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Demand Response Programs in the Greater Boston Area

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Demand Response Programs in the Greater Boston Area

An Interactive Qualifying Project Report:

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Eyuel Abebe

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James Chryssanthacopoulos

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Date: October 5, 2007

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Professor James Doyle

Professor Alexander Emanuel

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Acknowledgements

We would like to thank ISO New England for their time, help, and contributions to make this project possible. We would also like to thank Professors James Doyle and Alexander Emanuel for their time, effort, and guidance on this project.

Abstract

The goal of this IQP is to investigate the economic benefits and the societal impact of peak load reduction (PLR) devices. Such devices are meant to reduce the peak demand of electricity during days of unusually high demand, such as very hot summer days. They can be installed in order to connect and disconnect air conditioners, swimming pool pumps, water heaters, and refrigerators. In helping to significantly curb the amount of energy consumed they help to reduce pollution and to postpone the construction of more power plants.

The proliferation of PLR devices reduces the locational marginal price (LMP) of electric energy. An economic study is implemented that estimates the total savings obtained by using PLR devices by comparing the total cost of electricity on a high-demand day with the expected total cost after installation. The average effect a PLR device has on the indoor temperature of a typical house is also calculated. These two pieces of information are needed in order to inform prospective PLR-device users of the benefits and limitations of the device.

To test the public acceptability of Demand Response (DR) programs, a mail survey was distributed to a representative sample of 914 homeowners in the Greater Boston metropolitan area. The survey results indicated that there is a substantial amount of reluctance on the part of the homeowners to yield control of their air conditioners, with about 75% of respondents being slightly or strongly opposed to the idea. It was also learned that 15% of the homeowners will welcome PLR devices without requesting financial compensation while, sadly, 50% of the respondents expect an exaggerated $54 per month or more in order to participate in a DR program. The information gathered from the surveys will help regional transmission organizations (RTOs) determine the affordability of implementing DR programs in the future.

Executive Summary

The goal of this IQP is to investigate the economic benefits and the societal impact of peak load reduction (PLR) devices. Such devices are meant to reduce the peak demand of electricity during days of unusually high demand, such as very hot summer days. PLR devices can be installed in order to connect and disconnect air conditioners, swimming pool pumps, water heaters, and refrigerators. These devices have a relatively simple construction and can be easily mass produced. Effective energy reducers, they can help to significantly curb the amount of energy consumed, helping to postpone the construction of more power plants and reducing pollution.

A typical PLR device consists of a microprocessor-controlled contactor connected between a large load – like an air conditioner, pool pump, or compressor – and a 120/240 voltage AC supply. In the case of extreme demand the device receives a radio frequency (RF) input signal that triggers an on–off process referred to as *cycling*. The PLR device disconnects the load for a certain period followed by reconnection for another time interval. This cycling continues until another RF signal is received by the device, telling it to return to normal operation. The device also has the ability to detect so-called "brownout" conditions – when the peak or *rms* voltage decreases below a pre-established value – the detection of which also initiates cycling.

The proliferation of PLR devices will reduce the locational marginal price (LMP) of electric energy. The locational marginal price (LMP) is the cost of electricity at a given location in the electric grid, averaged over all nodes in New England. From the publicly available records of the Independent System Operator of New England (ISONE) both the demand (in megawatts) and the LMP (in dollars per megawatt-hours) for each day in summer 2006 were retrieved. From that data it was possible to implement an economics study to estimate the total savings obtained by using PLR devices by comparing the total cost of electricity on a high-demand day with the expected total cost after installation of the devices.

The effect a PLR device has on the indoor temperature of a typical house was also investigated by means of simulations. It was determined that the heat transfer in the house was governed by (1) the equivalent thermal time constant of the house (in hours) and (2) the power density of the air conditioner (in watts per meter-squared). The former parameter – assumed to lie somewhere between 5 and 20 hours – depends on the insulation of the walls and attic, the types of windows and doors in the house, and the weather conditions. Given a thermostat setting of 75°F, an outdoor temperature of 100°F, a time constant of 20 hours, a power density of 25 W/m^2, and an on–off time of 30 minutes, the increase in indoor temperature due to cycling was 12°F. The percent of energy saved due to the PLR device was thirty percent. This type of information was needed in order to inform prospective PLR-device users of the benefits and limitations of the PLR device.

To test the public acceptability of Demand Response (DR) programs, a mail survey was distributed to a representative sample of 914 homeowners in the Greater Boston metropolitan region. The goal was to determine how individual homeowners might react to offers to participate in various types of DR programs. This information will help regional transmission organizations (RTOs) or other load-serving entities determine the affordability of implementing DR programs in the future. The degree to which consumers might resist giving up full control of their air conditioning systems and the size of the financial incentive that would be required to overcome that resistance were two crucial pieces of information that had to be figured out by means of the survey.

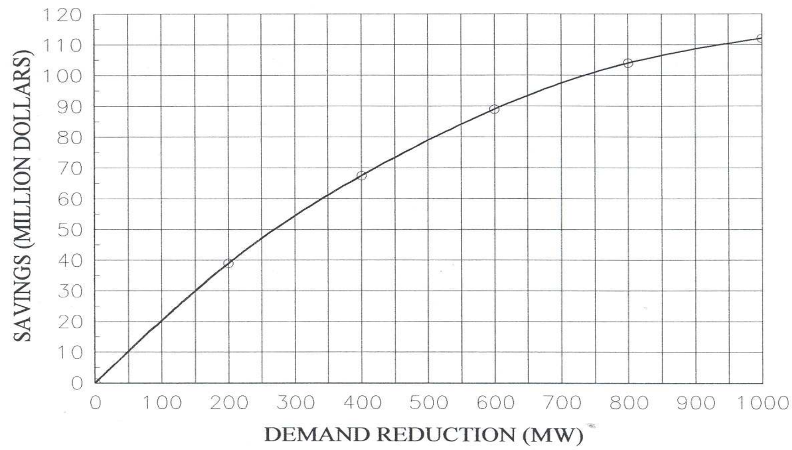
Of the 914 surveys sent out, 246 responses were received, a response rate of 26.7%. Among the topics covered on the survey were the consumers' past experiences with electricity interruptions and outages, their electricity and air-conditioning usage habits, their demographic information, and their attitudes toward the two hypothetical DR scenarios presented in the survey. The first hypothetical scenario was one in which consumers would be asked to adjust their thermostat on their own after receiving a request from the RTO or local utility. The second was one in which a PLR device would be installed and fully controlled by the RTO, local utility, or other controlling entity.

The survey results indicated a substantial amount of reluctance on the part of the homeowners to yield control of their air conditioners, with about 75% of respondents being slightly or strongly opposed to the idea. Moreover, twice as many respondents preferred the homeowner-controlled (scenario one) rather than the PLR-controlled (scenario two) DR program. For both scenarios about half of the respondents said that they require \$50 or more per month to participate; these individuals are likely not interested in participating in a DR program under any reasonable incentive scheme. Between 30 and 40% of respondents said they require a more modest amount ($15 to $45 per month). Lastly, between 10 and 15% of respondents, perhaps motivated by other reasons, indicated they would participate with no incentive at all.

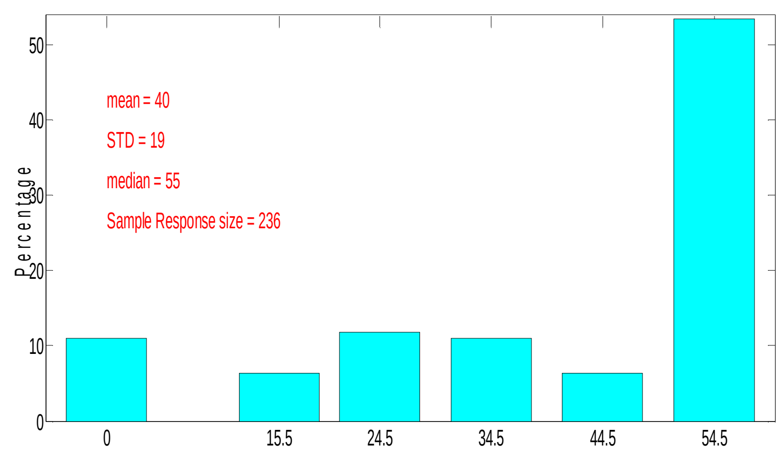
Using a multiple regression model two significant factors that predict the incentive required by consumers were identified: the summer thermostat temperature setting and the summer monthly electric bill of the consumers. As the thermostat setting increased, incentive required increased, all else being equal. It is likely that a higher summer thermostat setting indicated that the respondent is predisposed to conserve energy and, hence, is likely to have a favorable attitude toward DR programs. In addition, as the monthly bill increased, the incentive required increased, due in part because respondents might have calculated their incentive as a percentage of their monthly bill. Those who use more electricity, therefore, appear to be harder to recruit to a DR program.

Although only a small sample population responded to a survey describing two hypothetical DR scenarios, some general conclusions can be drawn. For one, there is substantial resistance to PLR devices among about half of the sample population. Secondly, a great majority of the sample population would require a substantial incentive to participate in a DR program. It also appears that the sample population does not have a good understanding of what size incentive is appropriate. A majority of the homeowners surveyed are not yet ready to accept PLR devices. An effective education program that promotes energy management and increases public knowledge about DR programs is therefore needed if PLR devices are to be successful in reducing peak demand.

The following figures summarize two results of significance: The first figure represents the total savings for New England in millions of dollars per day as a function of the demand reduction in megawatts. The second figure is a histogram that summarizes the amount of dollars per month required by homeowners as incentive to accept the installation of PLR devices. We learned that even a modest demand reduction of 200 megawatts translates into a significant $40 million savings. We also learned that 15% of the homeowners will welcome PLR devices without requesting financial compensation while, sadly, 50% of the respondents expect an exaggerated $54 per month or more in order to participate in a DR program.



Total savings (in millions of dollars) per day versus the demand reduction (in MW).



Financial incentive (in dollars per month) by percentage required by respondents for participation in PLR device-controlled DR program.

CHAPTER 1: Introduction

On August 2, 2006, the Independent System Operator (ISO) of New England, the company responsible for the reliability of the electric grid, recorded the highest consumption of electricity to date in New England. In fact, if 10% more energy had been consumed on this date, the consumption of energy would have exceeded the total maximum generation of New England at that time. ISO New England would have then had to cut off power to thousands of households and businesses, or else risk the onset of regional brownouts[1].

Every year peak energy consumption increases, and so the addition of new power plants and transmission lines cannot accommodate these peaks in a timely manner. Some devastating ramifications that peak days, like 08/02/2006, include the following: The increase in the overall price of electricity; increased pollution due to the fact that ISO New England is forced to use more environmentally inefficient generators; and an increase in the wear and tear of the transmission lines. One way to counteract these negative affects is by implementing programs called Demand Response. Demand Response programs reduce energy consumption during these peak times by giving financial incentives to residential, commercial, and industrial energy users in order to reduce energy usage during peak periods. This project focuses on the opinions of residential electricity consumers toward Demand Response.

Primarily, Demand Response programs serve to reduce peak energy consumption during hot days. In Figure 1.1, the system load, in megawatts, for the ISO control area is shown for two days: A typical summer day in 2006 (07/01/2006) and the very hot summer day in 2006 as already mentioned (08/02/2006)[2]. System load changes as time passes during the day, reaching a peak around midday when the heat is perhaps most intense. The peak of 08/02/2006 is significantly greater than that of 07/01/2006. Demand Response would work to the effect of lowering the peaks, particularly during very hot days when the ISO runs the risk of initiating widespread brownouts.

The price of energy is not constant either: The price changes as the system load changes (as time passes during the day), so one can speak of the price of energy at a particular time. In Figure 1.2, the locational marginal price (LMP), in dollars per megawatt-hour ($/MWh), for the ISO control area is shown as a function of load during the seven hottest days in summer 2006: July 17, 18, 27, 28, and August first through third[3].

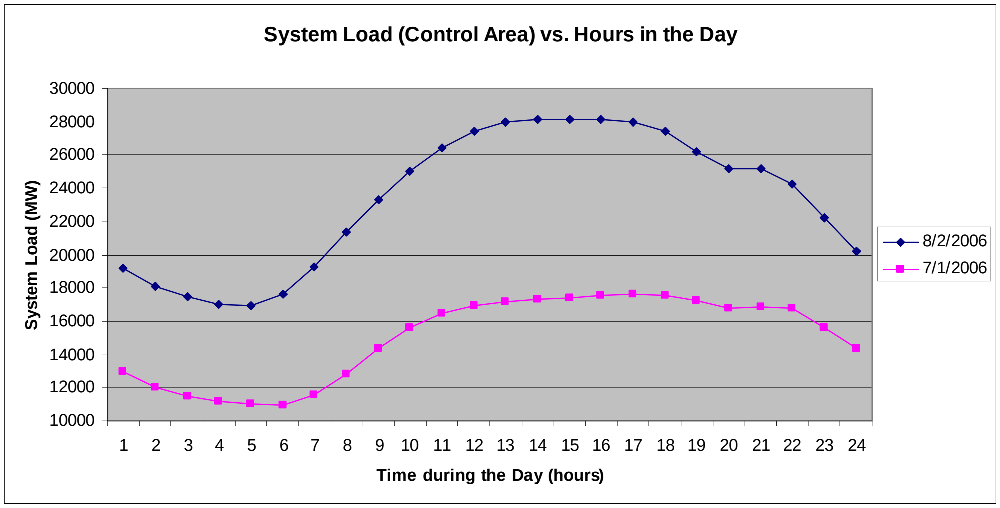


Figure 1.1: System load for the ISO control area on a typical and on a very hot summer day in 2006.

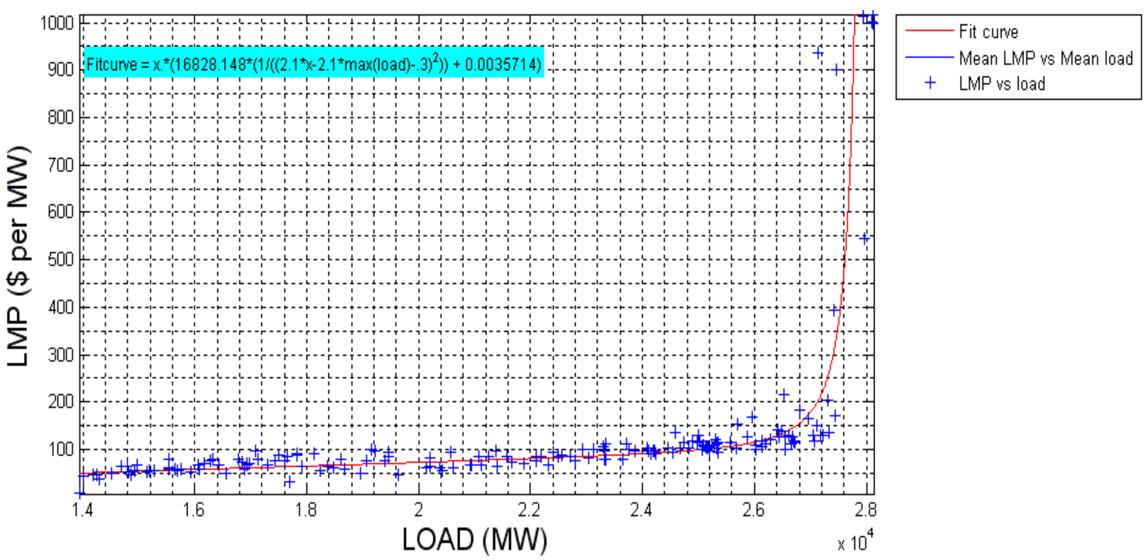


Figure 1.2: Locational marginal price for the seven hottest days in summer 2006.

Each blue point in Figure 1.2 represents one particular hour during one of the seven hottest days. Thus, 24 blue points are plotted for one day; this is done for each day. A red fit curve is applied to the data, as shown. The equation of the fit curve is in the upper left.

ISO New England divides New England into six regions based on energy consumption. This project takes a closer look at the Northeast Massachusetts (NEMA) region[4]. Although NEMA consumes approximately 26% of all the energy used by New England and has some of the oldest transmission lines and generators, the region has relatively few Demand Response programs currently in effect. For this reason, this project focuses exclusively on NEMA; more specifically, the Greater Boston area is the target audience for this project.

The IQP project consists of a mass mailing of 914 carefully-crafted surveys sent to Greater Boston residents to see what they think about different Demand Response programs, to find out what their biggest concerns about energy are, and to gauge what financial incentive Greater Boston residents would need in order to participate in these Demand Response programs.

CHAPTER 2: Summary of Demand Response

The 1973 oil crisis brought to light the danger of the United States' reliance on foreign oil as a means of providing energy, a reliance that threatened the stability of the country's economy and social wellbeing. Thus, in 1978, the United States Congress passed the National Energy Conservation Policy Act (NECPA), under which provisions were made to ensure that utilities maintained proper energy levels. This worked to the effect of conserving energy, as well as decreasing the demand in energy. However, several problems arose when the practical problem of energy conservation was considered more fully.

1. The production of electricity in the United States heavily depends on the use of nonrenewable resources. Figure 2.1 depicts the percentage of electricity generated by various renewable and nonrenewable energy sources, revealing that most electricity production comes from nonrenewable resources. Of 4,055 billion kWh of energy produced annually, 63% is produced by electric utility plants, while the remaining 37%, from combined heat and power plants and independent-power producers[5]. The nation's heavy dependence on nonrenewable resources in the production of electricity makes achieving a constant electricity supply problematic.
2. Moreover, the uninhibited use of nonrenewable resources pollutes the environment. In order to guarantee reliability in the production of electricity and to prevent further damage to the environment, it is imperative therefore that a system be devised that leads to the efficient use and cleaner production of electricity.

In previous decades, the electricity sector in the United States created competition among electricity-providing companies in order to raise the efficiency of electricity production, reduce costs, and provide the customers with choices. Unfortunately, due to the continued growth in the use of electricity, the exploitation of the competitive market is no longer sufficient in guaranteeing electricity efficiency[6]. Figure 2.2 gives some indication as to the extent of this continued growth, showing the annual electricity sales from 1980 to 2005 among the commercial, residential, and industrial sectors. Given this data, the electricity sales from 2005 to 2030 are projected to increase due to a heightened demand[7].

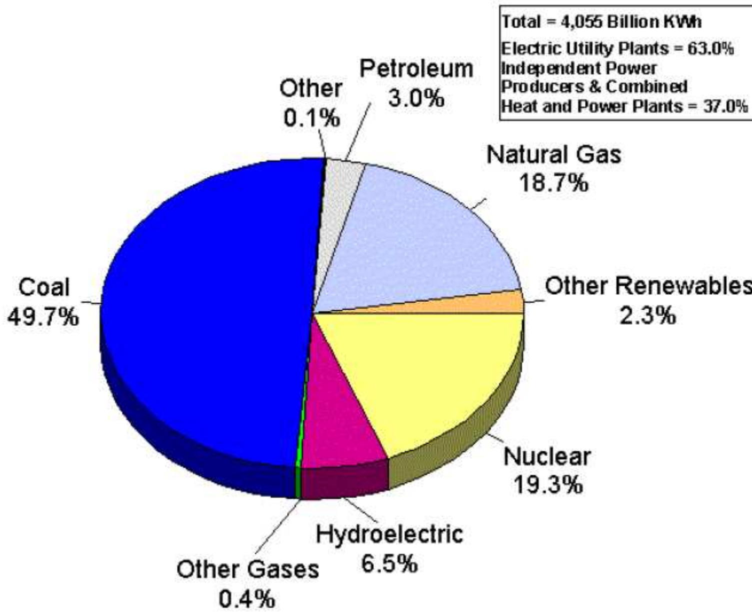


Figure 2.1: U.S. electrical power industry net generation by percentage[8].

Because of the conditions aforementioned, the Energy Demand Management Program, or Demand Side Management (DSM), was introduced in 1978. The DSM urged customers to use less electric energy while at the same time met their demand. To this end, the DSM gave customers incentives to decrease their energy use. Furthermore, those companies willing to employ energy-saving approaches as prescribed by the DSM were subsidized by the government. Such energy-saving approaches helped to avoid incidents of peak demand, during which electrical systems were overwhelmed with demand. The DSM did not necessarily reduce the total energy consumed; nonetheless, it helped to eliminate the need for creating additional power plants, the creation of which costs a great deal of money and the operation of which negatively impacts the environment[9]. *The process of implementing such DSM-created initiatives is referred to as Demand Response (DR).*

2.1 *Demand Response*

The United States Demand Response Coordinating Committee defines Demand Response as:

"Providing electricity customers in both retail and wholesale electricity markets with a choice whereby they can respond to dynamic or time-based prices or other types of incentives by reducing and/or shifting usage, particularly during peak periods such that these demand modifications can address issues such as pricing, reliability, emergency response, and infrastructure planning, operation, and deferral"[10].

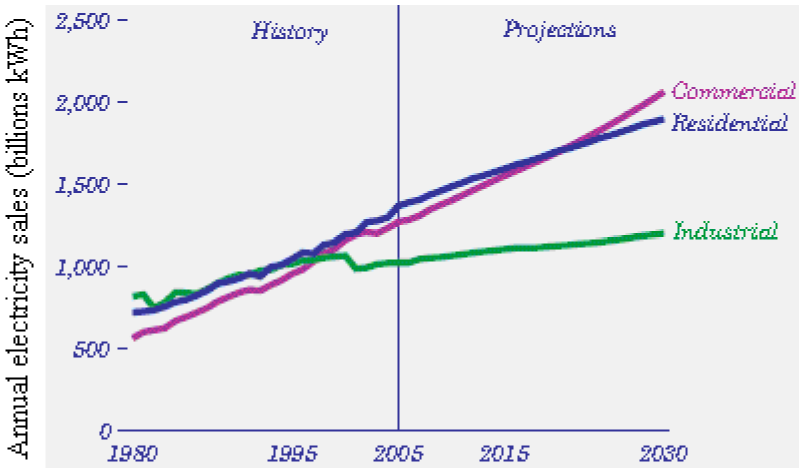


Figure 2.2: Annual electricity sales, in billions kWh, from 1980 to 2030[11].

Demand Response (DR) uses several methods to manage the demand from customers in response to the supply conditions. It is applied in different areas and in different ways to achieve efficiency in delivering power, making use of market resources, public policies, and market forces in achieving its objectives. DR resources could be deployed, depending on the situation, over a short period of time or over an extended period. Either way, this deployment can be done via interruption or circulation of power in response to peak demands or even at the customers' request as motivated by market conditions (such as high prices). Among other things, DR serves to regulate power markets through price-responsive methods (e.g., providing customers with incentives). It also moderates excessive energy use through retail pricing; lowers poor delivery by improving power jamming; and reduces long-term demand in a cost-effective and environmentally-responsible manner. These are discussed in more detail later in the report.

Dimensions of Demand Response

Demand Response attends to a variety of socioeconomic problems. The majority of DR focuses on a few specific areas[12]:

- **Electricity Demand –** DR is designed to meet the growing electricity demand as projected in Figure 2.2. Among the current DR resources in the United States aimed at meeting this demand include[13]:
    - *Real-time pricing tariffs*, in which the customer is charged by the hour and is therefore given the option of lowering consumption during times in which electricity is expensive. The customer is charged according to the wholesale market price for electricity.
    - *Volunteer Demand Response,* in which the customer is paid to decrease consumption upon request by system operators. There is, however, no contract under which the customer is obligated to decrease consumption. That is, he is under no contractual obligation to do so.
    - *Direct load control,* in which the customer's appliances are remotely cycled during times of peak demand. Cycling is the process by which a load is turned on and off for a given period of time. A load is said to be remotely cycled if the cycling is controlled by means of a device, the operation of which is prescribed by a company.
- **Electricity Pricing –** DR uses market-based pricing depending upon the frequency of peak demand and the availability of supply. Two studies, conducted by Carnegie Mellon University in 2006, have shown that a small decrease in peak demand will reduce electricity prices at the system level: "In a load-shifting simulation . . . half of all possible customer savings can be obtained by shifting only 1.7% of all MWh to another time of day, indicating that small demand-side changes can make a large difference." In a real-time pricing situation, a 1.7% shift in peak demand could, for example, result in savings as high as 4.3%, depending on the producer's surplus[14].

In Figure 2.3, the price of electricity supplied, plotted against the quantity of electricity produced, is monotonically increasing. The demand for electricity is price-inelastic – that is, regardless of the price, the quantity of electricity demanded remains the same. This is represented by a vertical demand curve. The point at which the supply and demand curves intersect is called the equilibrium point, representing the quantity and price at which the electricity should be produced and sold, respectively. As DR is implemented, the demand curve is shifted to the left, thereby shifting the equilibrium point down and to the left. In turn, the ideal price and quantity of electricity are decreased. Electricity becomes cheaper for the customer and less of it is produced[15].

- **Cost-effectiveness and Environment –** DR resources reduce long-term demand, thus lowering the stress on electrical systems. DR also has the potential of providing environmental benefits through the increased use of cleaner supply resources. Serious risks toward the environment are avoided, while at the same time investments into new electrical systems do not have to be made. DR guarantees less net environmental pollution and cleaner air over time.

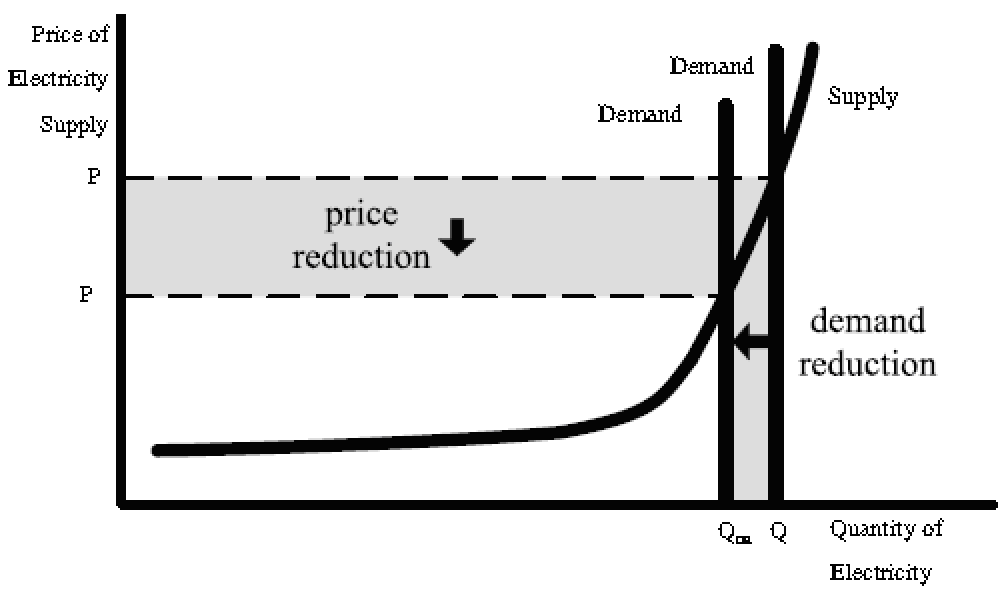


Figure 2.3: The quantity and price of electricity reduction with shift in demand[16].

Due to its importance, DR is put into service in many locations across the United States. This report, however, focuses on the application of DR in New England, specifically the Greater Boston region. The current effects of Demand Response, specifically in the residential sector, will be analyzed.

2.2 *Load Cycling*

Load cycling is the process by which air conditioners, pumps, compressors, and electric heaters are turned off and on. When the air conditioning, for example, is turned off, the temperature of the house will rise. When the air conditioning is turned back on, the temperature begins to decrease again. This process of turning off and on the air conditioning proceeds for some period of time, during which the net energy absorbed by the end-user decreases. The rate of temperature increase when the air conditioning is turned off is directly dependent on the quality of insulation in the house: In a poorly-insulated house, the rise in temperature may be significant since the house cannot retain the cool air well; in a well-insulated house, on the other hand, the rise in temperature is expected to be less than in a poorly-insulated house for the reason that a well-insulated house has a larger thermal time constant (better thermal insulation). The same argument holds if the air conditioning does not cool the entire house, but only a room, as in the case of a window unit.

A simulation was conducted to test the extent of the temperature variation caused by cycling in both types of houses – namely, the poorly-insulated house and the well-insulated house. In both houses, the thermostat setting was adjusted to 75°F and similarly for both the outdoor temperature was 100°F, a hot summer day temperature. The air conditioning was cycled off and on. The amount of time for which the air conditioning was turned off, T_{OFF}, equaled the amount of time for which it was turned on, T_{ON}, and as the simulation continued, T_{OFF} and T_{ON} were increased. For example, initially the air conditioning was turned on for 10 minutes and then off for 10 minutes; that is, $T_{OFF} = T_{ON} = 10$ minutes. After this, the on/off time was then increased to 20 minutes, followed by 30 minutes at the end of the simulation. In total, therefore, there were three intervals of cycling, each representing an on/off period.

For each interval of cycling the air conditioning off and on, the minimum and maximum temperatures reached in the house were obtained. These were aptly termed the lower and upper limits, respectively, and represented the extreme temperatures between which all the temperatures reached during the interval lied. In both houses, moreover, three air conditioners of different power were used – one was a 5 kBTU air conditioner, another 10 kBTU, and still another 20 kBTU. The extreme temperatures for each air conditioner were recorded.

These results are summarized in Figure 2.4 and Figure 2.5, representing the poorly-insulated house and the well-insulated house, respectively. Both graphs plot the extreme temperatures reached by the house, with the use of each of the three air conditioners mentioned above, as a function of the on/off time of the cycling. As such, several curves are presented in each Figure.

To be more explicit, in Figure 2.4, for each interval the minimum temperature reached with the use of the 10 kBTU air conditioner is the same as that reached with the use of the 20 kBTU air conditioner, and moreover this temperature remains constant throughout. With the 5 kBTU air conditioner, on the other hand, the minimum temperature increases as the on/off time increases. These lower-limit curves are depicted as dashed lines. Three solid-lined curves also exist, representing the upper-limit curves for the three air conditioners. All three curves are increasing, with the most noticeable increase seen in the 5 kBTU upper-limit curve. Figure 2.5 is similar, except in this case the 5, 10, and 20 kBTU air conditioners all share the same horizontal line lower-limit curve.

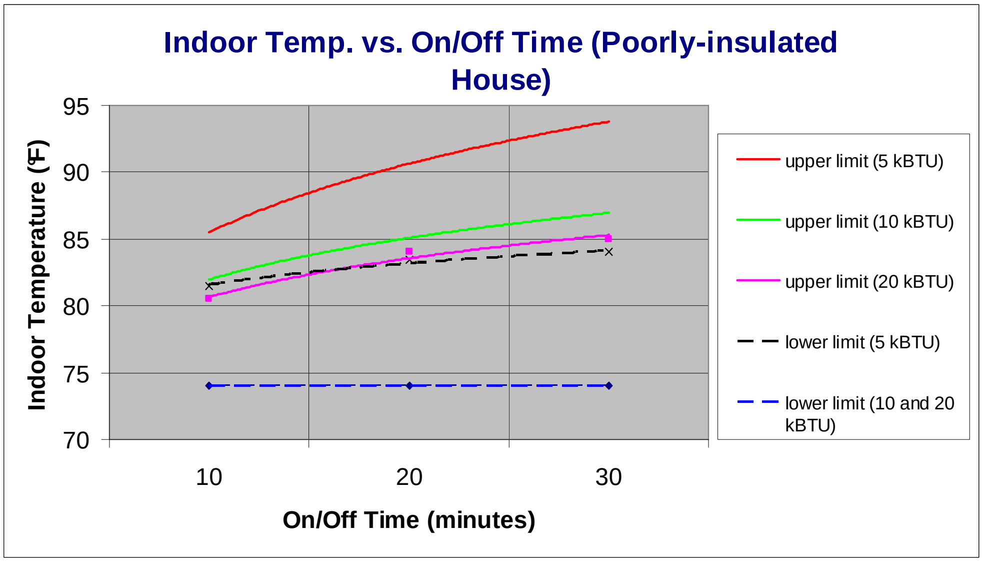


Figure 2.4: Poorly-insulated House – Extreme temperature versus cycling time.

In both Figures, one notices, as expected, a greater maximum temperature across all air-conditioning types as the on/off time increases from 10 to 20 to 30 minutes. Upon comparison of Figure 2.4 with Figure 2.5, moreover, one's intuition is confirmed: One's intuition states that the temperature variation in a well-insulated house ought to be smaller than that in a poorly-insulated house, and indeed that is what happens. As a final observation, it is interesting to note that the greatest rise in temperature is approximately 10°F, when the 5 kBTU air conditioner is used in the poorly-insulated house. This is the maximum recorded temperature variation among the data.

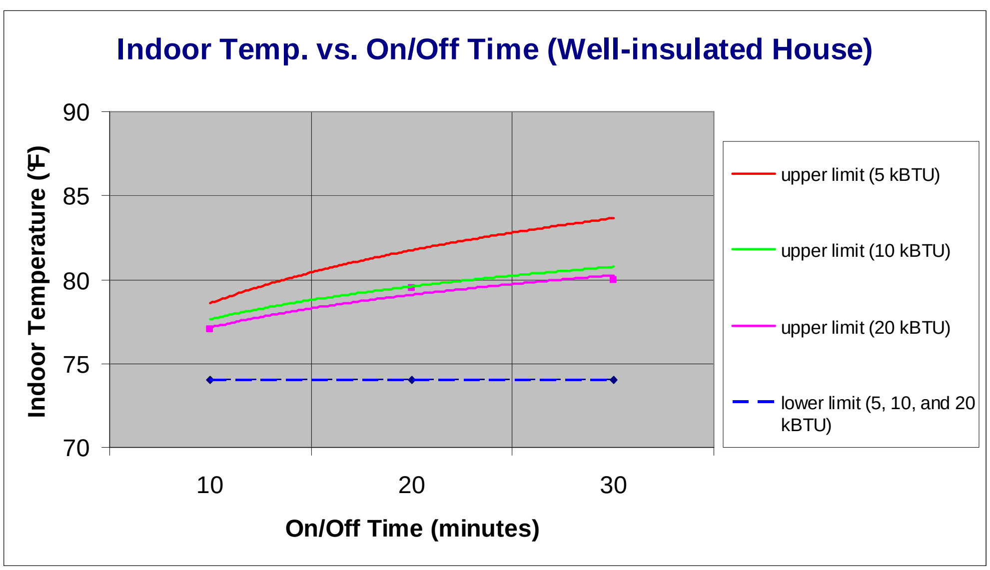


Figure 2.5: Well-insulated House – Extreme temperature versus cycling time.

Previously, the thermostat setting was adjusted to 75°F and the extreme temperatures reached in the house were recorded as the on/off time of cycling increased. This was done for three different air conditioners (5, 10, and 20 kBTU). And that, in total, was done for two different houses (poorly- and well-insulated houses). Now, however, a 5 kBTU air conditioner was used in a poorly-insulated house, the outdoor temperature still 100°F. The on/off time of the cycling remained fixed at thirty minutes: $T_{OFF} = T_{ON} = 30$ minutes. This cycling in which the air conditioning was turned off for thirty minutes and then on for thirty minutes continued as time went by, and the temperature of the house was also measured as time progressed. This was done for three settings of the thermostat – 75°, 80°, and 85°F.

Figure 2.6 summarizes the results of the data collection. Three curves are presented in the Figure: One represents the 75°F setting, another the 80°F setting, and still another the 85°F setting. One notices from the Figure that the first curve experiences a maximum temperature variation of 11°F, the second a variation of 9°F, and the last a variation of 5°F. Moreover, the temperature is seen to fluctuate sharply between maximum and minimum values for every thermostat setting. It is interesting to note that for the 85°F setting, the data oscillates on average 2°F within a time span of up to thirty minutes on the minima of the curve representing that data. The other two curves (for the 75°F and 80°F settings) do not demonstrate this behavior. All of them, however, display a fairly neat periodic motion, with only slight anomalies in the curves for early time.

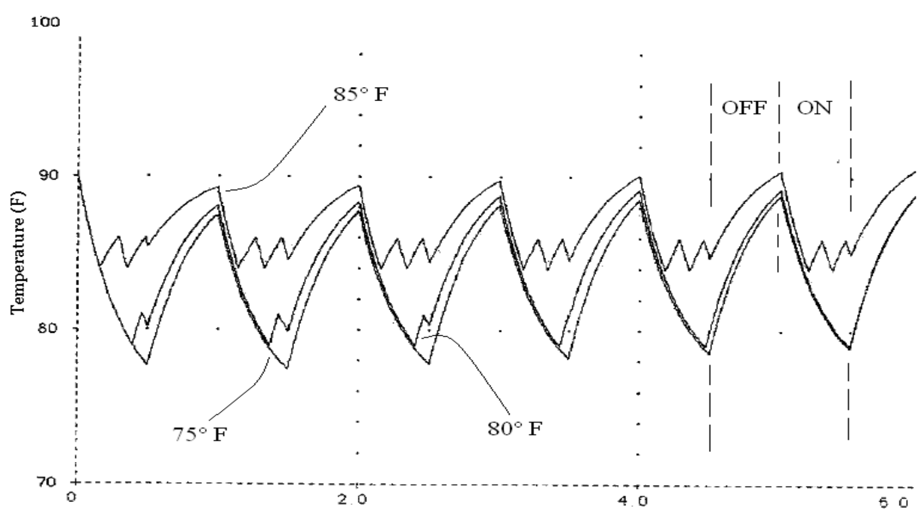


Figure 2.6: Temperature versus time for three thermostat settings.

2.3 *The Need for Application of Demand Response in New England*

In recent years, the demand for electricity in New England has increased and is still continuing to grow at an alarming rate. The Independent System Operator of New England (ISONE) believes that ". . . there is a risk there will be insufficient availability from gas-fired generating units to meet peak electrical demands"[17]. Figure 2.7 from ISONE displays the seasonal peak load (MW) during the summer and winter on an annual basis from 1980 to 2007[18]. As such, two curves appear in Figure 2.7 – one for the summer peaks, the other for the winter peaks. It must be noted that these are estimated seasonal peaks calculated assuming the weather at average peak-day conditions (weather normalized)[19]. Between the years 1980 and 1989, the biggest peak loads of the year all occurred during the winter: The winter peaks were greater than the summer peaks for those years. However, in recent years, the summer loads have become of greater magnitude, exceeding winter loads. Indeed, the summer peaks have been steadily increasing, the entire summer peak curve monotonically increasing. Granted, the winter peaks continue to increase, as well, but at a significantly slower rate; that is, the slope of the summer curve is greater than that of the winter curve in recent years. In contrast to the summer curve, moreover, the winter curve is not monotonic: There are relative high and low points of peak load between 1980 and 2007. Unless something is done to control the use of electricity, these trends, in which the peaks increase unabated, will continue in the future.

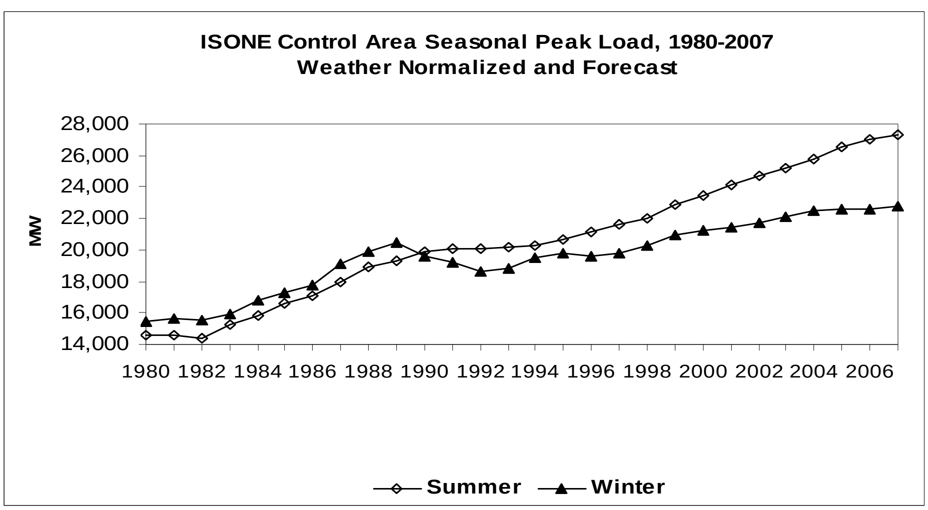


Figure 2.7: ISONE control area seasonal peak load from 1980 to 2007[20].

Figure 2.8 provides a means of further analyzing the history of peak demand in New England. In this figure, New England peak demand (MW) is again plotted, but this time on a monthly basis (January–December). Two continuous curves are represented on the same graph – one for the year 2004, the other for 2005. Upon analysis, Figure 2.8 is found to be in agreement with the conclusions obtained from Figure 2.7. In both 2004 and 2005, for example, the peak load season occurred during the summer months (primarily June to September), while the winter months experienced a visibly smaller peak load. Furthermore, within just a span of one year (2004 to 2005), the maximum value of the peak loads increased significantly during the summer season. In contrast, little change in peak loads from year-to-year is observed during the winter season. As Figure 2.7 displays, so now Figure 2.8 confirms, the dire need to control summer energy use.

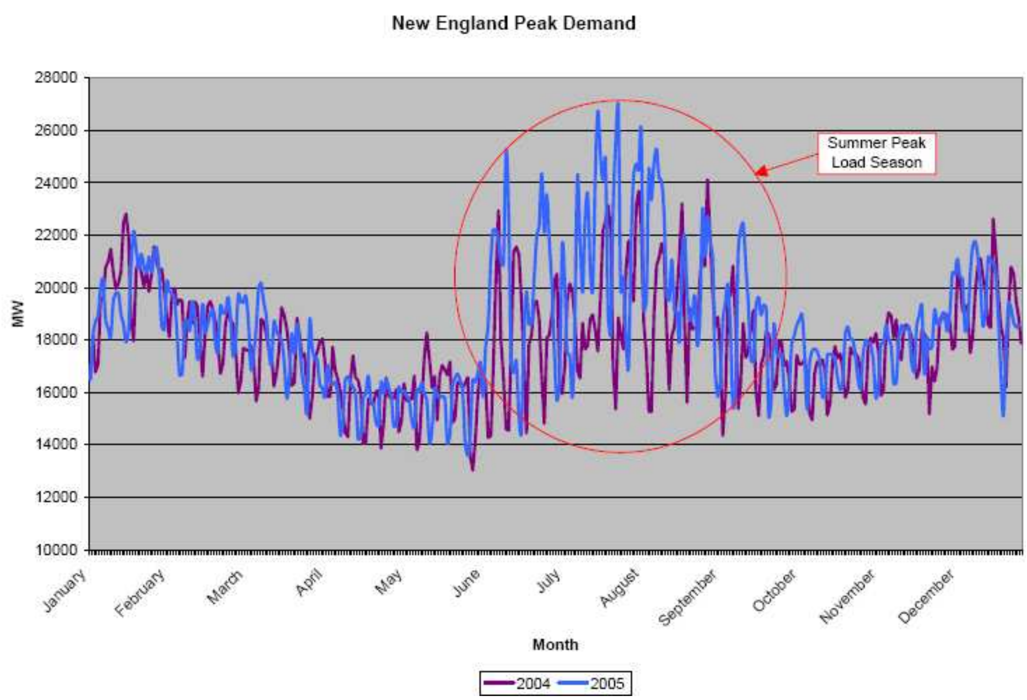


Figure 2.8: New England peak demand from January to December, 2004–2005.

A question one might ask is why has demand in recent years been greater in the summer than in the winter, that is, why has demand, in a sense, shifted from winter to summer. One might indeed point to the installation – and hence the use – of more and more heavy-duty electrical equipment during the summer months to explain this perceived increase in demand. In order to comfortably withstand the temperatures during the summer, many customers choose to circulate the air in their residences with air conditioners; the installation of swimming pools, moreover, is another luxury present in combating the summer heat. The use of these and other heavy-duty electrical equipment requires a great deal of power, significantly more than is required during the winter months. As the population increases, too, the massive amounts of power that need to be supplied in the aggregate have increased. Considering these facts, combined with the relative ease with which households can now afford heavy-duty electric equipment, the growth of peak loads during the summer months becomes very explicable.

In New England alone, the use of air conditioners has increased in a short period of time among residential customers. Figure 2.9 supplies some interesting results[21]. In it, the use of air-conditioning equipment among households is plotted in histogram form for the years 1981, 1987, and 1997. The Figure analyzes two types of air-conditioning equipment: Central air-conditioning equipment and window/wall air-conditioning. The use of air-conditioning equipment among households, for both types of air-conditioning, is classified according to the following categories which describe how often they used it: All Summer Long, Quite a Bit, Few Days or Nights, Not Used, and Don't Know/Missing. For both air-conditioning types, three histograms are plotted, one for each year (1981, 1987, and 1997), each representing the percentage breakdown of the households into each of the five categories.

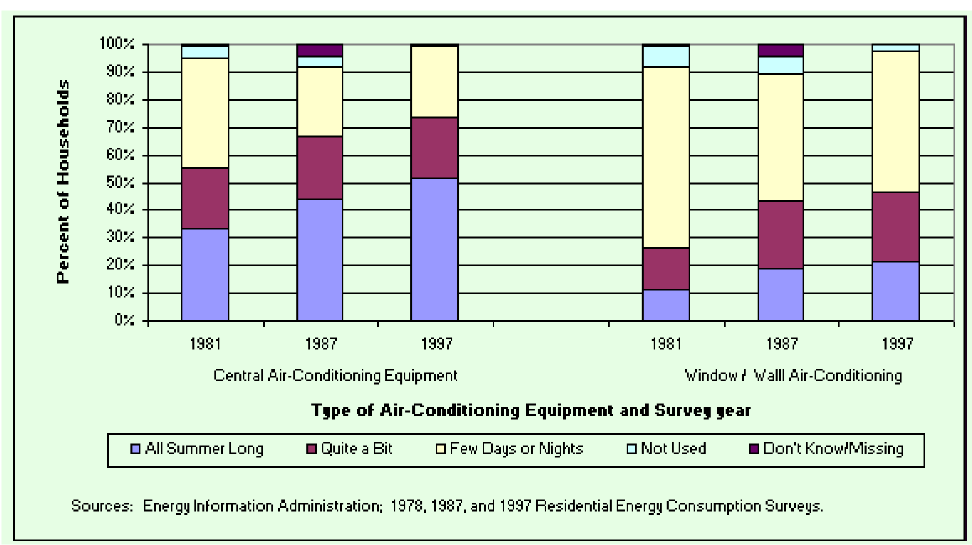


Figure 2.9: Percentage use of households during 1981, 1987, and 1997 for central and window/wall air-conditioning[22].

Several pieces of information are gathered from Figure 2.9. Firstly, it shows an approximate increase of 10% between 1981 and 1987, and a total of 19% increase between 1981 and 1997 for central air-conditioners. Secondly, for window/wall air-conditioners, there is about an 8% increase in use between the years 1981 and 1987; between 1987 and 1997, an increase of only 2% is observed, resulting in a net increase of 10% between 1981 and 1997. This serves to show, to some extent, how air-conditioning use has increased among residential customers.

The above arguments reveal the need for the application of DR programs in New England. As has been discussed, DR is designed to meet growing electricity demand: Incidents of peak demand would be avoided and long-term demand reduced. In this sense, DR becomes a viable means to an end when considering the increasing demand for electricity in New England, particularly during the summer, and the pressing need to restrain it. On top of this, DR helps to eliminate the need for creating additional power plants, ultimately reducing long-term costs, as well as prevents to a large degree further damage to the environment through the decreased consumption of fuel. The cost of electricity is also decreased, leading to monetary savings on the customer end.

2.4 *Purpose and Outline of the Report*

This report is concerned with DR programs that are currently being deployed in New England. Due to the growing interest in regulating electricity efficiently during the summer months, the reach of the report only extends so far as the application of DR during the summer. Understanding, furthermore, that a great portion of energy consumption during the summer is attributed to air-conditioning use, the work is focused on those types of DR aimed at controlling such use. Research into the currently available DR options in New England suggests three options that could be appealing to customers. The following summarizes these three options:

- **Option 1 –** An electric device is retrofitted with a voltage-sensing unit. When brownout conditions are observed, that is, when the voltage level falls below a certain threshold, the device is automatically disconnected.
- **Option 2 –** The disconnection of heavy-duty electric equipment, such as air conditioners and swimming-pool pumps, is remotely controlled. When high

demand conditions exist, loads are respectively disconnected and reconnected using a remote wireless controller operated by the electric utility or a designated company. The process of disconnection does not happen precisely when high demand conditions are met. Instead, there is a delay between the time the conditions are met and the time of disconnection. Different wireless controllers are programmed with different delay times. Thus, the disconnection of electric equipment due to these wireless controllers does not happen all at one time.

To duly compensate the customer, an incentive package may be offered by the electric utility in which substantial savings on energy costs are promised.

- **Option 3 –** A third option is to allow the residents themselves to take control of their energy consumption. To this end, the end-user would have a high demand sensor in an accessible location which would alert the end-user when a high demand period exists. The customer has the option of disconnecting the air conditioning or of increasing the thermostat setting.

Drawing upon the information acquired in this research, the first major task was to design and test a survey in a methodical manner so as to determine public opinion in regards to DR. The target audience were homeowners in the Greater Boston region, or more generally those who pay an electricity bill in that region, especially those households comprised of several members (such as families), as opposed to single-inhabitant occupancies. The survey was sent out to approximately 900 residential customers in the Greater Boston region.

It is to be mentioned beforehand that, although the proposed DR options have been implemented in the past in other regions, this approach has not yet been applied in the Greater Boston region. For this reason, the report is concerned with the potential public acceptance of DR in this region. **CHAPTER 3: Summary of Research on Demand Response Companies** expounds in detail the application of DR by other companies. Moreover, the survey was implemented keeping in mind the fact that the eventual underlying purpose of the survey was to evaluate the acceptance of proposed DR options among customers in the Greater Boston region. **CHAPTER 4: Survey Methodology** describes in some detail the reasons behind choosing to do a survey, as well as the many factors that must be taken into account when conducting an effective survey representative of the population.

The survey is a clear presentation of the benefits of DR, as well as of any obligations required of DR on the part of the customer. **CHAPTER 5: The Survey** works to the effect of describing in detail the rationale beyond every question asked in the survey, as well as lists some useful interrelationships between several variables. Predictions as to how these variables relate to each other are made within the pages of this chapter.

CHAPTER 6: Data Analysis and Discussion, moreover, explores into great detail the statistical analysis of the data collected from the surveys. Among the several topics of this chapter are the analysis of the demographical descriptions of the respondents and the regression plots for thirteen supposed correlations between variables present in the survey. **CHAPTER 7: Economic Model** presents a brief economic model, while **CHAPTER 8: Conclusion** briefly summarizes the final results of the entire report, particularly those obtained in the previous chapter.

Summarizing, the goals of this Interactive Qualifying Project (IQP) are the following:

1. To explore the proposed DR programs seeking to reduce peak demand during hot summer days,
2. To evaluate the acceptance of DR among customers in the Greater Boston region,
3. To determine the attitude of the community toward the reduction of peak demand,
4. To discover the willingness of those customers to participate in such programs,
5. To discover what would motivate customers to participate in DR programs, and
6. To estimate the benefits that result from the implementation of such programs.

CHAPTER 3: Summary of Research on Demand Response Companies

Demand Response (DR) technology is by no means new. Comverge Technologies and Honeywell are two companies that have employed DR programs in the past and that continue to do so. This chapter proceeds at length to detail information about these two companies regarding the implementation of their respective DR programs.

3.1 *Comverge Technologies*

Comverge Technologies is a leading provider of innovative energy intelligence and infrastructure for energy suppliers and their industrial, commercial, and residential customers. It accomplishes these tasks through the development and deployment of load management and control systems, backup capacity, and real-time energy data collection and management, as well as other initiatives to reduce energy costs and improve distribution system reliability[23].

One of the most successful programs in Comverge's history has been the CoolSentry program. The CoolSentry program is an innovative approach developed by Comverge Technologies as an emergency DR mechanism. It is essentially a quick response initiative that provides a robust tool to help forestall power emergencies in real-time, particularly during critical, hot summer weekday afternoons. The program is an entirely voluntary service that contributes to a more efficient and reliable electricity grid.

The CoolSentry program was initially introduced in Fairfield Connecticut on July 13, 2004 in direct response to the growing electricity peak demand concerns in Southwest Connecticut. Figure 3.1 depicts the regions in Southwest CT with the highest electricity demand and hence targets for Comverge's DR mechanisms – Fairfield County, New Haven County, Litchfield County, and Hartford County[24].

The concept behind the CoolSentry program is simple: When a severe shortage of electricity supply in Southwest Connecticut occurs, Comverge is notified of the situation by the regional power system operator, namely ISO New England. Comverge is then able to reduce electricity demand within minutes by sending paging signals that activate small, outdoor CoolSentry devices connected to central air-conditioning or heat-pump compressors. Once the paging signal is received, participants' compressors are cycled off in that the CoolSentry devices interrupt the flow of electricity to the compressors on the customers' air conditioner or heat pump. This interruption occurs up to 15 minutes each half hour, affecting only the flow of electricity to the compressors. In this way, the demand for energy is reduced and therefore the cost of electricity is kept sufficiently stable.

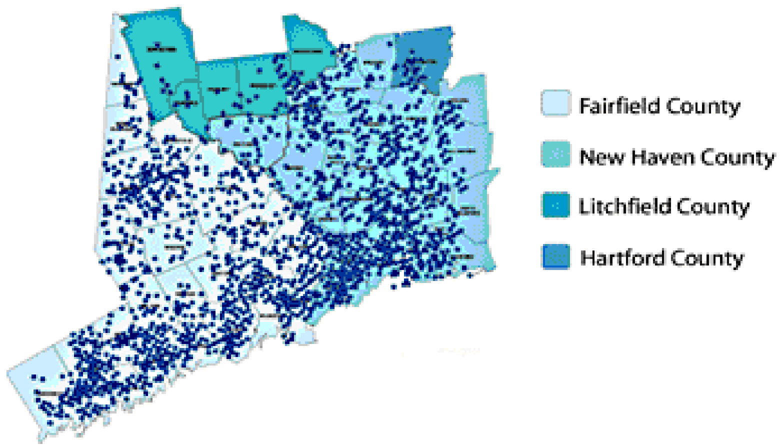


Figure 3.1: Regions in Southwest CT with the highest electricity demand[25].

In understanding the mechanics of the device itself, one notes that the CoolSentry device is a wireless receiver typically connected to the customer's outdoor central air-conditioning units via a low-voltage (24 V) wire that goes from the thermostat to the air conditioner's compressor. When the signal is sent to activate all the devices in the area in the event of an electricity shortage as previously described, the central air-conditioning units are temporarily turned on and off until the power emergency is resolved. Figure 3.2 depicts what these devices, installed near existing outdoor air-conditioning units, look like[26].

The device turns off the compressor just as if the customer had moved the thermostat setting to a high enough temperature so as to turn the air conditioner off for 15 minutes. Thus, the CoolSentry device is not only a receiver that receives the control signal from Comverge, but also one that does the control. The extent of these devices' control is significant in Southwest Connecticut, noting specifically how Figure 3.3 shows the widespread availability of these CoolSentry devices in the region[27].

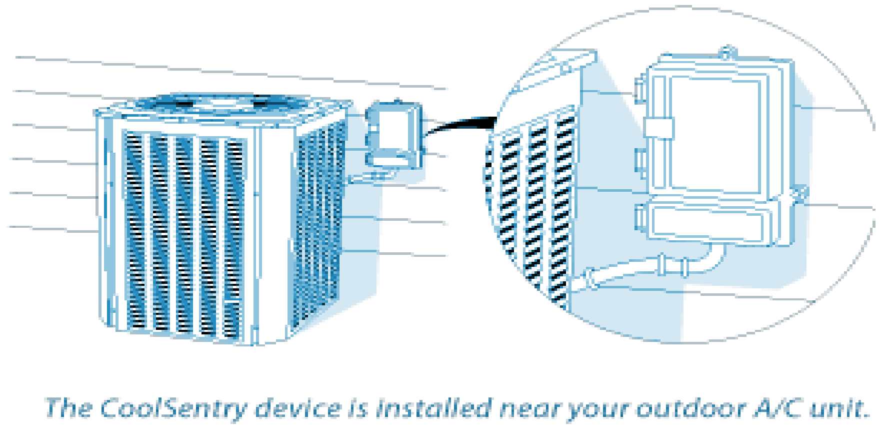


Figure 3.2: CoolSentry device implemented by Comverge Technologies[28].

Small businesses and residential customers who actually participate in the program are also offered an annual incentive package. This consists of a $20 thank-you bonus check or a CoolSentry Green Tag Certificate for residential customers. The Green Tag Certificate is a guaranteed purchase of clean renewable energy, including wind or solar power. Similarly, commercial customers receive a $50 thank-you check on an annual basis in addition to $30 for each mechanism installed on an outdoor central air-conditioning unit.

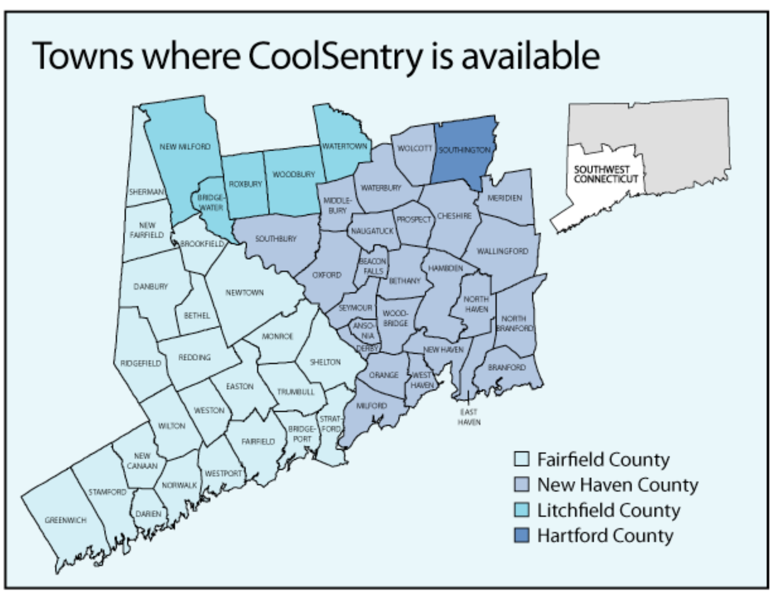


Figure 3.3: Regions in Southwest CT with CoolSentry devices[29].

Notwithstanding their already significant contribution to DR programs, it is expected that as enrollment in the program grows, CoolSentry will become increasingly more effective in helping with local power emergencies.

3.2 *Honeywell*

As an overview into a large company, Honeywell has more than 115 years of experience in building and optimizing facilities across the globe. Among the many services Honeywell provides, notable among them are its security solutions, maintenance upgrade and renovation services, and energy solutions. Honeywell also installs, integrates, and maintains the systems that keep facilities productive and energy-efficient.

Understanding the great need to alleviate the effects caused by peak-load situations and in an attempt to provide assistance to utility companies during crucial periods, Honeywell has developed a selection of demand reduction programs which they have made accessible to such companies. Their utility clients include Con Edison, City of Houston, and Reliant Energy, among others. Their clients control a total of 600 MW of load through the installation of over 600,000 load management devices controlling not only the use of central air-conditioning units, but also of other load types such as electric hot water, heat pumps, and pool pumps. Their programs are both residential and commercial in nature, impacting hundreds of thousands of consumers[30].

In general, Honeywell is also in the business of providing energy management solutions with the intent of delivering savings and improving efficiencies, one of several services that sets Honeywell apart from other companies. Their "Energy Affordability Programs," for example, promote consumer education and, in their implementation of energy-saving measures, have aided thousands of customers in using energy more wisely[31]. In the way of commercial programs, moreover, Honeywell offers what they call flexible and customized energy management services; through them they provide temperature controls and automation systems, install energy-efficient equipment, and help companies track their energy consumption, as well as report and analyze energy demand[32].

Moreover, Honeywell offers its customers an energy performance contract that guarantees energy savings. They begin by collaborating with the customer and its own staff so as to define the requirements of the contract. Then they conduct a thorough audit of the customer's utility operations – electrical, lighting, heating, cooling, and water – in order to determine how much money the customer can potentially save. Based on this information, Honeywell designs and implements a program to improve the energy efficiency of the customer's organization. Finally, Honeywell leverages the money saved on energy and operating costs to pay for building improvements. If the new energy systems fail to reduce costs as required in the contract, Honeywell makes up the difference of the loss. Any savings above the guarantee, however, are for the customer to keep[33].

CHAPTER 4: Survey Methodology

The main goal of this project was to determine the response of homeowners in the Greater Boston area to different demand response programs pertaining to the use of air conditioning during high demand times. An important objective of this survey addresses the incentive necessary to generate homeowners' participation. The initial proposal made to ISO New England, accepted in September 2006, was a twofold approach using focus groups and a mass mail survey.

The focus group would consist of approximately 10 to 20 randomly-selected people who live in the Greater Boston Area. There would also be several undergraduate students working on the project that would be leading the focus group. The focus groups would provide a good base of knowledge that would include what incentives or factors motivate people to participate in future demand response programs. This knowledge would be used to design a survey that would be more attuned to the target audience and hopefully raise response rates. However, the focus group idea was later dropped because of two main reasons:

1. There are many demand response programs active right now. Many of these programs have had successful focus groups and marketing strategies. Learning the strategies used by other companies, specifically Honeywell[34] and Comverge[35], would be more practical than starting a focus group. Both Comverge and Honeywell have a client base that exceeds any focus group we could construct.

2. The project had limited resources and team members. The cost of starting a focus group in the Greater Boston area required access to transportation, a sufficient financial incentive for the focus group, and a place to talk to the focus group for the required time. The cost of this procedure as well as the time needed to create and monitor a focus group exceeded the benefit of actually conducting it.

With this in mind, it was decided that the mass mail survey size could be scaled up from 800 surveys to 914 surveys. Each of these surveys would be constructed using Dillman's "Total Design Method" outlined in his book *How to Conduct Your Own Survey*[36]. This book outlined a simple method called the "Total Design Method" that uses both a simple approach and concentrates on minimizing errors. According to Dillman, there are four main errors that commonly render a survey ineffective:

1. Coverage Error

The coverage error occurs when potential respondents are not included in the total potential applicant pool. This can be caused by many reasons. A common reason is that the potential respondents are sometimes selected from a telephone book and that many people either do not own residences or are not listed in telephone books, thus misrepresenting the selected area. Another example would be obtaining a list of households that pay electricity. This list however would exclude all people who rent from a landlord who pays their electricity, as well as double counts people who own multiple dwellings in the selected area[37].

To counter this error, the project purchased a consumer list through the company Info USA, which specializes in generating consumer marketing lists that minimize coverage error. Info USA accomplished this by using multiple sources, such as electricity bills, phonebooks, and voter records[38].

2. Sampling Error

In addition to the coverage error, another main error that plagues surveys is sampling error. Sampling error occurs when the number of applicants in proportion to the total possible population of applicants is too small. This tends to cause inconsistent data. For example, if the survey size is too small, then the probability that the distribution of possible respondents accurately represents the total population is minimal. This will be explained later and in more detail in the survey results section when the data is examined[39].

3. Non-Response Error

The third error that causes survey inaccuracy is non-response error. This is described as follows. How many people respond to the survey is called the response rate, which is given as a percentage – the number of people who responded divided by the number of people asked to respond. If this percentage is too low, it is hard to gauge whether the survey is successful because not enough people responded to get an accurate ratio. This in effect reduces the sample size of the survey. Also, each non-respondent adds a significant chance that only a certain demographic of the population is answering, thus leading to an unwanted bias.

To minimize non-response several actions were taken: Primarily, we had a postcard delivered to each person notifying him/her that he/she would receive a survey. This was a courteous gesture that has been proven to increase response rates. Additionally, a follow-up postcard was sent after the survey to remind the non-respondents to respond if they did not already. If the survey was not received after the second postcard had been sent, then an additional survey with a cover letter was mailed again to remind the non-respondents to fill out the survey. In this way, each person was given three chances to fill out the survey. In addition to these reminders, a two-dollar incentive was included in an attempt to increase response rates.

Another factor that has been shown to increase response rates is the fact that the survey was sent out by a university and not a private company. However, not all of the non-response factors could be maximized, since the target audience was the general population that uses electricity in the Greater Boston area. That is to say, the survey was not specifically targeted to an audience that was most likely to respond. Moreover, considering the survey itself was regarding a technical subject and was not simply an opinion poll, the response rates were slightly reduced in light of this[40].

4. Measurement Error

The final error that must be accounted for is measurement error. Measurement error occurs when respondents do not fill out the survey as intended. Mistakes that cause measurement errors include unclear questions, questions filled out improperly, biases in the question wording, and even the sequence in which the questions are presented. There is no foolproof safeguard against measurement error. Each part of the survey was carefully scrutinized, and several non-technical test subjects were used to give feedback. There are also several questions that overlap as well as several open-ended questions that require some level of thought to answer properly, so careless respondents can be weeded out[41].

These are the basics of the survey concepts as promoted by the Total Design Method used by Dillman. Besides accounting for these errors mentioned above, variables were assigned to each question in the survey. In the data analysis, several correlations were made between different variables. Hence, questions that were very similar had to be consistent with each other such that a clear correlation could be determined in the analysis of the results.

CHAPTER 5: The Survey

The survey in its totality covers the following topics:

- Customer willingness to accept the peak demand notification device,
- Perception of the benefits, costs, and risks associated with the device,
- Customer's summertime use of air conditioning,
- Personal experience with power outages,
- Demographics, such as age, income, education, and gender, among others.

The survey is divided into four main subsections:

1) Preliminary questions on energy use,
2) Explanation of demand response programs and generic questions,
3) Presentation of prospective programs (Options One and Two) and questions,
4) Demographic questions.

5.1 *Preliminary Questions on Energy Use*

Overview: Consumers were first asked questions regarding their energy use. Since a large part of what demand response programs do is to help limit interruptions and outages, it was deemed of first importance to discover how familiar consumers were with interruptions and outages – that is to say, how many interruptions/outages they experienced in the past, their average duration, and the consumers' level of discomfort, among others. The reasoning was that consumers with more experience in this area would be more willing to participate in the programs. From there, and considering the main focus is the use of air conditioning during summer months (representing a large portion of energy use during the year), the team proceeded to investigate specifically their air-conditioning use. As preparation for the financial-incentive questions asked later on in the programs section, the consumer is asked to estimate not their monthly electric bill, but their summer monthly bill.

<u>Question 1</u>: Have you experienced any electricity interruptions/outages longer than half an hour at your primary residence in the last summer (June to August)?

Question 1 above works to the end of finding the reader's experience with interruptions and outages. This question is specific in two ways: Only those interruptions and outages longer than a half hour and experienced within the last summer are under consideration here. Their longevity is important in that short occurrences of electricity interruption are taken as being minimally inconvenient or even noteworthy. Besides confining the temporal scope to the summer months (which was agreed to be the months June to August), a further confinement to the most recent summer months is both pragmatic and necessary. Remembrance of interruptions/outages from long summer's past is most certainly rare and, even then, unreliable, and consequently of no avail in accurately gleaning information from the survey, perhaps only leading to frustration on the part of the reader.

<u>Question 1</u> (cont'd):

- **Please estimate how many you experienced in the last summer.**
- **How long did these interruptions last on average?**
- **How discomforted were you by these outages?**

The second part of Question 1 is contingent on the readers' response to the previous question. If readers confirmed previous experience, then three pieces of information are required to be supplied by them. In the first place, with again a special confinement to within the last summer, the number of interruptions experienced, as well as their average duration, becomes known. The underlying purpose for these follow-up questions is apparent when considering the end goal of the survey. That is, with this information, it is possible to find out the severity of interruptions/outages in a given region, and hence the necessity of demand response programs in general. Specifically, however, these serve as a barometer to gauge the impact of poor electricity performance on the reader. To complete the picture, the level of individual discomfort caused by outages is a clear indication as to where the reader's opinion lies. Those readers who deny any previous experience with interruptions/outages within the past summer (hopefully, a small minority) are free to move on to Question 2, since any further discussion of interruptions/outages never experienced is obviously meaningless.

As previously stated, the crux of the survey, and indeed the entire project, lies in controlling air-conditioning (heavy-duty equipment) use. As such, **Question 2** as to the existence of air conditioning in the primary residence is both necessarily asked and of obvious intention.

<u>Question 2</u>: Do you have air conditioning at your primary residence?

The emphasis on the primary status of the residence in question is added to remove any ambiguities inherent in the survey. As in Question 1, a contingency clause immediately follows.

<u>Question 2</u> (cont'd):

- **What type of air conditioning do you have?**
- **At what temperature do you usually set your thermostat during the summer?**
- **On a typical hot (greater than 90°) weekday during last summer, how long did you use your air conditioning?**
- **How often did you use your air conditioning between May 2006 and October 2006 during days when the temperature was less than 90°?**

This clause informs the team of first importance the kind of air conditioning in use, if this is known to the readers themselves. The flexibility of the readers to changes in their air-conditioning systems becomes lucid in light of this, while at the same time this question sheds light on the degree to which the air conditioning is used, that is, the power outputted on average by their air-conditioning systems. To this end, the number of hours per day the air conditioning was used during a typical day of last summer would be invaluable data in calculating the extent of the power use and, consequently, how much electricity can be saved in implementing a certain demand response program. With the addition of the information regarding the temperature at which the reader set his thermostat during the summer, it is possible to estimate the difference between the usual temperature of residences as uncontrolled by demand response and the temperature of those same residences under the implementation of demand response.

<u>Question 3</u>: What is your average summer monthly electric bill?

In what follows, **Question 3** is regarding finances. As the survey is geared toward summer use of electricity as opposed to yearly use (as the Chapter 2 served to show), the readers are asked to estimate their summer monthly electric bill for the following reason. If the participants are to be financially reimbursed for their participation in the implementation of demand response programs, and if this saving is to be oftentimes automatically discounted from their monthly bill, then the summer monthly bill must be known to the extent to which it is possible to ascertain the threshold of acceptability of the programs insofar as they work for the consumer in saving him money, money he both wants and needs and which must be made sufficiently large so as to facilitate, but not necessarily guarantee, participation.

<u>Question 4</u>: Overall, what is your biggest concern with electricity and energy?

This subsection of questions has its terminus in **Question 4,** a broad overview question, the answer to which makes known the general sentiment of the reader in regards to the present crisis, and of this sentiment the divisions are three and clearly drawn: Financial concerns (cost), comfort concerns (preventing interruptions/outages), and societal or environmental concerns (providing for renewable and clean energy). The existence of other concerns outside of these is acknowledged in the option of “Other,” the expressing of which is provided for by the space given immediately below.

5.2 *Explanation of Demand Response Programs and Generic Equations*

Overview: The next subsection begins by defining for the consumer demand response programs – what they are, what they do, and what the benefits are on the consumer level. One notes that even if the consumers do not own air conditioning, they are asked to proceed as if they did, eliminating the possibility of a blank returned survey. A major term that follows from the discussion of demand response programs is the term cycling, stated simply as “shutting off and turning on the air conditioning . . .”, the result of which is a temperature increase in the room, as the consumer is informed. “Will consumers be discomforted by this?” is the question necessary to ask, serving as an indicator as to whether or not they will participate in the programs. As the concept of cycling is very nebulous without an explanation as to the method by which a room is cycled, different ways of cycling air conditioners are naturally expounded. From the research, it is known that installing a device on pre-existing air-conditioning units is one such method. After a brief explanation of this method, the consumer is prompted to describe how he or she feels towards the situation in which the cycling is automated by the device.

Question 5: Do you believe you would notice, and be discomforted by, this change in temperature?

Question 5 has as its preface a brief discussion as to what demand response programs do to save power when energy use is high, that is, by the process of cycling as previously mentioned. The content of Question 5 then lies in understanding the level of discomfort the reader would most likely experience on account of this method which has been just proposed. The reasoning behind asking Question 5 is straightforward if one is under the reasoning that a lack of discomfort would generally indicate a favorable disposition to the method, whereas a strong discomfort would on the whole indicate the opposite, an unfavorable disposition, the assumption moreover being that such simple reasoning does not necessarily predict a chaotic reality where more factors come into play, factors which the survey in its entirety tries to deracinate.

Question 6: Which option best describes how you feel towards this situation?

Another such factor is not simply the method of cycling (theory), but the way in which the cycling is practically executed (practice). **Question 6** brings the readers to make their stance known regarding the matter of practice, specifically the practice (of foremost importance) of automated control. This question filters the information obtained in Question 5 when, for example, readers who would not be discomforted by cycling in theory make it expressly clear that they are opposed to the idea of automated cycling in practice due to their lack of control. On the other end of the spectrum, it is possible for individuals to not mind power companies controlling their air conditioning during peak hours, as the first option of Question 6 indicates. In the middle ground, the second option is added in the event that the trustworthiness of the company can be made sure in the mind of the reader, a nebulous concept, or alternatively, in the event that the power company can draft a contract under which the use of the cycling device can be systemically controlled by a proper and trustworthy agent. The extent to which the power company wishes to pursue such dealings would be made known by the collective results of the survey data and is hence contingent and uncertain.

5.3 *Presentation of Prospective Programs (Options One and Two) and Questions*

Overview: After the generic questions on demand response programs are dispensed, one arrives at the real crux of the survey – the examples of specific programs "under consideration for adoption in the Greater Boston area." There are two such examples, properly named Option One and Option Two, which again come from the research. In Option One, an energy reduction program, consumers are given the choice to either shut off their air conditioning completely or to raise the temperature of the room during days of an expected shortage of power. The consumers are informed that they can refuse participation at their discretion. In contrast to the choice presented in Option One, Option Two plays off the idea of cycling as presented in the previous section. Being now familiarized with the term cycling, consumers are told that Option Two is one in which a device is installed free-of-charge on their air-conditioning units. Furthermore, consumers aer given more information to make a decision by telling them for how many hours a day, as well as for how many days a year, cycling can be expected to occur. Apart from Options One and Two, in the research no other viable program options were found for use in the region.

Two questions following each program description are also asked and, for consistency, these two questions are the same for both programs.

Questions 7, 9: How interested are you in participating in this program?

In **Questions 7 and 9** the readers are out rightly asked to quantify their interest in Options One and Two, respectively, on a scale of one (not at all interested) to five (strongly interested). Without question, the reason beyond this is to quantitatively measure the favorability of each demand response program, both on an individual scale and on a larger, regional one, the latter of which is necessary to know when considering wide-scale implementation.

Questions 8, 10: If a financial incentive were offered, what incentive would increase your likelihood in participating in this program? (Please indicate the closest minimum amount.)

The second question – **Questions 8 and 10** – is interesting in that it shows how much the readers value their comfort (a non-market quantity) by indicating how much money they would have to receive to participate (contingent valuation). This, accordingly, serves as a barometer, revealing how much consumers would have to be compensated, on average, for their participation. Such is the main driving force behind the content of those questions.

Question 11: Which option is more appealing to you?

In **Question 11,** the readers are presented with the choice of choosing which option is more appealing to them. In the aggregate, this represents the ultimate favorability of one program over another and is hence a major factor in making a decision to implement, if any is implemented at all. Moreover, if the readers are unsure of their partiality to one or the other of the programs, or if they like both options equally, this is a good time for they to make a solid decision one way or the other. Either way, the readers are then asked to communicate the reasons behind their choice.

Thus concludes the questions regarding electricity use and demand response. In the next subsection, simply demographic questions are asked.

5.4 *Demographic Questions*

Overview: The demographic subsection concludes the survey with simple questions asking the consumer to identify such things as gender, age, ethnic background, and annual household income, among others. Such questions are also useful for anyone who wishes to study the influence of demographics on energy use in the future. The usefulness of the demographics for our purposes is visibly seen in light of the data analysis process that follows the return of the surveys. The dependence of the data on such factors as income, age, and residence type is to be considered as the ISO decides how to implement these programs. Regression patterns, as well as the statistical analysis of the data, will give us better insight into the significance of the data, and will help us decide the public's perception of the programs.

Among the demographics, of particular concern are the following: **Age, annual household income, the number of adults and children/minors living in the residence,** and **the type of residence.** Age would be a factor especially when households in which elderly individuals live in some respect are hindered from participated due to the apparent discomfort the programs would cause the elderly. With respect to annual house income, the trend would be that greater income requires a greater financial incentive to be offered, whereupon participation is contingent on the size of this incentive meted out to the consumer. Alternatively, it can be argued that with a greater income level, the decision to participate does not come from a desire to receive money, but from the feeling that one would be participating in a worthwhile, beneficial, and lasting program.

Moreover, the number of individuals living in a certain residence might play a role in that a larger household, for example, might have to, on the one hand, cater to a greater number of wants and desires (especially of children) or, on the other hand, make decisions with the intent of saving electricity and therefore money. The former might lead to the refusal of participation, whereas the latter might be a reason for participation. The type of residence, in and of itself, could be a deciding factor, of particular note being smaller residences (perhaps apartments which individuals rent) and larger residences (perhaps houses which individual own).

Following the demographic questions, the readers are left space to make their comments, concerns, or suggestions known if they so wish, concluding the survey.

5.5 *Interrelationships that can be Explored using Regression Analysis*

As shown on Figure 5.1, the survey explores the important interrelationships among the following variables.

- The **age** of the respondents is compared to:
  - The amount of air-conditioning (AC) they use,
  - The level of interest they have in both Demand Response (DR) programs, and
  - The financial incentive they need to participate in the programs.

  These relations will help in mapping the age distribution of respondents interested in DR and the financial incentive they require. It is expected that older respondents will use their AC more often and that therefore their financial incentive to participate in the programs would need to be larger to duly compensate them.
- **Educational background** is linked to:

  - Financial incentive,
  - The average summer monthly bill, and
  - The level of interest in the DR programs.

  The relations between these variables, particularly the relationship between educational background and financial incentive, might yield some useful information needed in developing economic plans for power-supply companies interested in implementing DR programs. Depending on the educational background of the respondents, the favorability to DR programs is expected to change; in particular, one expects that more highly-educated respondents are more likely to favor the DR programs.

- **Annual household income** is related to:
  - The level of interest in the DR programs,
  - The average summer monthly bill,
  - Financial incentive,
  - The amount of AC usage, and
  - The number of air conditioners.

  It is expected that the higher the annual household income is, the higher the average summer monthly bill will be, due to an increased use in AC. Moreover, respondents with higher monthly bills are expected to show more interest in the DR programs, although it is likely that they will require a larger financial incentive.

- The **number of air conditioners** is examined in comparison with:
  - Financial incentive, and
  - The average summer monthly bill.

  Simply put, the larger the number of air conditioners or the AC usage, the larger the monthly bill. For this reason, it is expected that the respondents will be more interested in DR programs and will consequently ask for a larger financial incentive.

- The **number of adults** is compared to:
  - The number of air conditioners, and
  - The amount of AC usage.

The number of adults is expected to be directly proportional to the number of air conditioners and hence the AC usage: A household with a greater number of adults is more likely to have a greater number of air conditioners in use; it follows that the AC usage for such a household would be higher than average.

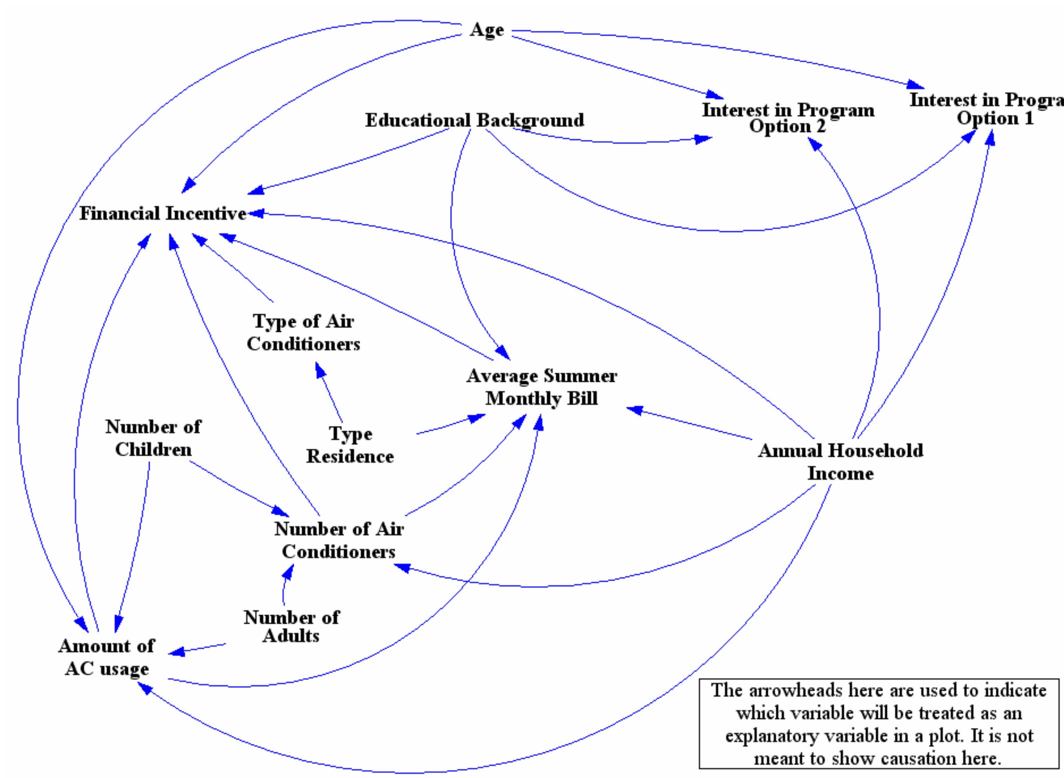


Figure 5.1: General graph showing variables that can be explored with regression analysis.

5.6 *Conclusion*

Upon consideration of the types of questions required of a good survey that well determines public opinion, it seemed the survey would do well to ascertain the proper information to that end. The completed survey, along with a letter introducing both the IQP team and the purpose in conducting the survey, was sent out to approximately 900 households. Prior to the arrival of the survey, consumers received a postcard greeting them with the message that a survey would be sent out shortly and that the team would appreciate their timely response.

CHAPTER 6: Data Analysis and Discussion

This chapter of the report will analyze the data collected from the surveys that were sent to homeowners in the Great Boston area. The analysis will look into possible correlations between various variables – such as annual household income, level of education, age of the respondents, the number of children and adults in the household, among others – with the willingness of the respondents to participate in a Demand Response (DR) program, the financial incentive they seek, the amount of air-conditioning they use, and more. Moreover, the opinions, choices, and demographics of the respondents are represented in histograms. The statistics obtained from the demographic data are compared to the demographic distribution in the Greater Boston area. This shows the extent to which the opinions of the respondents, falling into each category of interest (age, ethnicity, annual household income), represents the respective demographic group in the Greater Boston area.

Using the information acquired from this analysis, it is possible to draw a conclusion on the acceptability of DR programs among homeowners in the Greater Boston area. Furthermore, the financial incentive required to participate in a particular DR program will indicate the willingness of consumers to participate in a DR program. Analysis of the relationships between the most influential variables (those with strong correlation coefficients) will be carried out. Multivariable regression will be used to create a linear model that uses the most influential variables from the survey to predict the financial incentive required. This model will expose which factors predict the respondent's willingness to participate. That information will be valuable to companies such as ISONE and other power companies as they take a look at the generalized overview of respondents' response to DR programs.

The analysis was done with the aid of *Matlab* software. For brevity, the mathematics underlying the analysis was incorporated into the *Matlab* code that appears in **APPENDIX E: Matlab Code for the Survey.** (For an explanation on the variable names derived from the survey questions, refer to the tables in **APPENDIX B: Tables Explaining Variable Names.**)

6.1 *Demographics*

This section details the demographic data that were collected from the surveys. Figure 6.1, for instance, shows the gender distribution of the survey respondents: 54.7% of the respondents were male, while 45.3% were female, a fairly even distribution. The data are represented in the form of a histogram, with the sample response size appearing in red-lettering in the center of the Figure. The sample response size is the number of respondents who answered the question in the survey pertaining to the variable at hand; in this case, the variable is gender, and 236 of the respondents specified their gender, making that number the sample response size. In this way, those respondents who did not specify their gender are excluded from the histogram, and the percentages of males and females, respectively, add to 100%.

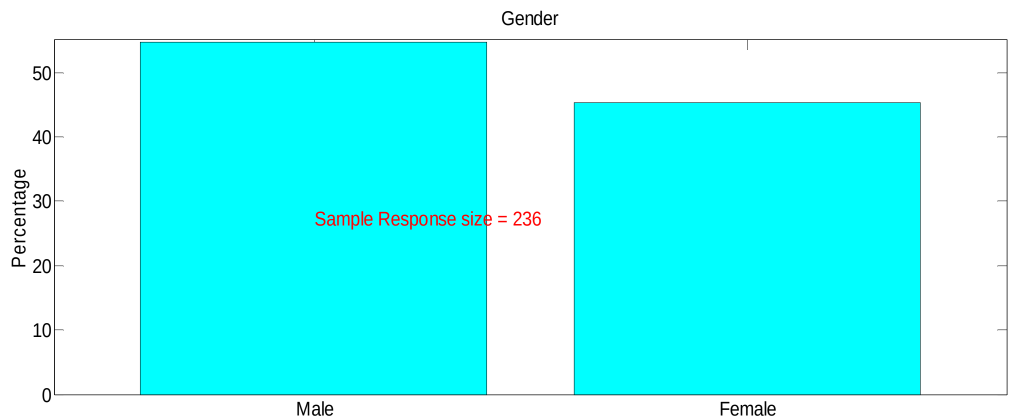


Figure 6.1: Gender distribution of 236 respondents.

A little more interesting is Figure 6.2, which shows the age distribution of the survey respondents. The mean, or average, among a sample response size of 242 is 56 years old, a relatively old age; the median, or the middle-point of the data, is also 56 years old. This high-age mean and median are most likely due to the fact that the target audience was mostly homeowners. The standard deviation, moreover, is 10 years: That is to say, approximately 67% of the respondents are between the ages of 46 and 66 (10 years younger or older than 56 years old). The mean, median, and standard deviation (STD) also appear in red in the Figure. To summarize, of the survey respondents, 9.92% were 30 to 39 years old, 22.4% were 40 to 49 years old, 24.4% were 50 to 59 years old, and, lastly, 43% were 60 years old or older, a plurality of the respondents.

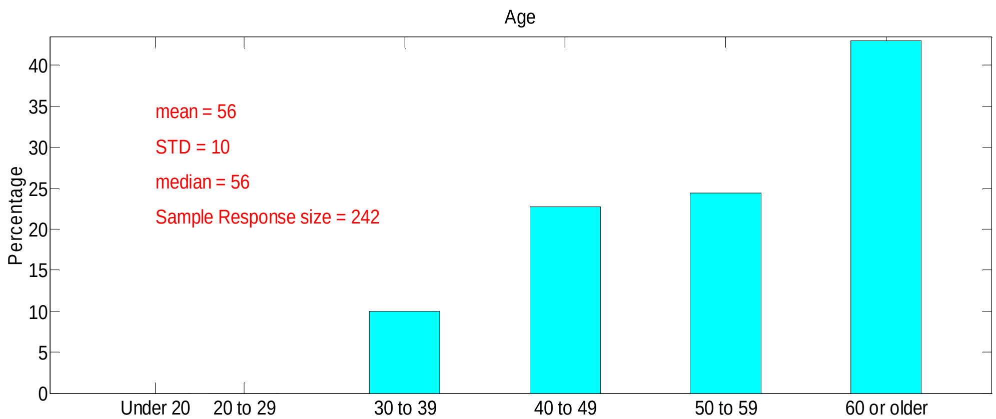


Figure 6.2: Age distribution of 242 respondents.

Next, in Figure 6.3, one sees the ethnicity of the 240 respondents who specified their ethnic background. An overwhelming 88.8% of the sample is White/Caucasian, the remaining percentage of the respondents divided among the other ethnicities as follows: 1.25% are Hispanic, 2.92% are Black/African American, 5% are Asian/Pacific Islander, and 0.417% are Native Americans. The remaining 1.67% specified themselves as "Other."

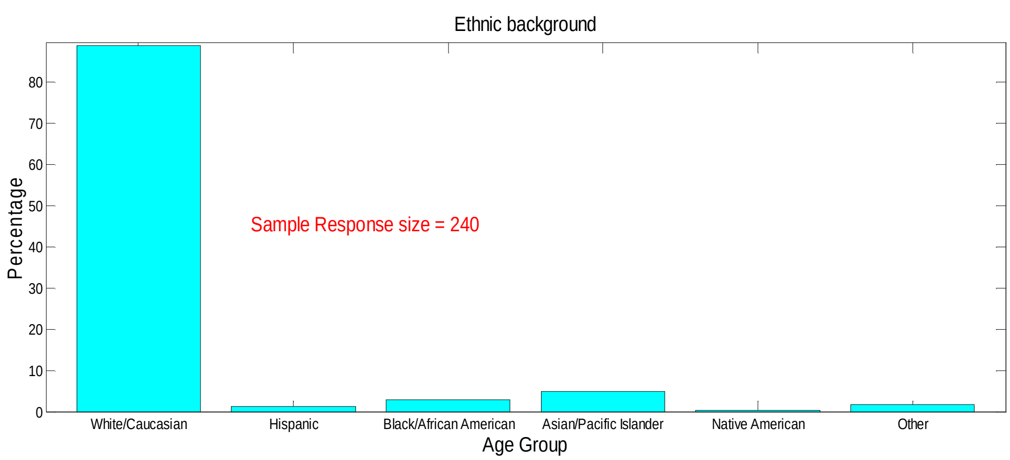


Figure 6.3: Ethnic distribution of 240 respondents.

The educational background of the respondents is summarized in the histogram of Figure 6.4. For purposes of clarity, the horizontal axis that represents the level of education of the respondents has discrete categories labeled A through H, which are to be deciphered in the following manner: A—Less than ninth grade; B—Some high school; C—High school graduate; D—Trade school; E—Some college; F—Associate's degree; G—Bachelor's degree; H—Master's or Ph.D. With this in mind, the percentage breakdowns are as follows: A, 0.4%; B, 1.63%; C, 9.39%; D, 0.82%; E, 18%; F, 3.67%;

G, 26.5%; H, 39.6%. Upon inspection of Figure 5.4, it is not illogical to conclude, therefore, that a fair percentage (indeed, even a majority) of the sample response size (245) is well-educated.

Subsequently, Figure 6.5 shows the average annual income, in dollars per year, of 206 respondents. It must be noted that the respondents did not specify their exact annual income, but rather checked off an option in the survey that corresponded to a range of incomes, in which their income was expected to lie. Thus, the histogram bars in Figure 6.5 represent the midpoints of the ranges as presented in the survey options; there were six such options in total. To summarize the Figure, 3.88% of the respondents said they had an average annual income of $12,500 or less; 8.74%, an average of $27,500; 7.77%, an average of $42,500; 14.1%, an average of $65,000; 24.3%, an average of $85,000; lastly, 41.3% said they earned over an average of $100,000 or more each year. Among these data, the mean is $80,328, the median, $85,000, and the standard deviation, $29,681, which reveals the relative wealth of the sample.

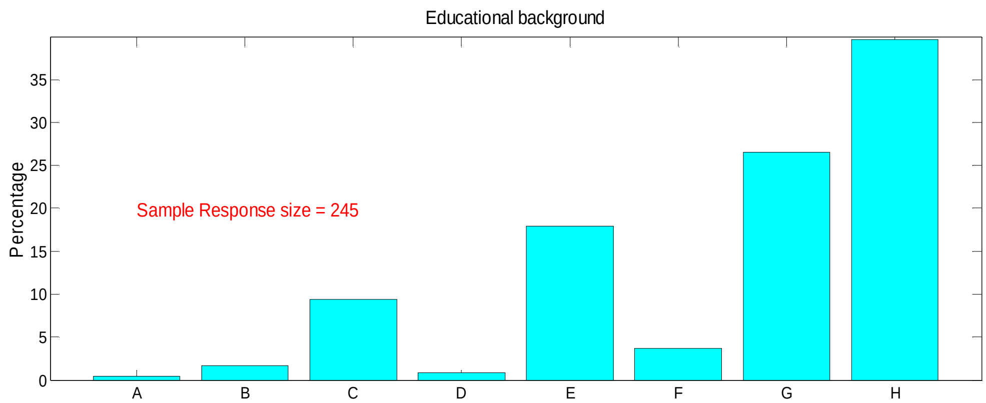


Figure 6.4: Educational background of 245 respondents.

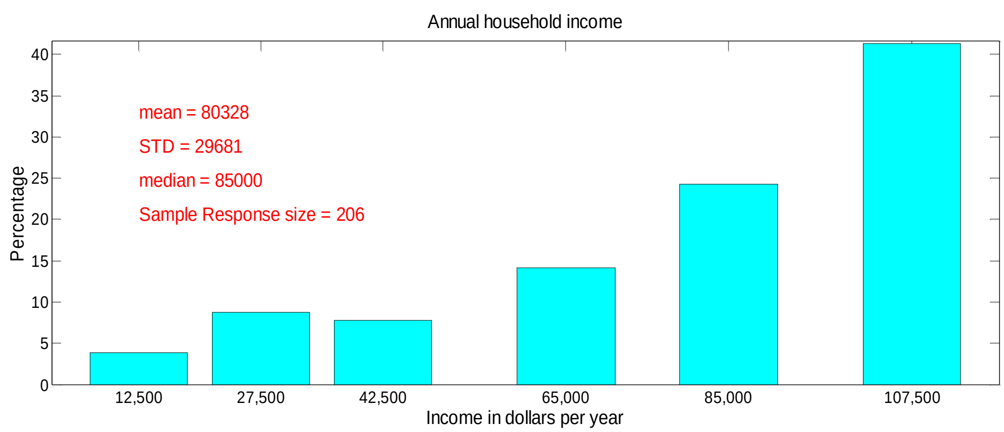


Figure 6.5: Annual household income of 206 respondents.

Regarding marital status, the survey presents the reader with three options: Single, married, or other. The distribution of the percentages of each option among those respondents who specified their marital status is shown in Figure 6.6. Of the 237 who responded, 22.4% are single, 61.6% married, and 16% responded with “Other”—either divorced, widowed, or engaged.

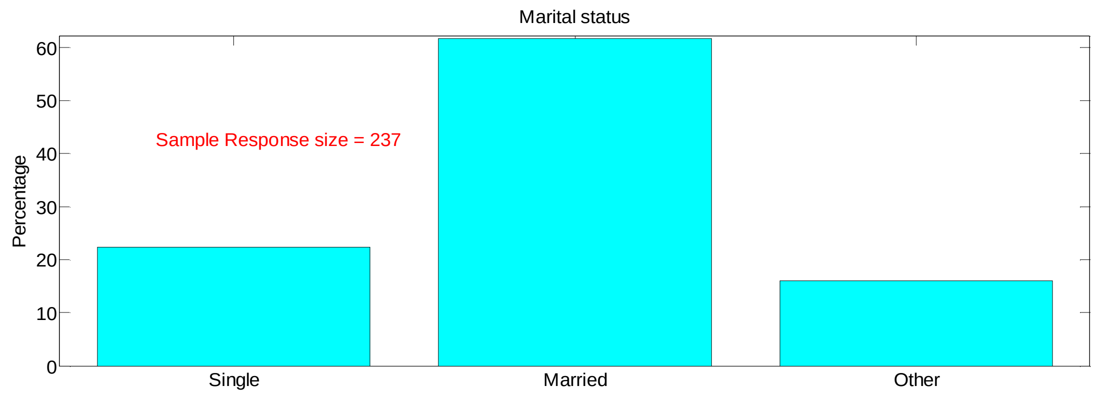


Figure 6.6: Marital status of 237 respondents.

Figure 6.7 shows the average number of adults living in the residences of the respondents. Keeping in mind that an adult is legally an individual older than 18 years of age, the percentage breakdowns are as follows: Among 231 respondents, 23.4% report having only one adult living in the residence; 59.2% report two adults; 12.1%, three adults; 5.19%, four adults living in one residence.

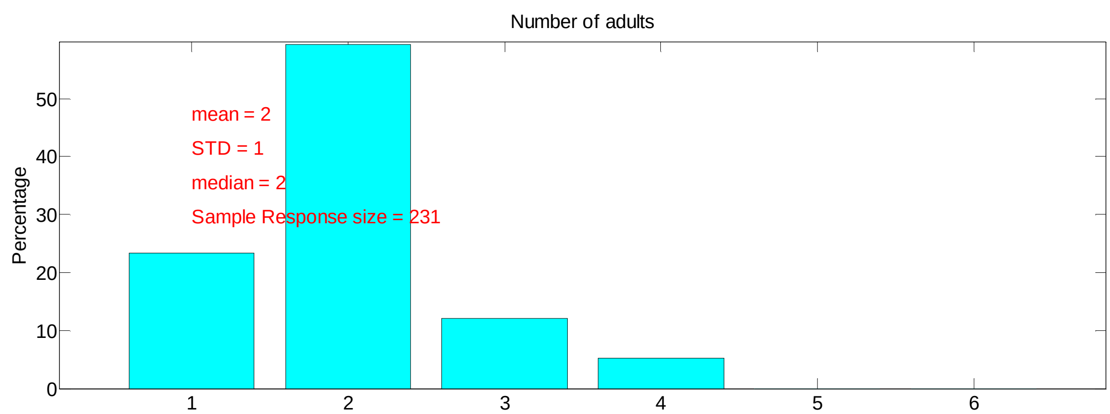


Figure 6.7: Average number of adults of 231 respondents.

Similarly, the histogram of Figure 6.8 reveals the distribution of the number of children (younger than 18 years of age) residing in the residence. Of the people who responded (227 in total), 66.5% reported no children living in their household; 11.5%

reported one child; 18.5%, two children; 3.52% reported three children living in their residence.

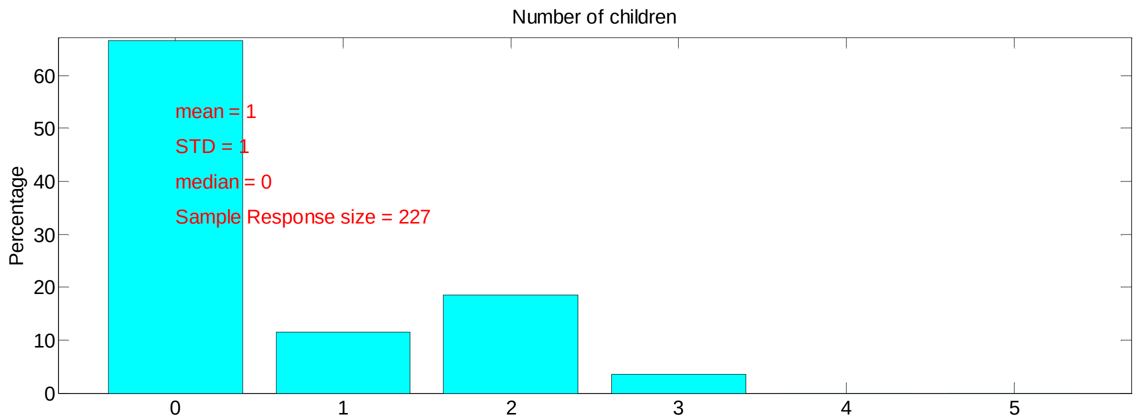


Figure 6.8: Average number of children of 227 respondents.

Lastly, Figure 6.9 illustrates the type of the residences in which the respondents currently live. An overwhelming number of respondents among the response size, namely 93.1%, claim they own their own residence, as expected. Only a meager 4.08% of the 245 respondents rent their current residence. Still a smaller percentage (0.816%) lives with family and friends. The remaining 2.04% has some other living accommodations. Because the analysis focuses on homeowners, this histogram reflects this focus and is a check on the homogeneity of the sample list.

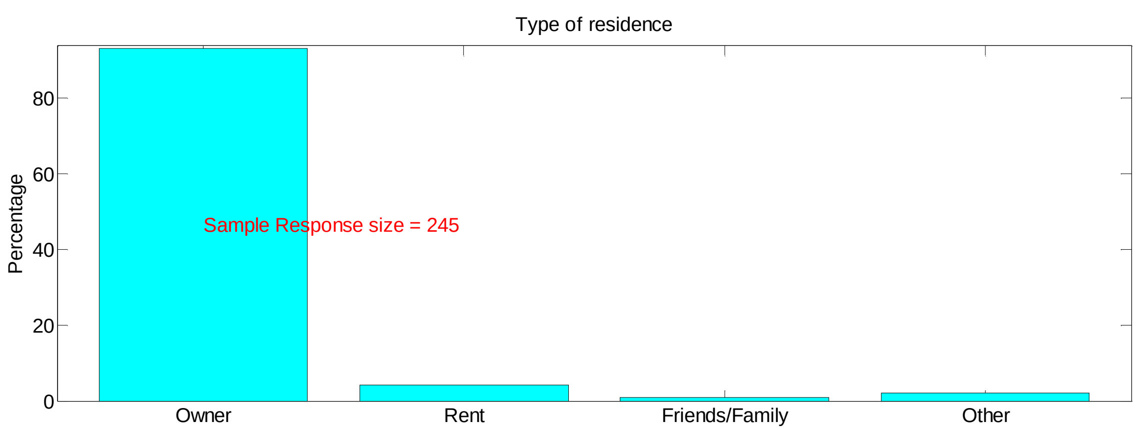


Figure 6.9: Type of residence of 245 respondents.

Bias Testing on the Collected Demographic Data

Because the data collection method was not a simple random sampling scheme, the data could be biased towards certain segments of the Greater Boston area (GBA) population. In order to decide the representativeness of the information gathered, therefore, it is necessary to check how biased the data are compared to the general GBA population. The null hypothesis is that the sample data adequately represents the GBA homeowner population. In order to test this hypothesis, sample proportion tests were carried out on two selected variables, namely, ethnicity and gender. The results are displayed in Table 6.1.

Bias Test					
Values	**Gender**	**Ethnicity**			
	Male	**White/Caucasian**	**African American**	**Hispanic**	**Asian/Pacific Islander**
n	236	240	240	240	240
P_0	0.5	0.91	0.033	0.016	0.0295
P	0.547	0.888	0.0292	0.0125	0.05
z	1.4441	–1.1909	–0.3295	0.4321	1.8769
p-value	0.0744	0.1168	0.3709	0.3328	0.0303

Table 6.1: Bias test on selected variables.

For the categories gender and ethnicity in Table 6.1, the value n is the sample size, P_0 the GBA population proportion[42], and P the sample proportion from the collected data. Moreover, the critical value z is the standardized deviation of P from P_0. It is used to calculate the p-value under the assumption that the sample is normally distributed. The p-value, in turn, is used to determine the probability that the deviation of the observed P from P_0 is due to chance alone.

With respect to a given tolerance level, the p-value shows how similar P is to P_0. When the p-value is less than the tolerance level, one can say that P is significantly different from P_0, and that the difference is not due to random variation in the data. For example, choosing a tolerance level of 0.01, one can see that the sample is not significantly biased with respect to any of the categories. The male sample proportion, 0.547, is not significantly more than 0.5. For Whites/Caucasians, the sample proportion of 0.888 is not significantly less than 0.91; for African Americans, the sample proportion of 0.0292 is not significantly less than 0.033; for Hispanics, the sample proportion of 0.0125 is not significantly less than 0.016; for Asians/Pacific Islanders, the sample proportion of 0.05 is not significantly more than 0.0295. Consequently, at the 0.01

tolerance level, the statistics support the hypothesis that the data adequately represents the GBA population.

However, at a 0.2 tolerance level, the sample data leans towards males and Asians/Pacific Islanders, but moves away from the White/Caucasian segments of the GBA population. This implies that the data under-represents females and Whites/Caucasians, while over-represents males and Asians/Pacific Islanders. It still represents Blacks and Hispanics adequately at this tolerance level. The usual tolerance level of 0.05 implies that the sample has a statistically significant difference, namely, fewer Asian/Pacific Islanders than normal are represented. The differences in the proportions for each ethnic group could have arisen from the geographical clustering of each group in the GBA. The respondents in the sample list might not have equally come from every geographic part of the GBA. Note that the ethnicity and gender variables were chosen for this analysis because data for them was available while it was not so for the others.

6.2 *The Opinions of the Respondents*

Attitudes toward Cycling and Loss of Control

The survey explicitly states, as has been previously mentioned, that when an air-conditioning unit is cycled, the temperature of the house may increase by as much as 10°F, depending on the outside temperature, the insulation of the house, and the thermostat setting. The readers are then asked to qualify their discomfort due to the temperature increase. Figure 6.10 depicts the level of discomfort of the respondents when presented with such a situation. For convenience, the horizontal axis is labeled A through D, which is to be understood to represent varying degrees of discomfort in the following way: A—Respondent would not notice the change in temperature; B—He would notice, but would not be discomforted; C—He would be slightly discomforted; D—He would be much discomforted. Of a sample response size of 235, the distribution is fairly dispersed: A, 8.94%; B, 30.2%; C, 47.7%; D, 13.2%. The plurality of the respondents, therefore, would only be slightly discomforted by the increase in temperature as described. Indeed, an overwhelming 86.8% would at most consider the cycling to be slightly discomforting.

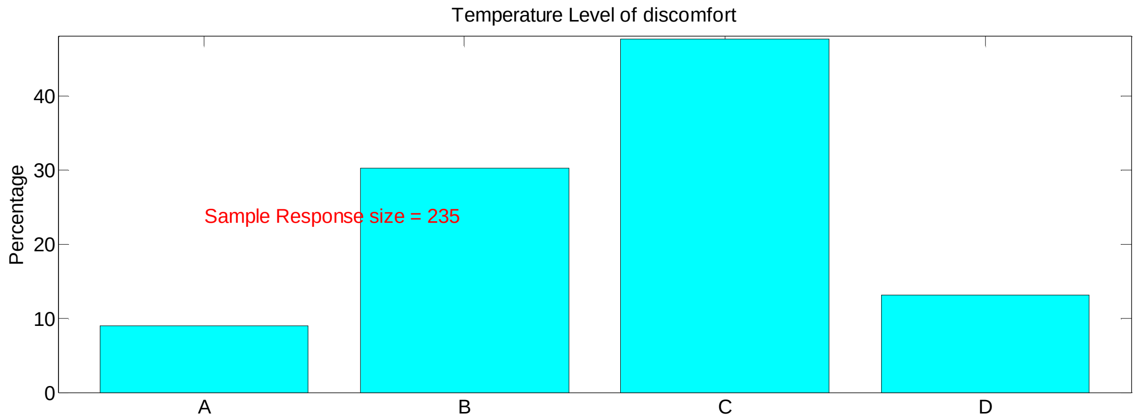


Figure 6.10: Level of discomfort during air-conditioning cycling.

Figure 6.11 shows the opinion the respondents have in regards to the power company, or a designated Demand Response company, having control over their home air-conditioning units. The different opinions are enumerated as follows: Opinion A is that the respondent does not mind the power company having control of his air-conditioning during peak hours; Opinion B is that the respondent does not mind if he knows and trusts the company, or if he has a contract to ensure when the cycling takes place; Opinion C is that he does not care either way; Opinion D is that he is slightly against the idea; Option E is that he is strongly opposed to the idea. The percentage breakdowns in Figure 6.11 are as follows: A, 6.38%; B, 17.9%; C, 2.13%; D, 31.1%; E, 42.6%. This reveals instantly that a vast majority of the 235 respondents, namely 73.7%, is either slightly opposed or strongly opposed to the idea of the power company asserting control over their air-conditioning use. Consequently, the minority, 26.3%, is either apathetic or is not particularly bothered by the idea.

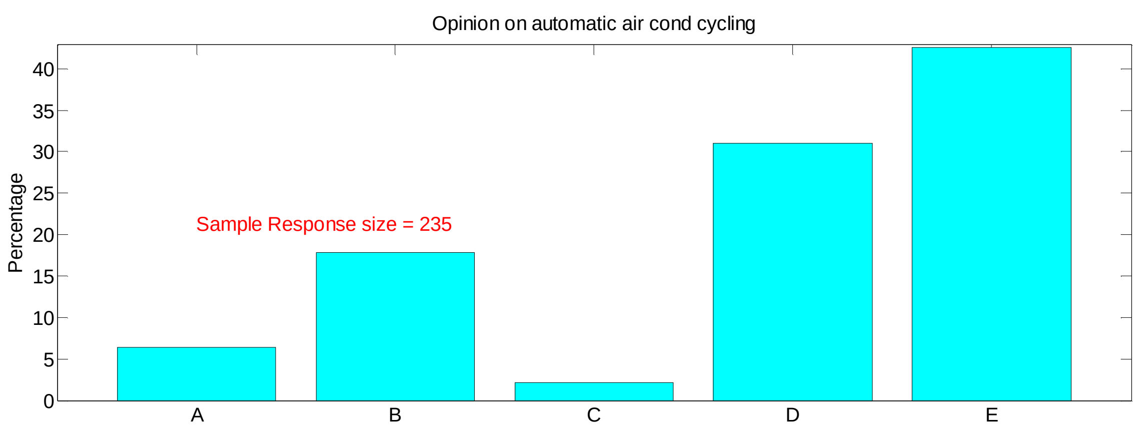


Figure 6.11: Opinion on automatic air-conditioning cycling.

Attitudes toward the Programs

In the course of the survey, the reader is asked to express quantitatively his level of interest in regards to the programs presented him. The level of interest is on a scale from one to five—one representing little to no interest, five representing strong interest. Figure 6.12 is the distribution of the responses for the interest level in Program One. In Program One, consumers receive a phone call the night before an expected shortage of power. Consumers are then asked to either shut off their AC completely or raise the temperature of the room.

Figure 6.12: Level of interest in Program One.

One sees that 36.9% of the 241 respondents are not interested at all in Program One (This percentage responded with a number one.); 12.95% are slightly more interested (number two); 23.7% have no interest in Program One either way (number three); 14.5% say they have a definite interest (number four); last of all, 12% express a strong interest in Program One (number five). In the aggregate, then, Program One was not well-received by the respondents.

To better analyze the respondents' attitude toward Program One, the distribution of the financial incentive requested by them was computed, and the output is displayed in Figure 6.13. These were the minimum financial incentives specified by the respondents which, if offered, would increase their likelihood of participating in Program One. The incentive would be discounted from their *monthly* bill. Again, it must be noted for clarity's sake that the choices in the survey were given in terms of price ranges, not exact amounts. Thus, the financial incentive labels on the horizontal axis are the averages of the ranges in the survey; the only exception is the left-most label, the histogram of which represents those respondents who indicated that they required no financial incentive. A further note is that the histogram of the $54.5 financial incentive represents all those respondents who required $50 or more in monthly savings.

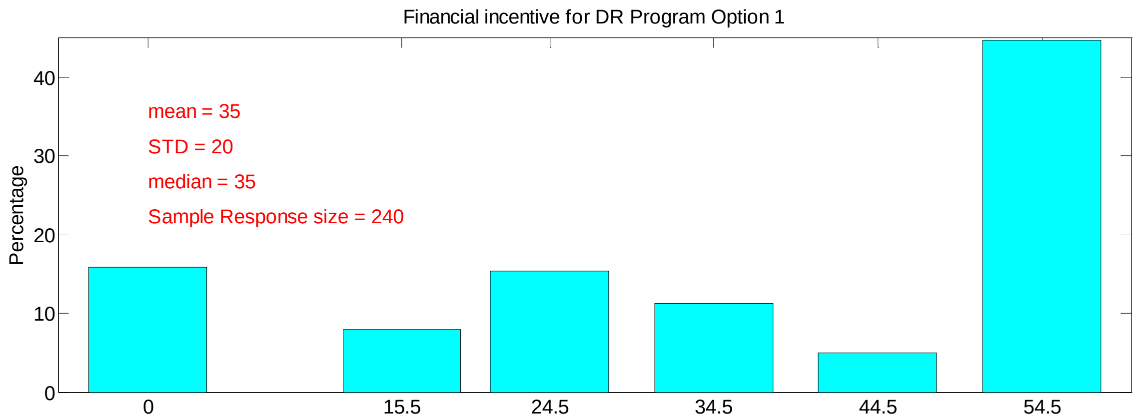


Figure 6.13: Requested financial incentive for Program One.

Of the 240 respondents, 15.8% indicated they need no incentive; 7.92% indicated an average of $15.5 in savings per month; 15.4%, an average of $24.5 per month; 11.3%, an average of $34.5; 5%, an average of $44.5; 44.6% responded that $50 dollars or more in monthly savings would increase their likelihood of participating in Program One. The mean and median were both $35; the standard deviation was $20. Figure 6.13 makes it clear that a disproportionately large percentage of the respondents would require a large incentive ($50 or more) in order to participate.

Figure 6.14 and Figure 6.15 show the same distributions as in Figure 6.12 and Figure 6.13, respectively, except now the favorability of Program Two is under consideration. In Program Two, the consumer's AC is cycled by a device installed on pre-existing AC units free-of-charge. Figure 6.14 is the histogram plot of the percentage breakdown of the respondents versus their level of interest in Program Two. Figure 6.15, similarly, is the distribution of the financial incentive requested by the respondents which, if offered, would increase their likelihood of participating in Program Two.

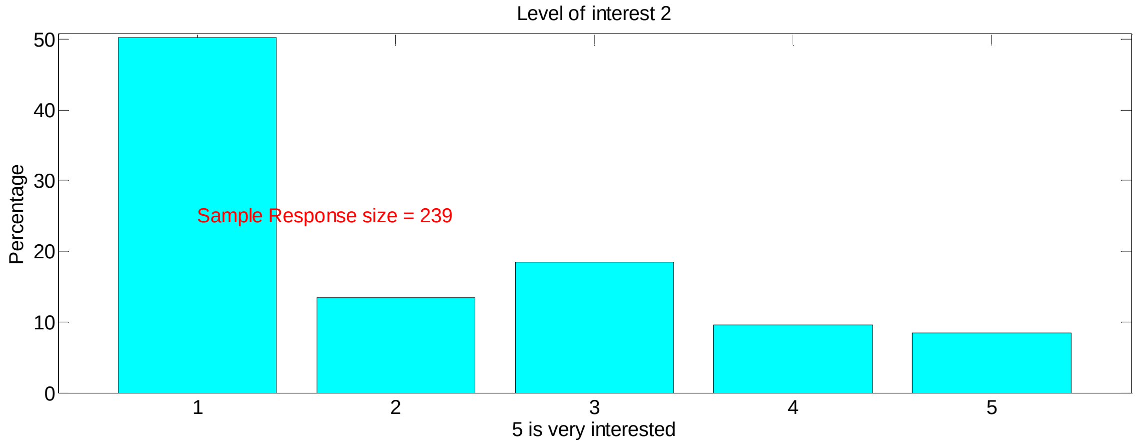


Figure 6.14: Level of interest in Program Two.

From Figure 6.14, the following information is gathered: 50.2% are not at all interested in Program Two; 13.4% are slightly more interested than this; 18.4% have no interest either way; 9.62% have a definite interest; 8.37% are strongly interested in the program. Thus, Program Two are even less well-received than Program One: A majority of the 239 respondents expressed no interest whatsoever in the program. Figure 6.15 seems to corroborate this conclusion: The majority of the 236 respondents, namely 53.4%, indicated that they required a minimum financial incentive of $50 or more. The remaining 46.6% are distributed in the following manner: 11% needed no incentive; 6.36%, $15.5 in savings; 11.9%, $24.5 in savings; 11%, $34.5 in savings; 6.36%, $44.5 in savings.

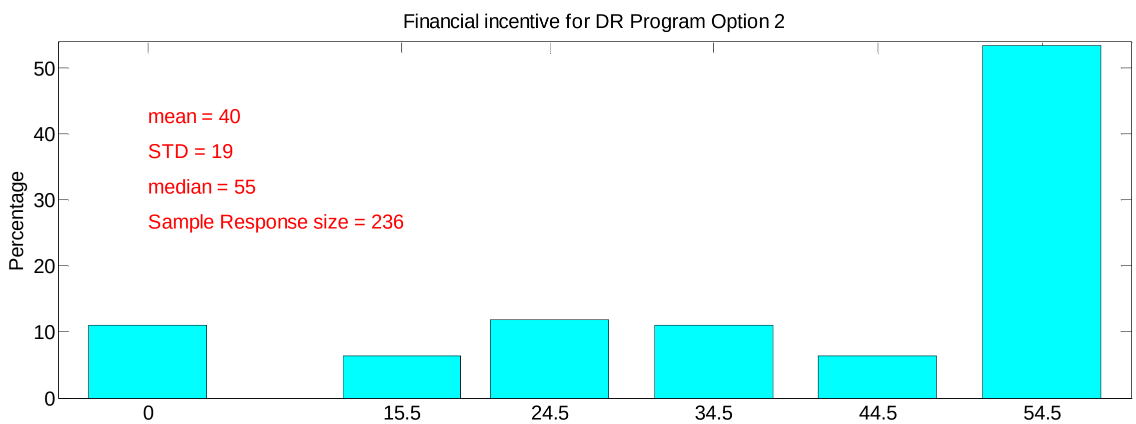


Figure 6.15: Requested financial incentive for Program Two.

Again, the numbers in Figure 6.15 are averages, being the midpoints of the ranges given in the survey. The mean and median of these average data are on the high end: They are $40 and $55, respectively. Approximately 67% of the data lie within $19 of the mean.

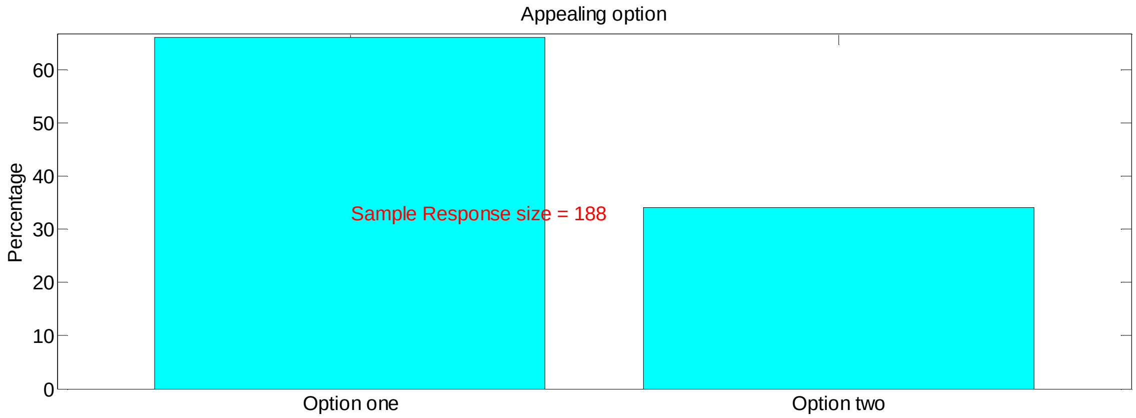


Figure 6.16: Most appealing option.

Figure 6.16 nicely summarizes the results of the last few Figures: It shows that 66% of the respondents prefer Program One over Program Two; the remaining 34% prefer Program Two. In a word, twice as many people like Program One. The sample response size is relatively small, only numbering 188.

There might have also been hidden variables that affected the respondents' favorability to the programs. For instance, many respondents commented that they preferred to manually control and/or program their AC thermostat. Therefore, such respondents would have disliked Program Two. In the same way, some respondents said they were not at home during the day, and thus felt no need to use the AC except at night to help them fall asleep. They thought, perhaps, that both programs did not apply to them. A third variable that might affect the correlations is the fact that many respondents do not like receiving phone calls in their primary residences; their favorability toward Program One would in this sense diminish. Please note that respondents who required no financial incentive and expressed absolutely zero interest in the program were reclassified as requiring maximum financial incentive before the analyses were done.

Miscellaneous Concerns

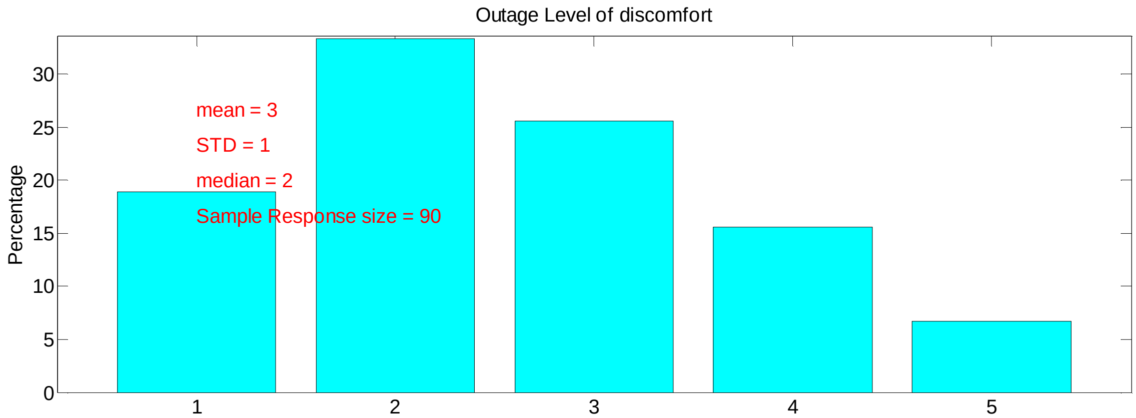


Figure 6.17: Level of discomfort due to interruptions/outages.

If the reader said that he experienced any interruptions or outages during last summer (June to August), he was asked to quantify his level of discomfort due these interruptions/outages on a scale from one to five, where, as before, one represents no discomfort and five represents much discomfort. Figure 6.17 shows the distribution of the responses among the 90 respondents who specified their discomfort. In general, most of the respondents hinted that their experiences with interruptions/outages were not very significant and, hence, that they were only slightly affected by them. Specifically, 18.9% of the respondents were not at all discomforted; 33.3% of them were only slightly so; 25.6%, somewhat more discomforted; 15.6%, definitely discomforted; 6.67%, much discomforted by their experiences with interruptions/outages.

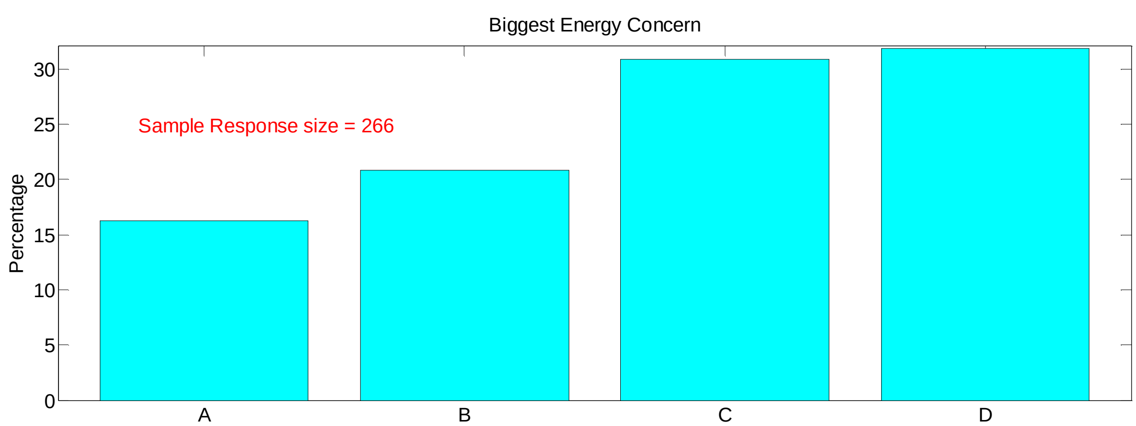


Figure 6.18: Biggest energy concern.

Finally, Figure 6.18 shows the biggest energy concern that the respondents said they had. Three major areas of concern were identified: A—Cost of electricity;

B—Preventing power interruptions/outages; C—Renewable/clean energy. If the respondents had other concerns apart from these, they could have specified their concern as being “Other,” and then manually could have written what it was in the space provided them. The abundance of “other” concerns appears as concern D in the Figure. The respondents were allowed the freedom to select more than one concern from among the choices. They are the following: A, 16.3%; B, 20.8%; C, 30.9%; D, 31.8%.

6.3 *Quantitative Data on Energy Use*

Respondents were asked whether or not they experienced interruptions or outages lasting longer than half an hour during the last summer (June to August). Figure 6.19 is the histogram of the distribution of the responses into either “Yes” or “No.” Evidently, most respondents said they had not had any significant experiences with electricity interruptions/outages. In fact, there were twice as many respondents who answered “No” (67.6%) to the question than answered “Yes” (32.4%) among a sample response of 244.

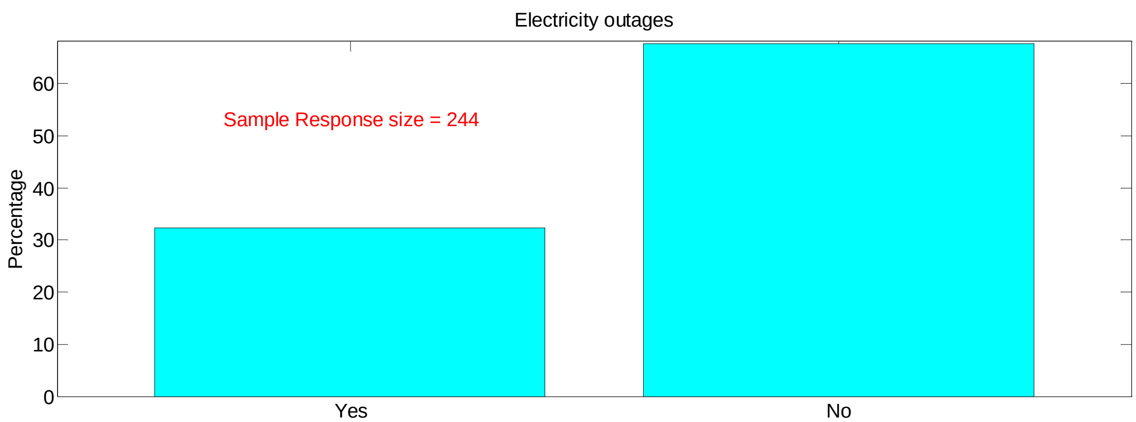


Figure 6.19: Personal experiences with electricity outages.

The minority of the respondents, who experienced electricity interruptions and outages lasting longer than half an hour last summer, were then asked to estimate the number of such interruptions/outages so experienced. The distribution of the frequency of the interruptions/outages among this minority is shown in Figure 6.20. It is seen that of the 88 respondents, a majority of 54.5% had experienced between four and six interruptions/outages, the modal (highest) frequency. The next significant percentage of respondents (42%) said they had only experienced one interruption or outage longer than half an hour during the past summer. This is followed by those who experienced from six to eight of them (3.41%).

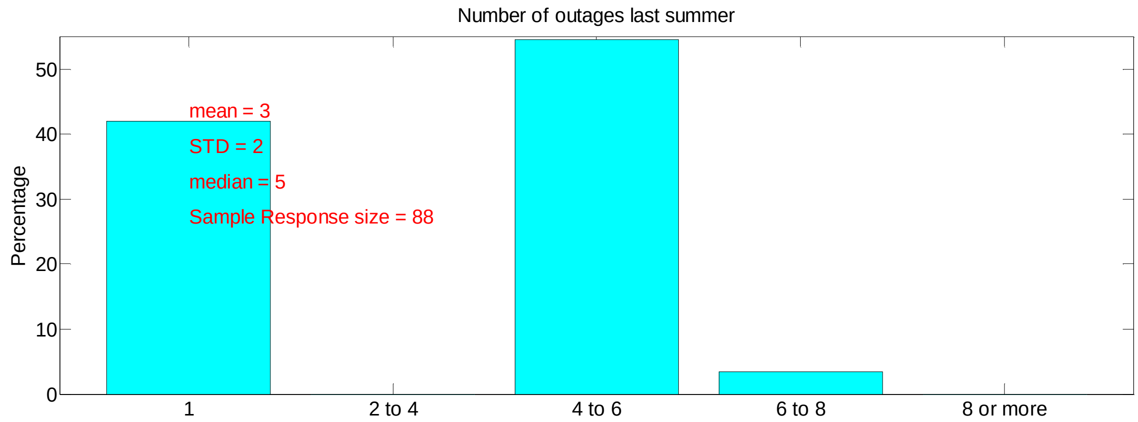


Figure 6.20: Number of outages respondents experienced last summer.

The average length of the electricity interruptions reported among 89 respondents is reported in Figure 6.21. The average duration of the interruptions falls into the following five categories, as shown in the Figure: 1—Interruptions lasted under an hour on average; 3—from one to two hours; 5—from two to four hours; 7—from four to eight hours; 9—Interruptions eight or more hours long on average. It is evident from the Figure that 67.4% of the respondents experienced interruptions that were eight hours or longer; 23.6%, under an hour in duration; 8.99%, from four to eight hours long.

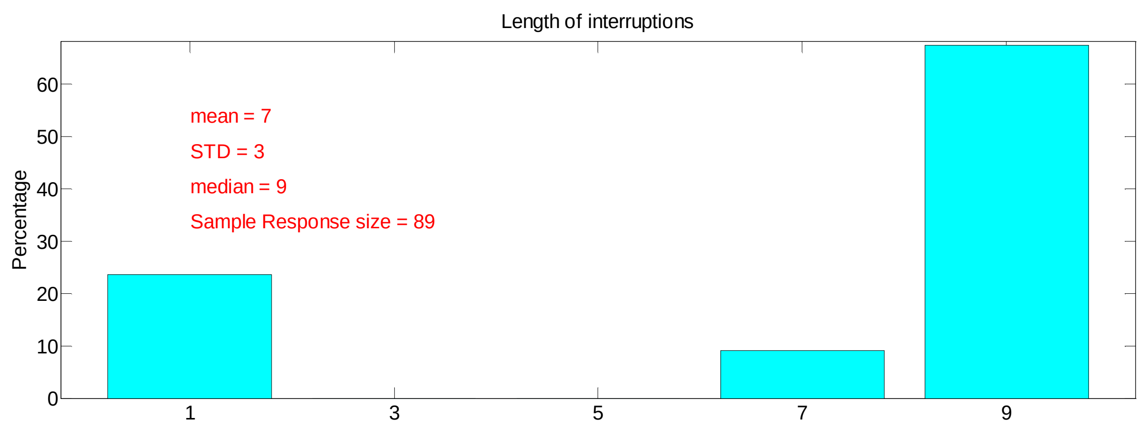


Figure 6.21: Average length of interruptions.

Regarding air-conditioning use, the number of respondents who said they had air-conditioning in their primary residence is shown in Figure 6.22. A vast majority of the 241 respondents (88.8%) answered "Yes" to the question of whether or not they have air-conditioning, while only a small percentage (11.2%) said that they do not own any form of air-conditioning.

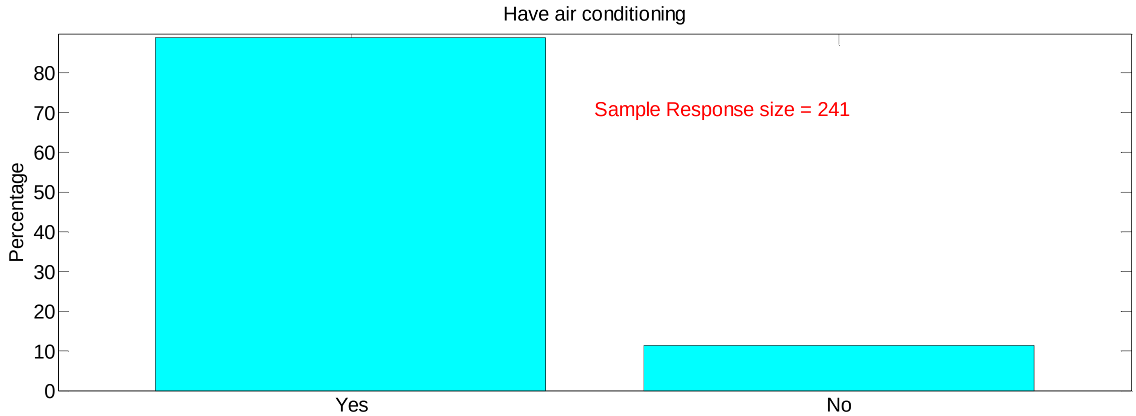


Figure 6.22: Distribution of air-conditioning ownership among respondents.

Among the majority of respondents who answered "Yes," as in Figure 6.22, a majority of them (61.7%) own exclusively window air-conditioning units. Roughly half as many respondents (34.9%) own exclusively central air-conditioning units, while only a handful of them (3.35%) own both. This distribution in the type of air-conditioning is summarized in Figure 6.23.

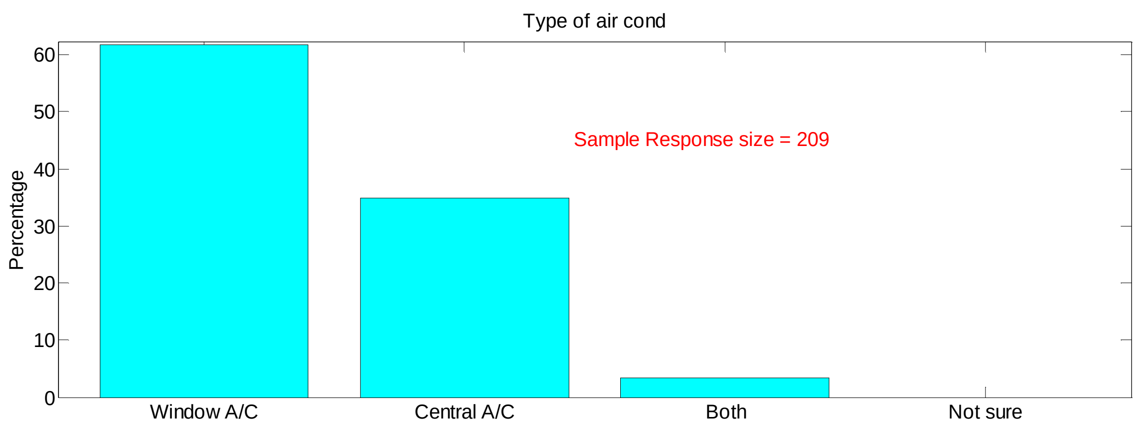


Figure 6.23: Types of air-conditioning among respondents.

Figure 6.24 shows the weighted number of air-conditioning units owned by the respondents. That is, the weight of a *central* air-conditioning unit is assumed to be equivalent to the weight of three *window* air-conditioning units. In one full hour of operation, central air-conditioning uses approximately 2,000 to 5,000 watts/hour, while window air-conditioning uses approximately 1,000 watts/hour[43]. In this way, if a respondent owns one central air-conditioning unit, that one central air-conditioning unit could be seen as being equivalent to approximately three window air-conditioning units.

As may be seen, fewer and fewer respondents own an increasingly larger amount of air-conditioning units. After weighting the numbers, 43.9% of the respondents own one air-conditioning unit; 31.1%, two units; 16.2%, three units; 6.76%, four units; 1.35%, five units; 0.676%, six units.

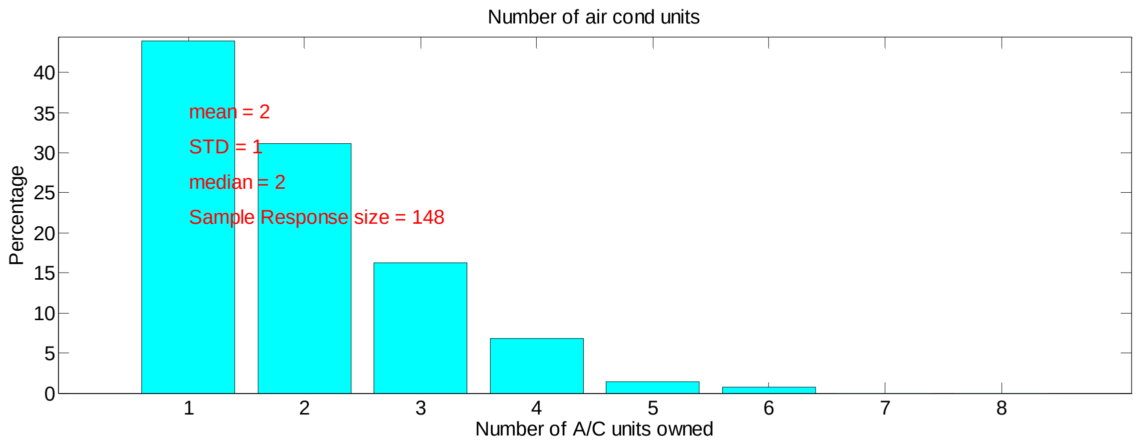


Figure 6.24: Number of air-conditioning units owned by the respondents (weighted).

Figure 6.25 shows the temperature settings at which the respondents usually maintain their thermostats during the summer. The corresponding question on the survey provided respondents with only a few ranges of temperatures. In the generation of the histogram plot, therefore, the midpoints of these ranges were taken. Summarizing the results of Figure 6.25, one finds that: 19% of the respondents said they usually set their thermostats to 62.5°F; 31.8% of them usually leave it at 67.5°F; 40.8%, at 72.5°F; 8.53%, at a temperature of 77.5°F.

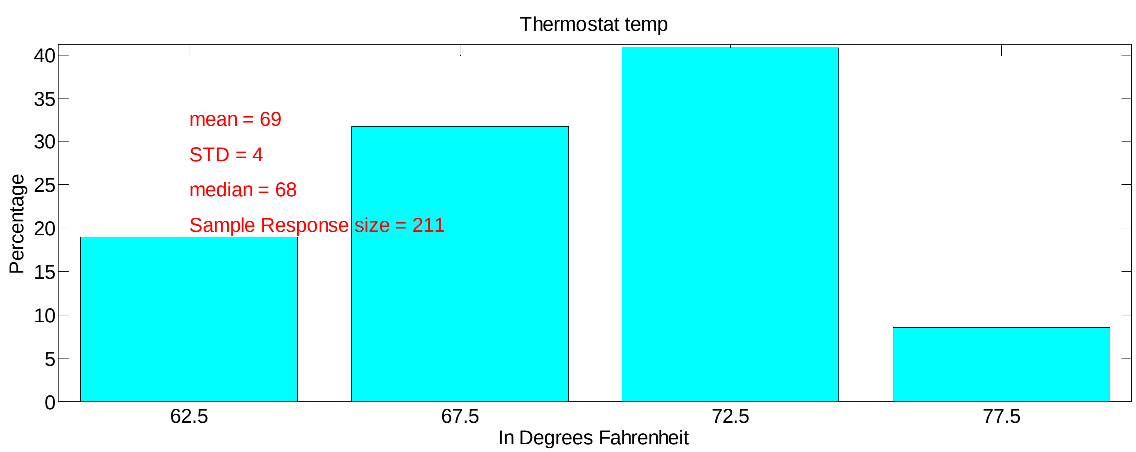


Figure 6.25: Thermostat temperature settings of the respondents during the summer.

The number of hours in which the respondents used their air-conditioning during a typical summer day (when the temperature was greater than 90°F) of last summer is shown in Figure 6.26. Of a sample response size of 217, 3.69% claimed they did not use their air-conditioning at all during such days; 9.22% used their air-conditioning for two hours a day; 30.9%, for nine hours a day; 30.4%, for 18 hours a day; lastly, 25.8% used their air-conditioning for 24 hours a day. The histogram representing last summer's daily air-conditioning usage when the temperature was *less* than 90°F is shown in Figure 6.27.

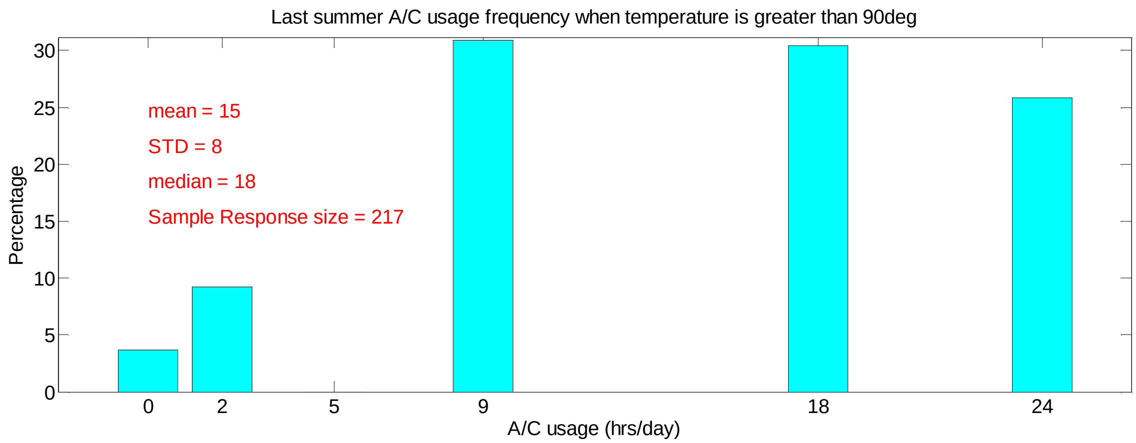


Figure 6.26: Last summer air-conditioning usage when the temperature was greater than 90°.

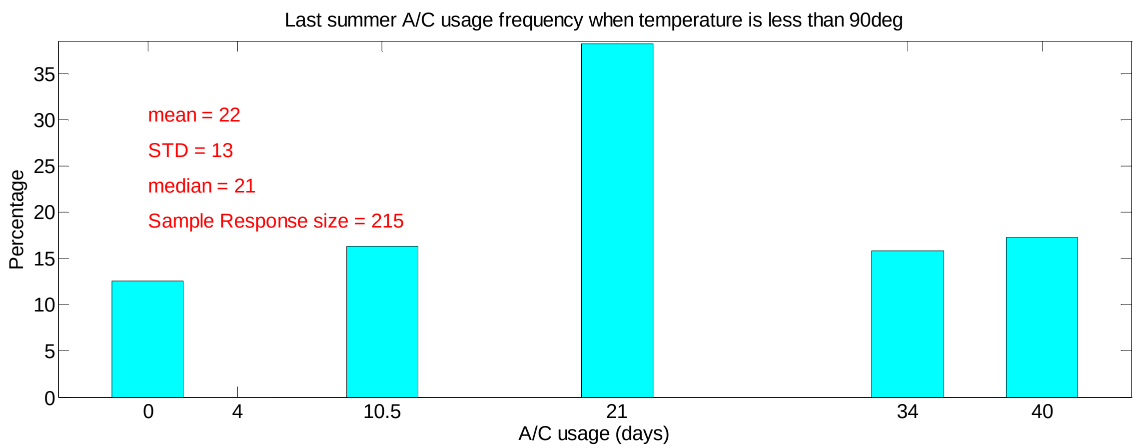


Figure 6.27: Last summer air-conditioning usage when the temperature was less than 90°.

Lastly, the distribution of the average summer monthly bills that the respondents pay was also computed, and the output is displayed as Figure 6.28: 19.7% of the 229 respondents says they pay an average of $50 in monthly bills; 12.7% says they pay $70 in monthly bills; 12.2% says they pay $90 monthly; 16.2% says they pay $110 monthly; 11.8% says they pay $130 monthly; 27.5% says they pay an average of $150 monthly.

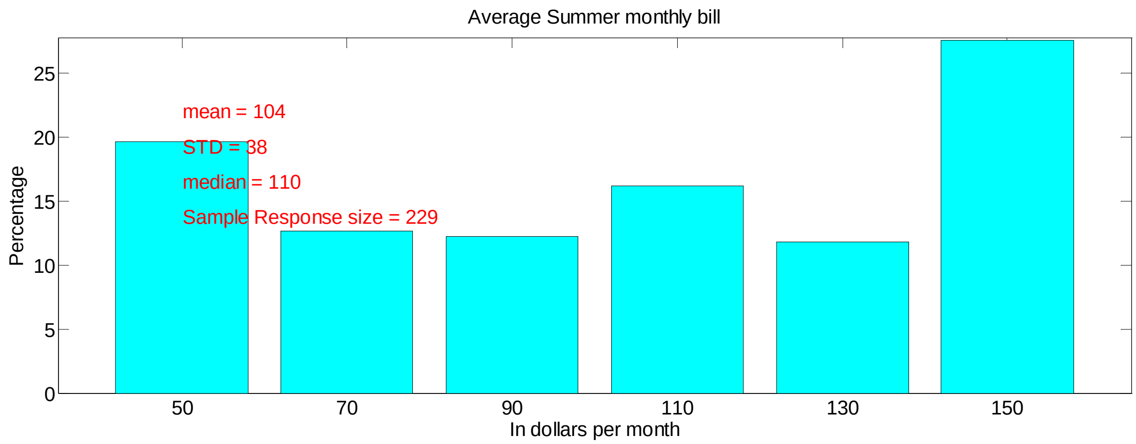


Figure 6.28: Average summer monthly bills of the respondents.

6.4 *Introduction to the Regression Plots: Explanation of Key Variables*

For each regression plot, a number of key pieces of information appear. In addition to plotting the original survey data that correlate two variables (say, for example, "Hourly AC usage in the Summer" with "Age"), a linear regression is also computed, and the resultant best-fit line is plotted along with the data. The vertical axis is the dependent variable, while the horizontal axis is the independent variable. Usually, however, what is plotted is the mean of a certain dependent variable among the sample. The blue line represents this mean response, with vertical bars at each point representing the standard deviation around the mean. Moreover, the best-fit line for the data appears as a red line. In each regression plot, a legend makes this information known to the reader, and in addition gives the numerical value for the correlation coefficient (labeled R), a constant that corresponds to the proportion of the variation in the dependent variable that is predicted by the best-fit line.

Furthermore, the equation of the best-fit line is given in the slope-intercept form of y = mx + b, where y is the dependent variable, x the independent variable, m the slope (the rate of increase of the dependent variable with respect to the independent variable), and b the y-intercept, which is the value of the dependent variable when the best-fit line crosses the y-axis (that is, x = 0) calculated by extrapolation. The two-sided p-value, given beneath the equation, represents how confident one is that the slope of the regression plot is significantly different from zero.

The p-value is interpreted in the following manner: If the p-value is less than 0.05 ($p < 0.05$), then one can say that he is 95% confident that the slope of the best-fit line is significantly different from zero; on the other hand, if the p-value is greater than 0.05 ($p > 0.05$), then one is *not* 95% confident that the slope is significantly different from zero. The threshold c is called the confidence level. Given a repeated, controlled, and randomized experiment, $(1 - c) \times 100\%$ represents the proportion of cases in which the confidence interval contains the true population mean: In general, "a level c confidence interval for a parameter is an interval computed from sample data by a method that has probability c of producing an interval containing the true value of the parameter"[44]. A proportion of 95% is equivalent, therefore, to a confidence of 0.05.

By duality, one can say that the exclusion of the number zero in the confidence interval (c-interval) also allows us to be 95% confident that the slope is significantly different from zero. More explicitly, if the number zero *does not* lie within the given confidence interval, then one is 95% confident that the preceding statement about the slope can be made. Conversely, if zero does lie within the interval, the slope is significantly similar to zero. That is to say, the interpretation of the size of the p-value (in comparison to the threshold value of 0.05) and of the exclusion of zero in the confidence interval are statistically equivalent ways of determining the same information. In each regression plot, the confidence interval is displayed below the two-sided p-value in the form (a, b), where a and b are the left- and right-most bounds of the interval, respectively.

The t-statistic, calculated from the raw data, is used in computing the p-value: That is, the t-statistic is the ratio of the slope to its standard error. The F-statistic, moreover, is the relative measure of the variance (square of the standard deviation), or spread of the data, around the line. For regression analysis, the F-statistic is the ratio of the regression variance to the variance of the residuals. It provides another way for testing how significant the slope differs from zero. For each graph, it checks how similar the plotted means are to each other. The ratio is approximately one when they are significantly similar. It is a large number when they are not[45].

Lastly, the sample response size is the number of respondents who gave values for both the dependent and independent variables, answering at the same time the questions that pertain to these variables within the survey.

Assumptions in the Regression Model

The following are the assumptions that were made in computing the regression models:

1. The regression slope represents the true slope of the population.
2. The standard deviation (variance) is constant along the regression line.
3. The relationship between the dependent and independent variables is linear.
4. The data fairly represents all the sections of the population.
5. The central air conditioners are equivalent to three window air conditioners in terms of power.

The Removal of Extreme Influential Outliers

Before any survey was removed from the analysis, it was checked to see whether it was an extreme influential outlier in the regression plots. If so, it was then checked to see whether that survey drastically broke general trends in the regression plots. If extreme influential outliers broke the trends, they were removed. Because the influential outliers control the slope of the regression line, they can make the line not follow the general trend shown by the rest of the data.

- Survey 637 was the only one with a household of five children and three adults. It was an outlier in all graphs that compared the number of children to other variables. Similarly, surveys 2 and 418 were removed because they were extreme outliers with households containing six and five adults, respectively. They did not follow the general trends.
- Two surveys, with respondents within the low age range of 20–29 years, were removed because they did not follow the general trend in all graphs that compared the age to other variables.

What follows is the explanation of thirteen regression plots. The thirteen independent variables (x) and thirteen dependent variables (y) to be analyzed in these regression plots are enumerated in Table 6.2.

Number	Independent variable, *x*	Dependent variable, *y*
1	Age	Hourly AC usage in the Summer
2	Annual Household Income	Average Summer Monthly Bill
3	Annual Household Income	Level of interest in Program Option 1
4	Annual Household Income	Level of interest in Program Option 2
5	Average Summer Monthly Bill	Financial Incentive for Program 1
6	Average Summer Monthly Bill	Financial Incentive for Program 2
7	Educational Background	Annual Household Income
8	Level of interest in Program Option 1	Financial Incentive for Program 1
9	Level of interest in Program Option 2	Financial Incentive for Program 2
10	Number of AC units	Average Summer Monthly Bill
11	Usual Summer Thermostat Temperature Setting	Level of interest in Program Option 1
12	Usual Summer Thermostat Temperature Setting	Level of interest in Program Option 2
13	Hourly AC usage in the Summer	Average Summer Monthly Bill

Table 6.2: List of comparisons that were made during regression analysis.

6.5 *Explanation of the Regression Plots*

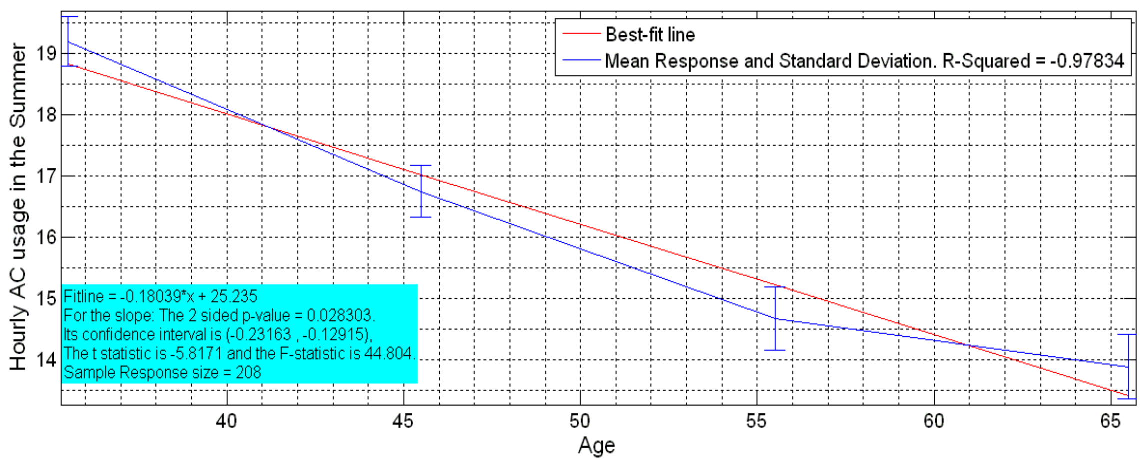


Figure 6.29: Hourly AC usage (in hours) in the summer regressed with age (in years).

Figure 6.29 is a regression plot of the <u>mean</u> hourly summer air-conditioning (AC) usage of the respondents (for days hotter than 90°F) compared with the age of the respondents. As is seen, as the age of the respondents increases, the mean hourly AC usage tends to decrease, the slope of the best-fit being –0.18039 and, because the *p*-value is 0.028303 (less than 0.05) and the zero-point does not lie within the confidence interval (–0.23163, –0.12915), this slope, with 95% assurance, is significantly different from zero. This precludes the possibility of a horizontal best-fit line – a horizontal best-fit implies no relation between the variables. Moreover, the correlation coefficient for the data (*R*, in the upper-right hand corner) is approximately –0.97834, the negative sign signifying the fact that the variables are negatively associated: As one increases, the other decreases, and vice versa. The closeness of R to the number one quantitatively serves to show how closely the variables are correlated: If R is closer to one, the correlation is stronger. The results of Figure 6.29 in which AC usage decreases as age increases, is contrary to expectation, which says that the elderly (65 or older) are inclined to use their AC more often.

The correlation between the average summer monthly bill and annual household income is shown in Figure 6.30. With a sample response size of 194, one notices that as annual household income increases, the summer monthly bill increases, perhaps owing to the fact that a higher income household uses more electricity than a household with a lower annual income. The slope (0.00043411) is different from zero, albeit small. This is so because the p-value is 0.0058886 or, equivalently, because the c-interval is (0.00029998, 0.00056824), to the exclusion of zero. It must be noted that the numbers along the horizontal axis are in units of tens of thousands of dollars ($\times 10^4$), such that the number 2 on the axis, for example, represents an income of \$20,000 and the number 10, \$100,000.

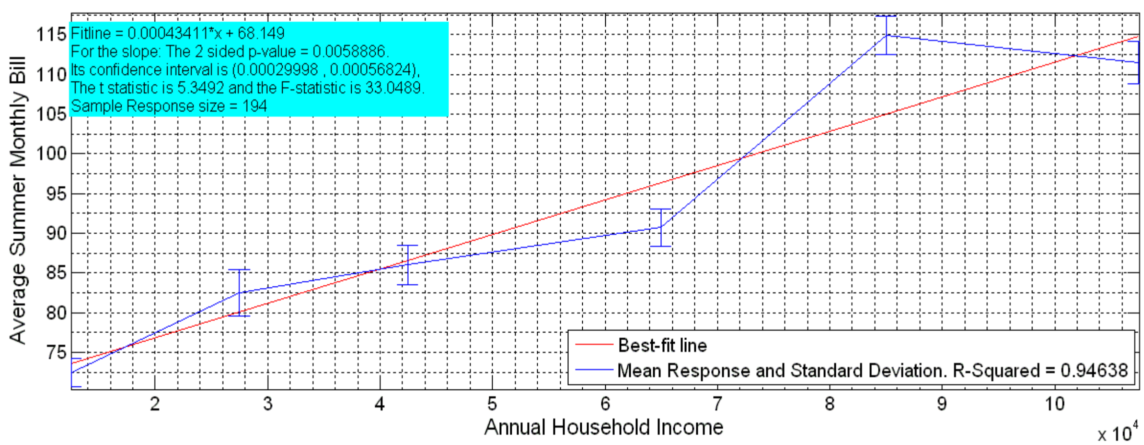


Figure 6.30: Average summer monthly bill (in dollars) regressed with annual household income (in dollars).

In the comparison of the mean level of interest in Program Option One with annual household income, an overall positive association is observed, as seen in Figure 6.31: Although the mean response, in blue, is not monotonic, the best-fit line, in red, is monotonically increasing with a slope of 7.2473×10^{-6}. In the survey, the level of interest is on a scale from one to five, one being little to no interest, five being strong interest.

The mean level of interest, however, is on a scale from 2 to 2.9; all mean interest levels fall within this range. The correlation coefficient for data, moreover, is 0.94753.

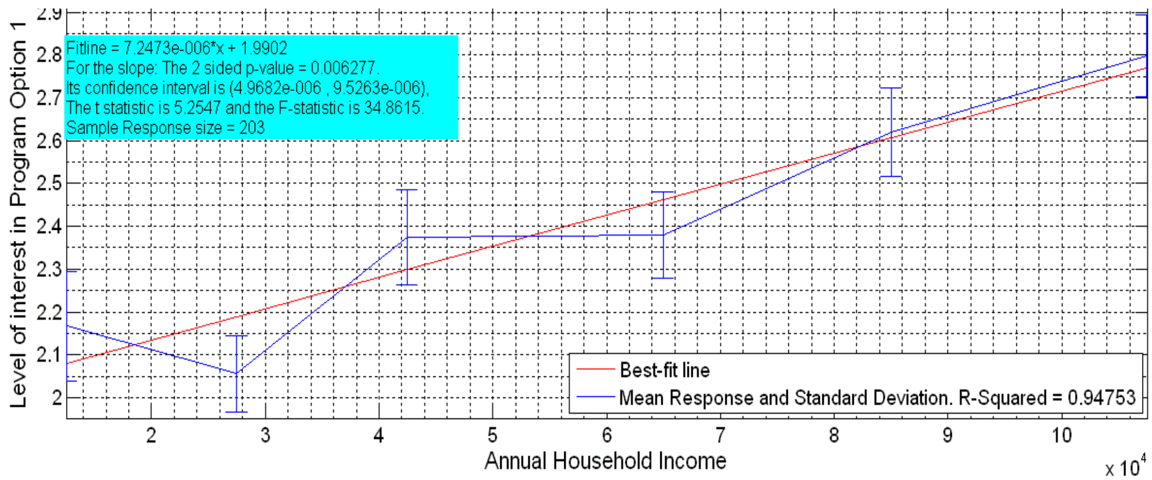


Figure 6.31: Level of interest in Program Option One regressed with annual household income (in dollars).

Regarding the mean interest level in Program Option Two, moreover, a positive relationship in relation to annual household income is again observed, as in Figure 6.32. The strength of the correlation is approximately the same as before, with an R of 0.95466; the slope is 8.9329×10^{-6}, which, though small, is significantly different from zero in a relative sense – in relation to the variance. That is, the F-statistic is 41.1023, which is very large, indicating that the slope cannot be zero.

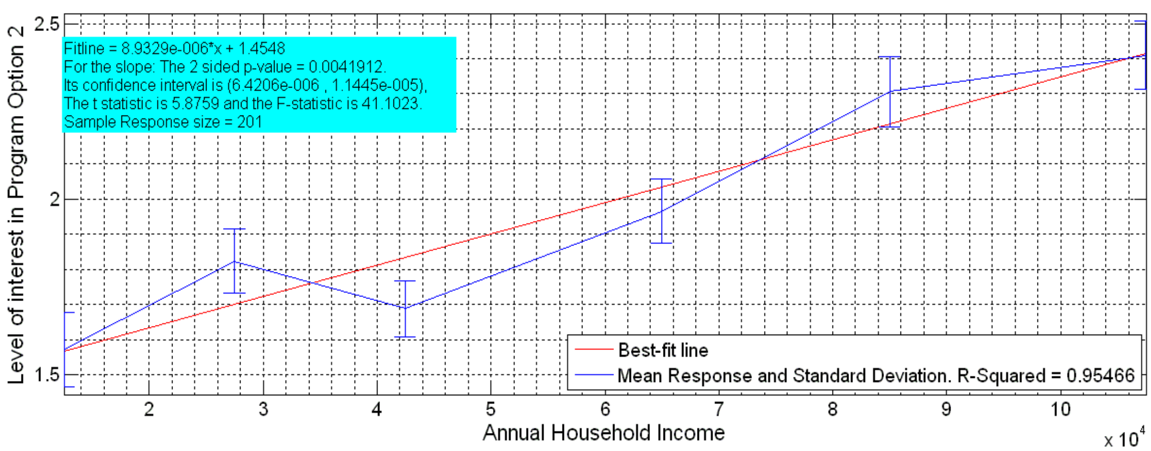


Figure 6.32: Level of interest in Program Option Two regressed with annual household income (in dollars).

Another important correlation is the one between the average summer monthly bill of the respondents and the financial incentive required by the respondents to participate in the programs, both in Program One (Figure 6.33) and Program Two (Figure 6.34). In Figure 6.33, a positive correlation exists between the financial incentive for Program One and the summer bill: From a sample response size of 224, the best-fit line has a slope of 0.12354, with a correlation coefficient of 0.92365. Although there are some small dips in the mean-response curve, the best-fit line is a fairly good approximation for the increasing nature of the relationship between the variables.

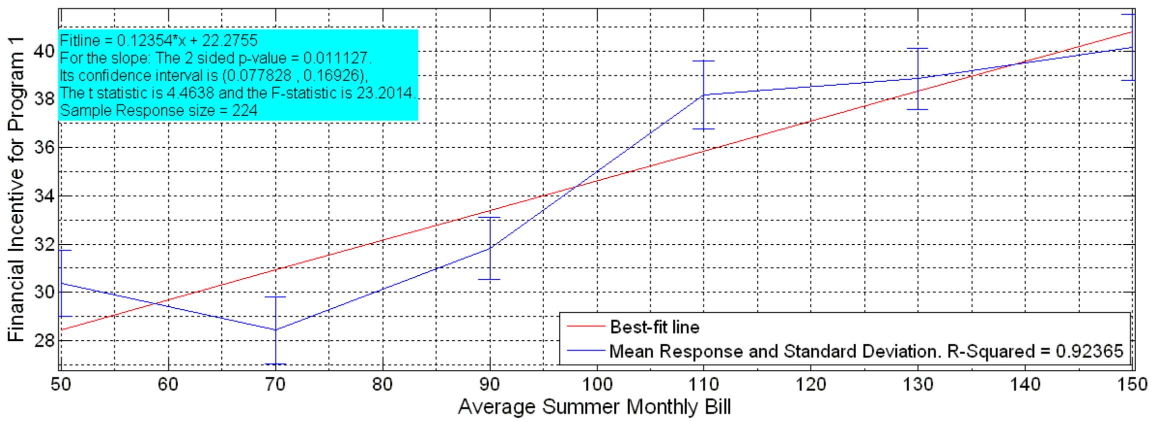


Figure 6.33: Financial incentive for Program One (in dollars) regressed with average summer monthly bill (in dollars).

In Figure 6.34, among a sample size of 222, the slope of the regression is 0.11465, with a correlation coefficient of only 0.88427. One notices that, upon comparison of Figure 6.33 with Figure 6.34, the correlation between financial incentive for Program One and the summer bill is stronger than that between financial incentive for Program Two and the summer bill: Graphically, the regression line of Figure 6.33 better fits its data than the regression line of Figure 6.34 does its data; numerically, the R in the former is greater than that in the latter. Both Figures, however, represent a positive correlation between the incentive and the bill: For a given household with a greater average summer monthly bill, in general such a household requires a greater financial incentive to participate in both programs, regardless of the strength of the respective correlations. Both Figures represent, approximately, the same sample response size.

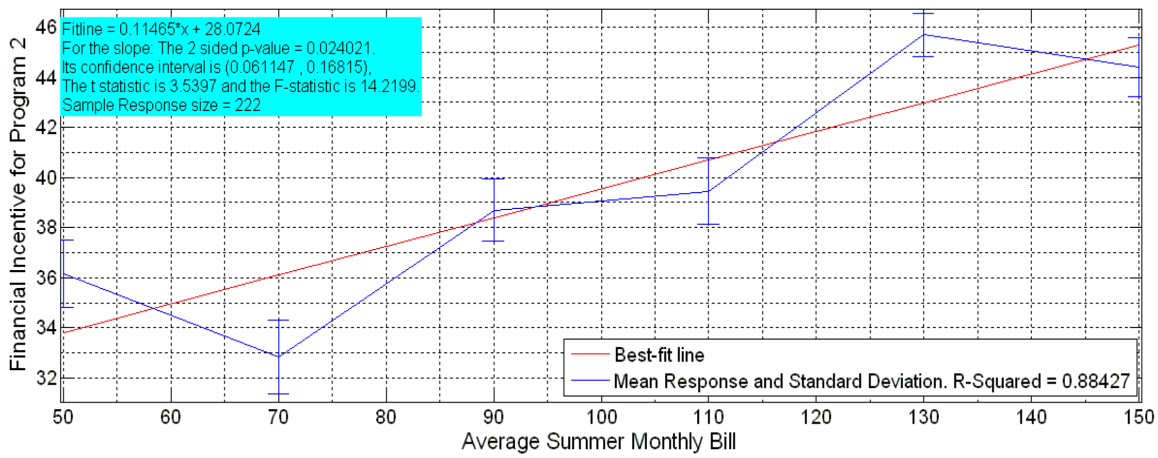


Figure 6.34: Financial incentive for Program Two (in dollars) regressed with average summer monthly bill (in dollars).

Among the demographics, educational background is found to have a strong correlation with the annual income of the household (Figure 6.35). With a correlation coefficient of 0.94141, the regression slope is approximately 9,854, a positive correlation: More educated individuals have in general a greater income, as expected. The units on the educational background axis, which range from one to eight, represent discrete levels of education attained by the respondent, which are enumerated in Table 6.3.

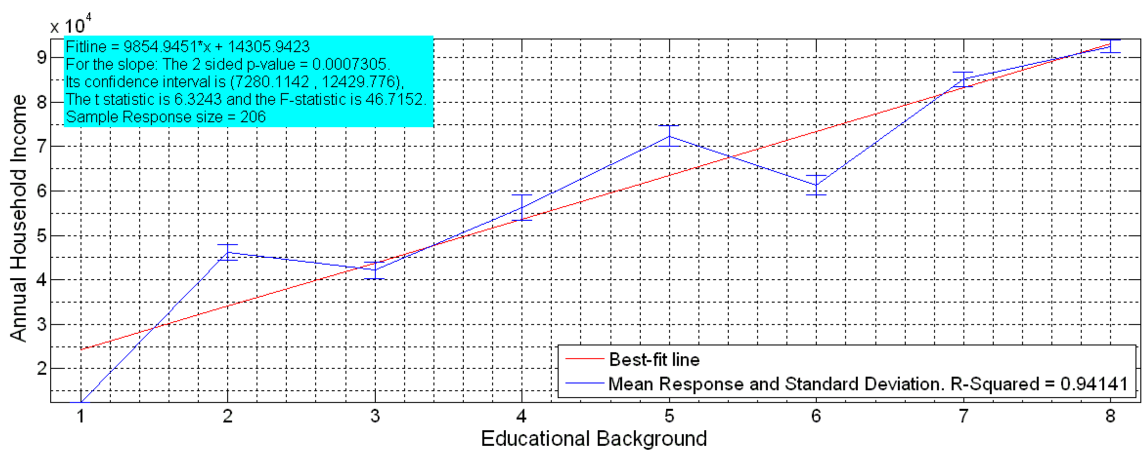


Figure 6.35: Annual household income (in dollars) regressed with educational background (see Table 6.3).

Number in Figure 6.35	Option in Survey
1	Less than ninth grade
2	Some high school
3	High school graduate
4	Trade school
5	Some college
6	Associate’s degree

7	Bachelor's degree
8	Master's/Ph.D

Table 6.3: Explanation of numbers on educational background axis in Figure 6.35.

It is also expected that as the summer hourly AC usage increases (again, for days greater than 90°F), the average summer monthly bill also increases. Figure 6.36, in which the mean summer bill is plotted against the hourly usage, corroborates this expectation.

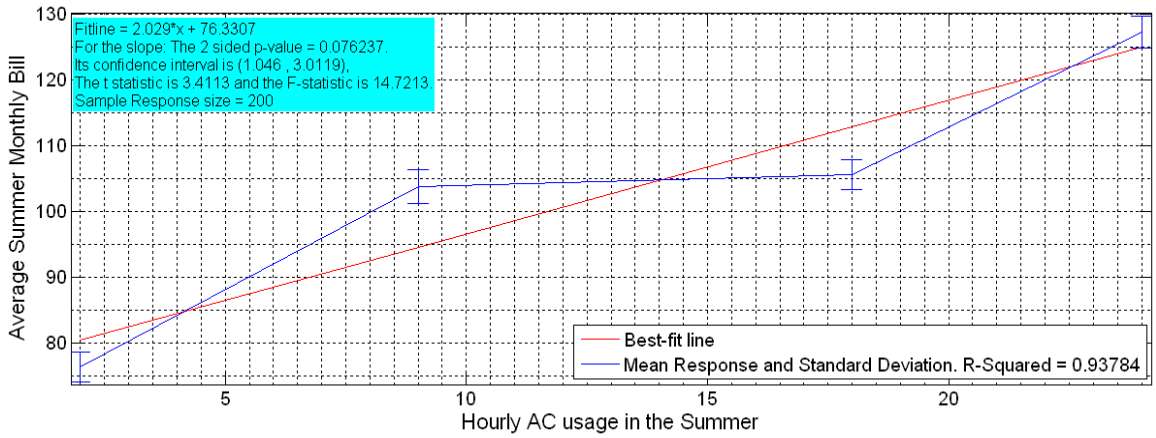


Figure 6.36: Average summer monthly bill (in dollars) regressed with hourly AC usage in the summer (in hours).

As the number of AC units in a household increases as well, the summer monthly bill increases. This is clear from Figure 6.37: The regression is not very linear, however, seeing as how $R = 0.83228$; the graph sinks and then rises up steeply.

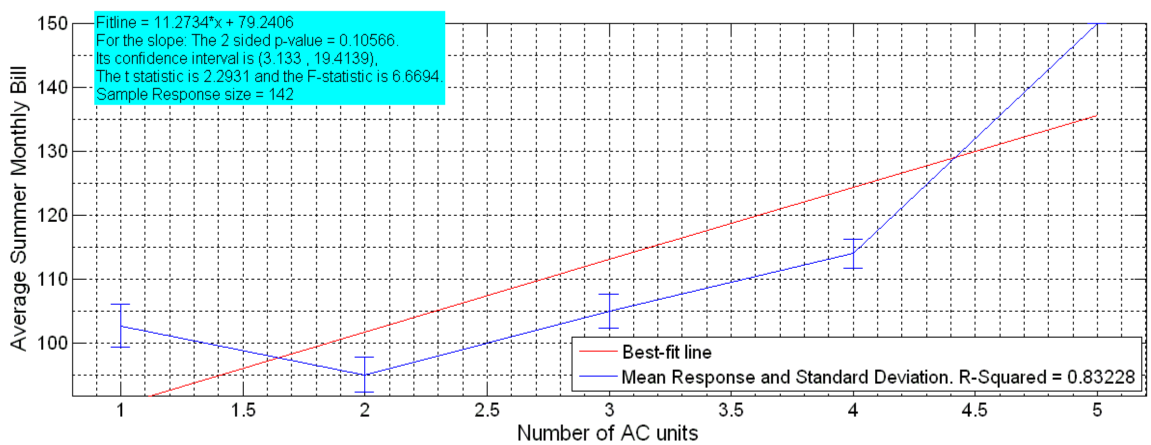


Figure 6.37: Average summer monthly bill (in dollars) regressed with the number of AC units.

The extent to which the level of interest in the programs affects the financial incentive required to participate in them is shown in Figure 6.38 and Figure 6.39. In

Figure 6.38, the mean financial incentive for Program One is regressed with the level of interest in Program One with a slope of –6.8736 and an *R* of –0.91936. The relationship between the variables is a negative one, hence the negative values for *R* and for the slope: Generally, as the level of interest increases, the required financial incentive decreases. Perhaps those individuals more enthusiastic about Program One do not need a significant amount of money to participate in the program on account of such a heightened willingness to get involved. The same applies for Program Two. In Figure 6.39, a negative relationship exists between the financial incentive to participate in Program Two and the level of interest in Program Two. The mean-response curve is in fact very linear, the best-fit line (with a slope of –8.3938) fitting the data with a correlation coefficient of –0.9921, the negative sign again signifying a negative correlation.

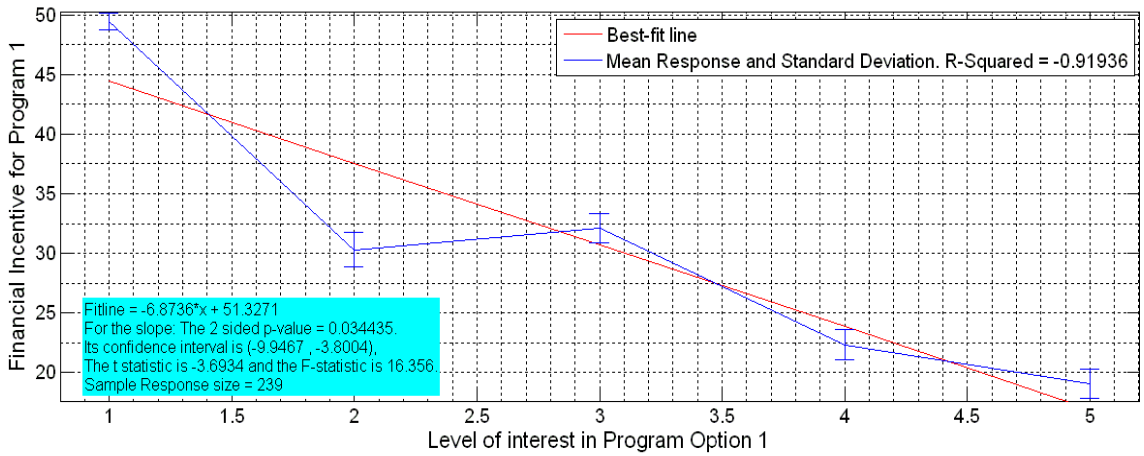


Figure 6.38: Financial incentive for Program One (in dollars) regressed with level of interest in Program One.

For clarity, it must be noted that the range of the level-of-interest axis is from one to five, as before, with the increments along the axis in half-integer steps. Although there is no option such as 1.5 or 2.5 in the survey, such numbers are included to make sense of the regression.

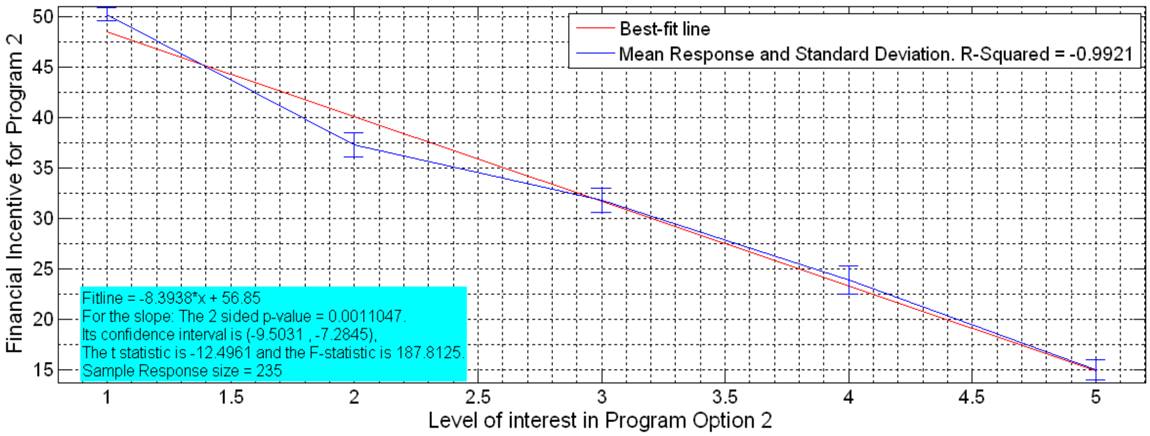


Figure 6.39: Financial incentive for Program Two (in dollars) regressed with level of interest in Program Two.

Previously the level of interest in the programs was the independent variable in Figure 6.38 and Figure 6.39; now it is the dependent variable, with the usual summer thermostat temperature setting instead being the independent variable. Figure 6.40 shows the regression of the level of interest in Program One with respect to the usual summer thermostat setting. Those households that usually set their thermostat settings to a high temperature typically are more interested in participating in Program One, as evidenced by their higher level of interest. This positive correlation has a slope of 0.090251 with a correlation coefficient of 0.97207.

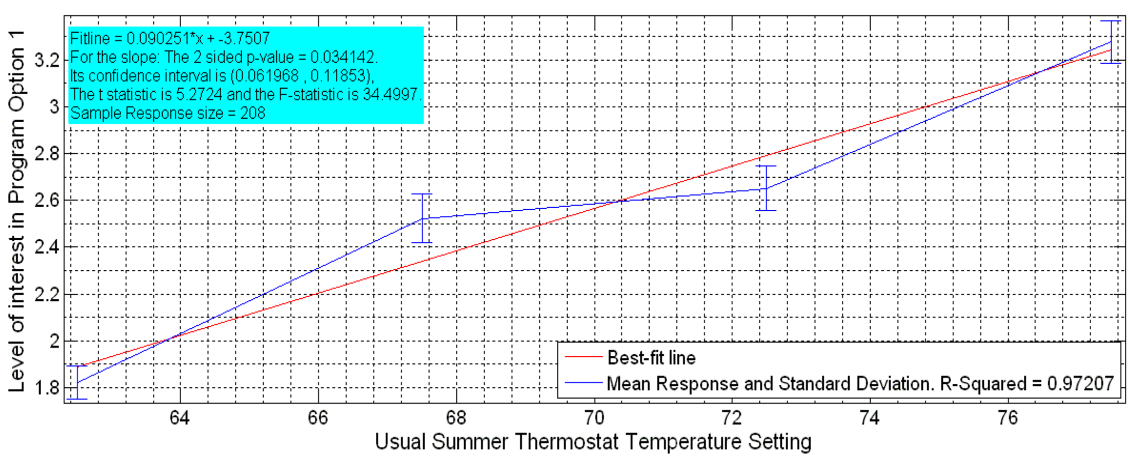


Figure 6.40: Level of interest in Program One regressed with the usual summer thermostat temperature setting (in °F).

Figure 6.41 is similar, expect in this case the level of interest in Program Two is examined. The mean-response is extremely linear, with a slope of 0.050526 and an R of

0.99869! Again, this serves to show that as a household's usual summer thermostat temperature increases, its level of interest in Program Two increases linearly.

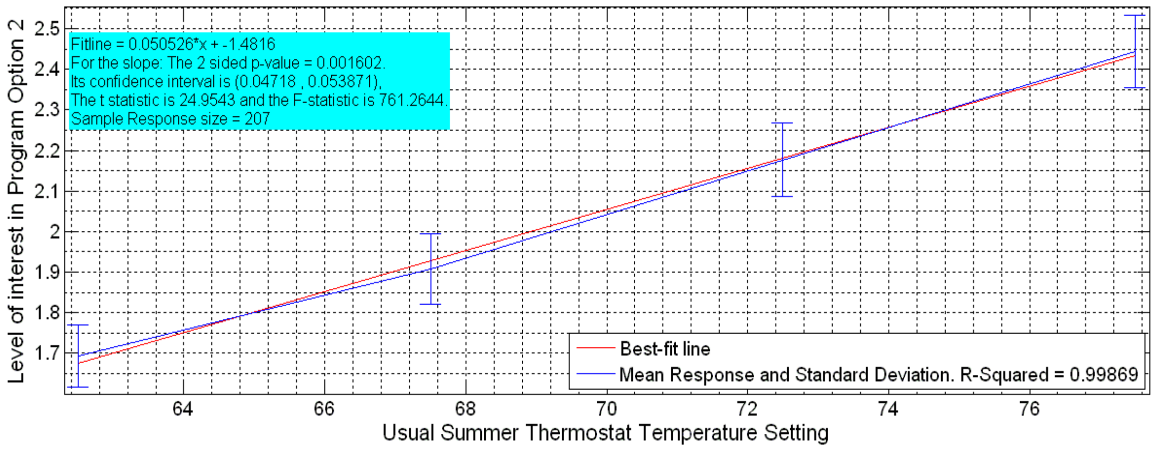


Figure 6.41: Level of interest in Program Two regressed with the usual summer thermostat temperature setting (in °F).

Summary of Associations

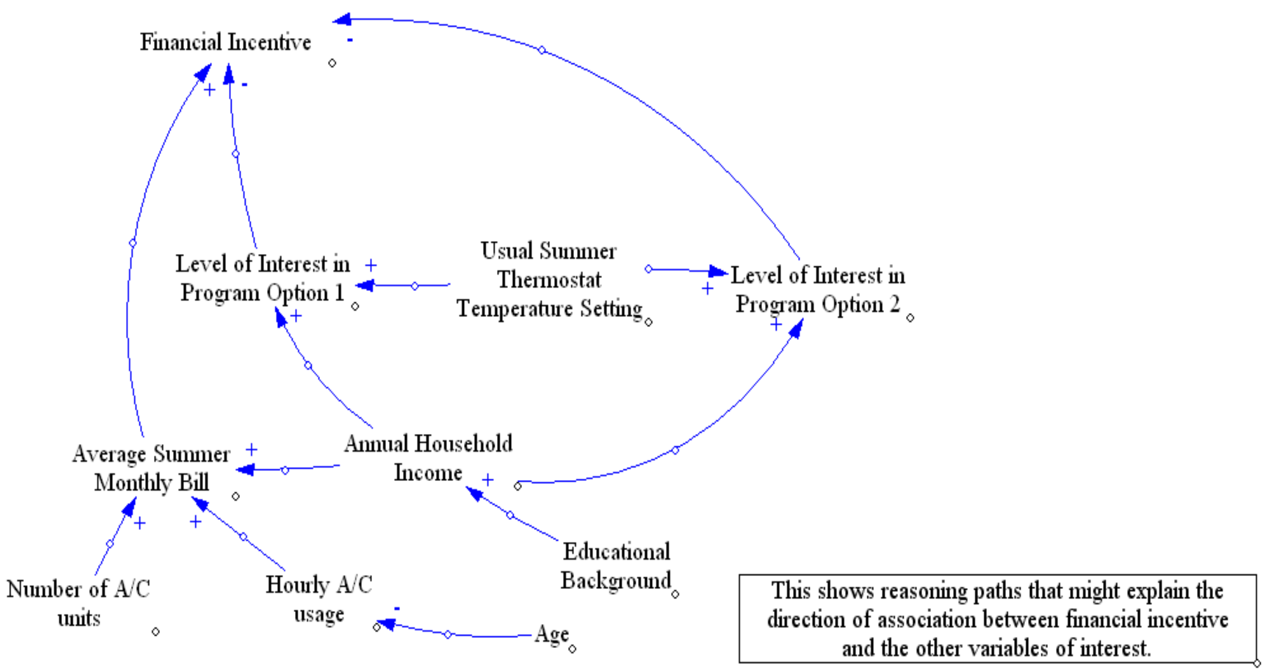


Figure 6.42: Diagram showing the signs of regression slopes.

Figure 6.42 shows the relationship between the variables that was derived from the collected data. The arrowhead signs (+, –) show the direction of association between the related variables. The “+” signs indicate positive relation between the variables, while “–” signs indicate a negative relation.

The regression plots and Figure 6.42 deal with pairwise relations in which two variables are taken at a time. The relationships included are those which have high correlation coefficients (greater than 0.8) and which have residuals that are uniformly distributed about the regression line. The other variables and links in Figure 5.1, which do not exhibit these two characteristics, are excluded under the assumption that their non-linear relationships imply the presence of confounding variables. Although this Figure should not be interpreted as showing a causal relationship due to the possibility of hidden variables that might confound results, it can be used as a basis for making hypotheses on the coefficients from multivariable regression. Also, it suggests possible routes through which each included variable might be able to influence the financial incentive variable. The financial incentive is the variable that will be predicted with multivariable regression in Section 6.6.

The following is an explanation of some of the anomalies found in exploring interrelationships in Figure 6.42:

- Although it was expected that older respondents will use their air-conditioning (AC) more frequently due to health reasons, the results show that hourly usage decreased with increasing age. A confounding variable in this case could be the level of insulation for the house. Those with poor insulation might feel the need to use the AC more often. It might also be possible that a respondent of any age, comfortable with a particular thermostat setting, maintains that setting without having the AC turned on as frequently. This variable could have reversed the expected direction of association.

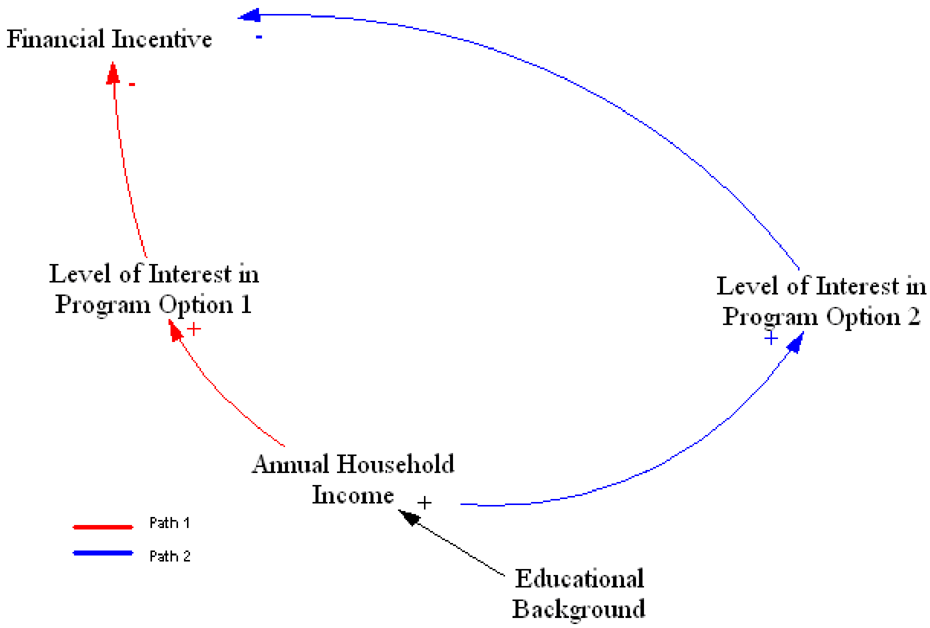


Figure 6.43: A section of Figure 6.42 showing two paths from educational background to financial incentive through the level of interest in Program One (path 1) and level of interest in Program Two (path 2).

- From Figure 6.43, one sees that educational background is positively associated with annual household income, which in turn is positively associated with the level of interest in both DR programs. Furthermore, the levels of interest in Programs One and Two are negatively associated with financial incentive. Assuming the property of transitivity is applicable, it can be hypothesized that educational background is associated with financial incentive. [Transitivity states that if *a* is related to *b*, and *b* is related to *c*, it follows that *a* is related to *c*.] To determine the direction of the association, the signs of the constituent paths are multiplied: The two paths from educational background to financial incentive (paths one and two in Figure 6.43) both contain two positive signs and one negative sign; thus, the association between these two variables is negative along both paths.

  The conclusion seems to be that more highly-educated consumers are expected to look more favorably toward DR programs and thus require less financial incentive to participate. However, the path that goes from educational background to financial incentive through the average summer monthly bill variable, shown in Figure 6.44, indicates an opposite association between the two:

The three positive signs along the path make a positive product. In this way, educational background and financial incentive would be positively associated. In light of their higher monthly bill, the desire to gain some money might influence respondents to ask for a higher incentive; this is one way of explaining the anomaly.

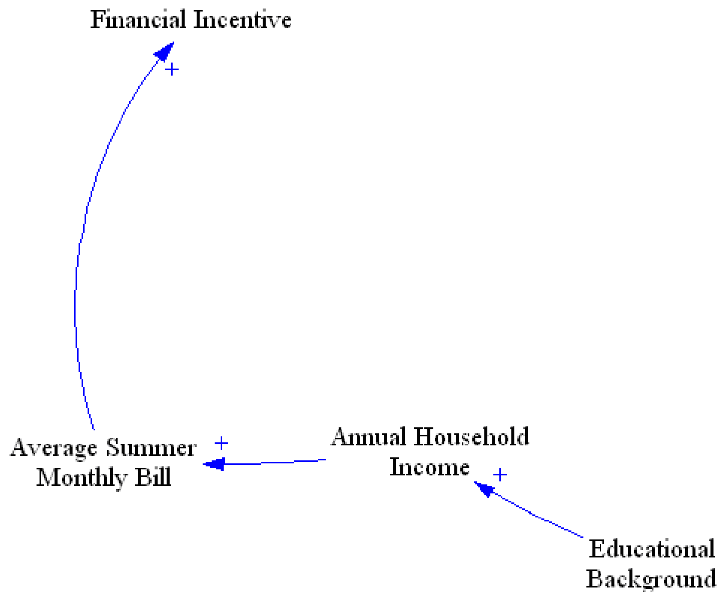


Figure 6.44: A section of Figure 6.42 showing the path from educational background to financial incentive through the average summer monthly bill.

In multivariable regression, all the variables present are taken into account when predicting a certain outcome. This can be used to predict the financial incentive required by consumers. Multivariable regression can also work to the effect of revealing the true direction of the association between educational background and financial incentive among the sample data. However, one should not interpret the regressions and the diagrams as being causal until an adequately controlled and randomized experiment clears doubts concerning the presence of confounding variables. (Correlation does not imply causation.)

6.6 *Multivariable Regression*

In order to predict the amount of financial incentive required by a respondent, it is necessary to build a robust model that incorporates all the factors that strongly affect the variable. From Figure 6.42, the financial incentive is correlated with nine variables, either positively or negatively. Two of the nine—the levels of interest in Programs One and

Two—are believed to be causally related to financial incentive; in addition, the strength of the association of these two variables to financial incentive is so strong as to mask the strength of the relationships of the other seven to the incentive. The directions of association of the nine variables with financial incentive are hypothesized in Figure 6.45. It is to be noted that the "level of interest" variable in the Figure is an aggregation of two variables, those for Programs One and Two.

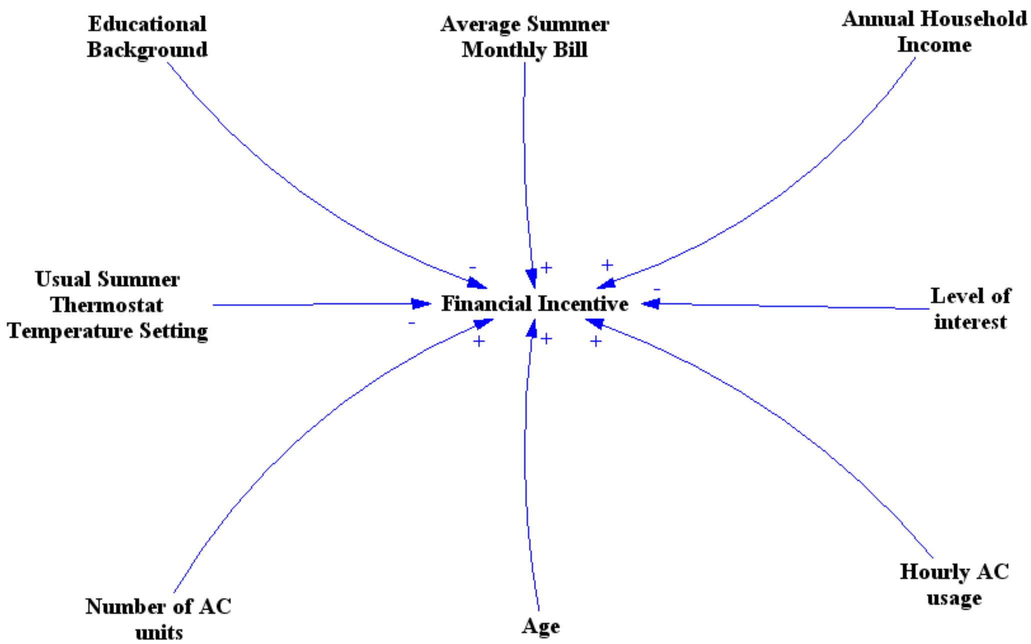


Figure 6.45: Hypotheses on the directions of association toward financial incentive.

The direction of the association hypothesized for a particular variable was determined by multiplying the signs along the path in Figure 6.42 that travels from that variable to financial incentive. Underlying the construction of these hypotheses is the assumption that the path shown in Figure 6.44 does not significantly affect the direct association between educational background and financial incentive. Consequently, educational background and financial incentive are hypothesized as being negatively associated to each other in Figure 6.45.

Results of the Multivariable Regression

Table 6.4 summarizes the results of the multivariable regression. (For the method behind the computations, see **APPENDIX E: Matlab Code for the Survey.**) The Table lists all independent variables and, accordingly, the two sets of coefficients related to each variable—one set for Option One, another for Option Two. These coefficients are used to predict the financial incentive requested by the respondents for participation in Option One and Option Two, respectively.

The Table is to be understood in the following manner: The total financial incentive required to participate in an option is hypothesized to be a weighted sum over all independent variables. In this case, the coefficients in Table 6.4 serve as the weights.

Independent Variables	***Option 1 coefficients***	***Option 2 coefficients***
Age	−0.059249883	−0.088701386
Annual household income	−7.34727E−05	−6.77236E−05
Average summer monthly bill	0.132183924	0.089322161
Educational background	−0.929461119	−0.328133969
Number of AC units	0.651054661	1.972938132
Usual summer thermostat temperature setting	0.7928553	0.762991566
Hourly AC usage in the summer	−0.018355573	0.168528518
Level of interest	−7.864779491	−8.358662411

Table 6.4: Multivariable regression coefficients for predicting financial incentive.

As shown by the coefficients in Table 6.4, the directions of association are the same for both Options One and Two, except for the hourly AC usage in the summer variable. For all other variables, the Option One and Option Two coefficients have the same sign. For both options, only average summer monthly bill and the usual summer thermostat temperature setting are positively associated with financial incentive. Age, annual household income, educational background, and level of interest are, on the other hand, negatively associated for both options. Lastly, hourly AC usage in the summer has a negative sign in Option One, but a positive sign in Option Two. As previously stated, the educational background remains negatively associated when directly regressed with financial incentive.

At the 0.05 confidence level, the confidence intervals for Option One and Option Two coefficients are tabulated in Table 6.5 and Table 6.6, respectively. In Table 6.5, the only independent variables with 95% confidence intervals that exclude zero are average summer monthly bill, usual summer thermostat temperature setting, and level of interest; such variables have *p*-values less than 0.05. In Table 6.6, moreover, usual summer thermostat temperature setting and level of interest are the only ones that satisfy the condition. It is seen, therefore, that for *both* options, the only two variables that have confidence intervals that exclude zero are usual summer thermostat temperature setting and level of interest. This suggests that one might need to relax the tolerance level to account for the buildup of random variations contributed by each variable involved.

Option One				
Independent Variables	***95% Confidence Intervals for Coefficients***		***p-value***	***t-statistic***
Age	−0.419465145	0.295915678	0.732703533	−0.342441053
Annual household income	−0.000229826	5.13723E−05	0.211062562	−1.258332057
Average summer monthly bill	0.050847904	0.24615112	0.003219865	3.01528156
Educational background	−3.223513894	1.429659087	0.446343726	−0.764399394
Number of AC units	−1.926983814	4.120008751	0.473679625	0.719095182
Usual summer thermostat temperature setting	0.279578249	1.218244275	0.002036107	3.163963763
Hourly AC usage in the summer	−0.44767256	0.531659159	0.8653024	0.170044431
Level of interest	−9.970378316	−5.316465939	2.5978E−09	−6.513012055

Table 6.5: 95% confidence intervals, *p*-value, and *t*-statistic for each Option One coefficient in Table 6.4.

Option Two				
Independent Variables	***95% Confidence Intervals for Coefficients***		***p-value***	***t-statistic***
Age	−0.424719572	0.2473168	0.60169327	−0.523598967
Annual household income	−0.00019784	6.239E−05	0.304336323	−1.032378847
Average summer monthly bill	−0.00210005	0.1807444	0.055396359	1.937932537
Educational background	−2.525810201	1.8695423	0.767714068	−0.296154704
Number of AC units	−0.869056722	4.814933	0.171539204	1.376960031
Usual summer thermostat temperature setting	0.317995786	1.2079873	0.000960072	3.400908906
Hourly AC usage in the summer	−0.314415319	0.6514724	0.490408117	0.692162281
Level of interest	−10.77427537	−5.9430495	5.35105E−10	−6.863420214

Table 6.6: 95% confidence intervals, *p*-value, and *t*-statistic for each Option Two coefficient in Table 6.4.

According to Figure 6.42, educational background was previously expected to influence the financial incentive through the annual household income. However, annual household income seems to have a weaker relationship with financial incentive than does educational background. This may suggest that a different route excluding annual household income might better explain the direction and strength of association between educational background and financial incentive.

The direction of the associations (+ or −) between the independent variables and financial incentive are presented in diagram form in Figure 6.46 and Figure 6.47. They reflect the signs of the coefficients for Options One and Two obtained using multivariable regression (as presented in Table 6.4). Such signs can be compared with the signs of the original hypothesis in Figure 6.45. Only the variable age had its sign reversed for both options. The hourly AC usage reversed its sign for the first option. However, as indicated by its *p*-values for Options One and Two, it is not very significant relative to the variables considered. The variables with the most significance are the average summer monthly bill, usual summer thermostat temperature setting, and the level of interest in Options One or Two.

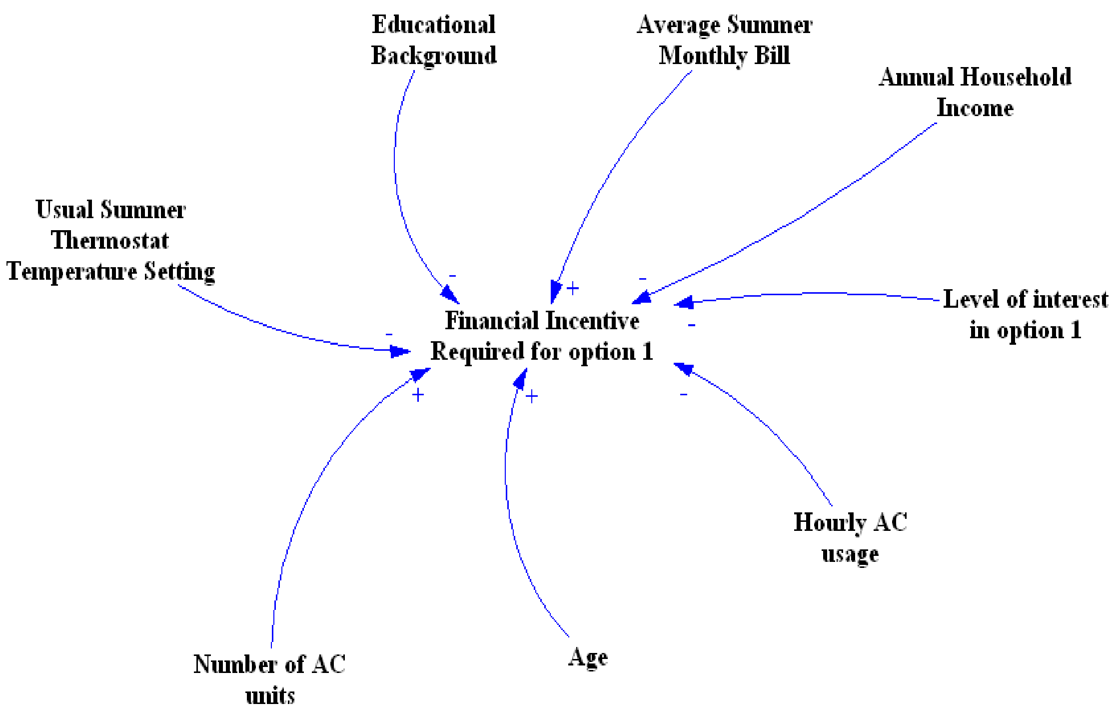


Figure 6.46: The associations for Option One that are developed from Table 6.4.

For the given data set from the sample, based on the strengths of the correlation coefficients and on the coefficients' *p*-values, the major predictors for financial incentive could be the variables displayed in this multivariable regression analysis. The variables with *p*-values above 0.05 are relatively weak predictors of required financial incentive. A *linear* model might not be adequate, since there might be interactions between variables that the linear model does not capture. In addition, there is a level of arbitrariness in answering the required financial incentive question, since the respondents, on the average, might have based their response on their level of interest, desire to get some compensation for their electric bill, and how much they feel they need air conditioning.

Note that the obtained results pertain to the sample data and is thus dangerous to be used as a basis for extrapolation. More precision might be obtained by including extra questions in a modified survey to minimize the effects of the identified confounding variables. The extra questions will also find out how much time the respondents spend at home during the day in the summer, as well as how many children stay at home during that time. In addition, making the data set more representative of the GBA homeowner population by increasing its size and giving every geographic section in the GBA an equal level participation in the sampling procedure would help to reduce potential geographical biases.

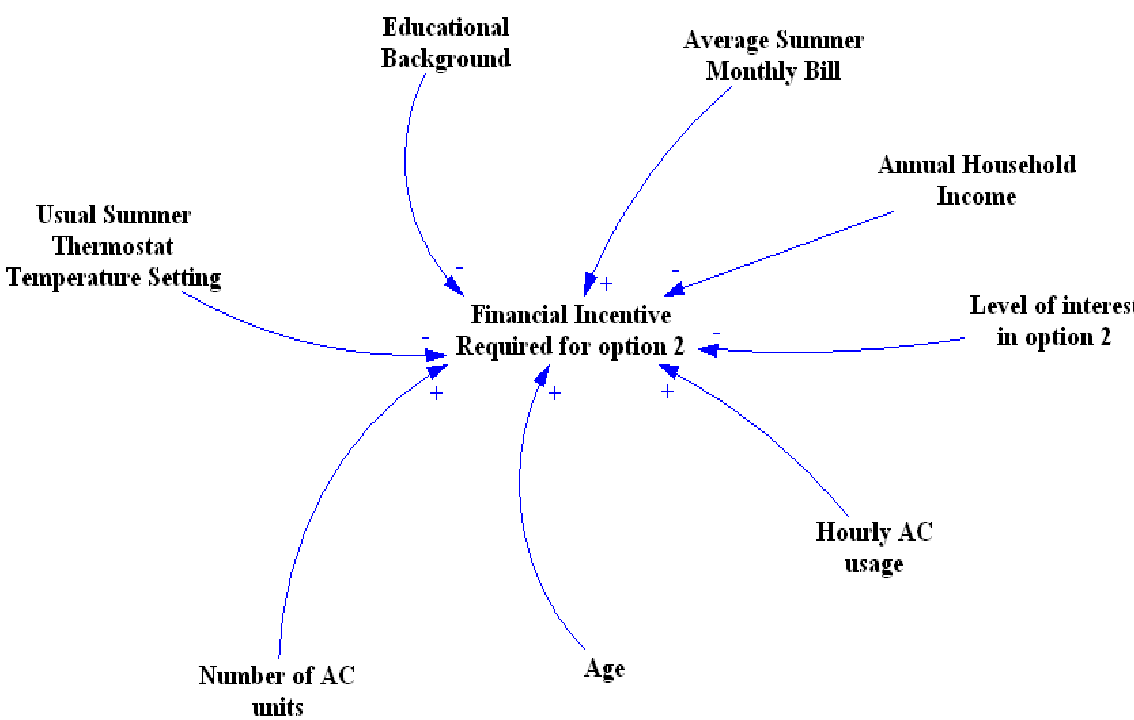


Figure 6.47: The associations for Option Two that are developed from Table 6.4.

CHAPTER 7: Economic Model

The implementation of Demand Response programs serves to reduce the average load (in megawatts) for the region in which they are implemented. Figure 7.1 shows how the average load as a function of time in hours of the day is reduced by 10% up to as much as 30%.

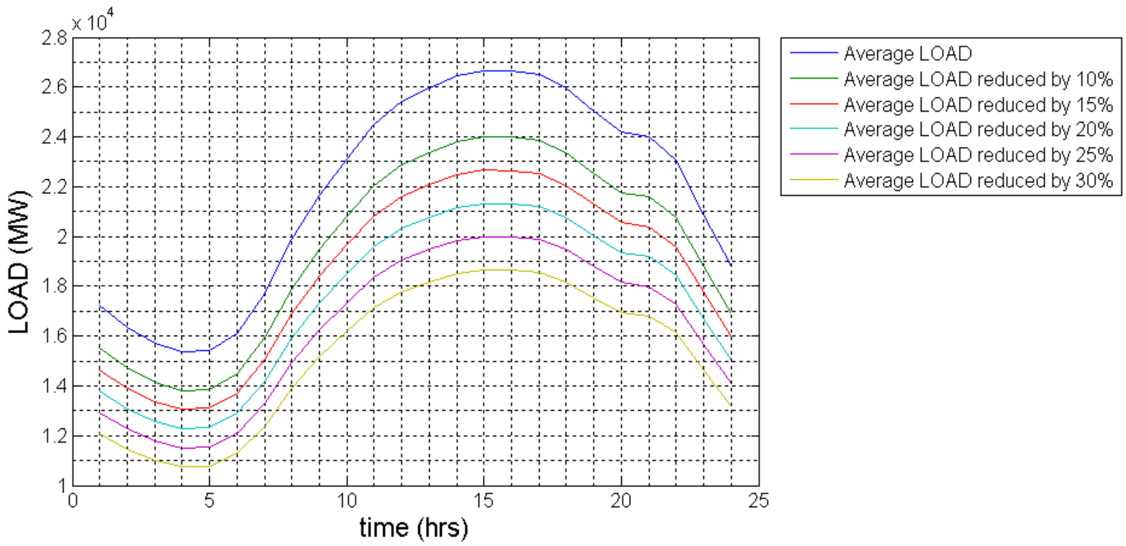


Figure 7.1: Average load (in megawatts) versus time (in hours of the day) for summer 2006.

Using the graphs from **CHAPTER 1: Introduction** (namely, Figure 1.2) in conjunction with Figure 7.1, one arrives at Figure 7.2, which shows the total cost saved (in millions of dollars) as a function of the percent reduction of the load. This total cost saved is for a seven-day period. (To see how the graphs in this section were generated see Section E.5: Code for Economic Model in **APPENDIX E: Matlab Code for the Survey.**)

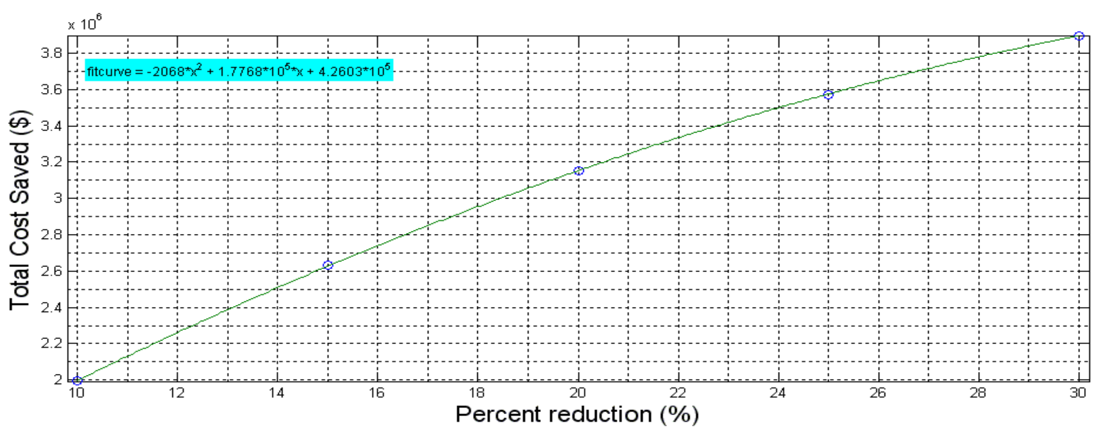


Figure 7.2: Total cost saved (in millions of dollars) versus percent reduction of the load.

CHAPTER 8: Conclusion

The overarching goal of the project was to report on the average person's perceptions of Demand Response programs and, to some extent, on the feasibility of such programs. More specifically, the study focused on the Greater Boston Area as part of the NEMA region. Two Demand Response options were proposed as described in the survey and in the earlier part of the report. The first option involved notifying the consumer of an expected shortage of power the next day, and urging the consumer to either shut off the AC or raise the room temperature by as much as 10°F. The second option proposed an automatic cycling of the consumer's AC in order to raise the room temperature by as much as 10°F.

It was interesting to study the responses participants had to some specific questions posed to them. When asked which of the two options is more appealing, the general consensus was that the first option was a better choice: Roughly twice as many preferred Option One over Option Two. Several respondents commented that they would prefer Option One over Option Two because they did not like the idea of losing control over their energy usage in the latter. Many more noted that they would not like either option since they involve a compromise with their day-to-day energy consumption. A few comments, however, were very encouraging and suggested that some people would be willing to participate in such programs provided there were incentives in the package. A few others noted that they would be more than willing to participate in the programs irrespective of the incentives provided.

Figure 8.1 shows, in general, why the respondents chose a particular option, with Table 8.1 explaining what each letter in Figure 8.1 stands for. The most popular reason was *E: For personal control of AC cycling* with 44 respondents; the second most popular was *O: Limited AC use in general (or in weekdays in particular)* with 15 respondents. The other reasons were not as significant. That is to say, most respondents who replied with comments said that they wanted to retain personal control of the AC (and so not participate in Option Two) or that they did not feel the need to participate in either program because their AC use was in general limited anyway.

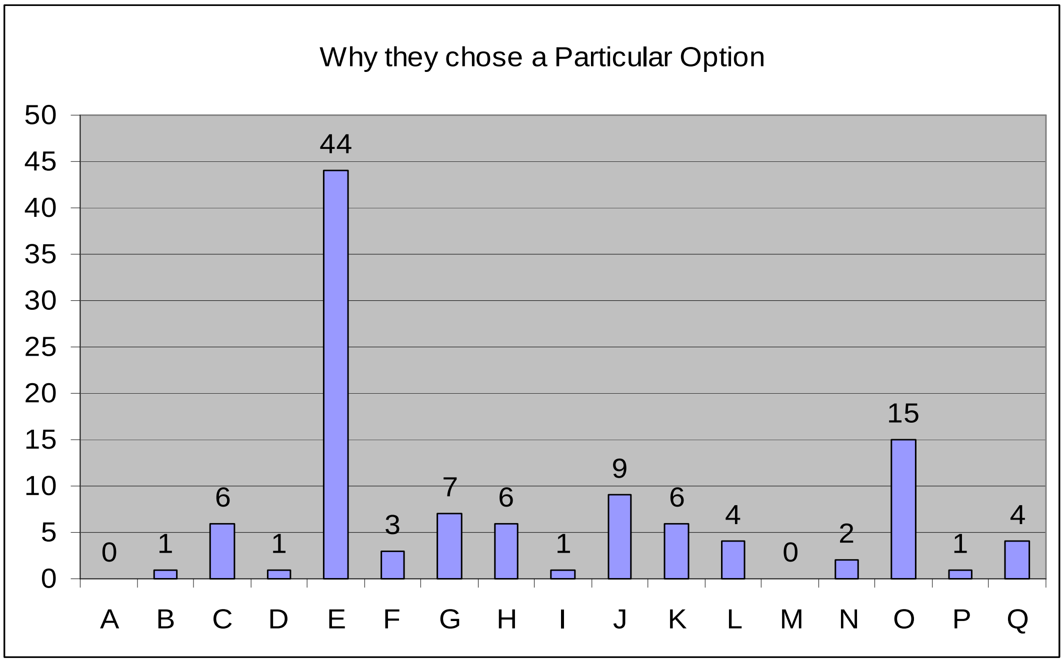


Figure 8.1: Why the respondents chose a particular option.

A	Against air conditioner cycling
B	For AC cycling
C	Against company control
D	For company control
E	For personal control of AC cycling
F	Worried program would result in too many interruptions
G	For phone: advance warning system
H	Against phone: annoying, unreliable, unavailable
I	Against an automatic device controlling AC
J	For an automatic device controlling AC
K	Health reasons
L	Already have an energy saving AC cycling system
M	Have good insulation
N	Have bad insulation
O	Limited AC use in general (or in weekdays in particular)
P	Worried that the device could not be removed in the future
Q	Distrust of utility company

Table 8.1: Option key for Figure 8.1.

Based on the responses in the survey, the IQP team attempted to determine the most important predictors of financial incentives for both programs. Having done a multiple regression for the financial incentive required for each of the variables (survey questions), it was found that the financial incentive required depended mainly on the consumer's average summer monthly bill and the usual thermostat setting. These were the only two variables (besides the level of interest participants said they had in these programs) that had *p*-values less than 0.05. What this means is that there is some significance to the slope relating the financial incentive required to the variable in question (assuming a linear model throughout).

Having determined these predictors, the last step was to determine how much financial incentive a consumer will require to participate in either of the two proposed options. There are essentially two ways of approaching this. One of the survey questions asked about the financial incentive (in dollars per month) a consumer would demand in order to participate in either option. The responses to this question give an indication of the financial incentive that might be required. Another option is to take the coefficients from the multiple regression analysis, and to multiply them with the values for the independent variables used in the model. Based on this weighted sum, it is possible to arrive at a rough estimate of the financial incentive a certain Demand Response program might require in order for a certain percentage of the population to participate.

In general, from the survey results, Figure 8.2 shows the average participation of the respondents based on the incentive required. That is, 12.50% would participiate in a DR program with no incentive; 35% would participiate with a moderate incentive; and 52.50% would not participate at all.

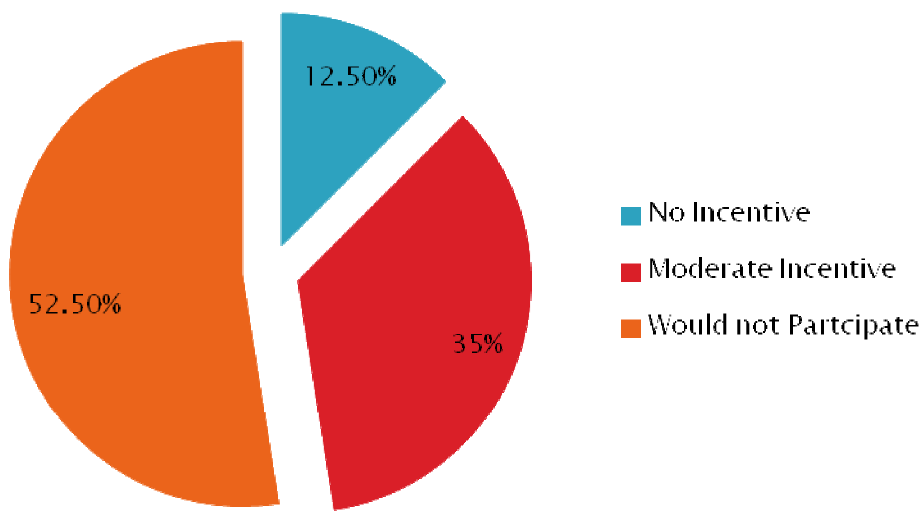


Figure 8.2: Average participation by percentage due to incentive.

Although only a small sample population responded to a survey describing two hypothetical DR scenarios, some general conclusions can be drawn. For one, there is substantial resistance to Program Two among about half of the sample population. Secondly, a great majority of the sample population would require a substantial incentive to participate in a DR program. It also appears that the sample population does not have a good understanding of what size incentive is appropriate.

In order to be able to gain a better confidence margin in the statistical analysis of the survey results, this survey could potentially be extended to a larger audience (sample size) with a greater diversity, more representative of the population in the Greater Boston Area. For instance, a better statistical sampling scheme could be to divide the survey participants into different categories by county or township in line with a representative sample of the GBA. Then a simple random sampling process can be used to select individuals within these groups. Furthermore, the set of questions could be expanded to mitigate the effect of the confounding variables as mentioned in the previous section.

It seems that a majority of the homeowners surveyed are not yet ready to accept Demand Response programs that control their AC usage. An effective education program that promotes energy management and increases public knowledge about DR programs is therefore needed if Demand Response programs are to be successful in reducing peak demand. This project has laid out a good foundation for future projects to build upon and investigate the economic implications of Demand Response programs for both the supplier (ISONE, in this instance) and the consumer (household).

APPENDIX A: Survey

First, we would like to ask you a few questions about your past summer energy use. Please mark your answers to the following.

1. Have you experienced any electricity interruptions/outages longer than half an hour at your primary residence in the last summer (June to August)?

□ Yes □ No

If *yes*,

- **Please estimate how many you experienced in the last summer.**

  □ One □ 6 to 8
  □ 2 to 4 □ 8 or more
  □ 4 to 6

- **How long did these interruptions last on average?**

  □ Under an hour □ 4 to 8 hrs.
  □ 1 to 2 hrs. □ 8 or more hrs.
  □ 2 to 4 hrs.

- **How discomforted were you by these outages? (1 = not at all; 5 = very discomforted)**

  □ 1 □ 2 □ 3 □ 4 □ 5

2. Do you have air conditioning at your primary residence?

□ Yes □ No

If *yes*,

- **What type of air conditioning do you have?**

  □ Window A/C unit (specify the number of working units you installed last summer) _______
  □ Central A/C unit
  □ Both
  □ Not sure

- **At what temperature do you usually set your thermostat during the summer?**

  □ Less than 65° □ 70° to 75°
  □ 65° to 70° □ Higher than 75°

- **On a typical hot (greater than 90°) weekday during last summer, how long did you use your air conditioning?**

  □ Not at all □ 7 to 12 hrs. a day
  □ 1 to 3 hrs. a day □ 13 to 23 hrs. a day
  □ 4 to 6 hrs. a day □ All day

- **How often did you use your air conditioning between May 2006 and October 2006 during days when the temperature was less then 90°?**

□ Not at all	□ 14 to 28 days
□ 1 to 7 days	□ 28 to 40 days
□ 7 to 14 days	□ 40 or more days

3. What is your average summer monthly electric bill?

□ Less than $60	□ $100 to $120
□ $60 to $80	□ $120 to $140
□ $80 to $100	□ $140 or more

4. Overall, what is your biggest concern with electricity and energy?

□ The cost of electricity
□ Preventing power interruptions/outages
□ Renewable and clean energy
□ Other (please specify in the space below)

Demand-response programs are voluntary programs offered by electricity suppliers that encourage consumers to use less electricity during peak periods such as summer heat waves. The programs help reduce the chance of service interruptions, blackouts and help reduce the pollution associated with generating electricity. Because reducing demand during peak periods saves power companies money, participants are often offered a financial incentive for their participation.

Now we would like to ask you some questions about your willingness to participate in demand-response programs to save energy during summer heat waves. ***If you do not own an air conditioner please answer as if you did.***

When energy use is high,

- A common way demand-response programs save power is by reducing the amount of energy air conditioners use.
- Shutting off and turning on the air conditioning so that it is not constantly running is one way of reducing energy demand. This is known as *cycling.*
- When A/C is cycled, users can expect the temperature of the room to increase as much as 10°, depending on the power of the A/C, the insulation of the room, and the outside temperature.

5. Do you believe you would notice, and be discomforted by, this change in temperature?

□ I would not notice.
□ I would notice, but not be discomforted.
□ I would notice, but be slightly discomforted.
□ I would be much discomforted.

There are different ways of cycling air conditioners:

- One way is to have consumers, during peak hours, turn off, or limit the use of, their air conditioners themselves. This has the effect of raising the temperature of the room.
- Another way is for power companies to control it by installing a device on consumers' pre-existing A/C that automates the cycling. (This may happen at least twice a year during heat waves on a typical summer.)

6. Which opinion best describes how you feel towards this situation?

□ I do not mind the power company controlling my air conditioner during peak hours.
□ I do not mind, if I trust the company or if I had a contract to ensure when the device is used.
□ I do not care either way.
□ I am slightly against the idea of other people having control over my A/C.
□ I am very much opposed to the idea.

The following examples are short descriptions of specific demand-response programs. These options are currently under consideration for adoption in the Greater Boston area; similar programs exist elsewhere in the country. Please answer the following questions as accurately as possible. Each of the programs has no fee for participating and all savings would be directly discounted from your electricity bill.

Option One

- This option is an energy reduction program. You can refuse participation at your discretion.
- In this program, consumers receive a phone call the night before an expected shortage of power.
- Consumers are then asked to either shut off their A/C completely or raise the temperature of the room by as much as 10°, depending on the power of the A/C, the insulation of the room, and the outside temperature.

7. How interested are you in participating in this program? (1 = not at all; 5 = strongly interested)

□ 1 □ 2 □ 3 □ 4 □ 5

8. If a financial incentive were offered, what incentive would increase your likelihood in participating in this program? (Please indicate the closest minimum amount.)

□ No financial incentive necessary
□ Less than $20 monthly savings
□ $20 to $29 monthly savings
□ $30 to $39 monthly savings
□ $40 to $49 monthly savings
□ $50 or more monthly savings

Option Two

- This option turns your A/C on and off (cycles), thus raising the temperature. The temperature of the room usually rises by as much as 10°, accordingly. The cycling is automated by a device installed on your pre-existing A/C free-of-charge.
- These planned shortages happen up to five hours a day, fours days a year. A/C cycling would occur during these times.

9. **How interested are you in participating in this program? (1 = not at all; 5 = strongly interested)**

□ 1 □ 2 □ 3 □ 4 □ 5

10. **If a financial incentive were offered, what incentive would increase your likelihood in participating in this program? (Please indicate the closest <u>minimum</u> amount.)**

□ No financial incentive necessary
□ Less than $20 monthly savings
□ $20 to $29 monthly savings
□ $30 to $39 monthly savings
□ $40 to $49 monthly savings
□ $50 or more monthly savings

11. **Which option is more appealing to you?**

□ Option One □ Option Two

Optional: Briefly explain why you chose this option in the space below.

Finally, we would like to ask you a few questions about yourself. Please mark your answers to the following.

Gender: □ Male □ Female

Age:

□ Under 20 □ 40 to 49
□ 20 to 29 □ 50 to 59
□ 30 to 39 □ 60 or older

Ethnic background:

□ White/Caucasian □ Asian/Pacific Islander
□ Hispanic □ Native American
□ Black/African American □ Other: _____________

Educational background:

□ Less than 9th grade □ Some college
□ Some high school □ Associate's degree
□ High school graduate □ Bachelor's degree
□ Trade school □ Master's/Ph. D

Annual household income:

□ Less than $20,000 □ $50,000 to $70,000
□ $20,000 to $35,000 □ $70,000 to $100,000
□ $35,000 to $50,000 □ $100,000 or more

Marital status: □ Single □ Married □ Other: ____________

Number of adults living at residence (people older than 18): _____

Number of children/minors living at residence (people younger than 18): _____

In what type of residence do you live?

□ I own my residence (house, townhouse, condominium, etc.)
□ I rent (apartment)
□ I live with friends or family
□ Other

Do you have any additional comments, concerns, or suggestions?

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

E-mail: demand-response@wpi.edu

APPENDIX B: Tables Explaining Variable Names

Survey Question Numbers	Variable Names
1	Electricity outages
	Number of outages last summer
	Length of interruptions
	Outage level of discomfort
2	Have air conditioning
	Type of air conditioning
	Number of air conditioning units owned
	Usual summer thermostat temperature setting
	Last summer AC usage greater than 90° (hourly AC usage)
	Last summer AC usage less than 90°
3	Average summer monthly bill
4	Cost of electricity
	Preventing power interruptions/outages
	Renewable/clean energy
	Other
5	Temperature level of discomfort
6	Opinion on automatic air condition cycling
7	Level of interest in Option 1
8	Financial incentive in Option 1
19	Level of interest in Option 2
10	Financial incentive in Option 2
11	Appealing option

Demographics	
Questions concerning the demographics of respondents	**Variable Names**
	Gender
	Age
	Ethnic Background
	Educational Background
	Annual Household Income
	Marital Status
	Number of Adults
	Number of Children
	Type of Residence

APPENDIX C: Regression Model Data

C.1 *Summary of Regression Data*

The following tables summarize the numerical results of the computations for the regression variables—the slope (*m*), the y-intercept (*b*), the *t*-statistic, the *F*-statistic, the *p*-value, the correlation coefficient *R*, and the critical value *t*-star. These variables, which are expressed in specific notation, were computed for all thirteen regression plots, as outlined in Section 6.5, Explanation of the Regression Plots, in **CHAPTER 6: Data Analysis and Discussion.** The sample response size for each regression equation is also tabulated.

Linear Coefficients (in the form y = mx + b)						
Equation Number	**Slope** (*m*)	**Intercept** (*b*)	***t*-statistic**	***F*-statistic**	***p*-value**	***R***
1	−0.1804	25.23	−5.817	44.80	0.028300	−0.9783
2	0.0004341	68.15	5.350	33.05	0.005889	0.9464
3	0.000007247	1.99	5.250	34.86	0.006277	0.9475
4	0.000008933	1.46	5.880	41.10	0.004191	0.9547
5	0.1235	22.28	4.460	23.20	0.011130	0.9236
6	0.1146	28.07	3.540	14.22	0.024020	0.8843
7	9855	14310.00	6.320	46.72	0.000731	0.9414
8	−6.874	51.33	−3.690	16.36	0.034430	−0.9194
9	−8.394	56.85	−12.500	187.80	0.001105	−0.9921
10	11.27	79.24	2.290	6.67	0.105700	0.8323
11	0.09025	−3.75	5.270	34.50	0.034140	0.9721
12	0.05053	−1.48	25.000	761.30	0.001602	0.9987
13	2.029	76.33	3.410	14.72	0.076240	0.9378

Equation Number	**Sample Response Size**	***t*-star (critical value)**
1	208	1.65228
2	194	1.65283
3	203	1.65247
4	201	1.65255
5	224	1.65175
6	222	1.65181
7	206	1.65236
8	239	1.65131
9	235	1.65142
10	142	1.65581
11	208	1.65228

12	207	1.65232
13	200	1.65259

C.2 *95% Confidence Intervals for the Slopes*

The following table summarizes the confidence intervals for each regression equation. The confidence level for these intervals is 95%, which means that if the number zero is excluded from the intervals, one can say with 95% confidence that the slope of the regression line is significantly different from zero. The slope being significantly different from zero (either positive or negative) precludes the possibility of having little to no correlation between the independent and dependent variables of the regression. Therefore, these confidence intervals are confidence intervals for the *slopes only*. For more on confidence intervals for the slopes, see Section 6.4, Introduction to the Regression Plots: Explanation of Key Variables, in **CHAPTER 6: Data Analysis and Discussion.**

Equation Number	95% Confidence Intervals for the Slopes	
1	−0.2316	−0.1292
2	0.0003	0.0005682
3	0.000004968	0.000009526
4	0.000006421	0.00001145
5	0.07783	0.1693
6	0.06115	0.1682
7	7280	12430
8	−9.947	−3.8
9	−9.503	−7.284
10	3.133	19.41
11	0.06197	0.1185
12	0.04718	0.05387
13	1.046	3.012

Note that in the table, the left-bound of the intervals appears in the middle column, while the right-bound appears in the right-most column.

C.3 *95% Confidence Intervals for each Equation*

95% Prediction Intervals for Equation 1	
18.70	18.96
16.92	17.14
15.11	15.34
13.29	13.55

95% Prediction Intervals for Equation 2	
71.82	75.33
78.44	81.74
85.01	88.18
94.79	97.94
103.40	106.70
113.00	116.60

95% Prediction Intervals for Equation 3	
2.053	2.109
2.163	2.216
2.273	2.323
2.436	2.486
2.580	2.632
2.740	2.798

95% Prediction Intervals for Equation 4	
1.535	1.598
1.671	1.730
1.806	1.863
2.007	2.064
2.184	2.244
2.382	2.448

95% Prediction Intervals for Equation 5	
27.87	29.04
30.38	31.46
32.88	33.91
35.35	36.38
37.79	38.88
40.22	41.39

95% Prediction Intervals for Equation 6	
33.11	34.50
35.45	36.74
37.78	39.01
40.07	41.30
42.33	43.62
44.57	45.97

95% Prediction Intervals for Equation 7	
21010	27310
31030	37000
41000	46750
50910	56540
60760	66400
70560	76310
21010	27310
31030	37000

95% Prediction Intervals for Equation 8	
43.19	45.72
36.44	38.72
29.61	31.80
22.69	24.97
15.70	18.22

95% Prediction Intervals for Equation 9	
48.00	48.92
39.65	40.48
31.27	32.07
22.86	23.69
14.42	15.34

95% Prediction Intervals for Equation 10	
86.28	94.75
97.97	105.60
109.40	116.70
120.50	128.20
131.40	139.80

95% Prediction Intervals for Equation 11	
1.85	1.93
2.31	2.37
2.76	2.82
3.21	3.28

95% Prediction Intervals for Equation 12	
1.67	1.68
1.93	1.93
2.18	2.19
2.43	2.44

95% Prediction Intervals for Equation 13	
78.46	82.31
92.90	96.28
111.10	114.60
123.10	126.90

C.4 *Multivariable Regression Statistics for Options One and Two*

Regression Statistics for Option 1	
Multiple R	0.908935238
R Square	0.826163266
Adjusted R Square	0.805050341
Standard Error	16.75541232
Observations	113

Regression Statistics for Option 2	
Multiple R	0.937292279
R Square	0.878516816
Adjusted R Square	0.860375813
Standard Error	15.50635614
Observations	110

ANOVA for Option 1					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	140095.3966	17511.92457	62.37687867	3.06225E−36
Residual	105	29478.10342	280.7438421		
Total	113	169573.5			

ANOVA for Option 2					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	177359.1478	22169.89347	92.20279742	6.25985E−43
Residual	102	24525.60223	240.4470807		
Total	110	201884.75			

APPENDIX D: Mathematics Behind Bias Calculations

The following are the formulas used in the section entitled *Bias Testing on the Collected Demographic Data* in **CHAPTER 6: Data Analysis and Discussion:**

$z = \dfrac{(P - P_o)}{\sqrt{\dfrac{P_o(1-P_o)}{n}}}$, which is used to calculate the standard deviation of P from P_0;

p-value = $1 - \dfrac{1}{\sqrt{2\pi}} \int_{|z|}^{\infty} \exp\left(-x^2/2\right) dx$, the probability that the deviation of the observed P from P_0 is due to chance alone.

APPENDIX E: Matlab Code for the Survey

E.1 *M-file for Regression and Correlation Analysis*

```
%This m-file code does regression and correlation analysis.

function coranalysis

varnames2 = {'interruptions', 'LastSummer', 'OnAverage',...
    'DiscomfortLevel', 'ACUnit', 'ACType', 'numberOfUnits',
'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill',...
    'Concern1', 'Concern2', 'Concern3', 'Concern4',
'sensitivityToChangeInTemperature',...
    'opinionOnACCyclingOptions', 'interestInProgram1',
'Prog1FinancialIncentive',...
    'interestInProgram2', 'Prog2FinancialIncentive',
'appealingOption',...
    'gender', 'age', 'ethnicBackground', 'education', 'income',
'maritalStatus',...
    'numberOfAdults', 'numberOfChildren', 'typeOfResidence'};

VarrIQP = {'Electricity_outages', 'Number_of_outages_last_summer',
'Length_of_interruptions', 'Outage_Level_of_discomfort',
'Have_air_cond', 'Type_of_air_cond',...
    'Number_of_air_cond_units',
'Thermostat_temp','Last_summer_AC_usage_greater_than_90deg',
'Last_summer_AC_usage_less_than_90deg',
'Average_Summer_monthly_bill',...
    'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Temperature_Level_of_discomfort',
'Opinion_on_automatic_air_cond_cycling',...
    'Level_of_interest_1', 'Financial_incentive_1_in_dollars',
'Level_of_interest_2', 'Financial_incentive_2_in_dollars',
'Appealing_option', 'Gender', 'Age', 'Ethnic_background',...
    'Educational_background', 'Annual_household_income',
'Marital_status', 'Number_of_adults', 'Number_of_children',
'Type_of_residence'};

varnamesNUM = {'Electricity_outages1',
'Number_of_outages_last_summer2', 'Length_of_interruptions3',
'Outage_Level_of_discomfort4', 'Have_air_cond5',
'Type_of_air_cond6',...
    'Number_of_air_cond_units7',
'Thermostat_temp8','Last_summer_AC_usage_greater_than_90deg9',
'Last_summer_AC_usage_less_than_90deg10',
'Average_Summer_monthly_bill11',...
    'Biggest_Energy_Cost_Concern12', 'Biggest_Energy_Cost_Concern13',
'Biggest_Energy_Cost_Concern14', 'Biggest_Energy_Cost_Concern15',
'Temperature_Level_of_discomfort16',
'Opinion_on_automatic_air_cond_cycling17',...
```

```
    'Level_of_interest_118', 'Financial_incentive_1_in_dollars19',
'Level_of_interest_220', 'Financial_incentive_2_in_dollars21',
'Appealing_option22', 'Gender23', 'Age24', 'Ethnic_background25',...
    'Educational_background26', 'Annual_household_income27',
'Marital_status28', 'Number_of_adults29', 'Number_of_children30',
'Type_of_residence31'};

varnamesNUM1 = {'Electricity_outagese1',
'Number_of_outages_last_summere2', 'Length_of_interruptionse3',
'Outage_Level_of_discomfortee4', 'Have_air_conde5',
'Type_of_air_conde6',...
    'Number_of_air_cond_unitse7',
'Thermostat_tempe8','Last_summer_AC_usage_greater_than_90dege9',
'Last_summer_AC_usage_less_than_90dege10',
'Average_Summer_monthly_bille11',...
    'Biggest_Energy_Cost_Concerne12', 'Biggest_Energy_Cost_Concerne13',
'Biggest_Energy_Cost_Concerne14', 'Biggest_Energy_Cost_Concerne15',
'Temperature_Level_of_discomforte16',
'Opinion_on_automatic_air_cond_cyclinge17',...
    'Level_of_interest_1e18', 'Financial_incentive_1_in_dollarse19',
'Level_of_interest_2e20', 'Financial_incentive_2_in_dollarse21',
'Appealing_optione22', 'Gendere23', 'Agee24',
'Ethnic_backgrounde25',...
    'Educational_backgrounde26', 'Annual_household_incomee27',
'Marital_statuse28', 'Number_of_adultse29', 'Number_of_childrene30',
'Type_of_residencee31'};

varunits = {'','','','','','','Number of A/C units owned','In Degrees
Fahrenheit','A/C usage (hrs/day)','A/C usage (days)',...
    'In dollars per month','','','','','','','5 is very
interested','','5 is very interested','','','','','Age
Group','','Income in dollars per year','','','',''};

%%%%%% list for pairwise regression

XXvar = {'age', 'income', 'income', 'income',
'averageSummerMonthlyBill',...
'averageSummerMonthlyBill', 'education',...
'interestInProgram1', 'interestInProgram2',
'numberOfUnits','usualSummerSetting', 'usualSummerSetting',...
'typicalHotDaySetting'};

YYvar = {'typicalHotDaySetting','averageSummerMonthlyBill',
'interestInProgram1',...
'interestInProgram2', 'Prog1FinancialIncentive',
'Prog2FinancialIncentive',...
'income', 'Prog1FinancialIncentive', 'Prog2FinancialIncentive',...
'averageSummerMonthlyBill', 'interestInProgram1',
'interestInProgram2',...
'averageSummerMonthlyBill'};

XXlabel = {'Age', 'Annual Household Income', 'Annual Household Income',
'Annual Household Income',...
'Average Summer Monthly Bill', 'Average Summer Monthly Bill',
'Educational Background',...
```

```
'Level of interest in Program Option 1', 'Level of interest in Program
Option 2',...
'Number of AC units', 'Usual Summer Thermostat Temperature Setting',
'Usual Summer Thermostat Temperature Setting',...
'Hourly AC usage in the Summer'};

YYlabel = {'Hourly AC usage in the Summer','Average Summer Monthly
Bill', 'Level of interest in Program Option 1',...
'Level of interest in Program Option 2', 'Financial Incentive for
Program 1', 'Financial Incentive for Program 2',...
'Annual Household Income', 'Financial Incentive for Program 1',
'Financial Incentive for Program 2',...
'Average Summer Monthly Bill', 'Level of interest in Program Option 1',
'Level of interest in Program Option 2',...
'Average Summer Monthly Bill'};

XXname = {'Age', 'Annual Household Income', 'Annual Household Income',
'Annual Household Income',...
'Average Summer Monthly Bill', 'Average Summer Monthly Bill',
'Educational Background',...
'Level of interest in Program Option 1', 'Level of interest in Program
Option 2',...
'Number of AC units', 'Usual Summer Thermostat Temperature Setting',
'Usual Summer Thermostat Temperature Setting',...
'Hourly AC usage in the Summer'};

YYname = {'Hourly AC usage in the Summer','Average Summer Monthly
Bill', 'Level of interest in Program Option 1',...
'Level of interest in Program Option 2', 'Financial Incentive for
Program 1', 'Financial Incentive for Program 2',...
'Annual Household Income', 'Financial Incentive for Program 1',
'Financial Incentive for Program 2',...
'Average Summer Monthly Bill', 'Level of interest in Program Option 1',
'Level of interest in Program Option 2',...
'Average Summer Monthly Bill'};

GVvarnames = {'numberOfUnits', 'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill',...
    'age', 'education', 'income', 'numberOfAdults', 'numberOfChildren',
'typeOfResidence'};

GVvarnames01 = {'numberOfUnits', 'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill','interestInProgram1','Prog1FinancialIncentiv
e',...
    'interestInProgram2', 'Prog2FinancialIncentive',...
    'age', 'education', 'income', 'numberOfAdults', 'numberOfChildren',
'typeOfResidence'};

GVvarnames03 = {'numberOfUnits', 'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill','interestInProgram1','Prog1FinancialIncentiv
e',...
    'interestInProgram2', 'Prog2FinancialIncentive',...
```

```
    'age', 'education', 'income', 'numberOfAdults', 'numberOfChildren',
'typeOfResidence'};

GVvarnames02 = {'numberOfUnits', 'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill','interestInProgram1','Prog1FinancialIncentiv
e',...
    'interestInProgram2', 'Prog2FinancialIncentive',...
    'age', 'education', 'income', 'numberOfAdults', 'numberOfChildren',
'typeOfResidence'};

GV1varnames = {'Number_of_air_cond_units',
'Thermostat_temp','Last_summer_AC_usage_greater_than_90deg',
'Last_summer_AC_usage_less_than_90deg',
'Average_Summer_monthly_bill',...
    'Level_of_interest_1', 'Financial_incentive_1_in_dollars',
'Level_of_interest_2', 'Financial_incentive_2_in_dollars', 'Age',...
    'Educational_background', 'Annual_household_income',
'Number_of_adults', 'Number_of_children', 'Type_of_residence'};

GV2varnames = {'Number of air cond units', 'Thermostat temp','Daily A/C
usage last summer', 'Hourly A/C usage last summer', 'Average Summer
monthly bill',...
    'Level of interest 1', 'Financial incentive for Program 1 in
dollars', 'Level of interest 2', 'Financial incentive for Program 2 in
dollars', 'Age',...
    'Educational background', 'Annual household income', 'Number of
adults', 'Number of children', 'Type of residence'};

GV3varnames = {'Number of air cond units', 'Thermostat temp','Daily AC
usage last summer', 'Hourly AC usage last summer', 'Average Summer
monthly bill',...
    'Level of interest 1', 'Financial incentive for Program 1 in
dollars', 'Level of interest 2', 'Financial incentive for Program 2 in
dollars', 'Age',...
    'Educational background', 'Annual household income', 'Number of
adults', 'Number of children', 'Type of residence'};

GV4varnames = {'Number_of_air_cond_units7',
'Thermostat_temp8','Last_summer_AC_usage_greater_than_90deg9',
'Last_summer_AC_usage_less_than_90deg10',
'Average_Summer_monthly_bill11',...
    'Level_of_interest_118', 'Financial_incentive_1_in_dollars19',
'Level_of_interest_220', 'Financial_incentive_2_in_dollars21',
'Age24',...
    'Educational_background26', 'Annual_household_income27',
'Number_of_adults29', 'Number_of_children30', 'Type_of_residence31'};

varnames = {'interruptions', 'LastSummer', 'OnAverage',...
    'DiscomfortLevel', 'ACUnit', 'ACType', 'numberOfUnits',
'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill',...
    'Concern1', 'Concern2', 'Concern3', 'Concern4',
'sensitivityToChangeInTemperature',...
    'opinionOnACCyclingOptions', 'interestInProgram1',...
```

```
    'interestInProgram2', 'appealingOption',...
    'gender', 'age', 'ethnicBackground', 'education', 'income',
'maritalStatus',...
    'numberOfAdults', 'numberOfChildren', 'typeOfResidence'};

%%%list for multiple regression

varnamesIQP = {'Electricity_outages', 'Number_of_outages_last_summer',
'Length_of_interruptions', 'Level_of_discomfort', 'Have_air_cond',
'Type_of_air_cond',...
    'Number_of_air_cond_units',
'Thermostat_temp','Last_summer_usage_greater_than_90deg',
'Last_summer_usage_less_than_90deg', 'Average_Summer_monthly_bill',...
    'Cost_of_electricity_concern', 'Preventing_outages_concern',
'Renewable_and_clean_energy', 'Other', 'Level_of_discomfort',
'Your_thoughts',...
    'Level_of_interest_1', 'Level_of_interest_2', 'Appealing_option',
'Gender', 'Age', 'Ethnic_background',...
    'Educational_background', 'Annual_household_income',
'Marital_status', 'Number_of_adults', 'Number_of_children',
'Type_of_residence'};

varnamesIQ2 = {'Electricity outages', 'Number of outages last summer',
'Length of interruptions', 'Level of discomfort', 'Have air cond',
'Type of air cond',...
    'Number of air cond units', 'Thermostat temp','Last summer usage
greater than 90deg fahrenheit', 'Last summer usage less than 90deg
fahrenheit', 'Average Summer monthly bill',...
    'Cost of electricity concern', 'Preventing outages concern',
'Renewable and clean energy', 'Other', 'Level of discomfort', 'Your
thoughts',...
    'Level of interest 1', 'Level of interest 2', 'Appealing option',
'Gender', 'Age', 'Ethnic background',...
    'Educational background', 'Annual household income', 'Marital
status', 'Number of adults', 'Number of children', 'Type of
residence'};
fontsz = [12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
12 12 12 12 12 12 12 12 12 12 12 12];

FF = exist('IQPdataNomnso&Tawkeer&James&Eyuel.mat','file');
if FF~=2;
    'IQPdataNomnso&Tawkeer&James&Eyuel.mat is not here';
end;

FF2 = exist('IQP_vars.mat');
if FF2~=2;
    'IQP_vars.mat is not here';
end;

if FF ==2;
    load IQPdataNomnso&Tawkeer&James&Eyuel.mat;
    load IQP_vars.mat;
    %Making sure that people who are not interested are not classified
as
    %requiring no financial incentive
```

```
    Prog1FinancialIncentive(find((Prog1FinancialIncentive==-
1|Prog1FinancialIncentive==1)&(interestInProgram1==1)))=6;
    Prog2FinancialIncentive(find((Prog2FinancialIncentive==-
1|Prog2FinancialIncentive==1)&(interestInProgram2==1)))=6;
    %Making sure to use only people who use the AC in the correlations
    frequencyOfUse(find(frequencyOfUse==1)) = -1;
    typicalHotDaySetting(find(typicalHotDaySetting==1)) = -1;

    binlength =
[2,5,5,5,2,4,8,4,6,6,6,4,4,4,4,4,5,5,6,5,6,2,2,6,6,8,6,3,6,6,4];
    for K = 1:length(varnames2);
        GGG = varnames2{K};
        if length(GGG)>=7;
            NN = strcmp(GGG(1:7),'Concern');
        end;
        if length(GGG)<7;
            NN = 0;
        end;
        if NN ~= 1;
            HH = eval(['find(' varnames2{K} '~=-1);']);
            varr1 = eval(varnames2{K});
            varr12 = varr1(HH);
            Hunique = unique(varr12);
            HvarnamesNum = eval(varnamesNUM1{K});
            for k = 1:length(Hunique);
                varr1(find(varr1==Hunique(k))) =
HvarnamesNum(HvarnamesNum(:,2)==Hunique(k),1);
            end;
            varr1 =varr1(:);
            eval([varnames2{K} '= varr1;']);
        end;
    end;

    GV2X = XXlabel;
    GV2Y = YYlabel;
    GV3X = XXname;
    GV3Y = YYname;
    gg1 = [];
    gg2 = [];
    gg3 = [];
    gg4 = [];
    gg5 = [];
    gg6 = [];
    gg7 = [];
    gg8 = [];
    gg9 = [];

    for K = 1:length(XXvar);
        GGG1 = YYvar{K};
        GGG2 = XXvar{K};
        if length(GGG1)>=13;
            NN1 = strcmp(GGG1(7:13),'OfUnits');
        end;
        if length(GGG2)>=13;
            NN2 = strcmp(GGG2(7:13),'OfUnits');
        end;
        if length(GGG1)<7;
```

```
            NN1 = 0;
        end;
        if length(GGG2)<7;
            NN2 = 0;
        end;
        NN = NN1*NN2;
        if NN ~= 1;
            A = eval(YYvar{K});
            B = eval(XXvar{K});
            [Bm,Am,As,A,B] = removeminusone(A,B);
%             [p] = polyfit(Bm,Am,1);
            [bb,stats] = robustfit(Bm,Am);
            f = polyval([bb(2) bb(1)],Bm);
            p = [bb(2) bb(1)];

            %%%%%%%%%%%%%%%%statistics%%%%%%%%%%%%%%%
            sampleres = length(B); %number of observations may be less
than the total due to any blank response
            n = length(Am);
            r = Am-f; %residuals
            sse = norm(r).^2;
            ssr = norm(f-mean(Am)).^2;
            dfe = n-2; %two degrees of freedom
            dfr = 2-1;
            F  = (ssr/dfr)/(sse/dfe);
            pvalue = stats.p;
            pvalueb = pvalue(2); %p-value for the slope
            s = sqrt(r*r'./(sampleres-2)); %the standard error of the
residuals about the line
            SEy = s*sqrt(1+(1/n)+((Bm-mean(Bm)).^2)/sum((Bm-
mean(Bm)).^2)); %standard error for the prediction
            SE = stats.se;
            SEb = SE(2); %s/sqrt(sum((Bm-mean(Bm)).^2));
            t = stats.t;
            t = t(2);
            b = bb(2); %the slope of the regression line
            tstar = tinv(0.95,sampleres-2); %for the .025 level
confidence interval
            cfb = [(b-tstar*SEb) (b+tstar*SEb)]; %the confidence
interval for .025 level
            cfy = [(f-tstar*SEy)' (f+tstar*SEy)']; %for a .025 level
prediction interval
            %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

            plot(Bm,f,'color','r');
            hold on;
            axis([(min(Bm-.2)) (max(Bm+.2)) (min(Am-As-As*.2))
(max(Am+As+As*.2))]);
            errorbar(Bm,Am,As);
            hold off;
            corra = corr(Bm(:),Am(:));
            BF = ['Best-fit line'];
            BF2 = ['Mean Response and Standard Deviation. R-Squared = '
num2str(corra)];
            xlabel(GV2X{K},'FontSize',16),
            ylabel(GV2Y{K},'FontSize',16),...
                if p(1)<0;
```

```
                    legend(BF,BF2,'Location','northeast');
                end;
                if p(1)>0;
                    legend(BF,BF2,'Location','southeast');
                end;

            gg1 = [gg1; p];
            gg2 = [gg2; pvalueb];
            gg3 = [gg3; [cfb]];
            gg4 = [gg4; [0 0]; [0 0]; [cfy]];
            gg5 = [gg5; tstar];
            gg6 = [gg6; F];
            gg7 = [gg7; t];
            gg8 = [gg8; corra];
            gg9 = [gg9; sampleres];

            g1 = ['Fitline = ' num2str(p(1)) '*x' ' + ' num2str(p(2)) '
'];
            g2 =   ['For the slope: The 2 sided p-value = '
num2str(pvalueb) '.    '];
            g3 = ['Its confidence interval is (' num2str(cfb(1)) ' , '
num2str(cfb(2)) '),       '];
            g4 = ['The t statistic is ' num2str(t) ' and the F-
statistic is ' num2str(F) '.'];
            g5 = ['Sample Response size = ' num2str(sampleres) '
'];
            g = {g1;g2;g3;g4;g5};
            if p(1)>0;
            text((min(B)-.1),(max(Am)+min(Am))/2+(max(Am)-
min(Am))*(1/2-.1),[g],'color','k','BackgroundColor',[0 1
1],'FontSize',12);
            end;
            if p(1)<0;
            text((min(B)-.1),(max(Am)+min(Am))/2-(max(Am)-
min(Am))*(1/2-.1),[g],'color','k','BackgroundColor',[0 1
1],'FontSize',12);
            end;
            grid on;
            grid minor;
            saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X{K} '
vs ' GV3Y{K}]],'bmp');
        end;
        if NN == 1;
            BA = eval(varnames2{6});
            B = eval(XXvar{K});
            A = eval(YYvar{K});
            if NN1 ==1;
                A(find(BA==2)) = A(find(BA==2))*3; %rating those who
have a central AC as being equivalent to having 3 window AC's
            end;
            if NN2 ==1;
                B(find(BA==2)) = B(find(BA==2))*3; %rating those who
have a central AC as being equivalent to having 3 window AC's
            end;
            [Bm,Am,As,A,B] = removeminusone(A,B);
            [p] = polyfit(Bm,Am,1);
            [bb,stats] = robustfit(Bm,Am);
```

```
            f = polyval([bb(2) bb(1)],Bm);

            %%%%%%%%%%%%%%%%statistics%%%%%%%%%%%%%%
            sampleres = length(B); %number of observations may be less
than the total due to any blank response
            n = length(Am);
            r = Am-f; %residuals
            sse = norm(r).^2;
            ssr = norm(f-mean(Am)).^2;
            dfe = n-2; %two degrees of freedom
            dfr = 2-1;
            F  = (ssr/dfr)/(sse/dfe);
            pvalue = stats.p;
            pvalueb = pvalue(2); %p-value for the slope
            s = sqrt(r*r'./(sampleres-2)); %the standard error of the
residuals about the line
            SEy = s*sqrt(1+(1/n)+((Bm-mean(Bm)).^2)/sum((Bm-
mean(Bm)).^2)); %standard error for the prediction
            SE = stats.se; SEfmu
            SEb = SE(2);
            t = stats.t;
            t = t(2);
            b = bb(2); %the slope of the regression line
            tstar = tinv(0.95,sampleres-2); %for the .025 level
confidence interval
            cfb = [(b-tstar*SEb) (b+tstar*SEb)]; %the confidence
interval for .025 level
            cfy = [f-tstar*SEy f+tstar*SEy]; %for a .025 level
prediction interval
            %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

            plot(Bm,f,'color','r');
            hold on;
            axis([(min(Bm-.2)) (max(Bm+.2)) (min(Am-As-As*.2))
(max(Am+As+As*.2))]);
            errorbar(Bm,Am,As);
            hold off;
            corra = corr(Bm(:),Am(:));
            BF = ['Best-fit line'];
            BF2 = ['Mean Response and Standard Deviation. R-Squared = '
num2str(corra)];
            if (NN1 == 1)&(NN2 ~= 1);
                xlabel(GV2{K},'FontSize',16),
                ylabel('Number of window AC','FontSize',16),...
                    if p(1)<0;
                    legend(BF,BF2,'Location','northeast');
                    end;
                    if p(1)>0;
                        legend(BF,BF2,'Location','southeast');
                    end;
            end;

            if (NN2 == 1)&(NN1 ~= 1);
                xlabel('Number of window AC','FontSize',16),
                ylabel(GV2{KK},'FontSize',16),...
                    if p(1)<0;
                    legend(BF,BF2,'Location','northeast');
```

```
                    end;
                    if p(1)>0;
                        legend(BF,BF2,'Location','southeast');
                    end;
            end;

            gg1 = [gg1; p];
            gg2 = [gg2; pvalueb];
            gg3 = [gg3; [cfb]];
            gg4 = [gg4; [0 0]; [0 0];  [cfy]];
            gg5 = [gg5; tstar];
            gg6 = [gg6; F];
            gg7 = [gg7; t];
            gg8 = [gg8; corra];
            gg9 = [gg9; sampleres];

            g = ['Fitline = ' num2str(p(1)) '*x' ' + ' num2str(p(2)) '
';...
                'For the slope: The 2 sided p-value = '
num2str(pvalueb) '.   '; ...
            'Its confidence interval is (' num2str(cfb(1)) ' , '
num2str(cfb(2)) '),       ';...
            'The t statistic is ' num2str(t) ' and the F-statistic is '
num2str(F) '.';...
            'Sample Response size = ' num2str(sampleres) '
'];
            text((min(B)-.1),(max(Am)+min(Am))/2+(max(Am)-
min(Am))*(1/2-.1),[g],'color','k','BackgroundColor',[0 1
1],'FontSize',12);
            grid on;
            grid minor;
            %     pause(1)
            saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X{K} '
vs ' GV3Y{K}]],'bmp');
        end;
    end;

    nname = {'PW Coefficients', 'PW p-value', 'PW Slope confidence
int', 'PW Prediction int', 'PW t-star', 'PW F-statistic', 'PW t-
statistic', 'PW R-squared', 'Sample Response Size'};
    gname = {'gg1', 'gg2', 'gg3',  'gg4', 'gg5',  'gg6',  'gg7',
'gg8',  'gg9'};

    for k =1:length(nname);
        J = [eval(gname{k})];
        save(['PW\' nname{k} '.txt'],'J','-ascii');
    end;

%%%%%%%%Multiple regression%%%%%%%%%%%%%%%%%%%%%

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%for Prog1%%%%%%%%%%%%%%%%%%%%%
if FF ==2;
    load IQPdataNomnso&Tawkeer&James&Eyuel.mat;
    load IQP_vars.mat;
    %Making sure that people who are not interested are not classified
    %as requiring no financial incentive
```

```
    Prog1FinancialIncentive(find((Prog1FinancialIncentive==-
1|Prog1FinancialIncentive==1)&(interestInProgram1==1)))=6;
    Prog2FinancialIncentive(find((Prog2FinancialIncentive==-
1|Prog2FinancialIncentive==1)&(interestInProgram2==1)))=6;
    %Making sure to use only people who use the AC in the correlations
    frequencyOfUse(find(frequencyOfUse==1)) = -1;
    typicalHotDaySetting(find(typicalHotDaySetting==1)) = -1;

    for K = 1:length(varnames2);
        GGG = varnames2{K};
        if length(GGG)>=7;
            NN = strcmp(GGG(1:7),'Concern');
        end;
        if length(GGG)<7;
            NN = 0;
        end;
        if NN ~= 1;
            HH = eval(['find(' varnames2{K} '~=-1);']);
            varr1 = eval(varnames2{K});
            varr12 = varr1(HH);
            Hunique = unique(varr12);
            HvarnamesNum = eval(varnamesNUM1{K});
            for k = 1:length(Hunique);
                varr1(find(varr1==Hunique(k))) =
HvarnamesNum(HvarnamesNum(:,2)==Hunique(k),1);
            end;

            varr1 =varr1(:);
            eval([varnames2{K} '= varr1;']);

        end;
    end;
    for K = 1:length(varnames2);
        varr1 = eval(varnames2{K});
        eval([varnames2{K} '= varr1(:);']);
    end;

GH11 = {'age', 'income','averageSummerMonthlyBill', 'education',...
        'numberOfUnits', 'usualSummerSetting', 'typicalHotDaySetting',
'Prog1FinancialIncentive', 'interestInProgram1'};

    GH12 = {'age', 'income','averageSummerMonthlyBill', 'education',...
        'numberOfUnits', 'usualSummerSetting', 'typicalHotDaySetting',
'Prog2FinancialIncentive', 'interestInProgram2'};

    rmvminusone1 = removeminusonevs(GH11);
    H1 = find(eval(rmvminusone1));
    rmvminusone2 = removeminusonevs(GH12);
    H2 = find(eval(rmvminusone2));

    GH1 = {'age', 'income','averageSummerMonthlyBill', 'education',...
        'numberOfUnits', 'usualSummerSetting', 'typicalHotDaySetting'};

    GH11 = [age(H1), income(H1),averageSummerMonthlyBill(H1),
education(H1),...
```

```
        numberOfUnits(H1), usualSummerSetting(H1),
typicalHotDaySetting(H1), interestInProgram1(H1)];

    GH12 = [age(H2), income(H2),averageSummerMonthlyBill(H2),
education(H2),...
        numberOfUnits(H2), usualSummerSetting(H2),
typicalHotDaySetting(H2), interestInProgram2(H2)];
end;
end;

J = [surveyNumber(H1) GH11];
save('Prog1.txt','J','-ascii'); %Saving translated table for usage in
Excel

J = [surveyNumber(H2) GH12];
save('Prog2.txt','J','-ascii'); %Saving translated table for usage in
Excel

%%%%%%%%%functions employed above

    function [Bm,Am,As,A,B] = removeminusone(A,B);
        HH = find((A~=-1)&(B~=-1));
        A = A(HH);
        B = B(HH);

        % a = min(B);
        % b = max(B);
        cnt = 0;
        Bp = unique(B);
        for kk = 1:length(Bp);
            k = Bp(kk);
            cnt = cnt+1;
            HH = find(B==k);
            if length(HH)~=0;
                Am(cnt) = mean(A(HH));
                As(cnt) = std(A(HH));
                Bm(cnt) = k;
            end;
            if length(HH)==0;
                cnt = cnt-1;
            end;
        end;
        As = As/sqrt(length(B)); %estimated standard deviation of the
sample mean, assuming it has a normal distribution

    function rmvminusone= removeminusonevs(varnames);
    g = ['(' varnames{1}];
    for K = 2:length(varnames);
        g = [g ['~=-1)&('] varnames{K}];
    end;
    rmvminusone = [g ['~=-1)']]];
```

E.2 *M-file for the Histograms*

```
%This m-file creates histograms

function minusone;

%close all;

varnames = {'interruptions', 'LastSummer', 'OnAverage',...
    'DiscomfortLevel', 'ACUnit', 'ACType', 'numberOfUnits',
'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill',...
    'Concern1', 'Concern2', 'Concern3', 'Concern4',
'sensitivityToChangeInTemperature',...
    'opinionOnACCyclingOptions', 'interestInProgram1',
'Prog1FinancialIncentive',...
    'interestInProgram2', 'Prog2FinancialIncentive',
'appealingOption',...
    'gender', 'age', 'ethnicBackground', 'education', 'income',
'maritalStatus',...
    'numberOfAdults', 'numberOfChildren', 'typeOfResidence'};

varnamesNUM = {'Electricity_outages1',
'Number_of_outages_last_summer2', 'Length_of_interruptions3',
'Outage_Level_of_discomfort4', 'Have_air_cond5',
'Type_of_air_cond6',...
    'Number_of_air_cond_units7',
'Thermostat_temp8','Last_summer_AC_usage_greater_than_90deg9',
'Last_summer_AC_usage_less_than_90deg10',
'Average_Summer_monthly_bill11',...
    'Biggest_Energy_Cost_Concern12', 'Biggest_Energy_Cost_Concern13',
'Biggest_Energy_Cost_Concern14', 'Biggest_Energy_Cost_Concern15',
'Temperature_Level_of_discomfort16',
'Opinion_on_automatic_air_cond_cycling17',...
    'Level_of_interest_118', 'Financial_incentive_1_in_dollars19',
'Level_of_interest_220', 'Financial_incentive_2_in_dollars21',
'Appealing_option22', 'Gender23', 'Age24', 'Ethnic_background25',...
    'Educational_background26', 'Annual_household_income27',
'Marital_status28', 'Number_of_adults29', 'Number_of_children30',
'Type_of_residence31'};

varnamesNUM1 = {'Electricity_outagese1',
'Number_of_outages_last_summere2', 'Length_of_interruptionse3',
'Outage_Level_of_discomfortee4', 'Have_air_conde5',
'Type_of_air_conde6',...
    'Number_of_air_cond_unitse7',
'Thermostat_tempe8','Last_summer_AC_usage_greater_than_90dege9',
'Last_summer_AC_usage_less_than_90dege10',
'Average_Summer_monthly_bille11',...
    'Biggest_Energy_Cost_Concerne12', 'Biggest_Energy_Cost_Concerne13',
'Biggest_Energy_Cost_Concerne14', 'Biggest_Energy_Cost_Concerne15',
'Temperature_Level_of_discomforte16',
'Opinion_on_automatic_air_cond_cyclinge17',...
```

```
    'Level_of_interest_1e18', 'Financial_incentive_1_in_dollarse19',
'Level_of_interest_2e20', 'Financial_incentive_2_in_dollarse21',
'Appealing_optione22', 'Gendere23', 'Agee24',
'Ethnic_backgrounde25',...
    'Educational_backgrounde26', 'Annual_household_incomee27',
'Marital_statuse28', 'Number_of_adultse29', 'Number_of_childrene30',
'Type_of_residencee31'};

varnamesIQP = {'Electricity_outages', 'Number_of_outages_last_summer',
'Length_of_interruptions', 'Outage_Level_of_discomfort',
'Have_air_cond', 'Type_of_air_cond',...
    'Number_of_air_cond_units',
'Thermostat_temp','Last_summer_AC_usage_greater_than_90deg',
'Last_summer_AC_usage_less_than_90deg',
'Average_Summer_monthly_bill',...
    'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Temperature_Level_of_discomfort',
'Opinion_on_automatic_air_cond_cycling',...
    'Level_of_interest_1', 'Financial_incentive_1_in_dollars',
'Level_of_interest_2', 'Financial_incentive_2_in_dollars',
'Appealing_option', 'Gender', 'Age', 'Ethnic_background',...
    'Educational_background', 'Annual_household_income',
'Marital_status', 'Number_of_adults', 'Number_of_children',
'Type_of_residence'};

varnamesIQ2 = {'Electricity outages', 'Number of outages last summer',
'Length of interruptions', 'Outage Level of discomfort', 'Have air
conditioning', 'Type of air cond',...
    'Number of air cond units', 'Thermostat temp','Last summer A/C
usage frequency when temperature is greater than 90deg', 'Last summer
A/C usage frequency when temperature is less than 90deg', 'Average
Summer monthly bill',...
    'Biggest Energy Cost Concern','Biggest Energy Cost
Concern','Biggest Energy Cost Concern','Biggest Energy Cost Concern',
'Temperature Level of discomfort', 'Opinion on automatic air cond
cycling',...
    'Level of interest 1', 'Financial incentive for DR Program Option
1', 'Level of interest 2', 'Financial incentive for DR Program Option
2', 'Appealing option', 'Gender', 'Age', 'Ethnic background',...
    'Educational background', 'Annual household income', 'Marital
status', 'Number of adults', 'Number of children', 'Type of
residence'};

varnamesIQ3 = {'1Electricity outages', '2Number of outages last
summer', '3Length of interruptions', '4Outage Level of discomfort',
'5Have air cond', '6Type of air cond',...
    '7Number of air cond units', '8Thermostat temp','9Last summer AC
usage frequency when temperature is greater than 90deg', '10Last summer
AC usage frequency when temperature is less than 90deg', '11Average
Summer monthly bill',...
    '12Biggest Energy Cost Concern', '13Biggest Energy Cost Concern',
'14Biggest Energy Cost Concern', '15Biggest Energy Cost Concern',
'16Temperature Level of discomfort', '17Opinion on automatic air cond
cycling',...
```

```
    '18Level of interest 1', '19Financial incentive for Program 1',
'20Level of interest 2', '21Financial incentive for Program 2',
'22Appealing option', '23Gender', '24Age', '25Ethnic background',...
    '26Educational background', '27Annual household income', '28Marital
status', '29Number of adults', '30Number of children', '31Type of
residence'};

{'1','2','3','4','5','6','7','8','9','10','11','12','13','14','15','16'
,'17','18','19','20','21','22','23','24','25','26','27','28','29','30',
'31'};

binlength =
[2,5,5,5,2,4,8,4,6,6,6,4,4,4,4,4,5,5,6,5,6,2,2,6,6,8,6,3,6,6,4];
KL = [.3 .14 .14 .14 .3 .14 .14 .031 .1 .1 .1 .14 .14 .14 .14 .14 .14
.14 .1 .14 .1 .3 .3 .1 .1 .1 .1 .17 .14 .14 .14];
fontsz = [16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
16 16 16 16 12 14 14 16 16 16 16 16];

% length(varnames)

FF = exist('IQPdataNomnso&Tawkeer&James&Eyuel.mat','file');
if FF~=2;
    'IQPdataNomnso&Tawkeer&James&Eyuel.mat is not here';
end;

FF2 = exist('IQP_vars.mat');
if FF2~=2;
    'IQP_vars.mat is not here';
end;

median_88 = [];
Average_88 = [];
STD_88 = [];
mode_88 = [];
interquartile_88 = [];
range_88 = [];
sum_88 = [];

if (FF ==2)&(FF2 ==2);
    load IQPdataNomnso&Tawkeer&James&Eyuel.mat;
    load IQP_vars.mat;

    %Making sure that people who are not interested are not classified
    %as requiring no financial incentive

    Prog1FinancialIncentive(find((Prog1FinancialIncentive==-
1|Prog1FinancialIncentive==1)&(interestInProgram1==1)))=6;
    Prog2FinancialIncentive(find((Prog2FinancialIncentive==-
1|Prog2FinancialIncentive==1)&(interestInProgram2==1)))=6;

    ghj = {''};
    cnt = 0;
    gvarn = [];
    for K = 1:length(varnames);
        GGG = varnames{K};
```

```
        if length(GGG)>=7;
            NN = strcmp(GGG(1:7),'Concern');
        end;
        if length(GGG)<7;
            NN = 0;
        end;
        if NN ~= 1;
            HH = eval(['find(' varnames{K} '~=-1);']);
            varr1 = eval(varnames{K});
            varr12 = varr1(HH);
            totalsurveyed = length(varr12); %number of people who
responded to a particular question
            Hunique = unique(varr12);
            HvarnamesNum = eval(varnamesNUM1{K});
            Hunique
            HvarnamesNum
            varnamesNUM1{K}
%             if VarnamesNUMunits(K) ==1;
                for k = 1:length(Hunique);
                varr12(find(varr12==Hunique(k))) =
HvarnamesNum(HvarnamesNum(:,2)==Hunique(k),1);
                end;
%             end;
            eval([varnames{K} '= varr12;']);
            Average_88 = [Average_88 round(mean(eval(varnames{K})))];
            STD_88 = [STD_88 round(std(eval(varnames{K})))];
            median_88 = [median_88 round(median(eval(varnames{K})))];
            mode_88 = [mode_88 round(mode(eval(varnames{K})))];
            sum_88 = [sum_88 round(sum(eval(varnames{K})))];
            interquartile_88 = [interquartile_88
round(iqr(eval(varnames{K})))];
            range_88 = [range_88 round(range(eval(varnames{K})))];

            varname = varnames{K};
            KKmean = round(mean(eval(varname)));
            KKstd = round(std(eval(varname)));
            KKmedian = round(median(eval(varname)));
            KKrange = round(range(eval(varname)));
            KKiqr = round(iqr(eval(varname)));
%             [n,xout]=hist(eval(varname),length(eval(varname)));
            %         subplot(3,1,1);
            n1 = histc(eval(varname),eval(varnamesNUM{K}));
            n=100*n1/totalsurveyed;

            bar(eval(varnamesNUM{K}),n);
            xout = eval(varnamesNUM{K});
%             hist(eval(varname),1:binlength(K));
%length(eval(varname))
            h = findobj(gca,'Type','patch');
            set(h,'FaceColor','c','EdgeColor','k')
            text(min(xout),max(n)*(1-.2),['mean = '
num2str(KKmean)],'color','r','FontSize',16)
            text(min(xout),max(n)*(1-.3),['STD = '
num2str(KKstd)],'color','r','FontSize',16)
            text(min(xout),max(n)*(1-.4),['median = '
num2str(KKmedian)],'color','r','FontSize',16)
```

```
            text(min(xout),max(n)*(1-.5),['Sample Response size = '
num2str(totalsurveyed)],'color','r','FontSize',16)
            axis([(min(xout)-KL(K)*max(xout)) (max(xout)*(1+KL(K))) 0
(max(n)*(1+.01))])
%             set(gca,'FontSize',12);
            title([varnamesIQ2{K}],'FontSize',16);
            vartitle = varnamesIQ2{K};
            vartitle3 = varnamesIQ3{K};
            vartitle2 = varnamesIQP{K};
            gvartitle = eval(vartitle2);
            g2vartitle = [];
            for L = 1:length(gvartitle);
                g2vartitle = [g2vartitle '                      '
gvartitle{L}];
            end;
            set(gca,'XTick',eval(varnamesNUM{K}));
            set(gca,'XTickLabel',gvartitle,'FontSize',fontsz(K));
            %             set(gca,'FontSize',20);
            %             axes('xticklabel',gvartitle);
            xlabel(varunits{K},'FontSize',16),
            ylabel('Percentage','FontSize',16),...
%                 if K==1;
%                 pause(60)
%                 end;
            saveas(gcf,['histograms_88\' vartitle3 '
histogram'],'fig');

            % %         subplot(3,1,2);
            boxplot(eval(varname),'notch','on');
            text(1+.1,max(eval(varname)+.02)*(1-.2),['range = '
num2str(KKrange)],'color','r','FontSize',14) %text is used to enter
text into the graph, along with position you want the text to occupy
            text(1+.1,max(eval(varname)+.02)*(1-.3),['iqr = '
num2str(KKiqr)],'color','r','FontSize',14)
            text(1+.1,max(eval(varname)+.02)*(1-.4),['median = '
num2str(KKmedian)],'color','r','FontSize',14)
            text(1+.1,max(eval(varname)+.02)*(1-.5),['mean = '
num2str(KKmean)],'color','r','FontSize',14)
            text(1+.1,max(eval(varname))*(1-.6),['std = '
num2str(KKstd)],'color','r','FontSize',14)
            set(gca,'FontSize',14);
            title([vartitle]);
            saveas(gcf,['boxplots_88\' vartitle3 ' boxplot'],'fig');
            ghj = {ghj,varname};
        end;

        if NN==1;
            cnt = cnt+1;
            HH = eval(['find(' varnames{K} '~=-1);']);
            varr1 = eval(varnames{K});
            varr12 = varr1(HH);
            eval(['TT' num2str(cnt) '= length(varr1(HH))']);
            Hunique = unique(varr12);
            HvarnamesNum = eval(varnamesNUM1{K});
%             if VarnamesNUMunits(K) ==1;
                for k = 1:length(Hunique);
```

```
                varr12(find(varr12==Hunique(k))) =
HvarnamesNum(HvarnamesNum(:,2)==Hunique(k),1);
                end;
%             end;
            gvarn = [gvarn; varr12*cnt];
            if cnt == 4;
                  totalsurveyed = length(gvarn);
            end

            Average_88 = [Average_88 round(mean(gvarn))];
            STD_88 = [STD_88 round(std(gvarn))];
            median_88 = [median_88 round(median(gvarn))];
            mode_88 = [mode_88 round(mode(gvarn))];
            sum_88 = [sum_88 round(sum(gvarn))];
            interquartile_88 = [interquartile_88 round(iqr(gvarn))];
            range_88 = [range_88 round(range(gvarn))];

            varname = gvarn;
            KKmean = round(mean(varname));
            KKstd = round(std(varname));
            KKmedian = round(median(varname));
            KKrange = round(range(varname));
            KKiqr = round(iqr(varname));
%             [n,xout]=hist(varname,length(varname));
            %     subplot(3,1,1);
            n1 = histc(varname,eval(varnamesNUM{K}));
            n=100*n1/totalsurveyed;
            bar(eval(varnamesNUM{K}),n);
            xout = eval(varnamesNUM{K});
%             hist(varname,-1:binlength(K)); %length(eval(varname))
            h = findobj(gca,'Type','patch');
            set(h,'FaceColor','c','EdgeColor','k')
            text(min(xout),max(n)*(1-.2),['mean = '
num2str(KKmean)],'color','r','FontSize',16)
            text(min(xout),max(n)*(1-.3),['STD = '
num2str(KKstd)],'color','r','FontSize',16)
            text(min(xout),max(n)*(1-.4),['median = '
num2str(KKmedian)],'color','r','FontSize',16)
            text(min(xout),max(n)*(1-.5),['Sample Response size =
'num2str(TT1+TT2+TT3+TT4)],'color','r','FontSize',16)
            axis([(min(xout)-KL(K)*max(xout)) (max(xout)*(1+KL(K))) 0
(max(n)*(1+.01))])
            title('Biggest Energy Concern','FontSize',16);
            vartitle3 = varnamesIQ3{K};
            vartitle2 = varnamesIQP{K};
            gvartitle = eval(vartitle2);
            set(gca,'XTick',eval(varnamesNUM{K}));
            set(gca,'XTickLabel',gvartitle,'FontSize',fontsz(K));
%             set(gca,'FontSize',20);
            xlabel(varunits{K},'FontSize',16),
            ylabel('Percentage','FontSize',16),...
            saveas(gcf,['histograms_88\' vartitle3 '
histogram'],'fig');

            %     subplot(3,1,2);
            boxplot(varname);
            set(gca,'FontSize',14);
```

```
            text(1+.1,max(varname+.02)*(1-.2),['range = '
num2str(KKrange)],'color','r','FontSize',14) %text is used to enter
text into the graph, along with position you want the text to occupy
            text(1+.1,max(varname+.02)*(1-.3),['iqr = '
num2str(KKiqr)],'color','r','FontSize',14)
            text(1+.1,max(varname+.02)*(1-.4),['median = '
num2str(KKmedian)],'color','r','FontSize',14)
            text(1+.1,max(varname+.02)*(1-.5),['mean = '
num2str(KKmean)],'color','r','FontSize',14)
            text(1+.1,max(varname+.02)*(1-.6),['std = '
num2str(KKstd)],'color','r','FontSize',14)
            title('Biggest Energy Concern');
            saveas(gcf,['boxplots_88\' vartitle3 ' boxplot'],'fig');
            ghj = {ghj,varname};
        end;
     end;

    g = [];
    for jj = 1:length(varnames);
        eval(['g = [g length(' varnames{jj} ')];']);
    end;
    kk = max(g);
    for jj = 1:length(varnames);
        eval([varnames{jj} '(kk+1) = 0;']);
    end;
end;

save('minusonedata.mat',varnames{1},varnames{2},varnames{3},varnames{4}
,...

varnames{5},varnames{6},varnames{7},varnames{8},varnames{9},varnames{10
},...

varnames{11},varnames{12},varnames{13},varnames{14},varnames{15},varnam
es{16},...

varnames{17},varnames{18},varnames{19},varnames{20},varnames{21},varnam
es{22},...

varnames{23},varnames{24},varnames{25},varnames{26},varnames{27},varnam
es{28},...
    varnames{29},varnames{30},varnames{31});

stats = [median_88' Average_88' STD_88' mode_88' interquartile_88'
range_88' sum_88'];
% [median_88' Average_88']
save('stats_88.mat','stats');

dafid=fopen('stats_88.txt','w');
fprintf(dafid,'%s\t%s\t%s\t%s\t%s\t%s\t%s\n','median_88', 'Average_88',
'STD_88', 'mode_88', 'interquartile_88', 'range_88', 'sum_88')
fprintf(dafid,'\n');
    fprintf(dafid,'%g\t%g\t%g\t%g\t%g\t%g\t%g\n',[stats]');
    fclose(dafid);
```

E.3 *M-file used to Enter Data*

```
%This program is used to enter data. IQPdata variables are initialized
%with zeros. The data you enter will overwrite them. Click 'cancel' to
%go back and 'ok' to go forward.

function Enterdata;
close all;

varnames = {'surveyNumber', 'interruptions', 'LastSummer',
'OnAverage',...
    'DiscomfortLevel', 'ACUnit', 'ACType', 'numberOfUnits',
'usualSummerSetting',...
    'typicalHotDaySetting', 'frequencyOfUse',
'averageSummerMonthlyBill',...
    'Concern1', 'Concern2', 'Concern3', 'Concern4',
'sensitivityToChangeInTemperature',...
    'opinionOnACCyclingOptions', 'interestInProgram1',
'Prog1FinancialIncentive',...
    'interestInProgram2', 'Prog2FinancialIncentive',
'appealingOption',...
    'gender', 'age', 'ethnicBackground', 'education', 'income',
'maritalStatus',...
    'numberOfAdults', 'numberOfChildren', 'typeOfResidence'};

varnamenum = {'','question 1.1', 'question 1.2', 'question 1.3',
'question 1.4',...
    'question 2.1', 'question 2.2', 'question 2.3', 'question 2.4',
'question 2.5', 'question 2.6',...
    'question 3', 'question 4.1', 'question 4.2',...
    'question 4.3', 'question 4.4', 'question 5', 'question 6',
'question 7',...
    'question 8', 'question 9', 'question 10',...
    'question 11', 'gender', 'Age',...
    'Ethnic Background', 'Educational Background', 'Annual household
income', 'Marital Status', 'Adults',...
    'Children', 'Residence'};

% length(varnames)
FF = exist('IQPdata.mat','file');
if FF~=2;
    'IQPdata.mat is not here';
end;

if FF ==2;
    load IQPdata.mat;

save('IQPdata2.mat',varnames{1},varnames{2},varnames{3},varnames{4},...

varnames{5},varnames{6},varnames{7},varnames{8},varnames{9},varnames{10
},...

varnames{11},varnames{12},varnames{13},varnames{14},varnames{15},varnam
es{16},...
```

```
varnames{17},varnames{18},varnames{19},varnames{20},varnames{21},varnam
es{22},...

varnames{23},varnames{24},varnames{25},varnames{26},varnames{27},varnam
es{28},...
    varnames{29},varnames{30},varnames{31},varnames{32});

    entry = 'yes';
    while strcmp(entry, 'no')==0;

        varname2 = inputdlg('please type in the survey number');

        if length(varname2)==0|length(varname2{1})==0;
            ansb = '';
            while length(ansb)==0|length(ansb{1})==0;
                ansb = inputdlg('Do you want to stop the program? type
yes or no');
            end;
            ansb = ansb{1};
            if strcmp(ansb, 'yes')~=1;
                varname2 = '';
                while length(varname2)==0|length(varname2{1})==0;
                    varname2 = inputdlg('please type in the survey
number');
                end;
                g = [];
                for jj = 1:length(varnames);
                    eval(['g = [g length(' varnames{jj} ')];']);
                end;
                kk = max(g);
                for jj = 1:length(varnames);
                    eval([varnames{jj} '(kk+1) = 0;']);
                end;
            end;
            if strcmp(ansb, 'yes')==1;
                entry = 'no';
                g = [];
                for jj = 1:length(varnames);
                    eval(['g = [g length(' varnames{jj} ')];']);
                end;
                kk = max(g);
                for jj = 1:length(varnames);
                    eval([varnames{jj} '(kk+1) = 0;']);
                end;
                display('program ended');
            end;
        end;
        if strcmp(entry, 'no')==0;
            surveynum = eval(varname2{1});
            eval([varnames{1} '(surveynum) = eval(varname2{1});']);
            k = 1;
            while strcmp(entry, 'no')==0&(k ~= length(varnames));
                k = k+1;
                varr1 = '';
                while strcmp(entry,
'no')==0&(length(varr1)==0|length(varr1{1})==0);
```

```
                    varr1 = inputdlg(['please type data for '
varnamenum{k}]);
                    h = varr1;
                    while strcmp(entry, 'no')==0&length(varr1)==0;
                        k = k-1;
                        if strcmp(entry, 'no')==0&k>=2;
                            g = eval(varnames{k});
                            g = length(g);
                            if g>=surveynum;
                                display(['the value of ' varnamenum{k}
' was ' num2str(eval([varnames{k} '(surveynum)']))]);
                            end;
                            if g<surveynum;
                                display(['the value of ' varnamenum{k}
' was empty']);
                            end;
                            [entry, varr1] =
stopprogram(varnames,k,varr1,entry,varnamenum);
                        end;
                        if strcmp(entry, 'no')==0&k<2;
                            k = 2;
                            g = eval(varnames{k});
                            g = length(g);
                            if g>=surveynum;
                                display(['the value of ' varnamenum{k}
' was ' num2str(eval([varnames{k} '(surveynum)']))]);
                            end;
                            if g<surveynum;
                                display(['the value of ' varnamenum{k}
' was empty']);
                            end;
                            [entry, varr1] =
stopprogram(varnames,k,varr1,entry,varnamenum);
                        end;
                        h = varr1;
                    end;
                    while strcmp(entry, 'no')==0&length(varr1{1})==0;
                        if length(varr1)~=0;
                            k = k+1;
                            if strcmp(entry,
'no')==0&k<=length(varnames);
                                g = eval(varnames{k});
                                g = length(g);
                                if g>=surveynum;
                                    display(['the value of '
varnamenum{k} ' was ' num2str(eval([varnames{k} '(surveynum)']))]);
                                end;
                                if g<surveynum;
                                    display(['the value of '
varnamenum{k} ' was empty']);
                                end;
                                varr1 = inputdlg(['please type data for
' varnamenum{k}]);
                            end;
                            if strcmp(entry,
'no')==0&k>length(varnames);
                                k = length(varnames);
```

```
                                g = eval(varnames{k});
                                g = length(g);
                                if g>=surveynum;
                                    display(['the value of '
varnamenum{k} ' was ' num2str(eval([varnames{k} '(surveynum)']))]);
                                end;
                                if g<surveynum;
                                    display(['the value of '
varnamenum{k} ' was empty']);
                                end;
                                [entry, varr1] =
stopprogram(varnames,k,varr1,entry,varnamenum);
                            end;
                        end;
                        h = varr1;
                        if length(varr1)==0;
                            varr1 = {0};
                        end;
                    end;
                    varr1 = h;
                end;
                if strcmp(entry, 'no')==0;
                    eval([varnames{k} '(surveynum) =
eval(varr1{1});']);
                end;
            end;
        end;
        g = [];
        for jj = 1:length(varnames);
            eval(['g = [g length(' varnames{jj} ')];']);
        end;
        kk = max(g);
        for jj = 1:length(varnames);
            eval([varnames{jj} '(kk+1) = 0;']);
        end;
    end;
end;

save('IQPdata.mat',varnames{1},varnames{2},varnames{3},varnames{4},...

varnames{5},varnames{6},varnames{7},varnames{8},varnames{9},varnames{10
},...

varnames{11},varnames{12},varnames{13},varnames{14},varnames{15},varnam
es{16},...

varnames{17},varnames{18},varnames{19},varnames{20},varnames{21},varnam
es{22},...

varnames{23},varnames{24},varnames{25},varnames{26},varnames{27},varnam
es{28},...
    varnames{29},varnames{30},varnames{31},varnames{32});

datafid=fopen('IQPdata.txt','w');
fprintf(datafid,'%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s
\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%s\t%
s\n',varnames{1},varnames{2},varnames{3},varnames{4},...
```

```
varnames{5},varnames{6},varnames{7},varnames{8},varnames{9},varnames{10
},...

varnames{11},varnames{12},varnames{13},varnames{14},varnames{15},varnam
es{16},...

varnames{17},varnames{18},varnames{19},varnames{20},varnames{21},varnam
es{22},...

varnames{23},varnames{24},varnames{25},varnames{26},varnames{27},varnam
es{28},...

varnames{29},varnames{30},varnames{31},varnames{32});

mlavesegdata=[eval(varnames{1})',eval(varnames{2})',eval(varnames{3})',
eval(varnames{4})',...

eval(varnames{5})',eval(varnames{6})',eval(varnames{7})',eval(varnames{
8})',eval(varnames{9})',eval(varnames{10})',...

eval(varnames{11})',eval(varnames{12})',eval(varnames{13})',eval(varnam
es{14})',eval(varnames{15})',eval(varnames{16})',...

eval(varnames{17})',eval(varnames{18})',eval(varnames{19})',eval(varnam
es{20})',eval(varnames{21})',eval(varnames{22})',...

eval(varnames{23})',eval(varnames{24})',eval(varnames{25})',eval(varnam
es{26})',eval(varnames{27})',eval(varnames{28})',...

eval(varnames{29})',eval(varnames{30})',eval(varnames{31})',eval(varnam
es{32})'];
  fprintf(datafid,'\n');

fprintf(datafid,'%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g
\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%g\t%
g\n',[mlavesegdata]');
    fclose(datafid);

display('Old file saved as IQPdata2.mat. New file saved as
IQPdata.mat');
display('A spreadsheet readable version has also been saved as
IQPdata.txt');

function [entry, varr1] =
stopprogram(varnames,k,varr1,entry,varnamenum);
ansb = '';
while length(ansb)==0|length(ansb{1})==0;
    ansb = inputdlg('Do you want to stop the program? type yes or no');
end;
ansb = ansb{1};
if strcmp(ansb, 'yes')~=1;
    varr1 = inputdlg(['please type data for ' varnamenum{k}]);
    display(varnames(k))
end;
if strcmp(ansb, 'yes')==1;
    entry = 'no';
```

```
    display('program ended');
end;
```

E.4 *M-file for Translating Values in Enterdata.m into Actual Responses*

```
%%This file is used to translate the values entered with Enterdata.m
%%into actual responses.

VarrIQP = {'Electricity_outages', 'Number_of_outages_last_summer',
'Length_of_interruptions', 'Outage_Level_of_discomfort',
'Have_air_cond', 'Type_of_air_cond',...
    'Number_of_air_cond_units',
'Thermostat_temp','Last_summer_AC_usage_greater_than_90deg',
'Last_summer_AC_usage_less_than_90deg',
'Average_Summer_monthly_bill',...
    'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Biggest_Energy_Cost_Concern', 'Biggest_Energy_Cost_Concern',
'Temperature_Level_of_discomfort',
'Opinion_on_automatic_air_cond_cycling',...
    'Level_of_interest_1', 'Financial_incentive_1_in_dollars',
'Level_of_interest_2', 'Financial_incentive_2_in_dollars',
'Appealing_option', 'Gender', 'Age', 'Ethnic_background',...
    'Educational_background', 'Annual_household_income',
'Marital_status', 'Number_of_adults', 'Number_of_children',
'Type_of_residence'};

varnamesNUM = {'Electricity_outages1',
'Number_of_outages_last_summer2', 'Length_of_interruptions3',
'Outage_Level_of_discomfort4', 'Have_air_cond5',
'Type_of_air_cond6',...
    'Number_of_air_cond_units7',
'Thermostat_temp8','Last_summer_AC_usage_greater_than_90deg9',
'Last_summer_AC_usage_less_than_90deg10',
'Average_Summer_monthly_bill11',...
    'Biggest_Energy_Cost_Concern12', 'Biggest_Energy_Cost_Concern13',
'Biggest_Energy_Cost_Concern14', 'Biggest_Energy_Cost_Concern15',
'Temperature_Level_of_discomfort16',
'Opinion_on_automatic_air_cond_cycling17',...
    'Level_of_interest_118', 'Financial_incentive_1_in_dollars19',
'Level_of_interest_220', 'Financial_incentive_2_in_dollars21',
'Appealing_option22', 'Gender23', 'Age24', 'Ethnic_background25',...
    'Educational_background26', 'Annual_household_income27',
'Marital_status28', 'Number_of_adults29', 'Number_of_children30',
'Type_of_residence31'};

varnamesNUM1 = {'Electricity_outagese1',
'Number_of_outages_last_summere2', 'Length_of_interruptionse3',
'Outage_Level_of_discomfortee4', 'Have_air_conde5',
'Type_of_air_conde6',...
    'Number_of_air_cond_unitse7',
'Thermostat_tempe8','Last_summer_AC_usage_greater_than_90dege9',
'Last_summer_AC_usage_less_than_90dege10',
'Average_Summer_monthly_bille11',...
    'Biggest_Energy_Cost_Concerne12', 'Biggest_Energy_Cost_Concerne13',
'Biggest_Energy_Cost_Concerne14', 'Biggest_Energy_Cost_Concerne15',
'Temperature_Level_of_discomforte16',
'Opinion_on_automatic_air_cond_cyclinge17',...
```

```
    'Level_of_interest_1e18', 'Financial_incentive_1_in_dollarse19',
'Level_of_interest_2e20', 'Financial_incentive_2_in_dollarse21',
'Appealing_optione22', 'Gendere23', 'Agee24',
'Ethnic_backgrounde25',...
    'Educational_backgrounde26', 'Annual_household_incomee27',
'Marital_statuse28', 'Number_of_adultse29', 'Number_of_childrene30',
'Type_of_residencee31'};

varunits = {'','','','','','','Number of A/C units owned','In Degrees
Fahrenheit','A/C usage (hrs/day)','A/C usage (days)',...
    'In dollars per month','','','','','','','5 is very
interested','','5 is very interested','','','','','Age
Group','','Income in dollars per year','','','',''};

Electricity_outages = {'Yes', 'No'};
Number_of_outages_last_summer = {'1', '2 to 4', '4 to 6', '6 to 8', '8
or more'};
Length_of_interruptions = {'1', '3', '5', '7', '9'}';
Outage_Level_of_discomfort = {'1', '2', '3', '4', '5'};
Have_air_cond = {'Yes', 'No'};
Type_of_air_cond = {'A', 'B', 'C', 'D'};
Number_of_air_cond_units = {'1', '2', '3', '4', '5', '6', '7', '8'};
Thermostat_temp = {num2str(65-(70-65)/2), '67.5', '72.5',
num2str(75+(70-65)/2)};
Last_summer_AC_usage_greater_than_90deg = {'0', '2', '5', '9', '18',
'24'};
Last_summer_AC_usage_less_than_90deg = {'0', '4', '10.5', '21','34',
'40'};
Average_Summer_monthly_bill = {'50', '70', '90', '110', '130', '150'};
Biggest_Energy_Cost_Concern = {'A','B','C','D'};
Cost_of_electricity_concern = {'Cost of electricity'};
Preventing_outages_concern = {'Preventing power outages'};
Renewable_and_clean_energy = {'Renewable and clean energy'};
Other = {'Other'};
Temperature_Level_of_discomfort = {'A', 'B', 'C', 'D'};
Opinion_on_automatic_air_cond_cycling = {'A', 'B', 'C','D', 'E'};
Level_of_interest_1 = {'1', '2', '3', '4', '5'};
Financial_incentive_1_in_dollars = {'0', num2str((20-(29-20)/2)),
num2str((20+(29-20)/2)), num2str((30+(39-30)/2)), num2str((40+(49-
40)/2)), num2str((50+(49-40)/2))};
Level_of_interest_2 = {'1', '2', '3', '4', '5'};
Financial_incentive_2_in_dollars = {'0', num2str((20-(29-20)/2)),
num2str((20+(29-20)/2)), num2str((30+(39-30)/2)), num2str((40+(49-
40)/2)), num2str((50+(49-40)/2))};
Appealing_option = {'Option one', 'Option two'};
Gender = {'Male', 'Female'};
Age = {'Under 20', '20 to 29', '30 to 39', '40 to 49', '50 to 59', '60
or older'};
Ethnic_background = {'White/Caucasian', 'Hispanic', 'Black/African
American', 'Asian/Pacific Islander', 'Native American', 'Other'};
%{'A', 'B', 'C', 'D', 'E', 'F'};
Educational_background = {'A', 'B', 'C', 'D', 'E', 'F', 'G', 'H'};
Annual_household_income = {'12,500', '27,500', '42,500',
'65,000','85,000', '107,500'};
Marital_status = {'Single', 'Married', 'Other'};
Number_of_adults = {'1', '2', '3', '4', '5', '6'};
Number_of_children = {'0', '1', '2', '3', '4', '5'};
```

```
Type_of_residence = {'Owner', 'Rent', 'Friends/Family', 'Other'};

VarnamesNUMunits = [0 1 1 1 0 0 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 0 0 1 0 0
1 0 1 1 0]
Electricity_outages1 = [1 2];
Number_of_outages_last_summer2 = [1, 3, 5, 7, 9];
Length_of_interruptions3 = [1, 3, 5, 7, 9];
Outage_Level_of_discomfort4 = [1, 2, 3, 4, 5];
Have_air_cond5 = [1 2];
Type_of_air_cond6 = [1, 2, 3, 4];
Number_of_air_cond_units7 = [1, 2, 3, 4, 5, 6, 7, 8];
Thermostat_temp8 = [65-(70-65)/2, 67.5, 72.5, 75+(70-65)/2];
Last_summer_AC_usage_greater_than_90deg9 = [0, 2, 5, 9, 18, 24];
Last_summer_AC_usage_less_than_90deg10 = [0, 4, 10.5, 21, 34, 40];
Average_Summer_monthly_bill11 = [50, 70, 90, 110, 130, 150];
Biggest_Energy_Cost_Concern12 = [1 2 3 4];
Biggest_Energy_Cost_Concern13 = [1 2 3 4];
Biggest_Energy_Cost_Concern14 = [1 2 3 4];
Biggest_Energy_Cost_Concern15 = [1 2 3 4];
Temperature_Level_of_discomfort16 = [1, 2, 3, 4];
Opinion_on_automatic_air_cond_cycling17 = [1, 2, 3, 4, 5];
Level_of_interest_118 = [1, 2, 3, 4, 5];
Financial_incentive_1_in_dollars19 = [0, 20-(29-20)/2, (20+(29-20)/2),
(30+(39-30)/2), (40+(49-40)/2), 50+(49-40)/2];
Level_of_interest_220 = [1, 2, 3, 4, 5];
Financial_incentive_2_in_dollars21 = [0, 20-(29-20)/2, (20+(29-20)/2),
(30+(39-30)/2), (40+(49-40)/2), 50+(49-40)/2];
Appealing_option22 = [1 2];
Gender23 = [1 2];
Age24 = [20, 25.5, 35.5, 45.5, 55.5, 65.5];
Ethnic_background25 = [1, 2, 3, 4, 5, 6];
Educational_background26 = [1, 2, 3, 4, 5, 6, 7, 8];
Annual_household_income27 = [12500, 27500, 42500, 65000, 85000,
107500];
Marital_status28 = [1 2 3];
Number_of_adults29 = [1, 2, 3, 4, 5, 6];
Number_of_children30 = [0,1, 2, 3, 4, 5];
Type_of_residence31 = [1 2 3 4];

Electricity_outagese1 = [[1 2]' [1 2]'];
Number_of_outages_last_summere2 = [[1, 3, 5, 7, 9]' [1, 2, 3, 4, 5]'];
Length_of_interruptionse3 = [[1, 3, 5, 7, 9]' [1, 2, 3, 4, 5]'];
Outage_Level_of_discomfortee4 = [[1, 2, 3, 4, 5]' [1, 2, 3, 4, 5]'];
Have_air_conde5 = [[1 2]' [1 2]'];
Type_of_air_conde6 = [[1, 2, 3, 4]' [1, 2, 3, 4]'];
Number_of_air_cond_unitse7 = [[1, 2, 3, 4, 5, 6, 7, 8]' [1, 2, 3, 4, 5,
6, 7, 8]'];
Thermostat_tempe8 = [[65-(70-65)/2, 67.5, 72.5, 75+(70-65)/2]' [1 2 3
4]'];
Last_summer_AC_usage_greater_than_90dege9 = [[0, 2, 5, 9, 18, 24]' [1,
2, 3, 4, 5, 6]'];
Last_summer_AC_usage_less_than_90dege10 = [[0, 4, 10.5, 21,34, 40]' [1,
2, 3, 4, 5, 6]'];
Average_Summer_monthly_bille11 = [[50, 70, 90, 110, 130, 150]' [1, 2,
3, 4, 5, 6]'];
Biggest_Energy_Cost_Concerne12 = [[1 2 3 4]' [1 2 3 4]'];
Biggest_Energy_Cost_Concerne13 = [[1 2 3 4]' [1 2 3 4]'];
```

```
Biggest_Energy_Cost_Concerne14 = [[1 2 3 4]' [1 2 3 4]'];
Biggest_Energy_Cost_Concerne15 = [[1 2 3 4]' [1 2 3 4]'];
Temperature_Level_of_discomforte16 = [[1, 2, 3, 4]' [1 2 3 4]'];
Opinion_on_automatic_air_cond_cyclinge17 = [[1, 2, 3, 4, 5]' [1 2 3 4
5]'];
Level_of_interest_1e18 = [[1, 2, 3, 4, 5]', [1 2 3 4 5]'];
Financial_incentive_1_in_dollarse19 = [[0, 20-(29-20)/2, (20+(29-
20)/2), (30+(39-30)/2), (40+(49-40)/2), 50+(49-40)/2]' [1 2 3 4 5 6]'];
Level_of_interest_2e20 = [[1, 2, 3, 4, 5]' [1 2 3 4 5]'];
Financial_incentive_2_in_dollarse21 = [[0, 20-(29-20)/2, (20+(29-
20)/2), (30+(39-30)/2), (40+(49-40)/2), 50+(49-40)/2]' [1 2 3 4 5 6]'];
Appealing_optione22 = [[1 2]' [1 2]'];
Gendere23 = [[1 2]' [1 2]'];
Agee24 = [[20, 25.5, 35.5, 45.5, 55.5, 65.5]' [1 2 3 4 5 6]'];
Ethnic_backgrounde25 = [[1, 2, 3, 4, 5, 6]' [1 2 3 4 5 6]'];
Educational_backgrounde26 = [[1, 2, 3, 4, 5, 6, 7, 8]' [1 2 3 4 5 6 7
8]'];
Annual_household_incomee27 = [[12500, 27500, 42500, 65000, 85000,
107500]' [1 2 3 4 5 6]'];
Marital_statuse28 = [[1 2 3]' [1 2 3]'];
Number_of_adultse29 = [[1, 2, 3, 4, 5, 6]' [1 2 3 4 5 6]'];
Number_of_childrene30 = [[0,1, 2, 3, 4, 5]' [0 1 2 3 4 5]'];
Type_of_residencee31 = [[1 2 3 4]' [1 2 3 4]'];
```

E.5 *Code for Economic Model*

```
function IQPgraphs
% close all;
load IQPgraphs.mat;
t = DateandHour1(:);
B = DateandHour1(:);
A = LOAD(:);
GV3X = 'time (hrs)';
GV3Y = 'LOAD (MW)';
[LLL,Bm,Am,As,A,B] = removeminusone(A,B);
numberofdays = LLL/24;
Am11 = Am*(1-0);
Am22 = Am*(1-.1);
Am33 = Am*(1-.15);
Am44 = Am*(1-.2);
Am55 = Am*(1-.25);
Am66 = Am*(1-.3);
axis([(min(Bm-.2)) (max(Bm+.2)) (min(Am-As-As*.2))
(max(Am+As+As*.2))]);
plot(Bm,Am,Bm,Am22,Bm,Am33,Bm,Am44,Bm,Am55,Bm,Am66);
xlabel(GV3X,'FontSize',16),
ylabel(GV3Y,'FontSize',16)
BF1 = ['Average LOAD'];
BF2 = ['Average LOAD reduced by 10%'];
BF3 = ['Average LOAD reduced by 15%'];
BF4 = ['Average LOAD reduced by 20%'];
BF5 = ['Average LOAD reduced by 25%'];
BF6 = ['Average LOAD reduced by 30%'];
legend(BF1,BF2,BF3,BF4,BF5,BF6,'Location','bestoutside');
grid on;
grid minor;
saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X ' vs '
GV3Y]],'bmp');

Ac = DateandHour1(:);
B = LOAD(:);
A = LMP(:);
GV3X = 'LOAD (MW)';
GV3Y = 'LMP ($ per MW)';
[LLL,Am,Bm,Bs,B,Ac] = removeminusone(B,Ac);
[LLL,Acm,Am,As,A,Ac] = removeminusone(A,Ac);
[LLL,Bm,Am,As,AA,BB] = removeminusone(Am,Bm);
Bm = Bm(:);
Am = Am(:);
As = As(:);
BC = [min(B):max(B)];
BC = BC(:);
BB = [[Bm.*1.*ones(size(Bm)) ] [Bm.*(+1./((Bm-max(B)-.3).^2))]];
kL = 10;
k = kL;
BBB = [[BC.*1.*ones(size(BC)) ] [BC.*(+1./((.21*k*BC-max(.21*k*B)-
.3).^2))]];
a = BB\Am
f = (BBB*a);
```

```
plot(BC,f,'color','r');
hold on;
errorbar(Bm,Am);
hold on;
plot(B,A,'+')
axis([(min(B-.2)) (max(B+.2)) (min(A-.2)) (max(A+2))]);
hold off;
xlabel(GV3X,'FontSize',16),
ylabel(GV3Y,'FontSize',16)
BF = ['Fit curve'];
BF2 = ['Mean LMP vs Mean load'];
BF3 = ['LMP vs load'];
legend(BF,BF2,BF3,'Location','bestoutside');
g1 = ['Fitcurve = ' 'x.*(' num2str(a(2)) '*(1/((2.1*x-2.1*max(load)-
.3)^2))' ' + ' num2str(a(1)) ')'];
text((max(B)+min(B))/2-(max(B)-min(B))*(1/2-
.01),(max(A)+min(A))/2+(max(A)-min(A))*(1/2-
.1),[g1],'color','k','BackgroundColor',[0 1 1],'FontSize',9);
grid on;
grid minor;
saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X ' vs '
GV3Y]],'bmp');

percent = [10,15,20,25,30];
GV3X = 'LOAD (MW)';
GV3Y = 'Cost ($ per MW)';
xx = Am11;
x = xx(10:20);
x = sort(x);
x = x(:);
y = eval(['x.*(' num2str(a(1)) ' + ' num2str(a(2)) '*(+1./((2.1*x-
max(2.1*B)-.3).^2))' ');']);
y = y(:);
cost1 =[];
for w = 2:6;
    eval(['xx = Am' num2str(w) num2str(w) ';']);
    x1 = xx(10:20);
    x1 = sort(x1);
    x11 = [x1(1) x1(2:11)-x1(1:10)];
    x11 = x11(:);
    x1 = x1(:);
    y1 = eval(['x1.*(' num2str(a(1)) ' + ' num2str(a(2))
'*(+1./((2.1*x1-max(2.1*B)-.3).^2))' ');']);
    y1 = y1(:);
    Y = (x11.*y-x11.*y1)*numberofdays;
    cost1 = [cost1 sum(Y)];
    plot(x1,y1,'o',x,y,'+')
    xlabel(GV3X,'FontSize',16),
    ylabel(GV3Y,'FontSize',16)
    axis([min(min(x1-.2),min(x-.2)) max(max(x1+.2),max(x+.2))
min((min(y1-.2)),(min(y-.2))) max(max(y1+2),max(y+2))]);
    BF2 = ['Cost at ' num2str(percent(w-1)) ' percent reduction'];
    BF3 = ['Cost'];
    legend(BF2,BF3,'Location','bestoutside');
    grid on;
    grid minor;
```

```
    saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X ' vs ' GV3Y
'at ' num2str(percent(w-1)) ' percent reduction']],'bmp');
    pause(.6)
end;

GV3X = 'Percent reduction (%)';
GV3Y = 'Total Cost Saved ($)';
cost1 = cost1(:);
percent = percent(:);
x1 = percent;
y1 = cost1;
x = min(x1):.05:max(x1);
y = -2068*x.^2 + 1.7768*(10^5)*x + 4.2603*10^5;
plot(percent,cost1,'o',x,y);
xlabel(GV3X,'FontSize',16),
ylabel(GV3Y,'FontSize',16)
axis([min(x1-.2) max(x1+.2) min(y1-.2) max(y1+2)]);
g1 = ['fitcurve = -2068*x^2 + 1.7768*10^5*x + 4.2603*10^5'];
text((max(x1)+min(x1))/2-(max(x1)-min(x1))*(1/2-
.01),(max(y)+min(y))/2+(max(y)-min(y))*(1/2-
.1),[g1],'color','k','BackgroundColor',[0 1 1],'FontSize',9);
grid on;
grid minor;
saveas(gcf,['coranal\meanplotsreg\reggraphs\'  [GV3X ' vs '
GV3Y]],'bmp');
J = [percent cost1];
save('CostvPercent.txt','J','-ascii')

function [LLL, Bm,Am,As,A,B] = removeminusone(A,B);
LLL = length(B);
cnt = 0;
Bp = unique(B);
for kk = 1:length(Bp);
    k = Bp(kk);
    cnt = cnt+1;
    HH = find(B==k);
    if length(HH)~=0;
        Am(cnt) = mean(A(HH));
        As(cnt) = std(A(HH));
        Bm(cnt) = k;
    end;
    if length(HH)==0;
        cnt = cnt-1;
    end;
end;
As = As/sqrt(length(B));
```

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