two months after installation. • In terms of using the monitors to achieve energy savings, homeowners were not given any specific advice or goals. • Minimal help was given to observe the extent to which the residents would be motivated to teach themselves energy savings using the monitor.						
Behavioral Response/ Customer Satifaction	• Some homeowners did not change their habits at all during the study. • Residents reported usability problems and thought that a more sophisticated, more easily navigable device might have helped them to better understand what the monitor was telling them. • Subsample households tended to think about their energy bill less, and discuss energy use with their household less than control households • This indicates that households who requested the monitor were less energy conscious than the control households. the monitor subsample was less likely to sacrifice comfort for energy savings						
Energy Related Impact	• Residents overwhelmingly reported an increased awareness of their energy use patterns, but minimal changes in behavior • No difference between the subsample and control groups in terms of environmental consciousness and motivation to conserve energy • Per capita percentage electricity use reduction did not differ significantly between subsample and total control groups.						
Conclusion	• It is possible that, if given more time, some households might become more accustomed to using the monitor, and would thus use it more and realize more energy savings over time. • This indicates that households who requested the monitor were less energy conscious than the control households. the monitor subsample was less likely to sacrifice comfort for energy savings						

Table 46.

Summary of SMUD pilot

<table>
<tr><th>Project Name</th><th>Year</th><th>Duration</th><th>Region Covered</th><th>Feedback Type</th><th>Home Energy Monitor /Mechanism</th><th>Sample Size</th><th>Overall Savings</th></tr>
<tr><td>SMUD</td><td>April 2008 - March 2009</td><td>12 month pilot</td><td>Sacramento, CA</td><td>Enhanced Billing</td><td>Enhanced Billing/ Home Energy Report</td><td>35,000</td><td>2.5%</td></tr>
<tr><td>Objective</td><td colspan="7">Evaluate Energy Savings through Enhanced Billing</td></tr>
<tr><td>Methodology</td><td colspan="7">• Groups Segregation
  • 35,000 customer treatment group
  • 25,000 receive report monthly
  • 10,000 receive quarter report and
  • 55,000 customer control group
• Testing multiple report schemes
  • Monthly vs. quarterly
  • Graphical vs. text-weighted designs
  • Different envelope formats
• Treatment group receives reports that provide a comparison of the customer’s energy consumption pattern to similar neighbors (e.g., 100 homes in their area of similar size)
• Also provides comparison to customers’ own historical consumption
• Report includes a limited number (3) of targeted tips that are customized based on the known demographic and housing factors
• Savings basis determined by comparing treatment and control groups (i.e. not a historical comparison)
• This ensures confidence that populations are subject to same weather, economic conditions, and media messaging
• Proprietary algorithms for customer segmentation, messaging</td></tr>
<tr><td>OPOWER</td><td colspan="7">• OPOWER Home Energy Reports (features)
• Industry’s first behavioral science driven, customer-centric, data analysis and communications software platform – the Home Energy Reporting System
• Utility clients securely transfer energy consumption data to Positive Energy’s software system (programs usually target 50,000 - 100,000 homes in the initial year)
• Demographic data elements are combined with this consumption data
• Energy profiles are created for each household, using rigorous segmentation and analysis
• Reports are generated detailing how each residential customer is doing relative to similar households (“neighbor benchmarking”) with respect to energy consumption, and specific recommendations on how to continue to reduce consumption are packaged with this benchmarking to residential customers both in the mail, online, and through a CSR tool
• Savings are measured using rigorous M & V</td></tr>
<tr><td>Behavioral Response or Customer Satifaction</td><td colspan="7">• 800 of 35,000 decided to opt out, demonstrating the broad reach of this type of program (as compared to opt-in programs such as customer purchase/installation of in-home feedback monitors)
• <1% of 35,000 responded to set personal goal
• Positive customer feedback
• Program manager reports increased customer engagement, requests for additional tips
• Taps into competitiveness (e.g., “I’m closing the gap between me and my neighbors”)
• E.g., “this is the best thing SMUD has ever done”
• Few very negative reactions from customers that take offense to the comparative feedback (e.g., “you don’t have the right to tell me”)
• Protocols to respond immediately to address customer concern and mitigate dissatisfaction (e.g., explain program, address concerns, discontinue reporting to customer, etc.)</td></tr>
<tr><td>Energy Related Impact</td><td colspan="7">• 2.5% energy savings achieved across total population (non-targeted)
o On pace to save 250 kWh per household, per year
o Could target program to achieve significantly higher savings, but would be applicable to fewer people
• 3¢ per kWh savings cost average
• Significantly higher savings achieved by:
o Higher energy consumers
o Green energy (renewable energy) customers</td></tr>
</table>

	• Indication of correlation of higher savings for lower income population

Table 47.

Summary of BC Hydro pilot

Project Name	Year	Duration	Region Covered	Feedback Type	Home Energy Monitor /Mechanism	Sample Size	Overall Savings
BC Hydro Power Smart Behavior Change Program	Early 2007	1 year Pilot	British Columbia and Newfoundland & Labrador / Canada	Online Feedback and Education	Electronic News Letter/Goal Setting	Not-known	(Refer energy saving section)
Objective	Pilot was conducted to test cash incentive program for customers achieving energy savings goal						
Methodology	• Employees of BC Hydro's largest customer recruited for the study • The test involved targeting participants with four different levels of reward • Participants who reduced their electricity consumption by 20% received a monetary incentive, equivalent in value to the 20% electricity reduction (paid out as a rebate) • Participants who reduced their electricity consumption by 10% received a monetary incentive, equivalent to half of the 10% reduction (paid out a rebate) • Participants who reduced their electricity consumption by 5% received a monetary incentive, equivalent in value to the 5% electricity reduction (paid out a rebate) • Participants who reduced their consumption by 10% were entered into a drawing for an ENERGY STAR® labeled appliance package • Participants chose their electricity savings target (5, 10, 15, or 20%), and were encouraged to reduce consumption strictly through education and information sharing • The company provided an online tool to track and compare their consumption over time (another form of indirect feedback), measure their performance against their goal, and receive tips and education to reduce consumption. • The 4 Different incentive rewards were tested • Quarterly Electronic Newsletter was effective in driving traffic to the online feedback and education tool • Cash rewards were more appealing than prize draw rewards						
Behavioral Response or Customer Satisfaction	• 20% savings goal found to be intimidating to customers • 5% savings target had hid free-rider rate (i.e., people achieving the goal without making effort) • Cash rewards more motivating than prize drawings • More frequent visitors to online tool achieved higher electricity savings • Reported behavior changes included turning off lights, changing laundry habits, shorter showers, unplugging chargers, turning down the thermostat						
Energy Related Impact	• 52% of pilot program participants reduced their energy consumption; 20% achieved their savings goal • 10% energy savings goal found to strike best balance between providing an achievable stretch target while not incurring too many free riders • 19% of participants for the 10% reduction target reached their goal with an average kWh reduction of 1,847 kWh • 33% of participants for the 10% reduction target saved energy despite not reaching the goal; an average of 395 kWh was saved by this group • 48% of participants for the 10% reduction target did not save energy with an average increase in consumption of 1,025 kWh (9% increase)						

APPENDIX B

THE ENERGY DETECTIVE

Components of TED. The TED consists of mainly three sets of components. The first part is the Measuring Transmitting Unit (MTU), Set of Current Transformers and Power Cables for the MTU. This part of the TED component fits into the electric panel of the home. The second part is a Gateway, which is basically a wall plug along with an Ethernet Cable. The Gateway receives and stores the information sent from the MTU. The third is the Wireless Display, Display Recharging Stand and a Low Voltage Power Adapter. This part of the component is where the resident can view the real-time data.

Figure 37. The Energy Detective 5000 (TED 5000) components (www.theenergydetective.com)

How TED works. TED quickly and easily installs in the home's breaker panel. By connecting two sensor clamps around the incoming power conductors that feed the home's panel, TED measures the flow of electricity within the home. Information is sent over existing electrical wiring in the home to the compact wall-plug Gateway. One can then view real-time data on the wireless display or via computer and/or smart phone.

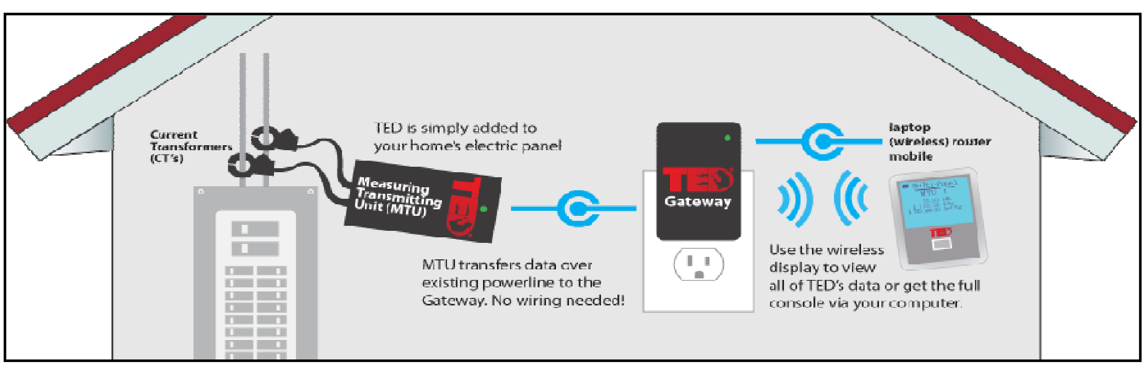


Figure 38. How TED 5000 works(www.theenergydetective.com)

Different Features in TED for saving electricity. The Energy Detective has a variety of features to help consumers save electricity around the home. They are as listed below.

Wireless display. By using the optional wireless handheld display to instantly discover phantom loads, the user can check usage of individual appliances, and see the difference by turning a switch on/off. One can instantly and conveniently view real-time electricity & dollar usage, recent electricity & dollar usage, month to date usage, projected monthly bill, spending detail,voltage, kW detail and the CO_2 consumption detail on the wireless display.

Figure 39. The TED 5000 display (www.theenergydetective.com)

Footprint software. By using TED's interactive Footprints Software the user can chart and graph usage, view historical data and trends, set up TED Advisor text messaging/e-mail alerts, enter local utility-rate information, and create load profiles for individual appliances. This software can easily be used to download the data at well.

Figure 40. TED 5000Footprint software (www.theenergydetective.com)

Text/email alerts. By using the TED Advisor, a Footprints Software-based program allows one to receive instant text message/email alerts, based on user-defined parameters. Whether the user wants to receive one text message a month when they are about to exceed their budget, or a daily text message stating their highest voltage reading for the day, they have the power to set what they want and when they want it.

Third party applications. By using one of TED's third-party apps to view real-time electricity data remotely the user can view interactive charts and graphs, set alerts, and receive instant data on their computer/laptop, iPhone, iPad, Android, Blackberry, and other Internet-enabled devices

At the dashboard study site only the wireless display device was chosen as a means to receive real-time energy usage

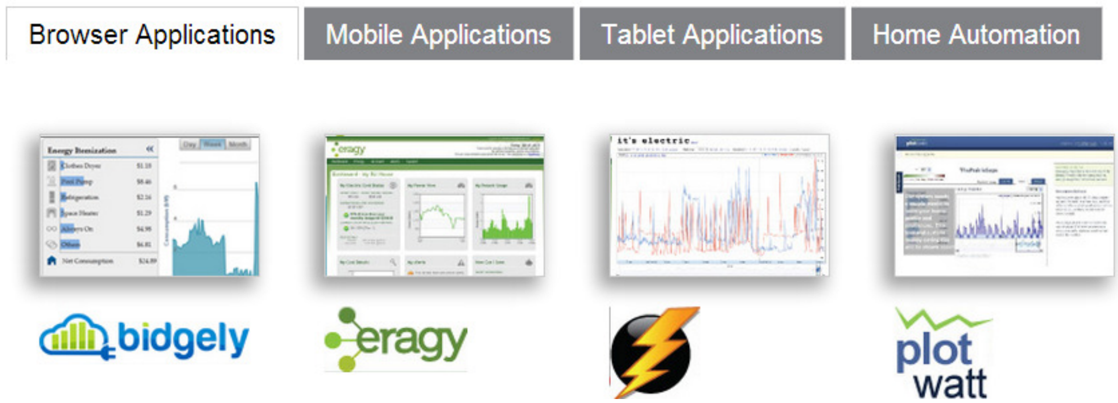


Figure 41. TED 5000 - Browser applications (www.theenergydetective.com)

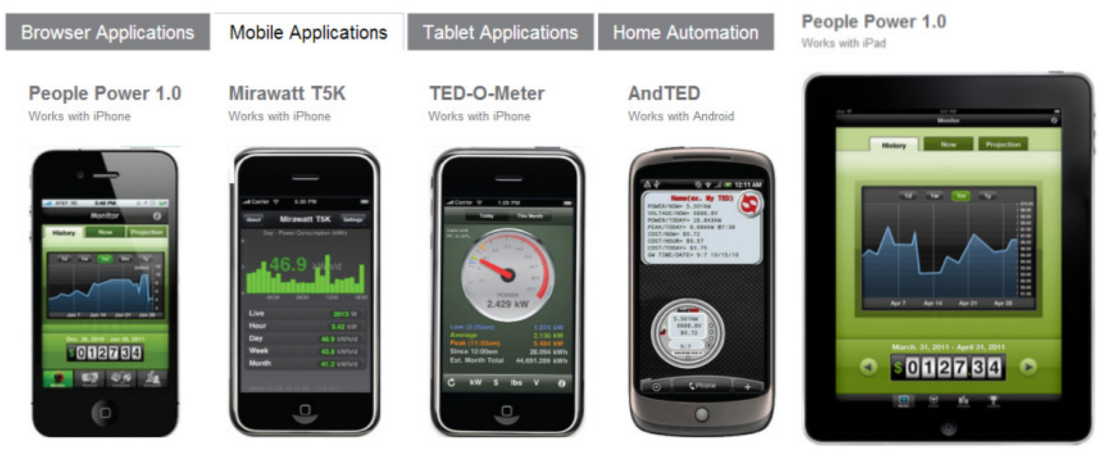


Figure 42. TED 5000- Mobile applications (www.theenergydetective.com)

Figure 43. Home Automation with TED 5000 (www.theenergydetective.com)

Monitoring Individual Appliance by creating Load Profile Option. TED has the option of creating load profiles for individual appliances as well. Through the footprint software one can choose the load profile option and then track up-to 5 devices.

Using the Load Profile Wizard, the user can create a software-based load profile for up to five devices/appliances. Large, single-stage loads (water heater, electric oven, some HVAC systems) can be profiled to be detected in software that will then provide an additional bar graph displaying the approximate time-of-use and associated cost. (Multi-stage loads require a dedicated MTU to be used in conjunction with the software.) Optionally by using the handheld Display, the user can instantly see how much an individual device/appliance uses when it is turned off/on or whether it is plugged/unplugged.

Other product features. Below mentions TED's features with respect to its accuracy, phase and operating system compatibility

Accuracy. According to the TED company website, the device is calibrated at the factory to be accurate to within 2%, however, the company claims that it is generally closer to 1%.

3-phase service. The TED 5000 series is designed for 120/240V electrical service (typically found in North America). TED5000 will not accurately measure 208/120V, which is derived from 3-phase service, TEDPRO would be required for this type of service. These are the 3-phase commercial TEDs now available.

Power. TED display battery is rechargeable

Compatibility with Operating Systems. It is compatible with Windows PC, Mac & Linux

APPENDIX C

GENERAL STEPS TO INSTALLATION AND SOFTWARE SET UP OF TED

This part of the literature has been referred from the official TED website. Though there are detailed descriptions available on the official website this manual is a more quick and general steps towards installation and software setup.

Step 1. This step involves indentifying all the components of TED, i.e., the part components going in to the panel (CTs, MTU & Power cable) and part components going inside the home (Gateway & Display).

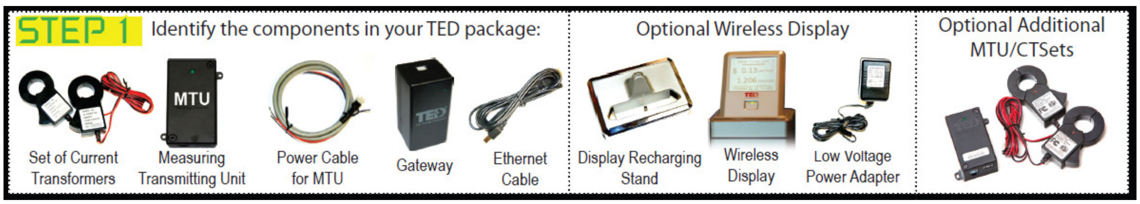


Figure 44. TED Installation Step 1

Step 2 & 3. These steps provide precautions and description about MTU Installation to the Circuit Breaker of the home. Two examples have been shown where MTU can sit inside or outside the panel.

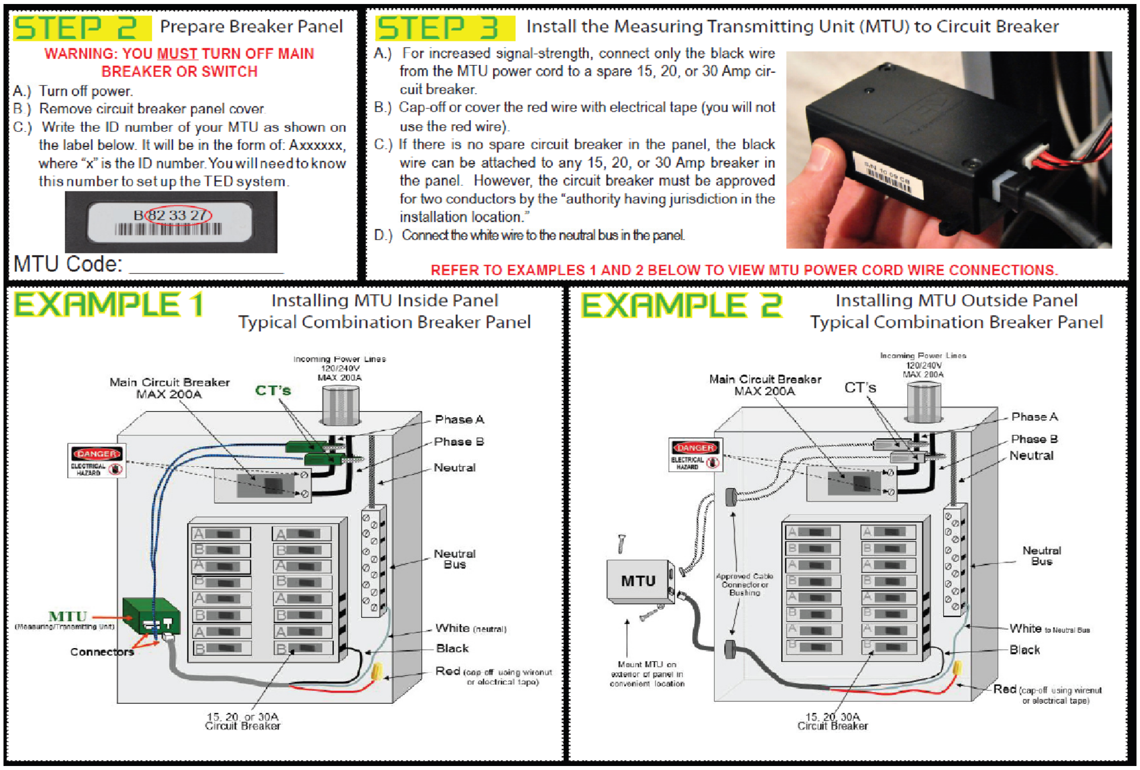


Figure 45. TED Installation Step 2 & 3

Step 4, 5 & 6. Step 4 & 5 gives the description of installing the CTs and mounting the MTU in the panel, making sure about CTs non-interference with other equipments and checking MTU's workability. *Step 6* is the next part where the gateway is plugged inside the home. It cautions not to plug it in a power strip or in an outlet with other electronic equipments plugged in. The green LED would flash initially when plugged in.

STEP 4 Installing and Connecting the Current Transformers (CTs)

A.) CAUTION - IF THIS IS A COMBINATION PANEL, THE LUGS ON THE PRIMARY SIDE OF THE MAIN BREAKER ARE PROBABLY STILL HOT.

B.) The Current Transformers must be installed with the red polarity dots both facing the source of power. If both CTs are not installed in this manner, the reading will be wrong.
NOTE: Do NOT install the CT over the neutral (N) grounded conductor.

C.) Install one CT over each incoming power conductor, by pressing on the handle to open the split core then clipping it over the power line.

D.) The CTs should be installed on the secondary side of the main switch or main circuit breaker, however, if this is not possible, such as in the case of a combination breaker panel, then install on the primary side of the main breaker.

E.) Ensure that the two sides of the split core CTs are mated tightly together over the incoming power line. ***NOTE: The CTs should be loose-fitting around the wires.***

F.) Connect the CTs and Power Cable to the MTU by plugging the plastic mating connectors together.
NOTE: The connectors are polarized and can only be inserted in one way. Do not force.

STEP 5 Mounting the MTU

A.) Determine the best location to mount the MTU:
1.) Choose a location where it will not interfere with existing equipment or wiring.
2.) The MTU may be attached using double-sided tape (if allowed in your jurisdiction), or with sheet metal or machine screws.

B.) Arrange and tie-wrap all wiring in a neat and tidy manner.

C.) Turn the power back on.

D.) The MTU will blink approximately 10 times when power is first applied.

E.) After initial blinking, it will blink when transmitting or receiving data.

F.) Replace breaker panel cover only after installing Gateway and ensuring the entire TED system is operational.

STEP 6 Plug in Gateway to Outlet

NOTE: DO NOT PLUG THE GATEWAY INTO A PLUG STRIP.

A.) Plug the Gateway into a 120V outlet. DO NOT plug the Gateway into an outlet connected to any other electronic equipment with an external power supply (such as a laptop or printer.)

B.) If setting up in a home office, we highly recommend that you purchase a filter to remove noise from your office electronics. You may purchase a filter online at the TED Store under "Accessories."

C.) The green LED will flash about 5 times when power is first applied.

IMPORTANT

Avoid a common mistake. Your TED components communicate via PLC (Power Line Communication), in other words, the data transmits over the existing wiring in your home. If, after you have installed your TED correctly and you find that there is no communication between the components, it is very likely a PLC-issue. To resolve this issue, please visit: www.theenergydetective.com/PLC

Figure 46. TED Installation Step 4,5 & 6

Step 7, 8 & 9. Step 7 is the display setup part and precautions to take while installing it. It is important to note the Display ID code since this would be used to set up initial connection of the MTU, TED and Display through the footprint Software in Step 9. Step 8 describes in detail about the footprint software setup. ID codes of MTU and Display are typed in the software to set up the initial communication between the TED components.

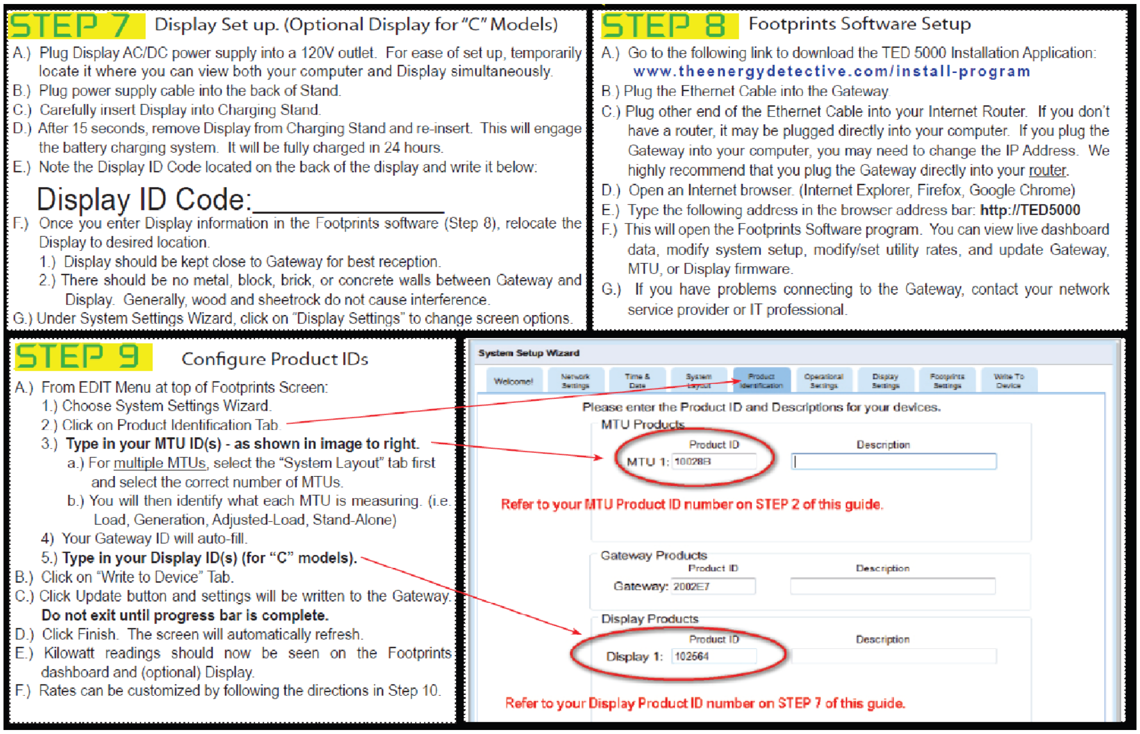


Figure 47. TED Installation step 7, 8 & 9

Step 10. This step describes the Utility Rate Wizard Setup. Here all the details related to Utility rate, plan type, meter read date etc are specified.

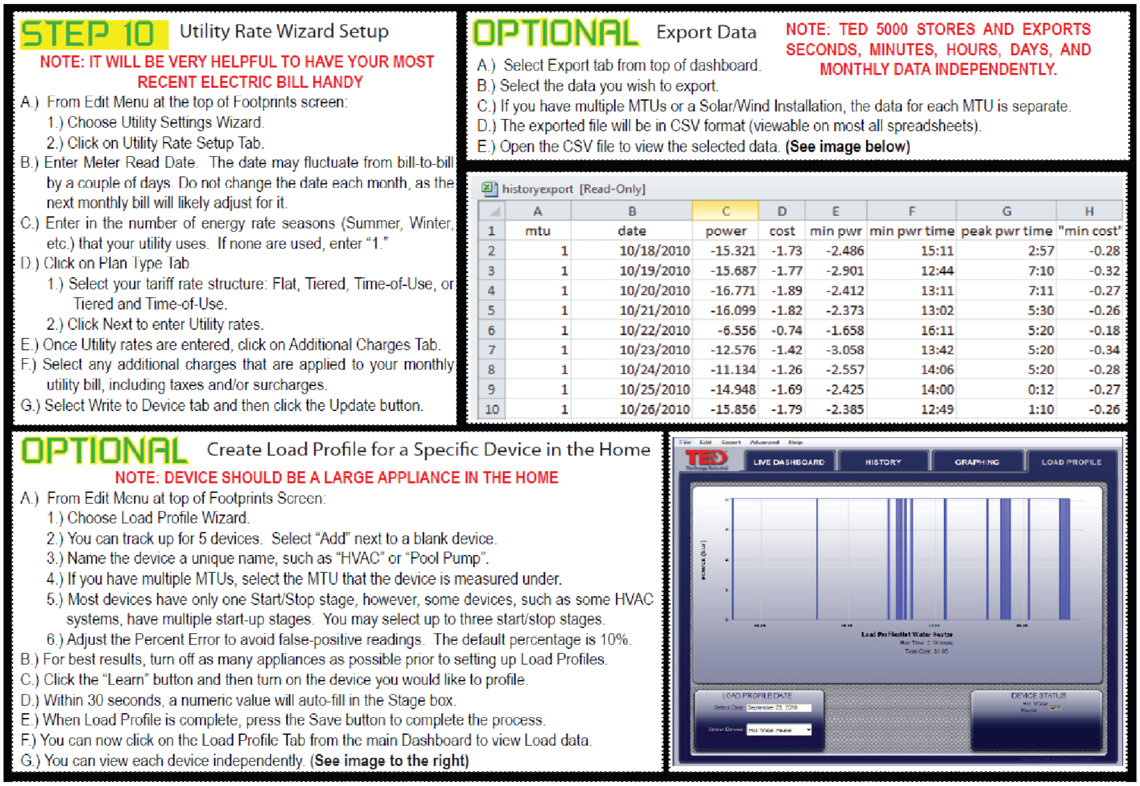


Figure 48. TED Installation step 10

Data export option. TED footprint software has an option of downloading seconds, minutes, hours, days and monthly data in a CSV format through the footprint software.

The gateway stores the received information from the home electric panel. To extract data, the user has to connect the gateway to a computer/laptop with the help of the ethernet cable provided in the TED toolkit and go into the Footprint software. On the footprint software one can use the export tab feature. TED 5000 stores 60 minutes of second-data, 48 hours of minute-data, 90 days of hourly data, 24 months of daily data and 10 years of monthly data in separate files. They can be exported independent of each other. The user can simply select the data they would like to export to analyze, and follow the on-screen instructions of the footprint software.

Figure 49. TED 5000 data export feature on Footprint Software

APPENDIX D

EDUCATION SESSION MATERIALS

Energy savings tips flyer given to all the participants

Tips to Save Energy at Your Home

1 MIMIMIZE PHANTOM LOADS, an appliance may consume energy when it is not actually turned on/in standby mode. To avoid this:

- Unplugging the appliances not in use.
- Using Smart Power strips for media centers (TV's, VCR/DVD) or other devices. When a plug strip is switched OFF, all the appliances plugged into the strip are disconnected from the power source.
- Using ENERGY STAR products, which have lower standby energy consumption.

2 USE OF AIR-CONDITIONER

- Keeping air conditioner/heat on "auto" position to save energy.
- During the summer, raising your thermostat from **72 degrees to 78 degrees** can decrease cooling costs by up to 18%.
- Leaving the ceiling fan to run mixes the air better and maintains a more even temperature throughout the house with the AC set on auto and temperature two degrees up.

3 MAINTAIN THE REFRIGERATOR

- Making sure the doors are air tight and replace any worn seals.
- Setting the temperature between **38 and 42 degrees**; the freezer 0 to 5 degrees. Ten degrees colder than necessary can increase energy consumption up to 25%.
- The freezer should be defrosted whenever 1/4 inch of frost develops and the condenser coils should be cleaned every 2 months.

4 USE ENERGY STAR CERTIFIED APPLIANCES

- Keep in mind if you purchase a new appliance to replace a model that is 12 years or older, it will use less than half the energy, in turn saving you money.
- In order to maximize energy efficiency, always look for the Energy Star® designation when purchasing new appliances.

5 UTLIZE ENERGY EFFICIENT LIGHTING

- Energy Star Bulbs are recommended to use to reduce energy consumption.

6 VENTILATE SPACES

- Use exhaust fan to remove moisture and heat from the kitchen and bathroom. However, care should be taken to switch these off after use.

7 REDUCE SOLAR GAIN by protecting openings with shades and/or draperies. Close draperies on the sunny side of the house to block the sun's rays.

General appliance usage information given to all the participants

Appliance Usage Information

Below are average amounts of energy and costs per month for a variety of home appliances. This represents average usage and may not reflect your actual costs.

Appliance	Operating Hours	kWh/month	Monthly cost @ $0.10/kWh
Air Conditioning and Heating			
Phoenix - cost per 500 sqft* (10 SEER)	24 hrs/day	351	$35*
Phoenix - cost per 500 sqft* (12 SEER)	24 hrs/day	291	$29*
Phoenix - cost per 500 sqft* (13 SEER)	24 hrs/day	270	$27*
Phoenix - cost per 500 sqft* (14 SEER)	24 hrs/day	249	$25*
Evaporative Cooling			
Phoenix - cost per 500 sqft*	24 hrs/day	86	$9*
Kitchen/Laundry			
Clothes Washer (no hot water)/(with hot water)	1 load/day	12,/60	$1,/$6
Coffee maker - small	1 brew/day	3	Less than $1
Dishwasher (no water heating)/(with water heating)	6 loads/wk	14,/70	$1,/$7
Disposal	2 minutes/day	1	Less than $1
Freezer (new)/Freezer(old)	24 hrs/day	47,/84	$5,/$8
Microwave	90 mins/wk	10	Less than $1
Refrigerator (typical 2002 model)	24 hrs/day	63	6
Refrigerator (typical older model)	24 hrs/day	95	10
Toaster Oven	0.5 hrs/day	17	2
Home Office			
Computer	4 hrs/day	20	2
Computer games	1hr/day	5	Less than $1
Fax machine	1 hr/day	5	Less than $1
Printer, ink jet, home application	1hr/wk	0	Less than $1
Printer, laser (energy star)	8 hr/day	10	Less than $1
Lights			
Lights (1 - 60 watt bulb)	6 hrs/day	11	1
Lights (1 - 100 watt bulb)	6 hrs/day	18	2
Lights (1 - 15 watt compact fluorescent bulb)	6 hrs/day	3	Less than $1
Outdoor lighting - 15 watt	12 hrs/day	5	Less than $1
Outdoor lighting - 75 watt	12 hrs/day	27	3
Entertainment			
Cable box	28 hrs/wk	2	Less than $1
Cable modem	typical usage	12	1
DVD player	1 hr/day	0	Less than $1
Radio	1 hr/day	0	Less than $1
Television (color)	4 hrs/day	19	2
Television (plasma)	4 hrs/day	40	4
Television (projection screen)	4 hrs/day	33	3
TV/VCR combo	5.5 hrs/day	51	5
VCR	4 hrs/day	1	Less than $1
Video Games	1hr/day	5	Less than $1
Miscellaneous			
Bath or kitchen exhaust fan	2 hr/day	2	Less than $1
Ceiling fans	4 hrs/day	8	Less than $1
Curling Iron	0.5 hrs/day	1	Less than $1
Hair Dryer	10 mins/day	8	Less than $1
Iron	1 hr/wk	5	Less than $1
Work lamp (100 watt)	10 hrs/wk	4	Less than $1

City of Phoenix

ASU Global Institute of Sustainability
Arizona State University

Appliance Inventory - Conducted and provided during education session for all participants

City of Phoenix ASU GLOBAL INSTITUTE of SUSTAINABILITY ARIZONA STATE UNIVERSITY

ELECTRICAL APPLIANCE INVENTORY AND ENERGY USE

Resident ______________________________ Apartment Number__________________

Date ______________________________

Please let us know which of the following items you own and how often you use them? Some devices, such as refrigerators and clocks are always on. Please consider these as used daily if they are always plugged in and running.

Appliance	Do you have one in you apartment?		Qty.	Hot often do you tend to use it? (during a typical summer)					Designation	Watts (Actual)		Condition	Comments
	Yes	No		Daily	4-6 times per week	1-3 times per week	1-3 times per month	Rarely	(amp, volts)	On	Off	(Bad, ok, good)	(Brand, size, Energy Star)
Kitchen													
Refrigerator (*)													
Stove top (burners)													
Oven (to bake)													
Dishwasher													
Microwave													
Garbage Disposal													
Toaster													
Toaster Oven													
Coffee Maker / Espresso Machine													
Office													
Desktop Computer													
Laptop Computer													
Modem/Router													
Printer / Scanner / Copier													
Cordless home phone													
Corded home phone													
Bathroom / Laundry													
Curling Iron													
Blow Dryer													
Electric Razor													
Electric Toothbrush													
Iron / Steamer (for clothing)													

* Temperature of Refrigerator (hand held thermometer)________ * Temperature of Freezer (hand held thermometer) ________

Thermostat setting (air conditioner) Day __________ Night___________ Temperature of space (general perception/measured)_________

The following are electronic devices that many people use daily. Please indicate how many of each device you own, & how many total hours/day you use them.

Appliance	Do you have one in you apartment?		Qty.	Average Daily Hours Used					Designation	Watts (Actual)		Condition	Comments
	Yes	No		1 or Less	1 - 4 hrs/day	4 - 12 hrs/day	12 - 23 hrs/day	Always On	(amp, volts)	On	Off	(Bad, ok, good)	(Brand, size, Energy Star)
Other Appliances													
Television #1 (*Circle* : Standard, LCD, Plasma, other: ___________)													
Television #2 (*Circle* : Standard, LCD, Plasma, other: ___________) *Respond "yes" if you have 2 or more TVs*													
Television #3 (*Circle* : Standard, LCD, Plasma, Other: ___________) *Respond "yes" if you have 3 or more TVs*													
Cable box / DVR,													
DVD player / VCR													
Video gaming system 1													
Video gaming system 2													
Stereo (CD player, Radio etc)													
Portable (plugged in) fans													
Ceiling Fan 1													
Ceiling Fan 2													
Table Lamp (how many ____)													

How many Personal Electronic Devices (cell phone, iPod, Nook)do you own? __________

Do you use CLF (twisty) lightbulbs? Yes/No

Are there any appliances in your home we did not ask about? (For example, mini fridge/freezer, wall mounted or portable AC unit, space heater, electronic medical devices, water cooler, fish tank, portable laundry machine) Please list.

________________________________ ________________________________

________________________________ ________________________________

________________________________ ________________________________

TED Information flyer given to group 2 and group 3 participants

TED Information - Wireless Display and Gateway

- ## How does TED work?

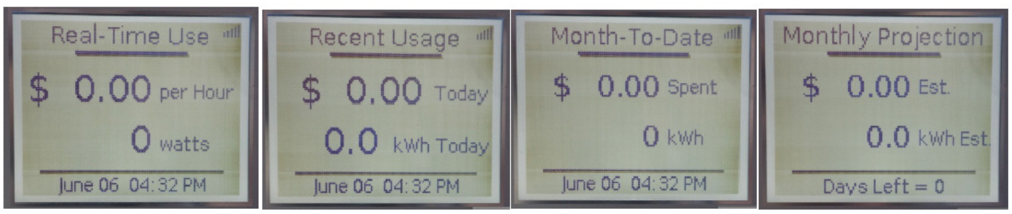
TED is installed in your breaker panel and gives you instant feedback on your electricity usage.

- ## How does TED save energy?

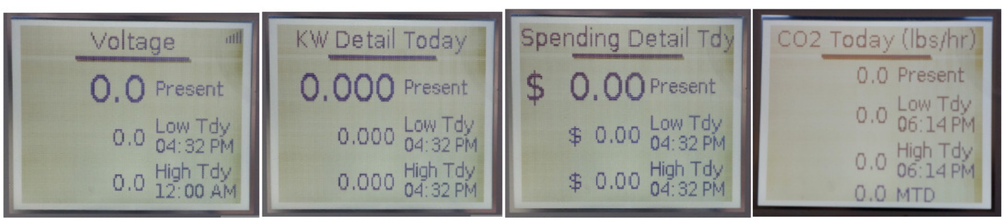
Use theportable Wireless Display to instantly discover the difference in the readings by turning an electronicdevice on/off. Try each of the following display screen options.

Change preferred screen options by pressing this button

Display Screen Options



Real-time Electricity Usage **Recent Usage** **Month-To-Date** **Monthly Projections**



Voltage **kW Detail Today** **Spending Detail Today** **CO2 Today**

- ## Tips to make sure Gateway and Wireless Display are functioning correctly

- Gateway should be plugged in ALL the time to enable reading the real-time data on the Wireless Display.
- Make sure that the green lights on the front as well as on the side of the gateway flashes all the time consistently (i.e. every 2 to 5 seconds), since this ensures the communication of the gateway with the wireless display device and the MTU in the electrical panel respectively.
- Gateway should be plugged into a 120V outlet. DO NOT plug the Gateway into an outlet connected to any other electronic equipment with an external power supply (such as a laptop or printer.)
- Wireless Display should be plugged into a 120V outlet.
- Wireless Display should be kept close to Gateway for best reception.
- There should be no metal, block, brick, or concrete walls between Gateway and Wireless Display.
- Make sure the Wireless Display device is charged.

Green Light on th front and side of Gateway should always be blinkin consistently

APPENDIX E

ARIZONA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS APPROVAL

Institutional Review Board (IRB), Human Subjects Training and Certification. Since the Dashboard study involved interaction with human subjects, Arizona State University requires Institutional Review Board (IRB) approval to ensure that subjects are treated ethically and that their rights and welfare are adequately protected. Everyone involved with recruitment or who would be working with the collected data was required to complete National Institute of Health (NIH) *Human Subjects Protection Training*.

This training is available at ASU through the Collaborative Institutional Training Initiative (CITI), which provides online research ethics education and certification via their website, https://www.citiprogram.org/default.asp?language=english. This training includes fifteen modules, takes 4-6 hours to complete, and involves passing quizzes with a minimum score.

Research protocol submittal and approval. All experimental designs and education materials were submitted to the IRB for approval.

Study program approval

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Susan Ledlow GIOS
From:	Mark Roosa, Chair Soc Beh IRB
Date:	03/12/2012
Committee Action:	**Expedited Approval**
Approval Date:	03/12/2012
Review Type:	Expedited F7
IRB Protocol #:	1203007555
Study Title:	Energize Phoenix Dashboard Study, Sidney P Osborn
Expiration Date:	03/11/2013

The above-referenced protocol was approved following expedited review by the Institutional Review Board.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date. You may not continue any research activity beyond the expiration date without approval by the Institutional Review Board.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Soc Beh IRB immediately. If necessary a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Soc Beh IRB. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.

Study Program Approval for September 2012 Follow-up

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Susan Ledlow GIOS
From:	Mark Roosa, Chair Soc Beh IRB
Date:	09/17/2012
Committee Action:	**Amendment to Approved Protocol**
Approval Date:	09/17/2012
Review Type:	Expedited F12
IRB Protocol #:	1203007555
Study Title:	Energize Phoenix Dashboard Study, Sidney P Osborn
Expiration Date:	03/11/2013

The amendment to the above-referenced protocol has been APPROVED following Expedited Review by the Institutional Review Board. This approval does not replace any departmental or other approvals that may be required. It is the Principal Investigator's responsibility to obtain review and continued approval of ongoing research before the expiration noted above. Please allow sufficient time for reapproval. Research activity of any sort may not continue beyond the expiration date without committee approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol on the expiration date. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

This approval by the Soc Beh IRB does not replace or supersede any departmental or oversight committee review that may be required by institutional policy.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Soc Beh IRB immediately. If necessary a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Soc Beh IRB. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.

Informed Consent Form

Energize Phoenix
Dashboard Study at Sidney P. Osborn
INFORMED CONSENT

5/20/2012

Dear Resident of Sidney P. Osborn:

We are a team of researchers at Arizona State University (ASU) who are working with the City of Phoenix and Arizona Public Service (APS) to evaluate the Energize Phoenix *program. We are interested in understanding the opinions of people who live in the Phoenix area, and would like to ask you to participate in a study examining the effects of energy feedback and energy-saving information on residential energy use.*

We are inviting your participation in this study, the duration of which will be up to 6 months of an experimental phase, and up to an additional 24 months of observation. Participants must be 18 years old or older to consent their participation. Your participation in this study is voluntary. You may skip any questions that you wish, or you may choose not to participate. If you choose not to participate, or to withdraw at any time, there is no penalty to you. It will not affect your rights to participate in any other programs sponsored by the City of Phoenix, ASU or APS.

- All participants will be asked to fill-out a short survey that will ask questions about your household demographics, home energy use, and personal attitudes, beliefs, and behaviors as they pertain to energy.
- All participants will be asked to participate in a Check-In every one to three months from our team, to answer a short series of questions about your household energy use, and to provide information to you about how much energy and money you have saved.
- 50% or more of households will be randomly selected for the installation of a TED (The Energy Detective) energy management system, which would allow you to see in real time your household energy use, to better understand where your energy is being used, and therefore to make more informed decisions on how and when you use energy. Homes will be randomly assigned to this group.
- Those households that are selected to receive the TED device will have the costs of installation and removal covered by the City. Installation and removal would be performed by a professional electrician hired by the City of Phoenix.
- Some participants may receive additional training and informational sessions about how energy is currently being used in their apartment unit.

For your participation in the experimental phase (approximately 6 months), each participating household will receive a gift basket of household energy saving devices and supplies, valued at approximately $75. Participants who receive an energy dashboard must return the dashboard to be eligible for this gift. If you choose to withdraw from the study, we will send an electrician to your home to uninstall the device. You would still be eligible to receive the gift basket at the end of the 6-month experimental phase as long as you return the dashboard.

If you choose to participate, the City of Phoenix and the apartment management team at Sidney P. Osborn will release your past energy usage records from April 1st 2011 to present, and future energy usage records from the present to January 1st, 2015 to the researchers at ASU. Any information from any other residence you inhabit during that time would not be shared. For instance, if you move from the building, your last shared record would be from your last billing cycle at Sidney P. Osborn.

The results of this research study may be used in reports, presentations, and publications. Your responses and energy use information will be completely confidential. While there are no foreseeable risks or discomforts to you for your participation, any negligent or willful acts or omissions of the participant related to the energy monitoring device which causes, or is alleged to have caused, in whole or in part, bodily injury or personal injury (including death), or loss or damage to tangible or intangible property, the participant shall indemnify, defend, save and hold harmless the city of Phoenix and its officers, officials, agents, and employees from and against any and all claims, actions, liabilities, damages, losses, or expenses (including court costs, attorney's fees, and costs of claim processing, investigation and litigation). Additionally, your participation in this study in no way obligates you to participate further in the Energize Phoenix program, nor does it obligate you to action of any kind.

The feedback we receive from this study will help us evaluate the effectiveness of the *Energize Phoenix* program, and how we may better address the interests and concerns of the community when it comes to matters of energy conservation.

If you have any questions or concerns, please feel free to contact Susan Ledlow at (480) 965-8645 (Susan.Ledlow@asu.edu), or Samantha Neufeld at 949-842-3497 (Samantha.Neufeld@asu.edu). If you have any questions about your rights as a participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Your signature below will be considered your willingness to participate in the study. Thank you very much for your valuable participation!

Sincerely,

Susan Ledlow

Susan Ledlow, Ph.D.
Curriculum and Faculty Development Specialist
School of Sustainability, Arizona State University

____
Print name

______________________________ ____________
Sign name Date

ASU IRB
Approved
Sign ______
Date ______

APPENDIX F

MEASURING ENERGY SAVINGS

Regression based approach. For measuring savings comparing pre-study and post-study method is used which assumes that interventions in the study are the sole reasons for changing energy consumption. Since energy consumption is influenced by weather conditions the changes in the consumption caused should account for these weather conditions as well. If they are not then the savings determined might be erroneous. The savings that do not adjust for these weather conditions are called 'unadjusted savings'.

One way to account for these changes is to develop a weather-dependent regression model of pre-retrofit energy use. The savings can then be calculated as the difference between the post-study energy consumption predicted by the pre-study model E_{Pre} and measured energy consumption during the post-study period E_{Meas}. The procedure to calculate savings is given by the equation:

$$S = \sum_{j=1}^{m} (E_{\mathrm{Pr}e,j} - E_{Meas,j})$$

where m is the number of post-study measurements.

The pre-study model, E_{Pre} , is called the baseline model. Savings measured using a baseline model, are called “adjusted” savings when the baseline model is adjusted to account for the weather conditions in the post-study period. Adjusted savings are more accurate than unadjusted savings, and should be used whenever the energy use data used to measure savings is weather dependent.

Weather correction using ambient temperature as the sole independent variable. Building energy consumption is most importantly influenced by environmental variables such as ambient temperature, ambient humidity and solar radiation. These variables are linearly related, causing multicollinearity in the regression model (Ruch et al, 1993a; Reddy et al,., 1998). When multicollinearity exists, the regression coefficients may not indicate the relative importance of the independent variables and in addition to that, the uncertainty of the regression coefficients may be so large that the model's usefulness for predicting purposes is compromised. "The use of ambient temperature as the single independent variable eliminates statistical problems due to multicollinearity and reduces data collection requirements to a single, accurately measured and widely available parameter" (Kissock, Reddy & Claridge, 1998,). For this reason, temperature-based regression model is widely used for determining weather adjusted savings (Kissock et al., year; Claridge et al., 1991; Greely et al. 1990, Fells and Keating et al., 1993 For the present residential dashboard study, a temperature-based regression model has been used to determine the weather adjusted savings.

Regression models. Kissock, Reddy & Claridge (1998) describe four basic functional forms of regression models applicable for measuring weather adjusted energy savings. It is characterised by the number of regression parameters.

Simple linear regression model. The functional form is of the type

$$E = \beta_1 + \beta_2 T_o$$

This is a two parameter model. It is the simplest empirical model appropriate for modelling weather dependent energy use in the linear relation. This parameter model is appropriate for modelling sub-metered cooling or heating energy use in constant-air-volume systems without added control features such as a hot desk reset or an economizer cycle, and without large latent loads.

Three, four and five parameter models. These are called change point models.

Three parameter cooling and heating. These models incorporate a change point temperature term i.e. β_3 in addition to constant $\beta_1$and slope $\beta_{2..}$ They are of the functional forms

$$E_c = \beta_1 + \beta_2 (T_o - \beta_3)^+$$

$$E_h = \beta_1 + \beta_2 (T_o - \beta_3)^-$$

The ( )+ ans ( )- symbols indicate that the quantities in the parenthesis should be set to zero when they are positive and negative respectively. These parameter models are appropriate for modelling envelope-driven energy consumption in buildings without simultaneous heating and cooling, such as residences, multi-family housing and small commercial buildings.

Four-parameter model(4P). These models are of the form:

$$E = \beta_1 + \beta_2(T_o - \beta_4)^- + \beta_3(T_o - \beta_4)^+$$

This model is appropriate for sub-metered heating and cooling energy use in variable-air-volume systems and/or in buildings with high latent loads. They are even appropriate for describing non-linear heating and cooling energy use caused by hot desk reset schedules and economizer cycled.

Five-parameter model(5P). These models are of the form:

$$E = \beta_1 + \beta_2(T_o - \beta_4)^- + \beta_3(T_o - \beta_5)^+$$

This model is appropriate for modeling energy consumption data that includes both heating and cooling as electric heat-pump data or whole building electricity data from buildings with both electric chillers or air conditioners and resistance heating. These models may also be appropriate for modeling fan electricity consumption in variable-air-volume systems.

Selection of most appropriate regression model. This could be done based upon best-fit criteria alone. This criteria may lead to a regression model which has been 'fit' to random variances in the data rather than the underlying relationship between energy consumption and weather. The 'fit' might not give the correct prediction of energy consumption under different weather conditions. Thus the choice of the functional form of the model should correspond to the expected relationship between energy consumption and weather for a particular heating and cooling system being considered. (Kissock, Reddy & Claridge, 1998)

ASHRAE's Inverse Modeling Toolkit (IMT). The inverse modeling toolkit (IMT) is a FORTRAN 90 application for developing regression models of building energy use. IMT can identify single- and multi-variable least square regression models. It can also identify variable-base degree-day and single- and multi-variable change point models, which have been shown to be specially useful for modeling building energy use. The report by Kissock et al. (2002) includes background information about IMT and the models, instructions for its installation and operation and the results of its accuracy and robust testing. IMT source and its executable files, along with sample data come in the software toolkit. This work was sponsored by ASHRAE research project 1050-RP project under the guidance of Technical Committee-4.7 Energy Calculations.

Model Used. The ASHRAE IMT was used to fit regression model for energy consumption for each apartment unit with temperature as the only independent variable. The analysis for all the apartment units to identify the best parameter model was done, i.e., models with least CV-RMSE [have you explained to your readers what CV-RMSE means?] values. The three parameter model regression (in this case, 3 point change cooling model) was identified to have the least CV-RMSE values compared to 2 parameter and 4 parameter models.

$$E_c = \beta_1 + \beta_2 (T_o - \beta_3)^+$$

$$E_c = Y_{cp} + RS (T_o - X_{cp})$$

Using this model, the IMT software calculates the Ycp, i.e., the energy consumption at the change point temperature, RS, i.e., the right slope, and Xcp, i.e.. the change point temperature. Through these values, the monthly energy consumption, i.e., the new baseline, can be predicted for the post-study period, i.e., 2012 year using the corresponding average monthly temperature of 2011 year for each apartment unit. This procedure is performed to calculate the savings, by comparing the new baseline with the actual energy consumption values or measured values of the post-study period, i.e., the measured consumption for the 2012 year. A downside is that the energy consumption for residential buildings depends on a lot of variables. Assuming the residential energy consumption at this complex to be only dependent on temperature was a vast generalization that was made.

APPENDIX G

ASHRAE IMT RESULTS FOR 83 APARTMENTS

Table 48.

Three parameter model results from ASHRAE IMT software for each apartment unit : Group one, two, three & control group's corresponding X_{cp}, Y_{cp}, RS, CV-RMSE, RMSE & R^2 Values

	APT ID	Change Point Temperature (X_{cp})	Energy at change point temperature (Y_{cp})	Right Slope (RS)	R^2	Root Mean Square Error (RMSE)	CV-RMSE
Group 1	10	71	397	41	0.94	102.22	14.9%
	19	65	234	33	0.98	60.55	10.2%
	35	63	306	46	0.97	111.95	13.0%
	39	67	348	41	0.96	90.73	12.5%
	43	68	273	42	0.97	81.95	12.9%
	45	60	229	42	0.98	75.89	9.3%
	46	68	393	40	0.98	57.72	7.8%
	67	59	319	33	0.93	129.64	16.2%
	79	66	189	48	0.97	97.47	14.3%
Group 2	6	71	462	25	0.83	109.86	17.2%
	7	77	275	23	0.69	111.73	29.5%
	8	67	166	72	0.97	144.39	17.6%
	18	65	301	36	0.96	94.29	13.7%
	26	67	222	55	0.93	171.05	23.6%
	49	65	365	43	0.83	237.93	28.7%
	50	61	295	39	0.92	158.06	19.3%
	51	65	410	57	0.96	144.17	14.0%
	53	69	177	48	0.82	238.49	42.2%
	63	62	296	50	0.96	140.47	15.2%
	64	64	947	56	0.96	150.37	9.5%
	69	72	175	35	0.96	70.28	17.4%
	73	62	185	41	0.98	84.10	11.9%
	75	63	399	35	0.89	160.99	19.5%
	83	63	391	39	0.93	135.56	15.8%
Group 3	2	66	167	39	0.89	164.44	29.9%
	5	61	613	37	0.93	138.08	12.6%
	12	70	453	33	0.74	198.00	28.1%
	28	66	386	55	0.98	102.73	11.1%
	41	75	447	29	0.55	217.43	36.2%
	48	66	382	40	0.96	95.79	12.1%
	59	63	314	56	0.97	123.39	12.5%
	68	69	267	56	0.86	235.34	32.7%
	71	55	480	34	0.98	67.73	6.3%
	77	57	544	44	0.95	157.09	12.7%
Control Group	1	65	319	57	0.97	118.89	12.6%
	3	69	159	42	0.96	96.20	19.1%
	4	60	382	41	0.98	84.15	8.9%
	9	64	217	43	0.96	104.21	14.7%
	11	71	472	49	0.89	170.11	20.9%
	13	66	209	43	0.98	66.23	10.7%
	14	65	226	26	0.94	79.11	15.5%
	15	82	199	49	0.75	133.69	40.4%
	16	69	167	63	0.94	160.86	23.8%
	17	64	201	52	0.98	94.39	11.9%
	20	67	375	47	0.96	106.00	13.2%
	21	65	291	38	0.91	147.20	21.0%
	22	69	463	61	0.98	96.31	10.1%
	23	66	219	62	0.96	149.48	17.5%
	24	62	258	19	0.72	155.69	31.6%
	25	55	337	34	0.93	150.84	16.0%
	27	61	211	42	0.97	103.56	13.6%
	29	63	493	42	0.76	305.14	30.5%
	30	66	218	55	0.98	102.01	13.5%

31	58	350	40	0.98	81.47	8.6%
32	67	217	47	0.93	142.30	21.8%
33	60	192	36	0.98	73.73	10.7%
34	63	164	47	1.00	40.97	5.6%
36	66	317	45	0.95	124.64	16.0%
37	67	135	42	0.95	108.25	20.8%
38	68	200	57	0.99	71.37	10.3%
40	67	166	30	0.95	76.24	17.4%
42	66	268	55	0.95	159.07	19.1%
44	69	382	58	0.95	139.43	16.4%
47	69	332	92	0.99	116.89	10.9%
52	64	320	57	0.98	105.83	10.9%
54	64	324	85	0.98	147.48	11.3%
55	63	242	52	0.96	142.20	16.4%
56	59	235	36	0.93	144.72	19.3%
57	70	172	44	0.97	80.33	16.0%
58	69	415	63	0.93	186.66	20.2%
60	61	337	32	0.88	167.04	21.7%
61	59	356	35	0.95	123.26	14.2%
62	66	342	56	0.96	140.63	15.4%
65	67	651	51	0.75	334.89	29.9%
66	64	378	36	0.90	156.40	19.8%
70	69	339	71	0.93	200.24	21.8%
72	68	240	50	0.80	272.22	40.3%
74	62	357	36	0.97	89.94	11.1%
76	62	615	39	0.92	157.28	14.2%
78	62	263	48	0.97	110.81	12.7%
80	67	394	41	0.95	109.17	14.2%
81	60	220	33	0.94	137.45	16.6%
82	66	177	60	0.97	130.61	16.5%

APPENDIX H

TED'S FUNCTIONALITY THROUGHOUT THE STUDY

Table 49.

Summary table of energy savings or loss with TED's functionality during the study period and its results with data download

Group #	Apt ID	Savings or Loss%	July	August	September	October	November	December
2	6	2.7%	Not Installed	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	7	8.1%	No Data	No Data	No Data	Opt Out	Opt Out	Opt Out
2	8	-7.7%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	18	21.3%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	26	-1.2%	Working & Complete Incorrect Configured Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	49	-5.7%	Working & Complete Incorrect Configured Data	Working & Complete Incorrect Configured Data	Working & Complete Incorrect Configured Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	50	-3.6%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Working (8 Days missing)	Working & Complete Month Data	Working & Complete Month Data
2	51	8.6%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	53	-0.7%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	63	-5.0%	Missing Days in data	Missing Days in data	Missing Days in data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	64	20.9%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Missing Days in data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	69	-17.8%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	73	-0.4%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
2	75	15.4%	Working & Complete Month Data	Working & Complete Month Data	Missing Days	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data

2	83	-6.4%	Working & Complete Incorrect Configured Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Missing Days in data
3	2	-17.6%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Working (1 day missing)	Working(1 day missing)	No data
3	5	21.0%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
3	12	-1.0%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
3	28	2.4%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
3	41	5.4%	Working & Complete Incorrect Configured Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
3	48	-4.2%	Working & Complete Incorrect Configured Data	Working & Complete Month Data	Missing Days in data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data
3	59	-9.7%	Missing Days in data	Working & Complete Month Data	Working & Complete Month Data	Missing Days in data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data
3	68	-5.4%	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data
3	71	2.9%	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Stopped Working &Incorrect Data	Working (3 days missing)	Working & Complete Month Data	Working & Complete Month Data
3	77	3.8%	Working (2 days missing)	Working & Complete Month Data	Working & Complete Month Data	Working & Complete Month Data	No Data	No Data