ASHESI UNIVERSITY

SMART HOME ENERGY MANAGEMENT SYSTEM USING INTERNET OF THINGS

CAPSTONE PROJECT

B.Sc. Electrical and Electronics Engineering

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2022

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronics Engineering.

Valentine Muriithi

2022

Declaration

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

………………………………Valentine…………………………………………………

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Date:

……………………27/04/2022………………………………………………………………………

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Date:

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Abstract

Global energy demand is increasing rapidly, and carbon dioxide emissions and global warming have become a worldwide central issue, prompting many countries to switch to renewable energy sources. However, the integration of variable renewable energy sources into the power grid, on the other hand, is posing technical issues to the traditional grids. Since residential and commercial buildings account for 40% of the national energy consumption and are still increasing due to population growth, the monitoring information for the deployed grids that serve them is only available on the operator side. Thus, there is a need to counteract the existing grid architecture by having a system that integrates renewable energy sources and has demand-side customer-driven management. There has been tremendous growth in the energy sector in recent years, where smart grid technology was invented and continuously improved. Through this project, a prototype of a smart home energy management system using the Internet of Things that integrates renewable energy sources and is customer-driven is designed and built. The system monitors the environmental conditions in the rooms like temperature and light intensity and the occupancy and controls the electrical appliances, respectively. It also shifts the loads to an energy storage battery during peak hours.

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Chapter 1: Introduction

1.1 Background

Global energy demand is increasing rapidly compared to the steady growth of energy generation and transmission setups [1]. As a result, the demand-supply mismatch has widened. In traditional grids, utilities address this problem by raising total generation capacity in response to peak demand [1]. However, the resulting system (generation and distribution) is significantly underutilized [1]. Furthermore, various environmental constraints have limited energy generation from conventional sources. The percentage of renewable energy generation has considerably risen and increased energy prices [2].

These challenges have resulted in recent discussions that aim to match electricity supply and demand [3]. Some of these measures under panels include actual metering consumption in real-time and shifting loads so that consumption follows the current supply of electricity [3]. Nonetheless, the incorporation of Variable Renewable Energy Sources into the energy system is already posing technical issues for existing grids, making grid flexibility a critical topic [4]. The power industry has thus shifted focus on intelligent demand-side management techniques [2]. Demand-side management will play a vital role in the future smart grid by intelligently managing loads [1]. The "Smart Home" is one of the advanced components in the intelligent grid system, and it is critical because of handling challenges of indeterministic behavior of occupants [5].

There are various ideas on how to get residential households to move loads to other times of the day when renewable electricity supply is available to achieve flexible demand [1]. Moreover, residential customers are becoming interested in energy storage devices, such as batteries, to minimize their utility's power use during peak periods [6]. Motivated by this need, this paper investigates an experimental Smart home Energy Management system that shifts the loads to an Energy Storage battery from the Mains grid supply during peak hours and controls the loads depending on the environmental conditions and occupancy in the house.

1.2 Problem Definition

As global energy consumption increases faster than energy generation and transmission setup, carbon dioxide emissions and global warming have become the worldwide central issue, prompting many countries to switch to renewable energy sources [7]. However, the integration of variable renewable energy sources into the power grid, on the other hand, is posing technical issues for traditional grids, making grid flexibility a key topic [4].

Considering that residential and commercial buildings account for 40% of the national energy consumption and are still increasing due to population growth, monitoring information for the deployed electricity grids that serve residential and commercial buildings is only available from the operator side [8]. Thus, there is a need to counteract the existing electricity grid architecture and address grid flexibility and energy management issues by having an efficient solution to reduce carbon emissions and energy costs.

1.3 Objectives

This project aims to design and develop a system that:

- shifts the residential electrical loads from the mains supply to an energy storage battery during peak hours,
- Monitors and controls the operation of the electrical appliances based on the environmental conditions,
- Calculate the energy consumed by the electrical appliances during peak and off-peak hours (different energy supplies).

Additionally, the design would implement a feature to allow communication to a database. This communication would send information about energy consumption during peak and off-peak hours. Later the information will be displayed to the consumer on a Web Application.

1.4 Expected Outcome

This capstone project's expected outcome is to design and construct an IoT prototype unit that can be deployed in a residential household with an alternative source of energy example, Solar energy.

The result of this project is to have a unit that can be deployed or replicated in a real-life setting with the following features; Intelligent, Automatic shifting of loads during peak hours to an alternative source of energy, Low Cost, Automatic control of Lighting and Heating system in a residential household, Energy Efficient.

1.5 Motivation of the Work

There is currently an energy crisis. There is current energy spikes, caused by a high energy consumption rate with limited supply. Too many countries are transitioning to renewable energy due to the continued high carbon dioxide emissions, causing major energy disruptions. As a result, this research aims to find effective ways to integrate renewable energy while also managing the energy we consume.

1.6 Research Methodology Used

The research methodology used in this project is:

- Literature Review of previous work done
- Smart Home Energy Management System Design and Prototyping

1.7 Facilities to be Used for the Research

This Research would be built from:

- Fab Lab of Ashesi University
- Workshop of Ashesi University

1.8 Scope of the Work

This capstone project's design, construction, and testing would be done on a smaller scale to mimic the real-life situation. On the other hand, this project is intended to integrate renewable energy and monitor and control energy consumption in a domestic setting. As a result, to implement this idea in residential houses, similar but more compatible components would be required.

Chapter 2: Literature Review

2.1 Demand Side Management

Demand Side Management (DSM) is a collection of techniques to improve the energy systems on the consumption side [9]. While DSM has always been a "utility-driven" activity, it may soon shift to a "customer-driven" one [9]. DSM can be categorized into the following: Energy Efficiency (EE), Time of Use (TOU), Demand Response (DR), Spinning Reserve (SR), and Demand Shifting [9].

2.1.1 Energy Efficiency

Improving the energy efficiency of buildings or industrial sites starts with understanding the activities involved [9]. Every client facility has hidden faults that waste energy [9]. Unless a tool for analyzing energy efficiency is utilized, such issues are frequently neglected. The following are typical components of such energy information systems: Data acquisition infrastructure (Sensor networks, data loggers, gateways, modems), An application server with database, calculation and analysis algorithms, alarming and reporting, and User Interfaces for visualization and configuration [9].

2.1.2 Demand Response

The distribution or transmission system operator often broadcasts a signal [9]. A price or an instruction for load shedding or load shifting could be included in this signal [9]. Considering demand is high between 4:00 pm to 10:00 pm. Thus, the billing of the electricity algorithm is based on demand. When the demand is high, the more expensive electricity is. Most utility companies introduce incentives to the customers so that whoever participates in load shifting or load shedding as indicated by the signal gets a reduced billing.

2.1.3 Demand Shifting

Load models are utilized when demand must be shifted to different times [9].

Suppose the weather and other forecasts anticipate a grid outage at 17:30 the next day. Intelligent consumers can plan ahead and complete their chores earlier or later if their systems allow it.[9].

2.2 Demand Side Management in a Smart Home

Demand-side management (DSM) based on Demand Response (DR) has emerged as an effective strategy for energy management in a power system that focuses on the consumer side [10]. It allows users to take part in energy management by altering their energy consumption patterns [10]. DSM is implemented at home using a system known as a home energy management system (HEMS) [10]. Home Appliances, Smart Meters, Energy Management controllers, home Area networks for Local Communication, Distributed Energy Resources, Energy Storage Systems, and Advanced Metering Infrastructure are the primary components of the HEMS design [10]. Demand response DSM can be used with home appliances with controllable characteristics that can be shifted in time [10]. Local energy generation, particularly renewable resources such as photovoltaic and wind turbines, is included in Distributed Energy Resources [10]. Local loads can be supplied by DERs [10]. Devices such as storage batteries are included in Energy Storage Systems, allowing DSM flexibility [10].

Advanced Metering Infrastructure (AMI) pricing information is relayed from the utility to the consumer, while consumption data is forwarded to the utility [10]. The smart meter is a critical component of AMI placed at the consumer end for data automation and communication [10]. The Home Area Network (HAN) is the communication infrastructure that connects the HEMS components inside the home [10]. The Energy Management Controller is a controller or scheduler embedded with HEMS algorithmic-based software that has computational intelligence for energy management optimization [10].

Demand-side management methods must be applied in developing countries as soon as possible [10]. It allows customers to save money on their power bills by participating in energy management programs that reduce generation costs, load shedding, and system stability [10]. Demand Side Management for Energy Management can be used in a variety of ways, including the utility's implementation of a real-time day-ahead or multi-stage time-of-use tariff and the installation of smart meters, persuading consumers to utilize HEMS, which includes smart appliances, software-based energy management controller/scheduler, and local communication network [10].

2.3 Introduction to Smart Home

Sensors, actuators, middleware, and a network are all part of a smart home, including two critical interacting components: a smart network and an intelligent load [11]. Smart house's primary goals are to increase home automation, facilitate energy management, and reduce environmental emissions [11]. A smart home energy management system allows homeowners and energy providers to communicate commands to optimize energy consumption [12]. This coordination between energy shareholders lowers customer electricity bills and enable electric utilities to manage peak loads better [12].

Smart Home energy management is a crucial feature of a smart home that allows the owner, utility, and others to monitor, manage, and conserve energy [11]. Smart Home energy management system is achieved through selection of efficient appliances, improvement in customers' knowledge of and experience with residential energy management, participation in demand-side management programs, and the deployment of an energy management system [11].

A smart home energy management system is comprised of a central unit, a monitoring unit, a control unit, a communication unit, and secondary elements [11]. The main unit has a graphic interface that uses sensors to control energy consumption in every room [11]. The user interface can interact with the control system through a TV, a mobile phone, the internet, or a wired phone [11]. Temperature and the presence of an inhabitant in a room are measured by the monitoring unit sensors [11]. The control unit's information terminals allow the user to do certain activities, such as lowering electricity bills and reducing emissions [11].

2.4 Smart Home Energy Management System Technologies

Various technologies, such as Bluetooth, Wi-Fi and Zigbee, the Internet of Things (IoT), Supervisory Control and Data Acquisition (SCADA), and the Global System for Mobile Communication (GSM), can be used to manage energy in a smart home [13]. These technologies have their advantages and disadvantages. However, the most commonly used technologies are IoT and SCADA in this fourth industrial revolution [14].

2.4.1 SCADA Home Energy Management System

SCADA (Supervisory Control and Data Acquisition) systems are used in energy management systems to collect data in real-time to control operations and monitor and control widespread equipment [15]. The SCADA system integrates various technologies used in modern structures (control of ventilation, temperature, illumination) [16]. The control method employs a hierarchical cascade controller, in which the inner loops are handled by a centralized SCADA system that communicates with the complete local PLC network. In contrast, a local PLC manages the outer loop (Programmable Logic Controller) [16]. The SCADA system can make controlling and monitoring the household consumer installation easier. It enables the creation of an interface for controlling and monitoring various resources such as loads, security, system status, and configuration [15].

2.4.2 GSM Based Smart Home Energy Management System

GSM (Global System for Mobile Communications) is a networked wireless mobile communication system [13]. This technology operates with the help of a mobile network signal and transmits commands via SMS [13]. A microcontroller, GSM phone with a GSM module, relay module, sensors, and smartphone application software make up a GSM-based smart house [13]. Weak mobile networks cause delays in sending commands in these systems [13].

2.4.3 Smart Home Energy Management System using Bluetooth

Bluetooth is a low-cost, adaptable technology that works with Android applications on smartphones in smart homes [17]. A Microcontroller Development Kit for ARM processors is used in various applications to construct home automation with Bluetooth [17]. This system is based on the Wince 6.0 operating system [18]. In another example, an HC-06 Bluetooth module was utilized with an Arduino Mega Microcontroller to communicate over ethernet and GSM [17]. MIT App Inventor [19] was used to create the graphical user interface [17]. The sensors were used to monitor and control room temperatures, water temperatures, gas leakage,and lights, and programming was done on the microcontroller [13], [18]. Another proposed method combines manual control of lights and motors via a mobile application program connected by Bluetooth [19].

2.4.4 Smart Home Energy Management System based on Zigbee

Zigbee is a short-range, low-complexity, low-power, low-data-transfer-rate, low-cost, two-way wireless communications system based on the IEEE 802.15.4 wireless standard [20]. Smart home system based on Zigbee technology primarily comprises of a wireless network transceiver chip based on ZigBee in a variety of home electronic devices. The wireless modules transmit data between sub-nodes to achieve a family of wireless interconnection of electronic devices and home automation [20]. In a smart home system, the ZigBee home networking module is primarily responsible for monitoring and collecting data from a range of household equipment and then transferring the processed data to the home network or data transmission to the external network via the gateway [20].

2.4.5 IoT based Smart Home Energy Management system

The Internet of Things (IoT) is a network of interconnected computing devices, communication technologies, and machines that can transmit data over a network without the need for human involvement [13], [21]. IoT systems in smart home energy management systems communicate with sensors and actuators via servers connected to the internet over Wi-Fi [17]. These systems combine data from various embedded devices, such as sensors and actuators [22]. Sensor and actuator signals are sent to a microprocessor, sending the data to a cloud system [17]. The cloud system is linked to a remote-control system and a database that collects real-time data from the system [21]. As communication between smart devices is primarily done over a wireless network, IoT systems have no distance constraints [13]. IoT systems have a challenge in collecting large amounts of real-time smart home data, necessitating the need for a Big Data Analytics framework to manage the data [23].

Chapter 3: Design

3.1 Introduction

The Smart Home Energy Management system comprises of blocks such as Lighting, Heating, Ventilation and Air Conditioning System (HVAC), energy monitoring and control, and load shifting/ shedding. This is implemented using sensors to collect temperature, occupancy, brightness, and peak and off-peak hours, which are used to control actuators, such as lights, fans, and other home appliances. Energy monitoring is performed using the current sensor, which measures the consumption of the loads in the home. In recent times, Internet of Things (IoT) Technology has dominated the Smart Home Energy Management industry. IoT based on Wi-Fi is cheaper, more efficient, and less complex than Programmable Logic Controllers (PLC) based systems. The IoT system's structure comprises of sensors and actuators, a microcontroller, a database, and a web application, all based on a star topology.

3.2 System Requirements and Architecture

No.	System Requirements	Justification
1.	Main Power Supply from the Power Grid	Energy Supply from the grid is required to power the loads during Peak hours.
2.	Energy Storage Battery	Energy Supply from the energy storage is required to supply energy to the loads during Peak hours, thus reducing the electricity bill paid by the home user.

3.	A Microcontroller with an Architecture to support analog and digital sensors and actuators.	An efficient microcontroller acts as the brain of the smart home system, and its efficiency impacts results.
4.	Measuring the Energy Consumption of the Electrical Appliances.	This helps the home user monitor the appliances' energy consumption identify patterns, and make meaningful decisions like load shedding.
5.	Sensor Values, Peak times, and Energy consumption of the appliances should be aggregated every one hour and sent to a database.	The Large data generated by the sensors need to be pr-processed before being processed to the database so as to increase the level of accuracy.
6.	Automatic Control of the Loads.	Based on the environmental conditions in the house, the loads are controlled respectively without compromising the occupant's comfort.

Table 3-1:Pugh matrix for selection of Communication Technology

Criteria	Weight (Out of 5)	Wi-Fi	GSM	Bluetooth	Zigbee
Range	5	0	-1	-3	+2
Data Rate	5	0	-1	-1	-1
Cost	5	0	-2	+1	0
Availability	5	0	-2	+1	-1
Total		**0**	**-30**	**-10**	**-16**

After comparison, Wi-Fi (IEEE 802.11ah) was selected due to its higher data rate, low-cost and long-range communication characteristics. This was selected over GSM, Zigbee, and Bluetooth.

Table 3-2: Pugh matrix for selection of Microcontroller

Criteria	Weights	ESP32	Raspberry pi	Arduino uno	KL25Z
Cost	3	+4	+1	+5	+2
Compatibility	5	+3	+1	+3	+3
Power Consumption	4	0	0	0	0
Availability	2	+2	+1	+1	0
Total		**+36**	**+8**	**+32**	**+21**

Considering the Pugh matrix above, the best option from the results is the ESP32 due to its compatibility and features for the project.

3.3 Materials

3.3.1 Node MCU ESP32

The Node MCU ESP32 is a low-cost, low-power microcontroller board. The ESP32 has 48 pins with multiple functions, but not all pins are exposed and cannot be used. The ESP32 has numerous peripherals. For this project, the Analog-to-Digital Converter Channels were used for the analog sensors, the Pulse Width Modulation (PWM) channels were used forthe controlling of the fans, bulbs. Since the WI-FI module was needed for this project to send data to the database, ESP32 was the best choice as it has an inbuilt WI-FI module. However, only channel 1 pins can be used with the WI-FI module and that was a considered during implementation.

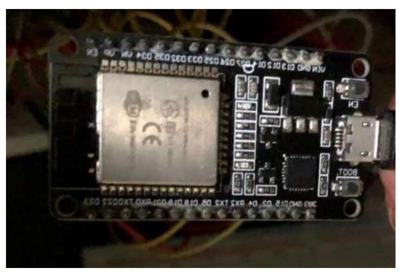

Figure 3-1:ESP32

3.3.2 Energy Storage Battery

Gel Battery was used as the energy storage battery. Gel battery is a rechargeable battery. It is easily used with solar panels as it can store energy. For this project, an assumption is made that the homesteads where this project can be implemented have solar energy and they can recharge the batteries. Using a power source selector concept, during on -peak hours, the loads shift from mains supply to the energy storage battery for the purpose of reducing electricity bills.

Figure 3-2: Gel battery

3.3.3 LM35 Temperature Sensor

The LM35 sensor is a temperature sensor that has an operating voltage range from 4V to 30V. It is an analog sensor. The temperature sensor gives a voltage output linearly proportional to the degrees. The LM35 sensor is used to collect temperature data in the environment for the purpose of controlling the fans in the smart home.

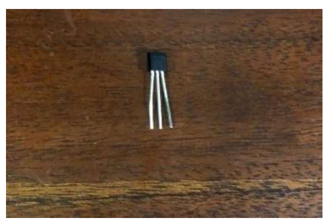

Figure 3-3:LM35 temperature sensor

3.3.4 Light Dependent Resistor (LDR) Sensor

Light Dependent Resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Thus, they are light-sensitive devices whose resistance decreases when light falls on it and increases in the dark. It is an analog sensor. The LDR is used to detect the level of brightness in the house so that it can inform the control of the lights in the house.

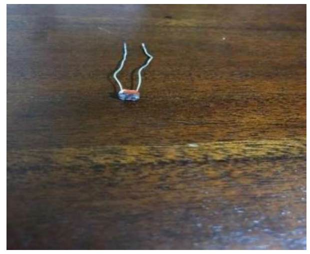

Figure 3-4:LDR sensor

3.3.5 HC-SR501 PIR Sensor

Pyroelectric infrared technology is used in the HC-SR501 sensor. People can be detected with the HC-SR501 Pyroelectric Infrared Sensor. The PIR sensor HC-SR501 will be used to detect motion in the room and inform the controlling of lights and fans in the room.

Figure 3-5: PIR sensor

3.3.6 ACS712 Current Sensor

ACS72 is an ultra-low-cost current sensor. In a circuit, the ACS712 module is used to measure both AC and DC. It has three rated current which are 5, 20 and 30. It takes a 5V input, and outputs an analog voltage proportional to the current recorded. The current sensor serves as an energy meter for calculating the amount of energy consumed by each bulb, fan in the house. Thus, every bulb and fan are connected to a current sensor.

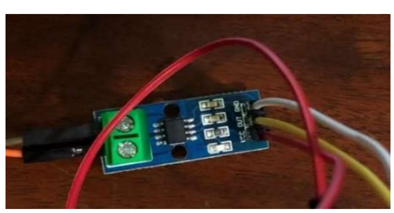

Figure 3-6: ACS712 current sensor

3.3.7 5V 4 Module Relay

The 5V Relay Module is a relay interface board which is controlled by the ESP32 microcontroller. The relay is an automatic switch which can control high-voltage circuits. It can provide both AC and DC to the respective loads. The relay is used to turn on and off the fan and the bulbs depending on the temperature, light intensity, and the occupancy in the house.

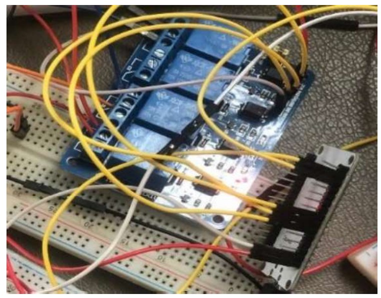

Figure 3-7: 5v 4module relay

3.3.8 XL6009 Boost Converter

XL6009 is a DC step up module which has a rated input voltage from 3V to 32V and an output voltage of 5V to 35V. It has a maximum input current of 4A. It is used in the smart home to power the LED indicator lights.

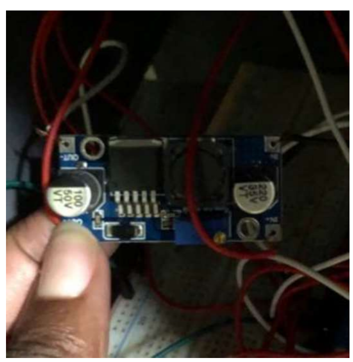

Figure 3-8: XL6009 boost converter

3.3.9 5V DC Fan

Its rated voltage is 5V DC with current of 0.1A. It is controlled using a relay which takes input from the temperature sensor. It will be used in place of the actual fans used in the house.

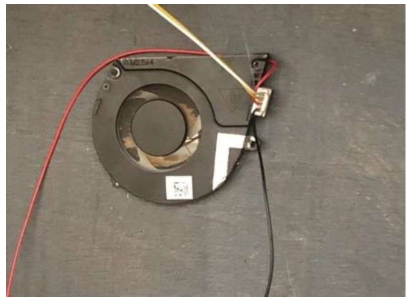

Figure 3-9: 5v dc fan

3.3.10 LED high Power Lamp

The LED bulb consumes 10 Watts and voltage between 180V to 260V. It is used in this project for illumination.

Figure 3-10: Led bulb

3.3.11 Power Supply

Power from the mains supply is stepped down by the adapter charger to 5V DC.

Figure 3-11: Adapter charger

3.4 Hardware Design

The Hardware design shows how the components are interfaced with each other to make the Smart Home Energy Management System.

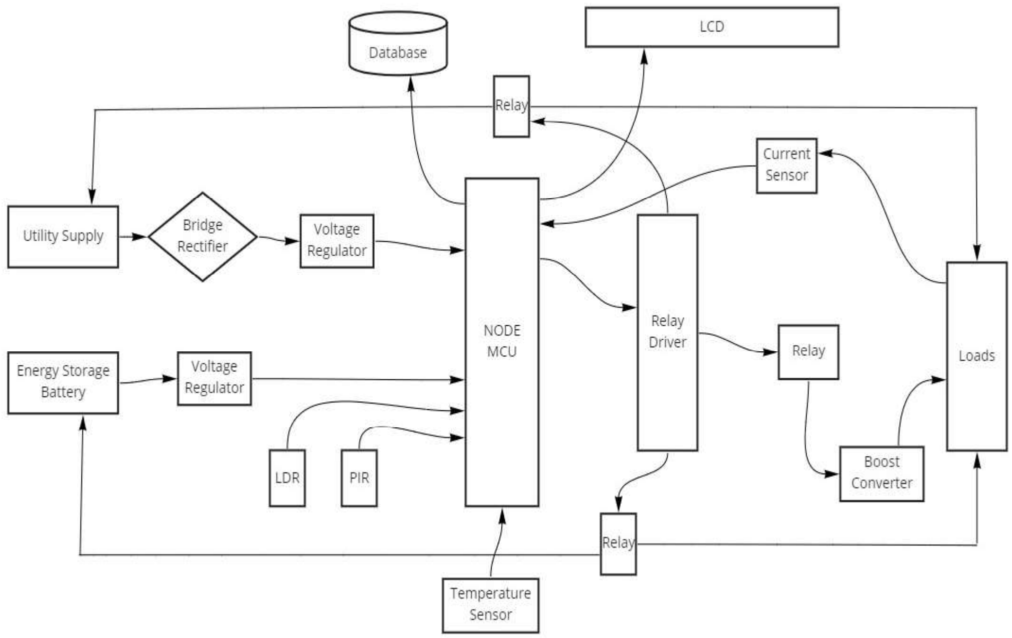

Figure 3-12: Block diagram

3.5 Circuit Design

The Main Circuit diagram showing the entire system connection was drawn using Eagle Software.

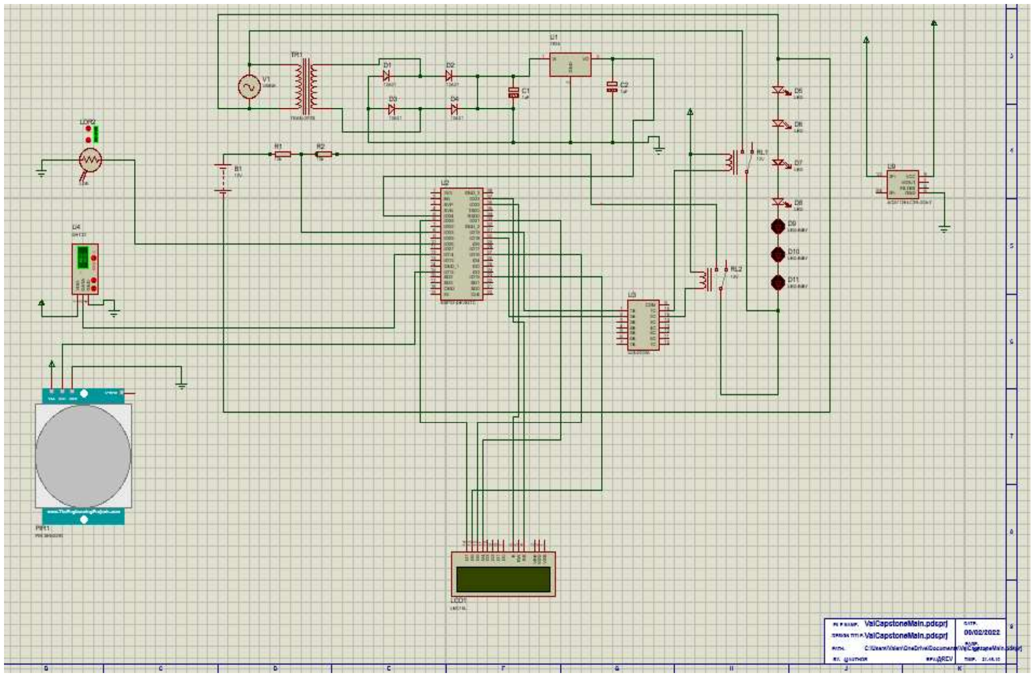

Figure 3-13: Main Circuit Design

The Circuit diagram shows how the various sensors and the relays will be connected to the microcontroller and which GPIO pins to be connected to. The circuit diagram was drawn using EASY EDA Software.

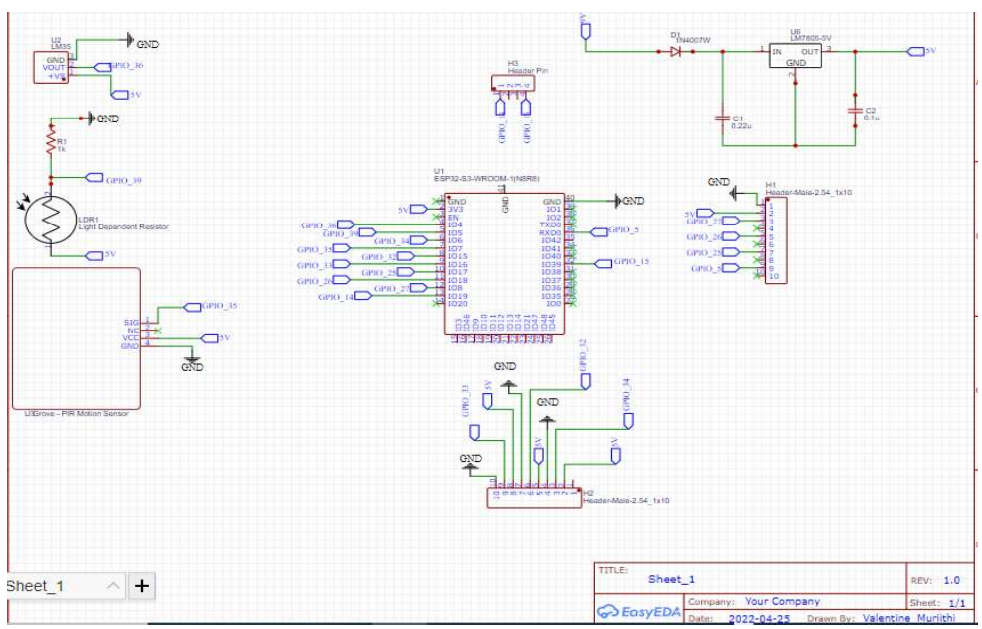

Figure 3-14: Circuit Design

3.6 PCB Design

A clear design of how the sensors will be connected to the ESP32 with dimensions and size.

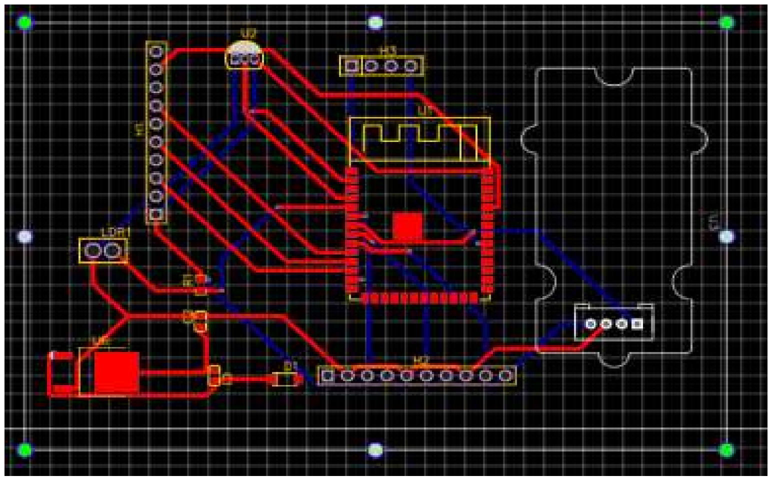

Figure 3-15: The PCB design

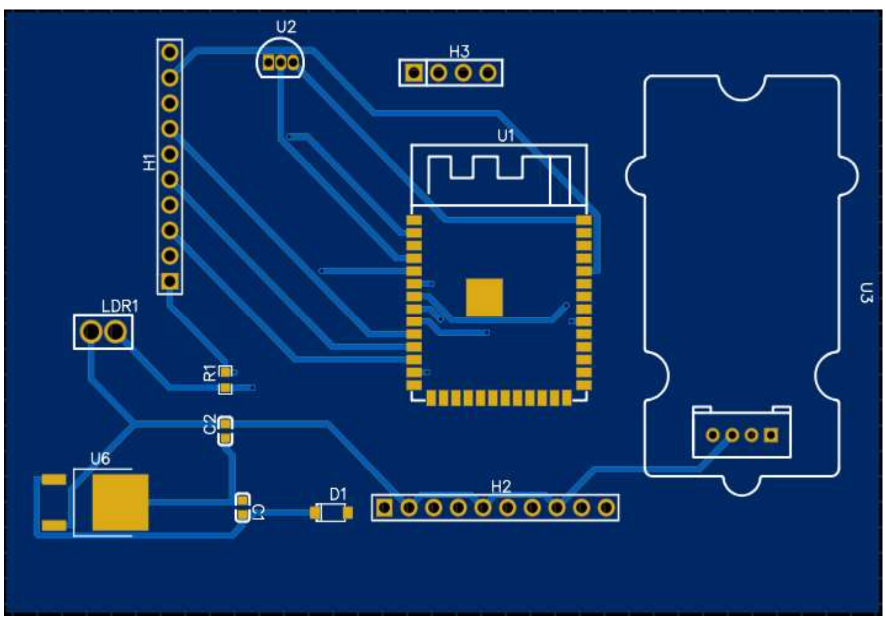

Figure 3-16: The PCB design in 2D

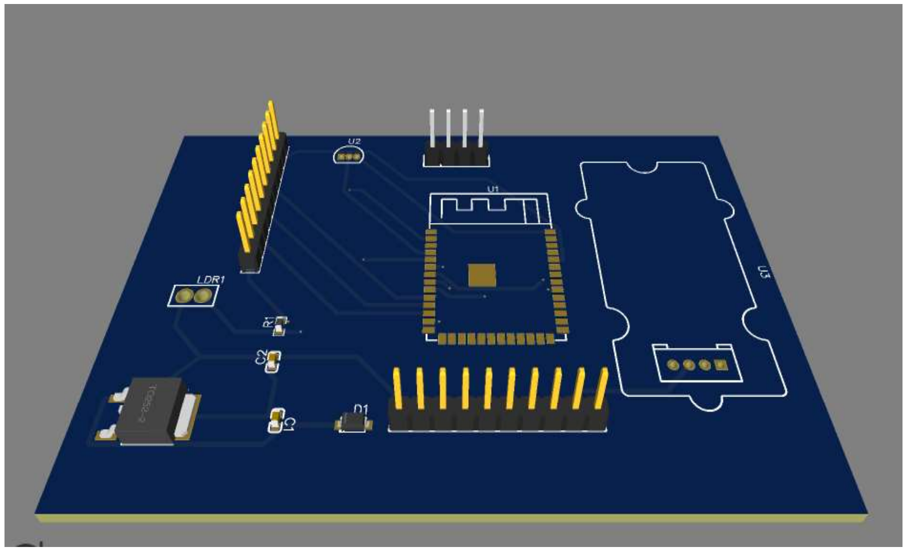

Figure 3-17: The PCB design in 3D

Chapter 4: Implementation

4.1 Overview

This chapter deals with the implementation of the smart home energy management system. The system is designed using Internet of Things (IoT) modules, which comprises of the ESP32 microcontroller as the brain, Energy Storage Battery and the Mains grid supply as the power sources. The PIR sensor, LM35 Temperature sensor, LDR Sensor as the monitoring sensors. Bulbs and Fan as the electrical appliances to be controlled. Relay modules as actuator controllers. ACS712 current sensor as the energy measuring sensor. The ESP32 internal Wi-Fi module as the communication protocol. This chapter provides the details and procedure involved in executing the design decisions for Smart Home Energy Management System project.

4.2 Automatic Power Source Selector

Since the electrical billing algorithm is based on demand, when the demand is high the cost of electricity is high, one of the objectives of the project is shifting of electrical loads during peak hours (when the demand is high) to an energy storage battery. Thus, the Analog to Digital Converter pins of the ESP32 are used to measure analog voltage. Since the ESP32 cannot measure AC voltage from the mains supply directly, an Adapter Charger is used as it contains a step-down transformer, bridge rectifier to stepdown the 220V to 5V. The ESP32 measures both the main grid and the energy storage battery voltage.

According to research the electricity demand is high between 4:00pm to 10:00pm, the Timer interrupt concept is used in the project to generate a scheduler. Using Millis () a simple event scheduler is designed such that the EPS32 counts. When its 4:00pm the Analog to Digital Converter pins of the ESP32 measure the Analog Voltage of both the mains supply and the Energy Storage Battery and a comparison is done. If the Energy Storage battery has voltage flowing in it all the electrical loads are shifted to it from the mains grid.

The relay module is connected to the ESP32 using the digital output pins, to facilitate the shifting of the electrical loads. The appliances are supplied power by the energy storage battery for 6 hours.

4.3 Monitoring of the Physical Quantities and Controlling of the Electrical Appliances

The Temperature, Light Intensity and motion of the rooms in the house are monitored using sensors. The LDR sensor is connected with a resistor to an input analog to digital converter pin of the ESP32. It measures the Light intensity of the monitored room. The LM35 Temperature sensor is also connected to the input analog digital converter pin of the ESP32. It measures the temperature of the monitored room. The bulbs and the fan are interfaced with a relay module and the relay module is connected to the digital output pin of the ESP32. The PIR sensor is connected to the input digital pin of the ESP32. It is used to detect motion in the room.

The light intensity, the temperature levels and the motion in the room are measured after every three second. When the three seconds pass, ten values of light intensity and the temperature are measured and an average is determined. The average is used to control the fan and the bulbs.

If the temperature in the room is above or equal to 26 degrees Celsius and motion in the room has been detected the Fan is turned off. If the light intensity records presence of too much light the bulb is turned off. The relay module facilitates the turning on and off of the bulb and fan.

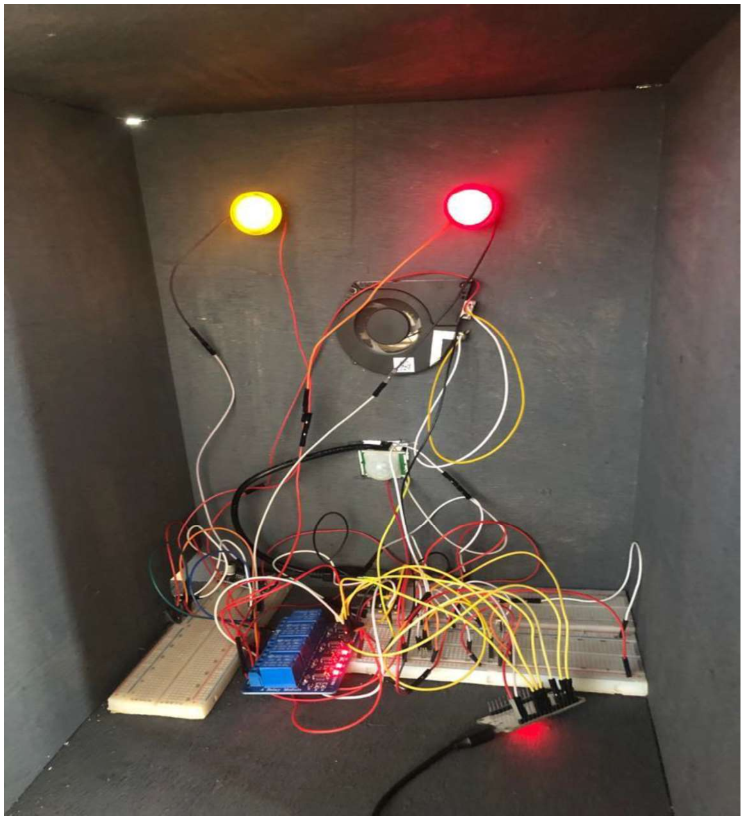

Figure 4-1: The monitoring and control system

4.4 Monitoring and Storing of the Measured Data

The ACS712 Current sensor is connected to each bulb and fan and connected to the output pin of the ESP32. It is used to measure the current consumed by each bulb and fan. The measured current is then used to compute the power consumed by the bulbs and the fan. The current is also measured ten times after three seconds and the average is determined.

After every one hour, the average of the power consumed by the bulbs and Fan, the average temperature, the average Light Intensity and the Average Occupancy is sent to the database using the internal Wi-Fi module of the ESP32. To enable the sending of the data to a database using Wi-Fi, every sensor had to be connected to channel 1 of the ESP32.

4.5 Wireless Communication Setup

The Wireless communication used in this project is Wi-Fi. The Wi-Fi setup requires a network SSID and a password. The command WIFI. Begin (ssid, password) starts the connection to the specified Wi-Fi network. To allow time for authentication and the connection, the code stays in a while loop until a connection isestablished to the Wi-Fi network. When a connection has been established data is then average data after every one hour is sent to the database.

4.6 Database

The database stores the average data collected after every one hour from the sensors. The data stored is visualized to monitor how much energy each appliance is consuming.

The database is created in PhpMyAdmin using XAMPP, which runs the Apache and MySQL servers. The data table is created with 7 columns: Data ID, Peak, Temperature, Light Intensity, Occupancy, Power Consumed by the Bulbs, Power Consumed by the Fan and the Recording time.

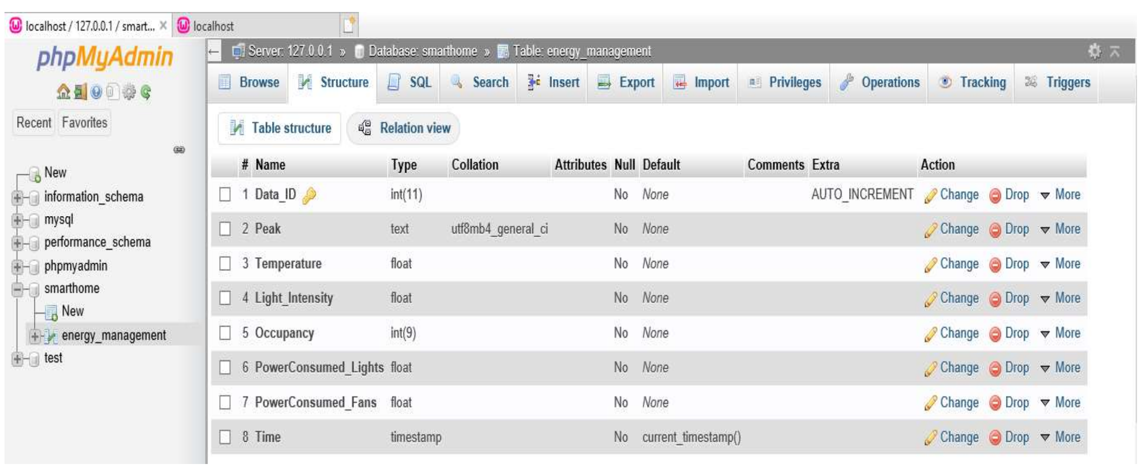

Figure 4-2: The smart home database

4.7 Sending of Measured Data to the Database

The ESP32 interacts indirectly to MySQL Server via HTTP/HTTPS. Interacting with MySQL server indirectly via HTTP/HTTPS solves all problems of direct access like the ESP32 running out of memory and security issues.

The ESP32 includes the data to HTTP/HTTPS request and send the request to the webserver. The Webserver runs a PHP script that handles the request from the ESP32. PHP script extracts the data from the HTTP request, processes the data, and then interacts with MySQL database. PHP script processes the result and returns only the necessary result to ESP32 via HTTP response.

```
COM3

...
WiFi connected
IP address:
192.168.43.87
connecting to http://192.168.43.88/energy_management/Energy.php?
HTTP Response code: 200
Connection Success!<br><br>success
connecting to http://192.168.43.88/energy_management/Energy.php?
HTTP Response code: 200
Connection Success!<br><br>success
connecting to http://192.168.43.88/energy_management/Energy.php?
HTTP Response code: 200
Connection Success!<br><br>success
```

Figure 4-3: Sending data to the database

	Data_ID	Peak	Temperature	Light_Intensity	Occupancy	PowerConsumed_Lights	PowerConsumed_Fans	Time
ete	7	off	19.8	2500	1	6.9	25.4	2022-04-24 01:54:44
ete	8	off	20.4	2595	1	7.3	33.6	2022-04-24 01:56:09
ete	9	off	22.7	2789	1	7.9	35	2022-04-24 01:58:40
ete	10	off	24.3	2400	1	5.9	37.6	2022-04-24 02:02:49
ete	11	off	28.9	1400	1	5.3	42.6	2022-04-24 02:04:44
ete	12	off	31.2	1395	1	5.1	47.3	2022-04-24 02:07:20
ete	13	off	34.7	1245	1	4.6	51.6	2022-04-24 02:10:30
ete	14	off	35.8	1385	1	5.6	55.9	2022-04-24 02:15:16
ete	15	on	36.7	2450	1	8.1	59.2	2022-04-24 02:18:55
ete	16	on	29.7	2695	1	8.3	61.2	2022-04-24 02:20:55
ete	17	on	29.8	3100	1	8.9	68.7	2022-04-24 02:23:21
ete	18	on	29.3	3145	1	9	69.6	2022-04-24 02:24:36
ete	19	on	28.7	3445	1	9.3	69.9	2022-04-24 02:26:01
ete	20	on	28.3	3495	1	9.5	70.1	2022-04-24 02:27:21
ete	21	on	27.6	3795	1	9.6	70.9	2022-04-24 02:28:23
ete	22	off	27.1	3895	1	8.1	61.7	2022-04-24 02:30:24
ete	23	off	26.8	3905	1	5	55.6	2022-04-24 02:32:07
ete	24	off	26	3955	1	4.7	45.2	2022-04-24 02:33:33

Figure 4-4: Received data in the database

4.8 User Interface

For the purpose of having a system that is customer driven, a web application was designed to display the data collected after every hour to the user. The user is able to monitor hourly the energy consumption of the appliances.

Moreover, at the end of the day the user can visualize their daily energy consumption on the web application in form of a pie chart. Additionally, they can tell the relationship between the temperature in the room and the power consumed by the fans, and also the relationship between the light intensity in the room and the power consumed by the bulbs, using a bar graph, and with that they can be able to reduce the speed of the fans, and also reduce the hours and the number of lights on, based on energy consumption.

SMART HOME ENERGY MANAGEMENT DATA

Data_ID	Peak	Temperature °C	Light_Intensity	Occupancy	PowerConsumedby_Lights W	PowerConsumedby_Fans W	Date $ Time
32	off	16.3	4095	1	3.5	20.8	2022-04-24 02:40:46
31	off	16.4	4095	1	3.7	21.1	2022-04-24 02:40:14
30	off	17.2	4095	1	3.9	23.1	2022-04-24 02:39:34
29	off	17.7	4095	1	3.9	23.2	2022-04-24 02:38:49
28	off	19.1	4095	1	4	24.3	2022-04-24 02:38:18
27	off	20.2	4095	1	4.1	27.3	2022-04-24 02:37:22
26	off	21.1	4095	1	4.1	30.3	2022-04-24 02:36:51
25	off	24.1	4000	1	4.3	35.7	2022-04-24 02:35:33
24	off	26	3955	1	4.7	45.2	2022-04-24 02:33:33
23	off	26.8	3905	1	5	55.6	2022-04-24 02:32:07
22	off	27.1	3895	1	8.1	61.7	2022-04-24 02:30:24
21	on	27.6	3795	1	9.6	70.9	2022-04-24 02:28:23
20	on	28.3	3495	1	9.5	70.1	2022-04-24 02:27:21
19	on	28.7	3445	1	9.3	69.9	2022-04-24 02:26:01

Figure 4-5: Web application displaying the data to the user

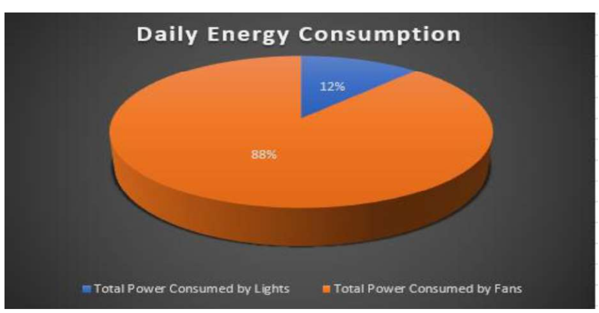

Figure 4-6: A Pie chart displaying the daily energy consumption to the user

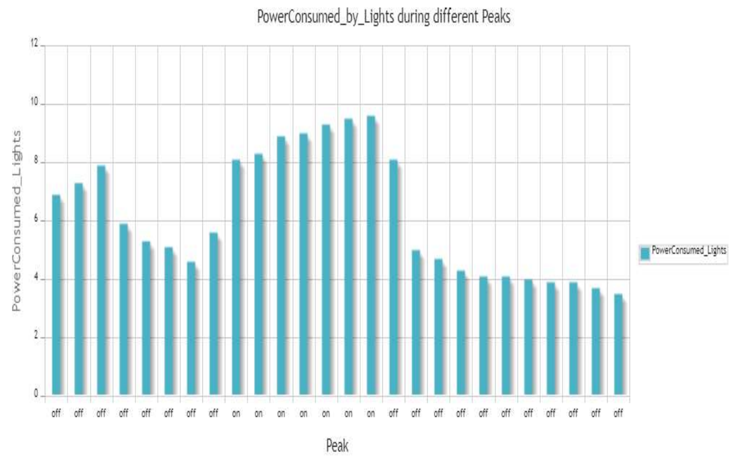

Figure 4-7: A bar graph showing the trend of energy consumption of bulbs to the user

Figure 4-8: A bar graph showing the trend of energy consumption of fans to the user

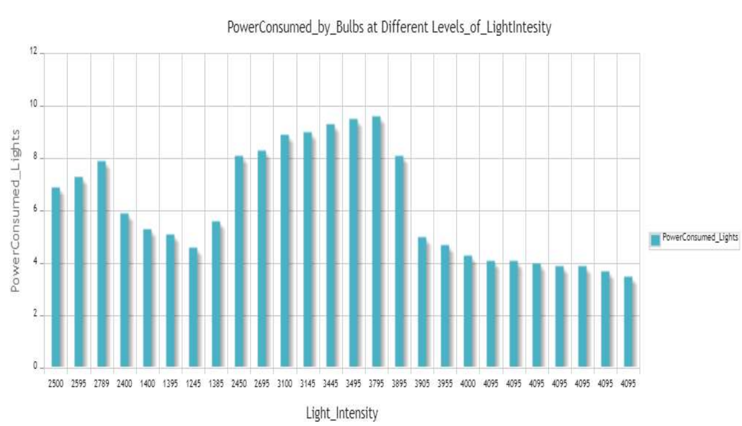

Figure 4-9: A bar graph showing the relationship between the energy consumption of the bulbs and the Light Intensity

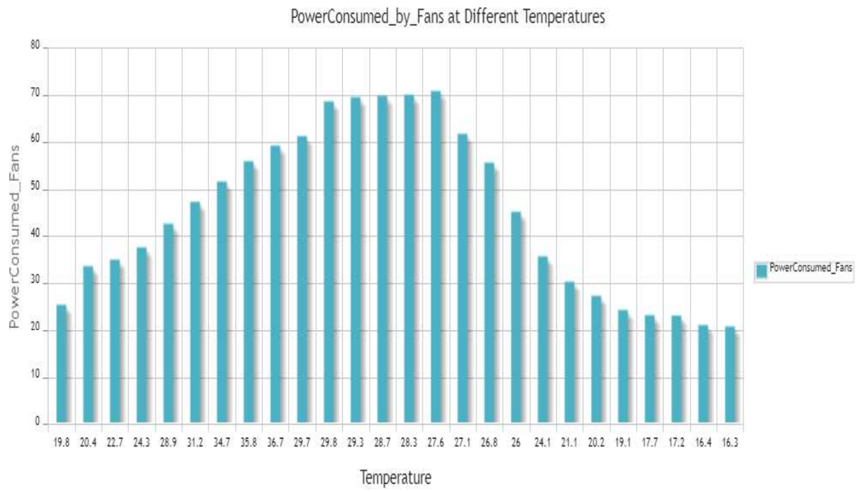

Figure 4-10: A bar graph showing the relationship between energy consumption of the fans and the temperature

Chapter 5: Testing and Results

5.1 Experimentation and Testing

This chapter mainly focuses on the experiments and tests that were done to illustrate and examine the capstone project's performance and relevance. The findings described in this chapter also demonstrate how the project and tests fit to the problem requirements and design specifications discussed in the project's early chapters.

5.1.1 Description of the Tests

For an effective and efficient Smart Home Energy Management System, the smart device, the IoT Network, the actuators, the user interface and the various use cases must function well. The Smart device must gather the correct data for the purpose of control of the actuators and transmit the right data to the database. The shifting of electrical loads during peak hours should be fast and accurate for reliability of the system.

Experiments and testing would be used to determine how well the project addresses the problem and adheres to the design specifications. The tests would concentrate on the management system's various systems and components. To make sense of the data, data and statistical analyses were performed and interpreted.

5.1.2 Accuracy

Test or the purpose of energy saving, the Smart Home Energy Management system uses the PIR sensor, the LM35 temperature sensor and the LDR sensor to monitor the home environments and control the bulbs and the fan accordingly. Thus, the accuracy of the PIR sensor, LM35 temperature sensor and the LDR sensor was carried out to determine if they are effective sensors for control of the home electrical loads.

5.1.2.1 PIR Sensor Accuracy Test

To measure how accurate the PIR sensor is in detecting motion and occupancy. The PIR sensor is connected to Led, a resistor and a 5V power supply. When the led goes on, it signifies motion is detected. When the setup is placed in a box with no occupancy and no motion, the led remains off. When my hand is moved inside the box the led goes on then off after sometime. When my hand remains stationary, the led remains off. I concluded that the PIR sensor can only detect motion in the room. Moreover, after conducting the test at different distances. There was increased sensitivity for motion closer to the sensor than far away. For objects far way more motion was needed.

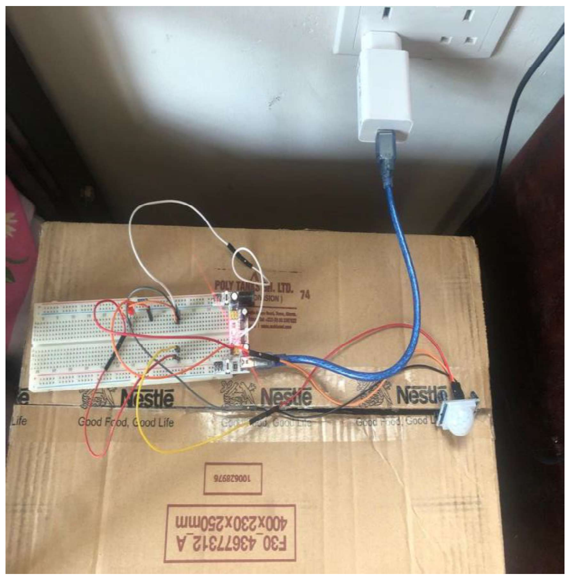

Figure 5-1: PIR sensor accuracy testing

5.1.2.2 LM35 Temperature Sensor Accuracy Test

Since the fans in the smart Home Energy Management system depends on the LM35 Temperature sensor it is necessary to make sure the sensor's accuracy is high. The LM35 Temperature sensor was compared to a LabQuest 2. The LabQuest 2 was used in this scenario as its more accurate. Both the LM35 and the LabQuest were placed in different temperature environments and the data collected. Ten samples were collected for each when placed in a hot environment, cold environment, room temperature and the outside environments.

Figure 5-2: Testing in a cold environment

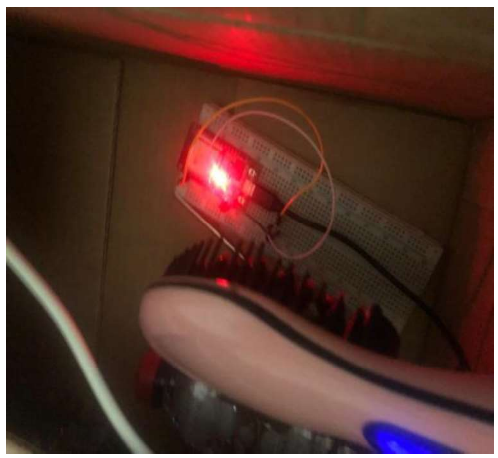

Figure 5-3: Testing in a hot environment

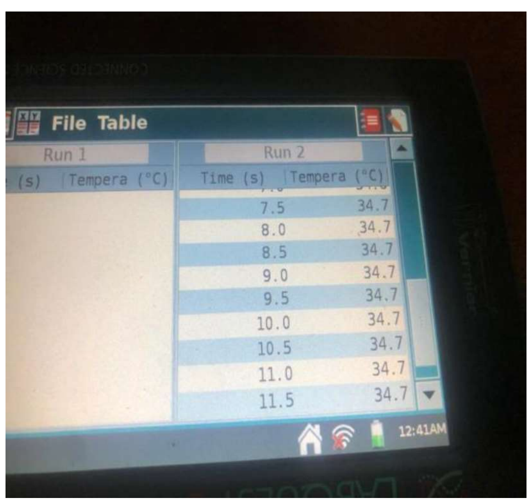

Figure 5-4: LabQuest Testing results

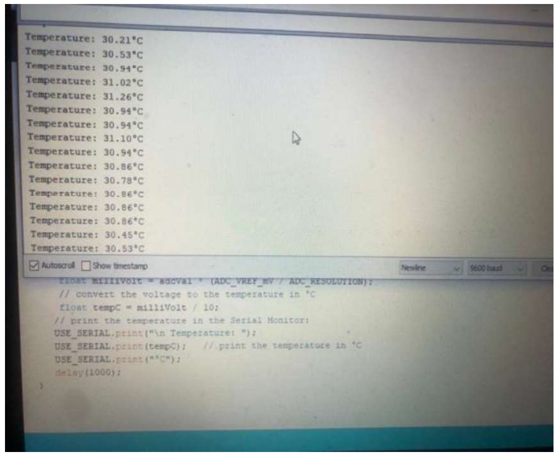

Figure 5-5: LM35 testing results

A paired two tail t-test was performed on excel on a sample size of 10.

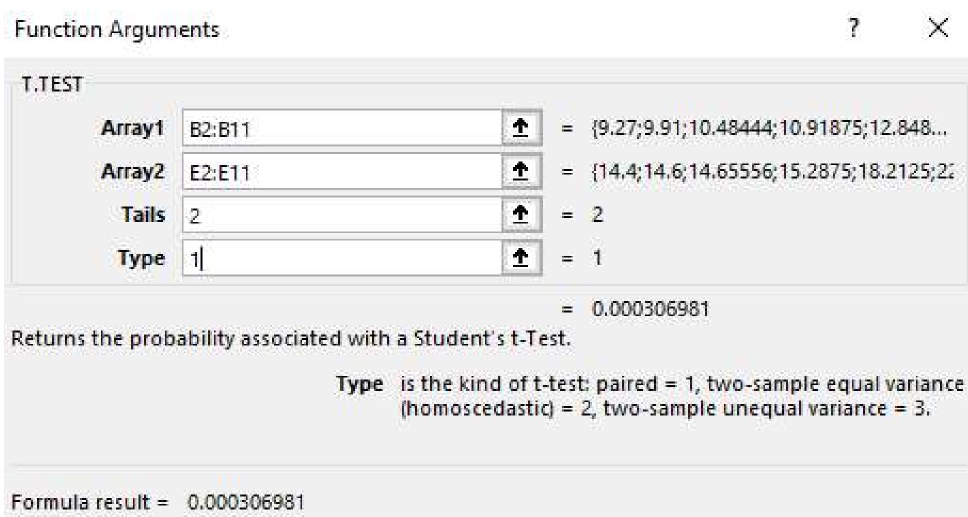

Figure 5-6: Temperature sensing accuracy t-test results on excel

From the test, the p value was less than the alpha value of 0.05. Thus, the null hypothesis which states that the mean temperature difference between the LabQuest 2 and the LM35 sensor narrows as the temperature level rises, was rejected. The Alternate hypothesis was accepted, the mean temperature difference between the LabQuest 2 and the LM35 sensor is not dependent on the temperature increase but rather by chance.

5.1.3 Energy Consumption Test

The Smart Home Energy Management System was designed to monitor the environmental conditions of the home surrounding and control the electrical appliances respectively, with an aim to lower the energy consumption. Energy Consumption Test was performed on the Smart Home to test if Energy consumption reduced when the electrical appliances were controlled. Power consumption data was collected from the smart home when the electrical appliances were controlled and another set of data when the electrical appliances were not being controlled.

The null hypothesis assumes that the daily total energy consumption is reduced when electrical appliances are controlled based on the environmental conditions and the household occupancy. The alternative hypothesis assumes that the daily total energy consumption reduces when electrical appliances are controlled but not based on only environmental conditions and occupancy. A tailed two t-test of unequal variance was performed on a sample size of 14.

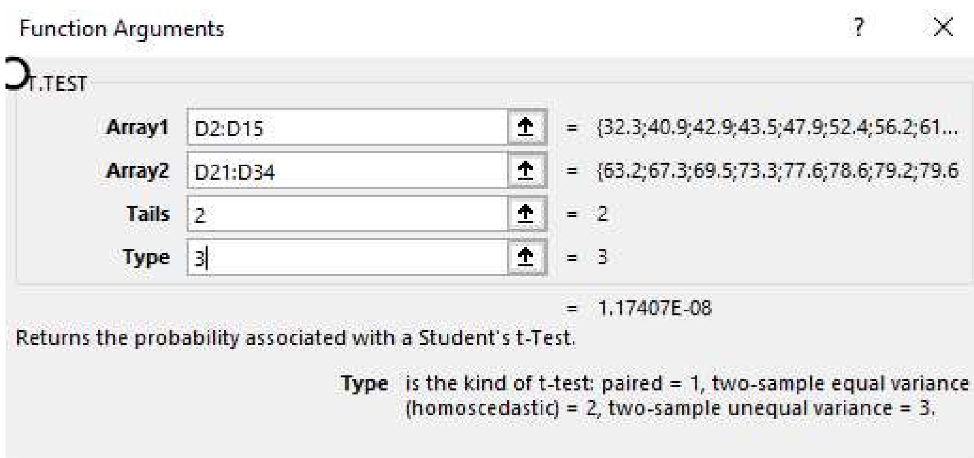

Figure 5-7: Energy consumption t-test results on excel

From the results the p value was less than the Alpha value of 0.05. Thus, the null hypothesis was rejected and the alternative hypothesis accepted. Meaning, that the daily total energy consumption reduces when electrical appliances are controlled but not based on only the environmental conditions and occupancy.

Chapter 6: Conclusion, Limitations and Future Works.

6.1 Conclusion

The Smart Home Energy Management System is designed to monitor and control the electrical appliances in a household based on the occupancy, Light Intensity, and Temperature levels and opt for an energy storage power source during peak hours, all to reduce energy consumption in a residential setup. The user can monitor the energy consumption of the various electrical appliances based on the occupancy, Light Intensity, and Temperature levels in the room using a web application.

The Smart Home Energy Management System was able to control the electrical appliances accurately and achieve the goal of reducing the energy consumption without compromising the occupant's comfort.

6.2 Limitations

As the project progressed, I needed knowledge on interfacing the Website and the Database to visualize the data as graphs and Pie-charts. I used a lot of time learning Website design and how to interface with the Database, which slowed down the project's progress. Therefore, I did a limited number of Statistical testing and analysis. Moreover, it prevented the possibility of investigating the Automatic Power Source Selector to other methods of Automatic Switching.

6.3 Future Works

More analysis can be done to compare the Response time of the Time interrupt concept used in the Automatic Power Source Selector and other methods of Automatic Switching. Moreover, a Machine Learning model can be developed.

References

[1] N. Javaid, I. Ullah, M. Akbar, Z. Iqbal, F. A. Khan, N. Alrajeh, and M. S. Alabed, “An intelligent load management system with renewable energy integration for Smart Homes,” *IEEE Access*, vol. 5, pp. 13587–13600, 2017.

[2] T. Molla, “Smart Home Energy Management System,” *Research Anthology on Smart Grid and Microgrid Development*, pp. 1132–1147, 2022.

[3] Paetz, A.-G., Dütschke, E. & Fichtner, W. Smart homes as a means to sustainable energy consumption: A study of consumer perceptions. *Journal of Consumer Policy*, 35(1), pp.23–41, 2011.

[4] D. Groppi, A. Pfeifer, D. A. Garcia, G. Krajačić, and N. Duić, “A review on energy storage and demand side management solutions in Smart Energy Islands,” *Renewable and Sustainable Energy Reviews*, vol. 135, p. 110183, 2021.

[5] A. Tascikaraoglu, A. R. Boynuegri, and M. Uzunoglu, “A demand side management strategy based on forecasting of residential renewable sources: A smart home system in Turkey,” *Energy and Buildings*, vol. 80, pp. 309–320, 2014.

[6] S. L. Arun and M. P. Selvan, “Smart Residential Energy Management System for demandresponse in buildings with energy storage devices,” *Frontiers in Energy*, vol. 13, no. 4, pp. 715–730, 2018.

[7] M. Tvaronavičienė, J. Baublys, J. Raudeliūnienė, and D. Jatautaitė, “Global Energy Consumption Peculiarities and Energy Sources,” *Energy Transformation Towards Sustainability*, pp. 1–49, 2020.

[8] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, and M. Z. Abd. Majid, “A Global Review of energy consumption, CO 2 emissions and policy in the residential sector (with an overview of the top ten CO 2 emitting countries),” *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 843–862, 2015.

[9] P. Palensky and D. Dietrich, “Demand side management: Demand response, Intelligent Energy Systems, and smart loads,” *IEEE Transactions on Industrial Informatics*, vol. 7,no. 3, pp. 381–388, 2011.

[10] B. Hussain and Qadeer-Ul-Hassan, “Demand side management for smart homes in Pakistan,” 2016 International Conference on Emerging Technologies (ICET), 2016.

[11] A. Saad al-sumaiti, M. H. Ahmed, and M. M. Salama, “Smart Home Activities: A literature review,” *Electric Power Components and Systems*, vol. 42, no. 3-4, pp. 294–305, 2014.

[12] A. R. Al-Ali, A. El-Hag, M. Bahadiri, M. Harbaji, and Y. Ali El Haj, “Smart Home Renewable Energy Management System,” *Energy Procedia*, vol. 12, pp. 120–126, 2011.

[13] V. D. Vaidya and P. Vishwakarma, “A Comparative Analysis on Smart Home System toControl, Monitor and Secure Home, based on technologies like GSM, IOT, Bluetooth and PIC Microcontroller with ZigBee Modulation,” in 2018 International Conference on Smart City and Emerging Technology (ICSCET), Jan. 2018, pp. 1–4, doi: 10.1109/ICSCET.2018.8537381.

[14] “IoT – SCADA: Complementary technologies for Industry 4.0,” Altizon Systems, Jun. 01, 2016. https://altizon.com/iot-scada-complementary-technologies/ (accessed Jan. 23,2020).

[15] F. Fernandes, H. Morais, P. Faria, Z. Vale, and C. Ramos, “Scada House Intelligent Management for Energy Efficiency Analysis in domestic consumers,” *2013 IEEE PESConference on Innovative Smart Grid Technologies (ISGT Latin America)*, 2013.

[16] J. Figueiredo and J. Sá da Costa, “A SCADA system for energy management in Intelligent Buildings,” *Energy and Buildings*, vol. 49, pp. 85–98, 2012.

[17] Hodey, D. M. "Energy monitoring for smart homes using Internet of Things," 2020.

[18] Gülay BAŞOL, Rüştü GÜNTÜRKÜN, and Erkan BAŞOL, "Smart Home Design andApplication," World Wide J. Multidiscip. Res. Dev., June 17.

[19] S. Das, S. Ganguly, S. Ghosh, R. Sarker, and D. Sengupta, "A bluetooth based sophisticated home automation system using smartphone," in 2016 International Conference on Intelligent Control Power and Instrumentation (ICICPI), Oct. 2016, pp.236–240, doi: 10.1109/ICICPI.2016.7859709.

[20] Dongmei Yan and Zhiguang Dan, "Zigbee-based Smart Home System Design," *2010 3rd International Conference on Advanced Computer Theory and Engineering(ICACTE)*, 2010.

[21] E. I. Davies and V. I. E. Anireh, "Design and Implementation of Smart Home SystemUsing Internet of Things," J. Digit. Innov. Contemp Res Sc Eng Tech, p. 10, Mar. 2019.

[22] Ahmed Talaat Totonchi, "Smart Buildings Based On Internet Of Things: A SystematicReview," Nov. 2018.

[23] Muhammad Rizwan Bashir and Asif Qumer Gill, "Towards an IoT Big Data Analytics Framework: Smart Buildings Systems," presented at the 2016 IEEE 18th InternationalConference on High Performance Computing and Communications, 2016.