Enhancing Smart Grid Technology to the Consumer Level

The consumer and energy provider working together to reduce the effects of global warming.

Varnika Sinha

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2 ABSTRACT

Consumers often waste electricity because they use their appliances inefficiently, contributing to the spread of global warming. Smart grid, an innovative technology which helps utility companies monitor electricity generation and consumption, promotes the use of renewable energy in households to reduce the consumption of fossil fuels. The goal of this project was to engineer a consumer extension of smart grid, a device which accurately monitors the electricity consumption of household appliances and educates consumers on how to use electricity efficiently. The device, featuring a microcontroller and a current circuit, measures the consumer's electricity consumption safely and non-intrusively from the appliance wire. An app was developed with the device to entice consumers to learn about their electricity consumption, such as a preferred amount of electricity to use and optimal times to use their appliances to minimize fossil fuel consumption. The device was tested on a variety of appliances with different energy efficiencies. The measurements obtained by this novel device were compared to measurements obtained from commercially available instruments. The device is extremely accurate ($p=0.99511$). When utilized, this project increases consumer awareness and guides consumers to learn about and decrease their electricity consumption to reduce the effects of global warming.

3 INTRODUCTION: ENERGY AND ITS FUNDAMENTAL IMPACT ON SOCIETY

Energy is a vital human resource. Humans are constantly using energy. The human body requires energy derived from food to operate the necessary processes of life. Like the human body, machines also require energy. Machines rely on electricity to operate. In today's world, electricity is a necessary source of energy for humans. However, humans are destroying the earth in the process of collecting and utilizing this energy.

Often, consumers are unaware of how they are wasting electricity when using appliances. **Figure 1** shows the annual cost and the average amount of electricity consumed by the most common household appliances by consumers per year. Consumers typically use appliances at suboptimal times when electricity is in great demand. The primary time consumers use their appliances is during the evening, specifically from 6-8 pm (C. Lavertu, personal communication, August 26, 2016). During this time, the vast majority of electricity sent to consumer homes is generated by fossil fuels. The overexertion of fossil fuels is the primary cause of global warming (U.S. Department of Energy, 2016). Global warming is a huge problem. Climates are changing, and the balance of many ecosystems throughout the earth is becoming shattered.

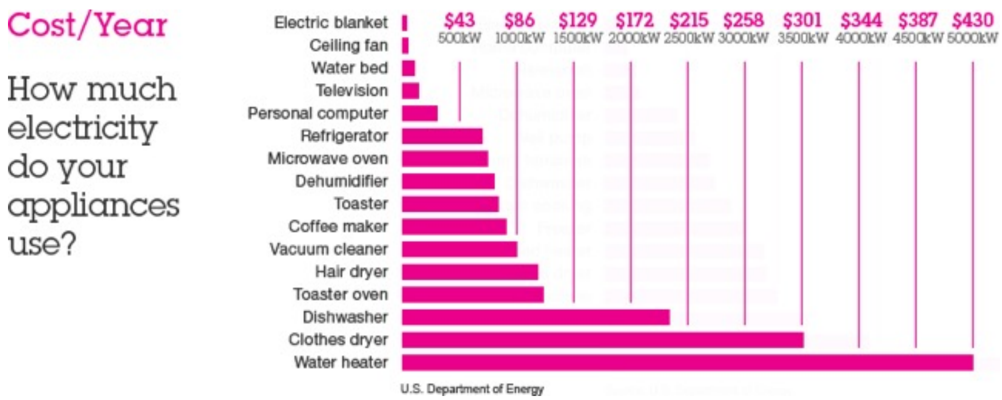


Figure 1: The graph above shows the cost (dollars) and the average electricity consumption (kWh) of the most common household appliances by consumers per year. Many consumers are unaware of the information displayed in the graph. (U.S. Department of Energy, 2016)

Renewable energy is promoted as a way to save the earth from the effects of global warming, but it is scarcely used in comparison to fossil fuels for generating electricity. Renewable energy is not integrated into many consumers' daily consumption of electricity (C. Lavertu, personal communication, August 26, 2016). Many consumers are unaware of how to use electricity wisely. This lack of awareness leads to overexertion of fossil fuels and minimization of renewable energy, both of which further the severity of global warming.

4 LITERATURE REVIEW

4.1 Electricity Generation

4.1.1 Energy Sources: When and How Much of Which Type

In order to fulfill a consumer's daily consumption, energy must be generated from a source that provides a potential of converting energy usable by humans. Planet Earth provides humans with many raw resources of energy that have the potential to be converted into usable energy. The primary types of electricity used by humans are thermal, nuclear, hydropower, photovoltaic, and wind (U.S. Department of Energy, 2016). **Figure 2** shows the percentage of each type of electricity used to generate electricity in the United States as of 2016.

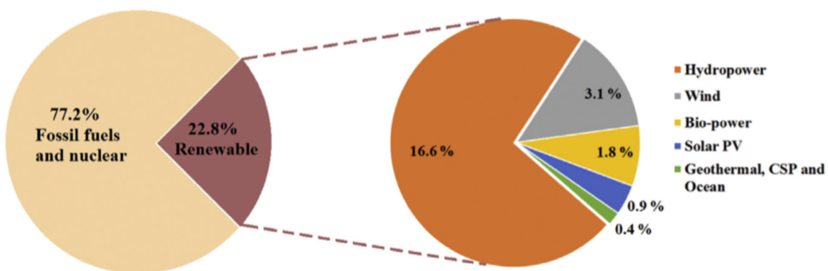


Figure 2: This chart displays the percent of each type of electricity used in the United States electricity generation. The pie chart on the left compares thermal energy to renewable energy, and the pie chart on the right compares the sources of renewable energy. (Ellabban and Abu-Rub, 2016)

Thermal energy is currently the most common method used to produce the world's electricity. Thermal energy is defined as raw resources that produce steam to turn turbines to generate electricity (Pierce, 2015). According to the U.S. Department of Energy, in 2015, the United States generated about 4 trillion kilowatt-hours (kWh) of electricity. About 67% of the electricity generated was from fossil fuels. Fossil fuels are a sub category of thermal energy. The electrical generation of fossil fuels is the leading cause of global warming.

When fossils fuels are used at electrical generation plants, these plants take raw materials such as coal, natural gas, and petroleum as fuel to heat water at high temperatures. These high temperatures produce steam which turns turbines to generate electricity. Excess materials, products from the chemical reactions, exit the plant as emissions. These emissions release harmful chemicals in the air which are harmful to humans and the earth. **Figure 3** displays the greenhouse effect using carbon dioxide as an example for an emission. The greenhouse effect is the process where excess energy heats up the earth to eventually high temperatures not suitable for life. The greenhouse effect subsequently causes global warming.

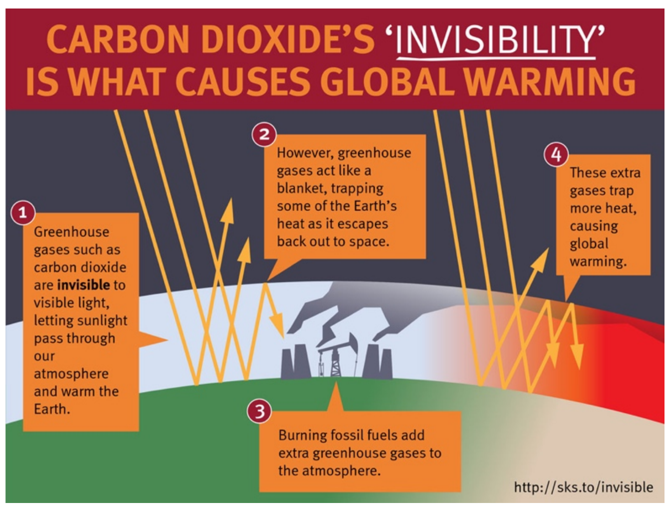


Figure 3: This figure selects carbon dioxide, one of the well-known emissions produced by fossil fuels, as an example to show how the greenhouse effect subsequently causes global warming. (Cook, 2013)

4.1.2 Renewable Energy Potential: Ways to Make Earth Cleaner

Renewable energy is a viable alternative to thermal energy. Renewable energy is a cleaner, more versatile, and more abundant resource than thermal energy. In fact, renewable energy is unlimited and can be found almost anywhere on Earth. However, it is less used than thermal energy. Renewable energy is underutilized in human electricity consumption (C. Lavertu, personal communication, November 23, 2016).

The main types of renewable energy are hydropower, photovoltaic (solar), and wind. These resources are constantly replenished on Earth. Harnessing renewable energy is much easier than harnessing thermal energy. These resources are also cleaner because they produce no harmful by products that would greatly affect the earth at large (Cook, 2013).

In **Figure 4**, a map of solar energy is shown. This map predicts the amount electricity harnessed kWh/m^2 if utilized. A lot of this energy is left unutilized simply because utility companies don't harness it. Solar energy is one of the most promising renewable energy sources (Pierce, 2016). Upon careful examination of **Figure 4**, solar energy has a lot of potential to be harnessed in developing countries. The most concentrated patches of solar energy are around the equator, where coincidentally, there are a lot of developing countries. Developing countries have problems with generating sufficient electricity to fulfill the necessary requirement of using electricity (Ellabban and Abu-Rub, 2016). If this solar energy shown in **Figure 4** was utilized, the developing countries within this area would have no problems in generating sufficient electricity.

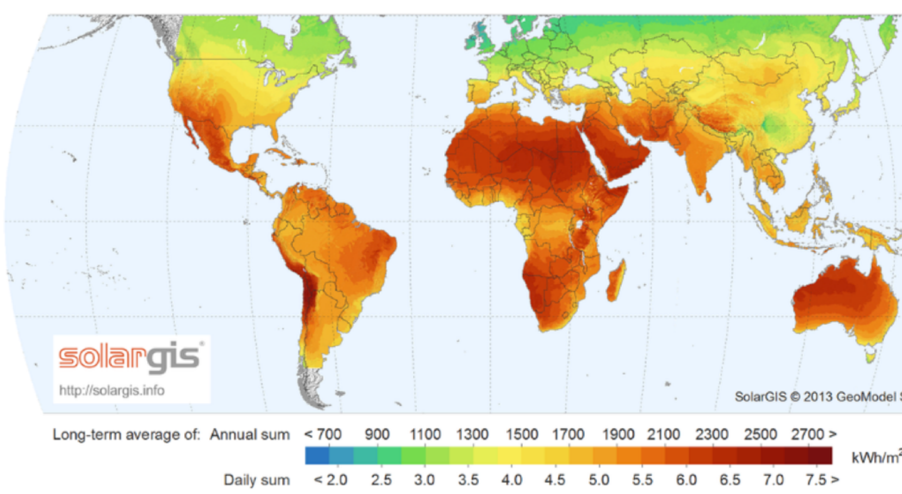


Figure 4: Map of predicted electricity generation if all solar energy was harnessed. (Solargis, 2016)

4.2 Household Power

After electricity is generated at electrical generation plants, the electricity is transferred through a system similar as displayed in **Figure 5**. Because there are third parties involved between the path electricity takes to get from generation plants to the consumers' homes, it is often difficult for consumers to understand how much electricity they are using. They are unaware of how much electricity is generated because they are not directly interacting with their electric supply (McNally, 2013).

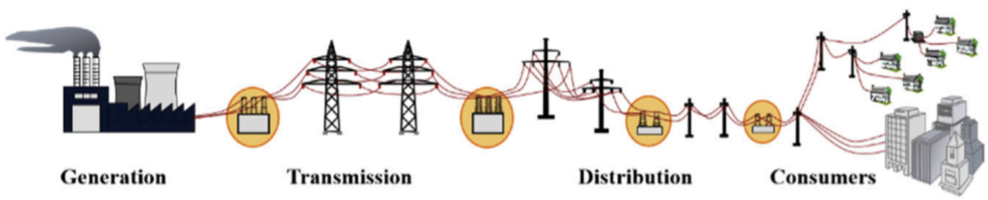


Figure 5: The figure above shows the path electricity takes from the generation plant to consumers' homes. (Ellabban and Abu-Rub, 2016)

To travel from generation plants to consumers' home, electricity must be converted into high voltages in order to travel quickly on the transmission lines. Electricity when generated is around 110 volts to 120 volts in the United States, but when it must be transferred it increases to 10,000 volts. The increase in voltage helps transfer huge amounts of electricity in short bursts of time. When electricity reaches the consumers home, it returns to the 110-120 volt range for the consumer to use safely (McNally, 2013).

Electricity flows in two ways, direct current (DC) and alternating current (AC). Direct current is when electricity is flowing in only one direction. When traveling from generation plants to consumers' homes, electricity is in DC, but when it reaches consumers' homes it converts to AC. Alternating current is when electricity is flowing in both directions. AC is safer for the consumer to handle because current is flowing in both ways, causing its charge to cancel out and prevent consumers from being shocked when handling their appliances.

But, because the charges cancel out in AC, electricity consumption becomes harder to monitor. **Figure 6** displays how AC flows in households (McNally, 2013).

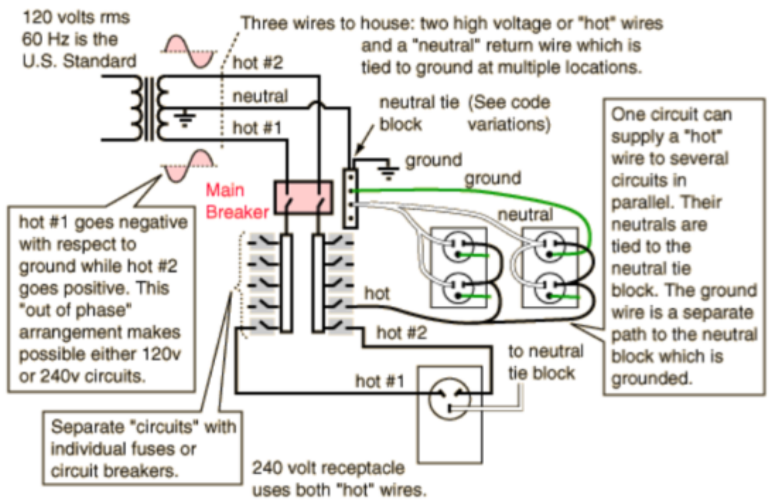


Figure 6: The figure above shows how electricity flows inside a consumer's house.

In order for electricity to be monitored, AC must split into DC. This split is possible because, as shown in **Figure 7**, AC wires have two DC wires. They consist of a ground wire that lets electricity into the household, a power wire that lets electricity out, and a neutral wire to neutralize the current. This system makes electricity monitoring possible (McNally, 2013).

4.3 The Current Power Grid

The current electric system is more than 100 years old and is in desperate need of modernization. The grid must change with expanding consumer expectations, increasing environmental regulation, and new technology (C. Lavertu, personal communications, November 23, 2016). Utility companies must find ways to improve service and meet their consumers' energy needs in a smart way (SGCC, 2016). Renewable energy must be implemented in order to effectively improve the grid. Smart grid can help solve these energy problems (C. Lavertu, personal communications, August 26, 2016).

4.4 Implementation of Smart Grid Technology

Recent technological advances in the energy grid and home meters now allow consumers to waste less and control the energy they consume (SGCC, 2016). Specifically, smart grid technology helps the utility industry determine when and how much of which type of electricity to use.

Smart grid is the evolution of the current electrical grid, utilizing modern technology to optimize the conservation and delivery of power. This technology promises to increase the efficiency of the current system by around 9% by 2030, annually saving more than 400 billion kilowatt-hours. With this technology, American consumers can save up to $42 billion in a single year (SGCC, 2016).

Many factors are involved in the electrical market and power pricing. **Figure 7** displays the components of an ideal smart grid. Electricity is more expensive during higher demand times, generally at hours between noon and evening during the middle of the week. During these specific times, high demand causes electricity rates to go up exponentially. This spike in electricity rates is because of the lack of electricity generation capability and availability. The current system relies on building and maintaining expensive power plants which sit idle most of the time. Smart grid allows direct communication with power equipment to reduce the demand during peak periods, lowering the need for costly power plants (SGCC, 2016).

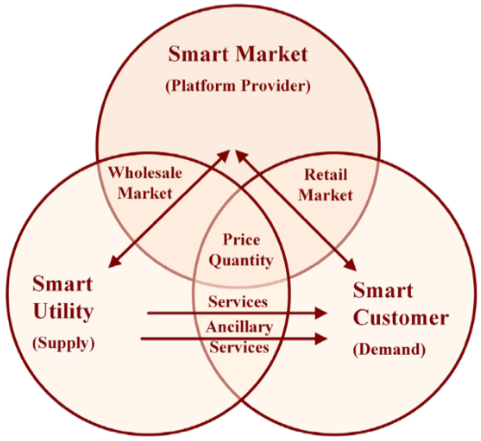


Figure 7: This Venn diagram displays how an ideal smart grid operates based on three pillars: smart market, smart utility, and smart costumer. Smart utility represents the efficient supply of energy, whereas smart customer represents the educated and aware consumer utilizing the supply of energy. Smart market controls these groups to provide the optimal price and quantity overall. (Ellabban and Abu-Rub, 2016)

Smart grid ensures that renewable power sources like wind farms and solar plants can be integrated into the grid (C. Lavertu, personal communications, November 23, 2016). Smart grid can enable the gird to rely more heavily on clean renewable energy. This implementation, in turn, will cut the environmental damage done by fossil fuels (SGCC, 2016).

Smart Grid provides potential benefits based on the opportunities for eliminating energy waste, lowering electricity costs, reducing environmental impacts, and improving power efficiency, safety, reliability, and quality (SGCC, 2016). Smart grid helps guarantee America's future by getting energy usage under control now. According to the U.S. Department of Energy, the “Environmental Defense Fund does not advocate merely any smart grid; they advocate a smart grid done right.”

4.5 Consumers: Awareness and Education of Electricity Consumption

Smart grid's energy management also helps families spend their money more wisely. The implementation of smart grid technology could result in $600 of savings for the average household each year. This implementation gives consumers control over their power bill by making it possible to monitor electricity and adjust their energy consumption (SGCC, 2016).

Smart grid also tracks when and how much the consumer uses electricity at home and helps the consumer identify ways to waste less energy. This method puts more money into the consumer's pocket and creates a cleaner planet. Real-time pricing information helps consumers reduce their electricity costs 10% on average and their peak consumption by 15% (Shannon, 2015). Ellabban and Abu-Rub suggest that if consumers are given the ability to monitor their energy use more frequently in greater detail, many may make energy saving changes, such as turning off unneeded appliances.

5 ENGINEERING PLAN

5.1 Engineering Problem

Consumers are unaware of wasting electricity when using appliances. This misuse causes consumers to use electricity inefficiently which leads to overexertion of fossil fuels and minimized utilization of renewable energy and furthers global warming.

5.2 Engineering Goal

The goal of this project was to engineer a device that could monitor and display the electricity usage per appliance and ensure the consumer is received accurate data to help the consumer use electricity efficiently.

5.3 Project Charter

This project built a sensor to read electricity from each appliance and display on smart device. This prototype will help the consumer use electricity smartly, such as conserve electricity and buy energy efficient appliances. With less fossil fuel and thermal used to generate electricity and efficient utilization of electricity, this sensor helps reduce the effects of global warming

5.4 Procedure

5.4.1 Development

The sensor included an Arduino board that is programmed to measured the voltage through its inboard voltmeter and received a measurement from the attached split core transducer to measure current. The code calculated power based on the readings for voltage and current. After generating a value for power, the Arduino sent the data collected to an app through the Intel Edison, a WiShield and Bluetooth.

5.4.2 Design Criteria

1. High Safety
2. User-Friendly App
3. Accurate Electricity Usage Readings
4. High Data Sending Speed
5. High Availability/Accessibility

5.4.3 Testing

The prototype's sensor was tested against the accuracy and precision of the commercial instrument, Kill-A-Watt. The prototype's success was measured on how well the sensor and the app communicate to each other.

6 METHODOLOGY

6.1 Materials

Table 1 below contains all the materials used during the experimentation of this project.

Table 1: List of Materials

Name of Item/Short Description (Amount)	**Brand/Place of Purchase**	**Cost**
Intel Edison + Arduino Breakout Board (1) - Dual-core CPU and including an integrated WiFi and Bluetooth LE - Digital pins 0 to 13 (and the adjacent AREF and GND pins), analog inputs 0 to 5, the power header, ICSP header, and the UART port pins (0 and 1) - Micro SD card connector, micro USB device port connected to UART2, and micro USB device connector and dedicated standard size USB 2.0 host Type-A connector	SparkFun Electronics	\$24.95
Non-Invasive Current Sensor (CT) Sensor (1) - 30 A max load - No load (burden) resistor built in	SparkFun Electronics	\$9.95
Resistor Assortment Packet (610) - All common resistors from 10 Ω to 10M Ω (Did not use all)	You-do-it Electronics	\$9.90
Jumper Wires Premium 4” M/M (30) (Did not use all)	SparkFun Electronics	\$1.45
Diodes IN4004 (20) - Maximum voltage 400 V - Maximum current 1 A (Did not use all)	RadioShack	\$1.99
IC (Integrated Circuit) LM358N	RadioShack	\$5.98
10 μF Capacitor (2) - Maximum voltage 50 V - 20% Radial	RadioShack	\$2.98

6.2 Safety Procedure

Before any true experimentation and testing was done, all parts underwent a safety test to make sure the user was safe when using the equipment. Whenever using any of the equipment, the user had a slight risk of contacting improperly contained electricity.

At the start of every experiment, the Intel Edison and Arduino Breakout Board was always tested with a code to ensure electricity was flowing correctly in the right direction and to check if the board had any damage before beginning. This code is presented in Appendix 1A. Based on the inboard LED, if the code ran successfully, the LED should have been on. Fortunately, the board was deemed safe before every experiment.

The non-invasive current sensor was regularly checked for loose wire insulation and was fitted accordingly if deemed unsafe. The insulation of the current sensor covered the entire expanse of the wire, except at the ends.

Resistors were routinely checked for overheating to ensure the success of the circuit. Any resistors that felt warm in comparison to others were taken out and checked for damage. If the resistor was in good order, the circuit the design was checked to see if there were any loose connections. Based on the assessment of the problem, a damaged resistor was replaced by a new resistor of the same value, and loose connections were fixed.

Before running the code, the jumper wires were also checked for loose insulation and loose connections and fixed accordingly.

If all the equipment above passed the safety test, or they were modified and passed the safety test, experimentation and testing began.

6.3 Prototype1

6.3.1 Development

The following circuit design in **Figure 8** was proposed after researching commercial instruments and previous attempts to monitor energy consumption.

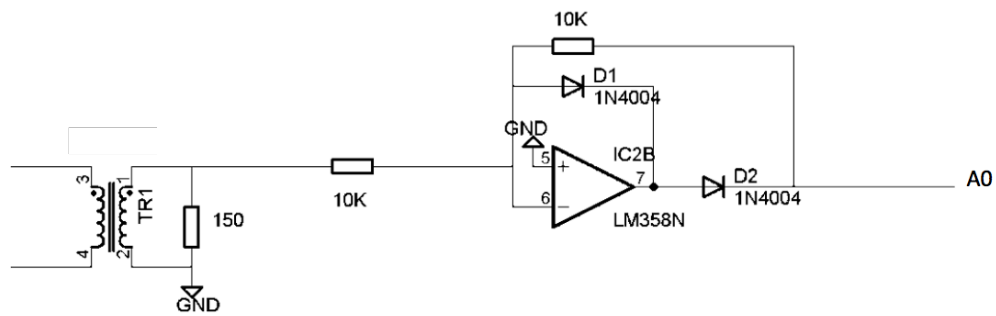


Figure 8: This circuit design uses a burden resistor of 150 Ω and uses an integrated circuit (IC) to improve the accuracy of current readings. (McNally, 2013)

TR1 in **Figure 8** was the split core current transducer used. The diagram was followed carefully and precisely. It was replicated on a breadboard. Lines are just jumper wire connections. Rectangles are resistors. The small triangles with perpendicular lines connected to the right are diodes. The large triangle is an integrated circuit (IC). The numbers written next to the lines extending from the IC symbol are the pin numbers of the IC that the wires must be connected to. Labels for the type of diodes and IC used are located at the bottom right of the symbols. Unless there is a dot where multiple lines converge, the wires were not in a junction. The split core's positive wire was put into the positive rail, and the split core's ground wire was put into the ground rail. A0 was the pin the circuit was connected to on the Intel Edison.

Code was also written in the Arduino environment for the Intel Edison to run when connected to the circuit. This code is displayed in Appendix 1B. The code was written with respect to the value it received from the Intel Edison from pin A0. The split core sent a value through the circuit, which changed for accuracy going through the resistors, diodes, and IC, and finally sent a value to the Intel Edison. Using Arduino-stored functions, like analogRead(), the value was manipulated into a value in amps out 1023; this value was divided 1023 to calculate the number of amps used.

6.3.2 Testing

The commercial instrument Kill-A-Watt was selected to compare to the prototype due to its invasive nature. Invasive devices provide a better accuracy for reading current since it is in direct contact with the outlet. The Kill-A-Watt was plugged into an outlet in between the outlet and the appliance wire and displayed its data on its LCD. The split core was put over the appliance wire and the device sent data to the computer where it was displayed on Arduino's serial monitor. The appliances chosen for this experiment were a desk lamp with an energy efficient LED lightbulb, a desk lamp with a traditional incandescent lightbulb, a toaster, and a microwave. The appliances were turned on and off, and 50 samples were collected in each phase. A one sample t-test was chosen as the statistical analysis test to be performed. Because the data displayed on the Kill-A-Watt was a constant in both phases, the value the Kill-A-Watt displayed was taken as the known or predicted value. The data displayed by the device was the sample set.

6.4 Prototype2

6.4.1 Development

After testing the first circuit design, more research was conducted to find a more accurate circuit design. The following circuit design in **Figure 9** was proposed after seeing it several times in several different papers (Barnicha, 2015; Evans, 2015; Mohamad, 2014). Because each circuit had slight modifications, **Figure 9** was developed as the general circuit.

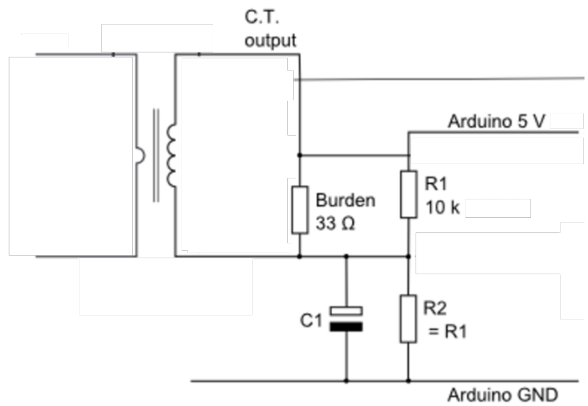


Figure 9: This circuit design uses a burden resistor of 33 Ω and uses a capacitor to improve the accuracy of current readings. (Barnicha, 2015; Evans, 2015; Mohamad, 2014)

C.T. output in **Figure 9** was the split core current transducer used. The diagram was followed carefully and precisely. It was replicated on a breadboard. The same symbols explained for **Figure 8** also apply for **Figure 9**. Also, the capacitor is represented as a white box on top and black box on bottom. This symbol indicates the capacitor must be in the position where white is power and black is ground. Instead of using the A0 pin, the 5V pin was used. There was no difference in using the A0 pin or the 5V pin, but the final prototype will use the A0 pin.

Code was also written in the Arduino environment for the Intel Edison to run when connected to the circuit. This code is displayed in Appendix 1C. The code was written with respect to the value it received from the Intel Edison from pin 5V. The split core sent a value through the circuit, which changed for accuracy going through the resistors and the capacitor, and finally sent a value to the Intel Edison. A library called EmonLib was created to calculate current. The library code is shown in Appendix 1D. The value sent through the Intel Edison was used in the function calcIrms(), which would return a value in amps to the consumer.

6.4.2 Testing

The same testing for Prototype1 was implemented for Prototype2.

6.5 App1

6.5.1 Development

When developing the app, the graphical user interface (GUI) was designed to be user-friendly. The coding was heavily focused on this aspect of the app. All the components were located on one tab for easy user navigation. The components that were included are shown in **Table 2**. The code is shown in Appendix 1E.

Table 2: Graphical Components

Component Name	Units
Power Now	W
Use Today	kWh
Use per hour	kWh
Use per day	kWh
Cost Now	$, €, £, ¥ (Consumer can select in settings)
Cost Today	$, €, £, ¥ (Consumer can select in settings)
Cost per hour	$, €, £, ¥ (Consumer can select in settings)
Cost per day	$, €, £, ¥ (Consumer can select in settings)
Suggested Times	HH:MM-HH:MM
Suggested Goal	W, kWh
Percentage of Goal Used	%

In addition to displaying these graphical components, the app needed to be connected to the circuit to stream live data. Intel Edison's WiFi needed to connect with the app to send data from the circuit. Terminal commands were used to configure and connect the WiFi to the app. These terminal commands can be found on Intel Edison's manual guide on the Intel website. A web server was utilized to keep data in the cloud when the Intel Edison sent data over Wi-Fi. The web server had an application program interface (API) key, which the app would connect to stream live data.

After configuration, the app as shown in **Figure 10** displays the data collected from the circuit in real time.

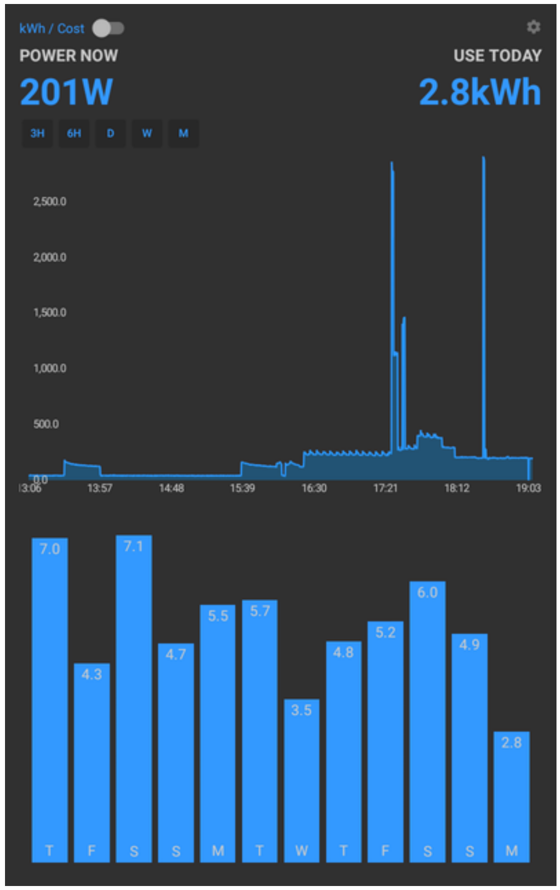


Figure 10: App streaming live data from the circuit. The user is shown how much power they are using.

6.5.2 Testing

To test how well the app streamed live data from the circuit, the speed at which the data was collected and displayed on the circuit was compared to the speed the data was displayed on the app. The data on the app was also checked to make sure it displayed the same values on the circuit.

7 RESULTS

7.1 Overview

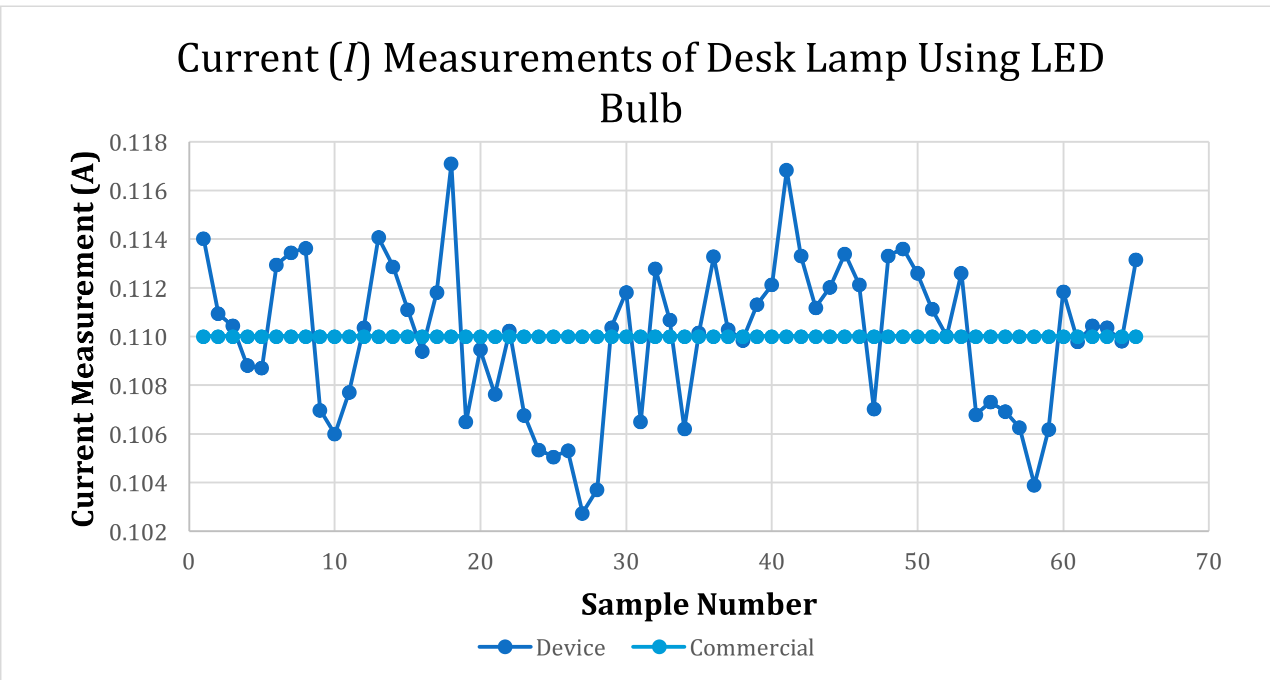
To insure the device was of expected quality as expressed in the specified design criteria, the device was tested on a variety of appliances with different energy efficiencies. The measurements of this novel device were compared to measurements obtained by commercially available instruments. The measurements were the current and power readings of the appliance as displayed on the device and commercial instrument. Because power is dependent on current, only current is displayed in this paper. When collecting the measurements, both the device and the commercial instrument were connected to the same appliance and collected measurements at the same time, resulting in the same number of samples. The appliances tested were a desk lamp with an LED, CFL, and incandescent bulb, a hair dryer at high and low, a toaster, a television when on and off, and a washing machine washing a small load.

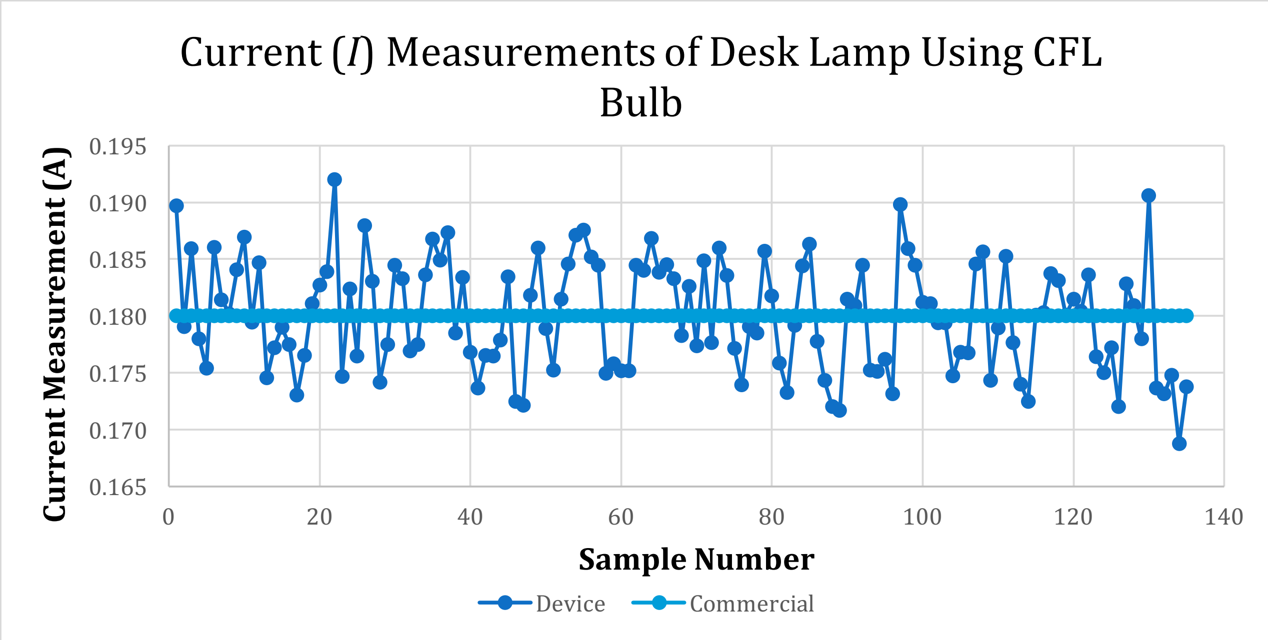
The selected commercial instrument chosen was the Kill-A-Watt. The Kill-A-Watt was chosen because of its popularity among consumers and electricians and its intrusive nature. Intrusive instruments are regarded as more accurate instruments than non-intrusive instruments because they are in direct contact with electricity, resulting in more accurate measurements of voltage and current. Appendix 2 includes more information about the Kill-A-Watt. One of the device's criteria is to have the same accuracy as an intrusive instrument while staying non-intrusive.

Appendix 3 shows the full table of measurements collected during the experiment with all appliances of all energy efficiencies.

7.2 Desk Lamp

A desk lamp was one of the appliances used to test the device's accuracy in comparison to the commercial instrument's accuracy. To change the energy efficiency of the desk lamp, three light bulbs were used. All light bulbs used were maximum 60-watt light bulbs that used 120 volts. The three bulbs used were a LED (Light Emitting Diode) bulb, a CFL (Compact Fluorescent) bulb, and an incandescent bulb with power usage of 9.5 watts, 14 watts, and 60 watts respectively. The lamp was turned on for each bulb with the device and the commercial instrument connected to collect measurements. **Figure 11** shows the measurements collected for each bulb.





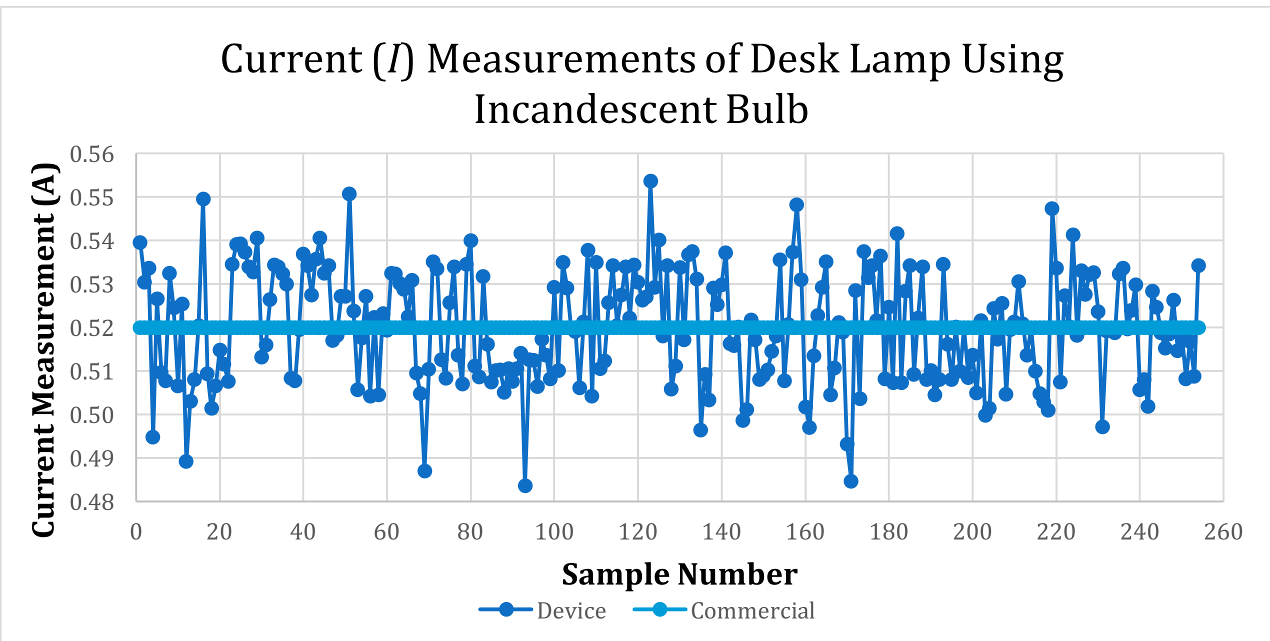
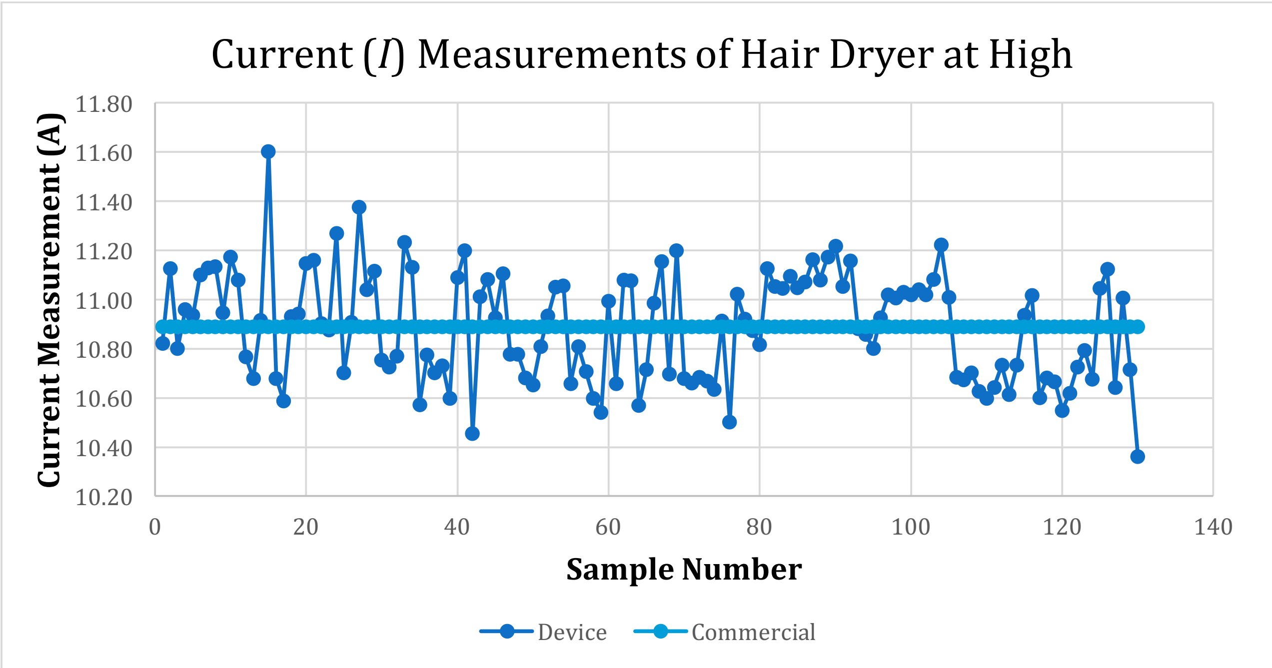


Figure 11: The current measurement displayed by both the device and commercial instrument when the desk lamp is using each of the three light bulbs.

7.3 Hair Dryer

A hair dryer, specifically the Windmere 1625, was another appliance used to test the device's accuracy against that of the commercial instrument's. The Windmere 1625 had two settings, a high and a low. **Figure 12** plots the current measurements for both the device and the commercial instrument when the Windmere 1625 is set to high and low.



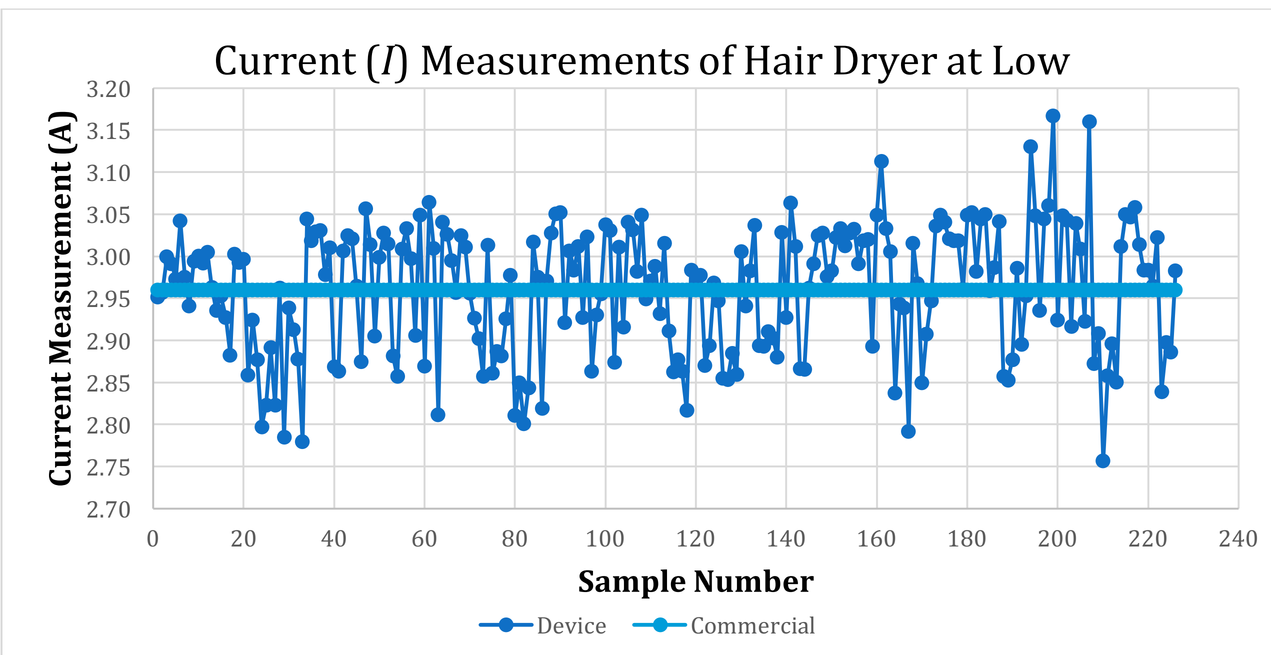


Figure 12: The current measurement displayed by both the device and commercial instrument when the Windmere 1625 is at the setting "high" and "low."

7.4 Toaster

An average toaster was another appliance used to test the device's accuracy against that of the commercial instrument's. **Figure 13** shows the current measurements for both the device and the commercial instrument for the toaster.

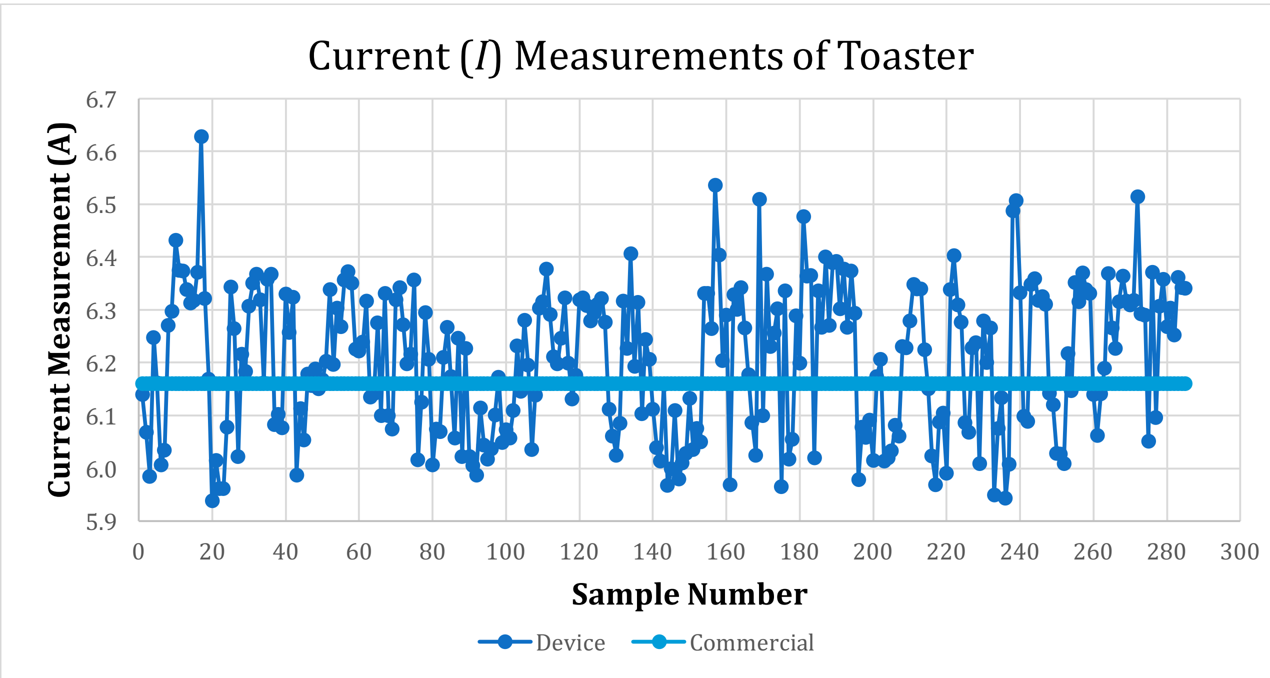
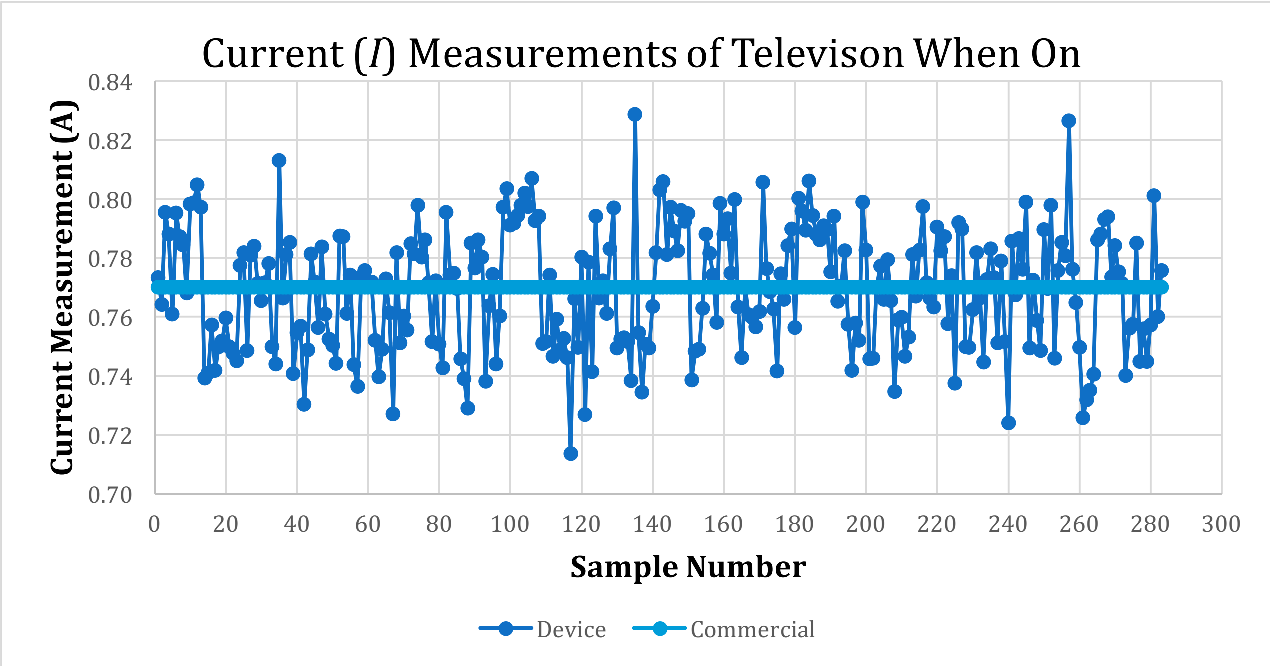


Figure 13: The current measurement displayed by both the device and commercial instrument for the toaster.

7.5 Television

A 60-inch Sony LCD Television was another appliance used to test the device's accuracy against that of the commercial instrument. The television was turned on and off. **Figure 14** shows the current measurements for both the device and the commercial instrument for when the television was on and off. Note that when the television is off, it is consuming phantom power. When certain appliances are off but still plugged in, they draw electricity from the outlet. Phantom power is an example of wastage of electricity by the consumer.



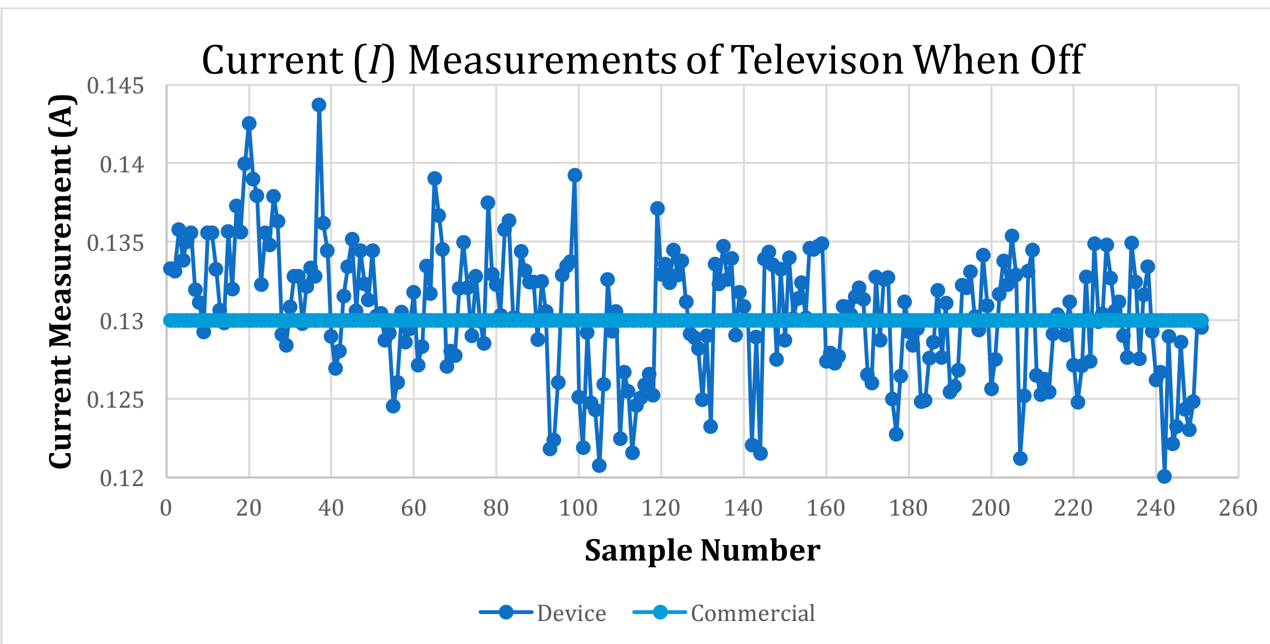


Figure 14: The current measurement displayed by both the device and commercial instrument for when the television is on and off.

7.6 Washing Machine

An average washing machine was another appliance used to test the device's accuracy against that of the commercial instrument's. To conserve energy during the experiment, a small load was washed when using the washing machine. **Figure 15** shows the current measurements for both the device and the commercial instrument for the washing machine.

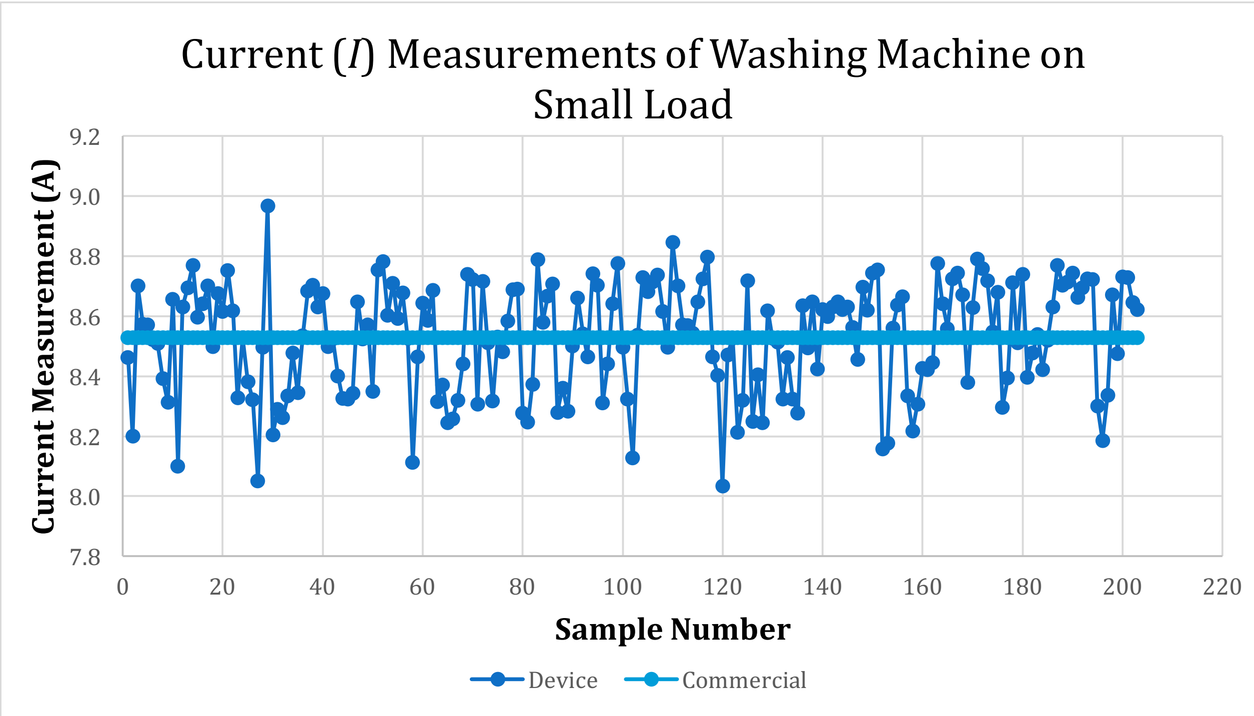


Figure 15: The current measurement displayed by both the device and commercial instrument for when the washing machine is washing a small load.

8 DATA ANALYSIS AND DISCUSSION

8.1 Overview

The measurements collected by the device were analyzed using a one-sample t-test. This method of analyzing the data allowed for the comparison between the device and known measurements obtained from the commercial instruments. Electricians consider the commercial instrument, the Kill-A-Watt, to be one of the most accurate electricity monitors. The Kill-A-Watt displayed only one value for each appliance with each energy efficiency rate. Thus, the measurements of the selected commercial instrument became the known or predicted value in the t-test.

For each appliance with each energy efficiency rate, the null hypothesis and alternate hypothesis was formed as:

H_0: There is no difference between the measurements obtained from the novel device and the measurements obtained from the commercial instrument, Kill-A-Watt.

H_1: There is a difference between the measurements obtained from the novel device and the measurements obtained from the commercial instrument, Kill-A-Watt.

If the prototype was recording values similar to the Kill-A-Watt, the p-value obtained from the t-test would be close to one. A precise and accurate prototype would result in failure to reject the null hypothesis and a high a p-value. For the purposes of this project, the device would be considered successful only if the p-value achieved for all appliances of all energy efficiencies was more than 0.5.

The t-test was performed using Microsoft Excel. The function used was T.TEST(data1, data2, 2, 2). data1 was replaced with measurements collected from the device and data2 was replaced with measurements obtained from the commercial instrument. The first two in the parameters denotes a two-tailed t-test. The second two in the parameters represents the type of test selected, which was one-sample. Assumptions made with the data are shown in Appendix 4.

8.2 Desk Lamp

The measurements collected from both the device and the commercial instrument, as shown in **Table 11,** were pasted into a Microsoft Excel document. A t-test was performed on the measurements collected from each individual bulb. The function returned a p-value of more than 0.05 for each bulb. The device when measuring the LED bulb returned a p-value of 0.99407. The device when measuring the CFL bulb returned a p-value of 0.99774. The device when measuring the incandescent bulb returned a value of 0.99515.

8.3 Hair Dryer

The measurements collected from both the device and the commercial instrument, as shown in **Figure 12,** were pasted into a Microsoft Excel document. A t-test was performed for the measurements collected both when the hair dryer was at the high setting and when the hair dryer was at the low setting. For the hair dryer, the function returned a p-value of more than 0.5. The device when measuring the hair dryer at high returned a p-value of 0.99670. The device when measuring the hair dryer at low returned a p-value of 0.99724.

8.4 Toaster

The measurements collected from both the device and the commercial instrument, as shown in **Figure 13,** was pasted into a Microsoft Excel document. A t-test was performed on the measurements collected from the toaster. For the toaster, the function returned a p-value of more than 0.5. The device when measuring the toaster returned a p-value of 0.99747.

8.5 Television

The measurements collected from both the device and the commercial instrument as shown in **Figure 14** was pasted into a Microsoft Excel document. A t-test was performed for the measurements collected both when the television was on and when the television was off. For the television, the function returned a p-value of more than 0.5. The device when measuring the television on returned a p-value of 0.99816. The device when measuring the television off returned a p-value of 0.98583.

8.6 Washing Machine

The measurements collected from both the device and the commercial instrument as shown in **Figure 15** was pasted into a Microsoft Excel document. A t-test was performed on the measurements collected from the washing machine when washing a small load. For the washing machine, the function returned a p-value of more than 0.5. The device when measuring the washing machine returned a p-value of 0.99469.

8.7 App

The final product of the app is shown in **Figure 16** with its key features highlighted.

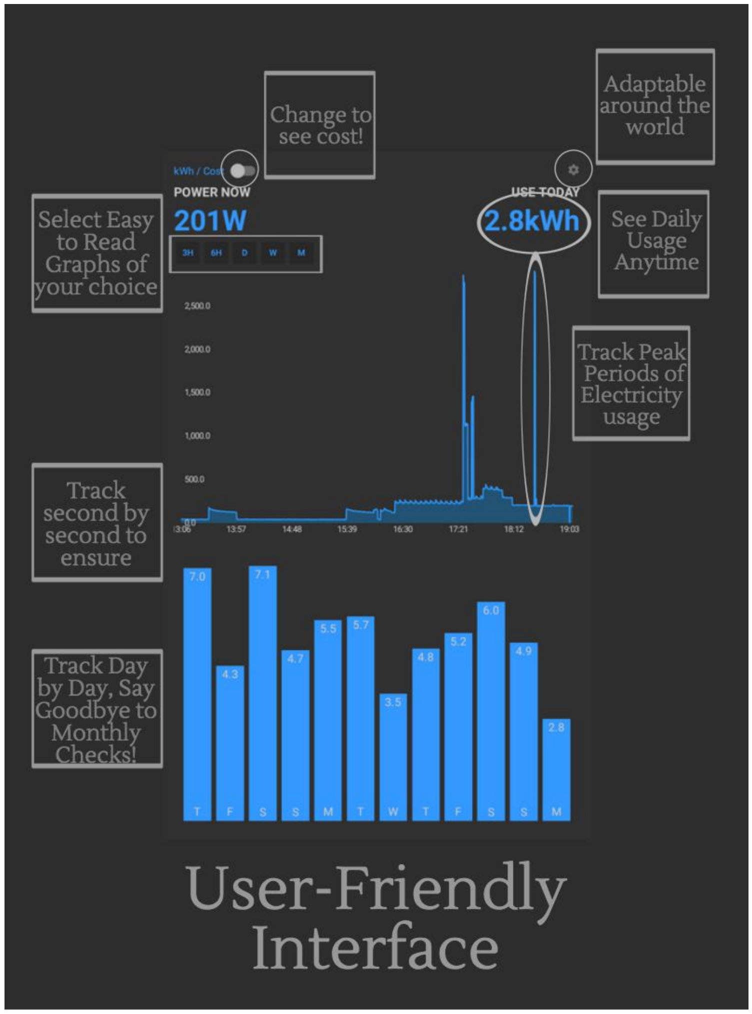


Figure 16: This infographic was created in Piktochart by the author to highlight key feature of the app that will be explained in the following paragraphs.

When using the app, consumers can change the settings by clicking the gear symbol at the upper right corner. The consumers may select a language and enter the cost per kWh in their local currency. The consumers may also select which feed type they want their electricity consumption in. **Figure 17** displays the screens the consumer receives when clicking on the gear symbol.

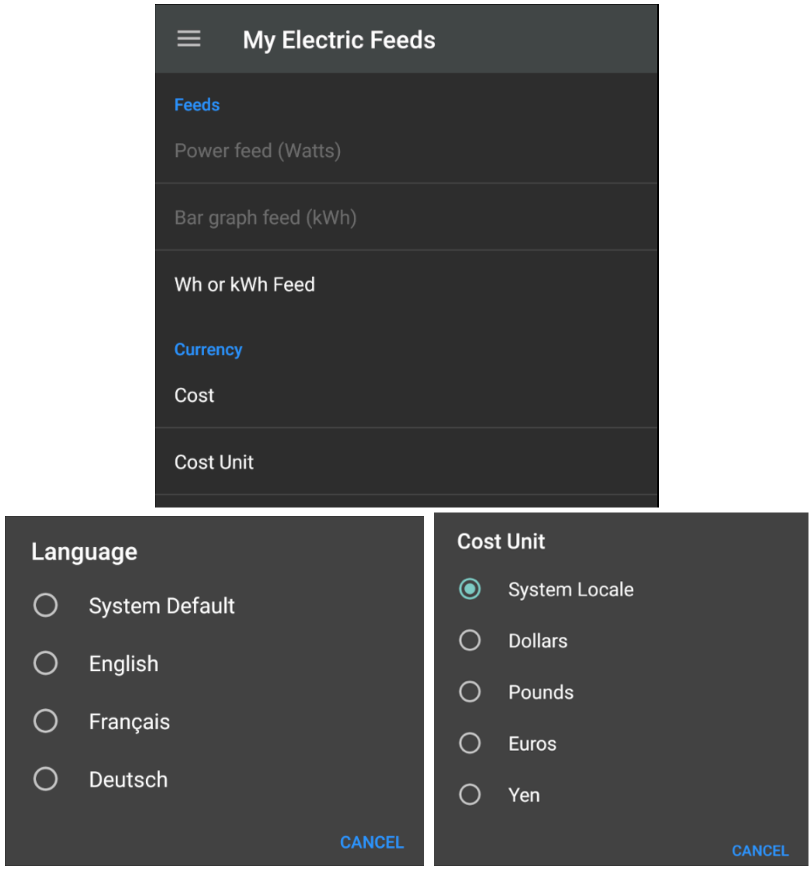


Figure 17: The screens that show up when the consumer clicks on the gear symbol. First, consumers can select whether they want their data displayed in watts, watt-hours, or kilowatt-hours. Then, they may select a language, which, at the moment, is only available in English, French, or German. Then, they may choose to display cost in dollars, pounds, euros, or yen. Last, the user inputs the cost per kWh.

The consumer may also use the slider to change between electricity consumption in kWh to electricity consumption in cost. This option changes the entire screen to reflect electricity consumption in terms of cost using the consumer's currency. The option to display cost broadens the influence of the app by conflating fiscal savings with the moral imperative to decrease electricity consumption.

Consumers can also select how they want to display their graphs. The electricity consumption display options include 3-hour, 6-hour, 1-day, 1-week, and 1-month intervals. Plus, the end consumer can also monitor their daily usage and track spikes in their electricity consumption by using the line graph and bar graph provided.

The data displayed on the app is in real time. It takes ten seconds for the data to travel from the device to the app. As long as there is a Wi-Fi connection and the device and smartphone are connected to it, the consumer will continuously get streaming data about their electricity consumption.

8.8 Safety

As discussed in the Methodology section, the device was checked for safety issues and all safety issues were resolved during experimentation. The device is safe for consumers to use.

8.9 Discussion

When determining the success of this project, the preset design criteria was reviewed to rate the project. To reiterate, the design criteria selected in order of precedence was:

1. High Safety
2. User-Friendly App
3. Read electricity usage accurately
4. High data sending speed
5. High Availability/Accessibility

As reviewed in the Methodology section of this paper, the device was determined safe after performing a safety procedure and amending anything that did not pass. The app was designed to be user-friendly by allowing for personalization (ex. Graph type, currency, language), and easy-to-use. The device was extremely accurate. The probability that the measurements recorded by this prototype were the same as those recorded by the commercial product was 0.995. Furthermore, the device was extremely precise 0.012 A. The data sending speed and availability was compatible with the app and does not interfere with the app's function, making the entire project a success. This project has met all the criteria and can help the consumer understand their current energy consumption as a way to decrease it.

9 CONCLUSION

This project establishes a way for consumers to learn more about their electricity usage and increases consumer awareness of their contribution to global warming. By utilizing the device and app engineered together, the consumer will be educated in new ways to reduce their contributions to global warming, such as using appliances at selected times and buying energy efficient appliances. This project takes the unconventional route of teaching consumers why to cut intake of fossil fuels rather than just cut the intake altogether. This project uses interactive components, such as an app, to connect to consumers and communicate ideas to them. The accuracy of the device helps the consumer to understand and rely on the device as a reliable source of monitoring their electricity consumption. Used in conjunction with Smart grid, the consumer and energy provider can work together to reduce the intake of fossil fuels. People who use this device will have the power to help secure the future of the Earth and its environment by decreasing their contributions to global warming.

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11 APPENDICES

11.1 Software Development of the Device

11.1.1 Appendix 1A- Safety Code

```
/*
  Blink
  Turns on an LED on for one second, then off for one second, repeatedly.

  Most Arduinos have an on-board LED you can control. On the Uno and
  Leonardo, it is attached to digital pin 13. If you're unsure what
  pin the on-board LED is connected to on your Arduino model, check
  the documentation at http://www.arduino.cc

  This example code is in the public domain.

  modified 8 May 2014
  by Scott Fitzgerald
 */

// the setup function runs once when you press reset or power the board
void setup() {
  // initialize digital pin 13 as an output.
  pinMode(13, OUTPUT);
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(13, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);              // wait for a second
  digitalWrite(13, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);              // wait for a second
}
```

11.1.2 Appendix 1B- Prototype1 Code

```
/*
 * Filename: VoltageRead1
 * For Prototype1
 * By Varnika Sinha
 * November 24, 2016
 *
 * This program reads the voltage fluctuations through the split core current transducer to
give an accurate reading of voltage to the user.
```

```
 * This reading is printed through the serial monitor, which can be opened by Tools>Serial
Monitor or Tools>Serial Plotter.
 */
const int vPin=A0; //sets pin to read voltage from to A0
int voltage=0; //intializes var voltage

void setup()
{
  pinMode(vPin, INPUT); //set vPin as input to Board
  Serial.begin(9600); //sets up serial monitor to plot data values by 9600 baud
}

void loop()
{
   voltage=analogRead(vPin); //sets var voltage to analog reading of pin AO
   //voltage=voltage*120/1023;
   Serial.println(voltage); //prints out values of var voltage in serial monitor
}
```

11.1.3 Appendix 1C- Prototype2 Code

```
/*
 * Filename: CurrentReader2
 * For Prototype1
 * By Varnika Sinha
 * December 3, 2016
 *
 * This program measures the current using the voltage
 */

#include "EmonLib.h" //Include EmonLib library

void setup()
{
  Serial.begin(9600);
  emon1.current(A0, 0.745);             // Current: input pin, calibration.
}

void loop()
{
  double Irms = emon1.calcIrms(3000);  // Calculate Irms only

  Serial.print((Irms)*118.5); // Apparent power
  Serial.print(" ");
  Serial.println(Irms);          // Irms
```

```
 //emon1.serialprint();
}
```

11.1.4 Appendix 1D- EmonLib Class Code

EmonLib.cpp

```
#include "EmonLib.h"

#if defined(ARDUINO) && ARDUINO >= 100
#include "Arduino.h"
#else
#include "WProgram.h"
#endif

//--------------------------------------------------------------------------------------
// Sets the pins to be used for voltage and current sensors
//--------------------------------------------------------------------------------------
void EnergyMonitor::voltage(unsigned int _inPinV, double _VCAL, double _PHASECAL)
{
 inPinV = _inPinV;
 VCAL = _VCAL;
 PHASECAL = _PHASECAL;
 offsetV = ADC_COUNTS>>1;
}

void EnergyMonitor::current(unsigned int _inPinI, double _ICAL)
{
 inPinI = _inPinI;
 ICAL = _ICAL;
 offsetI = ADC_COUNTS>>1;
}

//--------------------------------------------------------------------------------------
// Sets the pins to be used for voltage and current sensors based on emontx pin map
//--------------------------------------------------------------------------------------
void EnergyMonitor::voltageTX(double _VCAL, double _PHASECAL)
{
 inPinV = 2;
 VCAL = _VCAL;
 PHASECAL = _PHASECAL;
 offsetV = ADC_COUNTS>>1;
}

void EnergyMonitor::currentTX(unsigned int _channel, double _ICAL)
{
 if (_channel == 1) inPinI = 3;
```

```
  if (_channel == 2) inPinI = 0;
  if (_channel == 3) inPinI = 1;
  ICAL = _ICAL;
  offsetI = ADC_COUNTS>>1;
}

//---------------------------------------------------------------------------------
// emon_calc procedure
// Calculates realPower,apparentPower,powerFactor,Vrms,Irms,kWh increment
// From a sample window of the mains AC voltage and current.
// The Sample window length is defined by the number of half wavelengths or crossings
we choose to measure.
//---------------------------------------------------------------------------------
void EnergyMonitor::calcVI(unsigned int crossings, unsigned int timeout)
{
  #if defined emonTxV3
  int SupplyVoltage=3300;
  #else
  int SupplyVoltage = readVcc();
  #endif

  unsigned int crossCount = 0;                  //Used to measure number of times threshold
is crossed.
  unsigned int numberOfSamples = 0;             //This is now incremented

  //---------------------------------------------------------------------------------------------
--------
  // 1) Waits for the waveform to be close to 'zero' (mid-scale adc) part in sin curve.
  //---------------------------------------------------------------------------------------------
--------
  boolean st=false;                        //an indicator to exit the while loop

  unsigned long start = millis();    //millis()-start makes sure it doesnt get stuck in the loop
if there is an error.

  while(st==false)                         //the while loop...
  {
    startV = analogRead(inPinV);                //using the voltage waveform
    if ((startV < (ADC_COUNTS*0.55)) && (startV > (ADC_COUNTS*0.45))) st=true;  //check
its within range
    if ((millis()-start)>timeout) st = true;
  }

  //---------------------------------------------------------------------------------------------
--------
  // 2) Main measurement loop
```

```
//------------------------------------------------------------------------------------------------------------
--------
start = millis();

while ((crossCount < crossings) && ((millis()-start)<timeout))
{
  numberOfSamples++;                    //Count number of times looped.
  lastFilteredV = filteredV;            //Used for delay/phase compensation

  //-----------------------------------------------------------------------------
  // A) Read in raw voltage and current samples
  //-----------------------------------------------------------------------------
  sampleV = analogRead(inPinV);         //Read in raw voltage signal
  sampleI = analogRead(inPinI);         //Read in raw current signal

  //-----------------------------------------------------------------------------
  // B) Apply digital low pass filters to extract the 2.5 V or 1.65 V dc offset,
  //    then subtract this - signal is now centred on 0 counts.
  //-----------------------------------------------------------------------------
  offsetV = offsetV + ((sampleV-offsetV)/1024);
  filteredV = sampleV - offsetV;
  offsetI = offsetI + ((sampleI-offsetI)/1024);
  filteredI = sampleI - offsetI;

  //-----------------------------------------------------------------------------
  // C) Root-mean-square method voltage
  //-----------------------------------------------------------------------------
  sqV= filteredV * filteredV;           //1) square voltage values
  sumV += sqV;                          //2) sum

  //-----------------------------------------------------------------------------
  // D) Root-mean-square method current
  //-----------------------------------------------------------------------------
  sqI = filteredI * filteredI;          //1) square current values
  sumI += sqI;                          //2) sum

  //-----------------------------------------------------------------------------
  // E) Phase calibration
  //-----------------------------------------------------------------------------
  phaseShiftedV = lastFilteredV + PHASECAL * (filteredV - lastFilteredV);

  //-----------------------------------------------------------------------------
  // F) Instantaneous power calc
  //-----------------------------------------------------------------------------
  instP = phaseShiftedV * filteredI;    //Instantaneous Power
  sumP +=instP;                         //Sum
```

```
  //-------------------------------------------------------------------------
  // G) Find the number of times the voltage has crossed the initial voltage
  //    - every 2 crosses we will have sampled 1 wavelength
  //    - so this method allows us to sample an integer number of half wavelengths which
increases accuracy
  //-------------------------------------------------------------------------
  lastVCross = checkVCross;
  if (sampleV > startV) checkVCross = true;
             else checkVCross = false;
  if (numberOfSamples==1) lastVCross = checkVCross;

  if (lastVCross != checkVCross) crossCount++;
 }

 //-------------------------------------------------------------------------------------------------------------------
--------
 // 3) Post loop calculations
 //-------------------------------------------------------------------------------------------------------------------
--------
 //Calculation of the root of the mean of the voltage and current squared (rms)
 //Calibration coefficients applied.

 double V_RATIO = VCAL *((SupplyVoltage/1000.0) / (ADC_COUNTS));
 Vrms = V_RATIO * sqrt(sumV / numberOfSamples);

 double I_RATIO = ICAL *((SupplyVoltage/1000.0) / (ADC_COUNTS));
 Irms = I_RATIO * sqrt(sumI / numberOfSamples);

 //Calculation power values
 realPower = V_RATIO * I_RATIO * sumP / numberOfSamples;
 apparentPower = Vrms * Irms;
 powerFactor=realPower / apparentPower;

 //Reset accumulators
 sumV = 0;
 sumI = 0;
 sumP = 0;
//--------------------------------------------------------------------------------------
}

//--------------------------------------------------------------------------------------
double EnergyMonitor::calcIrms(unsigned int Number_of_Samples)
{

 #if defined emonTxV3
```

```
  int SupplyVoltage=3300;
 #else
  int SupplyVoltage = readVcc();
 #endif


 for (unsigned int n = 0; n < Number_of_Samples; n++)
 {
  sampleI = analogRead(inPinI);

  // Digital low pass filter extracts the 2.5 V or 1.65 V dc offset,
  //  then subtract this - signal is now centered on 0 counts.
  offsetI = (offsetI + (sampleI-offsetI)/1024);
  filteredI = sampleI - offsetI;

  // Root-mean-square method current
  // 1) square current values
  sqI = filteredI * filteredI;
  // 2) sum
  sumI += sqI;
 }

 double I_RATIO = ICAL *((SupplyVoltage/1000.0) / (ADC_COUNTS));
 Irms = I_RATIO * sqrt(sumI / Number_of_Samples);

 //Reset accumulators
 sumI = 0;
 //--------------------------------------------------------------------------------------

 return Irms;
}

void EnergyMonitor::serialprint()
{
 Serial.print(realPower);
 Serial.print(' ');
 Serial.print(apparentPower);
 Serial.print(' ');
 Serial.print(Vrms);
 Serial.print(' ');
 Serial.print(Irms);
 Serial.print(' ');
 Serial.print(powerFactor);
 Serial.println(' ');
 delay(100);
}
```

```
long EnergyMonitor::readVcc() {
  long result;

  //not used on emonTx V3 - as Vcc is always 3.3V - eliminates bandgap error and need for
calibration http://harizanov.com/2013/09/thoughts-on-avr-adc-accuracy/

  #if defined(__AVR_ATmega168__) || defined(__AVR_ATmega328__) || defined
(__AVR_ATmega328P__)
  ADMUX = _BV(REFS0) | _BV(MUX3) | _BV(MUX2) | _BV(MUX1);
  #elif defined(__AVR_ATmega644__) || defined(__AVR_ATmega644P__) ||
defined(__AVR_ATmega1284__) || defined(__AVR_ATmega1284P__)
  ADMUX = _BV(REFS0) | _BV(MUX4) | _BV(MUX3) | _BV(MUX2) | _BV(MUX1);
  #elif defined(__AVR_ATmega32U4__) || defined(__AVR_ATmega1280__) ||
defined(__AVR_ATmega2560__) || defined(__AVR_AT90USB1286__)
  ADMUX = _BV(REFS0) | _BV(MUX4) | _BV(MUX3) | _BV(MUX2) | _BV(MUX1);
  ADCSRB &= ~_BV(MUX5);   // Without this the function always returns -1 on the
ATmega2560 http://openenergymonitor.org/emon/node/2253#comment-11432
  #elif defined (__AVR_ATtiny24__) || defined(__AVR_ATtiny44__) ||
defined(__AVR_ATtiny84__)
  ADMUX = _BV(MUX5) | _BV(MUX0);
  #elif defined (__AVR_ATtiny25__) || defined(__AVR_ATtiny45__) ||
defined(__AVR_ATtiny85__)
  ADMUX = _BV(MUX3) | _BV(MUX2);

  #endif

  #if defined(__AVR__)
  delay(2);                                // Wait for Vref to settle
  ADCSRA |= _BV(ADSC);                          // Convert
  while (bit_is_set(ADCSRA,ADSC));
  result = ADCL;
  result |= ADCH<<8;
  result = READVCC_CALIBRATION_CONST / result;  //1100mV*1024 ADC steps
http://openenergymonitor.org/emon/node/1186
  return result;
  #elif defined(__arm__)
  return (3300);                           //Arduino Due
  #else
  return (3300);                           //Guess that other un-supported architectures will be
running a 3.3V!
  #endif
}
```

EmonLib.h

```
#ifndef EmonLib_h
```

```
#define EmonLib_h
#if defined(ARDUINO) && ARDUINO >= 100
#include "Arduino.h"
#else
#include "WProgram.h"
#endif

// define theoretical vref calibration constant for use in readvcc()
// 1100mV*1024 ADC steps http://openenergymonitor.org/emon/node/1186
// override in your code with value for your specific AVR chip
// determined by procedure described under "Calibrating the internal reference voltage" at
// http://openenergymonitor.org/emon/buildingblocks/calibration

#ifndef READVCC_CALIBRATION_CONST
#define READVCC_CALIBRATION_CONST 1126400L
#endif

// to enable 12-bit ADC resolution on Arduino Due,
// include the following line in main sketch inside setup() function:
//  analogReadResolution(ADC_BITS);
// otherwise will default to 10 bits, as in regular Arduino-based boards.
#if defined(__arm__)
#define ADC_BITS    12
#else
#define ADC_BITS    10
#endif

#define ADC_COUNTS  (1<<ADC_BITS)

class EnergyMonitor
{
  public:

    void voltage(unsigned int _inPinV, double _VCAL, double _PHASECAL);
    void current(unsigned int _inPinI, double _ICAL);

    void voltageTX(double _VCAL, double _PHASECAL);
    void currentTX(unsigned int _channel, double _ICAL);

    void calcVI(unsigned int crossings, unsigned int timeout);
    double calcIrms(unsigned int NUMBER_OF_SAMPLES);
    void serialprint();

    long readVcc();
    //Useful value variables
    double realPower,
```

```
    apparentPower,
    powerFactor,
    Vrms,
    Irms;

  private:

   //Set Voltage and current input pins
   unsigned int inPinV;
   unsigned int inPinI;
   //Calibration coefficients
   //These need to be set in order to obtain accurate results
   double VCAL;
   double ICAL;
   double PHASECAL;

   //--------------------------------------------------------------------------------------
   // Variable declaration for emon_calc procedure
   //--------------------------------------------------------------------------------------
   int sampleV;                    //sample_ holds the raw analog read value
   int sampleI;

   double lastFilteredV,filteredV;        //Filtered_ is the raw analog value minus the DC
offset
   double filteredI;
   double offsetV;                      //Low-pass filter output
   double offsetI;                      //Low-pass filter output

   double phaseShiftedV;                          //Holds the calibrated phase shifted voltage.

   double sqV,sumV,sqI,sumI,instP,sumP;            //sq = squared, sum = Sum, inst =
instantaneous

   int startV;                                  //Instantaneous voltage at start of sample window.

   boolean lastVCross, checkVCross;                //Used to measure number of times threshold
is crossed.
};
#endif
```

11.1.5 Appendix 1E- App Code

To look at the code utilized to engineer the app, please go to the link https://github.com/varksvader/AndroidApp.

11.2 Appendix 2- Kill-A-Watt Patent

To see more information about the Kill-A-Watt, please go to the link https://www.google.com/patents/US6095850.

11.3 Appendix 3- Full Results

	LED	
n	**Device**	**Commercial**
	(A)	**(A)**
1	0.11401	0.11000
2	0.11094	0.11000
3	0.11043	0.11000
4	0.10880	0.11000
5	0.10870	0.11000
6	0.11294	0.11000
7	0.11343	0.11000
8	0.11363	0.11000
9	0.10698	0.11000
10	0.10599	0.11000
11	0.10770	0.11000
12	0.11035	0.11000
13	0.11406	0.11000
14	0.11287	0.11000
15	0.11109	0.11000
16	0.10940	0.11000
17	0.11180	0.11000
18	0.11709	0.11000
19	0.10649	0.11000
20	0.10946	0.11000
21	0.10762	0.11000
22	0.11022	0.11000
23	0.10677	0.11000
24	0.10535	0.11000
25	0.10506	0.11000
26	0.10531	0.11000
27	0.10275	0.11000
28	0.10372	0.11000
29	0.11037	0.11000
30	0.11181	0.11000
31	0.10650	0.11000
32	0.11277	0.11000
33	0.11068	0.11000
34	0.10622	0.11000
35	0.11016	0.11000
36	0.11328	0.11000
37	0.11029	0.11000
38	0.10984	0.11000
39	0.11131	0.11000
40	0.11212	0.11000
41	0.11682	0.11000
42	0.11332	0.11000
43	0.11118	0.11000
44	0.11202	0.11000
45	0.11339	0.11000
46	0.11213	0.11000
47	0.10703	0.11000
48	0.11331	0.11000
49	0.11360	0.11000
50	0.11259	0.11000
51	0.11112	0.11000
52	0.11002	0.11000
53	0.11260	0.11000
54	0.10680	0.11000
55	0.10731	0.11000
56	0.10693	0.11000
57	0.10625	0.11000
58	0.10390	0.11000
59	0.10618	0.11000
60	0.11184	0.11000
61	0.10978	0.11000
62	0.11045	0.11000
63	0.11035	0.11000

64	0.10981	0.11000
65	0.11315	0.11000
Average	0.11000	
STDEV	0.00316	
p-value	9.9407E-01	

	CFL	
n	**Device**	**Commercial**
	(A)	**(A)**
1	0.18971	0.18000
2	0.17904	0.18000
3	0.18592	0.18000
4	0.17801	0.18000
5	0.17537	0.18000
6	0.18605	0.18000
7	0.18143	0.18000
8	0.18020	0.18000
9	0.18405	0.18000
10	0.18691	0.18000
11	0.17946	0.18000
12	0.18466	0.18000
13	0.17455	0.18000
14	0.17721	0.18000
15	0.17897	0.18000
16	0.17747	0.18000
17	0.17303	0.18000
18	0.17651	0.18000
19	0.18109	0.18000
20	0.18272	0.18000
21	0.18389	0.18000
22	0.19200	0.18000
23	0.17467	0.18000
24	0.18235	0.18000
25	0.17649	0.18000
26	0.18793	0.18000
27	0.18305	0.18000
28	0.17416	0.18000
29	0.17747	0.18000
30	0.18445	0.18000
31	0.18330	0.18000
32	0.17689	0.18000
33	0.17747	0.18000
34	0.18361	0.18000
35	0.18674	0.18000
36	0.18492	0.18000
37	0.18733	0.18000
38	0.17847	0.18000
39	0.18338	0.18000
40	0.17681	0.18000
41	0.17364	0.18000
42	0.17651	0.18000
43	0.17649	0.18000
44	0.17785	0.18000
45	0.18346	0.18000
46	0.17244	0.18000
47	0.17211	0.18000
48	0.18182	0.18000
49	0.18599	0.18000
50	0.17889	0.18000
51	0.17520	0.18000
52	0.18150	0.18000
53	0.18455	0.18000
54	0.18711	0.18000
55	0.18756	0.18000
56	0.18520	0.18000
57	0.18443	0.18000
58	0.17495	0.18000
59	0.17581	0.18000
60	0.17515	0.18000
61	0.17519	0.18000
62	0.18446	0.18000
63	0.18403	0.18000
64	0.18683	0.18000
65	0.18385	0.18000
66	0.18451	0.18000
67	0.18329	0.18000
68	0.17826	0.18000
69	0.18262	0.18000

70	0.17738	0.18000
71	0.18484	0.18000
72	0.17765	0.18000
73	0.18599	0.18000
74	0.18354	0.18000
75	0.17715	0.18000
76	0.17394	0.18000
77	0.17908	0.18000
78	0.17849	0.18000
79	0.18568	0.18000
80	0.18175	0.18000
81	0.17586	0.18000
82	0.17326	0.18000
83	0.17914	0.18000
84	0.18440	0.18000
85	0.18629	0.18000
86	0.17777	0.18000
87	0.17431	0.18000
88	0.17204	0.18000
89	0.17169	0.18000
90	0.18145	0.18000
91	0.18089	0.18000
92	0.18448	0.18000
93	0.17521	0.18000
94	0.17514	0.18000
95	0.17617	0.18000
96	0.17313	0.18000
97	0.18981	0.18000
98	0.18590	0.18000
99	0.18445	0.18000
100	0.18118	0.18000
101	0.18110	0.18000
102	0.17939	0.18000
103	0.17937	0.18000
104	0.17470	0.18000
105	0.17681	0.18000
106	0.17673	0.18000
107	0.18458	0.18000
108	0.18565	0.18000
109	0.17431	0.18000
110	0.17892	0.18000
111	0.18524	0.18000
112	0.17765	0.18000
113	0.17397	0.18000
114	0.17245	0.18000
115	0.18008	0.18000
116	0.18031	0.18000
117	0.18375	0.18000
118	0.18310	0.18000
119	0.18008	0.18000
120	0.18147	0.18000
121	0.18042	0.18000
122	0.18361	0.18000
123	0.17638	0.18000
124	0.17500	0.18000
125	0.17717	0.18000
126	0.17203	0.18000
127	0.18282	0.18000
128	0.18093	0.18000
129	0.17796	0.18000
130	0.19059	0.18000
131	0.17366	0.18000
132	0.17312	0.18000
133	0.17478	0.18000
134	0.16875	0.18000
135	0.17378	0.18000
Average	0.18000	
STDEV	0.00485	
p-value	9.9774E-01	

	Incandescent	
n	**Device**	**Commercial**
	(A)	**(A)**
1	0.53942	0.52000
2	0.53032	0.52000
3	0.53361	0.52000
4	0.49485	0.52000

5	0.52655	0.52000
6	0.50957	0.52000
7	0.50768	0.52000
8	0.53237	0.52000
9	0.52444	0.52000
10	0.50662	0.52000
11	0.52543	0.52000
12	0.48917	0.52000
13	0.50308	0.52000
14	0.50797	0.52000
15	0.52032	0.52000
16	0.54950	0.52000
17	0.50937	0.52000
18	0.50134	0.52000
19	0.50651	0.52000
20	0.51481	0.52000
21	0.51150	0.52000
22	0.50760	0.52000
23	0.53454	0.52000
24	0.53906	0.52000
25	0.53918	0.52000
26	0.53724	0.52000
27	0.53388	0.52000
28	0.53268	0.52000
29	0.54050	0.52000
30	0.51320	0.52000
31	0.51602	0.52000
32	0.52635	0.52000
33	0.53436	0.52000
34	0.53392	0.52000
35	0.53231	0.52000
36	0.52996	0.52000
37	0.50829	0.52000
38	0.50772	0.52000
39	0.51955	0.52000
40	0.53686	0.52000
41	0.53414	0.52000
42	0.52741	0.52000
43	0.53573	0.52000
44	0.54051	0.52000
45	0.53242	0.52000
46	0.53415	0.52000
47	0.51698	0.52000
48	0.51813	0.52000
49	0.52709	0.52000
50	0.52710	0.52000
51	0.55074	0.52000
52	0.52378	0.52000
53	0.50570	0.52000
54	0.51751	0.52000
55	0.52718	0.52000
56	0.50422	0.52000
57	0.52222	0.52000
58	0.50444	0.52000
59	0.52322	0.52000
60	0.51932	0.52000
61	0.53248	0.52000
62	0.53226	0.52000
63	0.53012	0.52000
64	0.52878	0.52000
65	0.52241	0.52000
66	0.53085	0.52000
67	0.50947	0.52000
68	0.50474	0.52000
69	0.48700	0.52000
70	0.51035	0.52000
71	0.53515	0.52000
72	0.53345	0.52000
73	0.51251	0.52000
74	0.50838	0.52000
75	0.52566	0.52000
76	0.53389	0.52000
77	0.51355	0.52000
78	0.50694	0.52000
79	0.53454	0.52000
80	0.53993	0.52000
81	0.51109	0.52000
82	0.50868	0.52000

83	0.53167	0.52000
84	0.51614	0.52000
85	0.50736	0.52000
86	0.51003	0.52000
87	0.51024	0.52000
88	0.50501	0.52000
89	0.51057	0.52000
90	0.50757	0.52000
91	0.51056	0.52000
92	0.51398	0.52000
93	0.48367	0.52000
94	0.51262	0.52000
95	0.51244	0.52000
96	0.50639	0.52000
97	0.51724	0.52000
98	0.51354	0.52000
99	0.50815	0.52000
100	0.52914	0.52000
101	0.51006	0.52000
102	0.53491	0.52000
103	0.52909	0.52000
104	0.51979	0.52000
105	0.51899	0.52000
106	0.50604	0.52000
107	0.52126	0.52000
108	0.53775	0.52000
109	0.50415	0.52000
110	0.53492	0.52000
111	0.51052	0.52000
112	0.51226	0.52000
113	0.52565	0.52000
114	0.53417	0.52000
115	0.52038	0.52000
116	0.52742	0.52000
117	0.53386	0.52000
118	0.52216	0.52000
119	0.53432	0.52000
120	0.53035	0.52000
121	0.52626	0.52000

122	0.52705	0.52000
123	0.55356	0.52000
124	0.52921	0.52000
125	0.54002	0.52000
126	0.51809	0.52000
127	0.53415	0.52000
128	0.50575	0.52000
129	0.51112	0.52000
130	0.53380	0.52000
131	0.51716	0.52000
132	0.53676	0.52000
133	0.53744	0.52000
134	0.53118	0.52000
135	0.49646	0.52000
136	0.50925	0.52000
137	0.50325	0.52000
138	0.52905	0.52000
139	0.52520	0.52000
140	0.52985	0.52000
141	0.53717	0.52000
142	0.51621	0.52000
143	0.51576	0.52000
144	0.52011	0.52000
145	0.49867	0.52000
146	0.50109	0.52000
147	0.52165	0.52000
148	0.51707	0.52000
149	0.50796	0.52000
150	0.50888	0.52000
151	0.51019	0.52000
152	0.51453	0.52000
153	0.51806	0.52000
154	0.53548	0.52000
155	0.50766	0.52000
156	0.52068	0.52000
157	0.53727	0.52000
158	0.54816	0.52000
159	0.53099	0.52000
160	0.50174	0.52000

161	0.49705	0.52000
162	0.51344	0.52000
163	0.52275	0.52000
164	0.52914	0.52000
165	0.53514	0.52000
166	0.50446	0.52000
167	0.51063	0.52000
168	0.52114	0.52000
169	0.51891	0.52000
170	0.49318	0.52000
171	0.48469	0.52000
172	0.52843	0.52000
173	0.50361	0.52000
174	0.53743	0.52000
175	0.53147	0.52000
176	0.53414	0.52000
177	0.52160	0.52000
178	0.53634	0.52000
179	0.50823	0.52000
180	0.52471	0.52000
181	0.50724	0.52000
182	0.54156	0.52000
183	0.50732	0.52000
184	0.52827	0.52000
185	0.53422	0.52000
186	0.50924	0.52000
187	0.52210	0.52000
188	0.53384	0.52000
189	0.50796	0.52000
190	0.51008	0.52000
191	0.50443	0.52000
192	0.50796	0.52000
193	0.53456	0.52000
194	0.51617	0.52000
195	0.50800	0.52000
196	0.52008	0.52000
197	0.51000	0.52000
198	0.51974	0.52000
199	0.50847	0.52000
200	0.51354	0.52000
201	0.50490	0.52000
202	0.52158	0.52000
203	0.49985	0.52000
204	0.50137	0.52000
205	0.52440	0.52000
206	0.51735	0.52000
207	0.52558	0.52000
208	0.50462	0.52000
209	0.51952	0.52000
210	0.52120	0.52000
211	0.53058	0.52000
212	0.52087	0.52000
213	0.51355	0.52000
214	0.51975	0.52000
215	0.50988	0.52000
216	0.50477	0.52000
217	0.50280	0.52000
218	0.50093	0.52000
219	0.54725	0.52000
220	0.53367	0.52000
221	0.50747	0.52000
222	0.52728	0.52000
223	0.52022	0.52000
224	0.54131	0.52000
225	0.51810	0.52000
226	0.53300	0.52000
227	0.52761	0.52000
228	0.53218	0.52000
229	0.53257	0.52000
230	0.52360	0.52000
231	0.49717	0.52000
232	0.51926	0.52000
233	0.51931	0.52000
234	0.51876	0.52000
235	0.53230	0.52000
236	0.53360	0.52000
237	0.51965	0.52000
238	0.52386	0.52000

239	0.52985	0.52000
240	0.50563	0.52000
241	0.50797	0.52000
242	0.50181	0.52000
243	0.52826	0.52000
244	0.52469	0.52000
245	0.51877	0.52000
246	0.51517	0.52000
247	0.51853	0.52000
248	0.52626	0.52000
249	0.51464	0.52000
250	0.51867	0.52000
251	0.50822	0.52000
252	0.51677	0.52000
253	0.50873	0.52000
254	0.53417	0.52000
Average	0.52000	
STDEV	0.01300	
p-value	9.9515E-01	

	Hair Dryer at High	
n	**Device**	**Commercial**
	(A)	**(A)**
1	10.82314	10.89000
2	11.12814	10.89000
3	10.80290	10.89000
4	10.96047	10.89000
5	10.93723	10.89000
6	11.10165	10.89000
7	11.12977	10.89000
8	11.13538	10.89000
9	10.94648	10.89000
10	11.17275	10.89000
11	11.08131	10.89000
12	10.76886	10.89000
13	10.67895	10.89000
14	10.91687	10.89000
15	11.60357	10.89000
16	10.67981	10.89000
17	10.58893	10.89000
18	10.93205	10.89000
19	10.94309	10.89000
20	11.14919	10.89000
21	11.16007	10.89000
22	10.90410	10.89000
23	10.87716	10.89000
24	11.26973	10.89000
25	10.70184	10.89000
26	10.90883	10.89000
27	11.37741	10.89000
28	11.04155	10.89000
29	11.11690	10.89000
30	10.75403	10.89000
31	10.72688	10.89000
32	10.77145	10.89000
33	11.23500	10.89000
34	11.13189	10.89000
35	10.57330	10.89000
36	10.77584	10.89000
37	10.70202	10.89000
38	10.73240	10.89000
39	10.59905	10.89000
40	11.09023	10.89000
41	11.19894	10.89000
42	10.45479	10.89000
43	11.01316	10.89000
44	11.08286	10.89000
45	10.92578	10.89000
46	11.10755	10.89000
47	10.77838	10.89000
48	10.77845	10.89000
49	10.68259	10.89000
50	10.65328	10.89000
51	10.80905	10.89000
52	10.93585	10.89000
53	11.05074	10.89000
54	11.05593	10.89000
55	10.65978	10.89000

56	10.81093	10.89000
57	10.70715	10.89000
58	10.59915	10.89000
59	10.54060	10.89000
60	10.99339	10.89000
61	10.65886	10.89000
62	11.08142	10.89000
63	11.07667	10.89000
64	10.56986	10.89000
65	10.71691	10.89000
66	10.98638	10.89000
67	11.15697	10.89000
68	10.69821	10.89000
69	11.20006	10.89000
70	10.67886	10.89000
71	10.66179	10.89000
72	10.68608	10.89000
73	10.66991	10.89000
74	10.63568	10.89000
75	10.91320	10.89000
76	10.50363	10.89000
77	11.02292	10.89000
78	10.92134	10.89000
79	10.87376	10.89000
80	10.81809	10.89000
81	11.12814	10.89000
82	11.05326	10.89000
83	11.04606	10.89000
84	11.09667	10.89000
85	11.04840	10.89000
86	11.07152	10.89000
87	11.16317	10.89000
88	11.08032	10.89000
89	11.17460	10.89000
90	11.21746	10.89000
91	11.05415	10.89000
92	11.15703	10.89000
93	10.88263	10.89000
94	10.85860	10.89000

95	10.80237	10.89000
96	10.92812	10.89000
97	11.02078	10.89000
98	11.00795	10.89000
99	11.03002	10.89000
100	11.02032	10.89000
101	11.04154	10.89000
102	11.01953	10.89000
103	11.08409	10.89000
104	11.22223	10.89000
105	11.00926	10.89000
106	10.68582	10.89000
107	10.67393	10.89000
108	10.70295	10.89000
109	10.62899	10.89000
110	10.59923	10.89000
111	10.64438	10.89000
112	10.73328	10.89000
113	10.61371	10.89000
114	10.73533	10.89000
115	10.93782	10.89000
116	11.01779	10.89000
117	10.60236	10.89000
118	10.68205	10.89000
119	10.66706	10.89000
120	10.55075	10.89000
121	10.62034	10.89000
122	10.72769	10.89000
123	10.79312	10.89000
124	10.67713	10.89000
125	11.04761	10.89000
126	11.12380	10.89000
127	10.64308	10.89000
128	11.00644	10.89000
129	10.71707	10.89000
130	10.36131	10.89000
Average	10.89008	
STDEV	0.22074	
p-value	9.9670E-01	

	Hair Dryer at Low	
n	Device	Commercial
	(A)	(A)
1	2.95156	2.96000
2	2.95708	2.96000
3	2.99937	2.96000
4	2.99159	2.96000
5	2.97319	2.96000
6	3.04208	2.96000
7	2.97546	2.96000
8	2.94078	2.96000
9	2.99467	2.96000
10	3.00003	2.96000
11	2.99225	2.96000
12	3.00534	2.96000
13	2.96333	2.96000
14	2.93581	2.96000
15	2.95345	2.96000
16	2.92739	2.96000
17	2.88274	2.96000
18	3.00236	2.96000
19	2.99261	2.96000
20	2.99696	2.96000
21	2.85878	2.96000
22	2.92434	2.96000
23	2.87702	2.96000
24	2.79725	2.96000
25	2.82329	2.96000
26	2.89132	2.96000
27	2.82302	2.96000
28	2.96212	2.96000
29	2.78458	2.96000
30	2.93854	2.96000
31	2.91306	2.96000
32	2.87779	2.96000
33	2.77946	2.96000
34	3.04493	2.96000
35	3.01869	2.96000
36	3.02936	2.96000
37	3.03120	2.96000
38	2.97806	2.96000
39	3.01061	2.96000
40	2.86866	2.96000
41	2.86355	2.96000
42	3.00623	2.96000
43	3.02478	2.96000
44	3.02132	2.96000
45	2.96435	2.96000
46	2.87469	2.96000
47	3.05689	2.96000
48	3.01391	2.96000
49	2.90550	2.96000
50	2.99873	2.96000
51	3.02795	2.96000
52	3.01524	2.96000
53	2.88171	2.96000
54	2.85711	2.96000
55	3.00871	2.96000
56	3.03284	2.96000
57	2.99716	2.96000
58	2.90622	2.96000
59	3.04887	2.96000
60	2.86962	2.96000
61	3.06438	2.96000
62	3.00962	2.96000
63	2.81166	2.96000
64	3.04042	2.96000
65	3.02613	2.96000
66	2.99545	2.96000
67	2.95711	2.96000
68	3.02512	2.96000
69	3.01131	2.96000
70	2.95606	2.96000
71	2.92655	2.96000
72	2.90250	2.96000
73	2.85713	2.96000
74	3.01331	2.96000
75	2.86094	2.96000

76	2.88715	2.96000
77	2.88176	2.96000
78	2.92594	2.96000
79	2.97790	2.96000
80	2.81054	2.96000
81	2.84939	2.96000
82	2.80074	2.96000
83	2.84380	2.96000
84	3.01728	2.96000
85	2.97492	2.96000
86	2.81898	2.96000
87	2.97042	2.96000
88	3.02747	2.96000
89	3.05031	2.96000
90	3.05208	2.96000
91	2.92145	2.96000
92	3.00673	2.96000
93	2.98394	2.96000
94	3.01180	2.96000
95	2.92767	2.96000
96	3.02354	2.96000
97	2.86329	2.96000
98	2.93041	2.96000
99	2.95563	2.96000
100	3.03790	2.96000
101	3.03112	2.96000
102	2.87434	2.96000
103	3.01119	2.96000
104	2.91575	2.96000
105	3.04081	2.96000
106	3.03178	2.96000
107	2.98190	2.96000
108	3.04932	2.96000
109	2.94921	2.96000
110	2.97057	2.96000
111	2.98846	2.96000
112	2.93182	2.96000
113	3.01528	2.96000
114	2.91156	2.96000

115	2.86285	2.96000
116	2.87677	2.96000
117	2.86323	2.96000
118	2.81719	2.96000
119	2.98355	2.96000
120	2.96425	2.96000
121	2.97784	2.96000
122	2.87024	2.96000
123	2.89409	2.96000
124	2.96873	2.96000
125	2.94674	2.96000
126	2.85483	2.96000
127	2.85347	2.96000
128	2.88447	2.96000
129	2.85955	2.96000
130	3.00550	2.96000
131	2.94111	2.96000
132	2.98287	2.96000
133	3.03697	2.96000
134	2.89383	2.96000
135	2.89281	2.96000
136	2.91065	2.96000
137	2.90284	2.96000
138	2.87996	2.96000
139	3.02875	2.96000
140	2.92749	2.96000
141	3.06343	2.96000
142	3.01163	2.96000
143	2.86655	2.96000
144	2.86581	2.96000
145	2.96215	2.96000
146	2.99111	2.96000
147	3.02481	2.96000
148	3.02769	2.96000
149	2.97567	2.96000
150	2.98279	2.96000
151	3.02225	2.96000
152	3.03331	2.96000
153	3.01284	2.96000

154	3.02768	2.96000
155	3.03206	2.96000
156	2.99122	2.96000
157	3.01900	2.96000
158	3.02005	2.96000
159	2.89299	2.96000
160	3.04924	2.96000
161	3.11313	2.96000
162	3.03306	2.96000
163	3.00586	2.96000
164	2.83734	2.96000
165	2.94316	2.96000
166	2.93840	2.96000
167	2.79193	2.96000
168	3.01560	2.96000
169	2.96735	2.96000
170	2.84946	2.96000
171	2.90765	2.96000
172	2.94746	2.96000
173	3.03583	2.96000
174	3.04941	2.96000
175	3.04069	2.96000
176	3.02061	2.96000
177	3.01867	2.96000
178	3.01872	2.96000
179	2.96079	2.96000
180	3.04934	2.96000
181	3.05234	2.96000
182	2.98208	2.96000
183	3.04419	2.96000
184	3.05009	2.96000
185	2.95894	2.96000
186	2.98657	2.96000
187	3.04122	2.96000
188	2.85693	2.96000
189	2.85299	2.96000
190	2.87729	2.96000
191	2.98615	2.96000
192	2.89533	2.96000

193	2.95290	2.96000
194	3.13039	2.96000
195	3.04846	2.96000
196	2.93575	2.96000
197	3.04488	2.96000
198	3.06064	2.96000
199	3.16719	2.96000
200	2.92399	2.96000
201	3.04807	2.96000
202	3.04319	2.96000
203	2.91704	2.96000
204	3.03959	2.96000
205	3.00857	2.96000
206	2.92294	2.96000
207	3.15995	2.96000
208	2.87230	2.96000
209	2.90797	2.96000
210	2.75707	2.96000
211	2.85789	2.96000
212	2.89626	2.96000
213	2.85031	2.96000
214	3.01144	2.96000
215	3.04974	2.96000
216	3.04712	2.96000
217	3.05791	2.96000
218	3.01384	2.96000
219	2.98370	2.96000
220	2.98352	2.96000
221	2.96446	2.96000
222	3.02240	2.96000
223	2.83909	2.96000
224	2.89776	2.96000
225	2.88621	2.96000
226	2.98265	2.96000
Average	2.96002	
STDEV	0.07659	
p-value	9.9724E-01	

	Toaster	
n	Device	Commercial
	(A)	(A)
1	6.13949	6.16000
2	6.06906	6.16000
3	5.98453	6.16000
4	6.24781	6.16000
5	6.16201	6.16000
6	6.00736	6.16000
7	6.03456	6.16000
8	6.27118	6.16000
9	6.29739	6.16000
10	6.43164	6.16000
11	6.37470	6.16000
12	6.37319	6.16000
13	6.33818	6.16000
14	6.31310	6.16000
15	6.31800	6.16000
16	6.37149	6.16000
17	6.62807	6.16000
18	6.32226	6.16000
19	6.16865	6.16000
20	5.93840	6.16000
21	6.01490	6.16000
22	5.96251	6.16000
23	5.96188	6.16000
24	6.07825	6.16000
25	6.34374	6.16000
26	6.26447	6.16000
27	6.02236	6.16000
28	6.21635	6.16000
29	6.18395	6.16000
30	6.30721	6.16000
31	6.35089	6.16000
32	6.36773	6.16000
33	6.31982	6.16000
34	6.16216	6.16000
35	6.35749	6.16000
36	6.36808	6.16000
37	6.08316	6.16000
38	6.10198	6.16000
39	6.07663	6.16000
40	6.33070	6.16000
41	6.25789	6.16000
42	6.32351	6.16000
43	5.98746	6.16000
44	6.11341	6.16000
45	6.05402	6.16000
46	6.17874	6.16000
47	6.15698	6.16000
48	6.18870	6.16000
49	6.15070	6.16000
50	6.16805	6.16000
51	6.20287	6.16000
52	6.33855	6.16000
53	6.19652	6.16000
54	6.30338	6.16000
55	6.26807	6.16000
56	6.35654	6.16000
57	6.37266	6.16000
58	6.35116	6.16000
59	6.22608	6.16000
60	6.22271	6.16000
61	6.23992	6.16000
62	6.31671	6.16000
63	6.13553	6.16000
64	6.14075	6.16000
65	6.27624	6.16000
66	6.09975	6.16000
67	6.33077	6.16000
68	6.10014	6.16000
69	6.07518	6.16000
70	6.31939	6.16000
71	6.34222	6.16000
72	6.27185	6.16000
73	6.19754	6.16000
74	6.21662	6.16000
75	6.35740	6.16000

76	6.01681	6.16000
77	6.12520	6.16000
78	6.29511	6.16000
79	6.20703	6.16000
80	6.00728	6.16000
81	6.07508	6.16000
82	6.06956	6.16000
83	6.20976	6.16000
84	6.26731	6.16000
85	6.17403	6.16000
86	6.05825	6.16000
87	6.24611	6.16000
88	6.02306	6.16000
89	6.22666	6.16000
90	6.02192	6.16000
91	6.00534	6.16000
92	5.98786	6.16000
93	6.11487	6.16000
94	6.04484	6.16000
95	6.01760	6.16000
96	6.03685	6.16000
97	6.10174	6.16000
98	6.17305	6.16000
99	6.04957	6.16000
100	6.07366	6.16000
101	6.05792	6.16000
102	6.11016	6.16000
103	6.23160	6.16000
104	6.14604	6.16000
105	6.28109	6.16000
106	6.19612	6.16000
107	6.03533	6.16000
108	6.13889	6.16000
109	6.30406	6.16000
110	6.31599	6.16000
111	6.37788	6.16000
112	6.29117	6.16000
113	6.21118	6.16000
114	6.19798	6.16000

115	6.24634	6.16000
116	6.32238	6.16000
117	6.19900	6.16000
118	6.13192	6.16000
119	6.17615	6.16000
120	6.31886	6.16000
121	6.32325	6.16000
122	6.30840	6.16000
123	6.27897	6.16000
124	6.29549	6.16000
125	6.31072	6.16000
126	6.32193	6.16000
127	6.27663	6.16000
128	6.11245	6.16000
129	6.06171	6.16000
130	6.02497	6.16000
131	6.08512	6.16000
132	6.31677	6.16000
133	6.22765	6.16000
134	6.40662	6.16000
135	6.19322	6.16000
136	6.31396	6.16000
137	6.10395	6.16000
138	6.24379	6.16000
139	6.20682	6.16000
140	6.11270	6.16000
141	6.03993	6.16000
142	6.01416	6.16000
143	6.15996	6.16000
144	5.96770	6.16000
145	5.99902	6.16000
146	6.10941	6.16000
147	5.97969	6.16000
148	6.01050	6.16000
149	6.02907	6.16000
150	6.13239	6.16000
151	6.03619	6.16000
152	6.07561	6.16000
153	6.05057	6.16000

154	6.33173	6.16000
155	6.33123	6.16000
156	6.26531	6.16000
157	1.61607	6.16000
158	6.53612	6.16000
159	1.25743	6.16000
160	6.40397	6.16000
161	6.20453	6.16000
162	6.29002	6.16000
163	5.96888	6.16000
164	6.32861	6.16000
165	6.30092	6.16000
166	6.34230	6.16000
167	6.26618	6.16000
168	6.17787	6.16000
169	6.08720	6.16000
170	6.02513	6.16000
171	6.50923	6.16000
172	6.10007	6.16000
173	6.36786	6.16000
174	6.23134	6.16000
175	6.25609	6.16000
176	6.30285	6.16000
177	5.96564	6.16000
178	6.33626	6.16000
179	6.01827	6.16000
180	6.05472	6.16000
181	6.28847	6.16000
182	6.19888	6.16000
183	6.47731	6.16000
184	6.36407	6.16000
185	6.36579	6.16000
186	6.02027	6.16000
187	6.33630	6.16000
188	6.26735	6.16000
189	6.40005	6.16000
190	6.27131	6.16000
191	6.38929	6.16000
192	6.39194	6.16000

193	6.30222	6.16000
194	6.37758	6.16000
195	6.26695	6.16000
196	6.37395	6.16000
197	6.29331	6.16000
198	5.97902	6.16000
199	6.07840	6.16000
200	6.05874	6.16000
201	6.09127	6.16000
202	6.01571	6.16000
203	6.17397	6.16000
204	6.20658	6.16000
205	6.01374	6.16000
206	6.02016	6.16000
207	6.03328	6.16000
208	6.08223	6.16000
209	6.06144	6.16000
210	6.23028	6.16000
211	6.22835	6.16000
212	6.27947	6.16000
213	6.34860	6.16000
214	6.33941	6.16000
215	6.33998	6.16000
216	6.22526	6.16000
217	6.15110	6.16000
218	6.02347	6.16000
219	5.96933	6.16000
220	6.08735	6.16000
221	6.10500	6.16000
222	5.99055	6.16000
223	6.33815	6.16000
224	6.40270	6.16000
225	6.30957	6.16000
226	6.27730	6.16000
227	6.08621	6.16000
228	6.06848	6.16000
229	6.22901	6.16000
230	6.23802	6.16000
231	6.00933	6.16000

232	6.27934	6.16000
233	6.20028	6.16000
234	6.26577	6.16000
235	5.94979	6.16000
236	6.07525	6.16000
237	6.13358	6.16000
238	5.94353	6.16000
239	6.00745	6.16000
240	6.48720	6.16000
241	6.50721	6.16000
242	6.33268	6.16000
243	6.09929	6.16000
244	6.08965	6.16000
245	6.34888	6.16000
246	6.35879	6.16000
247	6.31749	6.16000
248	6.32510	6.16000
249	6.31092	6.16000
250	6.14213	6.16000
251	6.12058	6.16000
252	6.02858	6.16000
253	6.02715	6.16000
254	6.00887	6.16000
255	6.21698	6.16000
256	6.14775	6.16000
257	6.35150	6.16000
258	6.31507	6.16000
259	6.37064	6.16000
260	6.33870	6.16000
261	6.33105	6.16000
262	6.14023	6.16000
263	6.06251	6.16000
264	6.14176	6.16000
265	6.18987	6.16000
266	6.36859	6.16000
267	6.26552	6.16000
268	6.22710	6.16000
269	6.31507	6.16000
270	6.36379	6.16000
271	6.31713	6.16000
272	6.30900	6.16000
273	6.31832	6.16000
274	6.51441	6.16000
275	6.29222	6.16000
276	6.28997	6.16000
277	6.05208	6.16000
278	6.37185	6.16000
279	6.09688	6.16000
280	6.30768	6.16000
281	6.35757	6.16000
282	6.26832	6.16000
283	6.30382	6.16000
284	6.25260	6.16000
285	6.36165	6.16000
286	6.34180	6.16000
287	6.34100	6.16000
Average	6.16010	
STDEV	0.46767	
p-value	9.9747E-01	

	TV On	
n	**Device**	**Commercial**
	(A)	**(A)**
1	0.77339	0.77000
2	0.76418	0.77000
3	0.79549	0.77000
4	0.78821	0.77000
5	0.76093	0.77000
6	0.79522	0.77000
7	0.78725	0.77000
8	0.78434	0.77000
9	0.76816	0.77000
10	0.79837	0.77000
11	0.79878	0.77000
12	0.80485	0.77000
13	0.79732	0.77000
14	0.73932	0.77000
15	0.74107	0.77000

16	0.75717	0.77000
17	0.74195	0.77000
18	0.74997	0.77000
19	0.75187	0.77000
20	0.75963	0.77000
21	0.74998	0.77000
22	0.74779	0.77000
23	0.74501	0.77000
24	0.77747	0.77000
25	0.78176	0.77000
26	0.74861	0.77000
27	0.78100	0.77000
28	0.78391	0.77000
29	0.77133	0.77000
30	0.76553	0.77000
31	0.77167	0.77000
32	0.77803	0.77000
33	0.74995	0.77000
34	0.74411	0.77000
35	0.81305	0.77000
36	0.76633	0.77000
37	0.78108	0.77000
38	0.78522	0.77000
39	0.74081	0.77000
40	0.75459	0.77000
41	0.75694	0.77000
42	0.73033	0.77000
43	0.74873	0.77000
44	0.78137	0.77000
45	0.77187	0.77000
46	0.75638	0.77000
47	0.78373	0.77000
48	0.76107	0.77000
49	0.75245	0.77000
50	0.75034	0.77000
51	0.74430	0.77000
52	0.78738	0.77000
53	0.78723	0.77000
54	0.76117	0.77000

55	0.77414	0.77000
56	0.74383	0.77000
57	0.73649	0.77000
58	0.77353	0.77000
59	0.77583	0.77000
60	0.77149	0.77000
61	0.77186	0.77000
62	0.75199	0.77000
63	0.73966	0.77000
64	0.74911	0.77000
65	0.77283	0.77000
66	0.76146	0.77000
67	0.72699	0.77000
68	0.78173	0.77000
69	0.75129	0.77000
70	0.76025	0.77000
71	0.75563	0.77000
72	0.78480	0.77000
73	0.78135	0.77000
74	0.79796	0.77000
75	0.78020	0.77000
76	0.78615	0.77000
77	0.77159	0.77000
78	0.75155	0.77000
79	0.77235	0.77000
80	0.75078	0.77000
81	0.74271	0.77000
82	0.79543	0.77000
83	0.77424	0.77000
84	0.77492	0.77000
85	0.76963	0.77000
86	0.74570	0.77000
87	0.73901	0.77000
88	0.72899	0.77000
89	0.78508	0.77000
90	0.77660	0.77000
91	0.78619	0.77000
92	0.78026	0.77000
93	0.73822	0.77000

94	0.76378	0.77000
95	0.77449	0.77000
96	0.74400	0.77000
97	0.76028	0.77000
98	0.79716	0.77000
99	0.80351	0.77000
100	0.79109	0.77000
101	0.79175	0.77000
102	0.79440	0.77000
103	0.79780	0.77000
104	0.80204	0.77000
105	0.79748	0.77000
106	0.80701	0.77000
107	0.79266	0.77000
108	0.79420	0.77000
109	0.75095	0.77000
110	0.75160	0.77000
111	0.77413	0.77000
112	0.74673	0.77000
113	0.75918	0.77000
114	0.74884	0.77000
115	0.75279	0.77000
116	0.74618	0.77000
117	0.71355	0.77000
118	0.76613	0.77000
119	0.74972	0.77000
120	0.78036	0.77000
121	0.72697	0.77000
122	0.77859	0.77000
123	0.74135	0.77000
124	0.79417	0.77000
125	0.76637	0.77000
126	0.77217	0.77000
127	0.76128	0.77000
128	0.78306	0.77000
129	0.79696	0.77000
130	0.74936	0.77000
131	0.75249	0.77000
132	0.75291	0.77000

133	0.75165	0.77000
134	0.73840	0.77000
135	0.82870	0.77000
136	0.75477	0.77000
137	0.73444	0.77000
138	0.75084	0.77000
139	0.74948	0.77000
140	0.76357	0.77000
141	0.78173	0.77000
142	0.80309	0.77000
143	0.80589	0.77000
144	0.78111	0.77000
145	0.79722	0.77000
146	0.78913	0.77000
147	0.78249	0.77000
148	0.79606	0.77000
149	0.79248	0.77000
150	0.79510	0.77000
151	0.73863	0.77000
152	0.74834	0.77000
153	0.74912	0.77000
154	0.76292	0.77000
155	0.78807	0.77000
156	0.78168	0.77000
157	0.77417	0.77000
158	0.75808	0.77000
159	0.79848	0.77000
160	0.78801	0.77000
161	0.79326	0.77000
162	0.77481	0.77000
163	0.79994	0.77000
164	0.76327	0.77000
165	0.74612	0.77000
166	0.77007	0.77000
167	0.76080	0.77000
168	0.75990	0.77000
169	0.75669	0.77000
170	0.76191	0.77000
171	0.80563	0.77000

172	0.77632	0.77000
173	0.76862	0.77000
174	0.76279	0.77000
175	0.74154	0.77000
176	0.77470	0.77000
177	0.76600	0.77000
178	0.78431	0.77000
179	0.78986	0.77000
180	0.75637	0.77000
181	0.80030	0.77000
182	0.79599	0.77000
183	0.78950	0.77000
184	0.80606	0.77000
185	0.79442	0.77000
186	0.78817	0.77000
187	0.78615	0.77000
188	0.79085	0.77000
189	0.78961	0.77000
190	0.77537	0.77000
191	0.79423	0.77000
192	0.76521	0.77000
193	0.77052	0.77000
194	0.78250	0.77000
195	0.75739	0.77000
196	0.74178	0.77000
197	0.75787	0.77000
198	0.75198	0.77000
199	0.79892	0.77000
200	0.78269	0.77000
201	0.74567	0.77000
202	0.74603	0.77000
203	0.77007	0.77000
204	0.77720	0.77000
205	0.76596	0.77000
206	0.77953	0.77000
207	0.76557	0.77000
208	0.73463	0.77000
209	0.75908	0.77000
210	0.75978	0.77000
211	0.74654	0.77000
212	0.75321	0.77000
213	0.78119	0.77000
214	0.76696	0.77000
215	0.78270	0.77000
216	0.79738	0.77000
217	0.77158	0.77000
218	0.76636	0.77000
219	0.76341	0.77000
220	0.79054	0.77000
221	0.78245	0.77000
222	0.78718	0.77000
223	0.75775	0.77000
224	0.77390	0.77000
225	0.73754	0.77000
226	0.79208	0.77000
227	0.78985	0.77000
228	0.74979	0.77000
229	0.74959	0.77000
230	0.76250	0.77000
231	0.78177	0.77000
232	0.76632	0.77000
233	0.74473	0.77000
234	0.77278	0.77000
235	0.78312	0.77000
236	0.77339	0.77000
237	0.75113	0.77000
238	0.77900	0.77000
239	0.75172	0.77000
240	0.72399	0.77000
241	0.78583	0.77000
242	0.76743	0.77000
243	0.78650	0.77000
244	0.77620	0.77000
245	0.79904	0.77000
246	0.74947	0.77000
247	0.77254	0.77000
248	0.75885	0.77000
249	0.74854	0.77000

250	0.78955	0.77000
251	0.76964	0.77000
252	0.79789	0.77000
253	0.74596	0.77000
254	0.77566	0.77000
255	0.78528	0.77000
256	0.78069	0.77000
257	0.82653	0.77000
258	0.77622	0.77000
259	0.76488	0.77000
260	0.74976	0.77000
261	0.72583	0.77000
262	0.73192	0.77000
263	0.73517	0.77000
264	0.74054	0.77000
265	0.78609	0.77000
266	0.78802	0.77000
267	0.79306	0.77000
268	0.79399	0.77000
269	0.77358	0.77000
270	0.78410	0.77000
271	0.77520	0.77000
272	0.77149	0.77000
273	0.74021	0.77000
274	0.75622	0.77000
275	0.75745	0.77000
276	0.78515	0.77000
277	0.74492	0.77000
278	0.75600	0.77000
279	0.74481	0.77000
280	0.75724	0.77000
281	0.80119	0.77000
282	0.76002	0.77000
283	0.77573	0.77000
Average	0.77000	
STDEV	0.02074	
p-value	9.9816E-01	

	TV Off	
n	**Device**	**Commercial**
	(A)	**(A)**
1	0.13329	0.13000
2	0.13315	0.13000
3	0.13579	0.13000
4	0.13384	0.13000
5	0.13501	0.13000
6	0.13556	0.13000
7	0.13197	0.13000
8	0.13114	0.13000
9	0.12925	0.13000
10	0.13559	0.13000
11	0.13558	0.13000
12	0.13327	0.13000
13	0.13066	0.13000
14	0.12985	0.13000
15	0.13567	0.13000
16	0.13198	0.13000
17	0.13728	0.13000
18	0.13561	0.13000
19	0.13996	0.13000
20	0.14256	0.13000
21	0.13899	0.13000
22	0.13794	0.13000
23	0.13226	0.13000
24	0.14239	0.13000
25	0.14663	0.13000
26	0.14700	0.13000
27	0.15381	0.13000
28	0.15678	0.13000
29	0.16682	0.13000
30	0.17163	0.13000
31	0.17140	0.13000
32	0.16972	0.13000
33	0.16004	0.13000
34	0.16404	0.13000
35	0.16665	0.13000
36	0.13556	0.13000

37	0.13482	0.13000
38	0.13788	0.13000
39	0.13631	0.13000
40	0.12912	0.13000
41	0.12841	0.13000
42	0.13084	0.13000
43	0.13282	0.13000
44	0.13283	0.13000
45	0.12981	0.13000
46	0.13215	0.13000
47	0.13335	0.13000
48	0.13283	0.13000
49	0.14374	0.13000
50	0.13620	0.13000
51	0.13444	0.13000
52	0.12897	0.13000
53	0.12694	0.13000
54	0.12803	0.13000
55	0.13155	0.13000
56	0.13344	0.13000
57	0.13516	0.13000
58	0.13061	0.13000
59	0.13445	0.13000
60	0.13234	0.13000
61	0.13132	0.13000
62	0.13442	0.13000
63	0.13028	0.13000
64	0.13043	0.13000
65	0.12872	0.13000
66	0.12919	0.13000
67	0.12455	0.13000
68	0.12603	0.13000
69	0.13051	0.13000
70	0.12863	0.13000
71	0.12948	0.13000
72	0.13180	0.13000
73	0.12716	0.13000
74	0.12834	0.13000
75	0.13346	0.13000

76	0.13172	0.13000
77	0.13903	0.13000
78	0.13669	0.13000
79	0.13450	0.13000
80	0.12705	0.13000
81	0.12803	0.13000
82	0.12778	0.13000
83	0.13205	0.13000
84	0.13496	0.13000
85	0.13206	0.13000
86	0.12902	0.13000
87	0.13279	0.13000
88	0.12997	0.13000
89	0.12852	0.13000
90	0.13751	0.13000
91	0.13294	0.13000
92	0.13230	0.13000
93	0.13034	0.13000
94	0.13578	0.13000
95	0.13636	0.13000
96	0.13017	0.13000
97	0.13008	0.13000
98	0.13438	0.13000
99	0.13316	0.13000
100	0.13245	0.13000
101	0.13245	0.13000
102	0.12879	0.13000
103	0.13250	0.13000
104	0.13058	0.13000
105	0.12183	0.13000
106	0.12240	0.13000
107	0.12603	0.13000
108	0.13289	0.13000
109	0.13347	0.13000
110	0.13374	0.13000
111	0.13923	0.13000
112	0.12513	0.13000
113	0.12188	0.13000
114	0.12921	0.13000

115	0.12473	0.13000	**154**	0.12204	0.13000
116	0.12430	0.13000	**155**	0.12896	0.13000
117	0.12074	0.13000	**156**	0.12154	0.13000
118	0.12594	0.13000	**157**	0.13390	0.13000
119	0.13259	0.13000	**158**	0.13434	0.13000
120	0.12932	0.13000	**159**	0.13355	0.13000
121	0.13059	0.13000	**160**	0.12750	0.13000
122	0.12247	0.13000	**161**	0.13324	0.13000
123	0.12669	0.13000	**162**	0.12874	0.13000
124	0.12549	0.13000	**163**	0.13399	0.13000
125	0.12159	0.13000	**164**	0.13013	0.13000
126	0.12457	0.13000	**165**	0.13138	0.13000
127	0.12508	0.13000	**166**	0.13239	0.13000
128	0.12590	0.13000	**167**	0.13017	0.13000
129	0.12659	0.13000	**168**	0.13459	0.13000
130	0.12525	0.13000	**169**	0.13454	0.13000
131	0.13712	0.13000	**170**	0.13472	0.13000
132	0.13295	0.13000	**171**	0.13490	0.13000
133	0.13359	0.13000	**172**	0.12741	0.13000
134	0.13240	0.13000	**173**	0.12792	0.13000
135	0.13446	0.13000	**174**	0.12727	0.13000
136	0.13291	0.13000	**175**	0.12773	0.13000
137	0.13378	0.13000	**176**	0.13089	0.13000
138	0.13117	0.13000	**177**	0.13084	0.13000
139	0.12913	0.13000	**178**	0.13037	0.13000
140	0.12892	0.13000	**179**	0.13149	0.13000
141	0.12821	0.13000	**180**	0.13208	0.13000
142	0.12496	0.13000	**181**	0.13133	0.13000
143	0.12904	0.13000	**182**	0.12654	0.13000
144	0.12325	0.13000	**183**	0.12600	0.13000
145	0.13357	0.13000	**184**	0.13277	0.13000
146	0.13234	0.13000	**185**	0.12872	0.13000
147	0.13471	0.13000	**186**	0.13261	0.13000
148	0.13259	0.13000	**187**	0.13274	0.13000
149	0.13395	0.13000	**188**	0.12501	0.13000
150	0.12906	0.13000	**189**	0.12274	0.13000
151	0.13178	0.13000	**190**	0.12645	0.13000
152	0.13089	0.13000	**191**	0.13117	0.13000
153	0.13001	0.13000	**192**	0.12925	0.13000

193	0.12841	0.13000
194	0.12945	0.13000
195	0.12483	0.13000
196	0.12491	0.13000
197	0.12758	0.13000
198	0.12860	0.13000
199	0.13191	0.13000
200	0.12763	0.13000
201	0.13109	0.13000
202	0.12543	0.13000
203	0.12581	0.13000
204	0.12683	0.13000
205	0.13222	0.13000
206	0.13208	0.13000
207	0.13308	0.13000
208	0.13023	0.13000
209	0.12937	0.13000
210	0.13415	0.13000
211	0.13092	0.13000
212	0.12566	0.13000
213	0.12751	0.13000
214	0.13165	0.13000
215	0.13380	0.13000
216	0.13230	0.13000
217	0.13536	0.13000
218	0.13291	0.13000
219	0.12122	0.13000
220	0.12520	0.13000
221	0.13314	0.13000
222	0.13446	0.13000
223	0.12650	0.13000
224	0.12527	0.13000
225	0.12626	0.13000
226	0.12543	0.13000
227	0.12915	0.13000
228	0.13037	0.13000
229	0.12990	0.13000
230	0.12906	0.13000
231	0.13119	0.13000
232	0.12715	0.13000
233	0.12478	0.13000
234	0.12711	0.13000
235	0.13275	0.13000
236	0.12740	0.13000
237	0.13489	0.13000
238	0.12990	0.13000
239	0.13042	0.13000
240	0.13480	0.13000
241	0.13268	0.13000
242	0.13062	0.13000
243	0.13117	0.13000
244	0.12903	0.13000
245	0.12765	0.13000
246	0.13494	0.13000
247	0.13244	0.13000
248	0.12754	0.13000
249	0.13164	0.13000
250	0.13342	0.13000
251	0.12931	0.13000
252	0.12621	0.13000
253	0.12671	0.13000
254	0.12005	0.13000
255	0.12900	0.13000
256	0.12214	0.13000
257	0.12325	0.13000
258	0.12860	0.13000
259	0.12435	0.13000
260	0.12302	0.13000
261	0.12483	0.13000
262	0.12984	0.13000
263	0.12955	0.13000
Average	0.13000	
STDEV	0.00393	
p-value	9.8583E-01	

	Washing Machine	
n	**Device**	**Commercial**
	(A)	**(A)**

1	8.46237	8.53000
2	8.20211	8.53000
3	8.70085	8.53000
4	8.57404	8.53000
5	8.57168	8.53000
6	8.52313	8.53000
7	8.50993	8.53000
8	8.39352	8.53000
9	8.31303	8.53000
10	8.65668	8.53000
11	8.10186	8.53000
12	8.63128	8.53000
13	8.69443	8.53000
14	8.77078	8.53000
15	8.59810	8.53000
16	8.64290	8.53000
17	8.70150	8.53000
18	8.49889	8.53000
19	8.67714	8.53000
20	8.61706	8.53000
21	8.75236	8.53000
22	8.61820	8.53000
23	8.32861	8.53000
24	8.52835	8.53000
25	8.38262	8.53000
26	8.32173	8.53000
27	8.05204	8.53000
28	8.49643	8.53000
29	8.96894	8.53000
30	8.20627	8.53000
31	8.29038	8.53000
32	8.26364	8.53000
33	8.33495	8.53000
34	8.47815	8.53000
35	8.34564	8.53000
36	8.53467	8.53000
37	8.68379	8.53000
38	8.70473	8.53000
39	8.63061	8.53000
40	8.67637	8.53000
41	8.49837	8.53000
42	8.52424	8.53000
43	8.40173	8.53000
44	8.32709	8.53000
45	8.32547	8.53000
46	8.34457	8.53000
47	8.64923	8.53000
48	8.52528	8.53000
49	8.57194	8.53000
50	8.35065	8.53000
51	8.75408	8.53000
52	8.78276	8.53000
53	8.60406	8.53000
54	8.71090	8.53000
55	8.59287	8.53000
56	8.67821	8.53000
57	8.52689	8.53000
58	8.11383	8.53000
59	8.46618	8.53000
60	8.64395	8.53000
61	8.58592	8.53000
62	8.68719	8.53000
63	8.31629	8.53000
64	8.37232	8.53000
65	8.24537	8.53000
66	8.25958	8.53000
67	8.32044	8.53000
68	8.44109	8.53000
69	8.73979	8.53000
70	8.72244	8.53000
71	8.30677	8.53000
72	8.71717	8.53000
73	8.51172	8.53000
74	8.31778	8.53000
75	8.53224	8.53000
76	8.48217	8.53000
77	8.58510	8.53000
78	8.68995	8.53000

79	8.69176	8.53000
80	8.27711	8.53000
81	8.24701	8.53000
82	8.37431	8.53000
83	8.78891	8.53000
84	8.57943	8.53000
85	8.66727	8.53000
86	8.70839	8.53000
87	8.28099	8.53000
88	8.36185	8.53000
89	8.28466	8.53000
90	8.50059	8.53000
91	8.66083	8.53000
92	8.54292	8.53000
93	8.46581	8.53000
94	8.74220	8.53000
95	8.70469	8.53000
96	8.31174	8.53000
97	8.44232	8.53000
98	8.64312	8.53000
99	8.77613	8.53000
100	8.49805	8.53000
101	8.32517	8.53000
102	8.12863	8.53000
103	8.53820	8.53000
104	8.73010	8.53000
105	8.68326	8.53000
106	8.71389	8.53000
107	8.73894	8.53000
108	8.61728	8.53000
109	8.49806	8.53000
110	8.84663	8.53000
111	8.70166	8.53000
112	8.57240	8.53000
113	8.56897	8.53000
114	8.54461	8.53000
115	8.64844	8.53000
116	8.72599	8.53000
117	8.79790	8.53000

118	8.46520	8.53000
119	8.40458	8.53000
120	8.03469	8.53000
121	8.47231	8.53000
122	8.52650	8.53000
123	8.21360	8.53000
124	8.32023	8.53000
125	8.71857	8.53000
126	8.25056	8.53000
127	8.40498	8.53000
128	8.24559	8.53000
129	8.61955	8.53000
130	8.52789	8.53000
131	8.51356	8.53000
132	8.32553	8.53000
133	8.46325	8.53000
134	8.32460	8.53000
135	8.27783	8.53000
136	8.63644	8.53000
137	8.49575	8.53000
138	8.64815	8.53000
139	8.42381	8.53000
140	8.62273	8.53000
141	8.59993	8.53000
142	8.63197	8.53000
143	8.64781	8.53000
144	8.62264	8.53000
145	8.63140	8.53000
146	8.56283	8.53000
147	8.45625	8.53000
148	8.69723	8.53000
149	8.62037	8.53000
150	8.74411	8.53000
151	8.75574	8.53000
152	8.15895	8.53000
153	8.17677	8.53000
154	8.56165	8.53000
155	8.63870	8.53000
156	8.66519	8.53000

157	8.33522	8.53000
158	8.21779	8.53000
159	8.30811	8.53000
160	8.42660	8.53000
161	8.42305	8.53000
162	8.44540	8.53000
163	8.77573	8.53000
164	8.64185	8.53000
165	8.55965	8.53000
166	8.72510	8.53000
167	8.74344	8.53000
168	8.67203	8.53000
169	8.38080	8.53000
170	8.62968	8.53000
171	8.79120	8.53000
172	8.75872	8.53000
173	8.71826	8.53000
174	8.54848	8.53000
175	8.68005	8.53000
176	8.29705	8.53000
177	8.39395	8.53000
178	8.71266	8.53000
179	8.51187	8.53000
180	8.74099	8.53000
181	8.39760	8.53000
182	8.47813	8.53000
183	8.54007	8.53000
184	8.42222	8.53000
185	8.51992	8.53000
186	8.63090	8.53000
187	8.76925	8.53000
188	8.70332	8.53000
189	8.71501	8.53000
190	8.74420	8.53000
191	8.66323	8.53000
192	8.69451	8.53000
193	8.72422	8.53000
194	8.72398	8.53000
195	8.30219	8.53000
196	8.18691	8.53000
197	8.33655	8.53000
198	8.67298	8.53000
199	8.47637	8.53000
200	8.73106	8.53000
201	8.73036	8.53000
202	8.64692	8.53000
203	8.62210	8.53000
Average	8.52991	
STDEV	0.18198	
p-value	9.9469E-01	

11.4 Appendix 4- Limitations and Assumptions

The project, Enhancing Smart Grid Technology to the Consumer Level, has certain limitations that should be kept in mind. When engineering this project, it was designed to be used by consumers in the United States. Because there are different outlet plugs in different parts of the world, the device, unless an outlet plug converter is used, cannot be plugged into a different outlet plug other than that of the United States. Also, the United States supplies a constant voltage between 110 and 120 volts. The device may not be used at any other range for electrical safety. The device is only to measure the amount of power consumed by household appliances. The device may not be used for any other purposes such as measuring the power consumed by an entire household or corporation. This action will overload the device to cause damage to it or to cause harm to the consumer using it.

Some assumptions were also made when engineering this project. First, it is assumed that all the data collected is a representative sampling of an average United States household appliance, depending on what the appliance is. It is also assumed that voltage does not fluctuate extremely and the sensor is accurate when reading data and is functioning correctly.

11.5 Appendix 5- Literature Review Procedure

When developing the Literature Review, background research was conducted. The following notes with keywords were used when writing the Literature Review.

MCNALLY, ARDUINO BASED WIRELESS POWER METER

Original URL	https://people.ece.cornell.edu/land/courses/eceprojectsland/STUDENTPROJ/2009to2010/csm44/DESIGN_REPORT.pdf		
File name of PDF	160913_McNally_ArduinoSensor		
Date Written	May 2010	**Date accessed**	September 14, 2016
Type of Paper	Original Research		
Goal of Paper	Build Arduino based wireless power meter to estimate power consumption to promote consumer to reduce electricity consumption.		
Major Findings	1. Update of rate was 20 Hz at its highest, which can be approved upon 2. Sensor using current divider was very accurate 3. Wi-Fi is not the best way to send data to the consumer		
Notes on Paper	• Very helpful paper for my research • Research the development of current measurement devices • Use GUI to make app more interactive • Research more on current transducers and rectifier circuitry • Research how to send signals from sensor to app • Make identifying devices based on electricity consumption more reliable • Research AC waveforms and how electricity works in the house • Include not only current data but build on previous data to build a user profile (New Idea!) • SAFETY around electrical equipment, sensor must be safe!		
Biases of authors	Very unbiased about electricity consumption, but is biased about the use of Wi-Fi due to it not collaborating with the project		
My opinions	It is a really helpful paper. It has almost everything I need. My project is heavily based on this paper with a few modification making it more reliable and resilient.		

on Paper	
Follow up questions & ideas	Why did you not measure voltage? Don't you need that for calculating the electricity consumption? P=IV? Why did you choose a single port on the router? Where did it go wrong?
keywords	Arduino, wireless, sensor, consumption, educate, user based

PIERCE, TOP NINE THINGS YOU DIDN'T KNOW ABOUT AMERICA'S POWER GRID

<table>
<tr><td>Original URL</td><td colspan="3">http://www.energy.gov/articles/top-9-things-you-didnt-know-about-americas-power-grid</td></tr>
<tr><td>File name of PDF</td><td colspan="3">160913_Pierce_BasicInfo</td></tr>
<tr><td>Date Written</td><td>November 20, 2014- 10:07 am</td><td>Date Accessed</td><td>September 15, 2016</td></tr>
<tr><td>Type of Paper</td><td colspan="3">Secondary Source</td></tr>
<tr><td>Goal of Paper</td><td colspan="3">Describe America's Power Grid in detail that is understandable to the general public</td></tr>
<tr><td>Major Findings</td><td colspan="3">None, Good Diagrams that have data</td></tr>
<tr><td>Notes on Paper</td><td colspan="3">
Distribution of electricity: low-high-low
Divided into three smaller grids: "Eastern Interconnection (Rockies), Western Interconnection (Pacific), and Texas Interconnection"
Grid updates by itself automatically to meet energy demands
Need to "enhance reliability" (less power outages)
Reliable=fewer and shorter connections
Needs to be resilient to severe weather
Prepare grid for global warming
Synchrophaser Technology= small fast health checker of grid (RESEARCH)
Reduces power outages
Integration of renewable energy sources
Microgrids= small network of backup generators for emergencies (power outage)
Very efficient, somehow integrate it in grid on a large scale
Cybersecurity needs to strengthen (Maybe check this area as well)
People steal others electricity data
</td></tr>
<tr><td>Biases of authors</td><td colspan="3">The author is part of energy.gov. Although it is government website, it does promote green energy to reduce fossil fuels, so some facts may be skewed.</td></tr>
</table>

My opinions on Paper	This is a really nice paper to get background information on how electricity travels through the power grid in general. The power grid is an integral part, and Smart Grid is based off of that, so it will be helpful to get information related to it on a smaller scale. I learned a lot of new facts about electricity in general that I didn't know as well.
Follow up questions & ideas	Why do we not try to expand microgrids since they are more reliable than large scale power grid? How do we change electricity to and from high and low voltage? Why does Texas get its own interconnection?
keywords	Electricity, power grid, voltage, synchrophaser, microgrids, green energy, data graphs, interconnections

AZTECH ASSOCIATES INC., IN-HOME DISPLAY USER MANUAL

Original URL	http://www.myaztech.ca/wp-content/uploads/2013/05/D097-0905-B01-User-Manual.pdf		
File name of PDF	160925_Aztech_appdisplay		
Date Written	2013	**Date Accessed**	September 25, 2016
Type of Paper	Primary Source		
Goal of Paper	Describe how data is displayed to the user		
Major Findings	App needs to be usable by all types of people		

Notes on Paper	• Don't want to have a long tutorial on how everything in app works
	• Don't make it confusing to the user
	  ○ Like adding a bunch of symbols to explain
	• Radio waves are used to send data
	  ○ Causes interference with tv
	  ○ Research other waves that can send data without interference
	• Patented Display
	• Show electricity used, cost, history, (best fit appliance, time)
	  ○ Create a user profile based on history that companies can use
	• Give goals to the consumer to achieve in electricity consumption
	  ○ Like an electricity diet, decrease slightly weekly
	• Allows to make immediate changes
	• Multiple displays
	  ○ Home screen: 24 hr
	  ○ Weekly/Monthly/Year (entire profile)
	• Have user preferences/settings to allow users to make it color-coded, text based, etc.
	• Use less electricity for battery (ironic)		

Biases of authors	Bias toward the Aztech product of in-Home Display Second Generation
My opinions on Paper	Really nice suggestions on how to develop app that is user-friendly. What to do and what not to have been explored, so not a lot of work on my part.
Follow up questions & ideas	Why do you have confusing symbols? Why not just make it text based, so you don't have to explain it?
keywords	app, display, usage, electricity, consumer, profile, confusing symbols, data

ELLABBAN, SMART GRID CUSTOMERS' ACCEPTANCE AND ENGAGEMENT

<table>
<tr><td>Original URL</td><td colspan="3">http://ac.els-cdn.com.ezproxy.wpi.edu/S1364032116302441/1-s2.0-S1364032116302441-main.pdf?_tid=34dbfa24-8379-11e6-95a5-00000aab0f6b&acdnat=1474846908_62dfc79627211e6692f8e676d8cb8dcf</td></tr>
<tr><td>File name of PDF</td><td colspan="3">160925_Ellaban_customeragree</td></tr>
<tr><td>Date Written</td><td>June 21, 2016</td><td>Date Accessed</td><td>September 25, 2016</td></tr>
<tr><td>Type of Paper</td><td colspan="3">Original Paper</td></tr>
<tr><td>Goal of Paper</td><td colspan="3">How customers react to Smart Grid Technology and what it could mean for the future of this technology (optimize energy consumption)</td></tr>
<tr><td>Major Findings</td><td colspan="3">Main thing is people need to like what is there, or they won't use it</td></tr>
<tr><td>Notes on Paper</td><td colspan="3">
Integrate RES (Renewable Energy Source)
Two-way system that interacts with the user
Need supply and demand to use electricity optimally
Electricity cannot be easily stored
Population increasing= demand increase=global warming increase
Goal: decrease global warming
Electricity generation is always fluctuating
Improve security of supply
Improved efficiency and reliability through smart energy management
Algorithms (look into checking electricity usage)
Automated control (all programmed, no programmer needed)
Opportunity to decrease gas emissions, in turn, global warming
Tell users the background of smart grid
Tell them what it is (most don't know)
Benefits globally
Saving costs
Engaging residential space is still a problem
</td></tr>
</table>

Biases of authors	Want Smart Grid to succeed and win amicable views to continue to be used Has really nice diagrams that can be used
My opinions on Paper	This has a lot of nice diagrams that can be used. A lot of arguments are made why consumers should use smart grid. It also talks about Global Warming, which is one of my universal goals of this project, and how I can lower it, through the incorporation of smart grid.
Follow up questions & ideas	Why have there been no storage units created to store electricity? They are very much needed, especially for solar. How do you get electricity to a high concentrate of voltage? What is the chemical process?
keywords	consumer, appreciation, smart grid, demand supply, diagrams, electricity generation, global warming

WEI, DATA-CENTRIC THREATS AND THEIR IMPACT TO REAL-TIME COMMUNICATIONS IN SMART GRID

Original URL	http://dx.doi.org/10.1016/j.comnet.2016.05.003		
File name of PDF	160925_Wei_threatsdata		
Date Written	May 3, 2016	**Date Accessed**	September 25, 2016
Type of Paper	Original Source		
Goal of Paper	Describe the impact of data-centric attacks in real-time communication of smart grid		
Major Findings	Cybersecurity of smart grid needs to secured		

Notes on Paper	• Hackers gain advantage of data through hacking the system
	• The data is not encrypted well enough like other resources
	    ○ Use prime numbers to encode carefully
	    ○ Use javascript encoder instead?
	    ○ Track GPS location of data
	    ○ Insert "chip-like" structure in data to track info of hackers
	• Hackers also sabotage the entire system
	    ○ Shuts down entire grid
	    ○ No electricity is supplied
	        ▪ Users depend on microgrids
	            • Small generators that work during power outages
	• Hackers=power outages
	    ○ Impact power supplies
	    ○ Applications stop responding
	    ○ System is unstable		

	- Real-time communication causes a distortion/delay in information when attacked - Make a 7 sec gap like live tv?
Biases of authors	Wants smart grid to succeed
My opinions on Paper	This paper opens up my eyes to the problem of sending data about smart gird. Apparently hackers also want to know your electricity information as well. I will need to make my data secured and encrypted to insure consumer safety.
Follow up questions & ideas	Why are hackers hacking into the system? What information is so valuable to them? Why is this an issue?
keywords	data, cybersecurity, primes, gps, appliances, hackers, problems, consumer protection, threat, data-centric, power outages

SHANNON, SMART DEVICES: MAKING GRID MODERNIZATION PERSONAL

Original URL	http://www.whatissmartgrid.org/featured-article/smart-devices-making-grid-modernization-personal		
File name of PDF	160913_Shannon_Personalization		
Date Written	September 1, 2015	**Date Accessed**	September 13, 2016
Type of Paper	Secondary Source		
Goal of Paper	How to make smart devices more individualized to fit personal consumer needs		
Major Findings	A lot of these can be used in app that can be updated to the user's wish		
Notes on Paper	- Simple - Apply to our daily lives - Smart devices are increasing in popularity - Used for daily communication on our phones (like an app) **Internet of Things**: network of objects that can be sensed and controlled remotely - May help smooth out the transition to flawless interconnectivity of smart devices - New technologies that can benefit my project and humans **Nest**: program itself based on your schedule and preferences, reducing energy costs, and **can be controlled from your phone** - Appliances: Companies' smart machines are able to be controlled by app		

	▪ Ex: Whirlpool's Smart Washing Machine lets smart grid area residents monitor energy usage so you can do your laundry at the most-effective time ○ Outlets: Belkin's Conserve series can track energy use and project costs and eliminates 'energy vampires' (Standby Power) by letting you set a time limit on usage. Can turn the outlet off even if you're away from home ○ Lighting: Philips Hue LED bulbs make your lights more energy efficient, lowering operating costs, and added features like adjusting the color of your lighting to match a photo from your phone's library ○ List is added to constantly as new things are discovered
Biases of authors	They want to promote the usage of smart grid and encourage people to use it at its fullest potential. They really want people to save electricity, and in fact, list a few brand names as where they could start. Maybe it was because they were funded by those companies. Whirlpool almost has every patent covered with appliances concerning smart gird tech.
My opinions on Paper	This is a really nice paper, it gave me extensions to think about other than appliances and how to promote it easily to the user. It also talks about appliances I can look into if I need help. Now I know if I need to look something up, Whirlpool's patents is the way to go. *I need to know more about stand by power and liked adding a time limit in for the user. Like you can only use it between this time and that time or this is how many specific hours of electricity you can use. Also turning on and off outlets sounds like a great idea.* **Search Belkin's Conserve series and Whirlpool's Smart Washing Machine**
Follow up questions & ideas	Why is Whirlpool dominating this specific industry? It's been a while since this has been published, is there any other modifications that can be added to this list?
keywords	Whirlpool, personalization, consumer, app, extensions, future, energy usage, examples, outlet, update, time limit, energy vampires, standby power

SGCC, WHY SMART INVERTERS AND ITS STANDARDS ARE IMPORTANT TO YOU

Original URL	http://smartgridcc.org/why-smart-inverters-and-its-standards-are-important-to-you/		
File name of PDF	160913_SGCC_SmartInverters		
Date Written	October 1, 2015	**Date Accessed**	September 13, 2016
Type of Paper	Secondary Source		
Goal of Paper	What are smart inverters and why are they important		

Major Findings	Ideal gadget in the house, may use in my sensor

Notes on Paper	• Check if appliances/gadgets are safe in your home
	• Reliably interconnect with local utility distribution grid
	• Inverters means
	    ○ Convert electricity generated to use in power lines
	    ○ Direct Current (DC) to Alternating Current (AC)
	        ▪ Made safe for consumers to use
	• Insures voltage does not fluctuate (India)
	• Addresses poor quality of electricity
	• Continues to adapt and change
	• Insures consumer's safe operations with outlets
	• Research different standards, which one was the best?
	• Helps companies back up from power outages
	Not a really helpful article to understand smart inverters

Biases of authors	Smart Inverters are important to help you conserve electricity, and it helps keep you safe. Being paired with smart grid, is a great idea.
My opinions on Paper	I think I am going to research more into smart inverters and maybe implement that into my sensor. They seem important to stop fluctuating voltage, and I do not want to electrocuted.
Follow up questions & ideas	Why does voltage fluctuate? Why doesn't the gird shut down when there is a power outage? How else can we make consumers safer to electricity?
keywords	smart inverters, voltage, safety, quality, electricity, AC, DC, outlets, power outages, sensor

WHIRLPOOL CORP., NETWORK CHANGING RESOURCE CONSUMPTION IN APPLIANCES

Original URL	https://patents.google.com/patent/US8027752B2/en?q=appliance&q=electricity&q=reader&q=usage		
File name of PDF	161009_Whirlpool_NetworkAppliances		
Date Written	October 31, 2007	**Date Accessed**	October 9, 2016
Type of Paper	Patent		
Goal of Paper	Appliance consumes least amount of resource while performing operations (Appliances use less electricity with working)		
Major Findings	It is possible to control an appliance through a network and force it to use electricity, rather than forcing people to shut it off		

Notes on Paper	• Use smart couplers to track GPS location of you and your appliance
	    ○ Easier to send signals when location is known
	• Network to connect with clocks
	    ○ Connecting multiple clocks is useful		

	▪ If power outages happen, the time will be reset, consumers won't have manually reset them ▪ User can send signal to stop appliance remotely from their laptop • Connect time to laptop /smartphone ▪ "Powering appliances up and down" • Appliances can dictate other appliances ○ Commands be like after washing machine is done start dryer • Users can tell their "smart system" to control their appliances through commands on laptop/smartphone • Internal clocks of appliances can set other internal clocks • User can control their appliances through preset commands
Biases of authors	Made for Whirlpool appliances only :(
My opinions on Paper	This was very interesting. I was talking to one my peers and he suggested I should control the flow of electricity. I did not know what he meant by that until I read this patent. This would be a nice feature to have. Most appliances take electricity even though they are not operating just because they are plugged in to an outlet. I don't know if I will have time to add to it though.
Follow up questions & ideas	Can it do tasks simultaneously? Like turn the dishwasher and the washing machine on at the same time, or can it only be one after another? Can you only communicate appliances through those clocks or can I use something else?
keywords	smart couplers, gps, networking, commands, clocks, control, flow of electricity, peer talks, whirlpool, on and off outlets

LSIS, ELECTRONIC SMART METER ENABLING DEMAND RESPONSE

Original URL	https://patents.google.com/patent/US20090198384A1/en?q=appliance&q=electricity&q=reader&q=usage		
File name of PDF	161009_LSIS_DemandResponse		
Date Written	February 4, 2009	**Date Accessed**	October 9, 2016
Type of Paper	Patent		
Goal of Paper	Use smart meters to gain information about electricity usage and send it back to companies		
Major Findings	It is possible to read electricity usage through current and voltage sensors and then send data to display it		
Notes on Paper	1. a power detector for detecting a current and a voltage of an electric line; and a second microprocessor for receiving an analog current and a voltage signal from the power detector and converting the analog current and the voltage signal to a digital signal and a numerical data		

	for metering of the measured values and transmitting the converted signal and data to the first microprocessor. 2. the integrated monitoring module comprises a demand controller for reporting various loads, power detection and load control of home electric appliance, load set-up and demand power of each load to the electric smart meter. 3. integrated monitoring module comprises: the automatic meter reader for receiving the metered data from various facilities meters; a facilities controller for receiving status signals of various facilities of a building structure; and an electric safety monitor receiving a signal of electric fault and a temperature measurement value. 4. the master server estimates and controls the rate system opted by a subscriber and power demands via power usage collected by the electric smart meter. 5. further comprising power stabilization means for supplying a stabilized direct current (DC) power source to each system and integrated monitoring modules.
Biases of authors	It's made for smart meters, smart-meter pro
My opinions on Paper	This is exactly what I need except I will represent the data to the consumer through an app, not a company program.
Follow up questions & ideas	Can you send it anywhere else? What is the range it can send to? How accurate is a smart meter? Do people even look at their smart meters?
keywords	smart meters, voltage, current, sensors, display, analog, data, microprocessor, response, demand, user

SALTER, UTILITY MONITORING DEVICE, SYSTEM, AND METHOD

Original URL	https://www.google.com/patents/US9171458		
File name of PDF	161019_Salter_UtilityMonitoringDevice		
Date Written	October 25, 2012	**Date Accessed**	October 19, 2016
Type of Paper	Patent		
Goal of Paper	The display provides a consumer with "at a glance" visual information on current usage. Optionally a digital display screen provides detailed numeric and graphical information through a number of selectable display modes.		
Major Findings	The monitoring device receives information from a smart meter, and displays usage through a display, illuminating an area using a color indicative of the current cost of consumption, and varying the illuminated area at a rate indicative of a rate of consumption. One or more devices may be networked,		

	and interface directly or indirectly with a transceiver of a smart metering system, or a retrofit transceiver for a conventional meter. Monitoring of other utilities and services may alternatively or additionally be provided.

Notes on Paper	• Device contains
	    ○ a receiver for receiving information relating to present consumption rate or aggregate consumption of the commodity
	    ○ a transmitter for sending information by a wireless communications system to a processor programmed to receive it
	    ○ local display to display a varying illuminated area whose color and area variation are each indicative of consumption
	• Based on the information sent, it will cause different areas of color to light up to indicate to the user how much they are consuming
	    ○ Not understandable, like charts or numbers
	    ○ Maybe can make red=bad, green=good

Biases of authors	The authors are part of the company Aztech. This company makes a lot of displays. Working for this company, there is a lot of bias surrounding how it is displayed. Most devices are the same except in size.
My opinions on Paper	This paper tells me some bad things to consider and improve upon, and some good things I should add to the project. Not the most helpful paper, but I have a direction as where to go with making the display.
Follow up questions & ideas	Is there a manual to tell the differences between colors? How did you think this was the easiest way to represent data? What transmitter did you use to send the information? What programming language did you use?
keywords	smart meters, sensors, display, data, graphical user interface, user, simple, colorful, user-friendly, charts

MILWAUKEE ELECTRIC TOOL CORP, TEST AND MEASUREMENT DEVICE WITH PISTOL-GRIP HANDLE

Original URL	https://www.google.com/patents/US8274273?dq=commercial+digital+clamp+meter&hl=en&sa=X&ved=0ahUKEwjSirz__43QAhWBQCYKHf2GA8cQ6AEIKzAC		
File name of PDF	161019_MilwakeeElectric_DigitalClampMeter		
Date Written	April 9, 2009	**Date Accessed**	October 19, 2016
Type of Paper	Patent		
Goal of Paper	Display an accurate and precise measurement of voltage and current using the device without electrocuting oneself		
Major Findings	Using only batteries and measuring non-intrusively on the wire, an accurate/precise reading of voltage and current can be garnered		
Notes on Paper	• receive a removable and rechargeable battery pack		

	• the clamp is operable to measure an electrical characteristic of a conductor based on an induced current
	• device includes a handle with trigger to open and close claws
	    ○ Claws include electrical leads that sense electricity flowing through the claws through infrared sensors
	    ○ Display is parallel to the claws but perpendicular to the handle

Biases of authors	The main concern of the device was safety. As this is a commercial product, safety is the biggest issue with consumers. Hence in some aspects, accuracy and precision can be improved upon.
My opinions on Paper	This was a very helpful paper. I was wondering how I would measure current non-intrusively. In physics, I learned you have to connect the ammeter in series with circuit to get a current reading. But this device does it with infrared sensors and explains well how it does it. I am going to buy this and disassemble it to look further.
Follow up questions & ideas	Is there another arrangement of the handle, trigger, claws, and display for the device that is perhaps more efficient to use? How accurate can an infrared sensor be? (Note: Look up more about infrared sensors. Maybe email the main engineer about this.)
keywords	voltage, current, sensors, analog, data, microprocessor, user, clamp, commercial, compare