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Energy Efficiency and Demand Response for Residential Applications

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Abstract

The purpose of this thesis is to analyze the costs, feasibility and benefits of implementing energy efficient devices and demand response programs to a residential consumer environment. Energy efficiency and demand response are important for many reasons, including grid stabilization. With energy demand increasing, as the years' pass, the drain on the grid is going up. There are two key solutions to this problem, increasing supply by building more power plants and decreasing demand during peak periods, by increasing participation in demand response programs and by upgrading residential and commercial customers to energy efficient devices, to lower demand throughout the day. This thesis focuses on utilizing demand response methods and energy efficient device to reduce demand. Four simulations were created to analyze these methods. These simulations show the importance of energy efficiency and demand response participation to help stabilize the grid, integrate more alternative energy resources, and reduce emissions from fossil fuel generating facilities. The results of these numerical analyses show that demand response and energy efficiency can be beneficial to consumers and utilities. With demand response being the most beneficial to the utility and energy efficiency, specifically LED lighting, providing the most benefits to the consumer.

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List of Abbreviations

AC	Air Conditioning
AGC	Automated Generation Control
CO_2	Carbon dioxide
CPP	Critical Peak Pricing
DOE	Department of Energy
DR	Demand Response
EIA	Energy Information Administration
GAMS	General Algebraic Modeling System
kW	kilowatt
kWh	kilowatt hour
MW	Megawatt
MWh	Megawatt hour
NHEC	New Hampshire Electric Co-op
OPF	Optimal Power Flow
PG&E	Pacific Gas and Electric Company
PV	Photovoltaic
RTP	Real Time Pricing
SCADA	Supervisory Control and Data Acquisition
TOU	Time of Use

Chapter One: Introduction

1.1 The Energy Market

To understand how demand response and energy efficiency can help the grid, utilities, and consumers one must first understand how the energy market works. A utility is an entity that controls the distribution of energy to consumers. This entity may or may not own generating facilities and transmission lines. In recent decades' deregulation has forced utilities, in certain markets, to sell off some or all their generating facilities to other companies to lower prices for consumers. Deregulation has not always worked and in some cases, has left utilities no choice but to implement rolling blackouts in some areas on the grid, due to a lack of supply available [1] [2]. For this thesis, a consumer is a person or entity that consumes power. Usually broken down into three categories; residential, commercial, or industrial. Key factors such as supply and demand, power generating facilities, energy forecasting, energy rates and emission from power generation must be analyzed to create a basis for the need to implement demand response and energy efficiency programs [3].

1.1.1 Supply and Demand

The energy market is just like any other market, in that it is driven by supply and demand. In this market the relationship of supply available and demand required is pertinent to maintaining stability on the grid [2].

When the grid is congested, meaning demand is nearing or has reached the limits of its infrastructure, a few events may occur. In the case of supply being slightly less than demand a brownout can occur. This occurs when the frequency and/or voltage on the grid slightly drops, causing consumers to experience symptoms such as flickering or dimming lights, and the slowing of motors. A blackout, otherwise known as grid failure, is a sudden loss of power to portions of or the entire grid. A blackout is a loss of power to consumers and can also cause physical damage to the grid infrastructure. Physical damage results in the need for time consuming hardware repair or replacement before the grid can be restored. To prevent this, the utility will usually, if able, increase the supply to the grid. If able, the utility will bring generators online, called peaking power plants, to maintain the stability of the grid. If increasing supply is not an option, the utility may implement a planned outage by shutting off power to select areas of the grid, to prevent damage to grid hardware. If the utility is unable to increase supply it may be forced to de-energize customers to maintain stability, meaning rolling blackouts will occur. In some cases, the utility can bypass damaged hardware and distribute power from other locations on the grid to avoid blackouts. In most cases, residential consumers are targeted first for outages and hospitals are usually not subject to outages [1].

There are times when supply reaches a point where it is going to surpass demand. In these cases, a few things can happen. The grid connected dispatchable generators can reduce generation automatically when they start to see the cycles surpass sixty cycles to maintain the voltage and frequency of the grid, both of which fluctuate when there is too little or too much generation supplying the grid. If this safety measure does not solve the problem, meaning there is still too much energy supply on the grid, the utility can sell off some of its energy to another connected grid that can handle the increased supply.

This constant balancing between supply and demand is a never-ending struggle for utility companies. It is what keeps the lights on for consumers and contributes to a stable electric grid environment. Supply and demand control is just as important, if not more important, to the utility companies than it is to any other market.

1.1.2 Demand Periods

Demand on the grid varies greatly depending on time of year and time of day. Utilities use up to four peak periods, off-peak, mid-peak, peak, and critical peak. Off peak periods are the time of day when demand is at a minimum, usually occurring at night when most people are asleep. Mid peak periods occur midday when most consumers are work and in the morning when people are getting ready for work. Peak period occurs in the afternoon and into the evening, when it is hottest and when consumers come home from work [4]. Critical peak periods are special cases that do not occur every day. These peaks happen when it is extremely hot outside and more consumers are running their air conditioning (AC) at higher rates [5]. An example of 24-hour demand graph can be found in Appendix C, Figure C1, showing a normal fall, winter, spring and summer day, in Denver. These figures show that peak demand is much higher during the summer than it is during the winter and that critical peak demand, on hot summer days, is higher than that of normal summer peak demand.

1.1.3 Power Generating Facilities

There are many different types of power generating facilities that help to power the grid in different manners. The more traditional types use fuel sources such as coal, natural gas, jet fuel, and kerosene. There are renewable energy sources such as wind turbines, PV solar cell arrays, geothermal, biomass, and hydroelectric. There is also nuclear power which some classify as a renewable energy source, due to its low CO_2 emissions. These facilities come in all shapes and sizes, whether it be a small 1 KW rooftop solar array or a large 7,965MW nuclear facility [6]. These facilities all work together to generate enough power to maintain grid stability and provide enough energy for all consumers.

Power generating facilities can be divided into two main categories, dispatchable or non-dispatchable. Dispatchable means their output can be modified, with varying response time dependent of the type of generating facility. Hydroelectric has the fastest response being able to go from minimum to maximum power output within seconds. While it is dispatchable, it can only be dispatched if there is enough water stored behind the dam. There is more water available in some seasons than others [1]. Making its available power output vary based more so on time of year rather than time a day as is the case with wind and solar. Natural gas, jet fuel, and kerosene generating facilities can be brought to full capacity in minutes. Coal, biomass and nuclear power can be brought online within hours, nuclear takes the most time. Non-dispatchable power generating resources such as solar and wind are only available when climate conditions are favorable [7]. Usually overnight for wind and midday for solar. Most of their production falls outside of peak periods [1].

Solar and wind do vary based on season, but the time of day factors have a greater affect than the seasonal variations do.

Dispatchable power generating facilities can be broken up into three subcategories, baseline power plant, load following, also known as cycling, power plants and peaking power plants, also known as peakers. Figure 1.1 shows a 24-hour demand curve for a summer day in Texas. This graph shows baseline power plants operate as the constant throughout the day. These facilities usually output enough power to meet the lowest demand point for the entire day. Baseline generating facilities are form of generation implementation that utilizes power plants that are the cheapest and/or unable to ramp up and down easily. Load following generating facilities handle the middle range of the demand curve, anything that is not covered by peak or baseline generating facilities. At about 4:00 a.m. load following generating facilities start to increase their power output until they reach their maximum at about noon. They then hold that output until about 8:15 p.m., the end of the peak period, where they start to decrease output until the about 4:00 a.m. Peaking power plants cover the top section of the demand curve, from about noon to 8:15 p.m. These times vary from grid to grid depending on the local market. Peaking power plants are used during peak and critical peak periods to meet the increased demand of the grid. They are usually generators utilizing jet fuel, kerosene, or natural gas. These generators usually cost more to operate and have greater CO_2 emissions than most other forms of generation supplying the grid. Peaking power plants are usually utilized during the summer months, since winter demand is substantially lower than that of the summer demand. Some peaking power plants are only utilized for a few days out of the year. Figure

1.2 shows a demand curve for a winter weekday, where only baseload demand and intermediate demand are utilized. Figure 1.2 maxes out below 13500 kWh, which is below the maximum of the intermediate demand, 18000 kWh, in Figure 1.1.

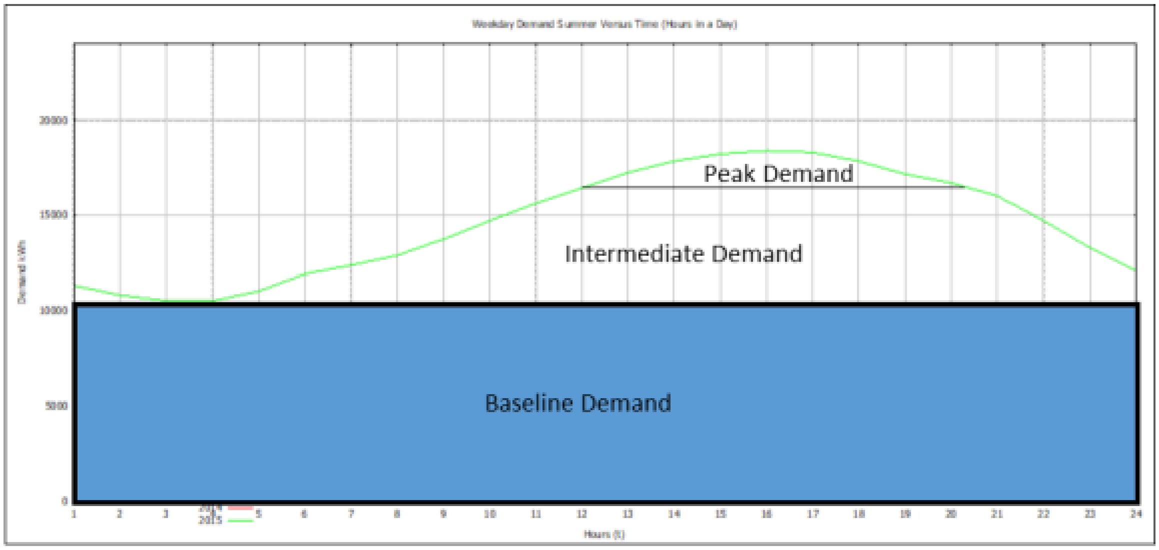

Figure 1.1 Weekday Demand Summer versus Time (Hours in a Day) Demand Curve for ERCOT in Texas *[8]***.**

While load following and peaking power plants may not be operating at full capacity during baseline generation periods, they are still generating a small amount of power all day. These generators can respond to demand changes much faster when they are operating at minimum capacities, as opposed to when they are off. Starting a generator from the off position is called a cold start. The speed at which a generator can increase or decrease generation output is called the ramp up or ramp down time, respectively. Peaking power plants have the fastest ramp up and ramp down times, which is one of the reasons they are utilized during the peak periods of the demand curve.

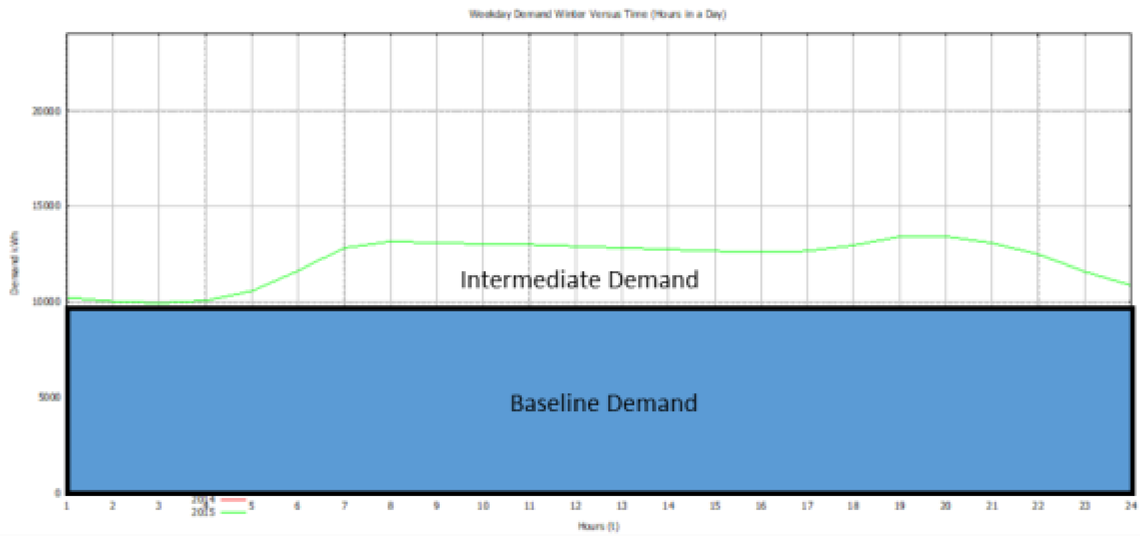

Figure 1.2 Weekday Demand Winter versus Time (Hours in a Day) Demand Curve for ERCOT in Texas [8].

1.1.4 Energy Forecasting

Forecasting is an important tool utilities and businesses in general use to predict future markets. Utilities use forecasting to determine potential supply from alternative energy resources (such as wind and solar) and demand (consumer energy usage) on the grid.

Forecasting can be broken up into three main categories, long-term, medium-term, and short-term. Long-term forecasting is used to determine the need for upgrades and the commissioning or decommissioning of generating facilities. These type of forecasting models usually look years into the past, analyzing data and variables such as population growth to determine the energy needs over the next one to ten years. Medium forecasting looks at a period of months to years, usually to plan maintenance and fuel scheduling. Short-term forecasting looks at intervals of five minutes to a week. In most cases this is used for unit commitment planning, determining which generators will be used to supply the grid at a specific time.

Short and medium term forecasting consider many different variables, including but are not limited to the time of day, day of week (usually broken up into weekday and weekend), demand side management (such as demand response programs), temperature, wind speeds and other weather conditions, holidays, price of energy, available generation, economic behavior, human behavior, and any other variable that may affect usage.

Analytical statistical methods are among the most common methods used in forecasting energy demand. Times series analysis, an analytical statistical method, looks for patterns in seemingly random variables. It can look at many different periods and resolutions of data to locate patterns. Time series analysis can be broken down into two categories, deterministic and stochastic. The deterministic method looks for the causes of change in demand and uses them to create a forecast broken down into many variables. The stochastic method assumes everything has a pattern and from these patterns variables can be broken down and analyzed to create a realistic model that is sound but not perfect. Econometric models consider the economic variables and breaks demand up into subgroups of customer types, such as size of home, devices in the household, then sums the subgroups up, factoring in how many customers are in each different subgroup. This is a cause and effect model. There are many different types of analytic forecasting methods and most forecasting models use combinations of these methods to predict future demand for different time intervals.

Some of these methods can also be applied to supply side forecasting. To forecast energy production from solar generation, forecasters need to know weather conditions such as solar radiation, cloud coverage, temperature and other environmental factors. To forecast wind turbine outputs, forecasters need to know estimated wind speeds, wind direction, air density, and other environmental factors. Forecasting can also be applied to other generating facilities, factoring in the need for maintenance, repairs, renovations and scheduled down time, a period a generator must be off or running at minimum capacity to prevent wear and tear or damage to the facility.

Using forecasting, on both the supply and demand side, utilities can predict, with some level of accuracy, the amount of energy needed to maintain a stable grid. Accurate forecasting will also lead to reduced costs for utilities and subsequently lowering the cost to the consumer. These are just a few of the countless methods used in the energy industry to forecast supply and demand [9] [10] [11] [12] [13] [14].

1.1.5 Utility Rates

Load benefits, also known as electricity rates, are used to determine the price consumer will pay for their energy needs. Standard rates are straight forward, broken down into two categories, summer and winter season. In most cases, each seasons' load benefits contain a set of prices known as tier pricing, where the price of energy goes up as the consumer's total monthly demand goes up. For example, Xcel Energy has three different rates. One rate is a straight winter season rate, $0.05461 per kWh. The summer period rate has two tiers. The first is what a consumer is charged for their first 500 kWh of usage,

$0.05461 per kWh. The second covering any demand greater than 500 kWh, $0.09902 [15].Some energy companies utilize more tiers for their residential customers. These rates do not include service charges and other fees the utility may charge just for having electric service. This basic tier rate is the most common rate utilized by electric companies. However, there are many other rate structures that some utility companies use.

1.1.6 Power Generation Rates & CO_2 Emissions per kWh

Power generation costs and emissions are an important factor to consider when analyzing the grid. The cost of electricity to the consumer is directly related to generation costs and the emissions these generators produce can affect the overall cost to the utility and other companies that own generating facilities. Table 1.1 shows information on CO_2 emissions and generating costs per kWh [16] [17]. The values are levelized, meaning the cost and emissions cover the entire lifespan of the generating facility, everything from construction through deconstruction and recycling, not just the fuel costs. Some people think that alternative energy sources have zero emissions, when in fact they have emissions from manufacturing, distribution and recycling. Solar emissions are the worst among traditional alternative energy sources and nuclear. Coal has the most emissions across the board [16]. All forms of coal are more expensive than non-peaking natural gas power plants. Peaking natural gas power plants do cost more than conventional coal power, however, this come from the increased cost of being able to ramp up faster. All forms of alternative energy are still more expensive than baseline and load following power generators [17]. For them to become more competitive prices need to come down. All this data must be considered in forecasting the future of the energy grid. Demand response and energy efficiency practices can reduce the need for coal and make alternative energy more viable in the energy market.

Table 1.1 Power Generation Costs and Emissions

Category	Sub-Category	Peaking Power Plant	Average Levelized CO2 Emissions in grams per kWh	Average Levelized Cost per kWh
Coal (Dispatchable)			800 to 1050	
	Conventional			$0.1000
	Advanced			$0.1230
	Advanced with CCS			$0.1355
Natural Gas (Dispatchable)			430 (average)	
	Conventional CC			$0.0671
	Advanced CC			$0.0656
	Advanced CC with CCS			$0.0934
	Conventional Combustion Turbine	X		$0.1303
	Advanced Combustion Turbine	X		$0.1046
Advanced Nuclear (Dispatchable)			6	$0.1084
Hydroelectric (Non-Dispatchable)			4	$0.0903
Photovoltaic solar (Non-Dispatchable)			60 to 150	$0.1443
Wind Power (Non-Dispatchable)			3 to 22	$0.0866

* CC stands for Combined Cycle & CCS stands for Carbon Capture and Storage [16] [17].

1.2 Demand Response

Demand response is designed to help lower peak and critical peak load on the grid. Demand response is a form of demand side management that allows users and/or utilities to make relatively fast changes to demand on the grid, based on price and supply. These changes are based on electricity pricing and an understanding of the relationship between supply available and demand required, to maintain grid stability. There are many forms of demand response in use today and more and more utilities are adding demand response to their available commercial and residential programs each year [1] [18].

1.3 Energy Efficiency

Energy Efficiency is a subject that covers a vast variety of topics. The overall goal of energy efficiency is to reduce energy consumption among residential, commercial, or industrial consumers. This can be done by making upgrades to a home, to increase thermal efficiency, by installing new curtains, blinds, windows and/or insulation. One could also be energy efficient by keeping their house closer to the outside temperature and adjusting their thermostat by only a few degrees when the property is unoccupied. For the focus of this thesis the term energy efficiency is used when describing the installation of appliances, devices and lighting that use less energy than their traditional equivalents. The Department of Energy (DOE) and Energy Star set standards for energy efficiency. If an appliance, device or form of lighting meets these standards then they are given the Energy Star Rating. Energy Star also provides a website that includes everything you need to know about usage characteristics of consumers for everything, as well as, comparisons and ratings for most appliances, devices and lighting on the market [19]. In Chapter 3 a numerical analysis of the costs and benefits of installing LED lighting and Energy Star rated products, in a residential home, will be addressed.

1.4 Utility Controlled Demand Response

Utility controlled demand response puts control of certain predefined loads in the hands of the utility. Rather than a consumer controlling when their energy is curtailed, meaning their demand is reduced, the utility has control of one or more circuit breakers at a site, or facility, allowing them to shut off an amount of the consumer's demand. In most cases this part of the load is usually limited to air conditioning or lighting. The utility gives the consumer some notice, except for emergency cases, before reducing their demand. In Colorado, there are residential programs strictly tied to a user's air conditioning called Saver's Switch. This program allows the utility to cycle a consumer's AC at 15-20 minute intervals during critical peak periods. [20]. There are also commercial and industrial programs, run by EnerNOC in combination with Xcel Energy, which are more in-depth with control over more devices [21]. This program is a combination of utility controlled and user controlled demand response, giving the user options on what will be utility controlled and what will be user controlled. Notifications for critical peak demand response events are given at least sixty minutes prior to the event. Events usually occur on weekdays during the day and will last between one and eight hours, usually between two and four hours.

Utility controlled demand response is more reliable, than consumer controlled demand response, because it allows the utility to create a more accurate forecasting model for grid stability. The utility can create a more reliable model by knowing exactly how much power is available from demand response resources on the grid.

In Chapter 4 Section 1 a numerical simulation will analyze the effects of utility controlled demand response on the grid, its pricing and its stability. The goal is to implement a system that can reduce the load of the grid and eventually eliminate the need for peaker power plants, while being mutually beneficial to both the customer and the utility.

1.5 Residential Demand Response

Chapter 4 Section 2 will investigate the effect that energy efficiency and demand response will have on a residential household. The goal is to show that by implementing both energy efficient devices in the home and by signing up for a residential demand response program a residential consumer can save on their overall yearly electric utility bill. Average usage statistics from Denver, Colorado, Department of Energy (DOE), and Energy Star are looked at to create two 8760-hour data sets. Two different usage profiles are analyzed, one for a completely energy efficient household and one for an energy inefficient household. Usage characteristics between the two profiles remain the same, while the efficiency of appliances, devices and lighting are upgraded to energy star standards. The sets are applied to Pacific Gas and Electric Company (PG&E) commercial Critical Peak Pricing plans and compared to standard for commercial energy pricing using GAMS. Commercial prices were used since there were no residential price programs were found. A simulation for New Hampshire Electric Co-op (NHEC) is also included. Ways to participate in demand response, without being a participant in an official program are also discussed.

1.6 Residential Real Time Pricing with Solar Generation and Battery Backup

Chapter 4 Section 3 investigate a means to simulate how real-time energy pricing can impact a consumer's energy usage behaviors and determine how much a consumer could potentially save or even earn by enrolling in such a program. This section also analyzes how a utility can benefit from these programs, by receiving load reduction information from the consumer up to three hours in advance. This section looks at a 72-hour period, analyzing a hot, cool and average summer day. There are five modules within the numerical analysis. Module 1 looks at typical utility rate pricing with solar generation. Module 2 implements real time pricing, a price structure with a resolution of anywhere from a minute to an hour. There are four price points that are dependent on temperature and the consumer is notified of the price three hours in advance. In Module 3 lighting reduction is explored. Module 4 covers AC reduction. Module 5 uses a backup battery system to store energy from solar generation and the grid when prices are low and sell energy back to the grid when prices are high [22] [23].

Chapter Two: Demand Response

2.1 Definition

Shifting peak demand, outside of peak hours, allows alternative energy sources to be utilized more effectively and allows demand to be available to justify the expansion of these forms of alternative energy. To achieve this, changes need to be made by utilities and consumers alike. One possibility is the implementation of and participation in demand response programs. Demand response allows for these shifts in demand to be made. The utilities can implement programs that entice the consumer to help balance the daily load curve.

2.2 Consumer Participation

Demand response is a type of program created to incentivize consumers to shift some of their demand from peak and critical peak periods to off or mid-peak periods. There are many ways demand response affects consumers, both those who participate in utility programs and those that do not. For those consumers who choose not to participate or are unable to participate, due to a lack of program availability in their area, the effect is simple. They will potentially see one of two things happen, the first being a decrease in their kWh rates. This comes from the fact that other participants have created a more reliable grid that is cheaper to maintain. Which creates a lower average supply cost, that translates into a lower cost to the consumer [24]. However, if enough people do not participate in demand response programs, or even demand response practices without the incentives, an increase in brownouts or blackouts on the grid during critical peak periods can occur. Those who do participate in these programs can experience little to no impact on their overall energy needs while reaping the benefits of their demand response program. Demand is always increasing due to population growth and the increased reliance on electronics. Without demand response, more peaking generating facilities will need to be constructed which will increase overall CO_2 emissions and other pollutants put out by electric grids throughout the world.

There are many ways a consumer can participate in demand response programs and practices. Simply by signing up the consumer will not see any price incentives. The average consumer will see a price increase if they sign up for a demand response program and do not change the power consumption habits. This is something that needs to be planned and takes effort from the consumer to curb their energy usage at the right times. There are many steps the consumer can take and many different approaches to the implementation of demand response. The first and most important step is responsible and intelligent use of air conditioning. Critical event dates occur on the hottest days of the year, when air conditioners are working their hardest and thus consuming the most energy. On critical event dates, there are two options to running your air conditioning in a manner that holds true to demand response practices. The first is simple, do not use the air-conditioning during critical peak or even peak hours. If temperature conditions are too extreme to take this approach, one can always cool their house a few degrees more during non-critical peak and non-peak periods, then turn the air conditioning off during critical peak and peak period, and resume use after these periods, to cool the household back to the ideal temperature. Running ceiling fans to circulate the cool air produced by the air-conditioner can also make the house seem cooler. One can simply raise the temperature on a thermostat a few degrees before leaving the home rather than turning the air conditioning completely off. Maintaining a temperature that is a few degrees higher than normal, while away, will use less energy than trying to lower the temperature four or more degrees upon return. Some utility companies, like Xcel Energy, have programs where you can connect your air conditioning to the grid, through a control box, and allow the utility to shut it off remotely during critical peak periods in exchange for some form of price incentive. This method is a form of demand response, often implemented on the commercial and industrial level, where the utility can give warning to the user that they will be shutting off a group of predetermined circuits for the duration of a critical peak period, known as utility controlled demand response. Other ways to participate are simple, be mindful of when appliances are used. If the hot water heater in a residence is electric, wait to take a shower or do the dishes until outside peak periods. Wait to run a dishwasher, washing machine or electric dryer until outside of these periods. If an electric car is owned do not plug it in until late at night. Some charging stations even include a function where you can tell the car when to charge, once it is plugged in. Ways to reduce energy consumption during peak periods or just overall can be as simple as turning the lights off when you leave a room, or opening the curtains if it is still light out. Keeping the thermostat one or two degrees warmer, then usual, during the summer, can make a substantial impact on an energy bill.

If demand response becomes effective, in years to come, it could eventually decrease, if not eliminate, the need for peaking power plants. This would drive the overall cost down for utilities and consumers, including those who do not participate in demand response programs. Peaker power plants tend to cost more to operate than baseline and load following power plants, per kWh. An alternative to reducing prices would be to reduce CO_2 emissions. Peaking power plants could be upgraded to serve as load following or baseline power plants to reduce the need for coal power. The natural gas peaking power plants would need to be converted to combine cycle natural gas power plants to allow them to serve as load following or baseline power plants. The jet fuel peaking power plants could also be converted to combined cycle natural gas power plants, but at a greater cost. Coal power is relatively cheap compared to natural gas and jet fuel, however, its carbon footprint is much larger than that of natural gas. Given the fact that it would be expensive to retrofit the peaking power plants to meet baseline and load following needs and that generation costs would go up, it may not be fiscally responsible to attempt these changes. The price to the utility would go up and in turn consumer electric rates would increase [25].

2.3 Utility Controlled versus User Controlled

There are two ways for demand response to be controlled. The first, user controlled, puts all control in the hands of the user. The user gets information on pricing from the utility, based on season and time of day, and the user chooses when to adjust their power consumption and how much to adjust it by. Utility control puts the consumer's power consumption in the hands of the utility. This method can be far more beneficial for the utility because it allows for more detailed forecasting, given the fact that the utility knows exactly how much demand is available for demand response reduction. The utility is tapped into some of the circuit breakers in commercial and residential locations and can simply shut off power to the controlled areas. The simplest example would be the utility can tap into a consumer's air-conditioning and shut it off during critical peak and some peak periods. The consumer is usually notified in advance of these events and in some programs, can opt out if they do not wish to discontinue use of their air-conditioning or other devices during the set period [25].

2.4 Price versus Rebates

Most forms of demand response can be broken down into two major categories, price-based and rebate-based demand response, with many subcategories for each. In price-based demand response, the user is encouraged to reduce or shift energy usage during peak and critical peak periods. This practice is incentivized by an increase in price, substantially higher than traditional pricing, during peak and critical peak periods. The user is then rewarded with a lower than traditional price during off-peak and mid-peak periods. If the user participates in demand response, by shifting their usage during peak and critical peak periods, the new pricing program will result in a lower utility bill for the consumer.

Four different forms of pricing can be used in this form of demand response, real time pricing (RTP), critical peak pricing (CPP), time of use pricing (TOU), and load based pricing. Time of use pricing is the most basic and common form of demand response available in the energy market. Pricing that is based off the time energy is used. During the winter, it usually consists of two price points, off peak pricing and mid peak pricing. During the summer, it usually consists of an additional price point, which is peak pricing. Critical peak pricing is a form of demand response pricing like time of use pricing. The difference is, critical peak pricing has one additional price point, critical peak, which occurs during the summer on extremely hot days where air conditioning usage is at its maximum, or close to it, and the power draw on the grid is substantially increased from that of regular peak periods. In most areas, critical peak periods occur about fifteen times a year. Critical peak periods usually occur sometime between noon and 9:30 p.m. Real Time is a form of pricing where the consumer's price is directly related to the price of generation, transmission, and utility fees at a given time on the grid. This is usually broken down into intervals of five minutes to one hour depending on the program. Real time pricing can also include warnings, in advance, when prices are going to increase so that the consumer can prepare. This can be done by raising air-conditioning output to lower the temperature in the building to allow for lower air-conditioning output during high rate periods. A consumer could also adjust lighting in the event of a high rate period. Different utilities may utilize variations and/or combinations of these pricing programs to best meet the needs of their consumers.

Rebate-based demand response is when a consumer is paid for reducing their demand during peak and critical peak periods from their average peak and critical peak usage. There is usually a minimum kWh reduction required during critical peak periods to qualify for this rebate. Users are paid when they meet this requirement or are paid for the amount they lower their peak demand. Payment is in the form of a rate per kWh of reduced power consumption, during specified time periods, below the consumer's average usage profile [26].

2.5 Conclusion

There are many forms of demand response being implemented across the nation, with many different subsets for each form. These programs are all relatively small as demand response is still in its beginning years [26]. As time passes there will be more programs added to different utilities and more customer participation. This will increase the effectiveness of demand response programs. There is no single demand program that can solve critical peak issues each market must find the program, or combination of programs, that is best for their needs.

Chapter Three: Energy Efficiency

3.1 Energy Star

3.1.1 Introduction

The purpose of this EnergyStarModule is to calculate potential Energy Star savings and other financial incentives when purchasing Energy Star rated LED bulbs and appliances. This module has two main functions, first to calculate the potential energy savings and other financial incentives of replacing existing incandescent (traditional) and compact fluorescent bulbs (CFLs) with light emitting diodes (LEDs) bulbs, second to calculate the energy savings and other financial incentives for replacing a non-functional appliance with an Energy Star rated appliance instead of one that does not hold an Energy Star rating. Many formulas and calculations were used in this module and will be explained throughout this section as well as the code to implement them [27].

3.1.2 Energy Star Module Readme File

This section is a readme file designed to give consumers an understanding of how to use the simulation to determine their potential costs and benefits of LED and Energy Star upgrades. It is designed to function as a standalone document paired with an Excel spreadsheet that can be distributed to potential consumers who may be interested in these upgrades. While it can be helpful for commercial applications it primary design is catered to residential applications.

3.1.2.1 Introduction

The Energy Star Module is used to calculate potential savings a consumer could receive by replacing current non-Energy Star appliances and lighting with Energy Star certified products. When analyzing lighting, this program assumes the consumer is replacing functional lighting with Light Emitting Diode (LED) technology. The value of bulbs currently installed is factored into the calculations for a more accurate output of benefits. A lighting guide for each light bulb type is shown in Appendix A, Figures A.1.1 through Figure A.1.3. The appliances section looks at the benefits of buying an Energy Star certified appliance over a traditional or inefficient model only in cases where the appliance needs to be replaced [28]. In most cases, the consumer would not see enough energy savings to offset the entire cost of a new Energy Star certified appliance over the appliance’s lifetime, when replacing a working appliance. However, an Energy Star certified appliance can produce enough energy savings in its lifespan to offset the difference in price, between it and a traditional appliance.

A test case has been done to give a baseline for savings when upgrading to LED lighting system. This case is based off a 1500 square foot home in the Denver area and assumed all lighting in the home was traditional lighting before the upgrade. A $0.13/kWh utility rate is used as the average rate in Denver. There were 2 flood lights, seventeen regular 60W lights, six decorative lights, and ten fluorescent tube lights in the home. The average usage time for each of these lights was four hours per day. The total cost to upgrade to LEDs was calculated to be $168.75. By upgrading to LEDs, the homeowner can expect to see energy savings equal to the cost of the lights in 242 days or six months, saving $254.71 a year. Over the lifespan of the bulbs, about 20 years, the LED system will save the homeowner $4399.45. When the price of bulbs that would have been purchased to replace burnt out bulbs is factored in that number jumps to $4930.14. By switching to LEDs from traditional bulbs the savings can add up fast. Switching a household with all CFL to LED lighting is still beneficial to the consumer, but the benefits are substantially less since CFL bulbs are much closer in wattage to LEDs. Appliance upgrade calculations were also considered in this test case. The most popular size for each appliance was selected. From this the cheapest traditional and energy star appliance was chosen for price inputs into the module. The result showed that buying an energy star rated appliance does not always save the consumer money over the lifespan of the device. The refrigerator and clothes washer save the consumer an estimated $22.00 and $190.00 over the lifespan of the devices, when factoring in the additional cost of the appliance. However, the dishwasher and the dryer cost $109.75 and $108.00 more to buy and operate over the lifespan of the device, using EIA average energy star statistics for residential appliances. Table A7, of Appendix A, shows both lighting and appliance upgrades for this example test case.

3.1.2.2 Basic Module Usage

In the Energy Star folder provided the consumer will find two files in addition to this readme file. The first file the consumer should look at is the EstarUserInputs.xlsx. The EstarUserInputs sheet is used to collect data on a residential home and determine which upgrades could prove beneficial to the consumer. More detail on how to fill out this Excel document will be given later in the document. Some of the values in this sheet are set to national averages. Each consumer's actual values will, in most cases, differ from the national average. The Results sheet is where the GAMS stores the results of the calculations, given the consumers inputs. Final_Estar_Module.gms is used to run calculations using the user inputs from the EstarUserInputs.xlsx file. This program determines many factors including upfront costs, payback period and total lifespan benefits. These factors show the consumer the costs and benefits of implementing a LED retrofit and/or upgrading to an Energy Star certified appliance. The consumer will need to save these three files in the their GAMSIDE project directory and run the file manually after inputting their household data.

There are fifty different variables in the EstarUserInputs sheet. Only fifteen variables are set to zero. These variables must be updated if the consumer wants to analyze potential savings in these categories.

There are four different styles of lighting and three different types of lighting. The different styles are flood, regular, decorative and florescent tube lighting. The three different types of lighting are LED, Compact Florescent Lighting (CFL) and traditional lighting. Florescent tube lighting is only an option for traditional and LED applications. At the end of this document is a reference sheet with pictures for each lighting type.

The remaining eight variables look at appliance upgrades. This Module looks at four types of appliances, dishwashers, refrigerators, clothes washers and dryers. If a consumer is considering replacing a functional appliance with an Energy Star Certified product the value for the traditional price variable can be set to zero. This action will more than likely result in a negative value for lifespan savings, meaning there will not be savings over the lifespan of the device. If the consumer is trying to decide between a new Energy Star certified appliance or a regular appliance the consumer should put the price for each appliance into the variables Estar-price and Traditional-Price respectively. If both values are left blank for a specific appliance no calculations will be done.

3.1.2.3 Intermediate Module Usage

There are thirty-five variables set with default values. Only two of these variables are important to update since these variables will substantially affect the accuracy of the calculated results. The first of these variables is listed as Average-Utility-Rate, the first variable on the sheet. For this variable, the consumer will need to look at their energy bills, for a year, and determine their average kWh utility rate. This will give a conservative result. If the consumer has a tiered utility rate it is better to look at the average kWh utility rate from their highest tier each month. This is done because by becoming more efficient the highest tier usage will be reduced. By reducing the usage in the highest tier the average kWh utility rate will go down. The second important optional variable to update, when considering an LED retrofit, is Average-Hours-Per-Day-Per-Light-Used. This variable is used to calculate yearly usage of each lightbulb in the consumer's household. It can be calculated by estimating how many hours each lightbulb in the household is used, adding these hours together and dividing by the total number of lightbulbs in the household. The Energy Star advertised average is three hours per lightbulb. This may not be the same for each consumer depending on factors such as size of house, work hours, and lifestyle. The more accurate the user inputs are for these variables the more precise the calculations will be. Rough estimates will be helpful in determining if these upgrades seem feasible but it is important to take the time to do the math for these updates before upgrading consumer lighting and appliances.

3.1.2.4 Advanced Module Usage

Advanced options allow the user to define the specifications and costs for lightbulb types in the system. The default values are set using information from The Home Depot [29]. The default costs for LED bulbs also include instant rebates. These rebates may differ by region, depending on the specific area the utility serves. For this simulation, Xcel Energy and manufacture rebates were used for the Denver, Colorado area. Utilities may also give additional rebates and credits for switching to EnergyStar products and it is important for consumers to check with their local utility to determine if additional rebates are available. When the regional price and additional rebates are determined, the consumer can update these values in the EstarUserInputs sheet to get a more accurate price for the upgrade. In Advanced Module section the consumer may also adjust the wattages and the lifespan in hours based on specific bulbs to be used.

3.1.2.5 Results

The results tab of the Excel document will show the consumer a breakdown of costs, usage and savings as it applies to their household. Each results tab generated will consider all the different presets and adjusted variables inputted by the user in sections 2-

4. The variables inputted create a unique set of outputs. The preciseness of these outputs depends on the accuracy of the data given to the program.

In the results tab the consumer will see many different outputs. These outputs have units of cost, savings, power consumption, and time. For all the outputs where cost or savings are a factor the units are in US dollars ($). For those relating to power consumption the units are kWh. The outputs relating to time have their units listed in their titles.

Four outputs are important in the LED output section. Total_Cost_of_LEDs indicates the upfront cost of the LED bulbs to implement the entire system. Days_to_Recover_Cost indicates how many days' worth of benefits it will take to offset the cost of the system. LED_Lifespan_Savings_of_System indicates the financial benefits from decreased energy usage alone over the lifespan of all the bulbs. LED_Total_Lifespan_Savings_of_System also factors in the amount that would be spent replacing traditional and CFL bulbs as they burn out.

The appliances section covers four major appliances, refrigerator, washer, dryer and dishwasher. All four have six outputs in common. Estar_Annual_Usage and Traditional_Annual_Usage show the yearly energy usage, in kWh, for the average number of cycles in a year, as defined by EnergyStar. Estar_Annual_Cost and Traditional_Annual_Cost show the energy cost, in dollars, to run the device for the average number of loads over a year. Years_to_Recover gives a rough estimate of how many years it will take to offset the additional cost of the EnergyStar device versus a traditional unit. Lifespan_Savings indicates how much will be saved over the lifespan of the device after recovering the price difference between the two devices. The washer, dryer and dishwasher results also include information on cycle usage so the consumer can see how much energy one load takes. The consumer should always choose two similar models, the only difference being one is EnergyStar Certified, when comparing two devices. Energy star devices are not always cheaper in the long run but remember even if the consumer does not recover the cost difference in energy savings the price difference for an EnergyStar model is not as large as it appears and is good for the environment and the stability of the grid.

3.1.3 Technical Work

3.1.3.1 Parameters and Sets

This four-part section covers the required sets and parameters used to run the simulation. The first part covers bulb and utility parameters. This includes required user inputs, optional user inputs and predefined values. The second part covers calculated parameter and the generated results used to show costs and benefits of a LED upgrade. The appliance replacement parameters store the inputted parameters and generated results for deciding between an energy star or non-energy star appliance when replacing a broken appliance. The final parameters are the user input table and the user output table which store the inputs from the user and the resulting outputs calculated by the simulation. Every parameter and set covered in this section work together to give the user the most accurate information for making energy star upgrades.

There are three types of lighting technology available for use in this simulation that are defined in the parameters section. LEDs consume the least amount of energy and are considered the most efficient. CFLs are also considered to be energy efficient, however they still consume more energy than LEDs. Traditional incandescent bulbs consume the most energy and are the least efficient. There are 12 LED, 16 traditional and 12 CFL parameters in the simulation. For each type of technology there are three to four fixture types, flood, regular, decorative, and fluorescent tube lighting. There is not a fluorescent option for CFLs. Each combination of technology and fixture type have a parameter for watts, cost and lifespan. The watts parameter stores how much power is required to light the bulb. The cost signifies the unit price of each bulb type. The lifespan shows how many hours the bulb is expected to run before burning out. The CFLs and traditional bulbs have a parameter for amount. This is used to signify how many of each type of bulb the user has in their household. Utility price per kWh and average hours per day used are defined to allow the simulation to calculate price and usage for the household's energy consumption. Together these variables provide the simulation with all the information needed to calculate outputs that will give the user an understanding of the costs and benefits of upgrading to LEDs in their household.

The parameters consist of data used to calculate the results, given the predefined and user inputs, as well as to store the simulated results. LED amount is calculated by adding the number of traditional and CFL lights, inputted by the user, together. This is done for all four bulb types. Eleven LED lifespan prices are defined for each bulb and technology type combination. These variables are used to calculate how much it will cost to run and in the case of the CFLs and traditional bulbs replace the bulbs multiple times. These variables use the energy and bulb prices as well as the rated lifespans of the bulbs to calculate these costs. The lifespan used is that of the LED bulb and for the LED bulb only the initial bulb cost is factored in. Cost per day and year is calculated for the CFL and traditional bulbs combined as well as the cost for the LED bulb. Savings per day and year is defined in this section to show the difference in cost between the combined traditional and CFL bulbs and the LED bulbs. Total cost of LEDs stores the initial cost to buy all the LEDs needed to replace the traditional and CFL bulbs in the user's household. Hours and days to recover cost stores the results showing how many days or runtime hours it will take to save enough on energy costs to offset the cost of the LED bulbs purchased to upgrade the household. LED lifespan savings of system shows the energy savings over the lifespan of the LED bulbs and LED total lifespan saving of system stores the same savings and factors in the amount saved by not having to replace the traditional and/or CFL bulbs when they burn out, due to the fact LEDs have a substantially longer lifespan than that of the CFL and traditional bulbs. Yearly energy usage for CFL and traditional combined as well as for LED is defined to show how much energy the original system consumes and how much energy the LED system will consume in a year. These parameters work together to provide the user with all the information needed to determine if a LED upgrade is right for them.

The final part of the parameters section covers replacing broken appliances and determining if an Energy Star appliance is more beneficial than that of a non-energy star appliance. Four types of appliances are covered in this section, dishwasher, dryer, refrigerator, and washer. This set of parameters is used to calculate both energy and water savings. For every appliance type, there is a set of variables inputted or calculated for both energy star and the traditional appliance. Annual usage covers the total usage per year in kWh. Annual cost looks at the cost to operate a specific device per year. Price is the cost of the appliance inputted by the user. Every appliance, other than the refrigerator, has a usage per cycle variable that calculates how much energy is consumed, on average, when the appliance is used. Energy Star parameters also have an annual savings value that shows how much money the consumer will save each year. Each appliance has an average lifespan stored in the program. This parameter is used to calculate the lifespan savings of the appliances. A variable is defined to calculate the years to recover the additional cost of an energy star appliance. Average water price, in gallons, and annual water savings are also defined to calculate the water savings on energy star devices, in addition to their energy savings.

With all the parameters defined a few sets are needed to populate some of the parameters with user inputs and allow the storage of all the results to the user outputs. These values are taken from and stored to an Excel spreadsheet that the user will fill out and refer to for the results. There are 17 required user inputs, some of these do have default value in case the user does not know what their utility rate is or some other value in the program. The appliance section is also set to zero in the event the user chooses not to run an appliance simulation. In addition to these required inputs there are 33 optional inputs that get more technical if the user wants a more specific result for their simulation. The sets are broken down into four types, user inputs, values, user outputs and results.

3.1.3.2 Predefined Inputs and User Inputs

A wide variety of user inputs were used for this simulation. These user inputs are in the User Guide. To call in the user inputs the GDX application was used. This allows for the simulation to open a specific Excel file and call in a range of data. For this case, the data called in the range (rng) A1 to B52 on the first sheet of the specified Excel workbook, EstarUserInputs.xlsx, for the sheet (par) User_Inputs_Table. The resulting line of code is '$CALL GDXXRW EstarUserInputs.xlsx par=User_Inputs_Table rng=A1:B52;'. The function $CALL GDXXRW is used to open the file and store it in a new EstarUserInputs.gdx file. The function $GDXIN loads the file to be copied into the simulation. The data is stored in the parameter User_Inputs_Table(a,b) using the function $Load. The GDX application is then closed using $GDXIN. [30]

3.1.3.3 LED Calculations

To calculate benefits and payback periods for the LED upgrade many formulas are used. Lifespans of the LED bulbs are used to determine how much energy each bulb type will use over the lifespan of an LED bulb. For example, to calculate the price of a traditional regular light bulb over the lifespan of an LED bulb the wattage of the traditional bulb is multiplied by the lifespan, in hours, of the equivalent LED bulb. It is then multiplied by the utility kWh price and divided by one thousand to convert the utility rate to watt-hours (Wh). This is done for all twelve bulb types including the LEDs. The result of this equation gives the cost to run each bulb technology and their associated bulb types for the lifespan of an LED. This calculation does not include the cost of replacing bulb as they burn out. This factor will be added in later.

The amount of LED bulbs of each type, needed to upgrade the system to full LED lighting, is then calculated by adding the number of CFL and Traditional bulbs the user has inputted together for each type of LED bulb. This calculation gives the simulation the information needed to calculate the cost of upgrading to LEDs and is also used to calculate the remaining financial incentives.

The cost per day, for the original and LED lighting system, is calculated by multiplying the Utility rate by the average hours per day the light bulbs in the system are drawing power. This value is then multiplied by the product of each bulb type's wattage usage and each bulb type's amount added together. The utility rate is then converted from kWh to Wh by dividing the equation by a thousand. The result shows how much the user is currently spending on energy for lighting each day as well as the calculated amount the user could be spending if they upgrade to a LED system. From these two values the savings per day is calculated by subtracting the cost per a day to run the LEDs from the cost per a day for CFLs and traditional bulbs. From the cost per a day values the yearly cost and savings are obtained by multiplying the values for cost by the number of days in a year. The savings per year are then calculated in the same manner as the savings per day are calculated, using the yearly costs.

The total cost of the LED system is calculated to calculate values such as payback period. This is done by taking the sum of all the LED costs multiplied by their appropriate amounts calculated from the user inputs. From this information, the payback period or days to recover cost, in days, is determined by dividing the total cost of the LED system by the savings per day.

There are two equations calculating the LED lifespan savings of the system. The first simply shows the energy savings and the second factors in savings of not having to replace bulbs as often. The first is calculated by taking the product of each price LED lifespan and their corresponding number of bulbs in the current system and summing them together. From here the equivalent sum of products LED calculation is subtracted from the traditional LED lifespan price. The cost of system is also subtracted from the original value giving the LED lifespan savings of system. The second equation for total lifespan savings takes the initial lifespan savings and adds in the savings for eliminated bulb replacement needs. To give a conservative value, the system assumes the user is replacing brand new bulbs with LEDs when most bulbs being replaced will be partially used. Each non-LED bulb's lifespan is divided into its LED bulb replacement's lifespan then one unit is subtracted to represent the initial bulb being replaced. This value is the multiplied by the price and amount of each original bulb type. These values are summed up and added to the initial lifespan savings of system. Giving the user a amount the system will save them over the lifespan of the LEDs installed.

Yearly energy usage for the original bulbs and the upgraded LED bulbs is also calculated in kWh. By multiplying the average hours per day by the days in a year and then multiplying that value by the product of sums for the amounts and watts of each bulb type, then dividing the result by one thousand, to convert to kWh from Wh, the yearly energy usage for both original and LED lights can be obtained.

3.1.3.4 Appliance Calculations

This section covers the calculations used to determine potential lifetime savings when buying an energy star rated appliance over a traditional appliance. Four major appliances are covered, dish washers, dryers, refrigerators, and clothing washers. By using six values, for both traditional and energy star appliances with some values being the same for both energy star and non-energy star, the years to recover and lifespan savings can be calculated. The pre-defined parameters used for these calculations are the average percent savings and average annual savings for energy star appliances, as well as the average cycles per year, when applicable and average lifespan of an appliance. The user inputs their average utility rate and the cost for both an energy star and non-energy star appliance. The two washers also factor in savings from using less water. Averages are being used in these calculations and the results give a rough estimate on savings. Actual savings will vary based on size and actual efficiency of the chosen appliance.

There are three user inputted values used in these calculations for each appliance. The costs for an energy star appliance and non-energy star appliance, equivalent in size and features, is inputted by the user as well as the user's average utility price. There are also two values already stored in the system. The energy star annual savings and the percent savings for each appliance covered. To calculate the energy star annual energy cost the annual savings is divided by the percent savings then multiplied by on minus the percent savings. From there the annual usage can be calculated by dividing the cost by the utility rate given by the user. The final energy star calculation determines the energy usage per cycle, when applicable, by dividing the annual usage by the average cycles per a year.

Statistics for the traditional appliances is calculated using the energy star variables. Traditional annual usage is calculated by dividing the energy star annual usage by one minus the energy star percent savings. Annual cost is calculated by multiplying the annual usage by the utility rate resulting in the total kWh used by the appliance in a year. Usage per cycle is then calculated by dividing the annual usage by the cycles per year, the same manner as the energy star cycles were calculated.

Years to recover are calculated by subtracting the traditional price from the energy star price and then dividing the result by traditional usage per cycle minus the energy star usage per cycle. The result of this subtraction is then multiplied average cycles per a year and the utility rate before being divided into the first result. This formula does not include the water savings, they are factored into the lifespan savings. Lifespan savings is calculated by subtracting the energy star usage per cycle from the traditional usage per cycle, this value is then multiplied by average cycles per year and average utility rate. The result is then added to the water savings calculated by multiplying the annual water savings by the average water price per a gallon. Water savings are only used in the dishwasher calculations. This sum is then multiplied by the average lifespan and final the difference in price between the energy star appliance and the non-energy star appliance is subtracted from the sum to calculate the total lifespan savings.

3.1.3.5 User Outputs

The final section of code deals with storing the outputs of the simulation back into the Excel workbook. Variables for these outputs can be found in Section 3.1.2.5.

An error checking section of the code was added to handle zero inputs in the appliances section. Before this section was added when a user left the appliance prices at zero it would run the calculations as if the appliances were free. This created a set of outputs that had no relevant information. To handle this the appliance inputs were checked in the results section. If a cost input was set to zero its appropriate outputs were set to 9999.999 to represent a lack of information to do the calculations appropriately. To output all the results of the simulation to the Excel workbook the GDX application was again used.

This simulation in combination with the user guide can be very helpful in determining whether upgrading to LED lighting and/or a new energy star appliance is good fit for a consumer. While the calculations will not be exact, they will still give the consumer a better idea of the costs and benefits that can occur with these upgrades. There are a few factors that may contribute to the inaccuracy of the simulation. The biggest variance comes from the hours used input where the user must input how many hours on average all the light in the house are used. This is a very rough estimate and many consumers may not realize how much their lights are on each day. Another factor comes from a consumer not doing research in manually inputting all the prices for each bulb they will be buying. This can raise or lower all the outputs from the simulation. The appliance section of the simulation is also inexact. It uses national average that may vary from appliance to appliance. While these variances may cause some inaccuracies in the coding it still creates a very helpful calculation for consumers to use.

3.1.3.6 Results

With this research, I convinced the owner of 12345 and 12211 W. Alameda LLC to retrofit their two buildings of about 75,000 and 20,000 square feet respectively to LED lighting. By being able to show them potential savings on switching to residential LED systems they realized that savings could be just as gainful on commercial applications. They proceeded to do some research and found a company that could come in to make the changeover to LED lighting. W. Alameda LLC made one of three lighting changes to all the lights in their buildings. First, they optimized their lighting by eliminating some unnecessary fixtures throughout the building, lowering their total number of light fixtures. Then the remaining four tube T8 ballasts were replaced by LED specific GE ballasts and GE T8 LED bulbs. In the case of three bulb T8 ballasts, LED bulbs were installed that worked with the already installed ballasts. Their total cost for the upgrades to both buildings was $93,663.00. Their average monthly savings between the two buildings comes out to $1,105.62. This creates a payback period of 7.1 years. The LED system is expected to last 70,000 hours with little to no maintenance. This translates to about 26.9 years assuming the lighting is utilized on average 50 hours per week [31].

A retail location, Denver Central Games, in Denver, Colorado, was also convinced to implement LED upgrades with information from this document. This 2400 square foot location utilized 48 T8 tube florescent lights at 40 watts per tube. Half these lights remain on for 24-hours per day and the other half are active for 12-hours per day. This gives an average time of use of 18- hours per a day for all the bulbs. Their utility rate is about $0.11 per kWh. New T12 Equivalent LED bulbs at 20 watts per a tube were installed. The bulb cost was $7.00 per bulb. This results in a daily saving of $1.90 and will take 177 days to recover given the $336.00 cost of the system. The company has also applied for rebates through Xcel Energy and is hoping to receive these sometime soon [32].

Six additional simulations were also run, for residential households. These households located in Colorado and California. The average cost for upgrading to LEDs from traditional and CFL lighting was $131.86 and the average savings per year came out to be $295.32, making the average payback period about 6 months. In all the cases, except for the entirely CFL household, the consumer saves between 50 and 75 percent on their lighting costs. Savings were higher in California since utility costs are almost double that of Colorado. Complete statistics for inputs and results can be found in Appendix A, Tables A2.1 through A2.8.

3.2 Conclusion

Energy efficiency upgrades have a great impact on the environment and in many cases, can save consumer money at the same time. Their implementation will also help reduce overall demand on the grid and in doing so help to stabilize the grid. The greatest impact comes from replacing traditional lightbulbs with LEDs. Some energy star rated appliances do save the consumer money, in the long run, however not all of them do. It is also good to upgrade CFLs to LEDs even though the upgrade is less profitable to the consumer. In years to come energy efficient devices will increase efficiencies such that it will be even more profitable to the consumer, over the lifespan of the device.

Chapter Four: Numerical Simulations

4.1 Utility Controlled Demand Response

For the purposes of this section national averages for power generating facilities' pricing and capacity were used to define generation for the facilities in the system. Several types of generators were used, advanced nuclear, coal, geothermal, and natural gas. These generators consisted of peaking, load following and baseline facilities. Xcel Energy's electricity rates for low and high consumption were used for base cases and then lowered by fifteen percent for demand response loads. This decrease in rate is the benefit the consumer receives for being part of the demand response program. Transmission losses were set to be 9.6% throughout the system. A constant voltage rating of 138 kV was used. A total of eight simulations were created to analyze the effects of utility controlled demand response. The first three looked at the grid profile for minimum, medium, and maximum supply and demand. Five looked at the effect of different amounts of demand response being available to the system. The supply and demand situations covered are a minimum, two mediums, and two maxima. From the results, it is possible to reduce or eliminate the need for peaker power plants using utility controlled demand response.

Power World Simulator was used to create a system to simulate utility controlled demand response. This system consisted of eight busses, seven different types of generators, nine transmission lines, and six loads. The loads are of both commercial and residential. Two of these loads are available for demand response. Nine simulations were run. The Automated Generation Control (AGC) optimization function was used to determine the minimum cost, for each simulation, by allowing the program to control the output of all generators and, for simulations five through nine, the two demand response loads. Minimum and maximum megawatt (MW) values were set for both generators and demand response loads to control how the loads are adjusted by the AGC function. A slack bus was defined to balance the active and reactive power of the system. This is also where the system's phase angle was defined. Line limits, as well as resistance and reactance for the lines, were programmed to simulate the power flow in the system and create line losses. Rate structures, for both generation and loads, were defined. These values were modeled from national averages from Energy Information Agency (EIA) for generators [33]. Xcel Energy rates for Colorado residents and companies were used to model project energy rates [15]. The project was ready for simulations once all the variables were calculated or generated, and then defined. Some of the load variables were changed between simulations to model different types of grid interactions. Rebate based pricing is the form of demand response used for this section, creating a rebate for the consumer based on how much energy was automatically reduced by the utility during a certain period. For this project, real-time load measurement was used to determine a consumer's price. This means if a consumer is using under 70% of their max load they receive the discounted rate. Every megawatt hour (MWh) used after this point comes at a higher price. This pricing mechanism was adjusted to be applied to real time demand, MW, rather than usage, kWh. Calculations and factors on how these prices were created will be discussed in a later section.

4.1.1 Technical Work Preparation

4.1.1.1 Understanding PowerWorld Simulator 19 Evaluation

Before starting this project, a few PowerWorld simulations were looked at to gain an understanding of how to design the project and run the simulations. The first example looked at was B2.PWB [34] [35] [36]. This example showed how a slack bus adjusts its output, to balance the grid, when generation throughout the grid decreases or demand increases. B2OPF.PWB showed how to output different variables and how AGC can automatically adjust both loads and generators due to changes on the grid. The most in-depth example looked at was B7OPF.PWB. The axillary file from this example, B7OPFLoadDispatchMinCost.aux, was used to set up the AGC and Optimal Power Flow (OPF) optimization functions to run demand response in the project. OPF uses AGC loads and generators to obtain the minimum value for the cost function or objective function. This is done by raising and lowering both demand and generation until the optimal solution is found, while at the same time maintaining the limits of the grid, including generation, load and transmission limits.

4.1.1.2 Project Variables

There are many variables that must be accounted for when designing a grid. For this grid, many things were simplified to focus on the relevant pricing data. The system was designed with no step-up or step-down transformers, leaving the system at a constant 138 kV. Line limits were set to 1000 MVA except for the line running from the nuclear facility, which is set to 1100 MVA, since the facility has a 1000 MW generating capacity.

The resistance (R) was set to 0.00750 p.u. and reactance (x) was set to 0.03 p.u. While line lengths were not accounted for, the schematic for the project is designed to show that some generators are further away, from the loads on the grid, then others. Other variables, such as supply and demand limits, as well as prices will be defined in the following sections.

4.1.1.3 Project Generators

Seven generators, using four different fuel sources, were used in this project to create the available power to the grid. Their total minimum capacities, meaning the amount of energy they must produce, are 1216 MW and their total maximum capacities or nameplate rating are 2000 MW. These generators can be broken down into three types of generation.

Baseline generators are facilities who are always operating at or near capacity. For this project, there were two baseline generators, advanced nuclear and geothermal, and they are operating at capacity. Nameplate capacity for nuclear is 1000 MW and for Geothermal it is 20 MW.

Load-Following or Cycling Generators are facilities who operate mostly during the day as demand increases throughout the day. This generation is enough to meet demand for a large percentage of the day. There are three facilities that meet this criterion, two coals and one natural gas. Their capacities are 300, 200, and 180 MW respectively.

Peaker generators are facilities who operate mostly during critical peak periods. These are the generators utilities go to when demand is extremely high. In most cases these generators have fast ramp up and ramp down times. They can also have high costs of operation and fuel and can be worse for the environment, emission wise, than some other forms of generation. For this project two natural gas facilities are implemented to meet simulated peak needs in the grid. Their nameplate capacities are 150 MW each. These facilities are located on busses that also have loads attached to them. This is because they are usually close to the bulk demand on an energy grid [9].

4.1.1.4 Project Loads

There are two types of loads used for this section, non-demand response loads, (loads that cannot be changed by the utility), and demand response loads, (loads that are available to the utility for curtailment during demand response periods). Non-demand response loads are not available to the AGC and OPF optimization functions for change at run-time. The load values change during each of the eight simulations to adjust the amount of demand on the grid. The loads represent blocks of residential or commercial consumers. There is one commercial load and three residential loads, available for demand response, controlled by the AGC and OPF functions, in this project. The generation parameters can be seen in Table B1 of Appendix B. Initial and final load parameters, including prices and price increase points, can be found in Table B2 and B3, of Appendix B, respectively. Demand response loads are like non-demand response loads except for they are AGC connected and can be dispatched by the OPF function. The demand loads were represented by a regular load tied to a load that could go from -500 or -150 to zero. These negative loads were set up with a cost of $85.00 per MW. This allowed the simulation to decrease the demand response negative load as if it were a generator. The regular load tied to the demand response load stays the same. The net of the two represents the demand response, meaning if one is at -500MW while the other is at 1000MW the net load is 500MW with a demand response of 500MW. The regular loads maximum price is $80.00 per MW meaning when demand response is implemented the consumer sees a $5.00 rebate per megawatt reduced. There are two demand response loads in the project. The larger represents industrial loads and the smaller represents residential loads.

4.1.1.5 Electricity Pricing

There are two types of pricing in this section. One pricing type for generation costs and the second pricing type for electricity rates passed onto the consumer. To calculate the cost for generation middle generation costs were defined by EIA documentation. These documents outlined national price averages for different types of generating facilities [37]. From these prices, a minimum and maximum tier price was generated by raising or lowering the given value by ten percent. The lower price for each generating facility, in the project, is defined as zero to twenty percent of the nameplate capacity. The medium price is defined as twenty to eighty percent of the nameplate capacity. The maximum price defined as eighty to one hundred percent of the nameplate capacity. Prices and MW levels for each price can be found in Table B1 of Appendix B. Load benefits, also known as electricity rates, were defined using Excel Energy’s standard residential rates. Since the project is looking at a single moment in time, rather than over a period of a month, the pricing was adjusted for real-time application. Normally a consumer’s rates are increased after they reach a certain kWh of usage, 500 kWh or about 70% of average summer usage.

For this project, a consumer's rates are increased when their demand surpasses 70% of their max demand. See Table B2 and B3 of Appendix B for load parameters. Demand response loads are represented by the same rates with a fifteen percent decrease in price for participation in the program.

4.1.2 Simulation Results

Simulation 1 uses the minimum load profiles and minimum generation, with no demand response, to simulate conditions on the grid during off peak conditions, usually overnight when all generation is at essentially minimum amounts. For this simulation, all generators are at or near their minimum capacity. Realistically all generators would not be running at their minimum during these off-peak periods. Minimum generation on a grid is usually designed to be lower than the lowest demand point in a year so that there is never too much energy under minimum generation conditions, a challenge faced annually by utilities. As population increases the minimum demand point goes up due to the increase in consumers. If population drops substantially or as new generating facilities are built some power generation facilities may be decommissioned, taken off the grid and shut down, this can be temporary or permanent. The opposite can also occur where there is too much generation at minimum demand during off peak periods. This can cause an increase in frequency on the grid, resulting in a need to sell energy to another entity to balance supply and demand at 60 cycles per second. Minimum generating capacity of this project's grid is 1216 MW. For this simulation generation turned out to be 1332.48 MW due to the fact demand was set to 1200 MW when this should have been lower, about 1100 MW, when factoring in line losses. The complete simulations result, for Simulation 1, can be found in Table B4 of Appendix B.

Simulation 2 uses median load profiles and median generation to simulate conditions on the grid during mid-peak conditions, usually starting in the morning and ending midday. Mid-peak conditions also occur in the late evening. For this simulation, the net load on the grid was set to 1550 MW which causes the generation to be automatically adjusted to 1734.05 MW to meet the demand of the grid and account for the line losses. Baseline generators and one load following generator were at a maximum. Another load following generator also had an increase in power output, to meet demand. No demand response is available for this simulation. Complete simulation results for Simulation 2 can be found in Table B5 of Appendix B.

Simulation 3 uses maximum load profiles and maximum generation to simulate conditions on the grid during peak or critical peak conditions, usually late afternoon to early evening. For this simulation demand was set to 1800 MW. This required a generator output of 1968.35 MW. This means that all generators were operating at capacity except for one which was only 31.65 MW below capacity. Complete simulation results for Simulation 3 can be found in Table B6 of Appendix B.

Simulation 4 shows grid failure when demand is set to 2300 which is above the maximum generation point of the grid. Simulation 9 shows that with demand response the grid can maintain itself at these levels. This is the final simulation where no demand response is available.

Simulation 5 uses the same minimum load profiles and minimum generation, as Simulation 1, to simulate conditions on the grid during off peak conditions, usually overnight. In this simulation demand response is available, but not used. Complete simulation results for Simulation 5 can be found in Table B7 of Appendix B.

Simulation 6 uses the same medium load profiles and medium generation, the same as Simulation 2, to simulate conditions on the grid during mid peak conditions, usually morning to midday. Again, demand response is available but not used. Complete simulation results for Simulation 6 can be found in Table B8 of Appendix B.

Simulation 7 uses slightly higher medium load profiles and medium generation to simulate conditions on the grid during mid peak conditions. Demand response is utilized at a low amount, 106.90 MW, for this simulation. Complete simulation results for Simulation 6 can be found in Table B9 of Appendix B.

Simulation 8 initially has 2150 MW of demand but this value is lowered to 1693.09 MW with the implementation of 456.91 MW of demand response. Without demand response, this simulation would have resulted in grid failure. Complete results for Simulation 8 can be found in Table B10 of Appendix B.

Simulation 9 had an initial load, before demand response was implemented, that was again greater than the network can handle. This means that without the implementation of demand response there would be major blackouts and potential grid failure. This simulation shows the about the maximum demand the grid can handle utilizing most of the demand response available. Complete simulation results for Simulation 9 can be found in Table B11 of Appendix B.

4.1.3 Conclusion

A comparison of the net hourly profits and $/MWh delivered from the nine simulations show that demand response can be beneficial for both the consumer and the utility. The utility makes the most profit during mid-peak periods and the most $/MWh during off-peak periods. When no demand response is utilized the results are the same for the first set of simulations where no demand response is available. However, the utility makes more during peak periods for when demand response is available and utilized for both net profits and $/MWh. Demand response also allows the utility to server a larger number of customers with current generation as shown in Simulations 4, 8 and 9.

It seems these price points for the consumers are fair because there is only about a 20% difference between the maximum and minimum $/MWh benefits the utility receives. These benefits are based strictly off the MWh rates and generation costs and therefor the utility is not making as much per an MWh as it appears, due to transmission cost, overhead and other cost the utility incurs when delivering energy to the consumer.

4.2 Residential Demand Response Participation

4.2.1 Introduction

This section provides information on residential applications of demand response. It also looks at the effect, on a consumer's energy bill, of switching to Energy Star rated appliances, devices and lighting. This analysis is broken down into three parts. Generating the data sets for both efficient and inefficient residential homes, creating the objective functions to calculate standard billing and demand response rates, then analyzing the data with respect to utility prices. Data sets were generated by looking at an assortment of average usage profiles, for residential consumption of energy. These profiles showed hourly, daily and yearly data, on energy usage, that were extrapolated to create four sample days of data. One daily data set represents the average usage for each season. The results were then compared to the average monthly residential usage provided by Xcel Energy [38]. The inefficient data set was averaged with the efficient data set and the result nearly matches the overall Xcel Energy average for each of the four months, July, October, January, and April. These two sets of four days of data were then turned into two 8760-hour data sets with about 91 copies of each day. As a subset of each of the two data sets, four simulations were run. Each of these simulations compared PG&E's standard commercial rates, as applied to a residential profile, to the rates set forth by PG&E's Critical Peak and TOU commercial billing [39]. Commercial rates were used because PG&E does not have a residential demand response program, nor did Xcel Energy at the time. The first simulation, for both efficient and inefficient residential data, looks at a home that had an electric car and shifts demand only during critical peak hours. Next, a home without an electric car was analyzed, only shifting usage during critical peak hours. The third analysis looks at a similar demand response profile, shifting usage during all peak hours. Finally, a profile where demand is shifted during peak hours and air conditioning is simply eliminated, to lower daily demand, during peak hours throughout the year. A ninth simulation was also run to see how savings on the NHEC demand response program compare to savings of the PG&E program. This simulation was run in the same fashion as the fourth simulation, changing only the price points for the program and only looking at the energy efficient home. Once all simulations were complete, they were analyzed and compared to each other to determine savings between the efficient and inefficient home and the best plan of action for implementing the demand response programs and maximizing benefits from the program. All designs analyzed were created to have little to no impact on the comfort and productivity of a consumer's life.

4.2.2 Technical Work Preparations

4.2.2.1 Data Sets

To generate the yearly data sets many variables were considered. Average usage profiles for four months out of the year were taken from Xcel Energy [8] to use as a baseline. The goal was to have the inefficient and efficient profiles average out to be like those energy demand statistics given by Xcel Energy and they did. Figure 1 shows the average energy demand rate of a Denver, Xcel Energy, residential consumer.

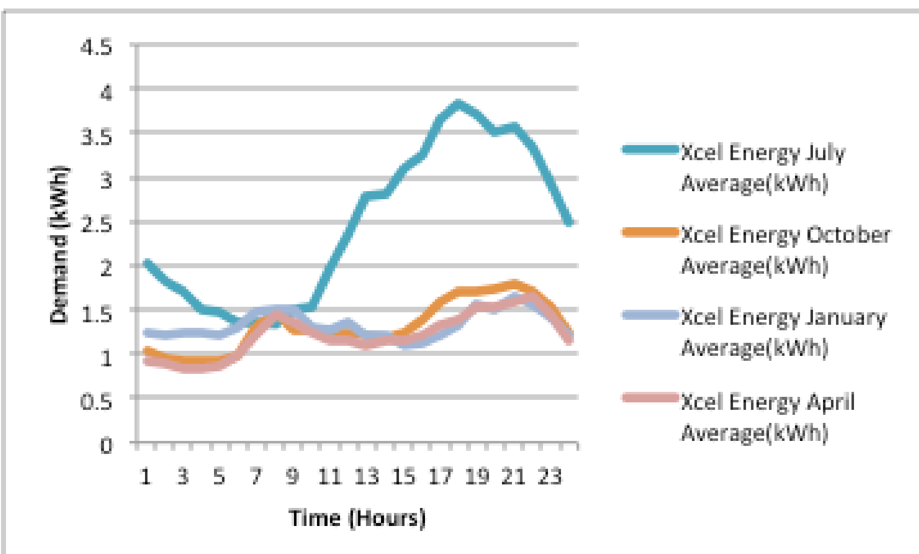

Figure 4.1: Average daily usage of a resident, in Denver, from Xcel Energy for July, October, January and April. [8]

Energy statistics for average yearly usage were found on the Energy Star website then broken down into hourly usage [19]. Values for active and inactive usage were estimated based off a paper on hourly load profiles for residential usage, broken down by appliance [40, 41, 42, 28]. Hourly load profiles for appliances such as refrigerators and freezer were simply calculated by taking the yearly usage and dividing it by 8760 hours. For generating the difference between efficient and inefficient appliances the percentage savings, given by Energy Star were used.

Many estimations and assumptions were used in creating these data sets. However, the data sets are relatively accurate by comparing the average of the inefficient and efficient data sets to the daily usage curves found at Xcel Energy's website [38]. The comparison between the average residential usage for a day in July in Denver and the average of inefficient and efficient data sets created from a day in July can be found in Figure 4.2, with the sum of Xcel total daily usage being 58.89 kWh and the generated data's average daily usage being 54.455 kWh.

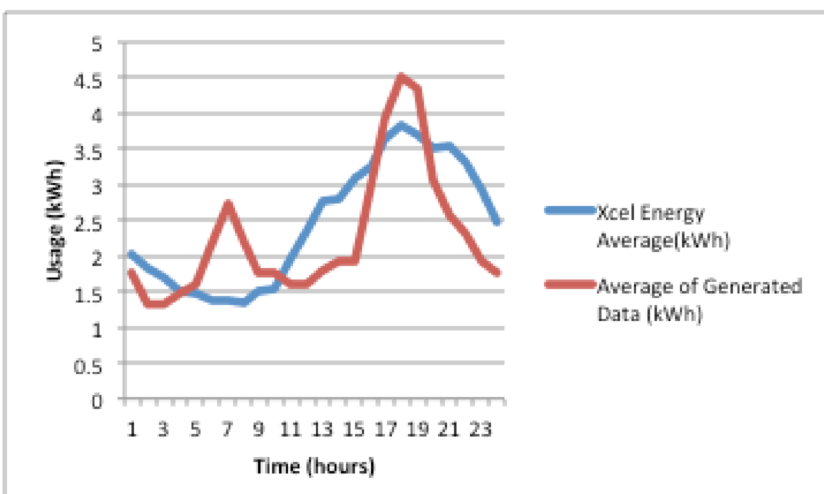

Figure 4.2: Average Daily Usage of a Resident, in Denver, from both Xcel Energy and Generated Data Sets, in July. [8]

There are some reasons why the Xcel Energy curve and the generated curve do not line up perfectly. The Xcel curve is an average of thousands of residents whereas the generated data is for a single household. The Xcel cure is smoother since not everyone uses his or her appliances, devices and lighting at the exact same time. Also in the generated curve, most usage takes place during peak hours, for this simulation peak hours were chosen to be from 4-8 p.m., rather than from 12-6 p.m., as defined by PG&E and NHEC programs [43] [44], to show the effect of demand response on residential consumption in more detail. 4-8 p.m. is the peak period of residential consumption in Denver. For simplicity, a seven-day peak/ off-peak schedule was used instead of a 5-2 schedule, for weekdays having peak and off peak and weekends consisting of just an off-peak period.

4.2.2.2 Objective Equation

The following equations look at demand response as a program that offers a discounted rate during off-peak hours, an increased rate during peak hours and an inflated rate during critical peak hours to consumers as part of a demand response program [45]. Table 4.1 shows the symbols for all the variables for Equation 4.1 and Equation 4.2.

Table 4.1: Variables Used for Objective Equation

a	Type of energy shifted or eliminated. (I.e. Lighting or HVAC)
$f_{N,t,cr}$	Regular Price of Energy ($\frac{\$}{kWh}$) for every hour of the year.
$P_{R,t,a}$	Regular Usage (kW)
$f_{rop,t,drpr}$	Demand Response Program Price ($\frac{\$}{kWh}$) for every hour.
$f_{shift,t,shift}$	Price after demand response shift to off peak hours ($\frac{\$}{kWh}$) for every hour.
$P_{DRE,t,a}$	Demand Response Usage Eliminated (kW)
$P_{DRS,t,a}$	Demand Response Usage Shifted (kW)
$T_{DR,t,e}$	Array of Demand response period consisting of 1s and 0s where 1s represent a Demand Response Event and 0s represent normal operation

$T_{op,t,ne}$	Array of no Demand response period consisting of 1s and 0s where 0s represent a Demand Response Event and 1s represent normal operation
T	Time of Simulation (8760 hours)
c	Total Cost of regular operation
Discount_Rate	Total cost of Demand Response Rate

Equation 4.1 shows how to calculate the normal rate with no demand response practices in place. This would be the bill a clear majority of consumers receive each year for the standard energy consumption.

$$C = \sum_{t=1}^{8760}\left(\left(\sum_{j=1}^{cr} f_{N,t,cr}\right) * \left(\sum_{i=1}^{a} P_{R,t,a}\right)\right) \quad \textbf{Equation 4.1}$$

Equation 4.2 calculates prices for period with demand response events and a demand response rate. This equation is broken down into three parts. It first calculates the price of energy throughout the year during peak or critical peak events, depending on the way T_{dr} is set up, by subtracting the shifted and eliminated loads from the total usage and multiplying by a predetermined price. Next it calculates the off-peak usage multiplied by a predetermined price. It then calculates the shifted demand multiplies by an off-peak price, assuming when a user shifts out of peak or critical peak periods, the shift to a period where the price in place is the off-peak price.

$$\sum_{t=1}^{8760}\left(\left(\sum_{j=1}^{drpr} f_{rop,t,drpr}\right) * \left(\sum_{k=1}^{e} T_{dr,t,e}\right) * \left(\sum_{i=1}^{a}(P_{R,t,a} - (\Delta P_{DRE,t,a} + \Delta P_{DRS,t,a}))\right) + \left(\sum_{l=1}^{drpr}(f_{rop,t,drpr})\right) * \left(\sum_{m=1}^{ne} T_{op,t,ne}\right) * \left(\sum_{n=1}^{a} P_{R,t,a}\right) + \left(\sum_{l=1}^{shift}(f_{shift,t,shift})\right) * \left(\sum_{p=1}^{e} T_{dr,t,e}\right) * \left(\sum_{p=1}^{a} \Delta P_{drs,t,a}\right)\right) \quad \textbf{Equation 4.2}$$

4.2.2.3 Coding

To create the code for this simulation, the objective functions and variables listed above were coded into GAMS. Each variable in the equation is a data set implemented from Microsoft Office Excel with 8760 rows of data. Some data sets, $f_{rop}, T_{dr}, T_{op}, f_{shift}$, consist of two columns, one for the time factor and the other for the price or event variable. The variables, $P_R, \Delta P_{DRS}, \Delta P_{DRE}$, represent the base usage parameters and the shifts implemented to those parameters during demand response events. These variables have either eleven or twelve columns depending on if the electric car was involved in the simulation [46].

4.2.3 Results

4.2.3.1 Efficient Residential Energy Usage vs. Inefficient

A comparison between simulations 1-4, for efficient residential households, and simulations 5-8 for inefficient households shows the user saves about $1200/year when switching from all inefficient appliances, devices and light to the efficient versions. This is a savings of 6200.29 kWh when looking at a simulation where AC is not eliminated and there is no electric car in the parameters, simulation 1 and 5. This is a kWh savings of 37.65% over one year. The biggest saving comes from upgrading the water heater, air conditioning and lighting to high efficiency energy star rated devices [19] [47].

4.2.3.2 Results of Each of the Nine Simulation

In the first simulation, shifts are only made during critical peak events, using the profile with a user that owns an electric car and lives in a completely energy efficient home. The price for a year's worth of usage, using PG&E's commercial base rate [39], is

$4086.28. The price for the demand response program using criteria listed above is $4038.10, which is a savings of $48.18 per year, or 1.179%.

In the second simulation shifts are only made during critical peak events, using the profile with a user that does not own an electric car and lives in a completely energy efficient home. The price for a year's worth of usage, using PG&E's commercial base rate, is $2015.19. The price for the demand response program using criteria listed above is $2016.00, which ends up costing $0.81 more per a year. This simulation was not beneficial for the user. However, if the user became more aggressive with their energy shifts the results would be beneficial.

The third simulation run is where shifts are made during all peak hours, including critical peak events. This simulation used the profile with a user that does not owns an electric car and lives in a completely energy efficient home. The price for a year's worth of usage, using PG&E's commercial base rate, is $2015.9. The price for the demand response program using criteria listed above is $1977.06, which is a savings of $38.13 per year, or 1.892%.

The final energy efficient PG&E simulation run is where shifts are made during critical peak and peak events. Instead of a shift in air conditioning usage to a different time, the usage is simply eliminated from the profile. The profile with a user that does not own an electric car was used. The price for a year's worth of usage, using PG&E's commercial base rate, is $2015.9. The price for the demand response program using criteria listed above is $1884.21, which is a savings of $103.98 per year, or 6.5%.

The fifth simulation run is where shifts are only made during critical peak events, using the profile with a user that owns an electric car and lives in a completely energy inefficient home. The price for a year's worth of usage, using PG&E's commercial base rate, is $5321.12. The price for the demand response program using criteria listed above is $5264.42, which is a savings of $ 56.70 per year, or 1.066%.

The sixth simulation run is where shifts are only made during critical peak events, using the profile with a user that does not own an electric car and lives in a completely energy inefficient home. The price for a year's worth of usage, using PG&E's commercial base rate, is $3250.03. The price for the demand response program using criteria listed above is $3242.32, which ends up saving $7.71 per year, or 0.237%.

The seventh simulation run is where shifts are made during all peak hours, including critical peak events. This simulation used the profile with a user that does not owns an electric car and lives in a completely energy efficient home. The price for a year's worth of usage, using PG&E's commercial base rate, is $3250.03. The price for the demand response program using criteria listed above is $3185.90, which is a savings of $64.13 per year, or 1.973%.

The final energy efficient PG&E simulation run is where shifts are made during critical peak and peak events. Also, instead of a shift in air conditioning usage to a different time the usage is simply eliminated from the profile. The profile with a user that does not own an electric car was used. The price for a year's worth of usage, using PG&E's commercial base rate, is $3250.03. The price for the demand response program using criteria listed above is $3015.86, which is a savings of $234.17 per year, or 7.205%.

The final energy efficient simulation run, with respect to NHEC rates [44], is where shifts are made during critical peak and peak events. Also, instead of a shift in air conditioning usage, to a different time, the usage is simply eliminated from the profile. The profile with a user that does not own an electric car was used. The price for a year's worth of usage, using NHEC residential base rate, is $1191.55. The price for the demand response program using criteria listed above is $1171.39, which is a savings of $20.16 per year, or 1.69%.

4.2.3.3 Comparison of the Four PG&E Simulation and Final NHEC Simulation

The first and fifth simulations were simulations where the user had an electric car and only responded to critical peak events, both had just over a 1% savings. The second and sixth simulations were simulations where the user did not have an electric car and only responded to critical peak events. Both had close to no savings. The third and seventh simulations were simulations where the user did not have an electric car and responded to all peak and critical peak events by shifting their usage outside the peak period, both had just under a 2% savings. The fourth, eighth and ninth simulations were the simulations with the best results. By both shifting usage and eliminating air conditioning during peak and critical peak hours a user could save the most, 1.69-6.50% among the different scenarios analyzed in this project.

4.2.4 Conclusion

Overall, when compared to each other, the scenarios that were the same, except for their efficiency, resulted in percentage savings that were almost identical. This shows that a home does not need to be efficient or inefficient to benefit from demand response programs. Finding the right price points for a demand response program, as it applies to the residential consumer, is the key to encouraging more consumers to switch to demand response pricing and do their part for the environment and grid stability, without forcing them to be extremely aggressive with their demand shifting and reduction and allowing the user to benefit from the program while still making some changes to their usage.

From the simulations run, demand response programs can be beneficial to the consumer given the right set of circumstances with regards to residential profiles. In the case of the NHEC program, the recommended shifts and eliminations of energy usage in these profiles were barely enough to overcome the $1.50 critical peak energy charge. If the user were to completely shut off all energy usage during an event, then the profile would most likely be as beneficial as the PG&E profile. However, given the available data, with a few behavioral modifications, such as a lower critical peak charge, demand response programs can be even more beneficial to consumers. In the case of the eight PG&E profiles, seven were beneficial to the consumer and the eighth was just barely non-beneficial to the consumer.

Steps towards energy efficiency turned out to be more beneficial to the consumer than the current demand response programs available. By simply changing out their light bulbs to LEDs a consumer can save up to 16 percent on their yearly electricity bill, 2649 kWh per year, for the average residential user. Utility companies are doing their part in offering rebates on Energy Star rated appliances, devices, and lighting. However, they could do more about getting the word out about these rebates and how they are beneficial to the consumer.

From an environmental impact perspective, all shifts towards demand response and energy efficiency are beneficial, by reducing the carbon footprint of the user. Therefore, more utility companies need to create voluntary demand response programs, even if there is not a price incentive to the program. In California, there is a program called Flex Alert, which is run by the California Independent System Operator, where consumers are notified on the television and radio of when critical peak periods are about to occur [48]. Programs like Flex Alert increase consumer awareness of critical peak periods and allow them to do their part in helping the environment and maintaining grid stability.

4.3 Residential Real Time Participation with Solar Generation and Battery Backup

4.3.1 Introduction

This platform looks at consumer participation in demand response on the highest level. The consumer gets hourly pricing, three hours in advance, and then makes decisions on how to adjust usage to prepare for higher price periods. Device usages such as lighting and AC will be reduced or shifted and a backup battery will be implemented to increase the user's benefits [49].

There are some real challenges in real world applications of this project. Currently most homes are equipped with a simple meter that tracks how much power is drawn from the grid or in the case of homes with generation the meter calculates the net amount of power drawn from or delivered to the grid. While the utility can track real time data on each home's demand, using traditional meters, most are not equipped to deliver real time prices to the consumer, nor do they track onsite generation without an upgraded meter. What this means is that in most homes hardware would need to be added to track usage on an hourly or even minute by minute bases. The upgraded hardware would also be required to communicate with the grid via the SCADA network, as mentioned before, to obtain the demand response or real-time prices.

There is also work that will need to be done on the utility side. Programs need to be created to handle these upgraded households and would require more monitoring than traditional households would require. Rates for all generation are already calculated in real time. A program would have to be created to adjust these rates and determine how much to charge the consumer, factoring in distribution, utility, and other costs incurred to deliver power to the consumer. While this seems like an easy task, it would require many customers to participate to make it profitable for the utility and in turn the consumer. These designs and procedures would have to be implemented before a real-time energy pricing program could become available to residential consumers.

While these programs will come with an upfront cost to the utility the long-term benefits should outweigh the costs. The first benefit comes from the increase in available information, when consumers participate in this program they can send information to the utility on how much energy they will use in the next three hours as well as how much they will reduce. This will allow the utility to update their forecasting models and plan appropriately for future demand and critical events. In turn, their costs will be decreased due to their forecasting models being more efficient, allowing them to plan generation more effectively. The utility will also benefit from the decrease in peak and critical peak usage. There will be less stress on the system leading to less maintenance and operational costs to maintain the grid. Some of these benefits will be passed on to the consumers since consumer prices are a function of generation and utility cost.

4.3.2 Technical Work Preparations

Many parameters and variables were defined. All variables and parameters were defined at the beginning of the program so that, in the future, any of them could be altered or refined. This makes the project more useful, in that, different usage, generation, pricing, time periods and battery sizes can be analyzed. The program can serve as a test platform that allows the consumer to decide for themselves if they are interested in participating and if it would be profitable for them to participate. Levels of participation can also be scaled to allow the user to test the amount of participation they would be interested in. There are no hardcoded values in the program, all limits, parameters, and variables are predefined to easily allow for changes based on the needs of the user. The parameters for price and AC usage are a function of temperature, since demand on the grid is loosely related to. This application of the project only looks at the summer period, which does vary based on temperature, due to an increase in AC usage and the large percentage of demand AC units consume. It is assumed that energy costs, for the purposes of the project, are directly related to the cost of energy and AC usage. However, it is not a direct relation. Energy costs are much more complex. They include a variety of different measures and weights, including but not limited to, type of generators utilized, fuel costs, time of day, amount of demand with respect to forecasted models, transmission costs and operational cost. To launch this platform, meters and communication systems must be considered to give more accurate data.

To create this platform, some research was used from other sections to define the parameters of the consumer. Usage profiles of residential consumers, from Xcel Energy Denver, were first analyzed to get an idea of how Denver residents consume energy. This data was then broken up into lighting, AC and baseline parameters. Baseline parameters were calculated using Energy Star and EIA data on residential usage. These parameters include all devices and appliances, other than AC and lighting, that are used in a traditional household. For Module 1 of this platform, it was assumed that the household was completely energy efficient. Meaning all devices are Energy Star approved, lighting was implemented using dimmable LED lights and the AC unit had a high efficiency. An energy efficient household was chosen because this shows that even the consumers who use the least amount of energy could benefit from a real-time pricing program. The theory behind this being the more energy consumption a consumer's baseline has the further they can benefit financially from this platform. Usage, with the exclusion of AC, was assumed to be the same for every day in Module 1. In later modules, these parameters were altered in response to an increase in price.

Solar generation parameters were also defined in this module. For this platform insulation and temperature values were taken from SolarTac, for the Denver area [50]. A derate was coded to be 0.725, which is the average derate factor for solar home systems, but this can easily be changed for other applications. The size of the solar generation was defined at 20kW, which is higher than necessary to power the average household, but allows for the impact of the battery storage to be more prevalent. Multiplying the derate, insulation and size of the solar system together gives the solar output, in kWh, at a given time.

Module 1 also calculates a traditional price, for a given hour, by first finding the net power and then calculating the rate. The net is calculated by subtracting the generation, that the solar panels produce, from the demand of the consumer's home. If the net is positive there was more demand than generation and if negative, there was more generation than demand. A negative value for the net will result in a payment from the utility to the consumer. A positive value will require the consumer to pay the utility.

Once these three aspects, of the module, were coded a set of base parameters were created for comparison with future models. To track the changes from module to module each time varying parameter was also given a second element to store which module the parameter is being calculated for. This created a two-dimensional array where the values of the rows are time and the value of the columns are the module numbers. At the end of each module, or the beginning of the next module unused parameters were copied over so that values were available in the most current module storage location for augmentation in future modules.

Module 2's job is to simply implement the real-time pricing model and apply it to the data. For this platform, real time pricing is simply a function of temperature. If the temperature is greater than a high point the price is at its max. When below a low point, the price is at a minimum. Two middle temperatures also exist creating a range for the low and mid prices. A set of rate parameters are then calculated to track the change in rate between Module 1 and Module 2. This step is taken near the end of every module.

Module 3's job is to reduce lighting based on price of energy. The lighting values of module one are reduced by either 25 or 50% depending on if the price of energy is at a price just below the maximum or at the maximum price. For all other price points, the lighting remains the same.

Module 4's task is more difficult than that of Modules 1 through 3. This is where the idea of looking ahead, for demand planning, is first introduced. The lighting values could be perceived as considering the future and their data can be sent to the utility three hours in advance, provided the price is available. However, they only need one-hours' worth of information to determine their reaction. This AC price module looks at the next three hours of pricing data, as well as the current hour's pricing data, to decide on what level of AC usage to implement. It also looks at changes made in the past hours to determine the level of AC usage. If at hour t+3, t being the hourly time index, there exists a spike in price, the AC is set on low for hour t, mid for hour t+1, high for hour t+2 and off for hour t+3. The AC usage for the current hour and the next two hours will not be lowered if values are already higher than what the system is trying to set them to. This is done to cool down the household, by ramping up AC usage, prior to the spike in energy prices. The system keeps track of how many hours the AC has been turned off for, to make sure the consumers comfort level is not hindered too much. If the prices are high and the AC has been off for more than four hours, it kicks back on in the low setting, to keep the user's comfort level at an acceptable level. If the high price period last more than seven hours, the AC will go into the mid setting. Since both AC usage and prices are a function of temperature this system only adjusts the AC when temperatures are either high or going to be high in the future.

Module 5 is the most complex of all the modules. It is broken down into conditional if else statements. These statements could be reprogrammed, using optimization equations with set parameters, to make the module more efficient and allow for the most optimal solution. This section of code is broken down into two if statements. The first executes when the price is high or at the mid-point. The battery supplies all available energy to the household and the grid, within its discharge and current charge limits. The second executes when the price is not at its high rate. Since it is most beneficial to sell energy, to the grid, at high price periods the system stores as much energy at possible in the battery during these time periods. If the battery reaches capacity and the price of energy is equal to or higher than the price of energy over the next three hours, it sells some of its energy back to the grid. At the end of this module the project stores the value for charge left in the battery to calculate the batteries net present value. This is used in determining the rate difference between this module and the others.

4.3.3 Results

There are five sets of resulting data that are important. In addition, the total rate, for each module, which proves the ability to increase a customer's payout, or decrease their bill depending on the initial parameters. The first graphical result is the graph of AC demand. From Figure D2, of Appendix D, you can see that when the AC module, Module 4, is implemented there is a substantial decrease in AC usage during the peak periods, which is the higher price periods. The battery charge graph, Figure D3, of Appendix D, shows the battery being used during higher pricing periods to run the household, allowing the consumer to avoid highest price periods. Figure D4, of Appendix D, shows the demand curve for the 5 modules. It can be seen from the data of Module 3 and Module 4 that the lighting and AC reduction lower the overall demand during high peak periods. It can also be seen that demand is equal to zero for most critical peak periods. Figure D5, of Appendix D, shows the net power. This includes demand, solar generation, and power being sold back to the grid during the high price periods and when the battery is at capacity. Figure D6, of Appendix D, shows the data the utility will receive three hours in advance. It shows how the consumers demand will change in response to future changes in price. By analyzing all these data points, specifically the net power, from demand and generation, the rates for each module were obtained. These can be found in Table D1, of Appendix D. As each module is added, to the simulation, the consumer's payout increases. Payouts for Module 1-5 are $28.891, $43.566, $44.536, $49.089 and $56.534. The payout for the fifth module is almost double that of the first.

4.3.4 Conclusion

Section 4.3 shows that some savings can be made, on energy rates, with minimal changes to lifestyles and comfort by enrolling and participating in a real-time pricing program. This project could benefit the utility, the consumer and the environment in many ways. There are challenges in implementing this project, however, the benefits of the project substantially outweigh the challenges. Hopefully, someday soon, consumers will have the technologies and programs available to them to allow for residential participation in real time pricing programs such as the on described in this section. This platform serves as a proof of concept for residential real time pricing's feasibility.

Chapter Five: Summary and Future Work

5.1 Conclusions

This thesis shows the costs and benefits of implementation of energy efficiency and demand response for residential applications. These numerical analyses show that current demand response programs and energy efficient upgrades do have a positive impact on the consumer, utility and environment. While demand response efforts do yield less economic benefits for the consumer, than that of energy efficiency, there are still some benefits that exist with current programs. In the future, these benefits could increase when demand response programs become more popular. With increased participation in demand response, rates could go down, which would increase the benefits to the consumer and the utility, factoring in more consumer participation.

The most effective and easiest way to lower an energy bill was to simply install LED lighting throughout a household. This showed price decreases of up to 75 percent for lighting and has a major impact on a consumer's monthly electricity bill. The next most effective means was the real-time demand response with solar and battery backup. While this is the most expensive form of participation, the simulation showed a consumer going from a $28.891 payout to a $56.534 payout, over a 72-hour summer period, for changing from a traditional solar generation model to a real time with battery backup model, while implementing demand response practices. These payout increases would not be as high year-round. The model only shows a simulation at or near the biggest payout period of the year. The residential demand response participation yielded the lowest percentage drop in a consumer's utility bill. The savings ranged between 0.25 and 7.5 percent. Price points and consumer participation must evolve before consumer controlled demand response can become effective. These four numerical analyses do show there is potential for great benefits to consumers and utilities alike, however, there is still work to be done to make these programs more popular among consumers. Demand response and energy efficiency could soon do great work for the environment and stability of the grid and help to overcome the issues of alternative energy and population growth, with respect to the stability of the grid.

Demand response, particularly utility controlled, does benefit the utility greatly. It leads to slightly greater benefits, for both the utility and the consumer, and the ability to meet a greater demand on the grid, thus providing for the increase in consumers and electronics. Utility controlled is one of if not the best for the utility because it allows for better forecasting and quicker response to grid fluctuations.

In conclusion demand response and energy efficiency are both important tools needed to handle the increased demand on the grid. Both programs benefit the consumer and the utility, each with varying effectiveness for each party. These tools could help reduce the need for peaking power plants and increase the ability to integrate alternative energy sources into the grid, while optimally utilizing their resources.

5.2 Future Work

There are a few different tasks that could be completed for future work on this thesis. Combing the numerical analyses into one final platform would be the first step. This combined platform could be created to first perform and energy audit on a consumer's home or commercial property. Measuring the output and calculating the usage for all devices, including lighting and any PV generation, in a home. The variables could then be utilized in a platform combining Section 3 and Sections 4.2-4.3. This would give the consumer and idea of how both basic demand response and real time demand response could affect their monthly utility bill. These results would be more accurate since the variables show their specific needs and their ability to shift usage. In addition, Xcel Energy's new TOU pricing could be used to rerun all simulations in the thesis for local Denver results. These are just a few of the options that could be implemented to further the research done in the creation of this thesis.

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Appendix A: Energy Efficiency

A1: Lighting Guide

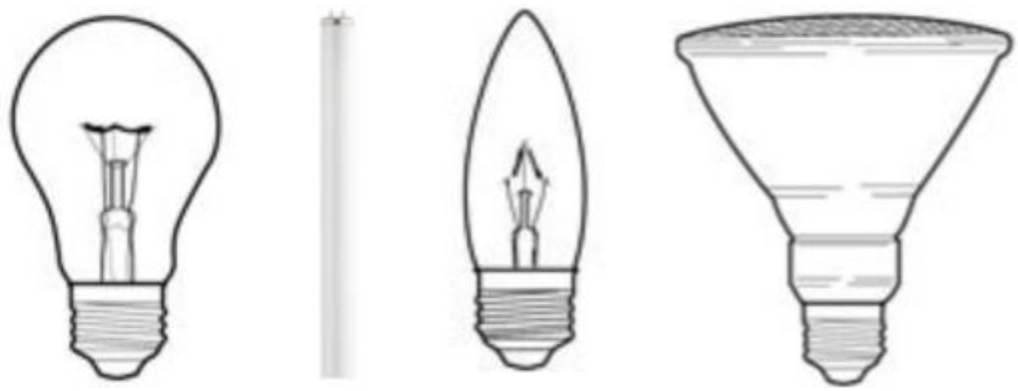

Figure A1.1: Traditional Lights: (Left to Right) 60W, Fluorescent, Decorative, Flood.

Figure A1.2: Compact Fluorescent Lights: (Left to Right) 60W, Decorative, Flood.

Figure A1.3: Light Emitting Diode Lights: (Left to Right) 60W, Fluorescent, Decorative, Flood.

Table A2.1: Denver Central Games Energy Efficiency Results for Denver, CO

Input	Value
Average-Utility-Rate	0.11
Number-Of-Traditional-Flood-Lights	0
Number-Of-Traditional-Regular-Lights	0
Number-Of-Traditional-Decorative-Lights	0
Number-Of-Traditional-Fluorescent-Lights	48
Number-Of-CFL-Flood-Lights	0
Number-Of-CFL-Regular-Lights	0
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	18
Output	**Results**
Cost_per_Day_LED	1.9008
Cost_per_Day_CFL_Traditional	3.8016
Savings_per_Day	1.9008
Cost_per_Year_LED	693.79
Cost_per_Year_CFL_Traditional	1387.6
Savings_per_Year	693.79
Total_Cost_of_LEDs	336
Days_to_Recover_Cost	176.77
LED_Lifespan_Savings_of_System	3465.6
LED_Total_Lifespan_Savings_of_System	3561.6
Cost_of_System	336
Yearly_Energy_Usage_CFL_Traditional	12614
Yearly_Energy_Usage_LED	6307.2
Years_Lifespan_Tube_LED	5.4795

Table A2.2: Ronald Smith Energy Efficiency Results for Antioch, CA

Input	Value
Average-Utility-Rate	0.2761
Number-Of-Traditional-Flood-Lights	1
Number-Of-Traditional-Regular-Lights	12
Number-Of-Traditional-Decorative-Lights	2
Number-Of-Traditional-Fluorescent-Lights	4
Number-Of-CFL-Flood-Lights	1
Number-Of-CFL-Regular-Lights	21
Number-Of-CFL-Decorative-Lights	9
Average-Hours-Per-Day-Per-Light-Used	4
Dishwasher-Estar-Price	599
Dishwasher-Traditional-Price	349
Output	**Results**
Cost_per_Day_LED	0.4749
Cost_per_Day_CFL_Traditional	1.5065
Savings_per_Day	1.0316
Cost_per_Year_LED	173.35
Cost_per_Year_CFL_Traditional	549.88
Savings_per_Year	376.53
Total_Cost_of_LEDs	157.85
Days_to_Recover_Cost	153.02
LED_Lifespan_Savings_of_System	6430.4
LED_Total_Lifespan_Savings_of_System	6843.6
Cost_of_System	157.85
Yearly_Energy_Usage_CFL_Traditional	1991.4
Yearly_Energy_Usage_LED	627.8
Years_Lifespan_Tube_LED	34.247
Dishwasher_Estar_Annual_Usage	137.62
Dishwasher_Estar_Annual_Cost	38
Dishwasher_Traditional_Annual_Usage	144.86
Dishwasher_Traditional_Annual_Cost	40
Dishwasher_Estar_Usage_Per_Cycle	0.6401
Dishwasher_Traditional_Usage_Per_Cycle	0.6738
Dishwasher_Years_to_Recover	125
Dishwasher_Lifespan_Savings	-229.8

Table A2.3: Garry Files Energy Efficiency Results for Elizabeth, CO

Input	Value
Average-Utility-Rate	0.1213
Number-Of-Traditional-Flood-Lights	11
Number-Of-Traditional-Regular-Lights	20
Number-Of-Traditional-Decorative-Lights	0
Number-Of-Traditional-Fluorescent-Lights	0
Number-Of-CFL-Flood-Lights	0
Number-Of-CFL-Regular-Lights	8
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	4.5
Output	**Results**
Cost_per_Day_LED	0.2006
Cost_per_Day_CFL_Traditional	1.1064
Savings_per_Day	0.9058
Cost_per_Year_LED	73.219
Cost_per_Year_CFL_Traditional	403.85
Savings_per_Year	330.63
Total_Cost_of_LEDs	90
Days_to_Recover_Cost	99.356
LED_Lifespan_Savings_of_System	4942.4
LED_Total_Lifespan_Savings_of_System	5840.9
Cost_of_System	90
Yearly_Energy_Usage_CFL_Traditional	3329.3
Yearly_Energy_Usage_LED	603.62
Years_Lifespan_Tube_LED	30.441

Table A2.4: Carol Reid Energy Efficiency Results for Parker, CO

Input	Value
Average-Utility-Rate	0.1231
Number-Of-Traditional-Flood-Lights	1
Number-Of-Traditional-Regular-Lights	14
Number-Of-Traditional-Decorative-Lights	13
Number-Of-Traditional-Fluorescent-Lights	0
Number-Of-CFL-Flood-Lights	4
Number-Of-CFL-Regular-Lights	50
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	3
Output	**Results**
Cost_per_Day_LED	0.2513
Cost_per_Day_CFL_Traditional	0.8054
Savings_per_Day	0.5541
Cost_per_Year_LED	91.728
Cost_per_Year_CFL_Traditional	293.99
Savings_per_Year	202.26
Total_Cost_of_LEDs	183
Days_to_Recover_Cost	330.24
LED_Lifespan_Savings_of_System	3858.7
LED_Total_Lifespan_Savings_of_System	4438.4
Cost_of_System	183
Yearly_Energy_Usage_CFL_Traditional	2388.2
Yearly_Energy_Usage_LED	745.15
Years_Lifespan_Tube_LED	45.662

Table A2.5: Cathlene Essinger Energy Efficiency Results for San Lorenzo, CA

Input	**Value**
Average-Utility-Rate	0.2761
Number-Of-Traditional-Flood-Lights	0
Number-Of-Traditional-Regular-Lights	0
Number-Of-Traditional-Decorative-Lights	0
Number-Of-Traditional-Fluorescent-Lights	0
Number-Of-CFL-Flood-Lights	4
Number-Of-CFL-Regular-Lights	15
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	6
Output	**Results**
Cost_per_Day_LED	0.2932
Cost_per_Day_CFL_Traditional	0.4407
Savings_per_Day	0.1474
Cost_per_Year_LED	107.03
Cost_per_Year_CFL_Traditional	160.85
Savings_per_Year	53.819
Total_Cost_of_LEDs	38.75
Days_to_Recover_Cost	262.8
LED_Lifespan_Savings_of_System	575.62
LED_Total_Lifespan_Savings_of_System	651.87
Cost_of_System	38.75
Yearly_Energy_Usage_CFL_Traditional	582.54
Yearly_Energy_Usage_LED	387.63
Years_Lifespan_Tube_LED	22.831

Table A2.6: Perry Harnage Energy Efficiency Results for Hayward, CA

Input	Value
Average-Utility-Rate	0.2436
Number-Of-Traditional-Flood-Lights	0
Number-Of-Traditional-Regular-Lights	14
Number-Of-Traditional-Decorative-Lights	12
Number-Of-Traditional-Fluorescent-Lights	6
Number-Of-CFL-Flood-Lights	0
Number-Of-CFL-Regular-Lights	2
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	5
Output	**Results**
Cost_per_Day_LED	0.3581
Cost_per_Day_CFL_Traditional	1.8759
Savings_per_Day	1.5178
Cost_per_Year_LED	130.71
Cost_per_Year_CFL_Traditional	684.69
Savings_per_Year	553.98
Total_Cost_of_LEDs	152.9
Days_to_Recover_Cost	100.74
LED_Lifespan_Savings_of_System	6931.6
LED_Total_Lifespan_Savings_of_System	7337.8
Cost_of_System	152.9
Yearly_Energy_Usage_CFL_Traditional	2810.5
Yearly_Energy_Usage_LED	536.55
Years_Lifespan_Tube_LED	27.397

Table A2.7: Christopher John Wellons II Energy Efficiency Results for Denver, CO

Input	Value
Average-Utility-Rate	0.13
Number-Of-Traditional-Flood-Lights	2
Number-Of-Traditional-Regular-Lights	17
Number-Of-Traditional-Decorative-Lights	6
Number-Of-Traditional-Fluorescent-Lights	10
Number-Of-CFL-Flood-Lights	0
Number-Of-CFL-Regular-Lights	0
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	4
Dishwasher-Estar-Price	399
Dishwasher-Traditional-Price	269
Dryer-Estar-Price	699
Dryer-Traditional-Price	399
Refrigerator-Estar-Price	629
Refrigerator-Traditional-Price	579
Washer-Estar-Price	649
Washer-Traditional-Price	399
Output	**Results**
Cost_per_Day_LED	0.1914
Cost_per_Day_CFL_Traditional	0.8892
Savings_per_Day	0.6978
Cost_per_Year_LED	69.846
Cost_per_Year_CFL_Traditional	324.56
Savings_per_Year	254.71
Total_Cost_of_LEDs	168.75
Days_to_Recover_Cost	241.82
LED_Lifespan_Savings_of_System	4399.5
LED_Total_Lifespan_Savings_of_System	4930.1
Cost_of_System	168.75
Yearly_Energy_Usage_CFL_Traditional	2496.6
Yearly_Energy_Usage_LED	537.28
Years_Lifespan_Tube_LED	34.247
Dishwasher_Estar_Annual_Usage	292.31
Dishwasher_Estar_Annual_Cost	38
Dishwasher_Traditional_Annual_Usage	307.69
Dishwasher_Traditional_Annual_Cost	40

Dishwasher_Estar_Usage_Per_Cycle	1.3596
Dishwasher_Traditional_Usage_Per_Cycle	1.4311
Dishwasher_Years_to_Recover	65
Dishwasher_Lifespan_Savings	-109.8
Dryer_Estar_Annual_Usage	492.31
Dryer_Estar_Annual_Cost	64
Dryer_Traditional_Annual_Usage	615.38
Dryer_Traditional_Annual_Cost	80
Dryer_Estar_Usage_Per_Cycle	1.7396
Dryer_Traditional_Usage_Per_Cycle	2.1745
Dryer_Years_to_Recover	18.75
Dryer_Lifespan_Savings	-108
Refrigerator_Estar_Annual_Usage	466.67
Refrigerator_Estar_Annual_Cost	60.667
Refrigerator_Traditional_Annual_Usage	512.82
Refrigerator_Traditional_Annual_Cost	66.667
Refrigerator_Years_to_Recover	8.3333
Refrigerator_Lifespan_Savings	22
Washer_Estar_Annual_Usage	923.08
Washer_Estar_Annual_Cost	120
Washer_Traditional_Annual_Usage	1230.8
Washer_Traditional_Annual_Cost	160
Washer_Estar_Usage_Per_Cycle	3.0769
Washer_Traditional_Usage_Per_Cycle	4.1026
Washer_Years_to_Recover	6.25
Washer_Lifespan_Savings	190

Table A2.8 Blank Energy Efficiency Form

Input	Value
Average-Utility-Rate	0
Number-Of-Traditional-Flood-Lights	0
Number-Of-Traditional-Regular-Lights	0
Number-Of-Traditional-Decorative-Lights	0
Number-Of-Traditional-Fluorescent-Lights	0
Number-Of-CFL-Flood-Lights	0
Number-Of-CFL-Regular-Lights	0
Number-Of-CFL-Decorative-Lights	0
Average-Hours-Per-Day-Per-Light-Used	0
Dishwasher-Estar-Price	0
Dishwasher-Traditional-Price	0
Dryer-Estar-Price	0
Dryer-Traditional-Price	0
Refrigerator-Estar-Price	0
Refrigerator-Traditional-Price	0
Washer-Estar-Price	0
Washer-Traditional-Price	0
Optional-Parameters-With-Defaults	0
LED-Flood-Watts	10.5
LED-Regular-Watts	9
LED-Decorative-Watts	4
LED-Fluorescent-Watts	17
LED-Flood-Cost	5
LED-Regular-Cost	1.25
LED-Decorative-Cost	6
LED-Fluorescent-Cost	10.15
LED-Flood-Lifespan	25000
LED-Regular-Lifespan	25000
LED-Decorative-Lifespan	15000
LED-Fluorescent-Lifespan	50000
Traditional-Flood-Watts	65
Traditional-Regular-Watts	60
Traditional-Decorative-Watts	40
Traditional-Fluorescent-Watts	32
Traditional-Flood-Cost	3.33
Traditional-Regular-Cost	1.5
Traditional-Decorative-Cost	1.25

Traditional-Fluorescent-Cost	2.25
Traditional-Flood-Lifespan	2000
Traditional-Regular-Lifespan	1533
Traditional-Decorative-Lifespan	3000
Traditional-Fluorescent-Lifespan	20000
CFL-Flood-Watts	14
CFL-Regular-Watts	14
CFL-Decorative-Watts	7
CFL-Flood-Cost	5
CFL-Regular-Cost	1.5
CFL-Decorative-Cost	4
CFL-Flood-Lifespan	8000
CFL-Regular-Lifespan	10000
CFL-Decorative-Lifespan	10000
Output	**Results**
Cost_per_Day_LED	0
Cost_per_Day_CFL_Traditional	0
Savings_per_Day	0
Cost_per_Year_LED	0
Cost_per_Year_CFL_Traditional	0
Savings_per_Year	0
Total_Cost_of_LEDs	0
Days_to_Recover_Cost	0
LED_Lifespan_Savings_of_System	0
LED_Total_Lifespan_Savings_of_System	0
Cost_of_System	0
Yearly_Energy_Usage_CFL_Traditional	0
Yearly_Energy_Usage_LED	0
Years_Lifespan_Tube_LED	0
Dishwasher_Estar_Annual_Usage	0
Dishwasher_Estar_Annual_Cost	0
Dishwasher_Traditional_Annual_Usage	0
Dishwasher_Traditional_Annual_Cost	0
Dishwasher_Estar_Usage_Per_Cycle	0
Dishwasher_Traditional_Usage_Per_Cycle	0
Dishwasher_Years_to_Recover	0
Dishwasher_Lifespan_Savings	0
Dryer_Estar_Annual_Usage	0

Dryer_Estar_Annual_Cost	0
Dryer_Traditional_Annual_Usage	0
Dryer_Traditional_Annual_Cost	0
Dryer_Estar_Usage_Per_Cycle	0
Dryer_Traditional_Usage_Per_Cycle	0
Dryer_Years_to_Recover	0
Dryer_Lifespan_Savings	0
Refrigerator_Estar_Annual_Usage	0
Refrigerator_Estar_Annual_Cost	0
Refrigerator_Traditional_Annual_Usage	0
Refrigerator_Traditional_Annual_Cost	0
Refrigerator_Years_to_Recover	0
Refrigerator_Lifespan_Savings	0
Washer_Estar_Annual_Usage	0
Washer_Estar_Annual_Cost	0
Washer_Traditional_Annual_Usage	0
Washer_Traditional_Annual_Cost	0
Washer_Estar_Usage_Per_Cycle	0
Washer_Traditional_Usage_Per_Cycle	0
Washer_Years_to_Recover	0
Washer_Lifespan_Savings	0

Appendix B: Utility Controlled Demand Response

Table B1: Generation Parameters

Source	Capacity Factor	location	Capacity (MW)	Low MW start	Low $/MWh
NG CCT	Peaking/30%	close	150	0	87.66
NG ACT	Peaking/30%	close	150	0	74.07
Adv. Coal w/ CCS	cycling/85%	intermediate	180	0	41.31
NG CCCT	cycling/87%	intermediate	200	0	63.00
Conventional Coal	cycling/85%	far	300	0	30.24
Adv. Nuclear	full power/100%	far	1000	0	21.60
Geothermal	full power/100%	far	20	0	11.07
Total Capacity			**2000**		
Source	**Mid MW start**	**Mid $/MWh**	**Max MW start**	**Max $/MWh**	**Min output**
NG CCT	30	97.40	120	107.14	30
NG ACT	30	82.30	120	90.53	30
Adv. Coal w/ CCS	36	45.90	144	50.49	36
NG CCCT	40	75.00	160	80.00	40
Conventional Coal	60	33.60	240	36.96	60
Adv. Nuclear	200	24.00	800	26.40	1000
Geothermal	4	12.30	16	13.53	20
Total Min					**1216**

Table B2: Simulation 1-4 Load Parameters with Prices

# of Bus	ID	AGC	Min MW	Max MW
10	2	YES	0	0
4	1	YES	0	0
9	1	NO	100	200
4	2	NO	100	250
7	1	NO	100	200
10	1	NO	1000	2000
# of Bus	**MW Break 1**	**MWh Price 1**	**MW Break 2**	**MWh Price 2**
10	0	40	0	77.5
4	0	40	0	77.5
9	0	46.04	140	90
4	0	46.04	175	90
7	0	46.04	140	90
10	0	46.04	700	90

Table B3: Simulation 4-9 Load Parameters with Prices

# of Bus	ID	AGC	Min MW	Max MW
10	2	YES	-500	0
4	1	YES	-150	0
9	1	NO	100	245
4	2	NO	500	750
7	1	NO	100	250
10	1	NO	100	250
# of Bus	**MW Break 1**	**MWh Price 1**	**MW Break 2**	**MWh Price 2**
10	-500	85	NA	NA
4	-150	85	NA	NA
9	0	46.04	171.5	80
4	0	46.04	525	80
7	0	46.04	175	80
10	0	46.04	175	80

Table B4: Simulation 1 – Minimum Load with No Demand Response

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**Max $/MWh**
10	1	YES	0	0	0	0	0
4	1	YES	0	0	0	0	0
9	1	NO	100	4604	100	200	46.04
10	2	NO	100	4604	100	250	46.04
7	1	NO	100	4604	100	200	46.04
4	2	NO	900	54171	500	2000	60.19
Totals			**1200**	**67983**	**800**	**2650**	**56.65**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	36	1487.16	36	180	41.31
2	1	YES	40	2519.96	40	200	63.00
7	1	YES	30	2222.10	30	150	74.07
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	176.48	5728.23	60	300	32.46
5	1	YES	1000	24000.00	1000	1000	24
Totals			**1332.48**	**38833.25**	**1216**	**2000**	**29.14**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			132.48	**17522.06**	**24.29**		

Table B5: Simulation 2 – Median Load with No Demand Response

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	0	0	0	0	0
4	1	YES	0	0	0	0	0
9	1	NO	100	4604	100	200	46.04
10	2	NO	100	4604	100	250	46.04
7	1	NO	100	4604	100	200	46.04
4	2	NO	1250	82171	500	2000	65.74
Totals			**1550**	**95983**	**800**	**2650**	**61.92**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	174.05	12644.28	40	200	72.65
7	1	YES	30	2222.10	30	150	74.07
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24
Totals			**1734.05**	**60084.18**	**1216**	**2000**	**34.65**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			132.48	**35898.82**	**23.16**		

Table B6: Simulation 3 - Maximum Load with No Demand Response

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	0	0	0	0	0
4	1	YES	0	0	0	0	0
9	1	NO	200	12434.20	100	200	62.17
10	2	NO	250	16434.20	100	250	65.74
7	1	NO	200	12434.20	100	200	62.17
4	2	NO	1150	74171.00	500	2000	64.50
Totals			**1800**	**115473.60**	**800**	**2650**	**64.15**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	200	14719.83	40	200	73.60
7	1	YES	150	12345.00	30	150	82.30
9	1	YES	118.35	11234.69	30	150	94.93
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24.00
Totals			**1968.35**	**80887.52**	**1216**	**2000**	**41.09**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			168.35	**34586.08**	**19.21**		

Table B7: Simulation 5 – Off-Peak Load with Demand Response Available but Not Used.

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	0	0	-150	0	0
4	1	YES	0	0	-500	0	0
9	1	NO	100	4604	100	200	46.04
10	2	NO	100	4604	100	250	46.04
7	1	NO	100	4604	100	200	46.04
4	2	NO	900	54171	500	2000	60.19
Totals			**1200**	**67983**	**150**	**2150**	**56.65**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	36	1487.16	36	180	41.31
2	1	YES	40.04	2520.04	40	200	63.00
7	1	YES	30	2222.10	30	150	74.07
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	176.44	5726.71	60	300	32.46
5	1	YES	1000	24000.00	1000	1000	24
Totals			**1332.48**	**38831.81**	**1216**	**2000**	**29.14**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			132.48	**29151.19**	**24.29**		

Table B8: Simulation 6 – Mid-Peak Load with Demand Response Available but Not Used

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	0	0	-150	0	0
4	1	YES	0	0	-500	0	0
9	1	NO	100	4604	100	200	46.04
10	2	NO	100	4604	100	250	46.04
7	1	NO	100	4604	100	200	46.04
4	2	NO	1250	82171	500	2000	65.74
Totals			**1550**	**95983**	**800**	**2650**	**61.92**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	174.05	12644.28	40	200	72.65
7	1	YES	30	2222.10	30	150	74.07
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24
Totals			**1734.05**	**60084.18**	**1216**	**2000**	**34.65**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			132.48	**35898.82**	**23.16**		

Table B9: Simulation 7 - Peak Load 1800 MW with 106.90 MW Demand Response Used

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**Benefit $/MWh**
10	1	YES	0	0	-150	0	0
4	1	YES	-106.90	-9086.61	-500	0	85.00
9	1	NO	200	12434.20	100	200	62.17
10	2	NO	250	16434.20	100	250	65.74
7	1	NO	200	12434.20	100	200	62.17
4	2	NO	1150	74171.00	500	2000	64.50
Totals			**1693.1**	**106386.99**	**800**	**2650**	**62.84**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**Cost $/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	199.99	14719.21	40	200	73.60
7	1	YES	120	9629.10	30	150	80.24
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24.00
Totals			**1849.99**	**69566.11**	**1216**	**2000**	**37.60**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			156.81	**36820.88**	**21.75**		

Table B10: Simulation 8 – Critical Peak Load, 2150 MW, with Demand Response Reducing the Load Down Below the Maximum

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	0	0	-150	0	0
4	1	YES	-456.91	-38837.28	-500	0	85
9	1	NO	200	12434.20	100	200	62.17
10	2	NO	250	16434.20	100	250	65.74
7	1	NO	200	12434.20	100	200	62.17
4	2	NO	1500	102171.01	500	2000	64.50
Totals			**1693.09**	**104636.33**	**800**	**2650**	**61.80**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	199.98	14718.14	40	200	73.60
7	1	YES	120	9629.10	30	150	82.24
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24.00
Totals			**1849.98**	**69565.04**	**1216**	**2000**	**37.60**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			156.89	**35071.29**	**20.71**		

Table B11: Simulation 9 - Maximum Critical Peak Load, 2300 MW, with Demand Response also near Maximum

Load							
# of Bus	**ID**	**AGC**	**MW**	**Hourly Benefit**	**Min MW**	**Max MW**	**$/MWh**
10	1	YES	-120.39	-10233.26	-150	0	85.00
4	1	YES	-499.92	-42492.79	-500	0	85.00
9	1	NO	200	12434.20	100	200	62.17
10	2	NO	250	16434.20	100	250	65.74
7	1	NO	200	12434.20	100	200	62.17
4	2	NO	1650	114171.00	500	2000	69.19
Totals			**1679.69**	**102747.55**	**800**	**2650**	**61.17**
Generation							
# of Bus	**ID**	**AGC**	**Gen MW**	**Gen Cost**	**Min MW**	**Max MW**	**$/MWh**
8	1	YES	20	246.00	20	20	12.30
6	1	YES	180	8262.00	36	180	45.90
2	1	YES	200	14721.10	40	200	73.60
7	1	YES	150	9629.10	30	150	64.19
9	1	YES	30	2629.80	30	150	87.66
8	2	YES	300	10080.00	60	300	33.60
5	1	YES	1000	24000.00	1000	1000	24.00
Totals			**1880**	**69568**	**1216**	**2000**	**37.00**
Nets			**MW losses ($)**	**Net Profit ($)**	**net $/MWh (delivered)**		
			200.31	**33179.55**	**19.75**		

Table B12: Nets - Table Showing Net Profit and Net $/MWh Delivered

Simulation	Demand Period	Initial Demand (MW)	Generation (MW)	Demand Response (MW)	Net Profits ($)	Net Profits Delivered ($/MWh)
1	Off-Peak	1200	1332.48	Not Available	17522.06	24.29
2	Mid-Peak	1550	1734	Not Available	35898.82	23.16
3	Peak	1800	1868.35	Not Available	34586.08	19.21
4	Critical Peak / Max	2300	Grid Failure	Not Available	0	0
5	Off-Peak	1200	1332.48	0	29151.19	24.29
6	Mid-Peak	1550	1734.05	0	35898.82	23.16
7	Peak	1800	1849.99	106.90	36820.88	21.75
8	Critical Peak	2150	1849.98	456.91	35071.29	20.71
9	Critical Peak / Max	2300	1880	620.31	33179.55	19.75

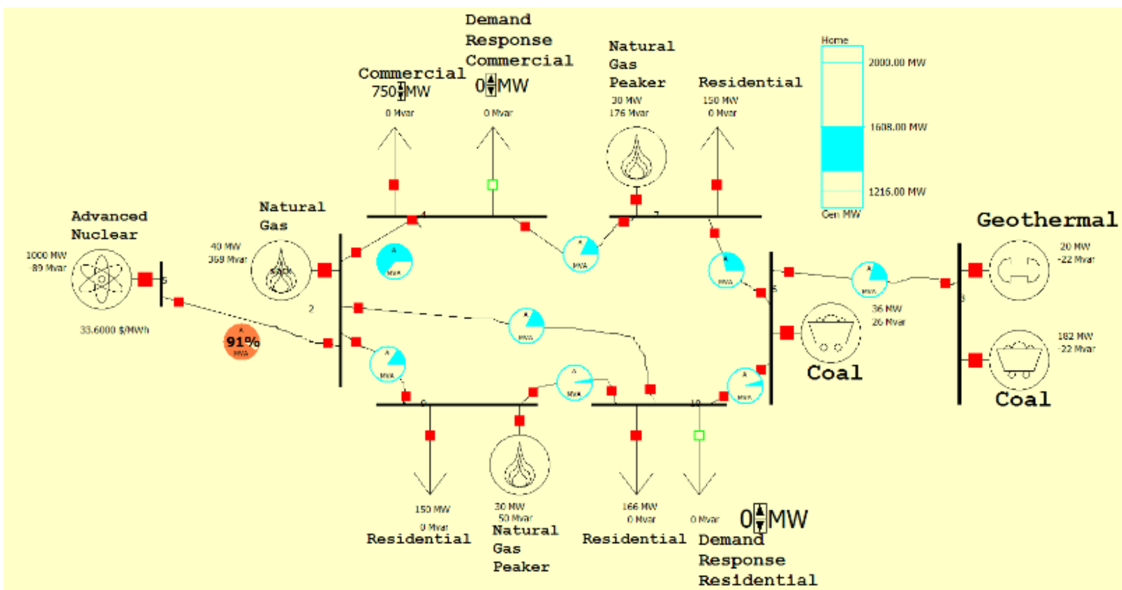

Figure B1: PowerWorld Simulation Diagram

Appendix C: Residential Demand Response Participation

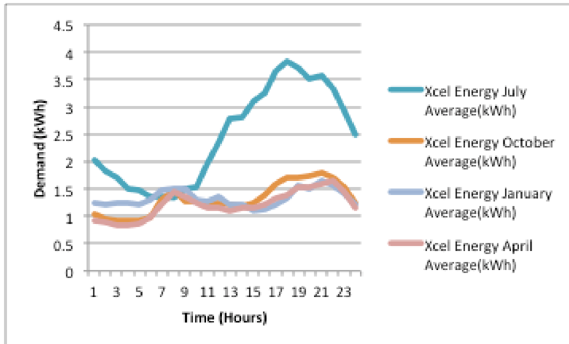

Figure C1: Average daily usage of a resident, in Denver, from Xcel Energy for July, October, January and April. [8]

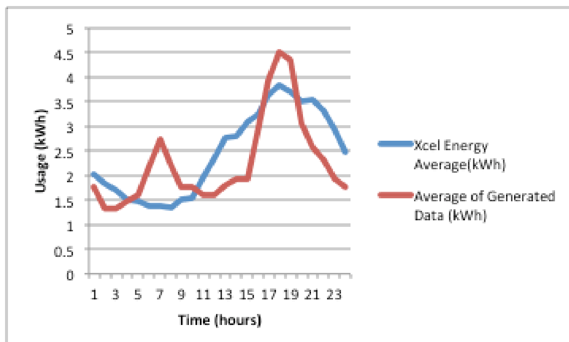

Figure C2: Average Daily Usage of a Resident, in Denver, from Both Xcel Energy and Generated Data Sets, in July. [8]

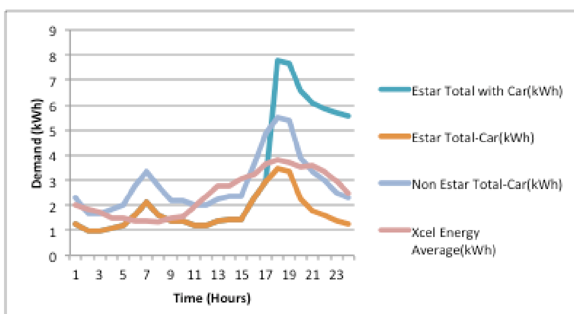

Figure C3: Average Daily Usage of a Resident, in Denver, from both Xcel Energy and Three Generated Data Sets, in July. [8]

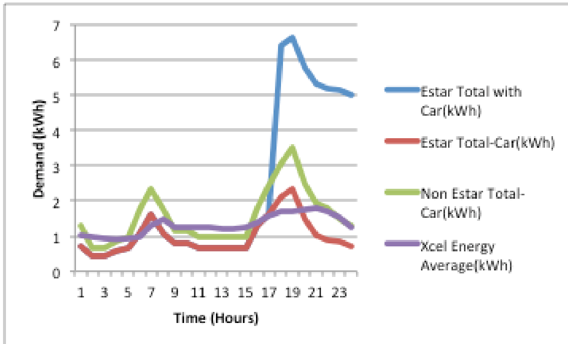

Figure C4: Graph of Average Daily Usage of a Resident, in Denver, from Both Xcel Energy and Three Generated Data Sets, in October. [8]

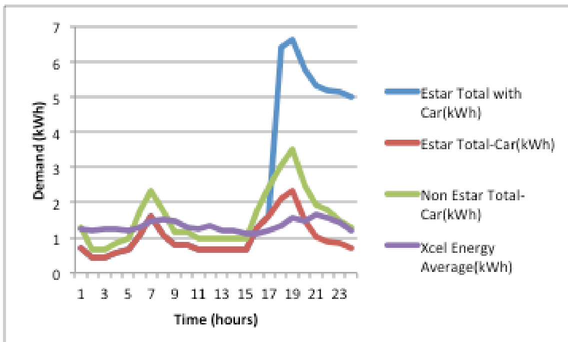

Figure C5: Graph of Average Daily Usage of a Resident, in Denver, from Both Xcel Energy and Three Generated Data Sets, in January. [8]

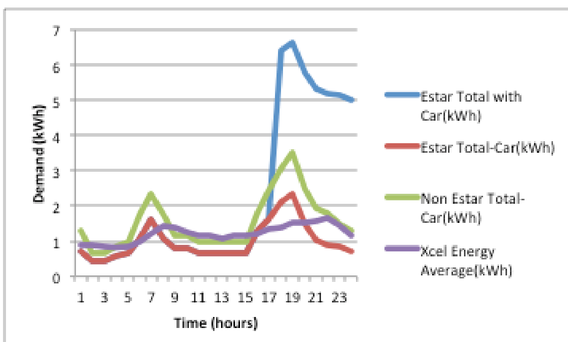

Figure C6: Average Daily Usage of a Resident, in Denver, from Both Xcel Energy and Three Generated Data Sets, in April. [8]

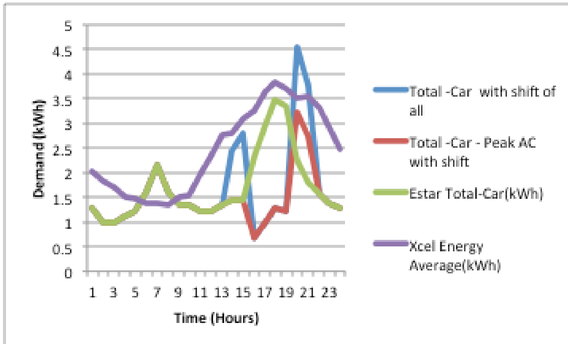

Figure C7: Average daily usage of a resident, in Denver, from Xcel Energy and three generated data sets, total Energy Star usage, with shifts and no car, total Energy Star usage with shifts, no car and eliminating peak AC, and finally total Energy Star usage with no demand response, in July. [8]

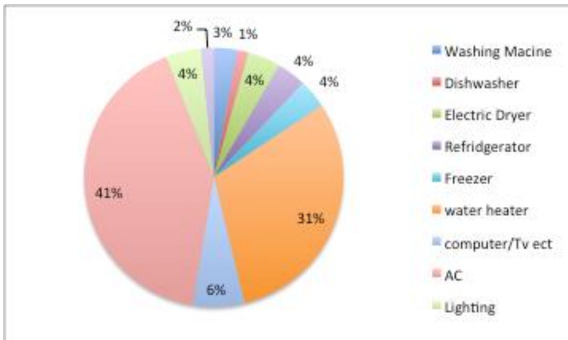

Figure C8: Pie chart of total appliance, device and lighting usage in July.

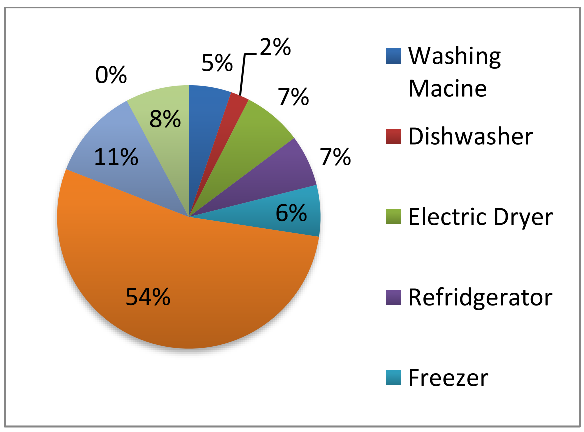

Figure C9: Pie chart of total appliance, device and lighting usage in January.

Table C1: Price of Energy for Pacific Gas and Electric.

	Winter		Summer			
	Off Peak	Mid Peak	Off Peak	Mid Peak	Peak	Critical Peak
Commercial Price	$0.16246		$0.23997			
Demand Response/ TOU	$0.15300	$0.17300	$0.21300	$0.24100	$0.25000	$0.85000

Table C2: Price of Energy for New Hampshire Electric Co-op.

	Winter		Summer			
	Off Peak	Mid Peak	Off Peak	Mid Peak	Peak	Critical Peak
Commercial Price	$0.10817		$0.12617			
Demand Response/ TOU	$0.10817	$0.10817	$0.08080	$0.22524	$0.22534	$1.52581

Appendix D: Residential Real Time Participation with Solar Generation and Battery Backup

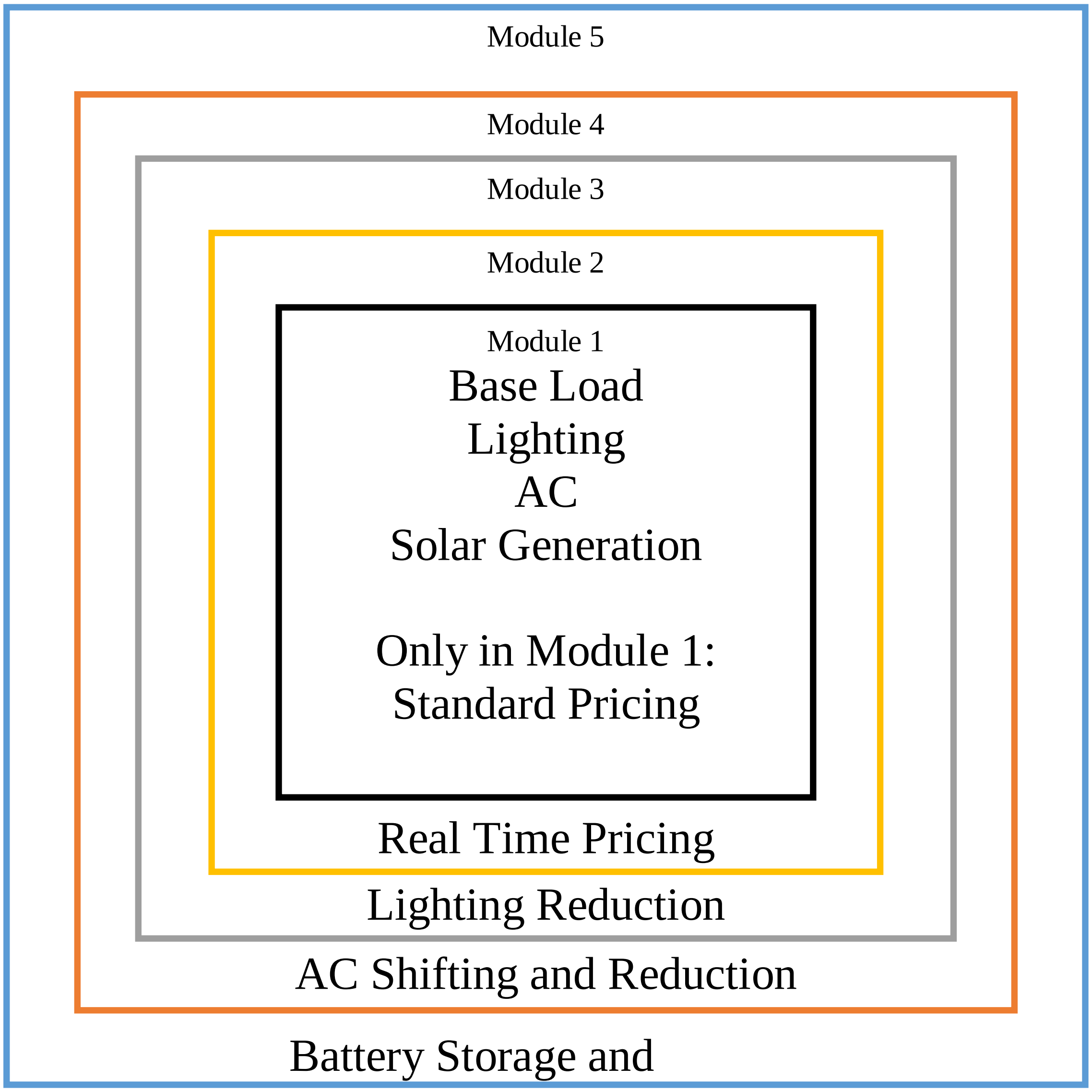

Figure D1: Project Module Hierarchy

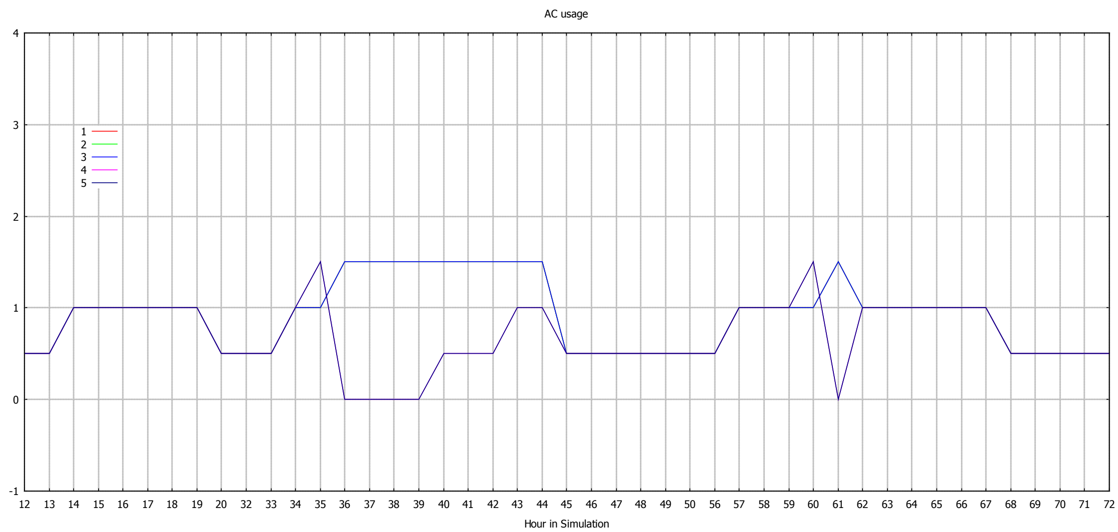

Figure D2: Graph of AC demand

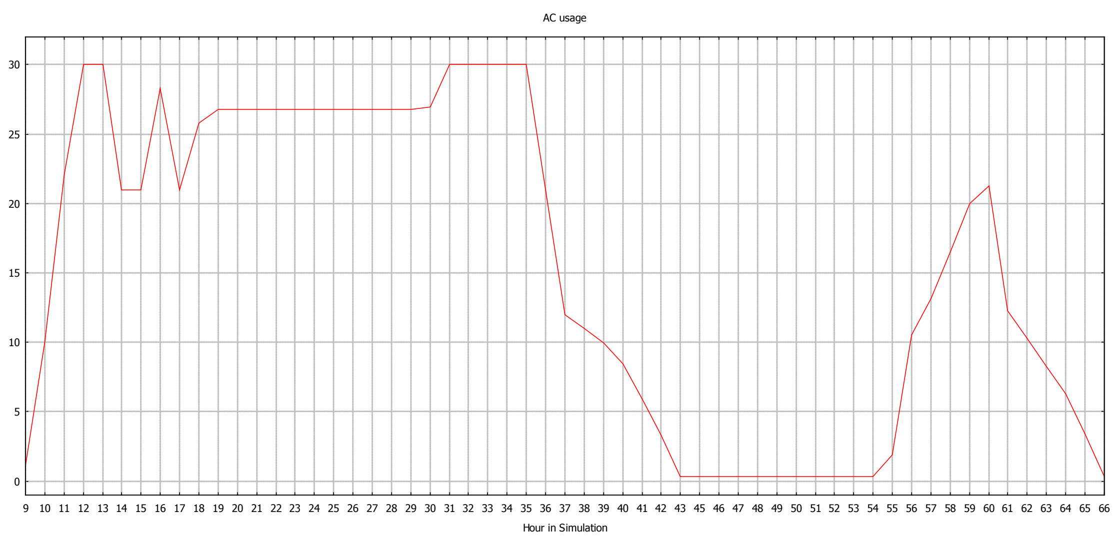

Figure D3: Graph of Battery Charge

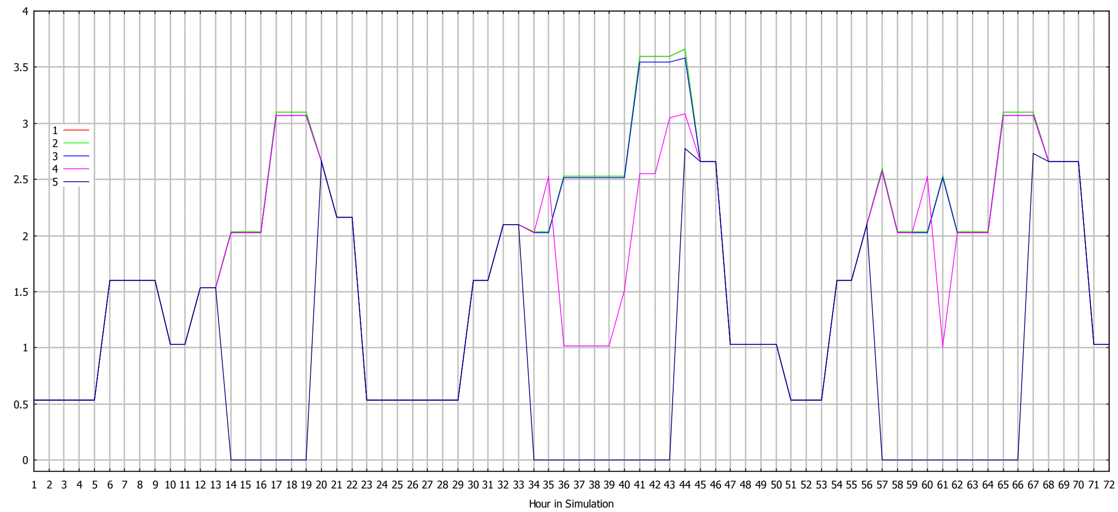

Figure D4: Resulting Demand

Figure D5: Resulting Net Usage

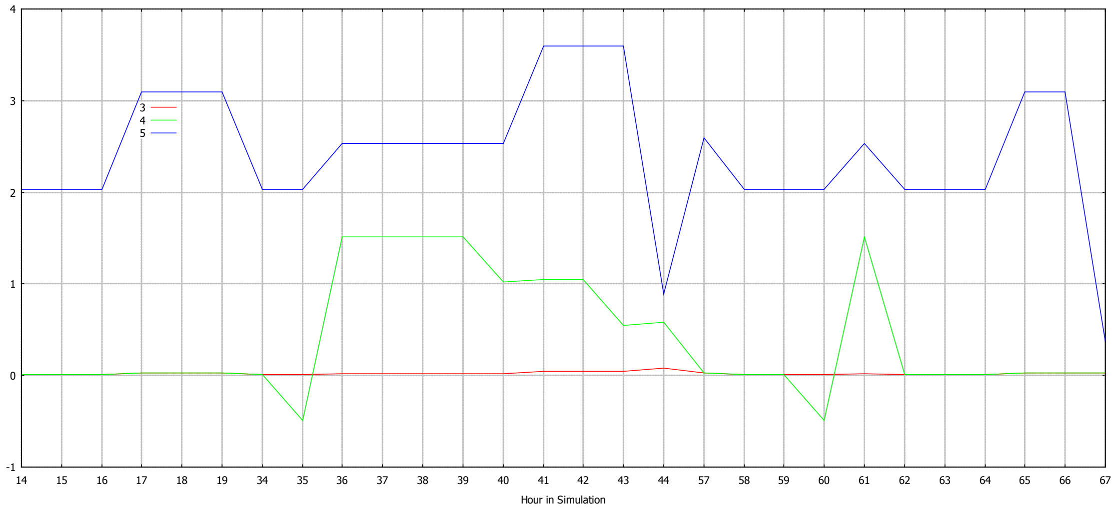

Figure D6: Resulting Demand Reduction

Table D1: Rates for Each Module

Section	Rate
1	-28.89
2	-43.57
3	-44.54
4	-49.09
5	-56.53