Engineering Problem

Consumers are unaware of the amount of energy wasted when using appliances. Because consumers use electricity inefficiently, this misuse leads to overexertion of fossil fuels and minimized utilization of renewable energy and furthers global warming.

Engineering Goal

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

Project Charter

- Engineer a sensor to read electricity from each appliance and display on smart device.
- Device will help consumer to use electricity efficiently by:
  - Buying energy efficient appliances
  - Conserving electricity
- With less thermal energy usage and more efficient utilization of electricity, this sensor will help to reduce global warming.

What is Smart Grid Technology?

A technology that helps utility companies to determine when and how much of which type of electricity to be used.

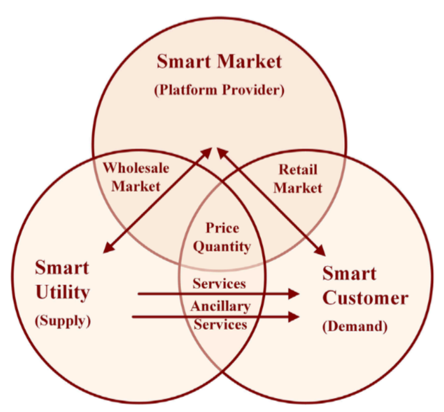

Figure 1: This Venn diagram shows how an ideal smart grid operates based on the three essential components: smart utility, smart customer, and smart market (Ellaban and Abu-Rub, 2016).

- Smart utility represents the efficient supply of energy
- 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

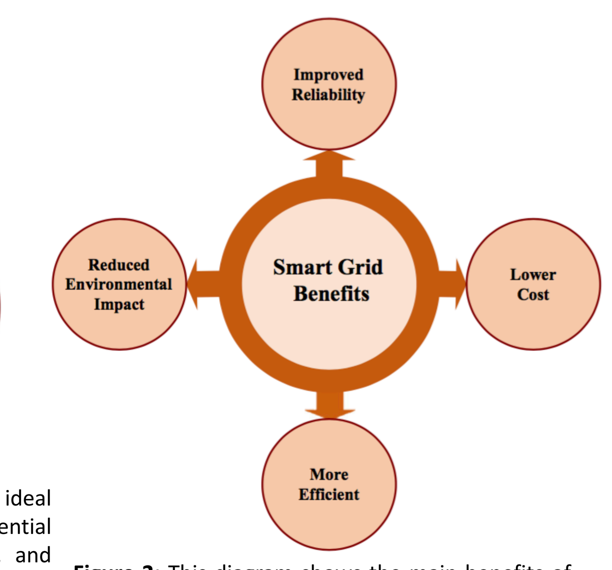

Figure 2: This diagram shows the main benefits of Smart Grid Technology (Ellaban and Abu-Rub, 2016).

Introduction

- Energy is a vital resource for humans; humans are constantly using it.
- However, humans are destroying the earth in the process of collecting and utilizing energy.
- Consumers are unaware of how they are wasting electricity when using appliances.
  - They use appliances at suboptimal times when electricity is in great demand. For example, during the evening, specifically from 6-8 pm when vast majority of electricity generated by fossil fuels
  - The overexertion of fossil fuels is the primary cause of global warming.
- Renewable energy is promoted as a way to save the earth from the effects of global warming.
  - It is minimally used in comparison to fossil fuels.

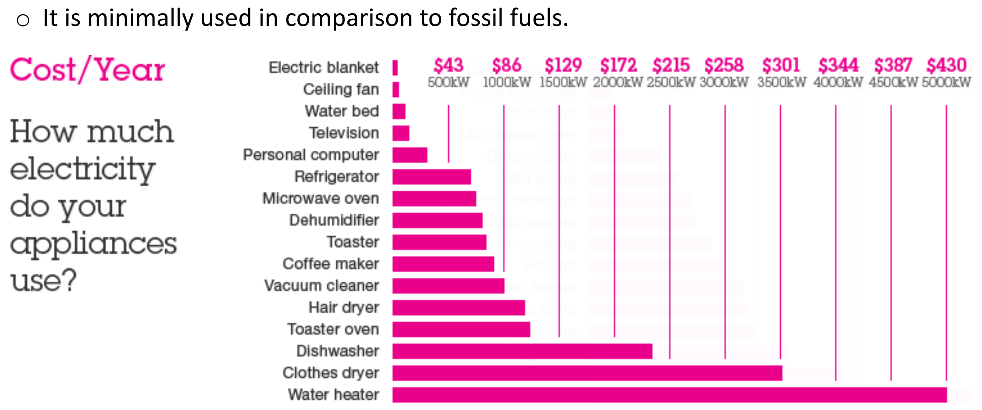

Figure 3: This graph shows the average annual amount of electricity a consumer uses for each appliance indicated (U.S. Department of Energy, 2016).

U.S. Energy Consumption by Energy Source, 2015

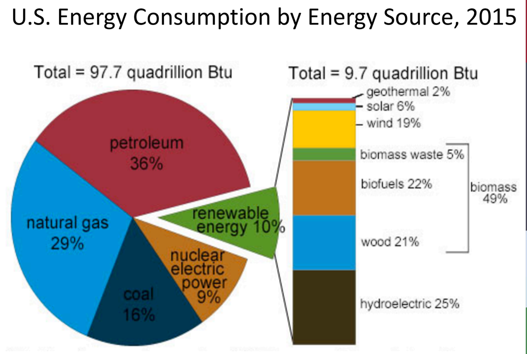

Figure 4: According to the U.S. Department of Energy, in 2015, the United States generated about 4 trillion kilowatt-hours (kWh) of electricity. About 67% of the electricity generated was from fossil fuels.

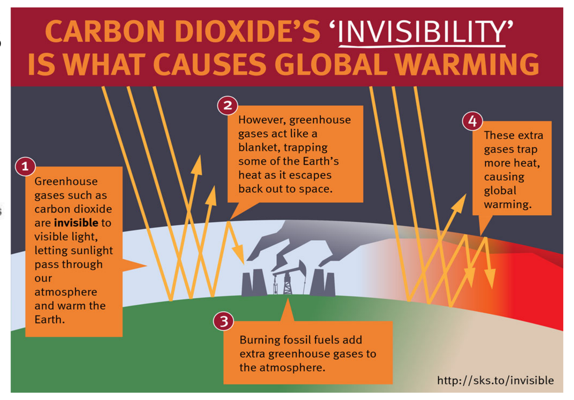

Figure 5: This infographic shows how CO_2, one of the greenhouse gases, causes global warming. Because of its 'invisibility,' many people are unaware they are releasing greenhouse gases causing global warming (Cook, 2013).

Engineering Process

Testing

- Tested safety and accuracy of individual parts separately before assembly
- Tested a variety of appliances with the device and selected commercial instrument
- Conducted a one-sample t-test to show the accuracy of the device

Device Development

- Engineered several circuits on Arduino
- Adjusted resistor values and connection of jumper wires to achieve accurate readings
- Attached split-core current transducer on wire of appliance

Device Software Development

- Developed EmonLib class in Arduino IDE
- Utilized EmonLib library to calculate current and power from device readings
  **EmonLib is C++ class file used to convert sensor feedback into user readable values

App Development

- Created user-friendly app interface with additions of several easy-to-use features
- Utilized web server Emoncms to send measurements from Intel Edison to app using Wi-Fi

Materials

- Intel Edison and Arduino Breakout Board
- Arduino IDE
- Jumper Wires
- 330 and 10 K Ω Resistors
- Breadboard
- Split Core Current Transducer
- USB to Micro-USB cable
- Microsoft Excel
- Appliances
- Smartphone
- Android Studio

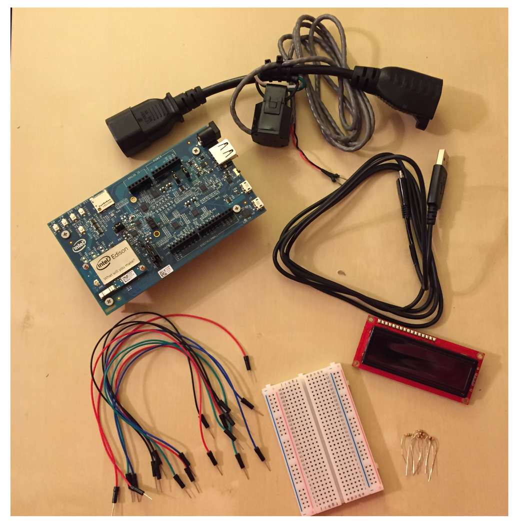

Figure 6: This photo shows the materials used throughout the project in the building of the device.

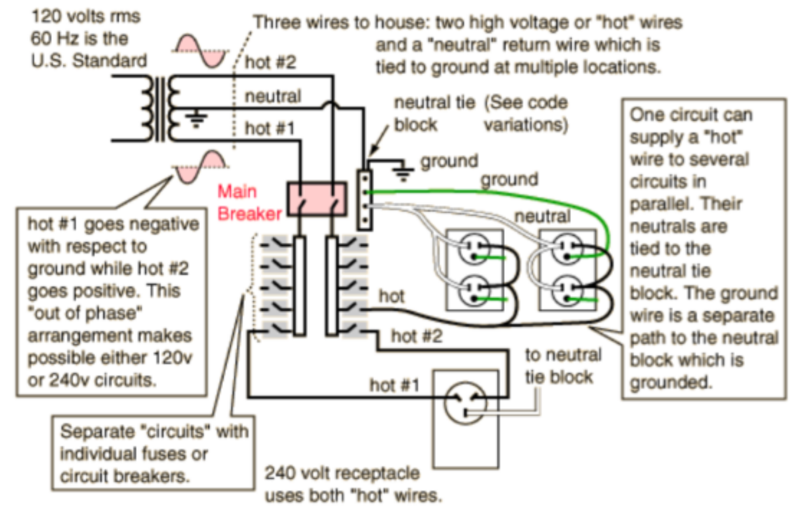

Figure 7: This diagram shows how electricity flows once it has entered the consumer's household. This diagram was used to help engineer a non-invasive device that accurately monitors electricity.

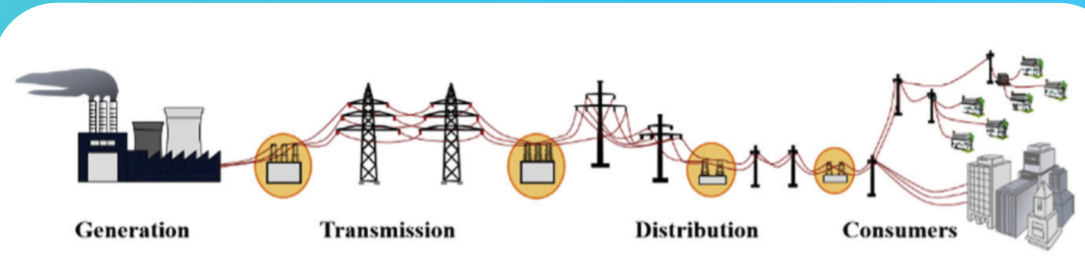

Figure 8: This figure shows how electricity travels after being generated at an electrical generation plant (Ellaban and Abu-Rub, 2016).

Results

To ensure 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. 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 selected commercial device chosen was the Kill-A-Watt. The appliances tested were a desk lamp with LED, CFL, and incandescent bulbs, a toaster, a hair dryer on high and low settings, a television turned on and off, and a washing machine washing a small load of clothes. These measurements were displayed in the app developed below.

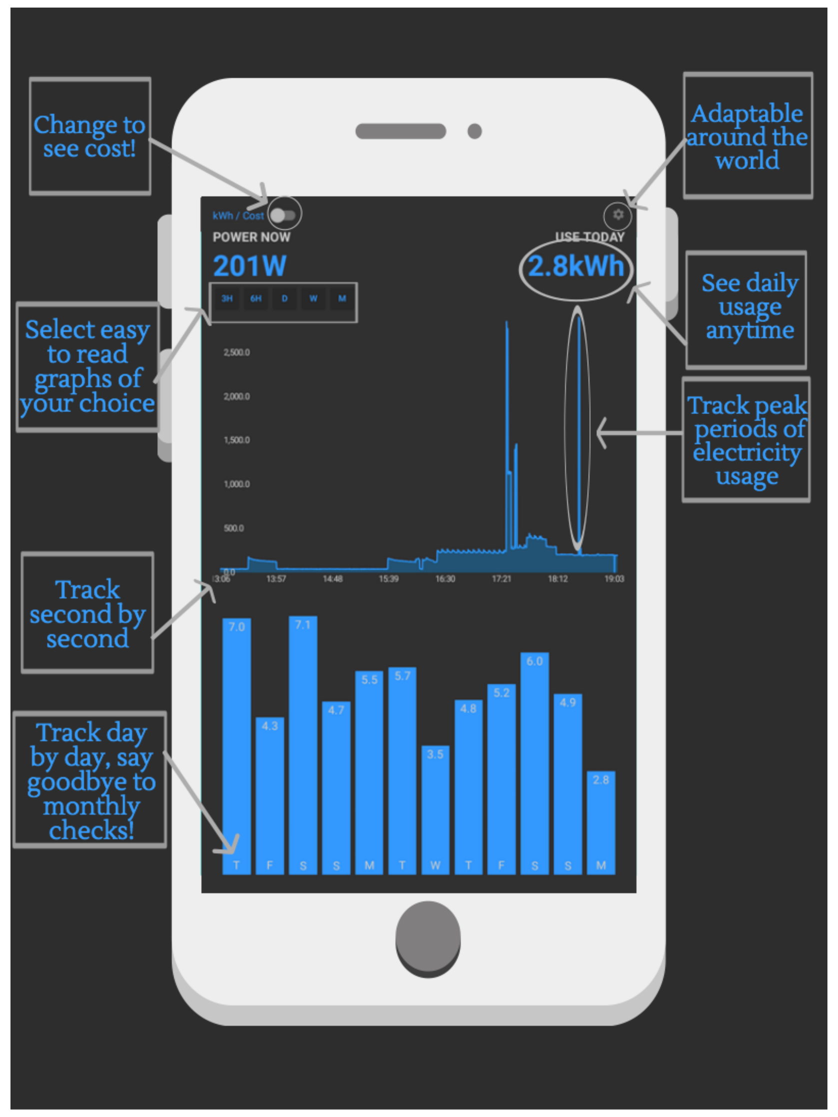

Figure 9: This infographic created by the creator in Piktochart highlights the key user-friendly features in the app developed to accompany the device. These universal features include personalizing graphs, easy-to-read numbers, adaptable goals, and others.

After the app, the graphs displayed are examples of some appliance readings.

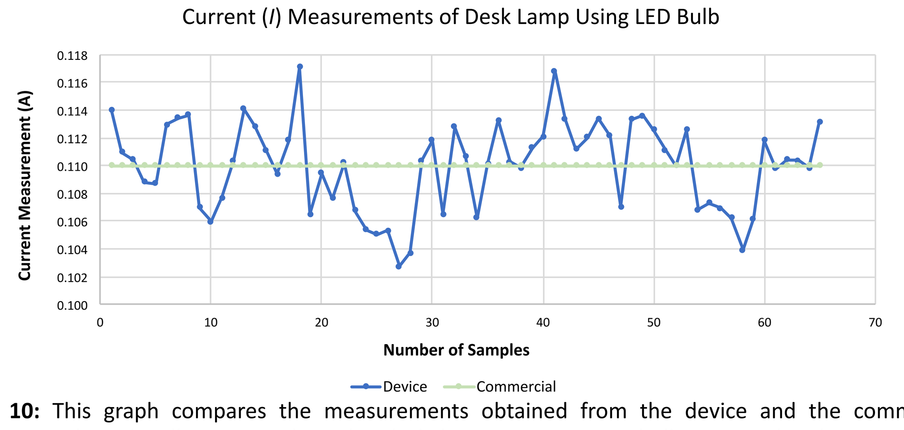

Figure 10: This graph compares the measurements obtained from the device and the commercial instrument selected, Kill-A-Watt, when the desk lamp uses an LED bulb. Note: The device and the commercial average are the same.

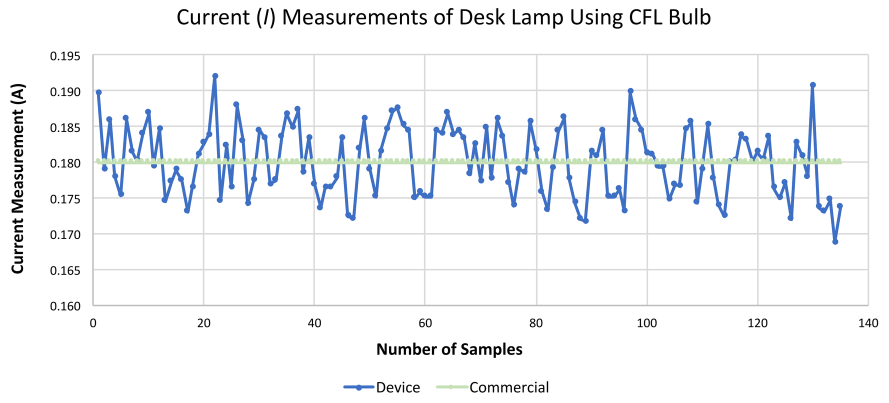

Figure 11: This graph compares the measurements obtained from the device and the commercial instrument selected, Kill-A-Watt, when the desk lamp uses an CFL bulb. Note: The device and the commercial average are the same.

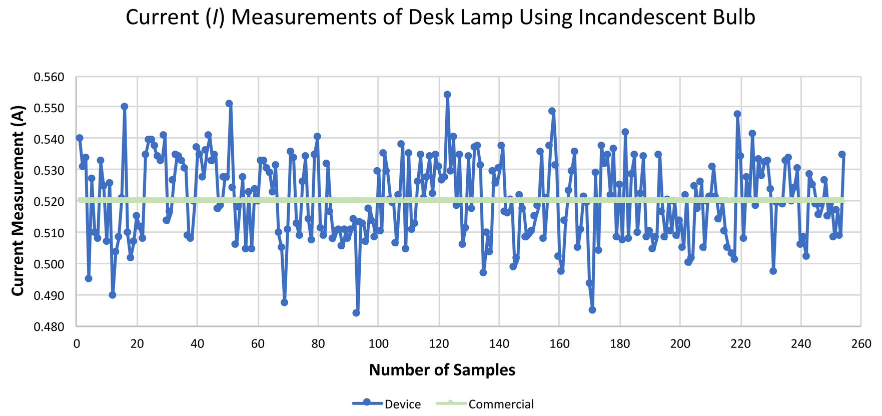

Figure 12: This graph compares the measurements obtained from the device and the commercial instrument selected, Kill-A-Watt, when the desk lamp uses an incandescent bulb. Note: The device and the commercial average are the same.

Additional App Features

Alongside the features displayed in **Figure 9**, the app also includes additional features that make it appealing to the consumer:

- Allowing the consumers to change their energy provider, currency, and language to their choice.
- Receiving data from the energy provider automatically to calculate costs and tracking changes in cost per unit of electricity
- Using machine learning to "learn" the behavior of the consumer when he or she uses electricity to create personalized monthly goals for the consumer.
- Gradually decreasing the suggested amount of electricity usage to allow the consumer to adjust easily.
- Notifying the consumer constantly on how much they have left of their monthly goals and telling them the optimal times to use their appliances.
- Suggesting which energy efficient appliances to buy to decrease the user's electricity usage.
- Differentiating tabs for each appliance to allow easier electricity tracking and managing for the consumer.
- Allowing the generation of electricity to be tracked in a different tab (i.e. consumer's roof-top solar panels).

Data Analysis

Because apparent power is directly proportionally to current, one-sample t-tests were only conducted on the measured samples for current. The measurements of the device were compared to the measurements obtained from the commercial instrument, Kill-A-Watt. 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 device and the measurements obtained from the commercial instrument, Kill-A-Watt.

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

The goal of each experiment was to achieve the null hypothesis and get as high a p-value possible. The device would be successful only if the p-value achieved for all appliances of all energy efficiencies was more than 0.5.

A one-sample t-test was performed on the measurements using Microsoft Excel.

Scoring Matrix

	Design Criteria	Max Score	Prototypes 1	Prototypes 2	Prototypes 3	Commerical Kill-A-Watt
1	High Safety	10	10	10	10	8
2	User-Friendly App	10	NA	5	10	NA
3	Accurate Electricity Usage Reading	9	1	6	8	9
4	High Data Sending Speed	8	NA	NA	7	NA
5	High Availability/Accessibility	6	NA	1	3	NA
	Total	43	11	22	38	17
	Percent	100	25.6	51.2	88.4	39.5

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 that will help reduce the effects of 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 how to cut the intake altogether. This project uses easy-to-use interactive components, such as an app which allows for personalization (ex. Graph type, currency, language) to connect to consumers and communicate ideas to them.

The accuracy and precision of the device (p-value = 0.995, STDEV = 0.012 A) help the consumer to understand and depend on the device as a reliable source of monitoring their electricity consumption. When the device is used in conjunction with smart grid, the consumer and energy provider can work together to reduce the consumption of fossil fuels.

People who use this device will have the power to help secure the future of the Earth and the environment by decreasing contributions to global warming.

Future Work

The following extensions will be implemented to the project:

- Averaging the output to show a steady value to the consumer.
- Increasing data sending speed closer to real-time.
- Adding a voltage circuit, instead of assuming voltage is always constant.
- Allowing the app to control features of the house, such as turning on and off appliances to conserve electricity.
- Adding a reward system to motivate consumers.