Home Power Management for Energy Efficiency through Smarter Appliances Adapters

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Contents

Abstract

The technology to support the fully integrated electricity Smart Grid is mostly available today. Because the capital and installation costs for enabling smart transmission lines and distribution substations are high, utilities and their regulating organizations are reluctant to invest the resources and pass the resulting costs on to the ratepayers. On the demand side it is more likely that businesses will be able to demonstrate that the costs for upgrading to Smart Grid capable demand response devices, such as Smart Meters and centralized automated control systems, can be recovered and will become bottom line benefits as electric rates increase and demand response and time of use pricing become available. Residential energy use is still a large component of delivered electric power. The residential customer base is large and the ability to drive consumer electric usage behavior to models which will be more efficient and conservative is not well known. This research focuses on residential demand side behaviors and will investigate the market potential for a smart appliance adapter plug, which would help the consumer learn and practice automatic and programmed electric use through a centralized home automation and control console. This smart adapter plug and control console technology will be developed and shown to be capable of enabling consumer behavioral changes which can contribute to a reduced energy use and lowered utility costs. A survey is conducted which will evaluate typical consumer attitudes about conservation, energy efficiency and willingness to use this new capability to actively control the total residential energy use.

Introduction

Galvin and Yeager, in *Perfect Power*, inform us that there are 50 million Advanced Metering Infrastructure (AMI), smart meters worldwide, and expect that there will be over 65million in the US by 2015. [1, p.196]. The ability to create changes in behavior in consumer electricity consumption through Demand Response (DR) and time of use pricing is dependent on providing the electricity consumer with reliable and real time information. The distribution and sharing of this information for electric grid management is a major component of the Smart Grid of the future.

The residential consumer of electricity can reduce his electricity costs through conservation practices to promote smaller consumption or replacing less efficient appliance with higher efficiency models. The time of use pricing and Demand Response allow the consumer to take advantage of lower electricity costs available at off peak hours, typically 3PM through 8PM. A typical example is to delay using the home dishwasher until after 9PM, when the time of use rates will decrease. The consumer can accomplish this delayed dishwasher cycling by purchasing a new Smart appliance from manufacturers such as Whirlpool [2] or GE. Typical smart appliances are dishwashers, clothes washers and dryers.

We will investigate a simpler alternative technology which we have named the “Smarter Appliance Adapter”. Our research project will develop the Smarter Appliance Adapter as a technology innovation, and determine the consumer adoption profile which we can use in the marketing model. We will develop this consumer adoption profile using the market research technique of the consumer survey. We designed a survey to elicit answers which will help us identify the consumer value and behaviors which will create demand for this product.

Electric Energy Growth, Energy Efficiency and Conservation

The US Department of Energy measures historical growth of all energy use and has a special interest in electricity generation, transmission, distribution and consumption. The rate of electricity use has moderated since the oil embargo and energy crisis of the 1970s. The growth in households, appliances and number of electronic devices such as computers, televisions has been somewhat offset by the higher efficiency of the newer appliances.

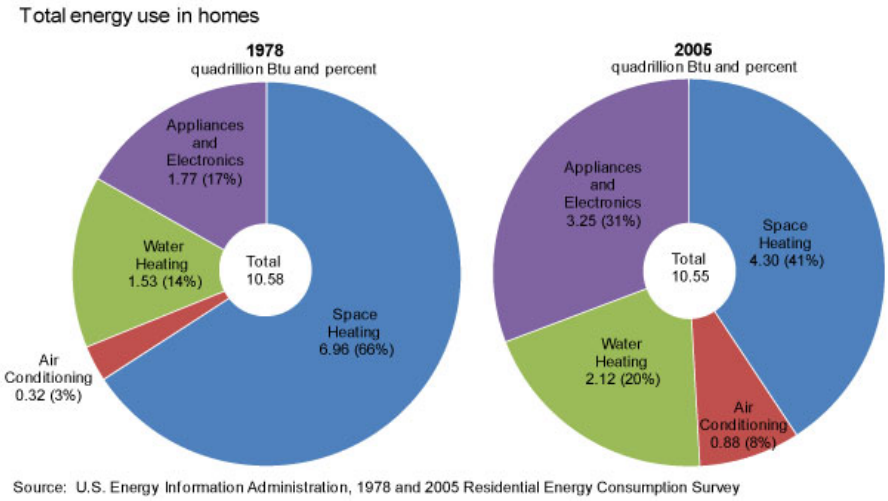

Figure 1 : Total energy us in US Homes [3]

It can be observed that the total energy consumed in US Homes has reduced from 10.58 quadrillion Btu in 1978 to 10.56 quadrillion BTU in 2005. Although this reduction is only 0.19% it is significant that it did not increase in over 25 years[3]. The largest reduction is in the space heating component which can be attributed to more efficient heating systems and some behavior changes which helped lower thermostats in winter. Water heating went up mostly as a result of population increasing. Air conditioning almost tripled, responding to the population shifts from colder climates to the Sun Belt states, where more residential air conditioning is used.

The component which includes appliances and electronics almost doubled. This is a result of more homes adding dishwashers, washers and dryers, microwaves and many more convenient kitchen appliances, multiple televisions per household and the plethora of newer electronic devices such as home computers, home theaters, video gaming consoles and the home networking devices to connect them. Almost every consumer friendly mobile device requires a battery and a charger. This increasingly large number of electronic gadgets in the home is a suitable opportunity to apply or smart appliance adapter technology. Since all of these appliances can be controlled and monitored by the Smarter Appliance Adapter, a very large number of adapters could be required to understand and change to energy use in a typical home.

Residential electric power use

The US Energy Information Agency has projected the total US residential energy demand using three scenarios, business as usual reference, using 2010 technology and expanded standards for appliances. Starting at about 11 quadrillion BTU in 2011 usage will grow to 12.8 quadrillion BTU by 2030 in the reference scenario. With adoption of 2010 appliance standards usage would only grow to about 11.8 quadrillion BTU. By adoption of the proposed expanded appliance standards the scenario predicts a reduction in total usage to about 10.9 quadrillion BTU.[4]

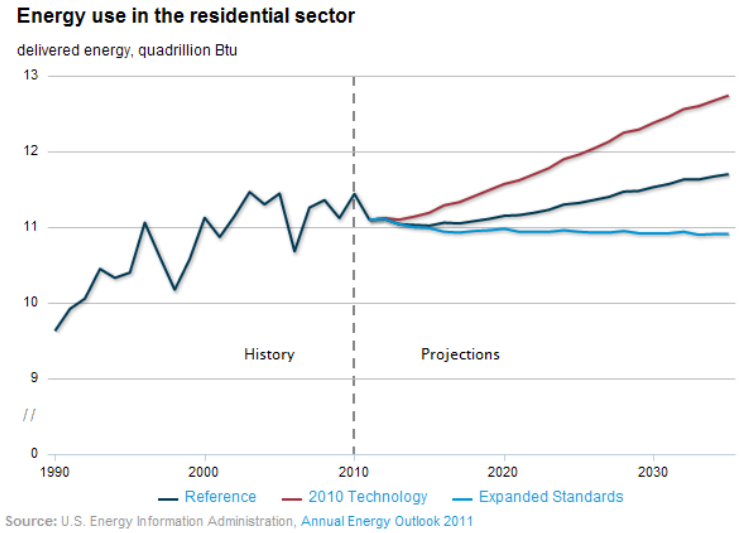

Figure 2 Residential Energy Growth Scenarios through 2035 [4]

For the reduced energy use scenario to be achieved, the 2010 technology with expanded standards for appliances will be necessary. The addition of incentives for consumers to improve their energy consumption behaviors may be necessary to continue to trends seen in the 1978 to 2005 time period discussed above. We feel that additional capabilities which will allow more automation and control of the energy used by home appliances can add significantly to the behavior changes, by making it "easier and convenient" for the residential consumer to adopt more energy efficient behaviors.

Energy efficiency and conservation as cheapest form of energy

As we have seen there are many ways to reduce the total energy consumption in the residential sector. The most important part of the reduction in the EIA scenarios depend on the replacement of older appliances with newer models manufactured to the 2010 appliance standards or the expanded standards. The electric power industry understands that energy efficiency and conservation are the lowest cost per kilowatt-hour for any form of energy generation. This has been validated by a number of guest lecturers in the Energy Technology Innovation program, including Kim Thompson[5], and Dan Russell. We can try to make energy efficiency more "convenient" or even fun or a "game" challenge for the residential consumer and hope that this will help drive behavior in the right direction.

Smarter Appliance Plug Adapter (SAPA) Product Description

The Smarter Appliance Plug Adapter, or Smart Plug Adapter, will be placed between the wall plug and the appliance cord plug, similar to currently available electric power monitoring devices, but includes the ability to be switched on and off remotely. It will use wireless technology to communicate with a master home control program operating on standard computing platform, workstation, laptop or tablet computer. Smarter Appliance Control Panel's "smart brain" control software will perform the monitoring and control of these appliances, allowing the customer and the utility to optimize the demand response decision logic. The remote control functions can even operate on a hand mobile device, such as a smart phone.

Figure 3 Smart Plug adapter

The smart plug adapter can be created as a normal US plug extension. The illustration in Figure 3 represents a standard plug adapter used in the UK. . Inside the smart plug adapter will be monitor and control circuitry which will use wireless two-way communications to control center. The control center will act as the hub and will allow link to the web and therefore the utility.

Figure 4 Programmable Intelligent control center

The Programmable Intelligent control center will be implemented usting a standard product such as PC laptop or tablet to minimize cost . In production we would use an custom built OEM tablet which can be preloaded with our unique software packages. Since we will save money on the hardware we will be able to invest more resources in developing good software.

Literature Review

Energy efficiency

Energy efficiency is the use of less energy to achieve the same level of energy service. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature [6]. Energy efficiency is usually achieved by adopting a more efficient technology or production process.

There are various motivations to improve energy efficiency. The improvements in energy efficiency can reduce energy use and result in financial cost saving to consumers if they implement an energy efficient technology [6]. Energy efficiency is considered as a key solution to the problem of mitigating the climate

change, reducing the fuel import dependency, and reducing emissions [7]. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases [8].

In many countries, energy efficiency is seen to have a national security benefit because it can be used to reduce a range of challenges including perceptions of resource scarcity, high energy prices, security of energy supply and environmental protection. And energy efficiency is becoming increasingly important part of government policy around the world, such as US's government [9], UK's government [10], and China's government [11].

Demand response

The original definition of demand response is to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices [12]. The more broad definition of demand response includes both modifications of electricity consumption by consumers in response to price and the implementation of more energy efficient technologies [13].

Many utilities have employed the broader definition and, as a result, many existing demand side management programs have been implemented [14]. And the time-varying pricing schemes of electricity have been widely discussed and implemented in multiple forms by utilities [15]. And, there is no generally accepted design which is considered to be best in terms of economic characteristics or ease of implementation or customer adoption behaviors.

Demand response is seen as a mechanism to encourage consumers to reduce demand during the phase of the peak demand for electricity, and it is also used to increase demand at times of high production and low demand [16]. Some systems thereby encourage energy storage to arbitrage between periods of low and high demand. At the same time, demand response is a component of smart energy demand, which includes energy efficiency, and building energy management [12]. Smart grid applications can improve the ability of consumers to make decisions about how and when to consume energy, and they increase the opportunities for demand response by providing real time data to consumers. Using the smart grid applications, consumers not only can adjust their usage to take advantage of fluctuating prices, but are able to closely monitor, shift, and balance load they have saved in the energy market [12].

Methodology

The goal of this study is to examine the impact of consumer's adoption behavior changes and adoption energy efficient productions on the reduction of residential electricity demand. The technology assessment and surveys about smart energy appliances were applied in this study.

Technology assessment

Improvements in residential energy efficiency and reduction in residential electricity demand can be achieved by using smart energy home technology. Among various available options, smarter appliance plug adapter and Whirlpool smart appliance are two alternatives. In order to have better understand about smart plug adapter and whirlpool smart appliance to help consumers to make decision on these two alternatives which one they would like to use, the technology assessment for these two alternatives need to be done. Therefore, in this study, we firstly attempt to provide a comprehensive evaluation for smart plug adapter and whirlpool smart appliance from four factors including cost, ease of installation, environmental impact, and system adaptability and programmability. And the technology assessment factors for Smarter Appliance Plug in Adapter and Whirlpool Smart Appliance is shown in Table 1 can be used as selection criterion.

Selection Factor	Smarter Appliance Plug Adapter (SAPA)	Whirlpool Smart Appliance
Cost	$250 for 1st SAPA system ($200 –controller,$ 50-adapter) $50 for each additional adapter	$1000
Use with existing appliance	Yes	No
Environmental impact	Less, since reusing existing	Larger, to manufacture new
Ease of Installation	Can be applied to many device loads Difficulty increases with the number of adapters in system	Easier depending on appliance
System adaptability and programmability	User has general purpose programmable control panel (PC) Difficulty increases with the number of adapters	Each smart appliance unique Manufacturer limits programmability
Savings – with Time of Use pricing	YES	YES + micro smart control
Ease of Installation/use	Can be applied to many loads Difficulty increases linearly with the number of adapters	Easier for each appliance
System adaptability and programmability	User has general purpose programmable control panel (PC) Difficulty increases with the number of adapters	Each smart appliance unique Manufacturer limits programmability

Table 1- Selection factors for choosing Smarter Appliance Plug Adapter

Survey for Customer Adoption

An exploratory survey was implemented to understand consumer attitude towards using energy efficient devices and appliances. The list of the potential respondents consisted of about 32 selected people who were mostly fellow student at Portland State University. The interview consisted of about 14 questions concerning the energy usage behavior for the day to day appliances at home and also their understanding of some of the key terms, such as, energy efficiency, energy star and conservation. In addition, respondents were also asked if they owned a house, lived in a rental property and if they stayed with their parents.

We identified six main factors which would play significant role in the adoption process of the smart energy efficient devices and they are classified as, Installation Cost, Energy Efficiency Improvement, Demand Response Cost Savings, Complex Programmability of the control devices, Green Consciousness and Ease of Use/Installation. The survey questionnaire was designed to incorporate these factors.

See the Appendix A for a detailed summary of the individual questions and the responses.

Smarter Appliance Adapter Features and Competitive Analysis

This section will discuss the features of the Smarter Appliance Adapter. It will then compare the use and selection of the Smarter Appliance Adapter and a typical smart appliance as might be found from Whirlpool or GE.

Comparing Smarter Appliance Plug Adapter technology and Smart appliance technology

The appliance consumer will generally be satisfied with the status quo. She will not spend money to purchase a new appliance unless it is her first purchase of an appliance, the existing one is broken or in need of repair, or she has been motivated for other reasons, such as achieving a more energy efficient operation. These three cases are summarized in Table 1.

Case #	Need Cases for appliance	Upgrade existing with SAPA	Purchase new Smart Appliance
1	1st time Appliance buyer	Buy less expensive or dumb new + SAPA	Buy new smart appliance
2	Appliance broken not repairable	Buy less expensive or dumb new + SAPA	Buy new smart appliance
3	Appliance upgrade	By SAPA system for existing appliance	Buy new smart appliance

Table 2 Three Cases for acquiring Smart Appliance Adapter (SAPA)

The typical consumer will give some attention to any large expense, but will not usually give a full cost benefit analysis as we have studied in the Technology Management program. It can be expected that given equal availability of product and performance, price will be the most important selection factor. The important selection factors are summarized in Table 1.

Marketing Plan for Smarter Appliance Plug Adapter technology

The marketing plan for the SAPA products is a simple two stage model. The first products, SAPA I, will consist of the Smart Appliance Plug Adapters and Control unit. This will be direct marketed to consumers and interested installers and contractors to get field validation information about performance and customer acceptance. This version of the product needs to be simple enough for the tech savvy consumer interested in improving energy efficiency to install herself. The second generation, SAPA II, will have full support for the large number of appliances needed for automating control of a large home. Due to the added complexity, and much more capable software requirements, it is anticipated that the only the most dedicated and tech savvy homeowner will be successful as a self-installer. We expect that develop our multi-channel supported network of contractors and installers similar to that used in the residential Solar PV business today. We have found a number of manufacturers currently in the home controls market and have a similar product and customer base. Table 3 lists some of the players currently in the automation and smart grid interfacing sectors.

Device	Monitor	Control	Smart Grid Ready
Sequentric	YES	YES	NO
TED	YES	NO	NO
Energy Hub	YES	NO	NO
Energy Aware	YES	NO	NO
Tendril	YES	YES	No
Smart Linc – Insteon	YES	YES	NO
X-10 systems	Yes	Yes	NO
SAPA I	Yes	YES	NO
SAPA II	Yes	Yes	YES

Table 3 - Competitive manufacturers in Home Power Control 2010

The Figure 5 is a graphic which helps understand the position of many of the current products in the home control domain. It is adapted from a marketing report from Whitney Michael of Cleantech Marketing Insight [17]. The Utility band along the top includes most of the Smart Grid capable products which would be sold through or with support of utilities. The SAPA products would be expected to be sold direct to consumer, or though appliance, home theater or home security contractors and thus occupy any of the lower sections, 1A, 1B, 1C, 2C. The first SAPA I products would fit solidly in the direct to consumer and the free or minimal and basic sections, 1A and 1B. As the software and hardware components are improved, we can expect SAPA II to occupy the high-end & direct to consumer section allowing entire houseful of appliances to be monitored and controlled. The developing marketing plan will include more of the contractors mentioned above as multichannel distributors allowing SAPA II will occupy the section labeled Multi-Channel and High End, 1C and 2C.

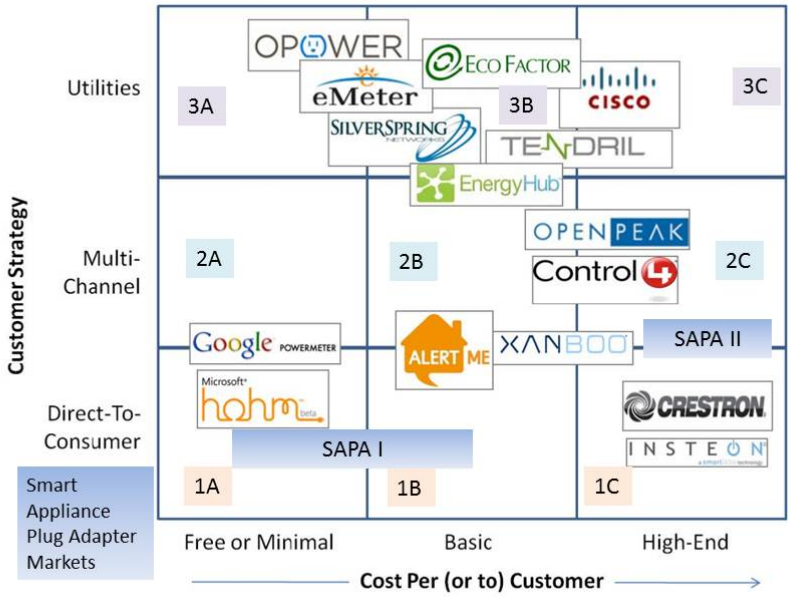

Figure 5 – SAPA I and SAPA II Competitive Marketing Domain [17]

Results of Survey for Customer Adoption

Garling and Thorgesen (2001) suggest that adopters have developed internal reference values based on knowledge and competence [18]. In other words, the actual cost of the innovation is not important; what matters is what it is worth to them as individuals. These values can transcend demographic or socio-economic categorization. For example, an electric vehicle will be more readily adopted by an individual who is more interested in improving air quality and reducing demand for natural resources, than by an individual who desires speed and performance. Many electric vehicle owners are impressed by the quietness of their cars; this maybe an unanticipated benefit. Solar power systems in particular are an innovation designed for reducing pressure on environmental resources and it seems logical that 'green' consumers should be attracted to buy them.

1. Energy Star Appliances
Energy Star is an international standard for energy efficient consumer products. Devices carrying the Energy Star logo, such as computer products and peripherals, kitchen appliances, buildings and other products, generally use 20%–30% less energy than required by federal standards.

2. Energy Efficiency
Energy efficiency is using less energy to provide the same level of energy service. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. Efficient energy use is essential to slowing the energy demand growth so that rising clean energy supplies can make deep cuts in fossil fuel use. If energy use grows too rapidly, renewable energy development will chase a receding target.

3. Energy Efficient Appliances
Home appliances look pretty much the same on the outside, but they vary greatly in terms of energy efficiency and operating costs. The more energy-efficient an appliance is, the less it costs to run. You can lower your utility bill and help protect the environment.

4. Smart Plug Adapter
The product would be a "Smart" wall plug or a multiple outlet extension device. This would permit a simple and cheap method to connect the existing appliances (which are not energy efficient or energy star rated) to an advanced level of smart energy savings and control without requiring to purchase multiple expensive replacements, such as the forthcoming GE and Whirlpool "smart" appliances. A typical wall-socket format device/monitor/GFAC should fit into a format like this Current Cost individual appliance monitor (IAM) as shown in fig1 and for a multiple outlet format we are considering a format something like a surge protector, like this Panamax toweMax surge suppressor as shown in fig2.

Figure 6 - Consumer Survey Introduction Information

We decided to conduct a survey of sample customers to help evaluate the likelihood of changing behavior by purchasing an energy efficiency enhancement such as our Smarter Appliance Plug Adapter compared with a new Smart Appliance. The sample set was certainly not random, but a selection of friends and ETM graduate students a sample of highly educated and environmentally aware individuals. Figure 6 is the only introduction to our problem that was known to respondents. In our survey we had 32 respondents of whom: 91% pay their own electricity bill, 50% own a house, 78% think energy efficiency if important, 71% are environmentally conscious, 59% have energy star appliances and 88% would like to improve energy efficiency in their home.

We were not very surprised by most of the results. We learned that for all respondents 38% would likely by a product like the SAPA in the next 12 months. Of the 16 out of 32 (50%) who were homeowners 59% would purchase a SAPA device.

Some of the responses that indicated behavioral change showed 78% of the respondents are willing to change their behavior on energy use to save 20% of their monthly electric bill. 21 of 32 (66%) respondents were willing to spend $300 or more to achieve a $300 annual savings. Surprisingly 16% would spend over $1000 to get the same $300 savings. This implies that they were satisfied with more than a 3 year payback period to accomplish personal environmental goals.

Recommendations

Future Research

Our team feels that we could learn more about consumer behavior in this area if we had the time to create second generation of survey questions. This would allow us to understand and correlate questions with respondent's lifestyle, incomes, profession, culture and environmental attitudes. With this version we could learn more about social perspective of the consumer. Once we had this version developed it might be appropriate to try understanding adoption behaviors in different countries.

A more detailed development of the product could be helped by understanding the user attitudes and desires for home automation and control.

Product development

There already are a large number of companies who have developed products in this market and many are commercially available. They seem to understand the market direction towards the Smart Grid compatibility, the technology innovations needs and have developed some products. They are probably considering the utilities as their design primary customer. The research in the field of adoption of electricity saving devices may still be a major hurdle.

Unless our organization developing the Smarter Appliance Plug Adapter products can gain a deeper understanding of the end user customers that will give us a competitive advantage, we would not recommend that this product be developed further.

Conclusions

We have verified the traditional knowledge of behavioral inertia that people will continue to do what they have been doing unless challenged to do something else. In the realm of electricity use in the home people will keep the temperature at a level of personal comfort, leave lights or the television on when not in a room. These behaviors may be an inefficient or even wasteful use of energy. For most Americans the cost of these behaviors in electric utility costs is below the level of concern or financial pain.

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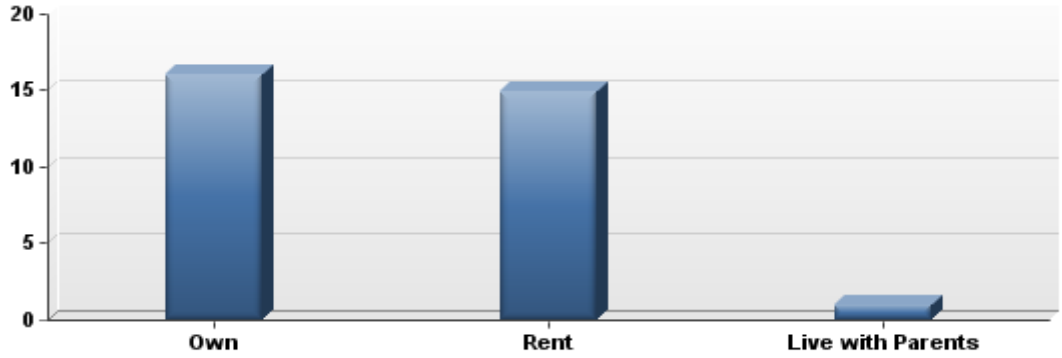
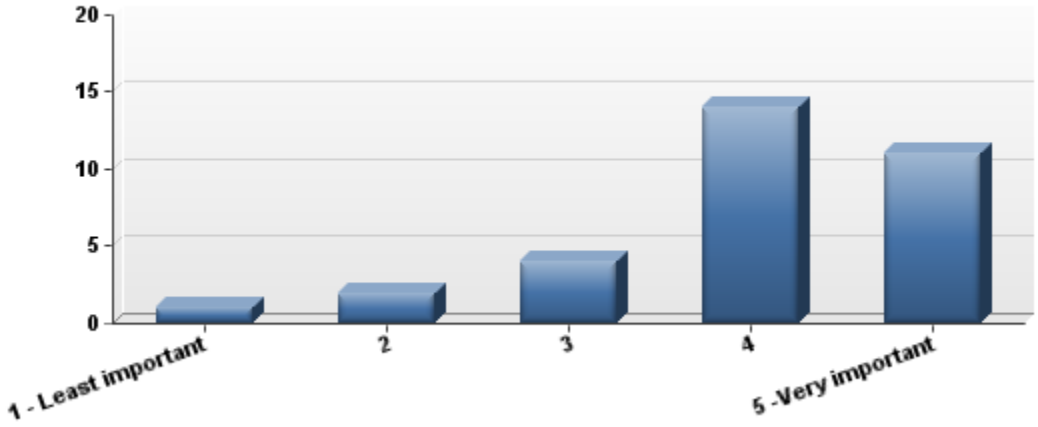
Appendix A: Survey Questionnaire

Q1. Do you pay your electric power utility bill at your residence?

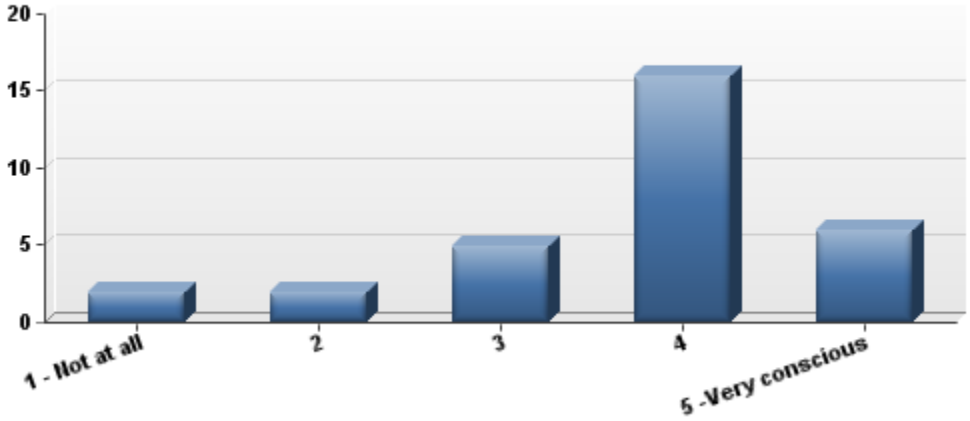
Q2. What is your living situation?



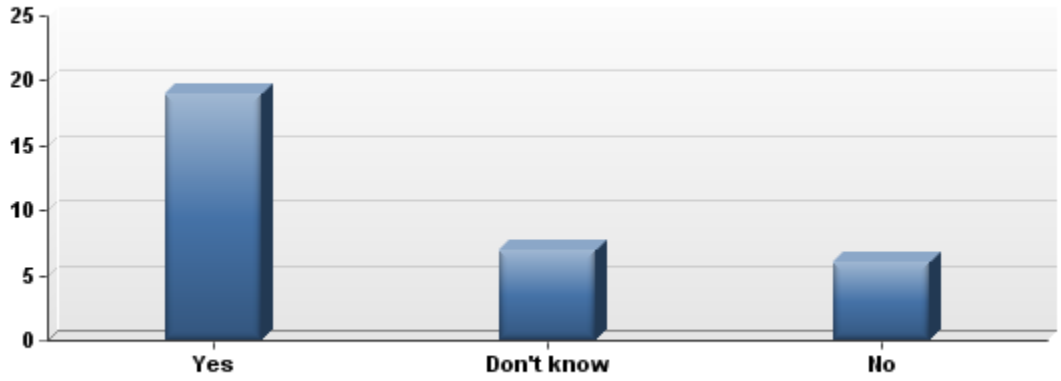
Q3. How important is saving energy for you? On a scale of 1 to 5, 1-being least to 5 being very important.



Q4. How environmentally conscious are you? On a scale of 1 to 5., 1- not at all to 5 - very conscious.

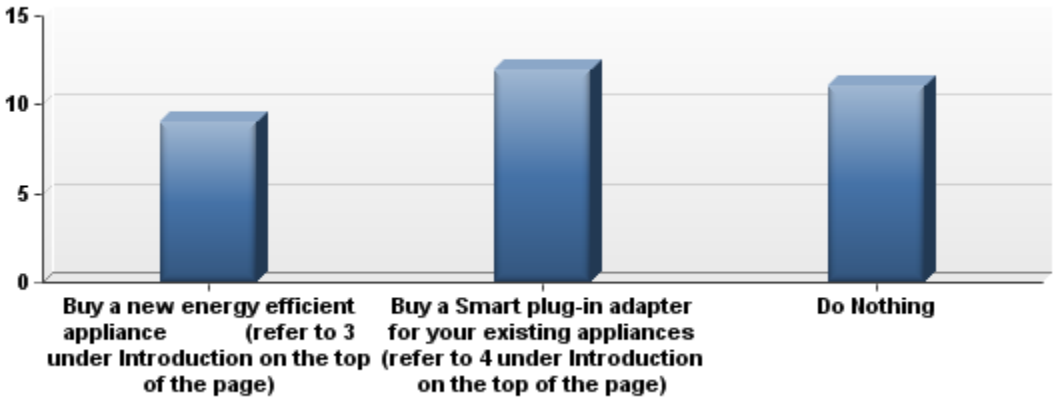


Q5. Do you have any energy star appliances?

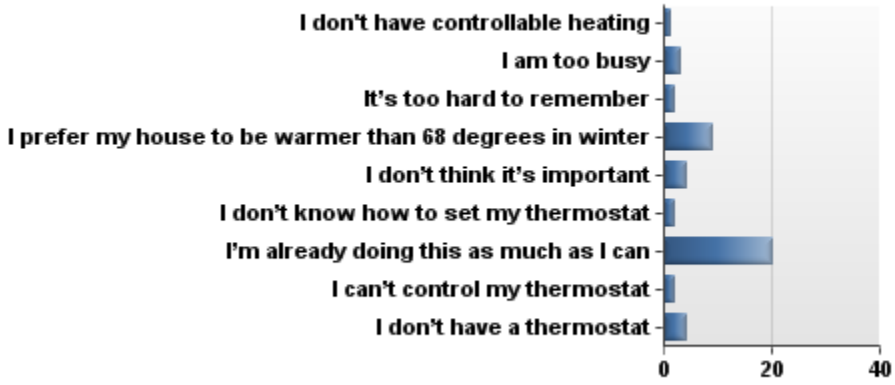


Q6. Is improving energy efficiency of your home important to you?

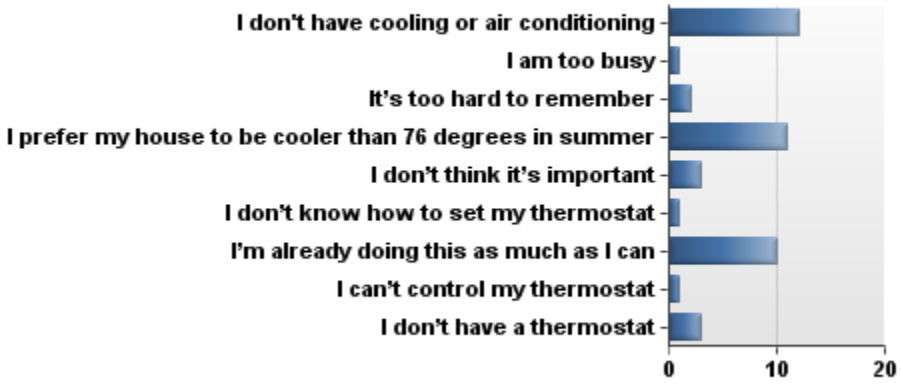
Q7. Which of the following best describes what you are likely to do over the next 12months?



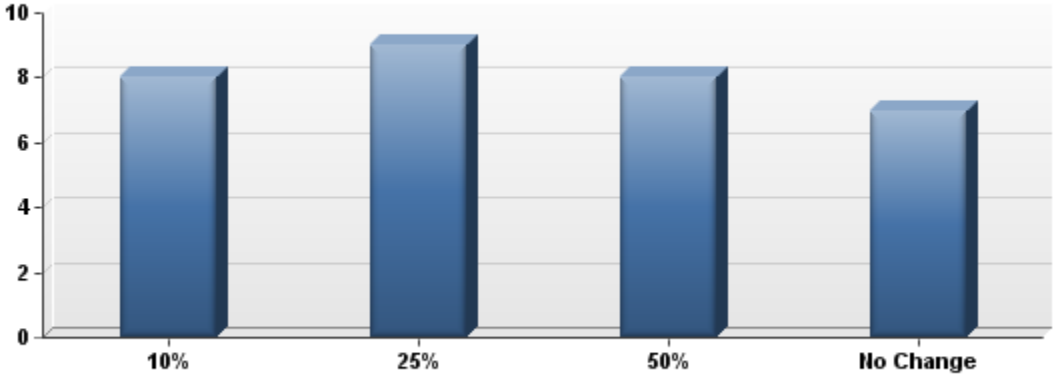
Q8. Energy Efficiency through Conservation: Less heat in winter. There are many reasons why people don't set the thermostat to 68 degrees or cooler in the winter. Please check all of the reasons below that apply to you



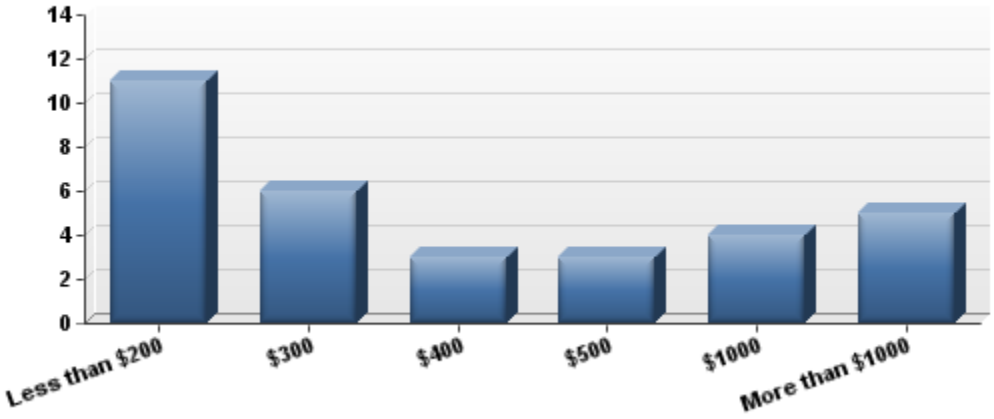
Q9. Energy Efficiency through Conservation: Less cooling in summer. There are many reasons why people don't set the thermostat to 76 degrees or warm in the summer. Please check all of the reasons below that apply to you



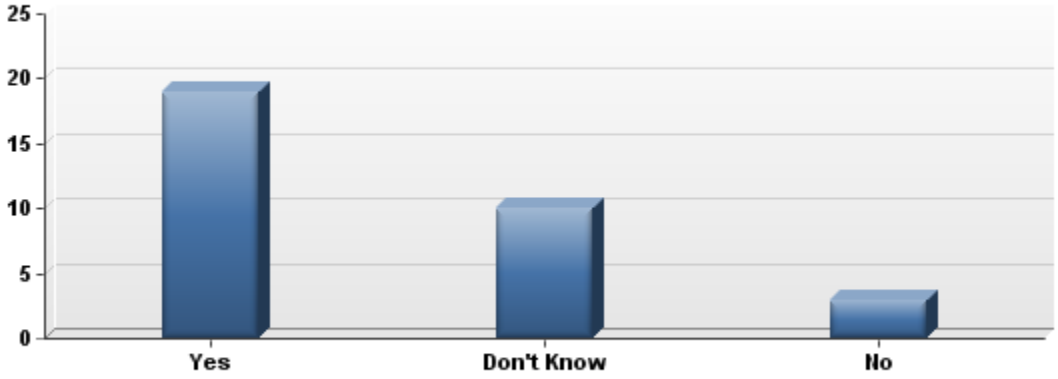
Q10. How much would you be willing to change your energy usage behavior to save 20% of your monthly utility bill?



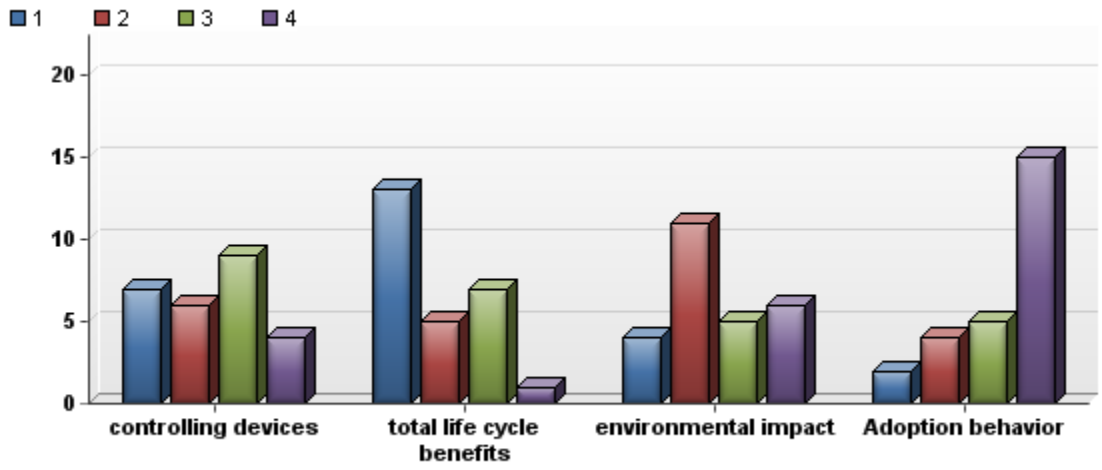
Q11. How much would you prefer to invest if you were to save $300 on your annual electricity bill?



Q12. If you could achieve cost savings of about 20% on your monthly electric bill with a smart-plug adapter which costs $250 (including Smart Adapter Control and Display Module), would you prefer to buy it instead of buying brand new smart-appliance which costs around $1000?



Q13. When you choose energy efficient devices and appliances, please rate the following features in the order of importance to you.



Q14. In choosing an energy efficient device or appliance, rate your preference for these characteristics in the order of importance. NOTE: for this question simply drag and drop the options into the preferred order from [1] - most important, [6] - least important.