Home Energy Management (HEM) System

EML 4911C-Senior Design- Spring 2016

FINAL REPORT

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Executive Summary

The goal of the Home Energy Management System through the advantage of Real-Time Pricing (RTP) provided by electric utility companies, consumers have the ability to adjust their energy usage in order to reduce their electricity bill. This will be achieved by reducing the usage of electricity during the time of the day when the electricity has a higher than average price. This fluctuation in price is due to the demand of power that the grid experiences. Through a combination of lowering the power usage during these demand load peak times while increasing the usage during the lower ends of the demand load, the HEM System also aims to normalize the overall demand curve. This normalization of this curve result in making renewable energy source more viable due to the fact that renewable resources aren't always a stable source of power. For example, if the demand of power is matched with the time at which solar power is most applicable then solar power can be become more widely used.

How exactly does the Home Energy Management System save you money? The HEM System is designed to intelligently use various inputs acquired by the system, like the real-time price (RTP) of energy, the consumption of loads, and the user specific settings, to control the energy consumption around your home. The HEM System use an algorithm specially designed for optimizing and reducing the consumption of your loads depending on the value of the RTP obtained from the utility company. Here's a brief look at how the system does its job:

1. The web application obtains the current RTP from the utility company, and then this RTP is fetched into the main controller through a socket connection.
2. The main controller uses the RTP to calculate the current consumption of the entire system (Σ *n* loads consumption).
3. Using the algorithm, the system compares the consumption to the maximum cost the user allowed to be used.
4. The system will adjust the consumption of the home by turning on/off the loads that have lower/higher priority. In order words, the system will always try to stabilize the consumption of the home depending on the settings specified by the user on the web application.
5. By using this algorithm, the HEM system is automating the control of the desired loads and saving money by scheduling to run these loads when the RTP is low, thus paying less for same amount of consumed energy.

The HEM system also offers the absolute user control of the connected loads from the web application, thus providing the user with the power deciding when to turn on/off a load and also giving the user control over the home temperature by providing a temperature schedule.

Introduction

This section aims to compile the research done on the use of programs, such as RTP, provided by the utility companies, the different forms of communication that can be used between the HEM System components.

Project Statement

The energy industry is rapidly approaching a significant bottleneck in the supply of energy causing a possible energy crisis in the world in the next few years. The problem is not essentially how much power is generated, but how much power get wasted or misused primarily due to the lack of a proper energy management system that will allow the control and monitor, in real time, of the energy resources. The management of real-time pricing of the demand is postulating itself as a real alternative that could help stabilize the supply and demand curve of the energy industry.

Utility companies are strongly considering the implementation of Real Time Pricing (RTP) in order to regulate the load demand on their systems. The concept of RTP describes how price will change at a certain frequency based on the demand and generation of energy. Likewise, RTP will make the use of renewable energy sources and other type of technologies more suitable due to the fact that the production of energy could be segmented into optimal times, i.e. only generated when demand exceed supply. RTP will help smooth the load curve and take full advantage of these resources.

With the implementation of the Home Energy Management (HEM) System and the advantage of RTP provided by electric utility companies, consumers will have the ability to adjust their energy usage in order to reduce their electricity bill.

Background

According to Brattle Group, a leading consulting firm, during the power crisis in the Western U.S. in 2000/01, a demand response program would have helped contain the energy crisis in California. If real-time pricing had been offered to large commercial and industrial customers, peak demand would have fallen by 2.5 percent, resulting in a drop of 18 percent in wholesale market prices [1].

Luckily, there are a number of companies who already implement energy saving programs. Figure below displays how in Florida, Gulf Power reported average load reductions of 40% during critical peak periods for groups of customers that could control multiple loads such as, A/C, water heating and pool pumps. After the energy crisis in California, the state began to use a number of energy saving programs. One of the most affect programs implemented is called Statewide Pricing Pilot (SPP) and it sought to quantify the impact of “smart thermostats” with critical peak prices. This program resulted in a 27% reduction during peak periods and approximately two-thirds of which was attributed to use of the smart thermostat. Overall, the average peak period load reduction was about 14% in the commercial sectors who implemented the program. These results reveal the technical potential for demand response in certain market segments when time-varying pricing is combined with enabling technology, which is what the HEM System will combine.

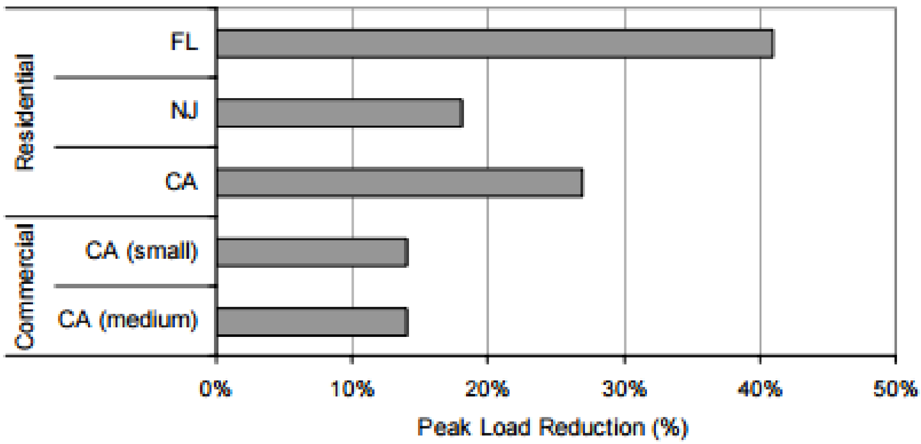


Figure 1: Load Response from Critical Peak Pricing and Demand Response Enabling Technologies [1]

To understand how the HEM System could be useful for the management of the energy resources of a home, a thorough study should be made in order to determine the regular patterns of energy use demonstrated by home users. In essence, it's important to know how much electricity an average household sustains so the system could be designed to optimize the use of these resources and to know exactly which the most common used loads in a home are.

According to the U.S Energy Information Administration, the amount of energy used in households directly depends on the climate and the type of energy devices used. The figure below shows the current average energy consumption of a household in the U.S. The graph is based in information gathered from 2009, and shows that energy mostly used for space heating (41%), followed by lighting, electronics appliances, and devices (35%), water heating (18%), and AC (6%).

As seen on the graph, most of the energy consumption comes from loads dedicated for space heating, lighting, and user appliances. The usage of these appliances could be optimized by the implementation of an energy management system, like the HEM System proposed.

Focusing on the state of Florida, the energy consumption data changes dramatically when compared to the U.S average since the most of the energy consumption is due to appliances (50%) and air conditioning (27%). As explained before, this change is mostly due to the fact of the difference in climate and the type of appliances used in Florida that differ to the ones used in other states across the U.S. More than a quarter (27%) of the energy consumed in Florida homes is for air conditioning, which is more than four times the national average. Half of energy consumed by Florida households is for appliances, electronics, and lighting.

The knowledge of the environment where the HEM System would be implemented is an important fact that could help in the development of an algorithm that react to the climate conditions of the zone and other unique factors.

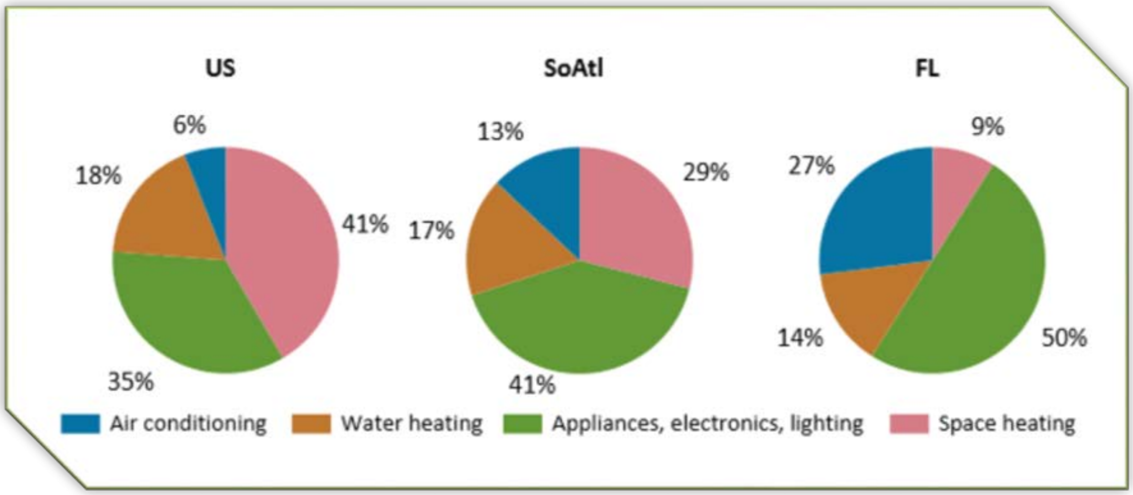


Figure 2: Average Energy Consumed (Residential) [1]

Now, projecting the consumption graph into the future of residential energy consumption, is safe to take into account a new load that could have significant impact in the energy demand and consumption of a home, the electric vehicle (EV). As seen on the figure below, the projected energy consumption of a residential consumer could increase significantly just by the acquisition of an EV. The EV is projected to take approximately 10 kW or 22% of the entire consumption of the household, making the utilization of energy management system almost necessary for the optimal control of the energy consumption.

Figure below displays the power needed assuming all appliances and are running at the same time. Loads are based on the U.S average and total house continuous rating is assumed to be 47.860 kW based on the calculated values. A more throughout comparison showing how the deployment of the HEM System could help to reduce the energy cost on a standard house is presented on the Results section.

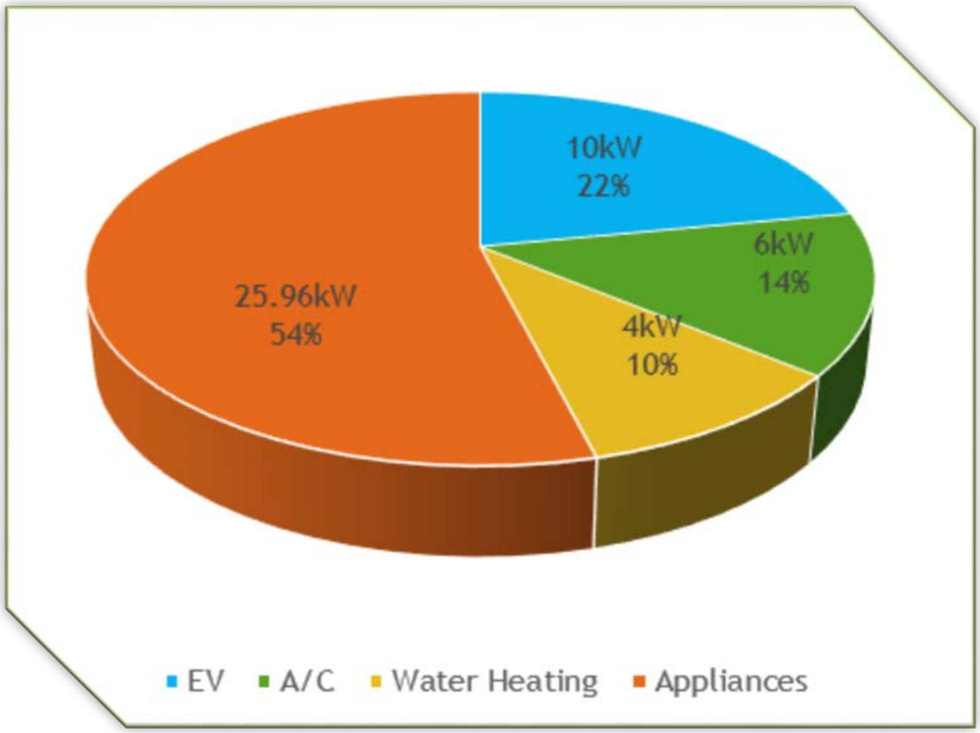


Figure 3: Projected residential loads per kW

A more detailed description of the loads present on a projected average household can be found on the table presented below. This table describes all the possible loads with their respective power rating.

Unit	Continuous Rating (W)
Electric Vehicle	10000
Central Air (40k BTU)-for a 1,500sqft home	6000
Electric Water Heater	4000
Refrigerator (1/4 HP)	500
Freezer (1/4 HP)	600
Dehumidifier	650
Computer System: CPU, Monitor, Laser Printer	1500
UPS System	2000
CD Player	100
Radio	100
Television	300
Microwave	800
Blender	300
Coffee Maker	1500
Electric Range (1 element)	1500
Toaster (2-slice)	1000
Dishwasher (Hot Dry)	1500
Electric Oven	3410
Washing Machine	1150
Electric Clothes Dryer	5400
Security System	500
Hair Dryer	1200
Garage Door Opener (1/3 HP)	750
Iron	1200

Table 1: Continuous Load Rating Per Average Household [2]

Furthermore, the application of an efficient energy management system, as the one described, could not only help with the reduction in energy consumption but could be a game changer in the stabilization of the energy demand curve. The figure shown below displays the average load demand curve on the state of Florida for summer and winter. As demonstrated by the curves, the peak hours, when utility has the highest energy demand, is between 5 and 7 AM and 6 to 9 PM respectively. This issue could be tackle with the use of the HEM System by reducing and rescheduling the consumption of high energy loads at those specific times, which happen to be the times when the RTP is at its highest.

The stabilization of the demand curve could also be achieved by the implementation of the energy management system combined with renewable energy sources, like solar power. The incorporation and management of renewable energy sources in homes is a trend that could help not only the utilities companies to regulate the energy consumption on the demand side, but also it could help the users to be self-sufficient.

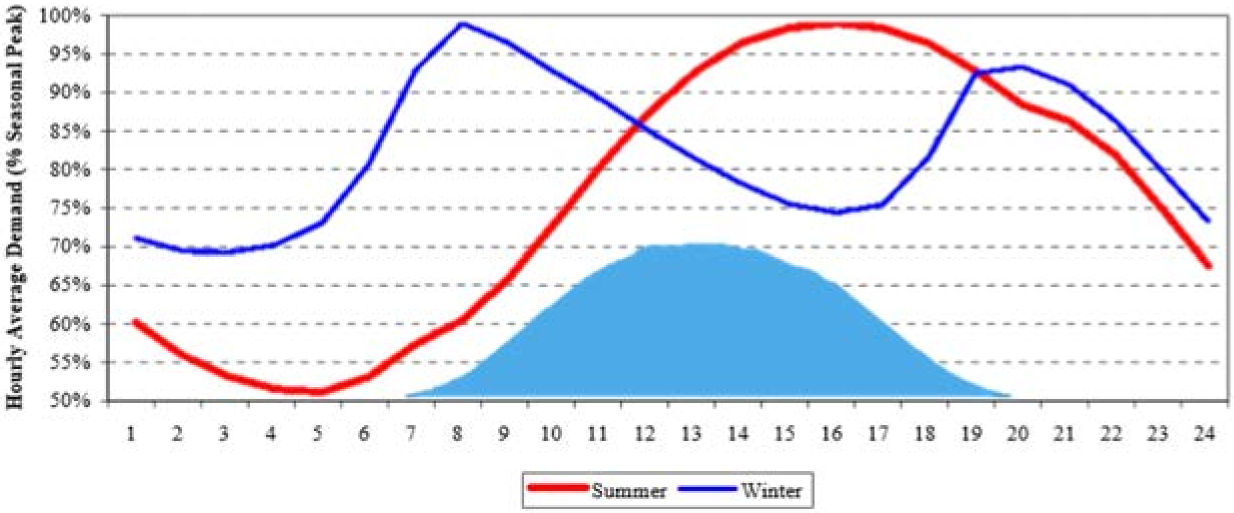


Figure 4: Demand Load Curve [3] [4]

Real Time Pricing

Real-time pricing (RTP) enables customers to pay for electricity at the wholesale price during a predetermined period of time, paying for energy at a rate that is linked to the hourly market price for electricity. This is often viewed as the purest form of price-based demand response, as the much smaller price-responsive interval periods lead to a closely linked cost/price ratio.

Results: The cost of generating electricity does not always match the price the end user pays for electricity, RTP allows customers to base their energy usage on the energy market price. Also as mentioned before, renewable energy can become a viable source that could help the normalization of the demand curve.

Figures below show an example of an RTP pilot project being used on Ameren, Illinois. The graphs show the change on the RTP throughout an entire week. As seen on the graph, the price of energy is hardly never constant and fluctuates throughout the day, making possible the implementation of an energy management system that could use this information to give a more reliable measure of the energy consumed in the demand side. Refer to the HEM System Simulation section for a more detailed demonstration on how the HEM System uses RTP to decrease the amount of money spent by the user in one month.

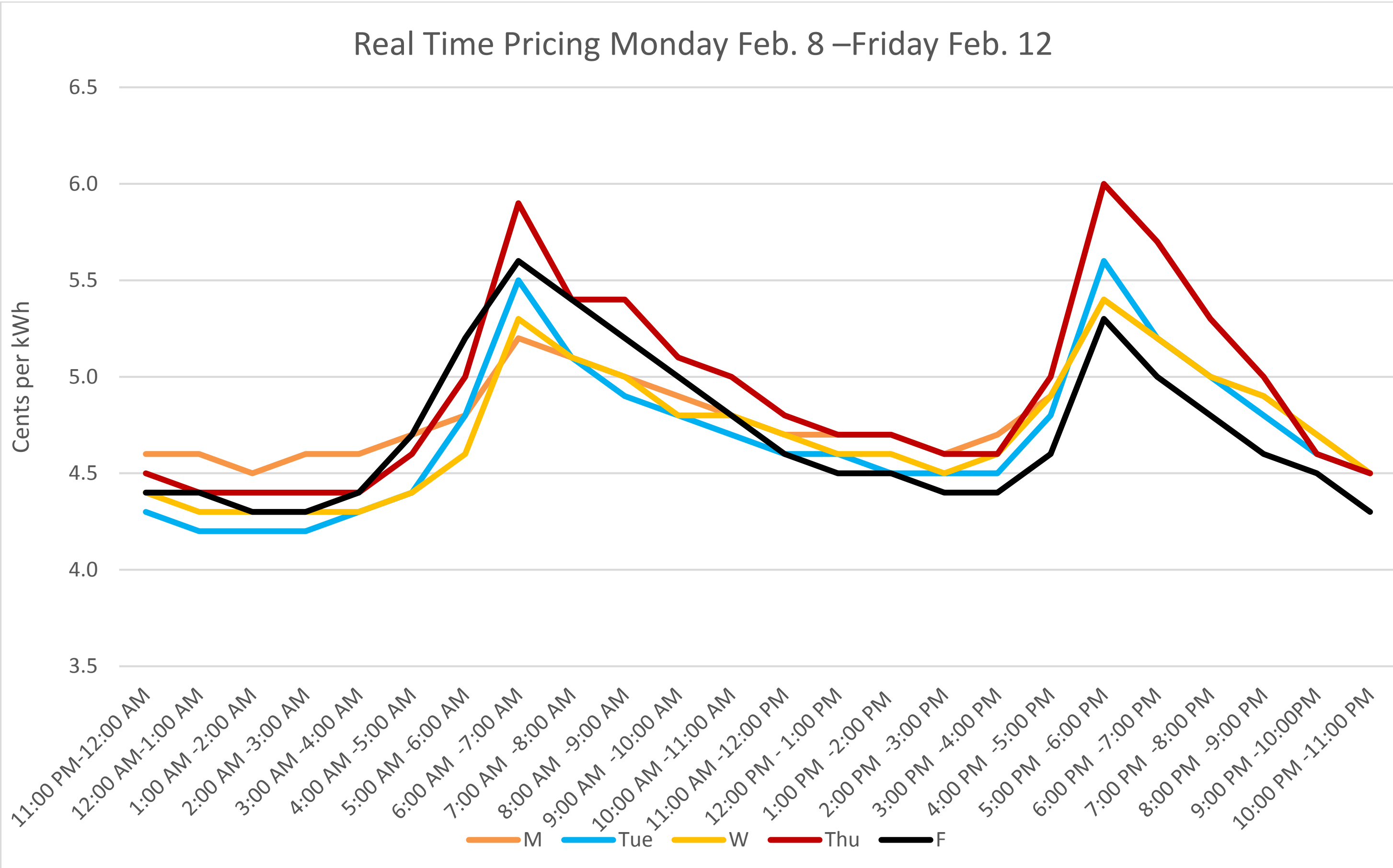


Figure 5: Weekday Collected RTP Data [5]

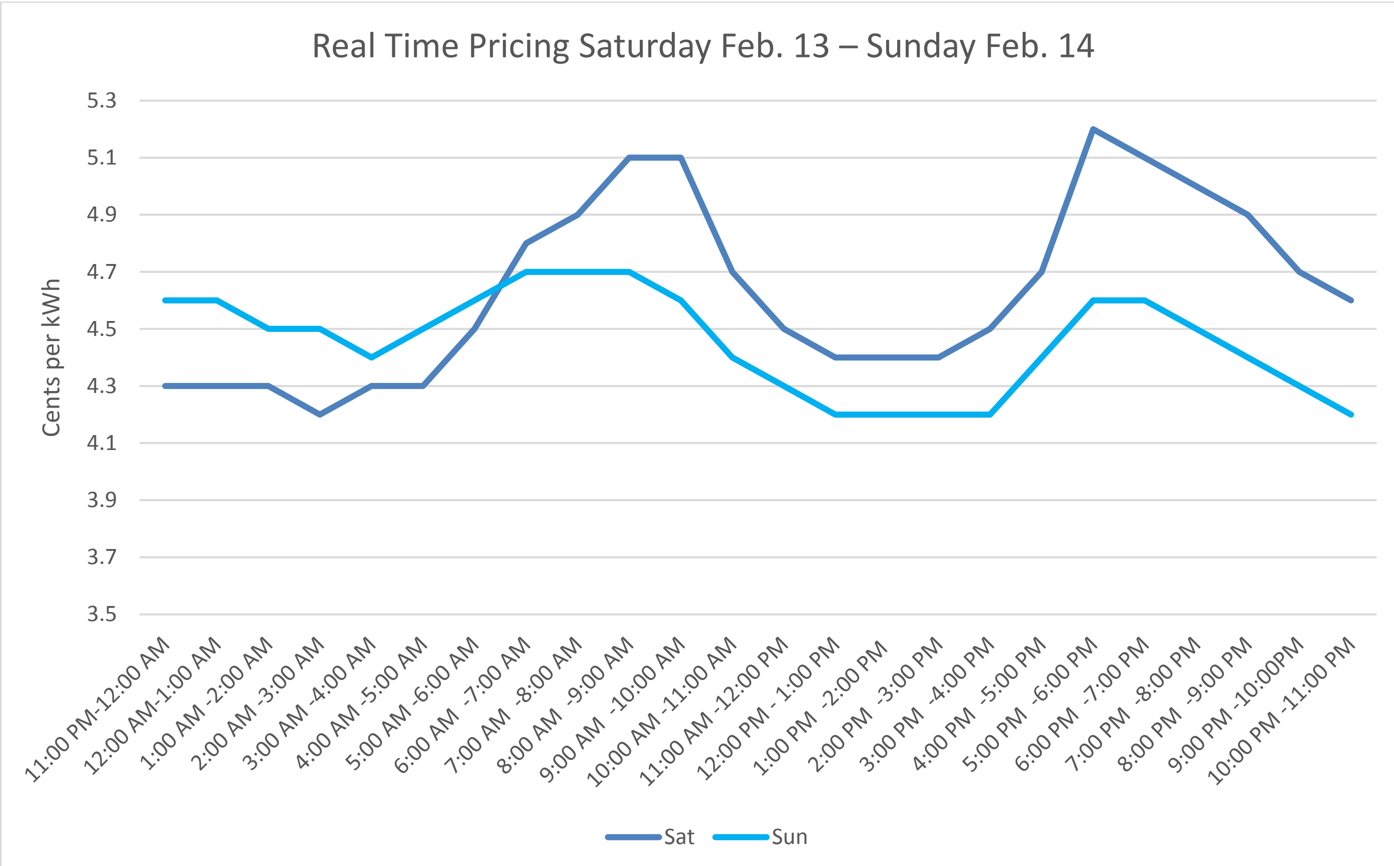


Figure 6: Weekend RTP Collected Data [5]

Average monthly utility: $87 for Illinois, $123 for FL.

State-of-the-Art Technologies

With the rise of new technologies such as smart grids, smart meters, and smart appliances, smart homes are being proposed as the next solution for utility companies and home owners alike. With smart meters, utility companies are able to monitor residential and commercial loads in real-time and effectively charge consumers accordingly. Smart homes will be the next integration between the utility companies and the consumer, where the utility company will benefit in lowering its electrical peak production (thus making generation more efficient and viable) and consumers will benefit by lowering their electric bill.

Currently, there are many proposed (as well as currently used) ideas, which are mostly aimed for the supply side or the utility company. The design in contrast is completely consumer based. One of these new technologies used by utility companies is the Demand-response (DR) program, which allows different payment methods for the consumer. DR programs fall into two categories: Dynamic Pricing (DP) and Direct Load Control (DLC).

Dynamic Pricing	Direct Load Control
DP consists of real-time pricing (RTP), where the utility company bases (e.g. Every 15 min) the electrical rates according on the real-time load demand. With the use of DP, the utility aims to shift the peak and off peak prices to smoothen out the load curve.	With DLC, utilities will have full control of the consumer loads. With this program, utility companies never risk in having an electrical outage (brownout or blackout) and can level out the load curve when unexpected spikes occur.

Power Line Communication (PLC)

PLC is a method based on a communication protocol that uses electrical wiring (AC or DC) to carry both electrical power and data. PLC send out high (greater than 60 Hz) frequency signals over power lines, which then get filtered out at the end point of the load connection. PLC is used in electrical transmission, distribution, home networking, and the automotive industry. For home networking applications it uses a communication protocol called Broadband over Power Line (BPL), which allows high-speed internet access through existing power lines. Since extensive infrastructure is already present, it offers a great benefit to using BPL over RF (Radio Frequency). There are many pros as to using PLC's over RF communication, yet the cons outweigh the pros. The pros for using PLC are as follows: the data speeds are extremely fast (ranging from 90Mbps to 200Mbps), since it uses power lines, it will have no trouble in communicating in various locations from the home where RF can fail. And lastly like already mentioned, the infrastructure is already present.

Although the pros may seem favorable, RF communication surpasses PLC due to the following cons: the hardware for PLC is more expensive, it does not function with filtering devices (surge protectors, power strips, and AFCI's), it is dependent on the electrical wiring in the house itself (if the house is improperly wired the breakers will trip and the system will fail), and lastly, transient noise (ON/OFF switching) degrades the performance of PLC and can cause the system to fail.

Current technologies

Most consumer load control technologies do not incorporate the utility company, since DR technology has not been incorporated yet, meaning home automation are basic on and off switches. Since the electrical rate is fixed, home automation only works when the user has forgotten to turn off his/her appliances when they are not at home to save money.

In some states such as California [6], Arizona [7], and Oregon [8] utility companies have incorporated time-of-use programs (TOU), where the electrical rate change based on the time of the year (e.g. summer and winter, when loads are higher) or based on weekdays and weekends. With these programs, the consumer can start taking advantage of smart appliances.

Current companies

There are many companies currently working on the development of energy managements systems in either the demand or supply side. One of these major companies is Trilliant [2], who has helped implement (TOU) billing for Hydro One in Ontario, Canada. Trilliant has also helped implement solutions for other leading utilities companies such as Centrica's British Gas and Iberdrola USA's Central Maine Power. Currently, Trilliant is working in implementing DR for utility companies, by installing smart meters, and setting up a communication infrastructure.

Schneider Electric is another company that is currently developing home automations systems in order to control and stabilize the energy consumption on the demand side. One of its pilot projects is the homeLynk [9], which is designed to control and monitor the energy consumption in a household and give the user information about energy metering.

Future and proposed solutions

Since DR programs are new, new ideas arise to make the generation and distribution of electrical energy more efficient for the utility companies, as well as make it more economic for the consumer. Like stated before, these proposed systems are more beneficial for the utility side, yet the consumer also benefits from the use of these type of systems. Two (concept) systems will be briefly covered, to which the design can be compared too. One system was developed by Trilliant and the other proposed in Control Mechanisms for Residential Electricity Demand in SmartGrids (CMRED) [2].

Trilliant System

Trilliant will implement utility managed programs, where the consumer can choose different payment plans with the utility company. One programs consist of the DLC, where Remote Appliance Controllers (RAC's) control the state of the appliance (ON/OFF) based on RTP. The RAC's will manage loads such as water heaters, pool pumps, and air conditioners and can be programmed for DLC or DP. The RAC's will receive the RTP information from smart meters (which connect to the utility company using PLC) via home area network (HAN) and near-me area network (NAN). An interesting take on the distributed networks that Trilliant proposed, is the use of electric vehicles and plug-in hybrid vehicles. Since both vehicles have a large energy capacity, they can be used as a supply of energy when the RTP is high, and charged when RTP is low.

CMRED

In the system proposed by CMRED, it is assumed that all appliances in the consumer side (being residential or commercial) are smart appliances which use energy management controls (EMC's). Similar to Trilliant, CMRED will receive RTP data via the smart meter (through HAN) to control the EMC's every 15 min. The EMC's will have two features, one that programmed based (which uses DLC) and one stand-by (user) based.
CMRED also proposed an interesting take with this new technology, where it will use DLC to a 'collection of neighboring homes' to reduce the peak demands when it is critical.

Design and Analysis

Design Requirements

The energy management system proposed needs to be able to position itself as a real competitor that could enter the energy management industry and take on the responsibilities of handling the home energy resources in efficient and valuable way. In order to fulfill the requirements needed in the development of an efficient management system, the HEM team will focus on the design using product specifications presented below:

1. Development of a system that will allow the real-time control and automatic adjustments of energy usage based on predefined settings provided by the user.
2. Development of load controller that will be responsible of controlling and monitoring the energy consumption of each assigned load.
3. Development of a main controller that will act as a local manager for controlling the communication and load interaction.
4. RF/Wireless will be the primary technology used for the communication between the main controller and the load controllers.
5. An algorithm will be develop to control all the loads according to real-time pricing provided by the utility company. Algorithm will process the information and decide which loads can be turn off based on consumer input settings stored on the website.
6. A low cost product is necessary for the correct implementation of the design in order to maintain it as a viable option for the market. This resulted in the use of low-powered microcontrollers and devices that can fit the budget.
7. Development of a website/web application that will act as the user interface and data server containing all the information regarding the usage of the loads. Also, the web application must be the primary connection to the RTP information provided by the utility company.

A throughout analysis on the main characteristics of the HEM system was performed, in order to find out if this approach was a feasible solution. According to the needs and requirements explained above, it can be observed that some of the requirements were more important than others when completing the final design of the project. The needs were evaluated using the comparison matrix showed in table presented below. The concept for the design was focused on four main points which can be used to compare the viability of the whole concept.

- High Performance
- Low Cost
- Power Consumption
- High Reliability

	High Performance	Low Cost	Power Consumption	High Reliability	Geometric Mean	Norm. Weight
High Performance	1	5	5/3	1	1.70	0.36
Low Cost	1/5	1	1/3	1/5	0.34	0.07
Power Consumption	3/5	3	1	3/4	1.08	0.23
High Reliability	1	5	4/3	1	1.60	0.34

Table 2 Comparison Matrix

As seen on the comparison table, the top points taken into account when developing the concept proposed were high performance and high reliability. In other words, the design must be catalogued as a reliable and efficient system. The other two remaining points were also taken into account when designing the project specifications but were considered as less important when deciding for an overall design.

Following these criteria was essential for the production of the final design, in which most of the needs are achieved by:

- High performance: is mainly achieved by the use of high performance microprocessors and controllers.
- High reliability: is achieved by using consistent and reliable software deployed on high performance hardware.
- Power consumption: is achieved by using low power consumption controllers.
- Low cost: is achieved by using moderate price hardware which is highly reliable and low cost compare to other options.

It’s important to note that an advantage of the design over other concepts, like PLC (Power Line Communications) is that this concept is designed to be easily deployed by the client with simple configurations done through the web application.

Design Description

Using the design requirements, the actual design of the system was planned out. The HEM System can be described by analyzing each of its main components: HEM System automation algorithm, the Main controller, Load Controller, Web application, and the thermostat (Temperature controller). These main components are described below.

Web Application

The web application is the main way of interaction between the user and the system. It provides user interface for the energy management system.

Main tasks:

- Provides the user with the user interface (UI) used for the real-time control of the loads.
- Sends data, commands, and RTP information to the main controller.
- Stores user specific information and gives back feedback to the user about the energy consumption on their own system.
- Contains the real-time price provided by the utility company and sends the information to the main controller in order to execute the automation HME algorithm.
- Gateway between the utility company and the user of the system.

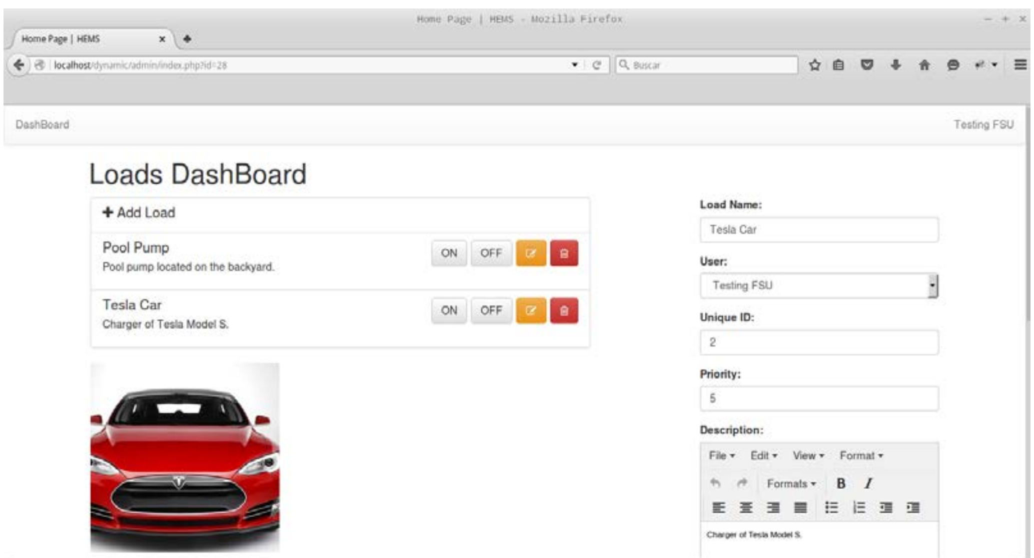


Figure 7: Web Application Interface

HEM System Algorithm

The HEM System's algorithm software solution in charge of automating the control of loads based on the RTP information given by the utility company. It provides the system with analysis it needs to adjust the load usage of wherever the system is implemented into. An overview of the algorithm can be seen below as well as its main tasks. A more detailed explanation of the HEM System's algorithm can be found in the Design Section of the report.

Main tasks:

- Automatic control of the loads based on the RTP information given by utility company.
- Performs discrimination of the loads depending on the priority status given by the user through the web application.
- Main software in charge of controlling the loads from the Main Controller.

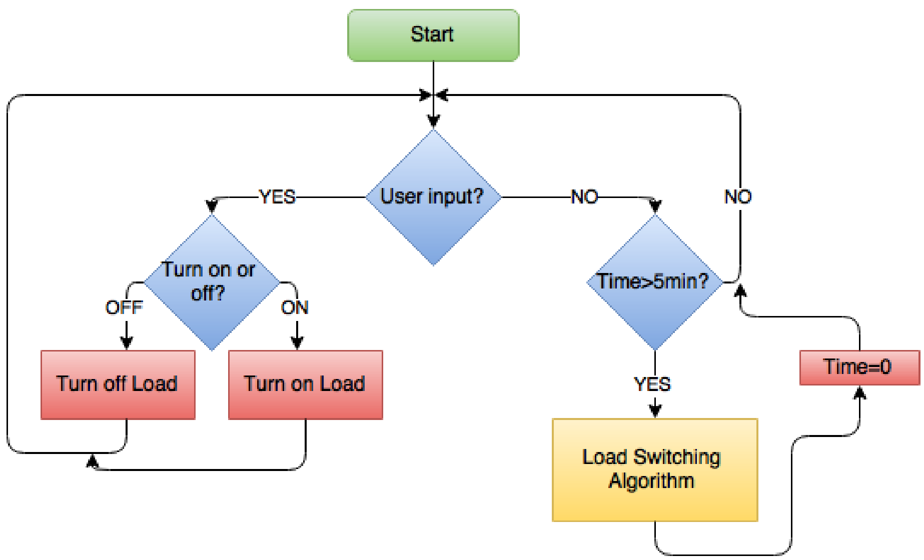


Figure 8: HEM System Algorithm Top Overview

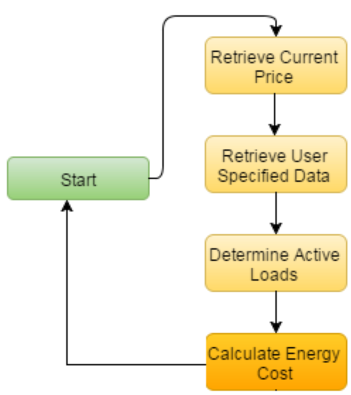


Figure 9: Load Switching Algorithm

Main Controller

As mentioned above, the algorithm describes how the system will react due to both RTP and user input. This software is contained in the Main Controller. The Main Controller is the main equipment installed in the user home/environment that give commands to the other legs of the system.

Main tasks:

- Executes the HEM algorithm developed that will allow the automation in the control of energy consumption.
- Controls all the Load Controllers within range.
- Serves as the gateway between the web application and the Load Controllers. The real-time user interaction commands are decoded here and passed to the Load Controllers.
- Receives data, like the RTP or user commands, from web application.

The main components used for the development of the main controller, with all their specifications are described below.

Main Controller Components:

1. **BeagleBone Black**

BeagleBone Black is an embedded computer designed by Texas Instruments. The BeagleBone was chosen for this project because it met the processing requirements. The BeagleBone's 512 MB of ram and quick 1 GHz ARM Cortex-A8 both have more than enough processing and memory requirements for handling threads and computing the algorithm. Connectivity was important for the system to communicate with the load controllers and the web application, so pins and an Ethernet port were essential.

Characteristics	Specification
Processor	AM335x 1GHz ARM® Cortex-A8
RAM	512MB DDR3 RAM
Storage	4GB 8-bit eMMC on-board flash
Connectivity	Specification
	Ethernet
	SPI (Serial Peripheral Interface)
	HDMI
	GPIO

Table 3: Beagle Bone Black Specifications

Figure 10: Beagle Bone Black

2. NRF24L01+

NRF24L01+ is a transceiver used for creating the communication scheme between the main controller and the load controllers. Developed by Nordic Semiconductor.

When choosing what transceiver to use the more popular XBEE (ZigBee) was compared to the NRF but the data rated baud for data transfer is higher on the NRF24L01+, meaning that more data can be transferred to the Load Controller per second, which can be seen in the table below.

Comparison Table (Antenna versions)		
Attributes	**NRF24L01+**	**XBEE (Zigbee)**
Frequency Band	2.4 GHz ISM	2.4 GHz ISM
Protocol	Proprietary	IEEE 802.15.04
Range	1100[meters]	1000 [meters]
Data Rate Max.	2 Mbps	250 Kbps
Price	$12.00	$42.00

Table 4: NRF24L01+ vs XBEE

The table above displays a comparison between both modules. As seen the two main differences between them are the data rates values and the price difference. As observed, data rate is higher on the NRF24L01+ giving it an edge over the XBEE protocol if more information is needed to be transferred between devices. Similarly, the price difference between both modules could be an important factor for big projects and business scalability. These are some of the main reasons why the NRF24L01+ was used instead of the more popular XBEE (Zigbee) transceiver.

Components	NRF24L01+ (Dollars)	XBEE (Dollars)
Box	5	5
Relays	6	6
Cables	4	4
PCB Circuits	7	7
MCU	13	13
Transceiver	12	42
TOTAL	47	77
x1000 Boxes	47000	77000
Price Difference	30000	

Table 5: Costs per Box on Large Scale

The table above show how much the price difference between these two modules could affect the overall production cost for a business model. As shown, the price difference could be a decisive factor for the feasibility of the final business design.

Another important thing to note is some of the limiting factors that the final design will have, which essentially refer to the amperage of the loads that the design will be controlling. Since the relay in each individual load controller can only handle up to 10A, this design is not suited to anything greater than that, for example a washing machine, oven, and central air unit. Yet, this design is only a prototype, and designed to show how by using this system the user will end up saving money on their electric bill.

Additional information on the NRF24L01+ can be seen in the table below.

Characteristics	Specification
RF Technology	2.4 GHz ISM Band Operation
Modulation	1 or 2 MHz Bandwidth
Information	Dynamic Payload 1 to 32 bytes

Table 6: nRF240L01+ Specifications

Figure 11: nRF240L01+

3. **<u>5V DC Power Supply</u>**

Standard 5V DC power supply in charge of powering the Beagle Bone Black.

Load Controller

Equipment that must be connected to the loads that the user wants to control.

Main tasks:

- Receives commands from the main controller in order to perform manipulation of loads.
- Sends back data to the main controller regarding the usage of the specific load.
- Controls the flow of electricity, ON/OFF action, by controlling relays that manage the flow of electricity.
- Load controller will be separated in to two or more types: regular load controller, which can be installed to any load that wants to be controlled, and a special thermostat load controller which will have additional functions regarding temperature measurements.

The main components used for the development of the load controller, with all their specifications are described below.

Load Controller Components

1. **NRF24L01+**

Transceiver used for creating the communication scheme between the Main Controller and the Load Controllers. Developed by Nordic Semiconductor.

2. **5V Relay Module**

Relay module that controls the flow of electricity, facilitating the ON/OFF action control on the system. Module reference SRD-05VDC-SL-C.

Characteristics	Specification
Max Current	10 [A]
Max DC Voltage	30 [V]
Max AC Voltage	250 [V]

Table 7: 5V Relay Specifications

Figure 12: 5V Relay

3. MSP432P401R

Microcontroller used for the control of the 5V relay module, control of the communication protocol with the Main Controller using the NRF24L01+ transceiver, and data acquisition from temperature sensor and current sensor used to monitor the specific load behavior. The MSP432P401R was desired for many reasons. The first is its number of pins. These were needed to connect to relay, temperature sensor, the LCD, and the NRF. Its relatively low processing power is enough for a load controller because there is not much processing done on the controller, unlike the BeagleBone that is running an OS and HEM software. It also draws very low power so as to not interfere with the load calculations.

Characteristics	Specification
MCU	48 MHz 32-bit ARM Cortex
Power	95 [uA]/MHz Active Operation 850 [nA] Standby Operation
Flash	256 KB
RAM	64 KB

Table 8: MSP432P401R Specifications

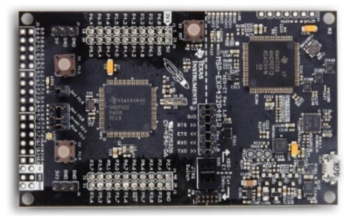


Figure 13: MSP432P401R

MSP432 vs Arduino Mega

The two microcontrollers considered for the load controller and thermostat were the MSP432 LaunchPad which is a 32-bit microcontroller (MCU) and the Arduino Mega an 8-bit MCU. Ultimately the MSP432 was chosen due to its low cost and superior features. The MSP432 leaves plenty of room to improve upon the load controllers without the need for a more powerful processor. The table below highlights the features of the two MCUs.

	Flash (kB)	Max Clock (MHz)	SRAM (kB)	EEPROM (kB)	Digital I/O	RTCC	16 Bit Timers	8 Bit Timers	32 Bit Timers	Floating Point Unit	Serial Ports (SPI)	Cost
MSP432	256	48	64	0	67	Yes	4	0	2	Yes	8	$13
Mega	256	16	8	4	54	No	4	2	0	No	4	$46

Table 9: MCU Comparison

4. Temperature Sensor

LM74 Delta-Sigma analog-to-digital converter. Sensor used for the calibration of the thermostat load controller.

Characteristics	Specification
Supply Voltage	2.65 [V] to 5.5 [V]
Supply Current	Operating: 265[uA]
Temperature Accuracy	−10°C to 65°C ± 1.25°C (max) −55°C to 125°C ±3°C(max)

Figure 14:LM74 Temperature Sensor Specifications

Figure 15: LM74 Temperature Sensor

The following design was used with the HEM system:

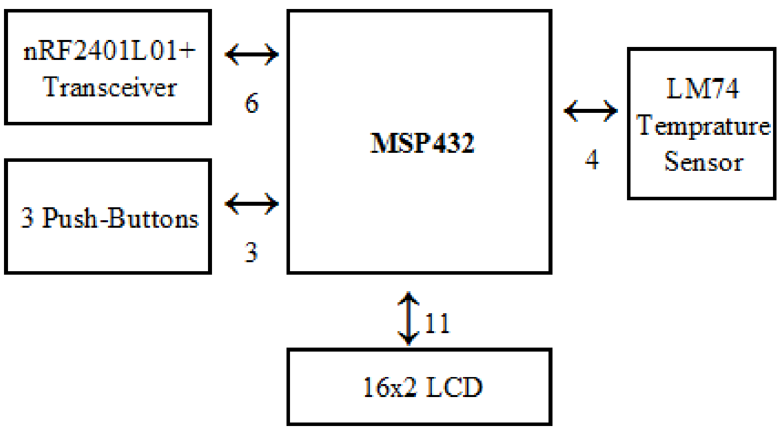


Figure 16: Thermostat Interface

- SPI
- 0.0625°C Temperature Resolution
- −55°C to +150°C (-66°F to 302°F)
- Accuracy: −10°C to 65°C, ±1.25°C (max)

5. Current Sensor

5600 Series Current sensor. 10 [A] max current. Sensor used for determining if a load is being actively used or not. The following circuit was design in order to detect the current of the load that is connected to the Load Controller.

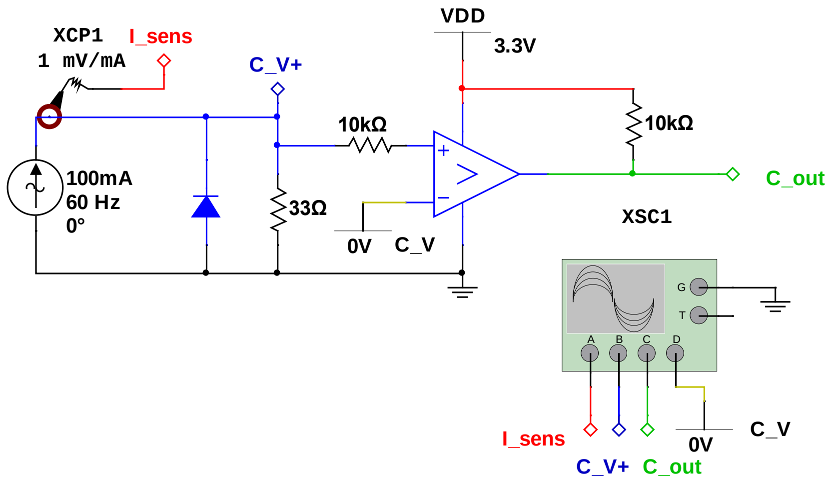


Figure 17: Circuit for Detecting Active Loads

6. 5V DC Power Supply

Standard 5V DC power supply in charge of powering the microcontroller.

Once each part of the system was designed and its corresponding components were chosen, a top-view schematic of the system can be made. A detailed breakdown description of how these components interact with each other in the energy management system proposed is given later on the breakdown section of the report.

Breakdown Description of the HEM System

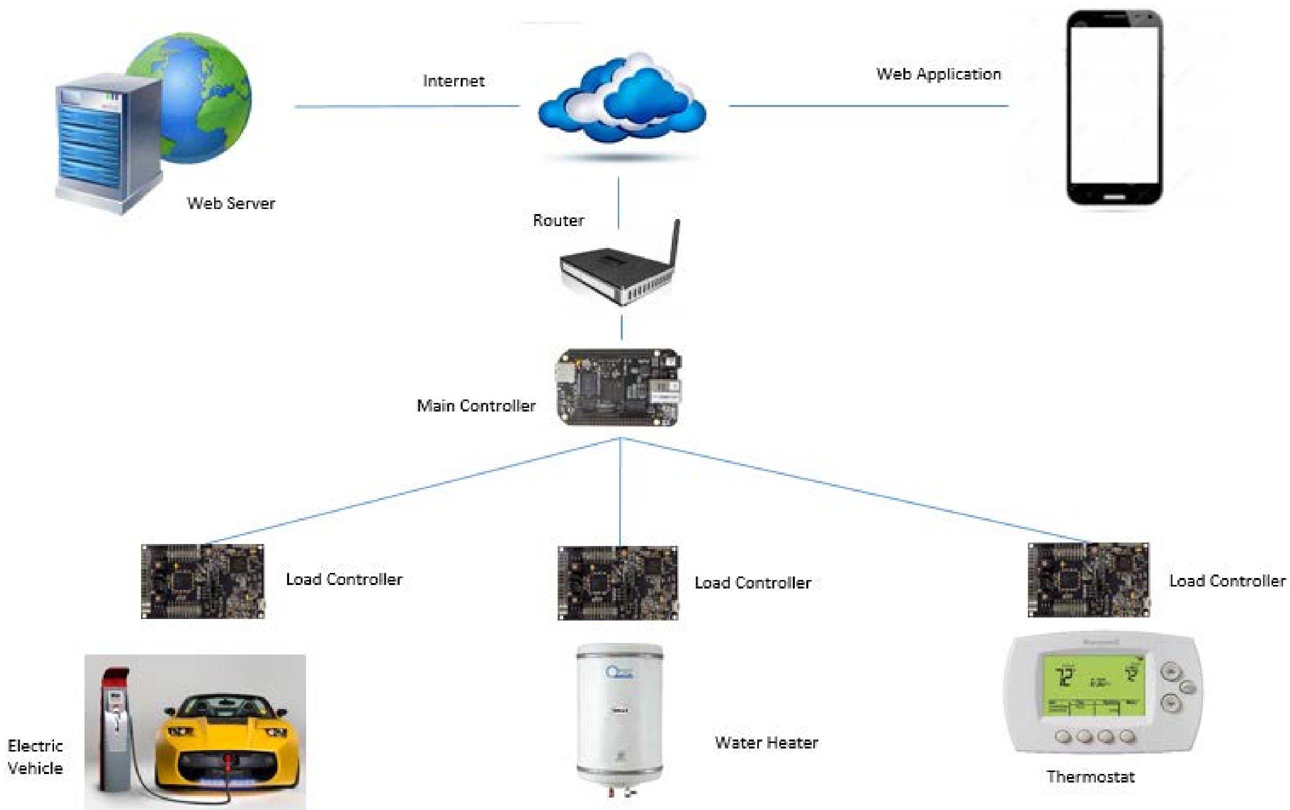


Figure 18: Displays the Top-Level Design of the Project

The figure above shows a depiction of the schematic representing the complete HEM system and the interconnection between all its components. As seen, the flow of information starts at the top of the schematic, essentially in the web application, which contains all the user information, pricing information and other variables that affect the algorithm executed on the main controller.

When the information arrives at the Main Controller, it executes the HEM algorithm which is in charge of deciding the commands that will be sent to the Load Controllers according to the user defined specifications.

Finally, the Load Controller will receive the command given and perform the specified action required by the user or the real-time price algorithm. The Load Controller will be able to send important information back to the main controller stating the current status of the specific load.

Figure 19: Displays model home with the install system

This figure depicts a possible real life implementation of the HEM system proposed. Possible potential home loads are shown on the image, including an electric car in the garage, a pool pump located next to pool, a refrigerator in the kitchen, the thermostat load controller in the living room, and televisions in each bedroom. The layout of the system is also presented by showing how the Main Controller will need to be strategically located at the center of the home in order to have the best signal reception across the house.

HEM Algorithm Evolution

Version 1.0

In order for the HEM System to save user money, it will rely on an algorithm. The algorithm will utilized the data the user enters in the website for all calculations and decisions. Since this is just the beginning of the project, the user will have to enter the load usage data on the website. Ideally in the future the system will include metering at each Load Controller. As the project progressed, so did the system's algorithm.

Information needed by the HEM algorithm. This information will be input by user using the website:

1. **Load Controller ID:** used by main controller to identify which load is connected to each load controller.
2. **Load Power Consumption:** this should be an estimate of the total power consumed by the load on average (usually provided by manufacturer)
3. **Priority for Each Load:** based on a 1-10 scale. Priority 1 are first loads to be turned off, and priority 10 loads are only turned off when price is at a maximum.
4. **Maximum Desired Electric Bill:** the maximum amount of money the user wants to spend per month. User should determine the price based on past bills. Due to usage changing throughout the season this price should be updated every other month. Future product may take care of this based on current month and weather forecast.
5. **Thermostat Schedule:** AC schedule and maximum deviation from scheduled temperature (ex. ± 5ºF).

The original algorithm, v1.0, starts by retrieving the required data from the website. This data includes the current real time price, the load data entered by the user, and the priorities for loads. Next the algorithm will communicate with the load controllers to determine all of the loads currently in use. Utilizing the real time price and the load data, the algorithm will then calculate the approximate cost of energy being utilized.

Once the price of energy currently being used is calculated, the algorithm will compare it to the price specified by the user. Equations 1 through 3 show how the current usage cost is calculated and compared to the monthly price specified by the user. As of now, the calculations are done based on a 5 minute interval, but this will eventually be increased or decreased in future versions of the algorithm.

$$\frac{monthly\ price}{31\ days} * \frac{1\ day}{24\ hours} = \frac{monthly\ price}{744\ hours}$$

Equation 1: Maximum Hourly Price

$$\frac{monthly\ price}{744\ hours} * \frac{1\ hour}{60\ minutes} * 5\ minutes = \frac{monthly\ price}{8928}$$

Equation 2: Maximum 5 Minute Price

$$sum\ of\ load\ usage\ [kW] * 5\ minutes * RTP\ \left[\frac{\$}{kWh}\right] * \frac{1\ hour}{60\ minutes}$$

Equation 3: Current Usage Price

Once the current price is compared to the maximum price the algorithm will start deciding what loads need to be turned off. The bullet points listed below show what conditions effect what loads.

- Current usage price is greater than 45% of the maximum specified price or current RTP is 25% of yesterday's maximum price
  - Loads with priorities 1 – 4 will be turned off.
  - AC will be adjusted 1º - 2º F
- Current usage price is greater than 75% of the maximum specified price or current RTP is 50% of yesterday's maximum price
  - Loads with priorities 1 – 7 will be turned off.
  - AC will be adjusted to half-maximum deviation
- Current usage price is greater than 95% of the maximum specified price or current RTP is 75% of yesterday's maximum price
  - Loads with priorities 1 – 10 will be turned off.
  - AC will be adjusted to maximum deviation

Version 2.0

Algorithm v1.0 showed a very simple implementation of an algorithm that should be implemented in the HEM System. Unfortunately, Algorithm v1.0 had its own problems and was not as efficient of an algorithm as it should be.

The priority system used in the precious version was not effective, as the algorithm simply grouped all ten priorities into three different priority categories. This minimized resolution when configuring the total consumption, because the system could end up turning off many loads grouped between the specified priorities ignoring the actual need of the system.

Algorithm v2.0 takes care of the problems presented above by changing the mechanics of shutting down loads. In version 2.0, a single threshold value is used to determine if loads need to be turned off or on instead of turning all loads in a group off. A more detailed explanation is presented below:

- Individual loads are turned off in series according to their priority value
  - Lowest priorities will turn off first.
  - No higher priority can turn off until the lower priorities are turned off.
  - After any load is turned off, a recalculation of the consumption is made.
- Two threshold values of 95%, and 20%, are used when turning off and on loads, respectively.

The figure below displays how the energy consumption of all the system is being calculated at a specific time. The information of the consumption is needed for the comparison with the maximum user price given by the user.

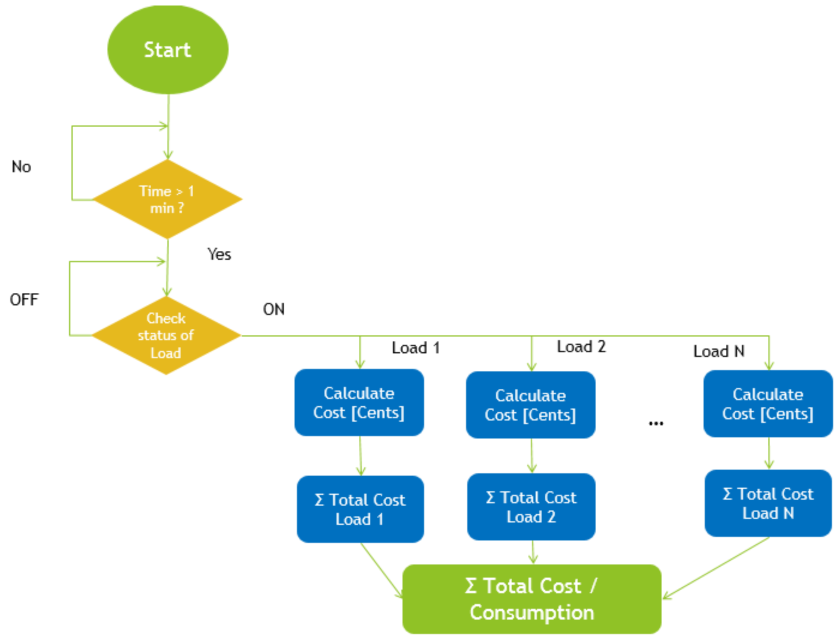


Figure 20: Energy Cost Calculation

After the current consumption of the system is calculated, the value is compared with the maximum user defined price given by the user. The turn off and turn on conditions are presented on the figure below. Also, as seen on the graph, the consumption calculation is performed every time a load is turned on/off in order to compare it to the threshold specified. In other words, the consumption will always be between the 95% and the 20% rate of the maximum user defined price.

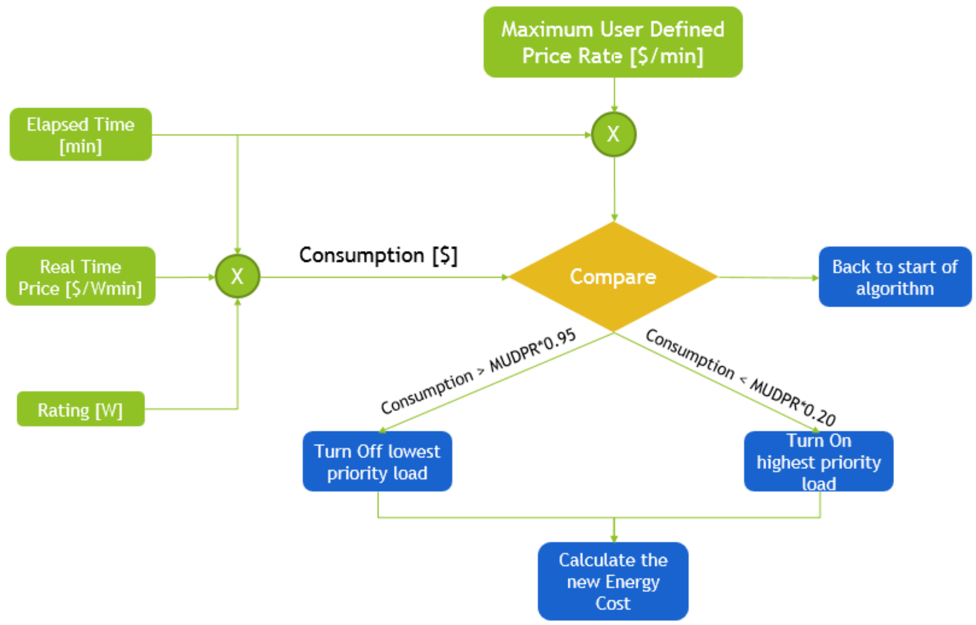
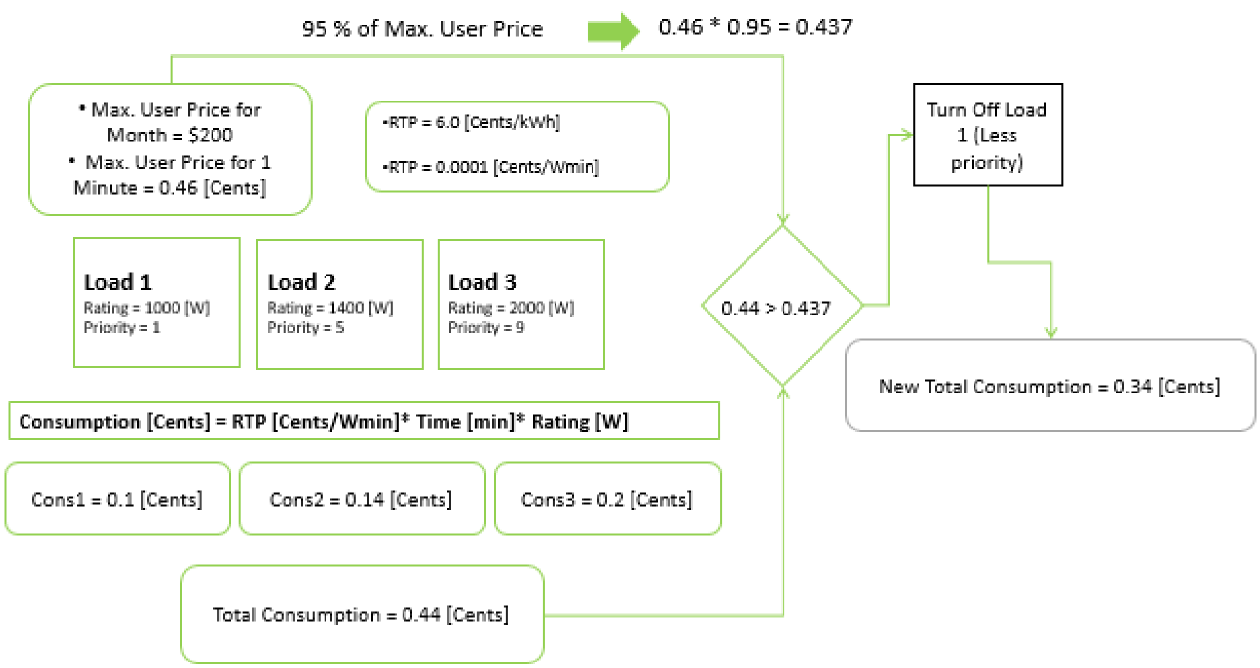


Figure 21: Algorithm 2.0's Load switching algorithm

The figure below presents an example of a step by step execution of the algorithm v2.0.



Version 3.0

HEM Algorithm version 2.0 fixed the issues found with the original algorithm but its own disadvatages were discovered as additional testing was completed. Algorithm version 2.0's main consumption calculation was based off the monthly max price that was defined by the user. As stated above in the Version 1.0 section, this month max price was divided out and the max price in cents per minute was calculated. This base value remained constant throughout the day no matter how high or low the actaul RTP was.

This constant cent per minute was found to be inefficient because of the large variations in RTP due to the increase and decrease of power demand seen throughout the day. As a result, the percentage change between the actual RTP was used in order to determine how to vary the orginally constant cent per minute price. Five weekdays worth of RTP was used to find a per hour average RTP. The average RTP per hour throughout five weekdays can be seen below.

	Dates					
	4-Jan	**5-Jan**	**6-Jan**	**7-Jan**	**8-Jan**	**9-Jan**
Time	**Monday (Dollar)**	**Tuesday (Dollar)**	**Wednesday (Dollar)**	**Thursday (Dollar)**	**Friday (Dollar)**	**Average (Dollar)**
12:00 AM	$1.70	$1.60	$2.70	$2.30	$1.60	$1.98
1:00 AM	$1.70	$1.60	$2.40	$2.20	$1.80	$1.94
2:00 AM	$1.60	$1.60	$2.10	$1.10	$1.80	$1.64
3:00 AM	$1.50	$1.60	$2.30	$2.30	$1.90	$1.92
4:00 AM	$1.40	$1.70	$2.30	$2.20	$1.80	$1.88
5:00 AM	$1.80	$1.80	$2.00	$2.30	$2.00	$1.98
6:00 AM	$2.20	$2.20	$3.00	$2.00	$1.60	$2.20
7:00 AM	$2.20	$2.20	$3.30	$2.80	$2.40	$2.58
8:00 AM	$2.30	$2.30	$6.30	$2.60	$2.50	$3.20
9:00 AM	$2.70	$2.20	$2.60	$2.70	$2.70	$2.58
10:00 AM	$2.60	$2.20	$3.20	$2.60	$2.70	$2.66
11:00 AM	$2.50	$2.20	$3.70	$2.40	$2.60	$2.68
12:00 PM	$2.60	$2.00	$4.30	$2.50	$2.50	$2.78
1:00 PM	$2.50	$2.10	$4.50	$2.20	$2.50	$2.76
2:00 PM	$2.60	$2.10	$5.10	$2.20	$2.40	$2.88
3:00 PM	$2.50	$1.80	$3.70	$2.30	$2.50	$2.56
4:00 PM	$2.80	$2.10	$5.30	$2.20	$2.40	$2.96
5:00 PM	$3.70	$2.40	$5.40	$3.00	$2.50	$3.40
6:00 PM	$3.60	$2.40	$5.50	$2.60	$2.50	$3.32
7:00 PM	$3.30	$2.30	$4.30	$2.60	$2.40	$2.98
8:00 PM	$3.70	$2.30	$4.40	$2.50	$2.30	$3.04
9:00 PM	$3.80	$2.10	$3.90	$2.40	$2.00	$2.84
10:00 PM	$3.10	$1.70	$2.30	$2.10	$1.80	$2.20
11:00 PM	$2.60	$1.60	$2.10	$1.70	$1.60	$1.92

Table 10: Hourly Average RTP Data

The average RTP calculations can be seen below.

$$RTP_n = The\ RTP\ at\ the\ same\ hour\ with\ integer\ n\ representing\ the\ day$$
$$RTP_H = Highest\ averaged\ RTP$$
$$RTP_L = Lowest\ averaged\ RTP$$

$$\sum_{n=0}^{5} RTP_{n+1} = RTP_{total} \rightarrow RTP_{ave} = \frac{RTP_{total}}{n}$$

Equation 4: Hourly Average RTP Calculation

With the RTP_{ave}, the highest and lowest values prices were used to see how far each hourly average RTP deviates from the lowest and highest values. The highest value was used as 100% while the lowest is 0%. The calculations can be seen below.

$$Percent_{div} = The\ percent\ each\ RTP_{ave}\ deviates\ from\ the\ RTP_H\ and\ RTP_L$$

$$\frac{RTP_{ave} - RTP_L}{RTP_H} * 100 = Percent_{Div}$$

Equation 5: Percent each average RTP varies from Max RTP

This value is then halved since if it wasn't it would alter the original base price too much and be counter effective The halved value is then subtracted from 100 to use is used as a multiplier to find how the original cent per minute should vary with respect to the hour of the day. The calculation used to find the varying max price can be seen below and an original base price of 0.23 cents was used.

$$Base\ Price = 0.23\ cents$$
$$Varying\ Max\ Price = The\ new\ price\ used\ in\ the\ consumption\ calculation$$
$$Percent_{Multi} = The\ percent\ used\ to\ adjust\ the\ Base\ Price$$

$$Percent_{Multi} = 100 - Percent_{Div}$$

Equation 6: Percent Multiplier Calculation

$$Varying\ Max\ Price = \frac{Percent_{milti}}{2} * Base\ Price$$

Equation 7: Varying Base Price Calculation

Time [Hour]	Average (Dollar)	Percentages Change [Percent]	Halved Percentages Change [Percent]	Percent Multiplier [Percent]	Varying Base Price [cents]
12:00 AM	$1.98	10.00	5.00	95.00	$0.22
1:00 AM	$1.94	8.82	4.41	95.59	$0.22
2:00 AM	$1.64	0.00	0.00	100.00	$0.23
3:00 AM	$1.92	8.24	4.12	95.88	$0.22
4:00 AM	$1.88	7.06	3.53	96.47	$0.22
5:00 AM	$1.98	10.00	5.00	95.00	$0.22
6:00 AM	$2.20	16.47	8.24	91.76	$0.21
7:00 AM	$2.58	27.65	13.82	86.18	$0.20
8:00 AM	$3.20	45.88	22.94	77.06	$0.18
9:00 AM	$2.58	27.65	13.82	86.18	$0.20
10:00 AM	$2.66	30.00	15.00	85.00	$0.20
11:00 AM	$2.68	30.59	15.29	84.71	$0.19
12:00 PM	$2.78	33.53	16.76	83.24	$0.19
1:00 PM	$2.76	32.94	16.47	83.53	$0.19
2:00 PM	$2.88	36.47	18.24	81.76	$0.19
3:00 PM	$2.56	27.06	13.53	86.47	$0.20
4:00 PM	$2.96	38.82	19.41	80.59	$0.19
5:00 PM	$3.40	51.76	25.88	74.12	$0.17
6:00 PM	$3.32	49.41	24.71	75.29	$0.17
7:00 PM	$2.98	39.41	19.71	80.29	$0.18
8:00 PM	$3.04	41.18	20.59	79.41	$0.18
9:00 PM	$2.84	35.29	17.65	82.35	$0.19
10:00 PM	$2.20	16.47	8.24	91.76	$0.21
11:00 PM	$1.92	8.24	4.12	95.88	$0.22

Table 11: Hourly Average RTP Percent Data

Another issue with the implementation of the algorithm v2.0 was found when performing the simulations of the HEM System using the rated loads presented on the Background section. The objective was to test the viability of the system on a simulated environment, by using the rated information of some of the loads and the RTP of an entire test day. The results yielded some issues with the performance of the algorithm since the maximum user price appeared to be a very low threshold limitation for a real viability of the system. In essence, the problem arises when the electric vehicle was introduced in the equation (as demonstrated in the simulation results section) making the system unable to handle high power rated loads.

The essence of the problem was the following:

1. Max User Price (for 1 minute) = ((($100 / 30 days)/ 24 hours)/60 min) = 0.23 [₵/min]
2. Using an RTP = 6.0 [₵/kWh] = 0.0001 [₵/Wmin]
3. The EV rating used was took from a Tesla Car Model S. Rating = 10 [kW]

4. Consumption = Rate [W] * RTP [₵/Wmin] * Time [min] = 10000 * 0.0001 * 1 = 1 [₵]

As seen above, algorithm v2.0 will compare the result obtained in 4 with the 95% of the result obtained in 1. For the system to be viable the consumption result, 1 [₵], needs to be close to the result 0.23[₵] * 95%, which clearly in not the case. This result creates a problem for the user since demonstrates that the algorithm will not be fully capable of handling large loads.

So, in order to solve this specific issue, the algorithm V3.0 was designed to implement a mechanism of multipliers that will depend the remaining monthly budget set by the user. This addition will still try to limit the total user consumption but at the same time will allow the utilization of loads with high power rating.

The concept of the use of multipliers is entirely based on the remaining monthly budget set by the user, as explained below:

Monthly Remaining Budget Left	Multiplier
10% - 0%	x1
20% - 10%	x2
30% - 20%	x3
40% - 30%	x4
50% - 40%	x5
60% - 50%	x6
70% - 60%	x7
80% - 70%	x8
90% -80%	x9
100% - 90%	x10

Table 12: Multipliers Table

Outer Network (Web Application ←→ Main Controller)

The network design for the HEM system can be separated in two main sections that describe the flow of information through the system. These two main sections are:

1. Outer Network Connection.
2. Inner Network.

In order to provide a detailed description of the outer network design developed in the system, a further division of its main components must be done. The analysis of the outer network will be done explaining all the elements that will be implemented at the end of the project and how all these modules need to work in order to achieve the correct operation of the system.

1. **Web Application / Web Server**

The web application of the design will be hosted using a hosting service company. When the website is hosted using this service, the most important data needed is the public IP where the website will be hosted and the DNS (Domain Name Service), which is in charge of assigning a domain name, or URL, to the public IP provided.

Ex:
Public IP: 8.20.45.180
URL: energymanagement.com

The web application is being developed using a server-side programming language (PHP) for real-time interaction, socket connection, and SQL database access. Client-side programming languages (JavaScript, HTML5, and CSS) are being used for the creation of the website and overall structure and design of the web application.

2. Main Controller

As explained before, the main controller will consist of Beagle Bone Black connected to the internet via Ethernet connection or Wi-Fi connection. The connection between the main controller and the web application will be done using a TCP socket connection between the two public IPs. Figure 10 shows the simple schematic explaining the real-time socket connection needed between these two modules. As seen, the needed information to bind these two IPs, using the socket specified, is the public IPs and the TCP ports used for the connection.

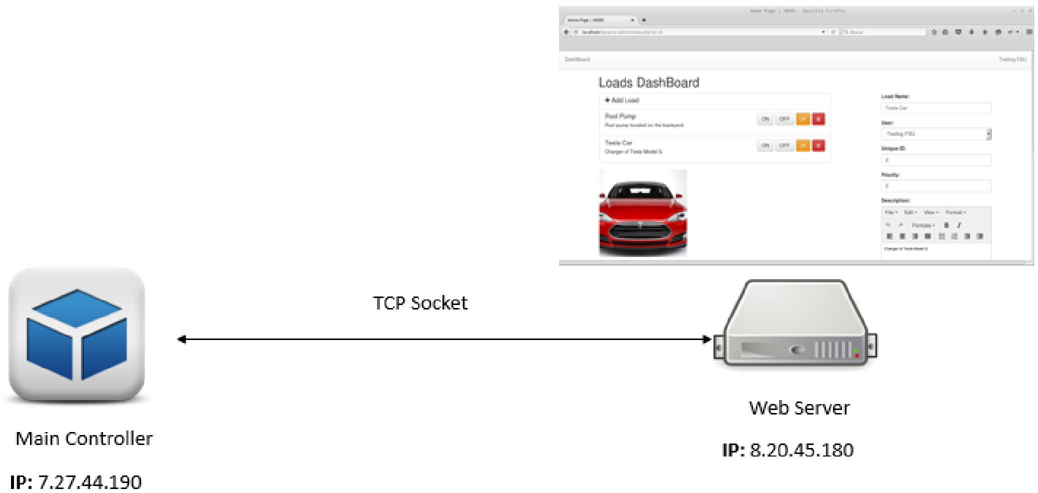


Figure 22: Socket Connection

Unfortunately, this ideal setup is very improbable, since most home or domestic users are provided with dynamic IPs (not static as the webserver) by their own ISP (internet service provider). This issue, together with the fact that most home users make use of a router (with a firewall) to connect to the internet, make difficult the TCP connection between the two IPs. Figure 11 shows how normal home users use their router to navigate the internet.

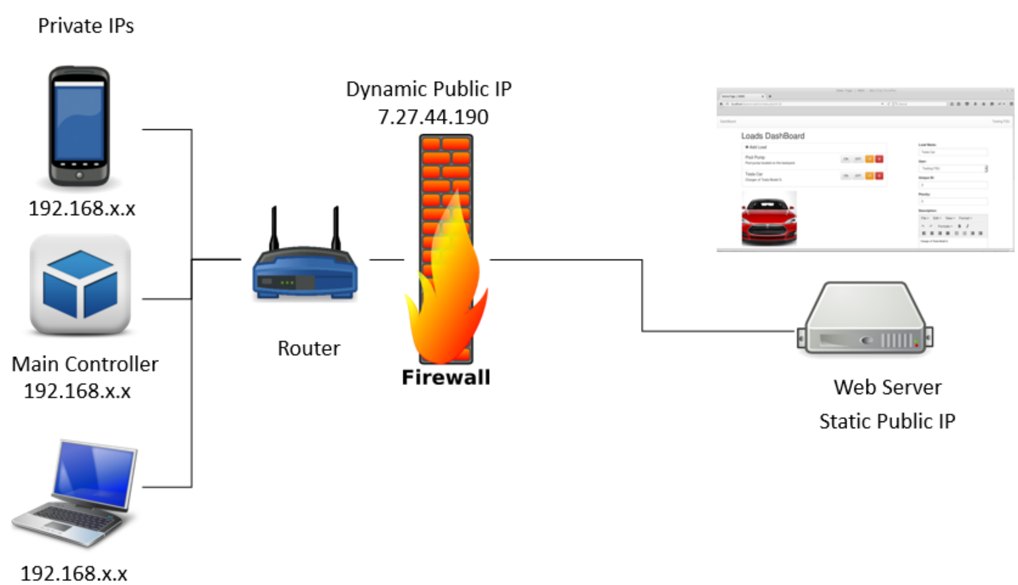


Figure 23: Normal Schematic of Home User Connection

As seen on this figure, there are two essential problems that need to be addressed for successful connection of the TCP socket. It's important to note that security is not a main concern on this implementation, yet. These problems can be summarize as:

- How to route the private IP of the main controller to the public IP of the connection.
- How to solve the dynamic IP issue, so that even if the IP changes, the connection is not lost.

The first problem arises from the fact that the webserver must be able to send information directly to the private IP of the main controller on the LAN (Local Area Network) of the user. This can't be achievable without the use of Port Forwarding. Port forwarding is defined as an application of NAT (network address translation) that redirects all communication requests from one IP address and port number to another, essentially the network gateway router.

By configuring port forwarding on the home user router, the main controller can be port forward to the public IP and the main controller will be "exposed" to the internet, allowing the TCP connection to happen.
This connection works correctly until the Dynamic Public IP of the home user changes. This change can't be predicted since it could happen at any time, and only the ISP has full control of this action. So, in order to solve this issue, the design must introduce the use of another technology called Dynamic DNS.

Dynamic DNS (DDNS) is, in essence, a method for the automatic update of the name server in the DNS with the active DDNS configuration present on the hostnames or host addresses. In other words, this is the method in charge of assigning a logical name, like "*logical.ns01.info"*, to the public dynamic IP assigned to the home user by the ISP.

By using this method, the configuration of the TCP socket connection doesn't need to be assigned using static IP addresses, since the use of logical names give the advantage of referring to this name when needed, which at the same time is being assigned dynamically to current IP address used by the home user.

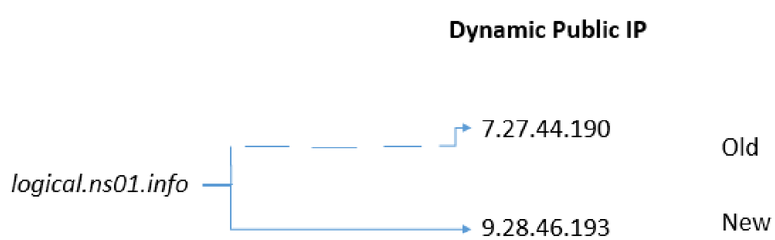


Figure 24: Example of Dynamic IP change

After the configuration of these modules, the TCP connection can be successfully done without any issue, other than possible security breaches caused by intrusion in the connection. The configuration of these modules, essentially the port forwarding and DDNS assigning, should be offered as a simple configuration done by the client using the main application of the HEM system. This configuration is aimed to be a straight forward, easy to follow, setup steps that any user could follow without any significant problems.

Inner Network (Main Controller ←→ Load Controller)

NRF24L01+ Transceiver Settings

To have both transceivers communicate with each other, the transmitter (TX) and the receiver (RX) need to initialize all the settings for each transceiver before sending or receiving data. In the following table, any address for the receiver as long as the transmitter knows the address can be observed.

Address	0xE7D3F035FF
Channel	Depends which RX the TX is sending info to
Data Rate	250 kbps
Dynamic Payload	YES
Power Amplification (PA)	$(11)_b$

Table 13: nRF24L01+ Transceiver Settings

1. **Address:** This address tells the transmitter which receiver to send info to. It doesn't matter what address you choose for each receiver as long as they are different so that the information is sent to only one receiver. If two receivers share the same address the transmitter sends data to both, so essentially they receive the same data.
2. **Channel:** The channel information tells the transceiver which RF frequency the TX needs to send the information on. The NRF24L01+ operates between 2.400 and 2.525 GHz. The RF channel sets the frequency using the following equation:

$$F_0 = 2400 + RF\_CH \text{ [MHz]}$$

Equation 8: Frequency Calculation

   RF_CH is the channel used; for example, if the channel were to be 76, the frequency used to transmit data would be 2.476 GHz.
3. **Data Rate:** Data Rate specifies the data rate used in transferring information. There is no need to worry about high data rates because the system is not sending a lot of information to each controller so the Data Rate can be specified to be 250 kbps.
4. **Dynamic Payload:** The Dynamic Payload tells the NRF24L01+ if the payload length in the packet needs to be defined or dynamically acquired. To reduce the possibility of error, the system needs to have the Dynamic Payload bit set to YES (or ON) so that a payload length is not necessary.
5. **Power Amplification:** The Power Amplification setting sets the output power from the NRF24L01+'s power amplifier. The system needs its max power potential so it needs to be set to 0dBm using $(11)_b$ as seen in the following table.

SPI RF-SETUP (RF_PWR)	RF output power	DC current consumption
11	0dBm	11.3mA
10	-6dBm	9.0mA
01	-12dBm	7.5mA
00	-18dBm	7.0mA

Table 14: PA Control Table

Conditions: VDD = 3.0V, VSS = 0V, TA = 27ºC, Load impedance = 15Ω+j88Ω.

Each of these settings are equally important for the communication setup for the NRF24L01+ but it is important to note that the system also needs to determine which NRF24L01+ is the TX or the RX which is determined if the system is sending data to or from the Beagle Bone Black and to or from the MSP432. The plan is to send information both ways so each of these settings need to adjust constantly while running the HEM.

Data Packet Architecture and ShockBurst™ Technology

Information sent between NRF24L01+ is wireless and therefore not seamless or error free. Nordic Semiconductors, the company that produces the NRF24L01+, knows this and developed the Enhanced ShockBurst™ technology to aid users in sending data wirelessly. Enhanced ShockBurst™ is a packet based data link layer that provides many handy features such as 1 to 32 bytes of dynamic payload, automatic packet handling, automatic packet transaction handling, and 6 data pipe Multiceiver for 1:6 star networks.

The automatic packet transaction handling is an especially helpful feature included in the Enhanced ShockBurst™ technology. The automatic packet transaction handling works as follows:

1. It begins by transmitting a data packet from the transceiver (TX) to the receiver (RX).
2. Then, the TX is then set to receive mode to wait for acknowledgement packet (ACK packet).
3. If this data packet is received by the RX, the RX sends the ACK packet to the TX and returns back to receive mode.
4. If the ACK packet is not received by the TX immediately, the data packet is sent again after a programmable delay

The following diagrams show how the packet architecture is organized:

Preamble 1 byte	Address 3-5 byte	Packet Control Field 9 bit	Payload 0 - 32 byte	CRC 1-2 byte

Table 15: An Enhanced ShockBurst™ packet with payload (0-32 bytes)

Payload length 6bit	PID 2bit	NO_ACK 1bit

Table 16: Packet control Field

1. **Preamble:** The Preamble is a bit sequence used to synchronize the receivers demodulator to the incoming bit stream.
2. **Address:** This address is the address for the receiver. It helps distinguish between nRF24L01+ if many are used.
3. **Packet Control Field:** The Packet Control Field is made up of three sections shown in table 9. It has the payload length field, a 2-bit PID field, and a 1 bit NO_ACK flag.
4. **Payload:** This section holds the data being sent from TX to RX.
5. **CRC:** The Cyclic Redundancy Check (CRC) is a mandatory error detection mechanism in the packet.

Testing Procedures

One of the first tests that was completed will be the communication between the Main Controller and Load Controllers. Communication has been established utilizing the NRF24L01+ transceivers to determine the quality of the communication in various operating conditions. These conditions will simulate the conditions present in various households, such as communication through walls from room to room, communication from first floor to second floor, and communication from opposite corners of the average sized house. The NRF24L01+ will be tested under the various conditions at different frequencies as well as data rates. This type of testing helped to determine the optimal position of the Main Controller and the optimal settings for the NRF24L01+ transceiver.

Inner Network Testing

To simulate a similar environment of a home where the HEM System's inner network would be place, the FSU-FAMU College of Engineering (COE) was selected as the testing environment. Testing was done in the Atrium of the 3rd floor of the COE with the Main Controller connected to a power source while the Load Controller was connected to a computer and taken to different testing points across all three floors of the COE. A set of bytes was continuously sent from Main Controller to Load Controller and the results were recorded and can be seen below.

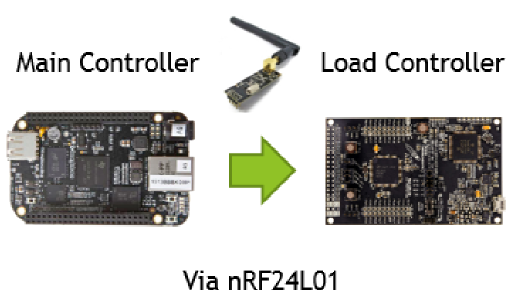


Figure 25: Inner Mesh Testing Diagram

The tables display how a *n* number of bytes was sent out from the Main Controller to the Load Controller. Depending on how many number of bytes the Load Controller received, the test either a passing or failing grade. The results showed that packets, groups of bytes, stopped being transmitted at around a distance of 150 feet when +12 bytes were being sent. This distance was calculated by find the angle at which the Load Controller was placed with respect to the Main Controller; therefore, the direct distance could be calculated even with the change in vertical distance the between floors. The following equations display how these calculations were completed.

$$D_h = The\ horizontal\ distance\ from\ Main\ to\ Load$$
$$D_v = The\ verticle\ distance\ between\ Main\ to\ Load$$
$$\theta = The\ angle\ between\ the\ Main\ to\ Load$$

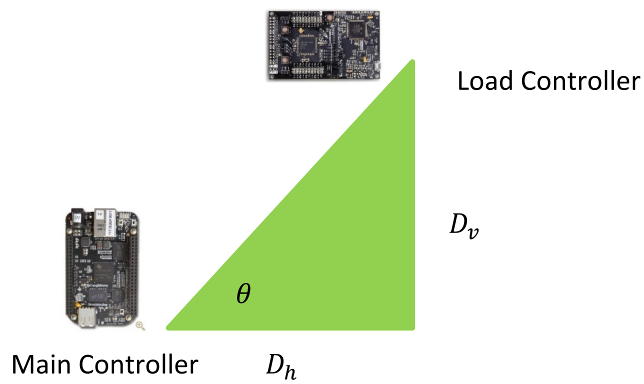


Figure 26: Triangle representation of the procedure

$$\tan(\theta) = \frac{D_v}{D_h} \rightarrow \theta = \tan^{-1}(\frac{D_v}{D_h})$$

Equation 9: Calculating the angle between Load and Main

$$\cos(\theta) = \frac{D_h}{D_D} \rightarrow D_D = \frac{D_h}{\cos(\theta)}$$

Equation 10: Calculating the direct distance between Load and Main

The direct distance on the same floor could be used to find the direct distance when the Load Controller is not on the same floor as the Main Controller.

$$D_{D2} = The\ direct\ distance\ when\ Load\ is\ on\ different\ floor\ from\ Main$$
$$D_f = The\ distance\ between\ floors = 25\ feet$$
$$\theta_2 = The\ angle\ between\ the\ Main\ to\ Load\ when\ on\ different\ floors$$
$$f = the\ difference\ of\ floors\ between\ Load\ and\ Main$$

$$\tan(\theta_2) = \frac{D_D}{D_f * f} \rightarrow \theta_2 = \tan^1\left(\frac{D_D}{D_f * f}\right)$$

Equation 11: Calculating angle between Load and Main on different floors

$$\cos(\theta_2) = \frac{D_f * f}{D_{D2}} \rightarrow D_{D2} = \frac{D_f * f}{\cos(D_{D2})}$$

Equation 12: Calculating the direct distance between Load and Main on different floors

This D_{D2} is the distance that is used when determining if the test passed or failed. In conclusion, because the Shock Burst™ is used when sending packets between the controller and the fact that a max of 8 bytes is being transmitted, the testing displayed how the communication would be successful inside a model home. Shock Burst™ is broken down in the Component Breakdown of HEM System section.

The results also demonstrated how walls within the B side of the COE affected the transmission of packets. The A side on the other hand had better transmission results since there is less interference due to the lack of walls. As the Load Controller was placed on different floors, it also began to receive less packets since the data had to travel through the mechanical system of the building. The data can be found in the tables below.

100 ft Indoor Test		
Floor	Payload Size [bytes]	Pass/Fail
3	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	PASS
	24	PASS
2	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	PASS
	24	PASS
1	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	PASS
	24	PASS

Table 17: 100 feet Indoor Test Results

150 ft Indoor Test		
Floor	Payload Size [bytes]	Pass/Fail
3	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	PASS
	24	PASS
2	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	PASS
	24	PASS
1	2	PASS
	6	PASS
	12	FAIL
	16	FAIL
	20	FAIL
	24	FAIL

Table 18:150 feet Indoor Test Results

180 ft Indoor Test		
Floor	Payload Size [bytes]	Pass/Fail
3	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	FAIL
	24	FAIL
2	2	PASS
	6	PASS
	12	PASS
	16	PASS
	20	FAIL
	24	FAIL
1	2	FAIL
	6	FAIL
	12	FAIL
	16	FAIL
	20	FAIL
	24	FAIL

Table 19: 180 feet Indoor Test Results

200 ft Indoor Test		
Floor	Payload Size [bytes]	Pass/Fail
3	2	PASS
	6	FAIL
	12	FAIL
	16	FAIL
	20	FAIL
	24	FAIL
2	2	PASS
	6	FAIL
	12	FAIL
	16	FAIL
	20	FAIL
	24	FAIL
1	2	FAIL
	6	FAIL
	12	FAIL
	16	FAIL
	20	FAIL
	24	FAIL

Table 20: 200 feet Indoor Test Results

All this information was combined and 3D models were made, they can be seen below. The red displays the areas were no packets were received. The orange sections are where only up to 16 bytes were successfully received. The green sections are where all the packets that were sent were received.

Figure 27: Results from the first Floor of the COE

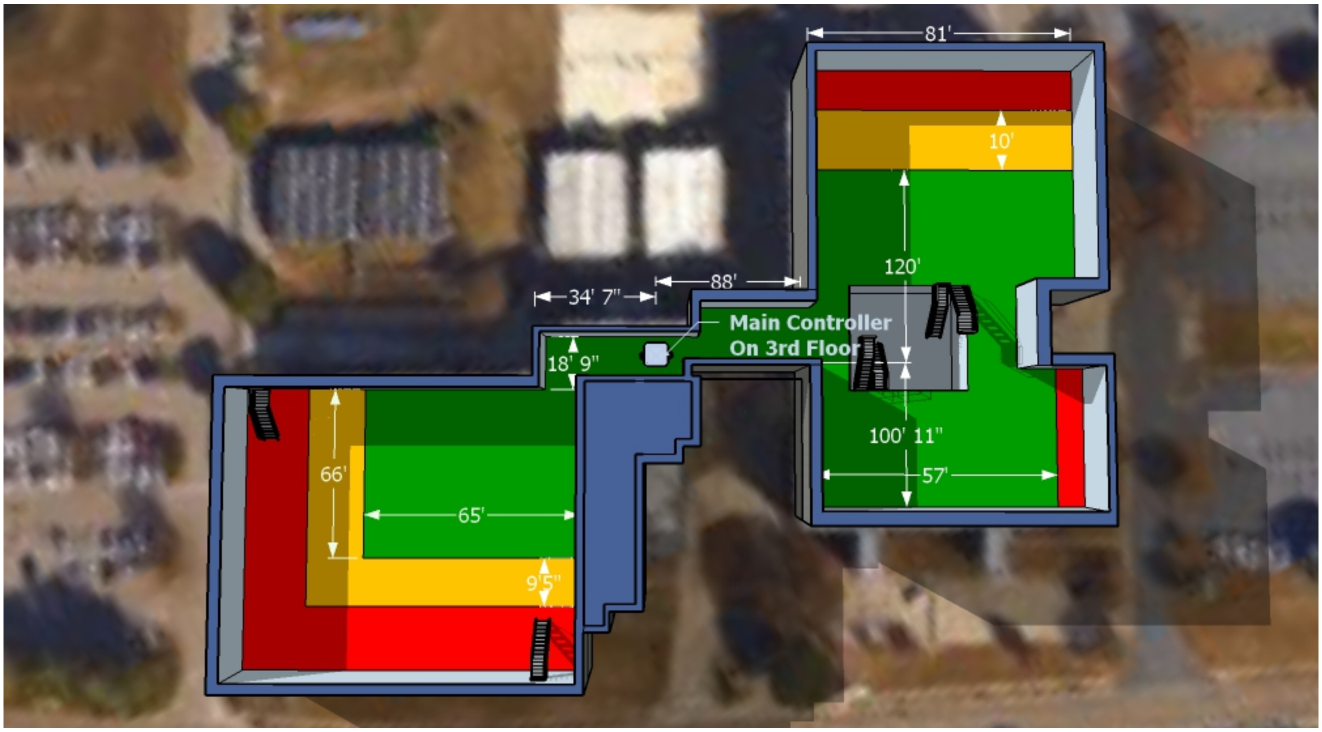


Figure 28: Results from the second floor of the COE

Figure 29: Results from the third floor of the COE

Overall System Testing

Once the system was function, testing the commands between the Main Controller to the Load Controller and the thermostat was completed. These tests were vital to making sure the software side of the system works correctly. The Main Controller sent out a set of commands that to which the recipients, the Load Controller and thermostat, had to respond accordingly. The following table displays the results.

Testing Results				
		Component		
		Main Controller	Load Controller/ Thermostat	Main Controller
		Task		
Test Number	Objective	Sent	Received	Returned
1	Decrease Temperature	Pass	Pass	N/A
2	Increase Temperature	Pass	Pass	N/A
3	Turn Loads Off	Pass	N/A	N/A
4	Turn Loads On	Pass	N/A	N/A
5	Check current temperature	Pass	Pass	Pass
6	Check status of the Load Controller	Pass	Pass	Pass
7	Update information of Load Controller	Pass	Pass	Pass
8	Update thermostat schedule	Pass	Pass	Pass
9	Turn thermostat schedule on/off	Pass	Pass	Pass
10	Set Max Price	Pass	N/A	N/A
11	Testing RTP price	Pass	Pass	Pass
12	Delete a load	Pass	N/A	N/A

Table 21: Overall System Testing Results

Each objective represents a different set of commands sent from the web application to the Main Controller then from the Main Controller to the Load Controller/thermostat. Test 1-2 from the table above for example, was when a decrease or increase of temperature was made by the user in the web application and this information was sent to the Main Controller. The Main Controller then adjusted the thermostat temperature accordingly. A similar concept is followed for tests 5, 8 and 9. When the user decides to turn a load on/off, the commands flows through the web application to the Main Controller who transfers it toing the Load Controller. This process flow is also seen in tests 3, 4, 6, 7, and 11. Test 11 is unique because uses the price set by test 10 to run a simulation of a fluxuating RTP to examine how the system reacts as a whole, meaning through the Main Controller to the Load Controllers. While test 12 consists of the user deleting a load from the web application and the Main Controller adjusting to load altercation. A “Not Applicable” is used in the tables when the set of commands isn’t required to follow the path stated by the table. For example, when the temperature is decreased in the thermostat, the information is not automatically relayed back to the Main Controller, unless the Main Controller asks for it so a N/A is used on the last column of the of test 1-2 in the table above.

Each time information is sent from web application to the Main Controller and then to the Load Controller/thermostat, it is packaged in a specific manner so the Main Controller can distinguish the data. This data is then broken down into sections and then used to talk to the Load Controller/thermostat. For example, a set of socket codes is sent from the web application to the Main Controller when the user wants to change the temperature of the thermostat. This set of codes is made of up a string consisting of "UD" followed by the address of the thermostat, which for now there is only one so an address is not needed since the address does not change. If more thermostats are added to the HEMS, then the address would be used. The socket code would then be followed by an integer the represents the desired temperature. The Main Controller divides out the code into sections and is able to know what component in the system it needs to communicate with thanks to the address string as well as what data to forward thanks to the temperature integer. A table containing all of the codes for the testing can be seen below.

Testing Commands								
	Socket Codes							
	Type (On main)							
Objective	**string**	**string**	**int**	**float**	**int**	**int**	**int**	**int**
Decrease Temperature	Code = UD	(Address)	Temperature	-	-	-	-	-
Increase Temperature	Code = UD	(Address)	Temperature	-	-	-	-	-
Turn Loads Off	Code = OF	Address	-	-	-	-	-	-
Turn Loads On	Code = OO	Address	-	-	-	-	-	-
Check current temperature	Code = TT	(Address)	-	-	-	-	-	-
Check status of the Load Controller	Code = LA	Address	-	-	-	-	-	-
Update information of Load Controller	Code = UL	Address	Priority	Rating	Algorithm Enabled	-	-	-
Update thermostat schedule	Code = UT	(Address)	ID (Num in table 1-10)	Week	Mode	Time	Sched_Temperature	-
Turn thermostat schedule on/off	Code = HO, SC	(Address)	-	-	-	-	-	-
Set Max Price	Code = P1	-	-	QUERY	-	-	-	-
Testing RTP price	Code = testing	-	-	QUERY	-	-	-	-

Table 22: Testing Commands Table

Scheduling and Resource Allocation

Gantt Chart

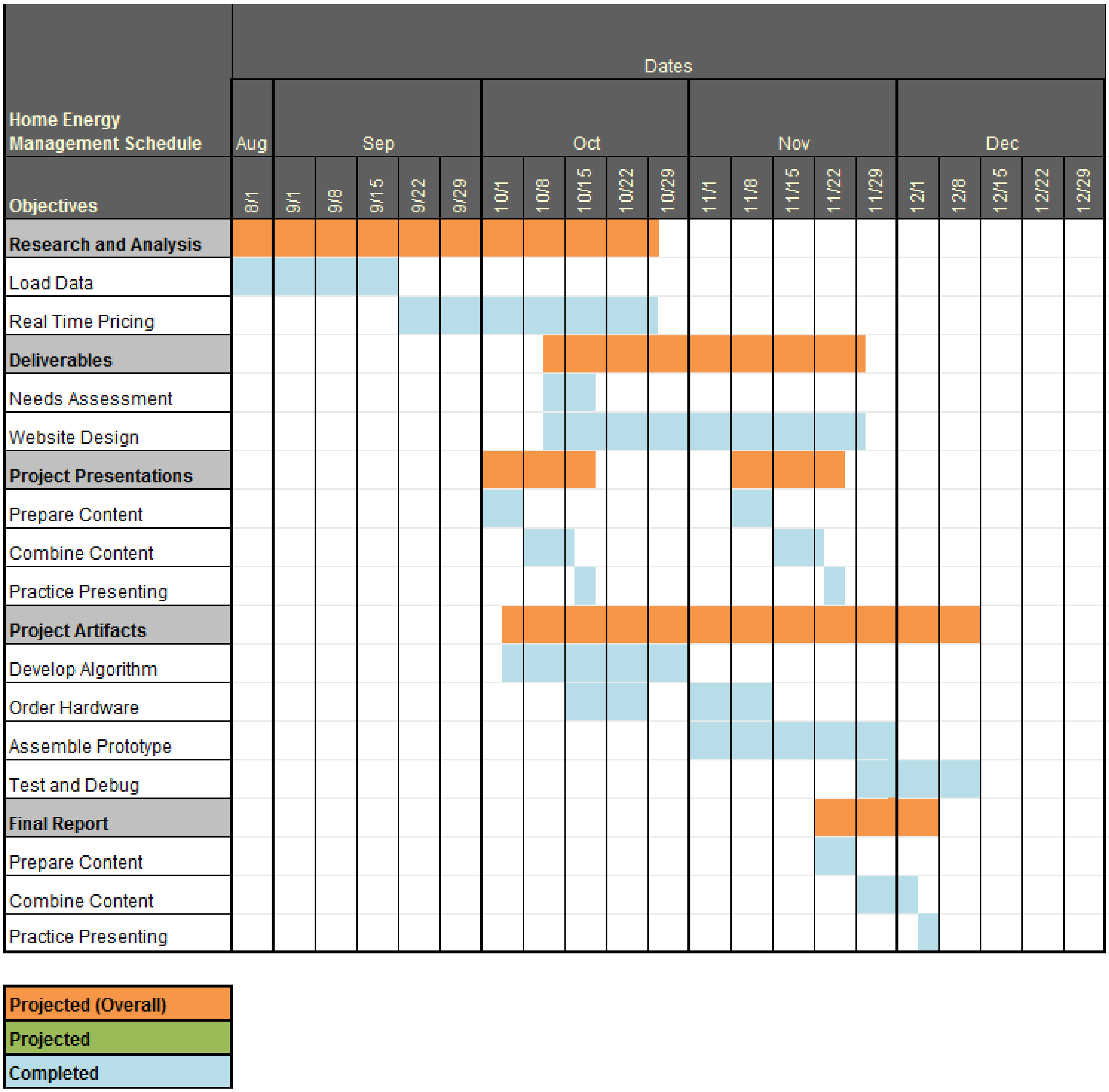


Figure 30: Displays schedule for the Fall 2015 Semester

As seen in Figure above, the project is on schedule with the projected timeline. The Fall 2015 semester was focused on the creation and design of a prototype, and next semester, Spring 2016, focused on further development and testing of the overall design.

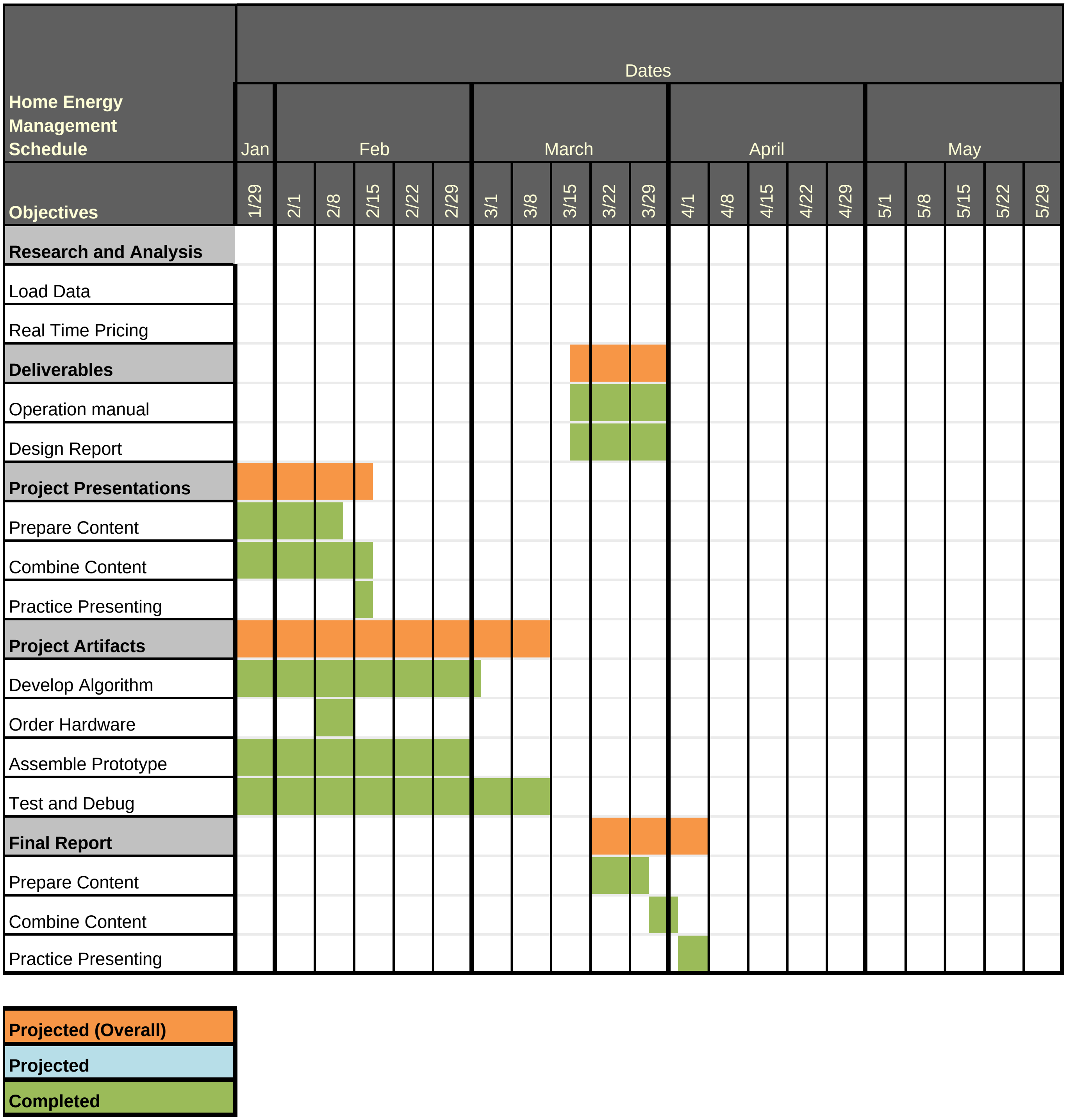


Figure 31: Displays schedule for the Spring 2016 Semester

Projected Hours

Estimated Hours for the Fall 2015 Semester					
	Fall 2015 Semester Months				
Weeks of the Month	January	February	March	April	May
First Week	N/A	5	7	10	10
Second Week	5	5	7	10	N/A
Third Week	5	5	7	10	N/A
Fourth Week	5	5	7	10	N/A
Total Monthly (Hours)	15	20	28	40	10
				Total Semester Hours	108

Table 23:Projected Hours required for the Fall 2015 Semester

Estimated Hours for the Spring 2016 Semester					
	Spring 2016 Semester Months				
Weeks of the Month	January	February	March	April	May
First Week	N/A	5	7	10	10
Second Week	5	5	7	10	N/A
Third Week	5	5	7	10	N/A
Fourth Week	5	5	7	10	N/A
Total Monthly (Hours)	15	20	28	40	10
				Total Semester Hours	108

Table 24: Projected Hours required for the Spring 2016 Semester

The hours of work will be distributed amongst the personnel responsible for the completion of the project. See table above for an estimation of the required hours. This estimation is per team personnel, not including Dr. Omar Faruque, the Senior Design Project Advisor. Between both semesters the estimated time of completion is about 752 hours.

The personnel consist of:

Dillon Wiggins – EE – Project Manager
Ivan Remete – EE – Electrical Engineer
Pablo Aguirre – EE – Systems Engineer
Juan Ospina – CE & EE – Hardware Engineer
Michael Garcia – CE – Software Engineer
Dr. Omar Faruque – Senior Design Project Advisor

Bill of Materials/Budget

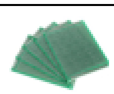
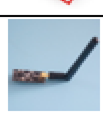
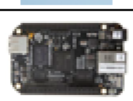
Budget Summary					
Image	Material	Vendor	Quantity	Price	Total
	MSP-EXP432P401R	TI	8	$12.99	$103.92
	Extension Cord 2ft 3-wire	Generic	3	$5.47	$16.41
	Black Universal AU Plug AC USB Power Home Travel Wall 1A Charger Adapter 1000mA	Generic	6	$3.99	$23.94
	LM74 - Temperature Sensor	TI	4	$1.84	$7.36
	5V Power Supply	Generic	1	$8.99	$8.99
	6x8cm PCBs 5pcs	Generic	1	$6.99	$6.99
	5V 1 One Channel Relay	Generic	6	$5.69	$34.14
	Nrf24l01+pa+lna: 1100m	Generic	6	$11.60	$69.60
	Beagle Bone	TI	2	$55.00	$110.00
		Budget Remaining	**$1,118.65**	TOTAL	**$381.35**

Table 25: Budget (First Purchase)

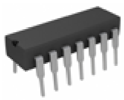
Budget Summary					
Image	Material	Vendor	Quantity	Price	Total
	56100C Current Sense Transformer	TI	10	$1.60	$16.00
	LM339AN - Comparator	TI	10	$0.30	$3.00
	Rocker Switch	Digikey	10	$0.66	$6.62
	10K Ohms Resistors	Digikey	50	$0.03	$1.44
	10u Capacitor	Digikey	20	$0.47	$9.40
	Push Button	Digikey	25	$0.07	$1.68
	Wi-Fi USB Adapter	Edimax	2	$9.99	$19.98
		Budget Remaining	**$1,060.53**	TOTAL	**$58.12**

Table 26: Budget (Second Purchase)

The tables above display the overall budget for the project. The budget was initially deducted by 25% in order to have buffer room in case of any unexpected expenses. After the buffer room was made, only 25% of the remaining budget has been spent.

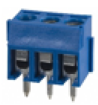
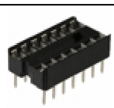
Budget Summary					
Image	Material	Vendor	Quantity	Price	Total
	Prototype Box	Digikey	5	$14.67	$73.35
	Hex Standoff Spacer ¼'	Digikey	100	$0.32	$32.00
	Hex Standoff ¼'	Digikey	100	$0.45	$45.00
	Hex Standoff ½'	Digikey	100	$0.34	$34.00
	Terminal Block	Digikey	15	$0.60	$9.00
	10 nF Cap	Digikey	100	$0.07	$6.72
	F-M jumper wires	Adafruit	4	$1.95	$7.80
	14 Pin Dip Socket	Digikey	10	$2.10	$21.00
		Budget Remaining	**$889.78**	TOTAL	**$228.87**

Table 27: Budget (Third Purchase)

Results

HEM Simulation

Real Time Pricing (RTP) allows a user to base their energy usage on market price. This implementation helps the user save on energy consumption when compared with standard usage cost. To estimate how effective the Home Energy Management System (HEMS) is when using RTP, a simulation was developed to determine the differences between the RTP system and a standard system. A handful of loads that would most likely be found in a household using the HEM System were gathered, along with their respective wattage rating and average usage time. For the electric vehicle, a Tesla model 3 was used with a NEMA 14-50 power outlet.

Standard Usage

Appliances	Energy (W)	Usage Time (hr)	Total kWh
Electric Vehicle	10000	4	40
Pool Pump	1000	4	4
A/C	3500	4	14
Water Heater	4000	1	4
Refrigerator	180	24	4.32
Desktop	1400	5	7
Washing Machine	700	2	1.4
Standard Light	60	6	0.36

Table 28: Standard usage load assumptions

The first part of the simulation was to determine the energy costs of a standard usage home, or a home without the HEM System incorporated to it. The cost per month will rely on the total cost per day, which can be found by multiplying the total power used in a day with the average RTP. The total power used will be determined by summing the energy usage of all loads.

$$Total\ kWh\ = 75.08\ kWh$$

Equation 13: Total kWh

$$Total\ Cost\ = Total\ kWh \times Average\ RTP = 75.08 \times 6.7 = 503.036 \frac{¢}{day}$$

Equation 14: Total Cost

$$\frac{Cost}{month} = \frac{Total\ Cost\ \times Days\ in\ month}{100} = 150.91\ \frac{\$}{month}$$

Equation 15: Cost per month

The user at this house can expect to pay $150.91 for each month the energy usage remains at the energy consumption level shown in Equation 9. In contrast to the standard pricing, the HEM System will take into account the best times each load can turn on according RTP values, found in Table 25, and if a load can turn off at certain times. A load’s ability to turn off depends entirely on that certain load. For example, the standard light and desktop should stay on while the user is home, but the washing machine can turn on in the middle of the night because that is when RTP is at its lowest. The water heater should also turn on as close to the 7:00AM mark as possible so that the user can have warm water for morning routines. Table 24 explains when the HEM System will turn on loads given the RTP values in Table 25.

	Electric Vehicle	Pool Pump	A/C	Water Heater	Refrigerator	Washing Machine	Standard Light	Desktop
12:00 AM	10000		3500		180			
1:00 AM	10000				180	700		
2:00 AM	10000		3500		180	700		
3:00 AM	10000				180			
4:00 AM					180			
5:00 AM				4000	180			
6:00 AM								
7:00 AM					180			
8:00 AM					180			
9:00 AM					180			
10:00 AM					180			
11:00 AM					180			
12:00 PM					180			
1:00 PM					180			
2:00 PM					180			
3:00 PM					180			
4:00 PM		1000			180			
5:00 PM		1000	3500					
6:00 PM		1000			180		60	1400
7:00 PM		1000			180		60	1400
8:00 PM					180		60	1400
9:00 PM					180		60	1400
10:00 PM			3500		180		60	1400
11:00 PM					180			

Table 29: HEM simulation over the course of any given day

Time	RTP	kWh	kWh*RTP
12:00 AM	4.5	13.68	61.56
1:00 AM	4.4	10.88	47.872
2:00 AM	4.4	14.38	63.272
3:00 AM	4.4	10.18	44.792
4:00 AM	4.6	0.18	0.828
5:00 AM	5	4.18	20.9
6:00 AM	5.9	0	0
7:00 AM	5.4	0.18	0.972
8:00 AM	5.2	0.18	0.936
9:00 AM	5	0.18	0.9
10:00 AM	5	0.18	0.9
11:00 AM	4.8	0.18	0.864
12:00 PM	4.7	0.18	0.846
1:00 PM	4.6	0.18	0.828
2:00 PM	4.6	0.18	0.828
3:00 PM	5	0.18	0.9
4:00 PM	5.5	1.18	6.49
5:00 PM	6	4.5	27
6:00 PM	5.9	2.64	15.576
7:00 PM	5.7	2.64	15.048
8:00 PM	5.3	1.64	8.692
9:00 PM	4.9	1.64	8.036
10:00 PM	4.6	5.14	23.644
11:00 PM	4.5	0.18	0.81

Table 30: Total wattage and RTP values

With RTP, the price for each load every hour will fluctuate, unlike the standard price that will stay constant over the entire day. As shown in Equation 12, the overall cost the user will spend over any given month will be \$105.75. Directly compared with the standard price calculation of \$150.91/mo., the HEM Systems saves the user \$45.16/mo.

$$\frac{Cost}{month} = \frac{30\,\frac{days}{month} \times \sum(kWh \times RTP)}{100\,\frac{cents}{dollar}} = \$105.75/mo$$

Equation 16: Cost per month

The HEM System saves this amount by reconfiguring when to turn loads on/off based on when the RTP is at its lowest or highest. From Figure 30, the largest difference between the RTP*kWh and SP*kWh curves can be found during the low RTP times. The larger the difference between these two curves the larger the savings in energy cost. The small differences in energy costs arise when the user is expected to be at home and using loads, which is assumed to be from 4:00PM to 10:00PM. These loads, such as lighting, the desktop, and the pool pump, are not meant to turn off so as to not disturb a user's regular routine. A/C was configured to turn on prior to the high RTP values in the late afternoon so as to cool/heat the house on the user's arrival from work.

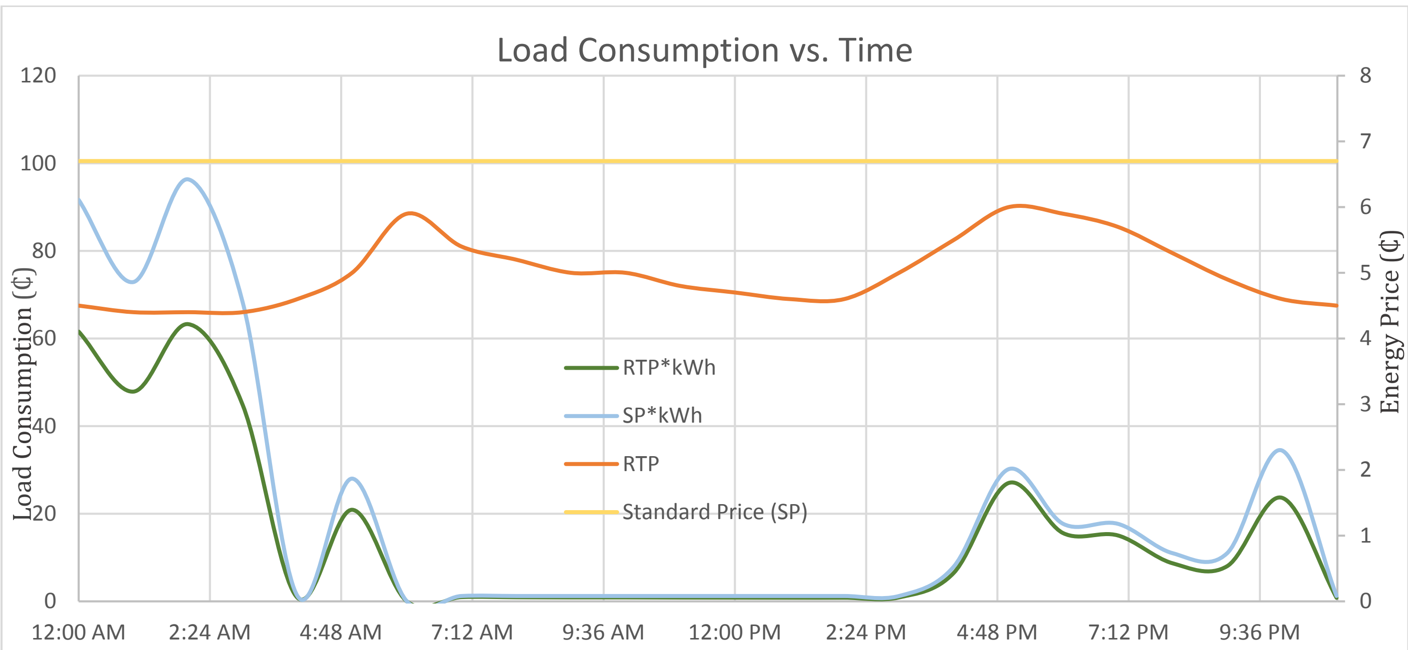


Figure 32: Load consumption vs time graph

The take away from this simulation is that the actual implementation of this algorithm should use a more exact approach when determining the times a certain load should turn on/off. It leaves any estimation or human error, when determining what loads should turn on/off, out of the calculation. This simulation also shows that the HEM System will work best at night. During the night hours, loads that are not very critical, and consume a sizable amount of power when on, can turn on and not run the risk of using power when RTP is high. Overall, this simulation shows that the HEM System theoretically saves the user a sizable amount of money by reconfiguring when energy is consumed throughout the day.

Risks

Risks are minimal in this design project. There are two categories of risks, one is during the prototyping stage and the other is during the use of the design. During the prototyping stage, the risks that factor in are that of low voltage (120 VAC) electrical shock and burns caused by the soldering iron. The risks that come with the use of the finalized design, and the actual use of the design project, is the security associated with the design. Since the design will not have any added security, the design project is vulnerable to hacking.

User Guide

HEM System Anatomy

Main Controller

The brain behind the HEM system is the Main Controller as seen in Figure 2. The Main Controller is made of up different components that play a specific role in the Main Controllers function.

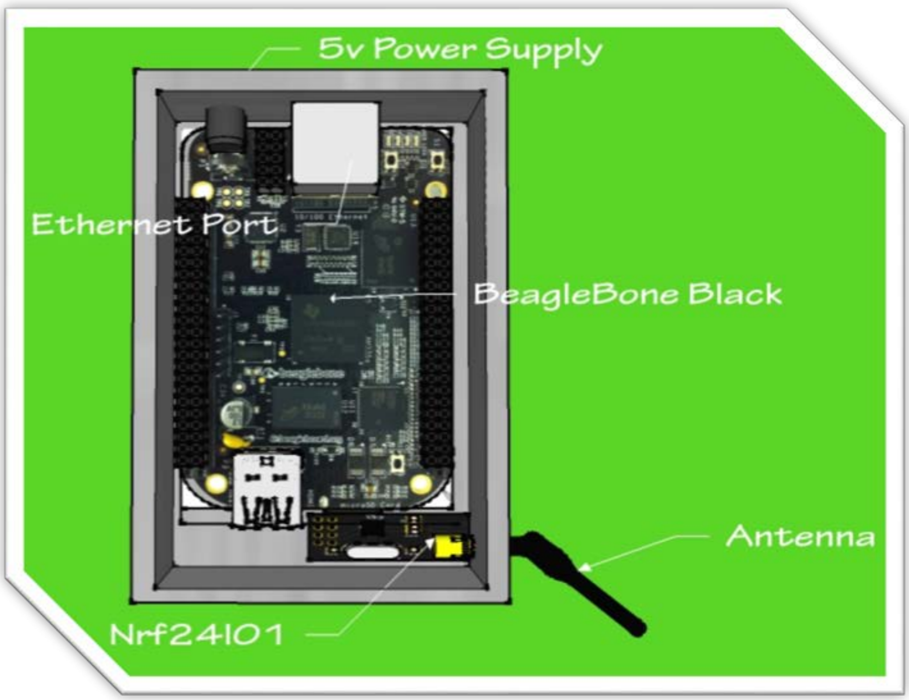


Figure 33: Main Controller

Component	Description
5V Power Supply	A 5V power supply plugs into the Main Controller and provides power to all the components
Ethernet Port	RJ45 Ethernet connector for LAN. User may use this for programming purposes as well as connecting the Main Controller to the website via internet.
BeagleBone Black	It is a lower-cost, high-expansion focused microprocessor using a low cost Sitara XAM3359AZCZ100 Cortex A8 ARM processor from Texas Instruments. It serves as the brains of the HEM System.
Nrf24l01	Used for communication via a 2.4GHz RF transceiver, RF synthesizer, and baseband logic including the Enhanced ShockBurst™ hardware protocol accelerator supporting a high-speed SPI interface for the application controller.

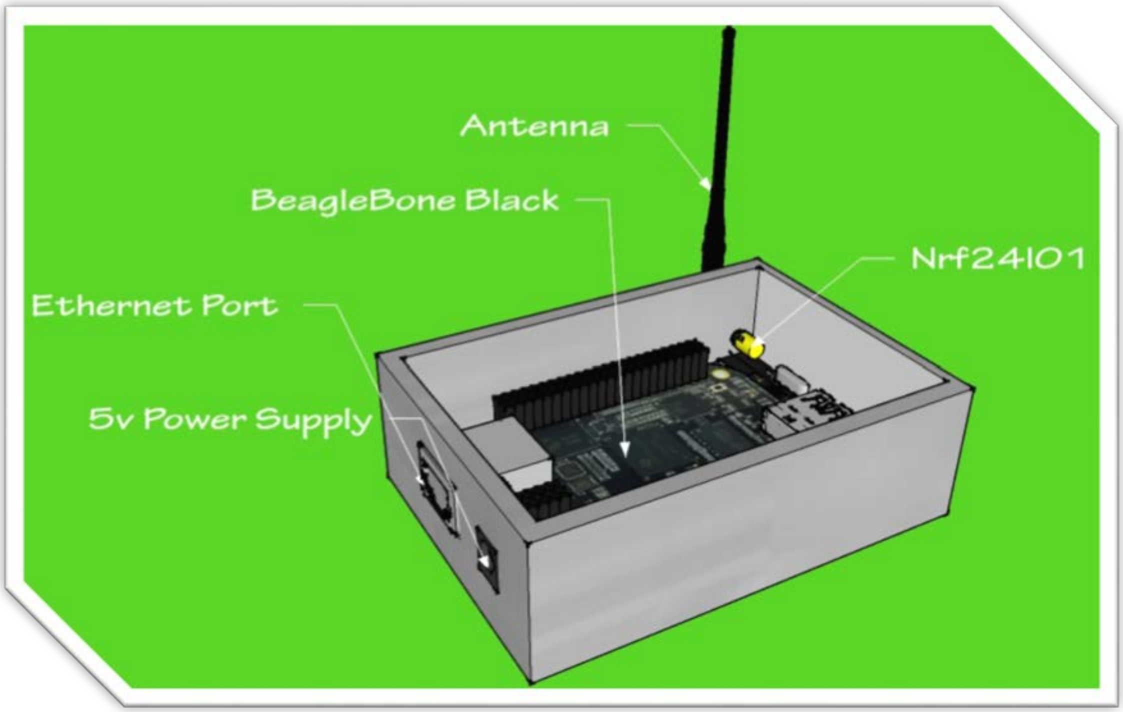


Figure 34 Main Controller Side View

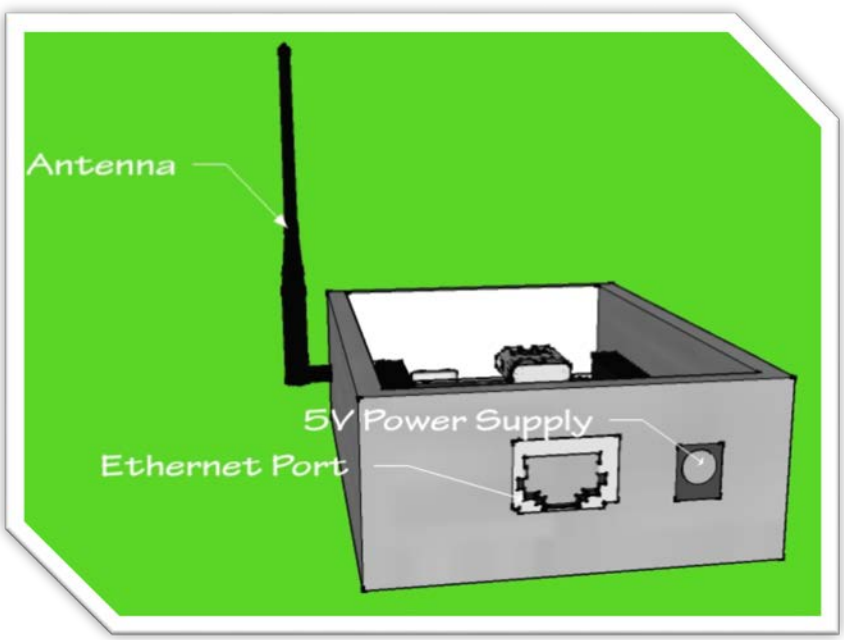


Figure 35: Main Controller Front View

Load Controller

The second main aspect of the HEM System is the Load Controller. The Load Controller is mainly in charge of turning the connected load on and off based on the Main Controller's command. The Load Controller can be seen in the figure below.

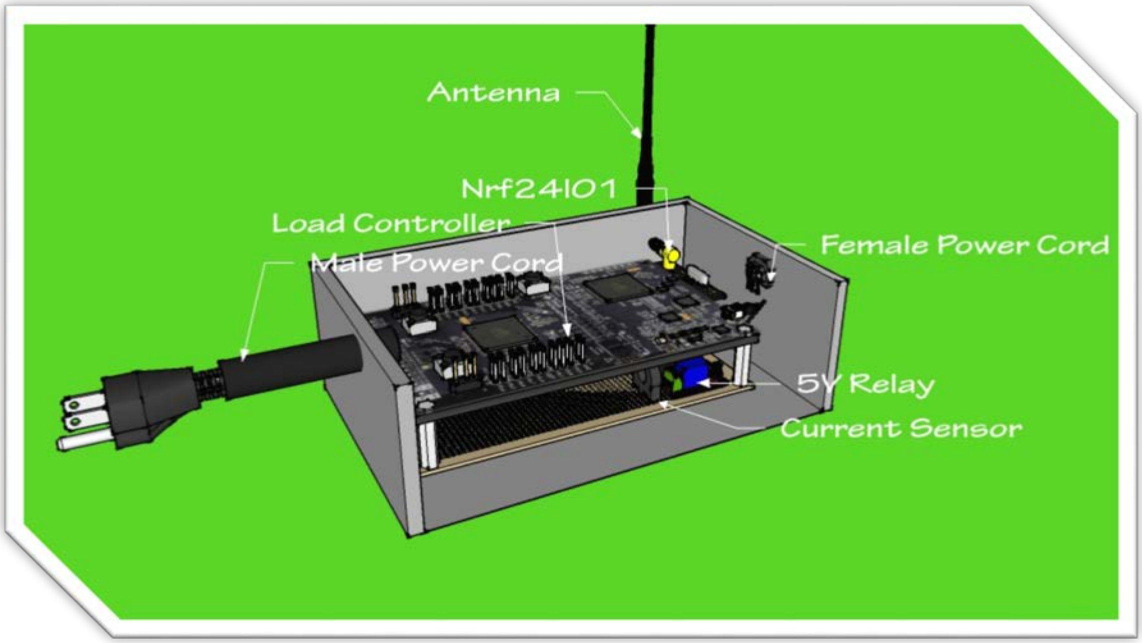


Figure 36: Load Controller

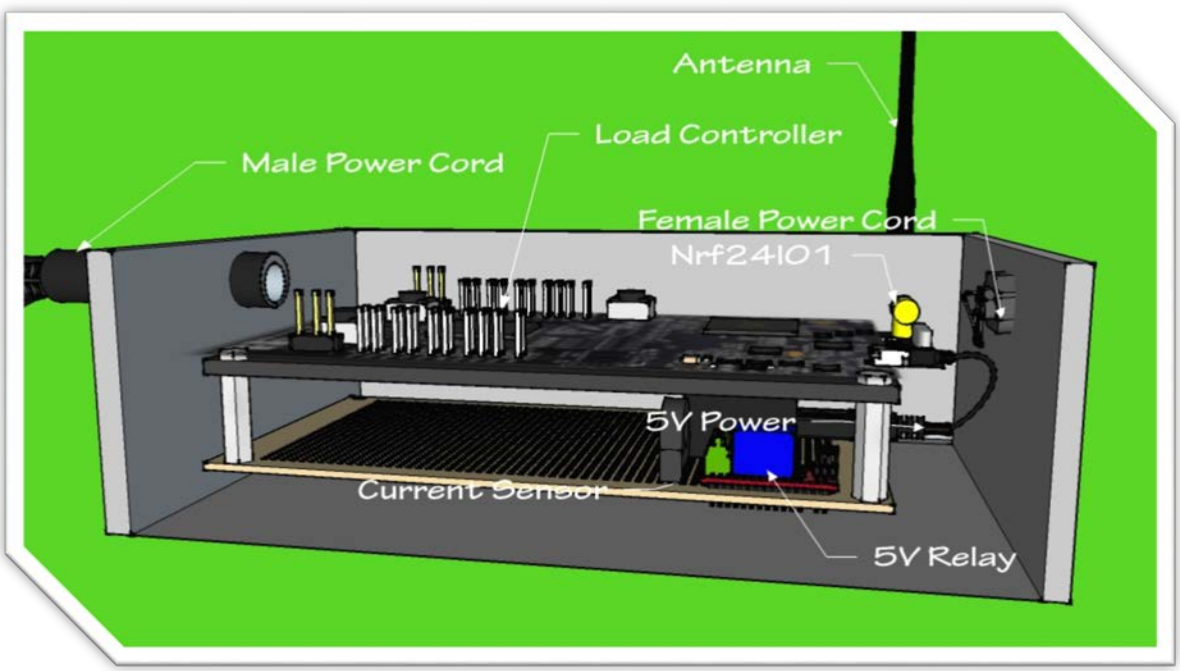


Figure 37: Load Controller Close-up

Component	Description
Male Power Cord	120V main power line for the main controller. This cord powers all of the components inside the Main Controller.
Ethernet Port	RJ45 Ethernet connector for LAN. Allows the user to connect to the internet as well as program the BeagleBone Black.
Load Controller	MSP-EXP432P401R which is a mixed-signal microcontroller family from Texas Instruments. It is based on a 32-bit ARM Cortex-M4F CPU, and extends their 16-bit MSP430 line, with a larger address space for code and data, and faster integer and floating point calculation than the MSP430.
Nrf24l01	Used for communication via a 2.4GHz RF transceiver, RF synthesizer, and baseband logic including the Enhanced ShockBurst™ hardware protocol accelerator supporting a high-speed SPI interface for the application controller.
5V Power	Black Universal AU Plug AC USB Power Home Travel Wall 1A Charger Adapter 1000mA.
5V Relay	5V One-Channel Relay used for turning the loads on and off.
Current Sensor	56100C Current Sense Transformer used to detect the current of the connected load.

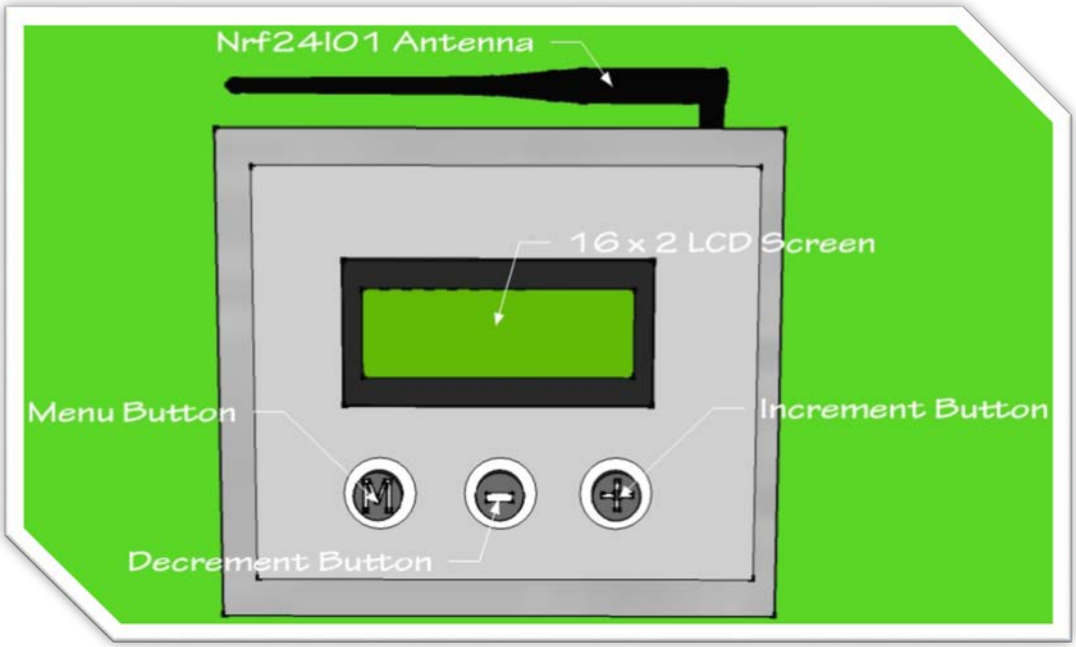


Figure 38: Thermostat

Component	Description
Nrf24l01	Used for communication via a 2.4GHz RF transceiver, RF synthesizer, and baseband logic including the Enhanced ShockBurst™ hardware protocol accelerator supporting a high-speed SPI interface for the Thermostat to control with the Main Controller.
Menu Button	Menu Button allows you to enter the Thermostat's menu.
Decrement Button	Decrement button allows you to decrement your choice once in the Thermostat's menu.
Increment Button	Increment button allows you to increment your choice once in the Thermostat's menu.

Setup Guide

Follow these simple steps to get started with your HEM System. For additional Operation Instruction Section.

Figure 39: Display model home with the system installed

Installing the System

STEP 1: The Main Control

- In a centralized location of your home as shown in figure 8, place the main controller in an uncluttered area. **NOTE:** The main controller requires a connection via Ethernet cable. Make sure the centralized location has an Ethernet port nearby or has the router of your home nearby.
- Plug in the 5V DC power into the main controller and the other end into a wall outlet.
- Connect the Ethernet cable into the Ethernet port of the main controller, and the other end into the router Ethernet connector. **NOTE:** The main controller Ethernet port can be connected directly to a router.

STEP 2: The Load Controller

- Determine which loads you would like the HEM System to control.
- Once determined, disconnect the load from the wall outlet.
- Connect the load controllers input to the wall outlet, and the output to the desired load.
- Repeat **STEP 2** until you have connected all of the load controllers to the desired loads which you would like the HEM System to control.

STEP 3: The Thermostat

- Replace your current thermostat with the controllable thermostat provided.

Connecting the Main Controller to the inner network (LAN)

NOTE: The LAN Network can only be accessed in your personal home. To access the website remotely please refer to Connecting the Main Controller to the outer network remotely.

STEP 1: Access your router's web interface

- Open the Network and Sharing Center in the Windows Control Panel

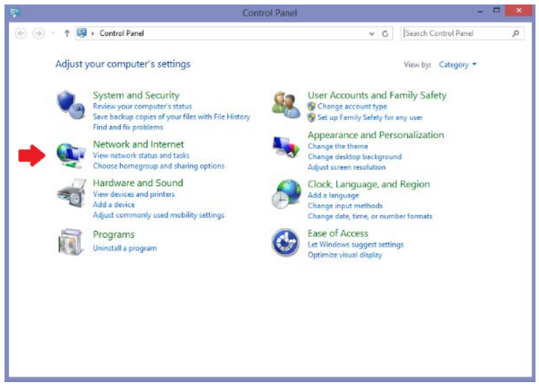


Figure 40: Control Panel

- Once opened, click on your personal Wi-Fi's name under **Connections**.

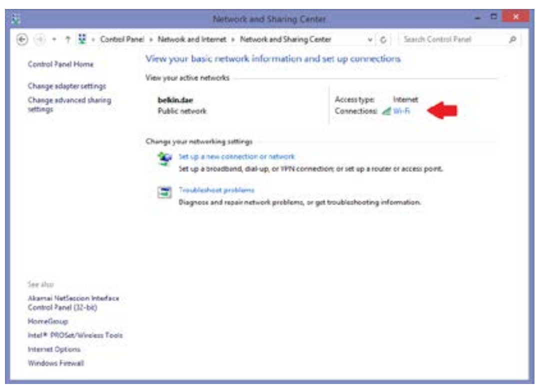


Figure 41: Network and Sharing Center

- Once opened, a **General** panel will appear. Click on the **Details** bar. The **Network Connection Details** will give you the routers IP Address under **IPv4 Default Gateway** as 192.168.X.X

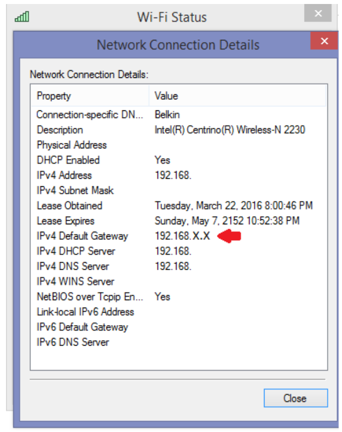


Figure 42: Wi-Fi Status

- Once the **IPv4 Default Gateway** is obtained, plug in the IP address into your web browser's address bar. You will need to log with your username and password. Once you've logged in, you can obtain the Main Controller's IP address.

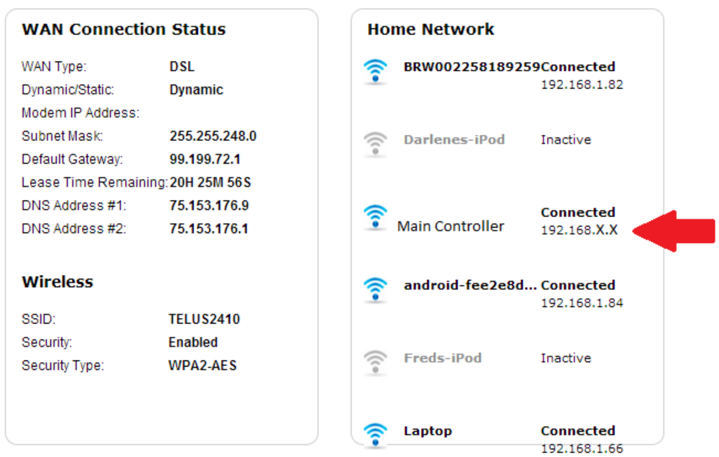


Figure 43: Wi-Fi Networks

STEP 2: Accessing the HEM System website

- Use the IP address obtained from the previous step to access the HEM System website locally by imputing the IP address into the web browser. **NOTE:** For instructions on using the HEM System website refer to the **System Operation** section.

Type on URL: 192.168.x.x (IP of your main controller)

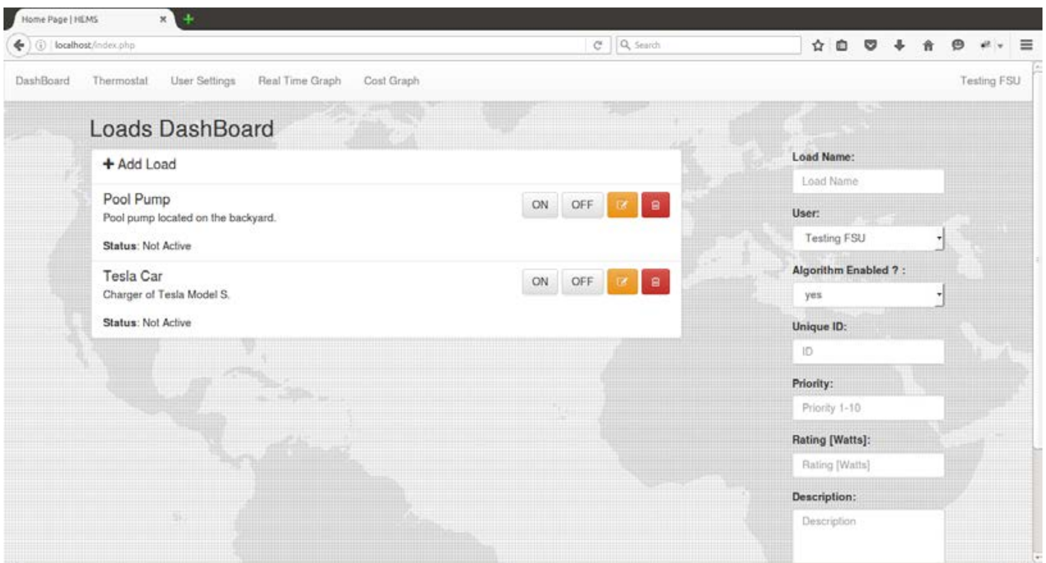


Figure 44: HEM Website Interface

Connecting the Main Controller to the outer network remotely

For accessing the HEM system remotely, you must first connect the main controller to your own LAN following the instructions explained on **Connecting the Main Controller to the inner network (LAN).** After your system is working on your own LAN, you must **port forward** the private IP of the main controller following the next steps:
NOTE: Before attempting these steps, please make sure the LAN connection is working correctly.

Port Forwarding

STEP 1: Access your router by typing the IP on the address bar of your web browser. This will open your router's configuration page. Most routers have 192.168.0.1, but that's not always the case, so please check the router's manual.
STEP 2: Log in to your router's configuration page by typing your username and password. This information should be available on your router's user manual.
STEP 3: Find the Port Forwarding section. On most routers it can be found on Advanced Settings or Applications.
STEP 4: Create a custom entry. In this part, the user should add the internal IP to the list of Forwarding and list the port 4000 (if you want to use a specific port for communication). For the service type use TCP option.
STEP 5: Click on Add and Enabled, then save current settings. You might need to restart your router for the changes to take effect.

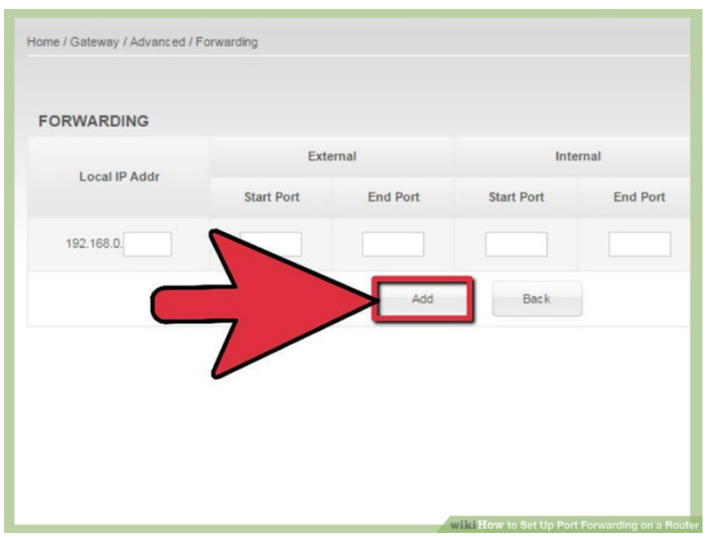


Figure 45: Port forwarding

This connection works correctly until the Dynamic Public IP of the home user changes. This change can't be predicted since it could happen at any time, and only the ISP has full control of this action. So, in order to solve this issue, the design must introduce the use of another technology called Dynamic DNS.

Dynamic DNS (DDNS) is, in essence, a method for the automatic update of the name server in the DNS with the active DDNS configuration present on the hostnames or host addresses. In other words, this is the method in charge of assigning a logical name, like "logical.ns01.info", to the public dynamic IP assigned to the home user by the ISP.

You can find free and paid services available; some examples are www.noip.com or www.dyn.com.

Warning: The HEM System group doesn't encourage the use of this method for the system, since giving remote access to the entire system could be extremely dangerous due to security flaws on the network. Exposing your inner network to remote access should be done taking serious security considerations.

System Operation

Log in/out to/from the Web Application

Log in to the web application (create a profile if it's your first use – Click on create a new profile and follow the instructions).
Enter your registered email address and password to access the personal system.

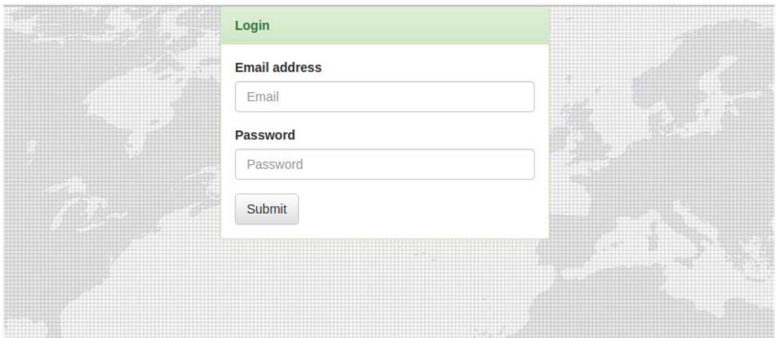


Figure 46: Login Interface

To log out from the website go to upper right side of the page, click the name of the current user and press **Log Out**.

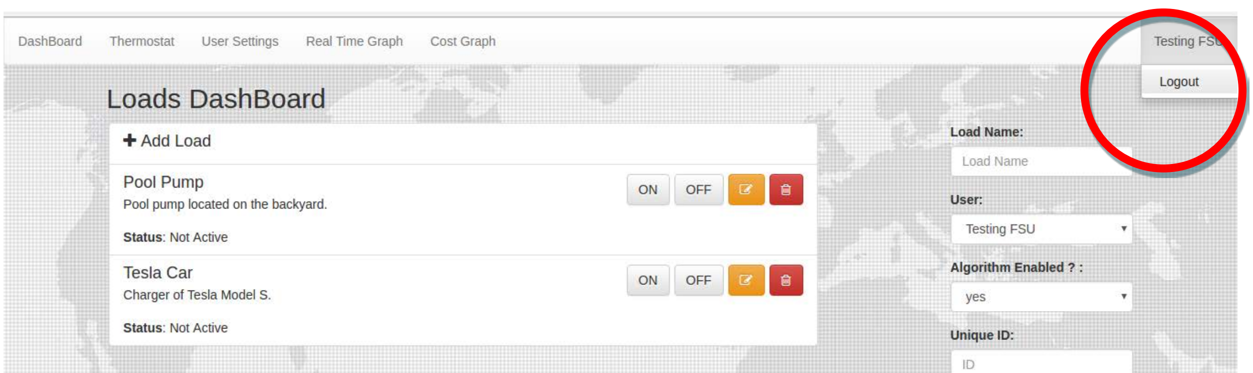


Figure 47: Logout from Web Application

Adding Loads

To add loads to the system, disconnect the load you wish to add to the system and connect it to a Load Controller box. Write down the ID located on the top of the Load Controller box, since it will be used later when added to the web application.

- Log in to the web application (create a profile if it's your first use – Click on create a new profile and follow the instructions).
- Click on **Load DashBoard** to access the dashboard where all your registered loads are displayed.
- Click on **+Add Load** and fill out the information located at the right side of the page.

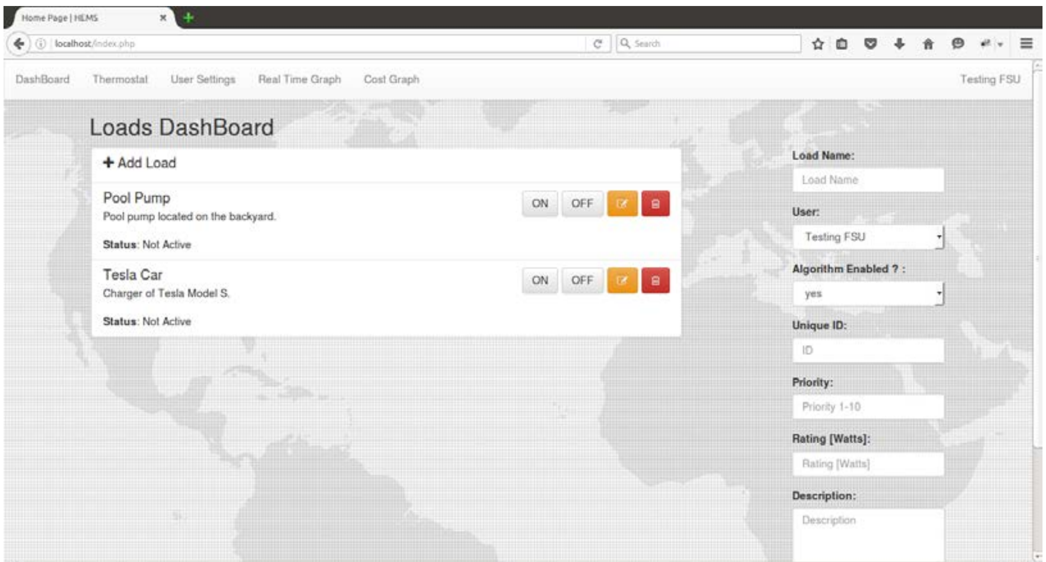


Figure 48: Load Dashboard

1. **Load name:** fill out with the name you want to give to the load.
2. **User:** Select the administrative user of the load.
3. **Algorithm Enabled? :** Select yes if you want the system to use the algorithm to turn on/off the load depending on the parameters specified: RTP, consumption, priority, etc…
4. **Unique ID:** fill out with the unique ID located on the front of the Load Controller box. It's important to use the correct ID number.
5. **Priority:** fill out with a number from 1 to 10. 1 is the lowest priority, 10 is the highest priority. Lower priority loads turn off first when using the algorithm response.
6. **Rating:** fill out with the specific power rating of the load you are connection to the Load Controller box. This information is necessary for a correct consumption calculation and algorithm response.
7. **Description:** fill out with a brief description of load you are connecting to the system. (Optional)
8. **Save/Update Button:** saves or updates the information of the specific load.
9. **Image Dropzone:** An image can be assigned to any load. Drag and drop the preferred image to the dropzone that appears below the Save/Update button.

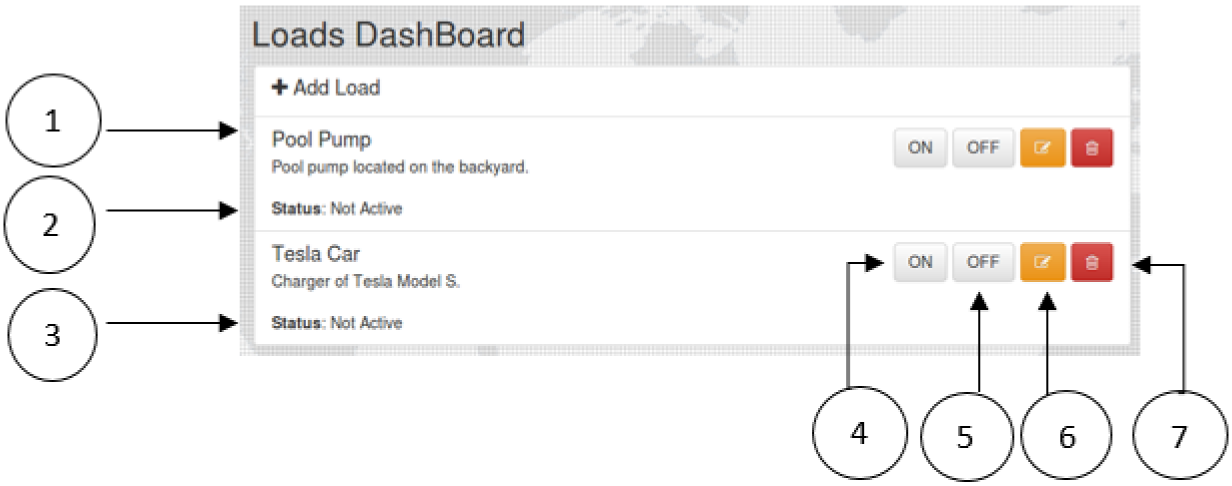


Figure 49: Details and Buttons

1. **Load name**
2. **Load description**
3. **Status:** Active/Not Active – tells the status of the load.
    a. **Active:** Load Controller box relay is ON (letting possible current to pass) and the load is drawing current. Load Controller is ON and Load is ON.
    b. **Not Active:** Load Controller box relay could be ON (letting possible current to pass) but the load is not drawing current. Load Controller is ON and Load is OFF.
4. **ON Button:** Press this button to turn ON the specific load.
5. **OFF Button:** Press this button to turn OFF the specific load.
6. **Edit Button:** Press this button to edit the information of the specific load.
7. **Delete Button:** Press to delete the specific load from the system.

Editing Loads

Press the **Edit** button to edit the information of the selected load. When the **Edit** button is pressed, the right side text boxes, containing the information of the selected load, are populated.

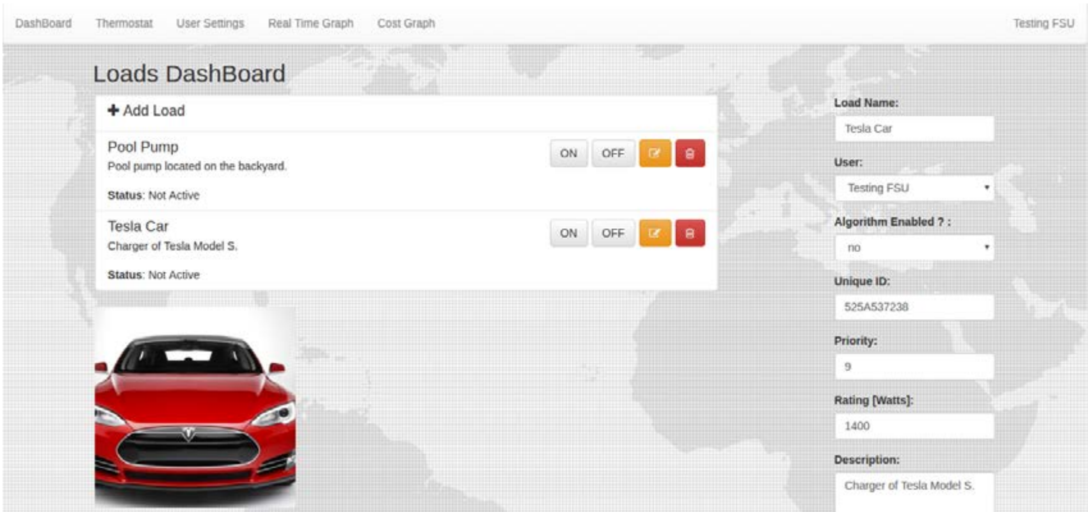


Figure 50: Loads Dashboard Editing Load with Images

When the **Edit** button is pressed, the image of the selected load will appear at the bottom of the load's list. This image is the one uploaded by the user using the Dropzone option.

Using the Thermostat Controller

Access the Thermostat section of the web application by clicking on **Thermostat.**

- **Thermostat Controller Interface**
  - To change the temperature, click on the **Up/Down** arrow.
  - **Set** indicates at which temperature the system has been set
  - **Current** indicates the current temperature of the home.

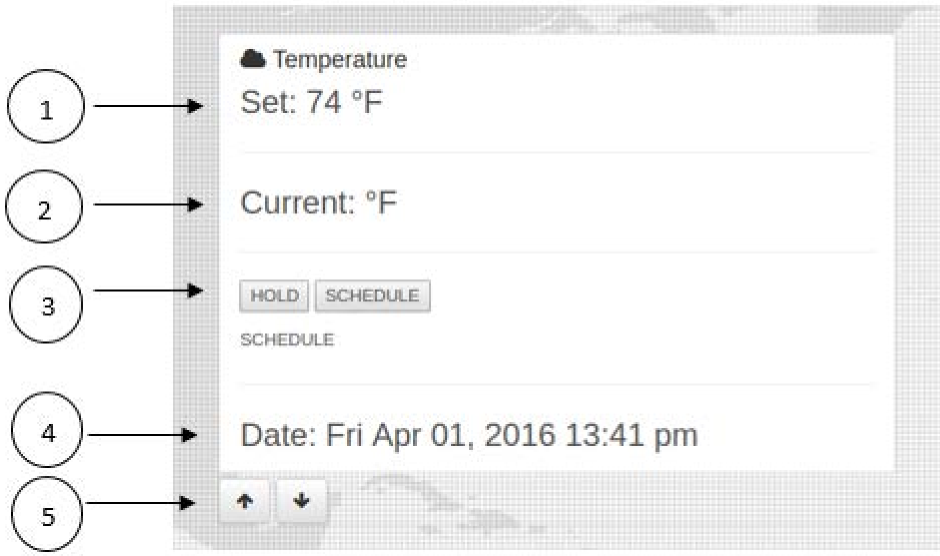


Figure 51: Thermostat Controller Interface

1. **Set:** temperature set on the system.
2. **Current:** current temperature of the home.
3. **Hold/Schedule:** Select the option that defines how the system will work.
    a. **Hold:** The system will maintain the **Set** temperature until changed to **Schedule**.
    b. **Schedule:** The system will run the schedule given by the user. For details in how to change the **Schedule** settings go to **Using the Thermostat Schedule**.
4. **Date:** shows the current date and time.
5. **Up/Down arrows:** Press the Up/Down arrows to change the **Set** temperature (desired temperature).

Using the Thermostat Schedule

The Schedule section offers the possibility of having up to 10 different scheduled temperatures at different times.

Setting up the schedule: to change a specific scheduled temperature, click the **Edit** button located at the right of the selected temperature. This will populate **the text boxes** located at the right side of the page. Change the settings to your preference and click **Update**. See Figure 21.

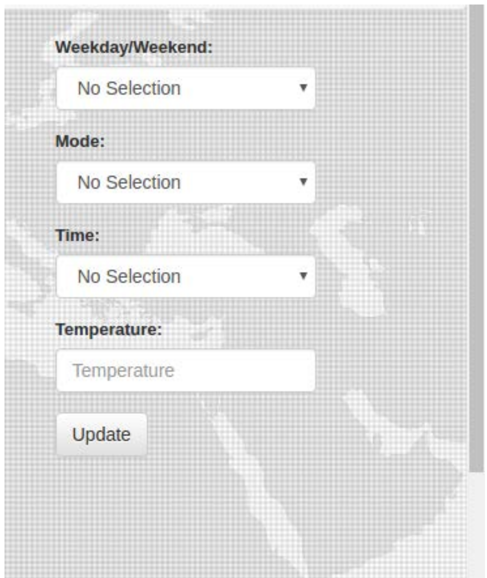
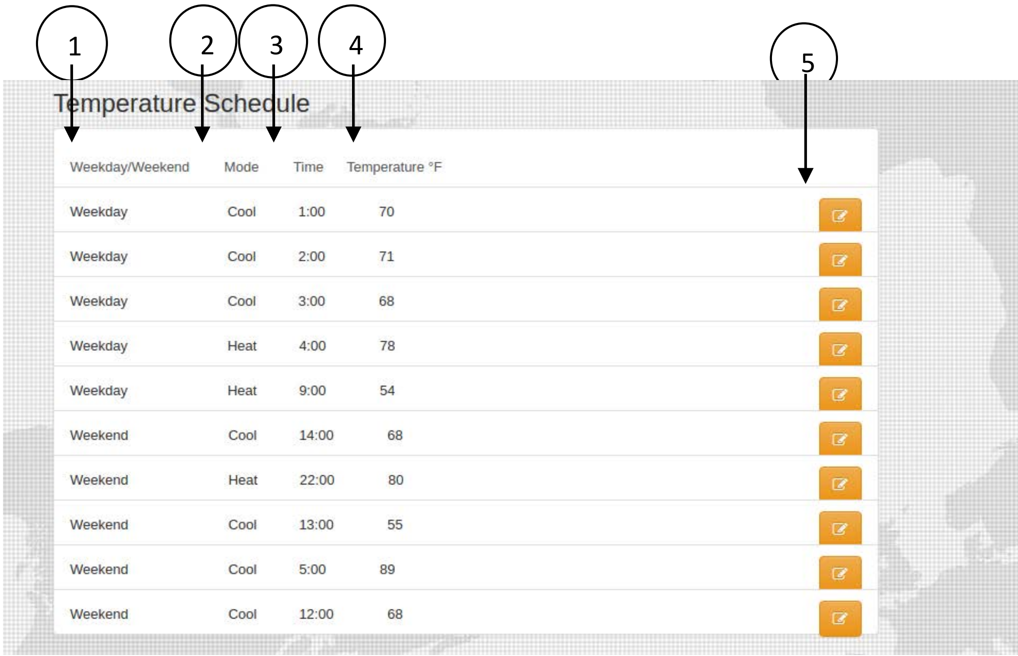


Figure 52: Edit Text Boxes



Weekday/Weekend	Mode	Time	Temperature °F	
Weekday	Cool	1:00	70	
Weekday	Cool	2:00	71	
Weekday	Cool	3:00	68	
Weekday	Heat	4:00	78	
Weekday	Heat	9:00	54	
Weekend	Cool	14:00	68	
Weekend	Heat	22:00	80	
Weekend	Cool	13:00	55	
Weekend	Cool	5:00	89	
Weekend	Cool	12:00	68	

Figure 53: Temperature Schedule

1. **Weekday/Weekend**
   a. **Weekday:** Monday – Friday
   b. **Weekend:** Saturday – Sunday
2. **Mode**
   a. **Cool:** Cooling mode.
   b. **Heat:** Heating mode.
3. **Time:** Select the Time for the scheduled temperature (1-24).
4. **Temperature:** Select the desired temperature for the selected time.
5. **Edit Button:** Press to change the settings for the selected temperature.

Thermostat Hardware Control:

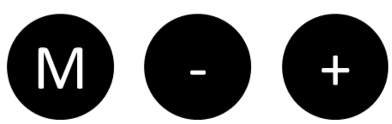


Figure 54: Thermostat Buttons

M: Press to enter Menu Mode and to cycle through the settings

- : Press to decrement Desired Temperature or decrement setting in Menu Mode

+ : Press to increment Desired Temperature or increment setting in Menu Mode

Thermostat Display:

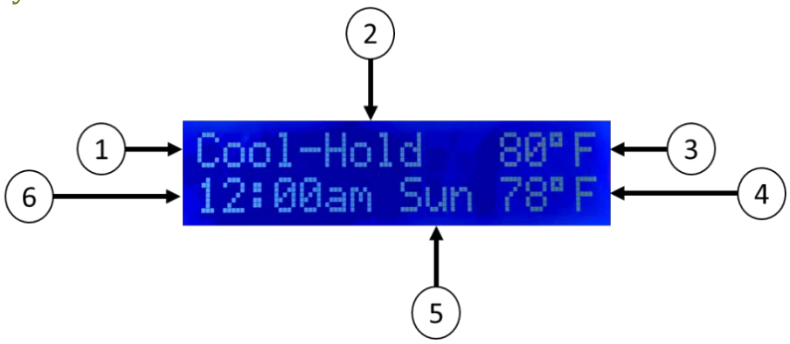


Figure 55: Thermostat Display 1

Figure 56: Thermostat Display 2

1. Cool or Heat
2. Hold or Schedule
    a. When Hold is selected, the thermostat will not utilize the schedule and the desired temperature can only be changed via the “+” and “-” buttons.
    b. When schedule is selected, the thermostat will execute the schedule that is set on the website. The temperature can be changed via the “+” and “-” buttons but will resume the schedule at the next set time.
3. Desired Temperature: This is the temperature that is desired by the user.
4. Actual Temperature: This is the ambient temperature as detected by the thermostat.
5. Day of the Week: Will be displayed using the first three letters of the day.
6. Time: Displayed using hh:mm format and utilizing am or pm.

Menu Mode:

In order to enter menu mode first press the “M” button. Once the button is pressed, the current selection will blink at approximately 1 Hz. In order to change the current selection utilize the “+” or “-” button. To move to the next setting press the “M” button again. When the current selection is the “Day of the Week” and the “M” button is pressed, Menu Mode is exited.

User Settings

Enter Maximum Monthly Price: Enter on the text box the value in $ (dollars) of the maximum price you want to pay per month and click **Send**. The system will store the specified value and perform its calculations based on it.

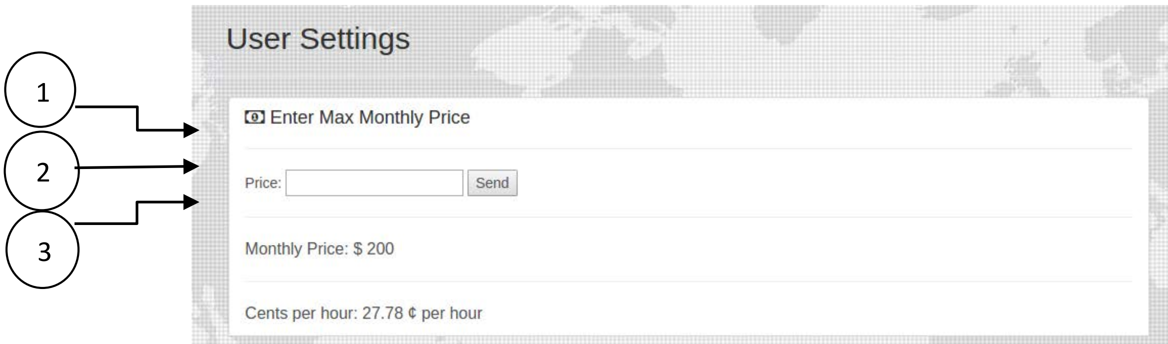


Figure 57: User Settings

1. **Price Text Box:** Enter the desired maximum price for the system.
2. **Maximum Monthly Price:** Display of the maximum monthly price entered.
3. **Maximum Price per Hour:** $\dfrac{\left(\dfrac{\text{Monthly price}}{30\text{ days}}\right)}{24\text{ hours}}$

Real-Time Price Graph

The web application offers users the opportunity to see the real-time price of electricity given by the utility company throughout the day (using a 24-hour span).

Figure 58: Real-Time Price Graph

Consumption Graph

The web application offers users the opportunity to see the historical consumption of electricity throughout the day (using a 24-hour span).

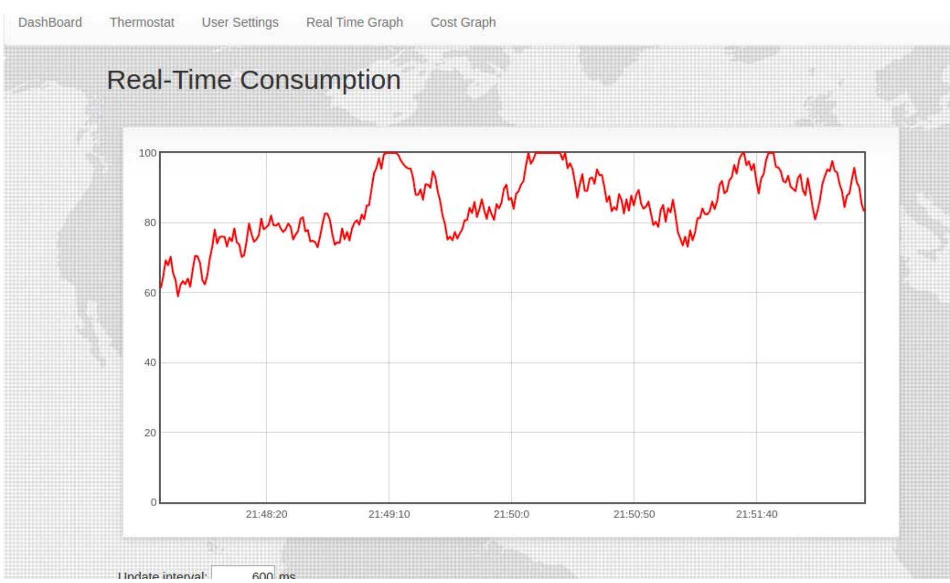


Figure 59: Consumption Graph

Important Safety Information

This appliance can be used by adults only and persons with reduced physical, sensory or mental capabilities or lack of experience and knowledge if they have been given supervision or instructions concerning use of the system in a safe way and understand the hazards involved. Children shall not play with the system. Cleaning and user maintains shall not be made without unplugging the component.

Read all safety and operating instructions before operating system.

- Retain the safety and operating instructions for future reference.
- Heed all warnings in the owner's manual.
- Follow all operating and use instructions.
- Do not use a load controller or thermostat with a damaged cord or plug. If the cord or plug is damaged, it must be serviced by the manufacturer or similarly qualified persons.
- Never handle the load controller or thermostat with wet hands.
- Please ensure voltage rating for enclosed load controller matches standard outlet voltage.
- Load controllers are for indoor use only
- Use load controller only in dry environments.
- Do not spray or pour liquids on load controller or thermostat

CAUTION: DO NOT REMOVE THE COVER OF LOAD/MAIN CONTROLLERS OR THERMOSTAT.

Troubleshooting & FAQ

How should I determine a load's priority number?

A priority 1 should describe a load that has the least amount of importance to your home because these will be the loads the algorithm decides to turn off first. For example, a general accent lighting could be a priority 1 while a more important accent lighting could be a priority 2. Ultimately, the user decides what they find more important.

Why is the load not responding?

1. Check to see if load is on the website. If not, refer the **Adding Loads** section for more information.
2. Make sure all connections are made and the power is supplied to the load controllers.
3. If the load is not being manipulated by the algorithm when it should be, it might not be *algorithm enabled* which can be defined for each load on the website.
4. Some loads might not have the correct priority and therefore do not turn off/on when reaching

How do I tell a load's wattage rating?

Usually most appliances have their wattage rating displayed in their manual. If not, a quick online search could find the wattage rating of most consumer appliances.

My thermostat is acting weird, what should I do?

Try unplugging it and plugging it back in. This will reset the thermostat module to its default settings. Time, temperature, schedule mode, and heat/cool will bet set to 12:00AM, 80 degrees, hold, and cool, respectively. From there you can use the menu button to reset these values with the correct values.

My router is not detecting the main controller, what should I do?

Try disconnecting the main controller from the router and unplug it from the wall. Wait 30 seconds and connect the cable to the router.

Networking: Port Forwarding Issues

See **Connect the main Controller to the outer network remotely** under **Setup Guide** and if you need more information go to the following website http://www.wikihow.com/Set-Up-Port-Forwarding-on-a-Router

For further questions, contact customer support at HEMSystemFSU@gmail.com

Conclusion

The absence of a decent energy management system is one of the reasons the energy industry is facing generation problems and high electricity demands. As stated before, real-time pricing of energy could be a solution to the energy crisis, if the data generated by the utilities companies is managed correctly. The solution proposed on this report attempts to use the RTP information provided by the utility company in order to help stabilize the supply and demand curve presented by the energy generation. Many companies have active development of state-of-the-art technologies that aim to use the RTP information generated by the utility companies in order to have full control of consumers' energy usage.

The HEM system develops an idea, similar to the state-of-the-art technologies, that gives the user the ability to control the energy usage by implementing a user friendly web application that communicates with the system developed. The system contains a main controller optimized with an automation algorithm that allows the user to personalize his own settings and have real-time control of the loads where the system is deployed.

So, why developed something similar to what's already being implemented by some of the leading companies in the industry? The answer is simple, the HEM team not only wants to give control of the energy usage to consumers, but also wants to implement a state-of-the-art software that will allow the automation of the energy demand from the user's perspective, giving them the ability to predefine their own personal settings for energy consumption allowing the automation of energy management to become a real possibility in the industry.

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