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GSM Based Smart Home Energy Management System with Hybrid Energy

BY

Nazha Rostom Ghadban

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COMMITTEE PAGE

The members of the committee approve the Project of Nazha Rostom Ghadban Defended on December 27, 2017:

Dr. Farayi Musharavati

Thesis/Dissertation Supervisor

Dr. Shaligram Pokharel

Committee Member

Dr. Dinesh Seth

Committee Member

ABSTRACT

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Title: GSM Based Smart Home Energy Management System with Dynamic Price Response

Supervisor of Project: Dr. Farayi Musharavati

Energy management is one of the perennial problems in the world. In many places around the world; 100% of the energy production comes from non-renewable sources which pollute the environment around us. In addition, the usage of non-renewable sources such as natural gas is quite expensive. In which, one day this source will expire and will no longer exist in this world. This project outlines the importance of establishing a "Smart Home Energy Management (SHEM) system in Qatar" that is used to manage the use of alternative renewable sources of energy in supplying energy for household use. In this project, a SHEM system was developed based on data collected from a case study villa in Qatar. Alternative energy sources in the case study villa included solar PV, wind energy, battery bank and Liquefied Petroleum Gas (LPG).

An algorithm for selecting the optimal mix of energy sources was developed. The optimal energy mix was selected based on the least energy cost option. A prototype of the SHEM system was developed, using the Arduino board, to test the functionality of the proposed SHEM system. Experiments with the prototype showed that the SHEM system is able to select the least cost energy source at different times. The SHEM system was also able to send a message to the user's smartphone to give updates about the system status through GSM modem. This feature allows the user to interact with the SHEM system. The data and information availed to the user allows the user to

monitor and manage energy consumption parameters at household level. Numerical simulation of the SHEM system showed that the electricity bill at household level can be reduced by 4.4%. It was observed that implementation of the proposed SHEM can result in annual household savings of in the order of 909 QAR. Implementing the SHEM system to all houses in Qatar will result in savings to the order of 183,062,799 QAR. In addition, significant environmental benefits can be accrued by implementing the proposed SHEM systems in all houses in Qatar. Therefore, the proposed SHEM system can provide energy savings in homes.

DEDICATION

Completing this project took days, weeks and months of hard work and sleepless nights. Accordingly, I would like to dedicate this project to the people that I love the most and who never left me. Of course, my father and my mother who helped me to reach this stage. My brother and my sisters who were always next to me and supported me throughout all stages. Finally, I would like to dedicate to my friends who encouraged me to complete my masters' degree.

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CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Qatar population has been increasing rapidly in the last few years reaching 2,340,427 in 2017 (Worldometers, 2017). Due to the rapid development and economic growth, many people are migrating to Qatar and many more are expected as Qatar tries to meet the construction demands, general logistics and preparations for the FIFA World Cup 2022 and beyond. World Bank figures shows that energy consumption rates in Qatar are relatively high in comparison to the EU, for example: in 2014 the energy consumption in Qatar was 15,309 kWh per capita, while that in the EU was 5,908 kWh per capita (World Bank, 2014). In addition, population influx often leads to higher energy demands and consumption in houses, thus putting a strain on energy requirements and supply. This calls for the need to establish effective methods for managing energy end-use and hence consumption at houses as well as the need to explore different sources of energy, such as renewable energy and find ways of integrating such alternative sources into the power grid.

This project contributes to these needs by designing and developing a GSM based Smart Home Energy Management System (SHEMS). The proposed SHEMS is flexible enough to allow integration of renewable energy sources with energy from the conventional grid. This integration allows switching from one energy source to another at any convenient time based on real time information on current energy prices and sources. It allows the consequent advantages of reducing electricity bills. The system also provides the homeowners with updated information about the system's current situation. The long-term impact of the proposed SHEMS is an overall reduction in energy consumption at household level, thus reducing the strain on the energy demands and supply requirements from the utility companies.

1.2 Home Energy Management System

Home Energy Management System (HEMS) is defined as a system that measures, analyzes, observes and perform an action in order to manage energy at home. This requires implementation of home automation components at household level (Bojanczyk, 2013).

Home Energy Management Systems (HEMS) possess a variety of important characteristics. One of the most important characteristics is that the system optimizes energy use based on prices. In addition, the system is able to switch from one energy source to another based on its own observations. Moreover, the system is able to manage different appliances at home in order to reduce energy consumption (Sustainable Energy Authority of Ireland, 2017). When facilitated with a console that can relay real-time data and information about the state of consumption, homeowners can receive information about the system. Homeowners can then use this information to influence energy use and consumptions at household level.

An important factor in Home Energy Management system (HEMS) is not to depend on one source of energy but to use different sources at houses (hybrid energy supply) and to switch between these sources in the right timing. This capability can result in economic savings (if the switching is based on dynamic price response) or economic gains in cases where the local tariff system allows selling excess power to the main grid.

1.3 Problem Statement

Consumption of domestic energy in the state of Qatar has been increasing over the years. Qatar General Electricity and Water Corporation, known as Kahramaa – the utility company in Qatar, reported that the domestic consumption constituted 57% of overall electricity consumption in the country in 2014, which mainly consisted of residential consumption (Gulf Times, 2015). This has a value of (22,215,842 MWh). The corporation also reported that the domestic energy consumption increased from 4,105MW per day to 4, 795 MW per day between the years 2010 to 2014 (Gulf Times, 2015). Since the population has increased exponentially since 2014, the domestic energy consumption in 2017 is expected to be far much higher than the quoted figures.

Currently, Qatar generates electricity from natural gas. This resource is nonrenewable which means after sometime in the future the resource may be depleted. This is not sustainable and may lead to a number of negative environmental impacts. Although the local utility companies have embraced the sustainability benefits that comes with renewable energy, relatively very little and isolated use of renewable energy exists in Qatar. Use of renewable energy and other forms of alternative energy sources helps in reducing the current heavy dependency on conventional electricity. Implementing measures for controlling energy end-use and techniques for managing energy at household level can go a long way in conserving and reducing energy consumptions at household level. If mechanisms, schemes and techniques for countrywide implementations of appropriate Home Energy Management Systems are put in place, the long-term effect is reducing the supply/demand strain on the main utility grid. This project explores opportunities for developing and implementing Smart Home Energy Management Systems in residential areas in Qatar.

1.4 Aims and Objectives

The aim of this project is to design and develop a GSM based Smart Home Energy Management System (SHEMS). The analysis is based on data and information collected from a case study villa in Qatar. The SHEMS will be facilitated with the following two critical components:

- GSM Modem

- Arduino DUE microcontroller

Key elements of the SHEMS include: AC loads, DC loads and thermal Loads. In order to meet this aim, the following objectives that will be addressed in this project are:

1. To analyze the use of solar photovoltaic (PV) technology for generating electricity at household level.
2. To analyze the use of wind energy technology for generating electricity at household level.
3. To develop an algorithm for controlling energy loads at household level.
4. To design a hardware prototype that can switch between five energy sources which are: solar photovoltaic, wind, grid, battery bank and gas.
5. To evaluate the energy savings that will occur by using SHEMS.

The Smart Home Energy Management System will help Qatar residents to take control of their energy consumption at household level. It will also help the nation in conserving the natural gas resources by opening opportunities for countrywide integration of renewable energy. Furthermore, the Smart Home Energy Management System will have a great impact on the total domestic energy used in Qatar due to the anticipated reduction in energy consumptions in residential buildings. This will lead to a reduction in the pressure persisted on Kahramaa by allowing Kahramma to adequately match and mitigate the effects of energy supply and demand. In addition, this will also have an impact on the national energy bill, and residents will be able to pay less in electricity bills and hence save money.

1.5 Scope

This study focuses on different aspects required in order to have an effective energy management system in houses, i.e. the use of solar photovoltaic energy and wind energy in houses, and identifying how an energy management system can be applied to houses in Qatar. The project will be achieved in the following stages:

1. Explore the different literature and research accomplished in the area of energy management.
2. Collect data from Kahramaa about energy consumption and price in Qatar.
3. Develop an algorithm and hardware to achieve proof of concept.
4. Develop the hardware prototype and perform testing.

1.6 Significance of the Study

Smart Home Energy Management System will introduce different benefits to the country. The system will lead to important savings from the reduction of using electricity at houses to the reduction of the use of nonrenewable resources such as natural gas. The system will work on switching between five sources of energy in order to minimize costs of energy.

CHAPTER 2: LITERATURE REVIEW

2.1 Background Theory

In order to apply a Smart Home Energy Management system (SHEMS); it is important to understand the concept of sustainability and sustainable energy. This importance is because a smart home energy management system cannot be accomplished without investigating and implementing sustainable energy sources such as solar PV and wind. SHEMS is about using different sources of renewable energy and non-renewable to optimize energy uses.

2.1.1 Sustainability

Sustainability is mainly defined as a process of change that aims at meeting current and future human needs (The World Commission on Environment and Development, 2017). Additionally, the Forum for the Future's Sustainable Wealth London stated that sustainability has five main principles: “quality of life; fairness and equity; participation and partnership; care for our environment and respect for ecological constraints”. They mentioned sustainability is mainly about understanding that the environment has limits (Global Foot Prints, 2017). This project focuses mainly on two of the above principles: quality of life and care for the environment. Sustainable energy supply provides adequate access to electricity thus increasing the human’s quality of life. Moreover, sustainable energy produces less CO_2 emissions meaning it is environment friendly.

2.1.2 Sustainable Energy

Sustainable Energy has two main characteristics: the energy resource is naturally refilled and the resource has long term availability. Sustainable energy is the type of energy that existed since long time ago and will still exist in the future; the energy is able to satisfy current and future demand if properly harnessed.

The different sources of renewable energy are all types of sustainable energy and these can be classified as follow: solar, wind, geothermal, hydropower, wave and tidal power (Conserve Energy Future, 2017). In this project, the main focus will be on the use of *solar photovoltaic energy* and *wind energy* in order to have an effective smart home energy management system (SHEMS).

- Solar Photovoltaic Energy

All concepts related to solar photovoltaic energy should be understood and discussed since this works on supporting the concept of sustainability and it is one of the renewable energies that can be used. This section focuses on solar PV energy concepts and these are: solar PV definition, the system itself, the advantages, the uses and the applicability of the concept to houses in Qatar.

Solar photovoltaic energy is a type of energy generated through the direct conversion of sunlight into electricity without the use of any type of engine (Parida, Iniyan, & Goic, 2011). Meanwhile, solar Energy Industries Association (2017) defined a photovoltaic system as one that generates electricity from sunlight through semiconductors. The semiconductors have different electrons that get unattached when exposed to sunlight; these electrons can power electrical devices when they pass through an electrical circuit. Meanwhile, Parida, Iniyan, & Goic (2011) described photovoltaic system as system that is made up of many components such as cells, mechanical connections, electrical connections, and ways of controlling electrical output. New Dawn Energy Solutions (2017) stated that a photovoltaic system is like any other electrical power generating system in which the equipment differ from the ones used for generating the conventional electricity. Furthermore, there are three types of solar photovoltaic systems that can be installed on houses; each type has its own characteristics. These include grid-connected solar PV, stand-alone solar PV and hybrid solar systems. The systems will be described below (Horgan, 2017).

a) Grid-connected Photovoltaic System

The first required component for any photovoltaic system is the solar panel which absorbs sunlight and converts it into DC current; the other required component in a grid-connected PV system is an inverter which converts DC load into AC load. Afterwards, the AC load produced is used to supply electricity in homes and any extra electricity will be transferred to the grid. During the night period when PV system is not able to supply enough electricity; the electric utility will supply any power needs from the main power grid. Figure (1) shows the detailed process.

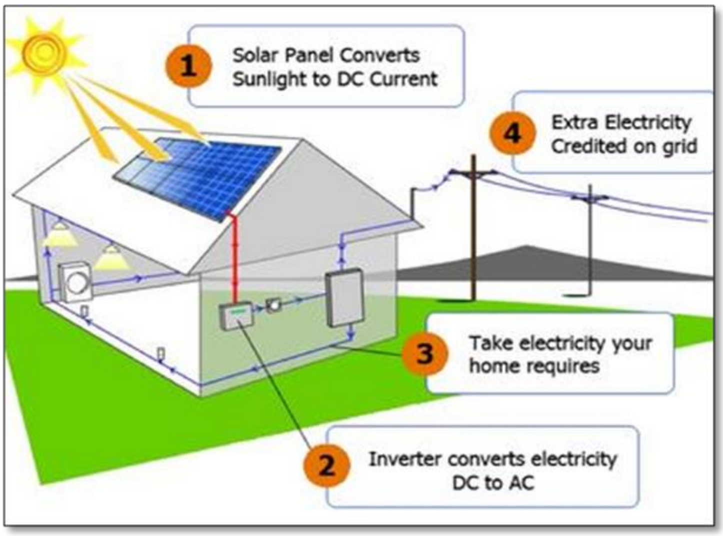


Figure 1. Grid-connected Photovoltaic System

b) Stand-alone Photovoltaic System

Similarly, the first required component in a stand-alone PV system is the solar panel. However, in this type of system other components may be used such as a wind turbine. No electric utility is required. The other components used are an inverter, battery charging controller and batteries.

The inverter will supply the house with electricity (AC Load) and any extra electricity will be transferred to the battery charge controller to be stored in the batteries. Later on, the electricity stored in the batteries can be used at night. Figure (2) shows the detailed process.

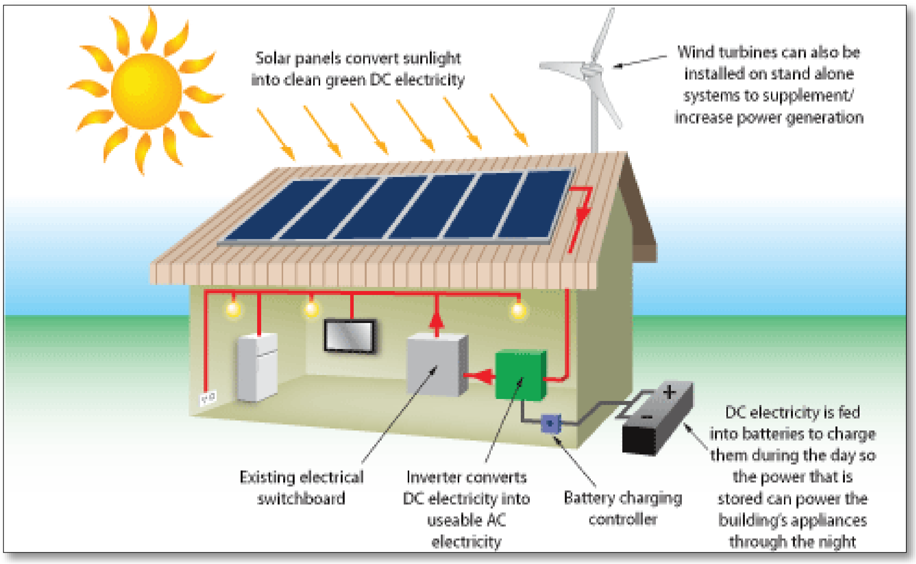


Figure 2. Stand-alone Photovoltaic System

c) Hybrid Solar Photovoltaic System

A hybrid solar PV system applies both concepts of the grid-connect PV system and the stand-alone PV system at the same time. A Hybrid Solar PV System has the ability to store electricity into batteries to be used by the house later when needed. As well as transferring the extra electricity through the grid. Figure (3) shows the detailed process.

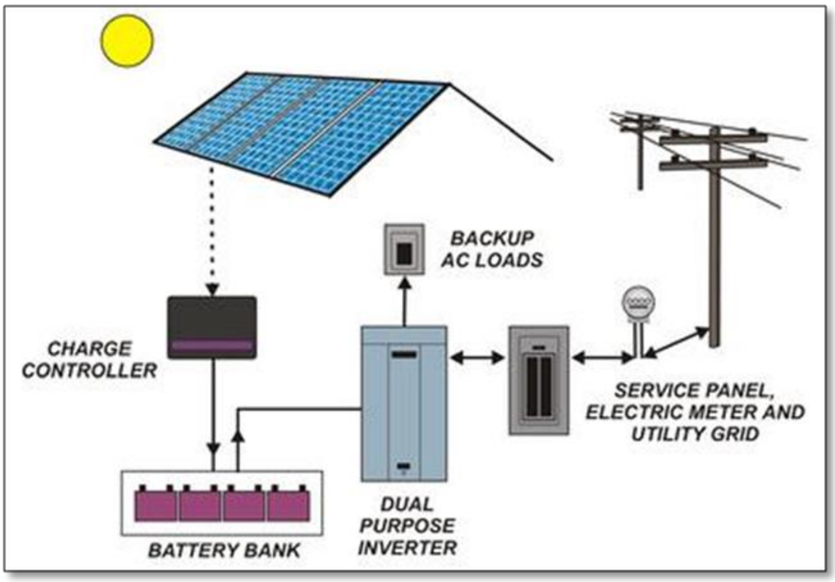


Figure 3. Hybrid Solar PV System

Moreover, renewable Energy World (2017) mentioned many advantages of using solar PV energy and the most important ones can be classified as follow:

- Generating electricity through PV panels produces less greenhouse gas emissions than other sources like gas.
- The source of solar energy is free since it is generated from the sun.
- Solar energy is a renewable source of energy and is available for anyone.

- The cost of solar energy panels has been reducing over the years and further reduction is expected.
- Solar energy panels can be installed easily on all houses and do not have any effect on the houses nor the residents.

Solar PV has many usages; the electricity generated from solar PV usually is in the form of DC load. However, an inverter will convert it to AC load as mentioned previously; this allows it to be used in different applications such as power source, solar home systems, satellites, water pumping, and for different plants (Horgan, 2017).

The concept of solar PV requires sunlight and solar panels in order to generate electricity. According to Qatar's weather; the country is known to be sunny most of the year. This motivates the concept of solar energy and makes it valid. The only left part is to purchase the solar panels and install them on the rooftop of all houses and to raise cultural awareness. Moreover, Qatar has initiated a major solar plant project in 2017 and it is supposed to be completed by 2020 in Qatar. The plant has an initial capacity of producing 200 MW of electricity. This initiation supports the concept of this project and helps in applying solar energy concept in the houses. Siraj Power will develop the project, which is a joint venture between QEWC (Kahramaa) and Qatar Petroleum (Trade Arabia, 2017).

- Wind Energy

All concepts related to wind energy will be discussed since wind energy makes a good source of renewable energy. This section discusses wind energy concepts, which are wind definition, wind energy system, system advantages, the uses and the applicability of using the system in houses in Qatar.

Wind energy is obtained through the use of turbines in which these turbines work by converting the kinetic energy in the wind into mechanical power. The mechanical power is converted by a generator into electricity (Office of Energy Efficiency & Renewable Energy, 2017).

The main component of a wind energy system is the turbine. The blades of the turbine are moved by the wind and these turbines are used to supply mechanical energy to a generator. This generator uses mechanical energy in order to generate electricity (Wind Energy Development Programmatic EIS, 2017). The home wind turbines are divided into two types: rooftop wind turbines shown in figure (4) and freestanding mast wind turbines shown in figure (5) **(**Home Wind Turbines, 2017). The advantage of using free standing mast wind turbine over rooftop wind turbine is that free standing mast can be placed far from the house since wind turbines could make very loud and noisy sounds.

Figure 4. Rooftop Home Wind Turbine

Figure 5. Free Standing Mast Home Wind Turbine

Wind energy has many advantages; the most important ones can be summarized as follow (Conserve Energy Future, 2017):

- Wind energy is a renewable source of energy and has no limitations.
- Energy generated from wind is not harmful to the environment since it is a clean source and does not produce greenhouse gas emissions.
- Wind energy is not costly since the use of wind is free and the only cost required cost is the turbines' cost.

Wind energy concept is quite applicable to Qatar; according to "Weather online Reports" Qatar has wind from March till August through the year and strong wind can occur sometimes. Therefore, wind turbines must be installed in Qatar in order to initiate the wind energy concept in the houses. To support this concept, Vodafone Qatar and Alcatel-Lucent is working on developing a powered base station using solar and wind energy. For wind energy production, a 2.5kW wind turbine will be used in the station (Norton Rose Fulbright, 2017).

2.1.3 Solar PV Energy and Wind Energy Impact on the Environment

Evans, Strezov & Evans (2008) compared the gas emissions that occur from energy generation in terms of carbon dioxide per kW h. Table (1) shows the gas emission for different types which are solar photovoltaic, wind, hydro, geothermal, coal and gas. The main focus is the difference between the carbon dioxide emissions between photovoltaic, wind and gas. It is clear that gas generates higher carbon dioxide emission in comparison with the solar photovoltaic and wind; 543 CO_2 / kW h, 90 CO_2 / kWh and 25 CO_2 / kWh respectively.

As mentioned previously Qatar uses gas in order to generate electricity. Thus, using solar photovoltaic energy and wind energy will help to protect the environment and will be less harmful.

Table 1

Gas Emission for Energy Sources

Source of energy	CO_2 / kW h
Photovoltaic	90
Wind	25
Hydro	41
Geothermal	170
Coal	1004
Gas	543

2.2 Home Energy Management System Overview

2.2.1 HEMS Concept

Home Energy Management System can be defined as a system that manages energy consumption in a house. This process starts by monitoring how energy is usually consumed at houses; and focusing on the devices that are used more frequently and have high energy consumption. The system works on managing these appliances by switching between the different sources of energy and selecting a certain type of energy for a certain appliance in order to reduce energy costs in a house (Rossell&Soler, 2011). Figure (6) shows specifically the different goals of HEMS.

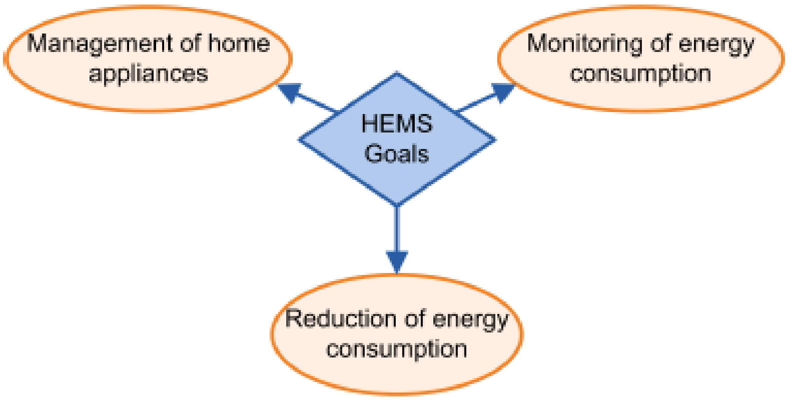


Figure 6. HEMS Goals

2.2.2 HEMS Necessity

The International Energy Agency (IEA) confessed that the utilization of electricity expanded by 30% during the last 30 years. The IEA mentioned that the main reason behind this raise in usage is an increase in the number of home appliances being used at houses (Rossell & Soler, 2011). Accordingly, a Home Energy Management

System (HEMS) must be established in order to manage this increase in energy consumption by home appliances. Otherwise, the expenditure in electricity use will keep on increasing and will have an unfavorable impact on the environment.

2.2.3 HEMS Functionalities

After exploring the architecture of a home energy management system, it can be concluded that a home energy management system has five main functions that can be classified as shown in figure (7) (Zhou et al., 2016).

HEMS modules	Service description
Monitoring	Monitoring offers easy access to real-time information on energy consumption and allows users to focus on the electricity saving. It can also provide display services for the operational modes and energy status of each home appliance.
Logging	Logging is to collate and save the data information on the amount of electricity usage from appliances, generations from energy storage state. This service also contains demand response analysis for real-time prices from grid utility.
Control	There are two types of control, namely, direct control and remote control. Direct control is implemented on both the equipment and control system; whereas, remote control means customers can online access to monitor and control the usage patterns of in-home devices via handheld personal computer or smart phone from outside.
Management	Management is the most important function of HEMS to enhance the optimization and efficiency of electrical power usage in smart house. It covers a range of services including renewable energy system management service, energy storage management service, home appliance management service, and Plug-in EV and battery management service.
Alarm	Alarm will be generated and sent to the smart HEMS center with information on the fault locations, for example, if there is any abnormality detected.

Figure 7. HEMS Main Functions

2.2.4 HEMS Requirements

In order to have a successful home energy management system; the system must satisfy the following requirements (Rossell & Soler, 2011):

- A system that can be installed easily: the energy management system must be a system that can fit easily into the houses. The system should not require new infrastructure should fit within the current situation.

- A system with an applicable communication network: the energy management system should have a communication network that is able to connect all appliances in a house.
- A secure system: the data of the energy management system must be encrypted and authenticated to protect the system from any outside threats.
- A system with an easy set-up: the energy management system must have a configuration that allows any homeowner to do the set up.
- A system that displays information for the user: the energy management system must display for the user the daily energy consumption.
- A system that allows user interface: the energy management system should allow user interaction.
- An intelligent system: the energy management system should be intelligent in which the system should be able to take information from the environment and should react towards it by reducing energy consumption in houses.

2.2.5 HEMS with Different Types of Electrical loads

- AC Load

AC load can be defined as the type of electrical load generated by the electricity companies to supply houses. AC load is usually used by the different appliances and devices found at home (ABS Alaskan, 2017).

- DC Load

DC load can be defined as the type of electrical load generated by the renewable energy systems such as the solar panels. Moreover, batteries usually store this type of load; DC load is used as well for lighting and refrigerators (ABS Alaskan, 2017).

- Thermal Load

Thermal load can be defined as a load that is generated from a gas source. In Qatar LPG gas is usually used by ovens for cooking in homes.

2.3 Smart Home Energy Management System Overview

2.3.1 Smart Homes Definition

A smart home can be defined as a home that uses new technologies and mainly automation to allow monitoring and control of the different functions at the house. All devices in smart homes can be controlled easily. In order to make a home smart certain tools must be installed such as sensors and computer controls (Smart Home Energy, 2017).

2.3.2 Smart Homes Internal Structure

Zhao, Dong, Li, & Song (2015) described the internal structure of a smart home and mentioned that a smart home is mainly made up of DC and AC loads, main grid, renewable energy source, and batteries. A DC bus is built and connected to the PV source and the batteries. Moreover, the DC bus is connected to the AC Bus through a Bi-directional converter. On the other hand, the AC bus is connected to the main grid that supplies electricity from the local company. The internal structure allows direct use of DC load and direct storage before converting the load into AC load. This is shown in figure (8).

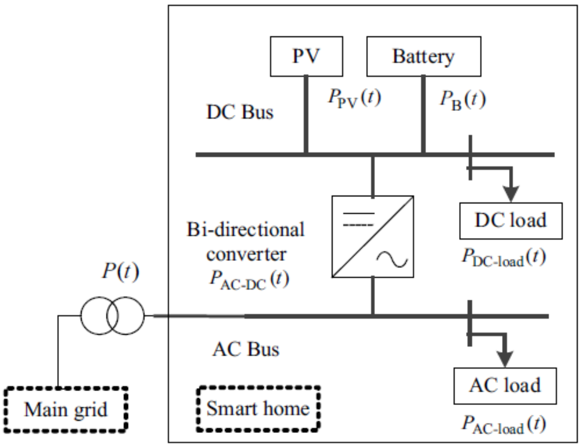


Figure 8. Smart Home Internal Structure

2.3.3 *Smart Homes Energy Management System Architecture*

A Smart Home Energy Management System (SHEMS) is made up of different components to be able to perform its functionality successfully. Figure (9) shows the components. The different components can be classified as follow (Zhou et al., 2016):

- Communication and networking system: the network connects all the other components of a home energy management system in a smart home. This allows an interface to occur between the components.
- Main panel: real time data from all appliances (schedulable and non-schedulable) are collected by the main panel in order to perform an optimal demand dispatch.
- Power utilities (electrical grid): the network that delivers electricity from the source to all houses.
- Smart meter: the meter is used as an internal point between the power utilities and all appliances in the house. Once a demand signal is received by the smart

meter from the power utilities; the meter will schedule the appliances in order to optimize the electricity consumption.

- Smart HEMS center: the center receives data from the smart meter and the main panel, and then it allows the homeowner to monitor the devices and control/schedule their usage timings. It also contains the system algorithm.
- Solar panels/ Wind turbines: the sources that generate renewable energies such as solar energy and wind energy connected to HEMS through the communication network.
- Home energy storage system: the storage system is used for storing the extra energy generated from the solar panels/wind turbines; to allow the use of the renewable energies even when the sun and wind are not there.
- Schedulable appliances: all appliances at home that can be scheduled such as: washing machine, iron, air-conditioning and water heater.
- Non-schedulable appliances: the appliances that are usually used at different timings such as: printers, television and hair dryer.

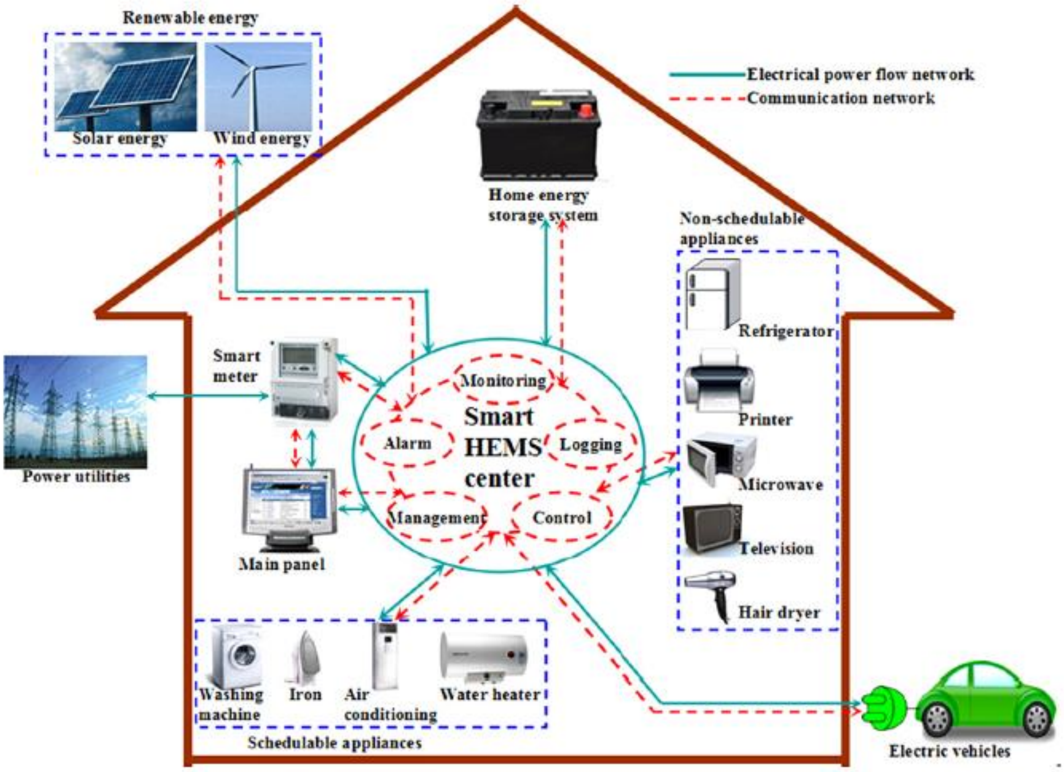


Figure 9. Architecture of HEMS

2.3.4 HEMS Algorithm

Beside the hardware components described in the HEMS Architecture, an algorithm is required to control the appliances off and on timings and to switch between the energy sources, the electricity generated from the electrical grid and the electricity generated from the solar panels and wind turbines. The algorithm is usually based on data obtained from outside resources such as the weather, the market of energy, and from the homeowner entries. In addition, the market of energy means the prices of the different sources of energy. Therefore, based on all the data entered the algorithm will manage the energy consumption in a house**.** The algorithm can be accomplished using different languages; however the most used languages are: MatLab and Arduino (Missaoui, Joumaa, Ploix, & Bacha, 2014).

Different types of algorithms were developed in proposing a home energy management system. In 2012, three researches developed an algorithm to be used in a smart house. The explanation of the algorithm is divided into two parts: overall algorithm and the decision making process. These are shown in figures (10) and (11). The algorithm only focuses on four types of electrical devices considering them as the devices that have the highest energy consumption. These appliances are: water heater (WH), cooling/heating unit (AC), clothes dryer (CD) and electrical vehicle (EV). The algorithm main aim is to control the loads considering user input (load priority and comfort level settings) and respond to demand considering demand limit and duration (Pipattanasomporn, Kuzlu & Rahman, 2012).

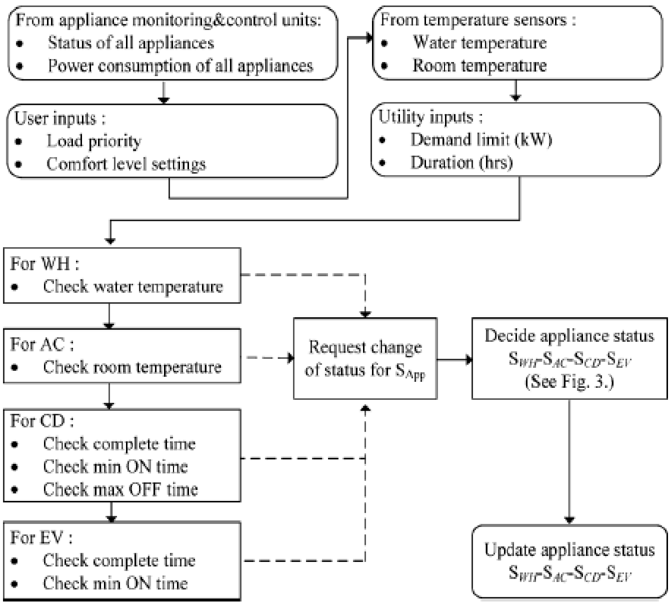


Figure 10. Overall Algorithm

Note: S_{App} is the status of appliance that violates the comfort level.

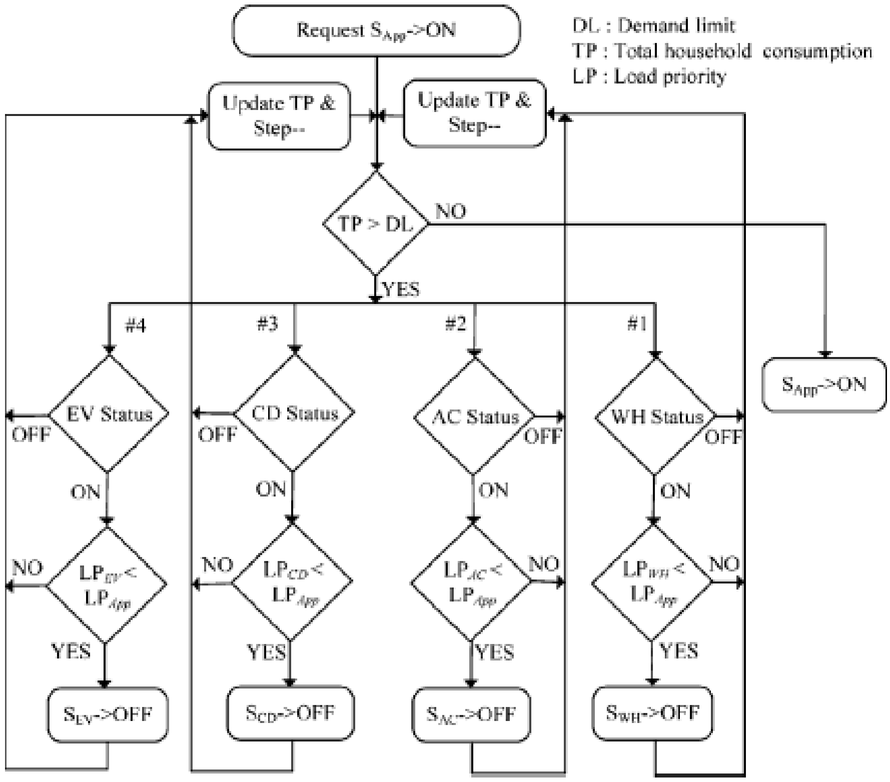


Figure 11. Decision-making Process of the Algorithm

On the other hand, another algorithm was achieved where this algorithm has considered renewable resources of energy. The main aim of this algorithm is to reduce the bills of the consumer where the algorithm tries to use renewable energy when it's applicable. In the algorithm, SOC stands for state of the charge of the batteries; where batteries are only charged from renewable resources. The algorithm is shown in figure (12) (Boynuegri, A., Yagcitekin, B., Baysal, M., Karakas, A., & Uzunoglu, M., 2013).

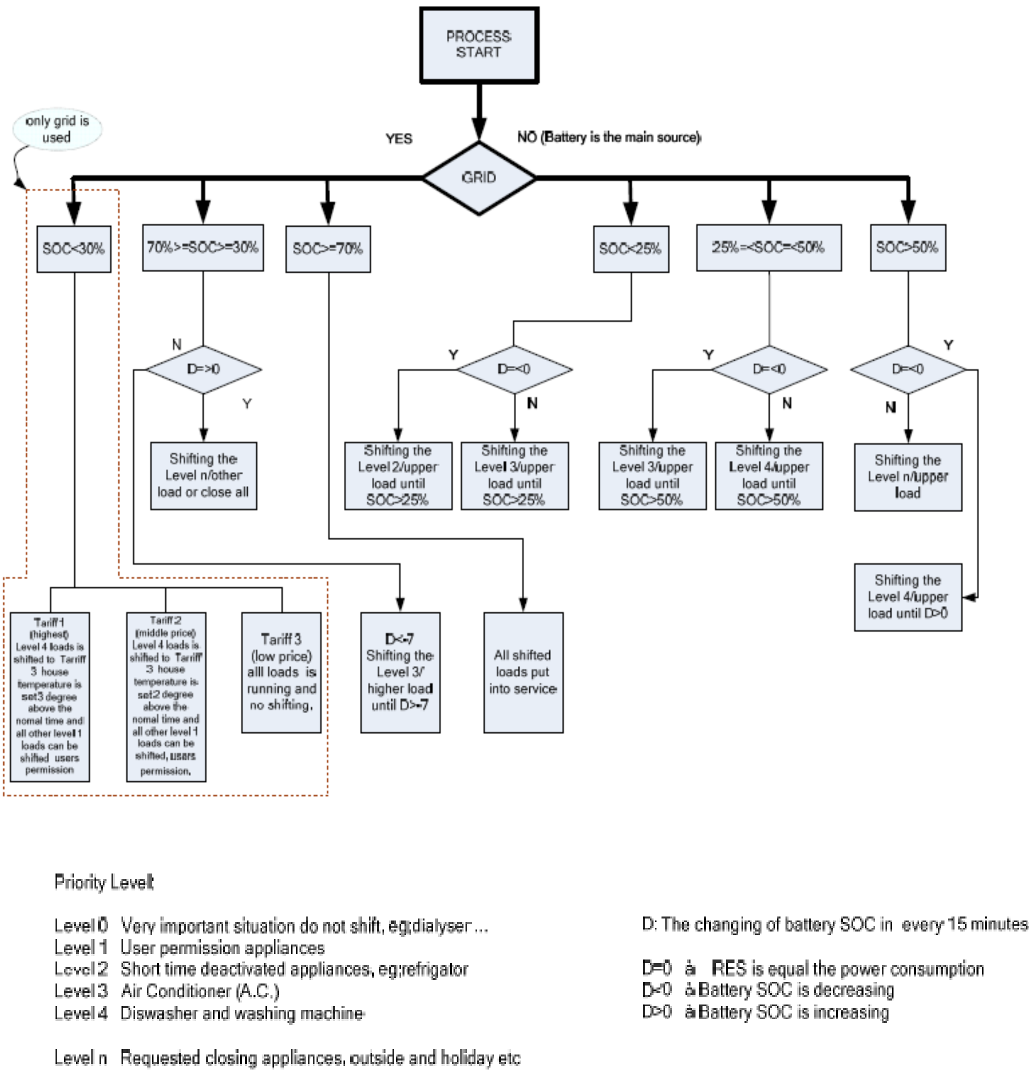


Figure 12. Algorithm with Renewable Sources of Energy

In this project, a specific algorithm will be developed for the Smart Home Energy Management System for the state of Qatar. The algorithm main aim will be to reduce energy consumption from the grid and use renewable sources of energy. In addition, the algorithm will work on reducing the electricity bills for consumers in Qatar. The main and special feature of the proposed algorithm will be using five different sources of energy which are: solar PV, wind, battery, grid and gas. This feature is important because it allows reducing the electricity bills as well as protecting the environment.

2.3.5 HEMS Microcontroller Technology

There are different types of microcontrollers that could be used for developing the hardware of the home energy management system. However, in this project the focus will be on Arduino microcontrollers. This is due to the advantages the Arduino microcontrollers have over other controllers. These advantages can be summarized as follow (Fabio, 2011):

- Arduino microcontrollers are easy to use; they can be connected to a computer directly just using a USB.
- Arduino microcontrollers offer both analog and digital input.
- Arduino microcontrollers are not expensive and are affordable.
- Arduino microcontrollers can be controlled by a written code where these codes can be considered easier than others since many of them are available online.
- Arduino offers examples of codes that are ready to use in the software.

Three different types of Arduino are shown in figures (13), (14) and (15); Arduino UNO, Arduino Due and Arduino Mega 2560. In this project, Arduino Mega 2560 will be used because it is already available at the University and it satisfies the requirement. Therefore, it can be concluded that there is no difference between using Arduino UNO, Arduino DUE or Arduino Mega 2560 in this project.

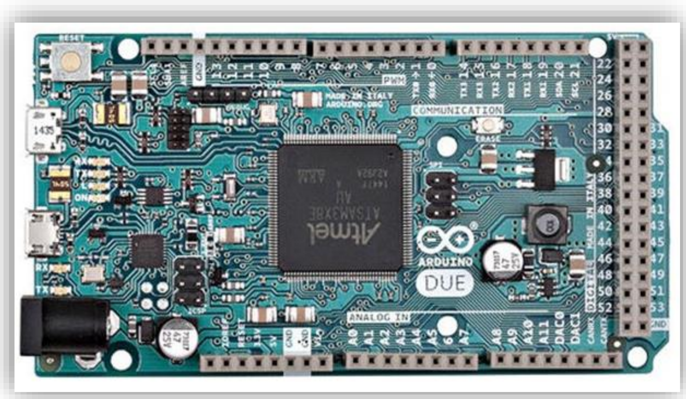


Figure 13. Arduino UNO

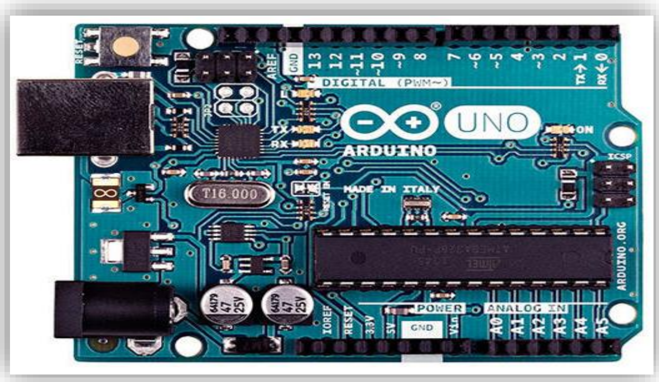


Figure 14. Arduino DUE

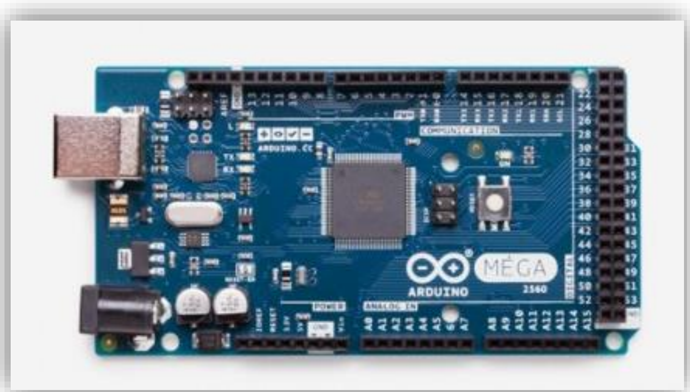


Figure 15. Arduino Mega 2560

2.3.6 HEMS Communication Technology

There are many available communication technologies used in building Home Energy Management Systems. However, this section will focus on two technologies according to their reliability and popularity. These technologies are: GSM and Internet of Things.

a) GSM

Global System for Mobile Communication (GSM) is defined as a digital mobile telephony system that is used around the world. It allows wireless phone calls and it is known as the most known technology that used by 80% of the cellular companies (TechTarget, 2017).

A Smart Home Energy Management System with GSM Technology allows users to control their homes from any part of the world. The user does not have to be at home; rather they can use their mobile phone to communicate with the system and to provide it with instructions. All home devices and appliances can be controlled through SMS. Moreover, information about the state of the devices can be provided to the users through SMS. All communications will be done through GSM network (Singh, Chotalia, Pingale, & Kadam, 2016).

The GSM Modem is used in building the hardware of the energy management system. It is required since it will communicate with the users' mobile phones via radio waves (Singh, Chotalia, Pingale, & Kadam, 2016).

b) Internet of Things

Internet of Things technology allows users to control over things that are far from them via the internet. Moreover, it provides users information about the status of different things even when they are busy with other activities (Singh & Ray, 2017).

A Smart Home Energy Management system with Iot Technology allows controlling and monitoring all home appliances and devices using the internet via web server. The user can access the system through a desktop computer, laptop or mobile phone that is connected to the internet through a web browser using server IP (Vinay sagar&Kusuma, 2015).

In order to build a hardware for an energy management system using the IoT technology; Intel Galileo development board should be used. The board must be built with a WiFi card port. The card inserted in the board will act as the web server (Vinay sagar&Kusuma, 2015).

In our project, GSM technology will be used according to the different advantages that this technology have over others (McDonnell, 2017). These can be listed as follow:

- GSM Modems are widely available and can be purchased easily.
- GSM Modems are affordable and are not expensive.
- GSM technology is widely used and it allows you to connect with over 200 countries.
- GSM network is fast and can transfer data with a speed of 42 Mbps.

2.4 Issues related to Smart Home Energy Management System

2.4.1 Global Issues

This section aims at understanding the technologies that were used around that world in developing a home energy management system. The different algorithms and hardware used will be discussed here.

Dwivedi, A. K., Narayan Y., &Shimi S. L. (2015) completed a research on home energy management system in India. The research worked on developing the hardware of the system using Arduino Uno and GSM. The Arduino works as the controller of the system and GSM works as the communication system. The algorithm of the system was developed using Arduino software. Moreover, in 2016 in India Singh, P., Chotalia, K., Pingale, S., & Kadam, S. proposed a system for home energy management system that insisted on using GSM modem with any microcontroller. The hardware system was simulated using "Proteus software". The software showed how the different tasks of the system could be accomplished which are: automating home devices and updating the home users about the status of different home devices and appliances. The research showed that using GSM will improve the communication process and will increase the quality of life. On the other hand, another research was done in 2016 in Ghana; the research also suggested the usage of GSM with Arduino microcontroller in accomplishing a home energy management system. The GSM receives messages from home owners leading the microcontroller to do a certain action. In this research it was stated that GSM was preferred over the internet because it is known to be a more secure technology (Effah E., Aryeh F. L.,&Kehinde W. K., 2016).

Another research that was done recently in 2017 in India; showed that the most practical solution for a home energy management system is to develop the system using Arduino microcontroller and GSM modem. In addition, Arduino 1.6.1 was used to develop the controlling code of the system (Patil, Potnis, &katkar, 2017).

In this project, the GSM modem and Arduino microcontroller will be used. The literature proved that this combination provides an efficient SHEMS with high reliability.

2.4.2 Regional Issues

This section aims on understanding the technologies that were used in the Middle East in developing a home energy management system.

In 2015, collaboration between universities in Saudi Arabia and Egypt was done to accomplish a research in the area of home energy management. The research implied that a home energy management system can be developed through the usage of two main components which are: "PIC18F452" microcontroller and GSM Module SIM (900). The research suggested the usage of this microcontroller because it is widely available and can be programmed easily (Shawki, Dessouki, Elbasiouny, Almazroui&Albeladi, 2015).

Another research was done in 2015 in Egypt; the research was entitled as “Enhancement of a GSM Based Control System”. The study was working on automating the house electrical appliances through the use of GSM and Arduino microcontroller. The research also described other microcontrollers such as “PIC 18F442” and “PIC 18F452”. However, it suggested at the end the Arduino microcontroller according to its reliability (Hassan A., 2015).

2.4.3 Local Issues

After going through deep research and investigations, no papers or studies in the public literature were done in this area. Moreover, an interview was done with Siemens Company where they stated there is no clear evidence yet of an established energy management system done in Qatar in any of its commercial building or its houses. Therefore, this project will work on introducing the concept of home energy management system in the country. As mentioned before, the proposed Home Energy Management System will be accomplished using Arduino microcontrollers and GSM Modem.

2.5 Literature Review Summary

The main contribution of this project is to develop and implement a Smart Home Energy Management System in Qatar. After deep research, it has been found that Qatar never developed nor implemented such system. Meanwhile, this research area has been investigated by different parts of the world to reduce energy consumption and make the world better. After reviewing the literature, it has been found that developing such system in Qatar will be very beneficial. This is because Qatar is developing really quick and its population has been increasing rapidly. Hence implementing a smart home energy management system will benefit the residents and the utility company in Qatar. The proposed Smart Home Energy Management System (SHEMS) will use five types of energy resources which are: solar PV, wind, battery, main grid, and gas. An algorithm will be developed in order to switch from one source to another at the right time and for the right electrical device/appliance based on real time information on energy prices. The algorithm will also update the homeowner about the system status every hour. The algorithm that will perform the required calculation for optimization of resources will be written using MATLAB. The code for the hardware prototype will be written using Arduino for proof of concept. This code will provide signals to control the hardware prototype by turning on one source and switching to another based on MATLAB data. Serial communication will be used in order to send the optimized solution from MATLAB to Arduino. The hardware of the SHEMS will consist of different components, the most important two are: the GSM Modem and the Arduino Mega 2560 microcontroller.

CHAPTER 3: METHODS AND MATERIALS

In order to develop a Smart Home Energy Management System, this project will be carried out in different stages. The first stage of the project is carrying out a literature review in order to understand the problem and the actual meaning of a Smart Home Energy Management System.

The second stage is to select a home in Qatar as a case study and to define the different electrical appliances/devices used in a typical house in Qatar. This is required to be able to collect data from "KAHRAMAA" based on our case study. It also allows us to calculate the number of solar panels and wind turbines for generating electricity. The third stage consists of data collection from KAHRAMAA; where the hourly energy consumption of each electrical appliance/ device mentioned in our case study is collected and the number of hours each electrical appliance/device used in a typical house as well as obtaining the average cost of AC current per hour.

The fourth consists of selecting the type, size and the number of solar panels and wind turbines for our case study. As well as, selecting the type of the battery bank; that will be used for power reliability in the house. The fifth stage consists of developing an algorithm that uses the data obtained from stages three and four. The algorithm provides information on the type of energy that must be used in a certain hour in order to reduce the total energy cost.

The sixth and last stage consists of developing the actual hardware for constructing a prototype of the Home Energy Management System. This hardware will use the algorithm mentioned above in order to optimize the energy consumption in a house. It will show us how sources of energy can be changed when a signal is received. The stages above are summarized in a process flow shown in figure (16).

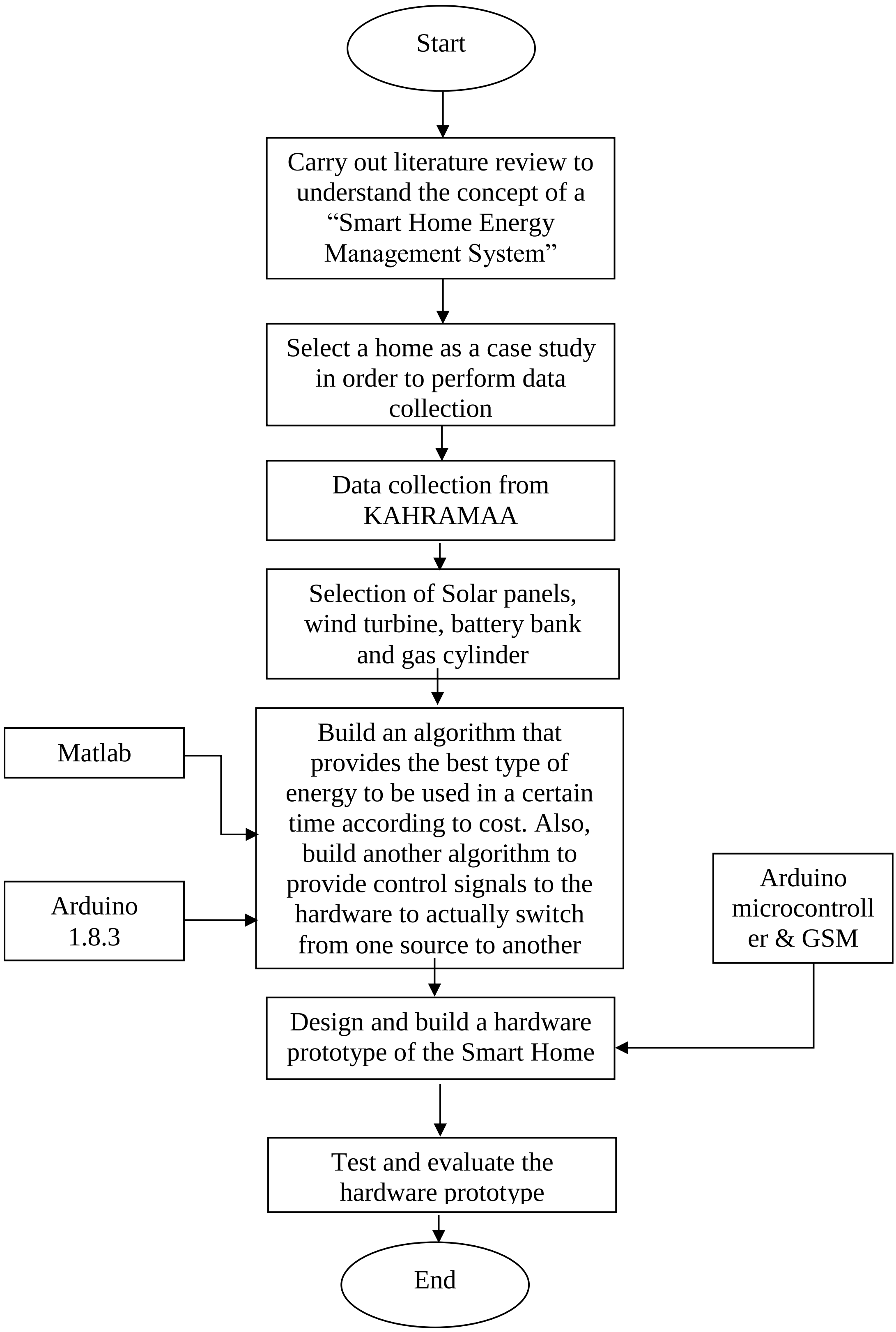


Figure 16. Project Flow Chart

3.1 Home Selected as a Case Study

In order to apply the concept of a Home Energy Management System; a home was selected to carry out the data collection and calculations for this project. Different residential types are available in Qatar, however a villa was selected since it is most preferable and common type for residents in Qatar. An assumption was made that 10 people live in this villa. The villa selected is shown in figure (17).

Figure 17. Example of a Villa in Qatar

The villa has the following dimensions: ground floor is 210 m^2 and first floor is 242 m^2. The roof of the villa is made up of concrete which can hold up to 150 kg of weight per m^2. A typical villa consists interiorly of a living room, kitchen, dining room, four bedrooms, 5 bathrooms and guests sitting room. In each part of the villa, certain electronic devices and appliances are used. These can be listed as shown in table (2).

Table 2

Typical Electrical Devices in a House

Room type	Electronic device/ Appliance	
Living Room	Air Conditioner, Television	
Kitchen	Air Conditioner, Fridge, Oven, Washing Machine, Clothes dryer, Microwave, Blender, Kettle, Dishwasher, Toaster	Vacuum Cleaner
Dining Room	Air Conditioner	
Bedroom	Air Conditioner, Hair dryer, Hair Iron, Clothes Iron	
Bathroom	Water Heater, Water cooling system	
Guests Sitting Room	Air Conditioner, Television	

3.2 Data Collection from Kahramaa

In order to achieve the objectives of this project, the collection of certain data from Qatar General Electricity and Water Corporation (KAHRAMAA) is required. The process of data collection was achieved by doing an actual visit to KAHRAMAA Head Office and a meeting was done with Eng. Yahya Chaker. The meeting resulted in the collection of important data.

3.3 Selection of Solar Panels, Wind Turbines, Battery Bank and Gas Cylinder

A Home Energy Management System must be supplied with renewable sources as mentioned before and it was decided that solar panels and wind turbines will be added to the houses. As well as, implementing a battery bank for reliability purposes.

Therefore, a design selection method will be followed at this stage to select the type of the solar panel, wind turbine and battery bank that will be implemented in the case study. The factor rating method was used for selecting the solar panels and the battery bank. Meanwhile, the consumer rating was used for selecting the wind turbines. Finally, for gas cylinders only certain type with certain size exists from Woqood.

3.3.1 Solar Panels

There are three common types usually used for solar panels; Monocrystalline, Polycrystalline and Thin-films made of amorphous silicon (a-Si). The design selection will be done through factor rating method where a weight is given to each criterion between 0 and 1 and a grade between 0 and 100 is given to see which alternative satisfy the criteria. Table (3) shows the criteria for each type (Maehlum, 2013).

On the other hand, table (4) shows the available solar system sizes with the annual KWh production and number of solar panels (Tarbi, 2017). The selection of the system size will be based on Qatar's needs.

Table 3

Types of solar panel and their criteria

Criteria/ Type	Monocrystalline	Polycrystalline	Amorphous
Typical module efficiency	15-20%	13-16%	6-8%
Area required for 1 kWp	6-9 m^2	8-9 m^2	13-20 m^2
Typical length of warranty	25 years	25 years	10-25 years
Lowest price	0.75 $/W	0.62 $/W	0.69 $/W
Temperature resistance	Performance drops 10-15% at high temperatures	Less temperature resistant than monocrystalline	Tolerates extreme heat

Table 4

Solar System Sizes

System Size	Average Annual KWH production	Estimate number of solar panels
3.5kW	4,954	14
5kW	7,161	20
7kW	9,909	28
10kW	14,165	40
12kW	16,987	48
15kW	21,234	60

After deciding on the solar panels type and system size, the solar power generation can be estimated using this equation: Solar power capacity = Stated wattage of the panel x Number of panels x Efficiency of the panel x Solar irradiance (KWh/m^2/day) x Temperature effect on solar panel production. (Eq. 1)

The average solar irradiance for one day in each month based on Qatar's weather is shown in figure (18) (Efficient Energy Saving, 2017). The efficiency is assumed to be 80% since monocrystalline solar panels will be used. Also, the temperature is expected to reduce the solar panels efficiency by 20% thus obtaining 80% of the total production. Based on these assumptions the power capacity available from the solar energy per day was calculated.

Jan	Feb	Mar	Apr	May	Jun
3.32	4.22	4.82	5.72	6.89	7.37
Jul	Aug	Sep	Oct	Nov	Dec
6.98	6.47	5.76	4.80	3.66	3.12

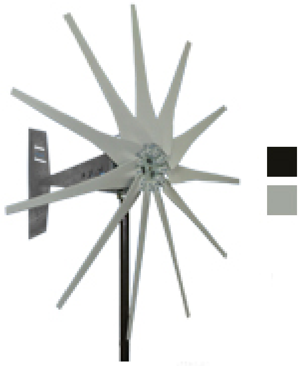
Figure 18. Solar Irradiance (KWh/m2/day)

3.3.2 Wind Turbines

A range of wind turbines exist for houses; selection will be done among the best ones. It will be done through customers' rating. The wind turbine with the highest rating will be selected. These are shown in table (5) (Tiny House Huge Ideas, 2017).

Table 5

Wind Turbines Types

Wind Turbine	Picture	Rating	Rotor Diameter (m)
WINDMILL 1500W kit		4.1	1.7
Missouri Raider 1600W		4.0	1.6
WINDMILL 600W Kit		3.6	1.3
Windmill DB-400		3.4	1.2

The number of wind turbines required will be selected by investigating Qatar's average wind speed and with considering the power of the selected wind turbine. Figure (19) shows the average wind speed (m/s) for each month in the state of Qatar (World Weather & Climate Information, 2016).

Meanwhile, figure (20) shows the power generated from the WINDMILL 1500W wind turbines based on the wind speed (Sun Force Products, 2017)

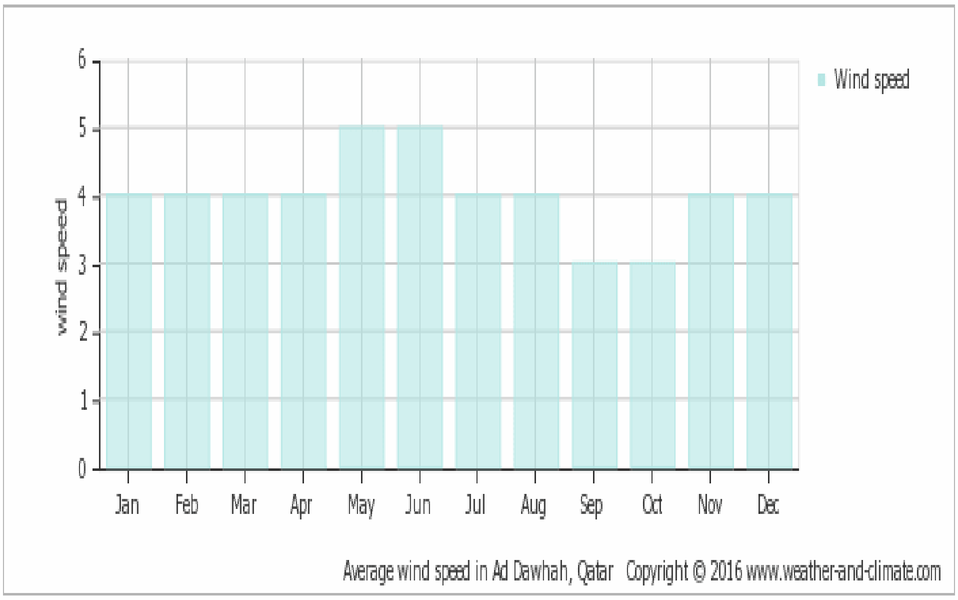


Figure 19. Average wind speed per month for Qatar State

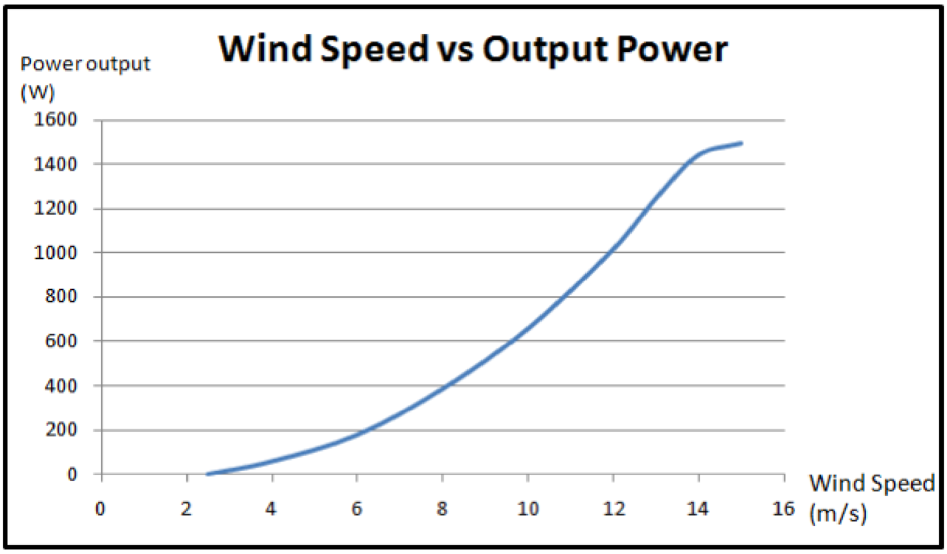


Figure 20. Power Output based on the Wind Speed

3.3.3 Battery Bank

The selection of an appropriate battery bank type requires investigating certain criteria; where usually three types of battery bank used. These are: Flooded lead-acid, AGM and Gel-cell (Kinnear, 2017). The characteristics of each battery are shown in table (6).

Table 6

Types of battery banks and their criteria

Criteria/Type	Flooded lead-acid	AGM	Gel-cell
Efficiency	charges and discharges at 35% amperage	highly efficient- charges and discharges at 100% amperage	charges and discharges at 35% amperage
Maintenance	Requires regular maintenance	Maintenance free	Maintenance free
Durability	Can leak and will corrode without maintenance	Spill-proof, vibration and impact-resistant	Durable – even if the battery cracks it will still function
Cost	Cheapest	More expensive than flooded lead-acid	More expensive than flooded lead-acid

The next step is to select the size of the battery bank. The size of the battery bank is found based on these steps (Leading Edge, 2016):

1. Determine the daily electrical energy consumption (KWh/day) from renewable resources.
2. Multiply the daily electrical energy consumption by the number of days the system should work without sun.
3. Select a maximum depth of discharge (DoD).
4. Determine the lowest temperature the battery will adhere to know the effective capacity.

5. Select a voltage for the battery bank.

An online calculator that uses these steps was used.

3.3.4 Gas Cylinder

According to Woqod one cylinder of gas has 12 kg, which is equivalent to 163 KWh (Woqod, 2017). For the gas power capacity, an assumption of using one cylinder per month can be done so it will be 163KWh per month.

3.3.5 Cost of Sources of Energy

The cost of the different sources will be used as an input for the algorithm. The costs will be in QAR/KWh for each source. They are obtained from previous researches done for Qatar. The costs are shown in the results section.

3.4 Developing an Algorithm for accomplishing a "Smart Home Energy Management system"

One of the main objectives of this project is to develop an algorithm that has the ability to control five different sources of energy. The algorithm will work on switching from one energy source to another at the right time to save money. After setting the structure of the algorithm (inputs, set of rules and outputs); the algorithm was written using MATLAB software and the output was a selection of the sources to be used. The proposed algorithm is shown in figure (21).

A summary of the Smart Home Energy Management System (SHEMS) algorithm is as follow: the algorithm will work based on users' inputs which are: AC, DC and gas loads, power supply conversion factors, prices of energy and instantaneous power capacity at each source. The algorithm will include a set of rules to modify the energy source prices based on both the current prices and the power supply conversion factors. For example, if the PV energy source is selected to supply the power to AC loads, the modified price of the PV power will be equal to the current price of PV power multiplied by 1/DC_AC. DC_AC is a factor that considers the DC to AC power supply conversion losses. The modified prices for the different energy sources are stored in a matrix called "Cost matrix" as shown in Table (7). The energy sources are then sorted by price in ascending order to prioritize the low price energy sources. The MATLAB sort function returns the original index of the cost matrix element which is used in determining the load type (AC, DC or gas) and the power source (PV, WT, Battery, Grid and Gas) from which the power should be drawn. Based on the look table and on the returned index, the algorithm assigns the load to its corresponding energy source.

A "for-loop" with a maximum number of iterations equal to the number of the sorted cost matrix columns (15 elements) is employed in this algorithm to repeat a code block that calculates how much power can be drawn from the cheapest energy source in order to reduce the overall power consumption cost. The code block also calculates the remaining source power and uncovered loads. In the second iteration, based on the previous values, the loop calculates how much power can be drawn from the second cheapest energy source in order to cover the remained loads, if any. The remaining source power and uncovered loads are then re-calculated. After all iterations are complete, all loads should be covered except if the summation of the available powers coming from all energy sources are less than the current loads.

Finally, as shown in Table (7), the algorithm outputs power amounts that should be drawn from each power source in order to have the power consumption cost minimized. The output values of the proposed algorithm can be scaled and then passed to power inverters to control the actual cost of power consumption in buildings. Moreover, the algorithm will work on giving commands to the Arduino microcontroller. It will give orders to open a certain energy source and to switch from one energy source to another at a certain point of time for cost savings. The code of the proposed algorithm written in Matlab is included in appendix 1.

Table 7

Cost Matrix

Cost matrix element number	Load type	Energy source	Cost matrix element number	Load type	Energy source
1	AC	PV	9	DC	Grid
2	AC	WT	10	DC	Gas
3	AC	Battery	11	Thermal	PV
4	AC	Grid	12	Thermal	WT
5	AC	Gas	13	Thermal	Battery
6	DC	PV	14	Thermal	Grid
7	DC	WT	15	Thermal	Gas
8	DC	Battery			

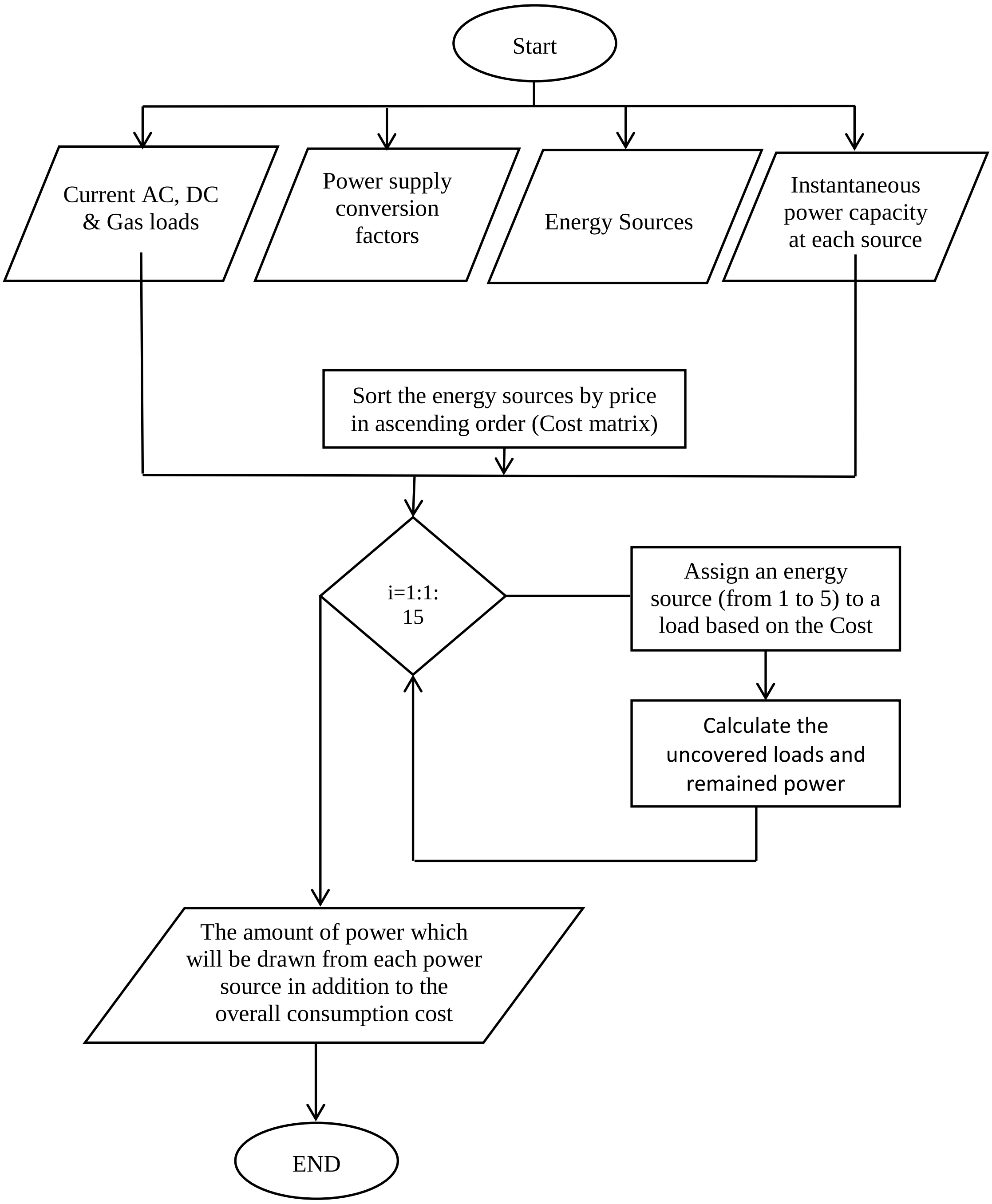


Figure 21. Proposed Algorithm

3.5 Developing an Algorithm for Running the Hardware Prototype of the "Smart Home Energy Management system"

In order to run the hardware prototype; two algorithms will be used. The first one is the Matlab discussed in section 3.5. The focus will be on the AC part only; since 90% of the home appliances in Qatar consume AC loadThis code is required to give the optimal sources to be used at a specific time in which these values will be sent to the Arduino microcontroller through serial communication. This requires adding a small code for the serial communication which allows Matlab and Arduino to communicate and the code is written in appendix 2.

The second one is written in Arduino 1.8.3 and will be uploaded to Arduino Mega 2560. The algorithm steps are described in details in a flow chart and this is shown in figure (22). The algorithm is written in appendix 3.

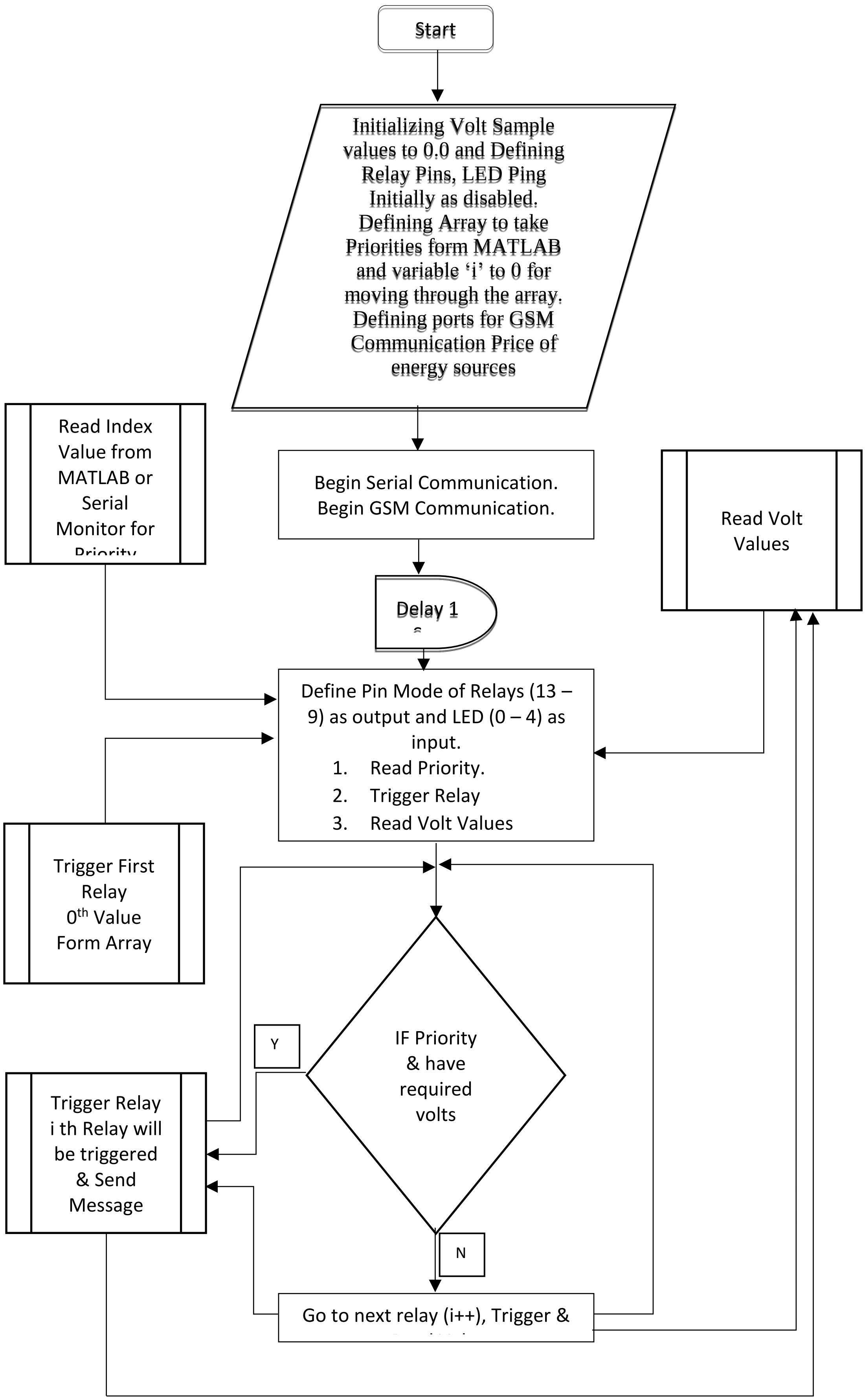


Figure 22. Arduino Code Flow Chart

3.6 Developing a Hardware Prototype for accomplishing a "Smart Home Energy Management System"

Another main objective of this project is to develop a hardware prototype for a SHEMS. After going through the literature review; the following components were chosen to develop the hardware and are shown in table (8). The hardware system was constructed as shown in figure (23).

Table 8

Hardware Components

Component	Description	Figure
Arduino Mega 2560	Arduino Mega 2560 acts as the controller of the system. It provides the other components instruction to switch from one source to another.	

USB Cable

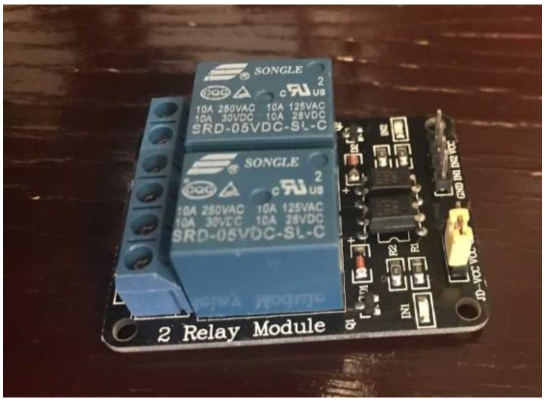
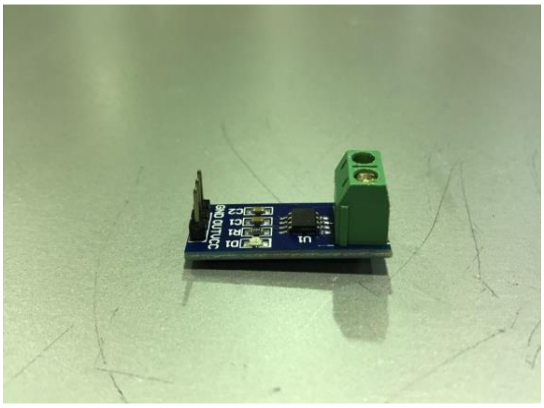
The USB cable is used to connect the Arduino Mega 2560 microcontroller to the computer.

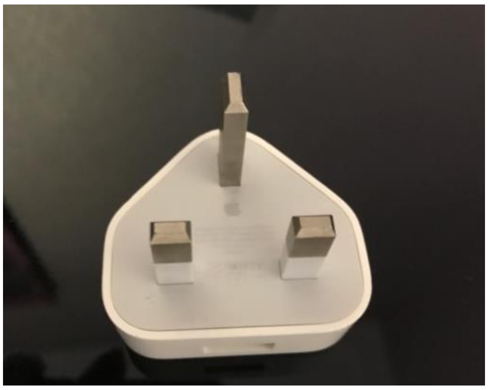
GSM Modem

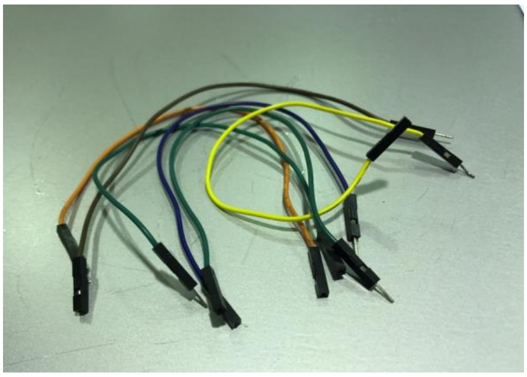
GSM Modem acts as the communication system. It provides the user with information and updates about the system through text messages.

SIM Card

The SIM card will be inserted in the GSM modem. It is required so the user can send and receive messages from the GSM modem.

Relays	Relays are required to open and close the different sources of energy when it receives a signal/current from the Arduino microcontroller. Five of this 2 relay module was used for the five different sources.	
Current sensor	The current sensor is required to measure the power capacity of each energy source.	
12 V and 6 V Batteries	The batteries will be used to represent the four different sources of energy: solar PV, wind, battery bank and grid. Batteries with different	

	voltages used to represent that not all sources have the same power capacity.	
Power Supply	The power is required for the relays since they require 5v to work.	
Junction	The junctions are required to make common ground and common positive since all power will go the same light bulb from all sources.	
Light bulbs	The light bulb will be used to represent the load. It will turn on whenever any of the energy sources is used. Two light bulbs are used as shown; each one will	

	consume 3W of power.	
Fan	The fan is used to represent the load as well. It will turn on whenever energy is supplied. It consumes 1.1W of power.	
Jumper wires	The wires are required to connect relays, current sensors and LEDs to the arduino.	
Electrical wires	The electrical wires are required to connect all components together: relays, current sensors, DC/AC converter and the light bulb.	

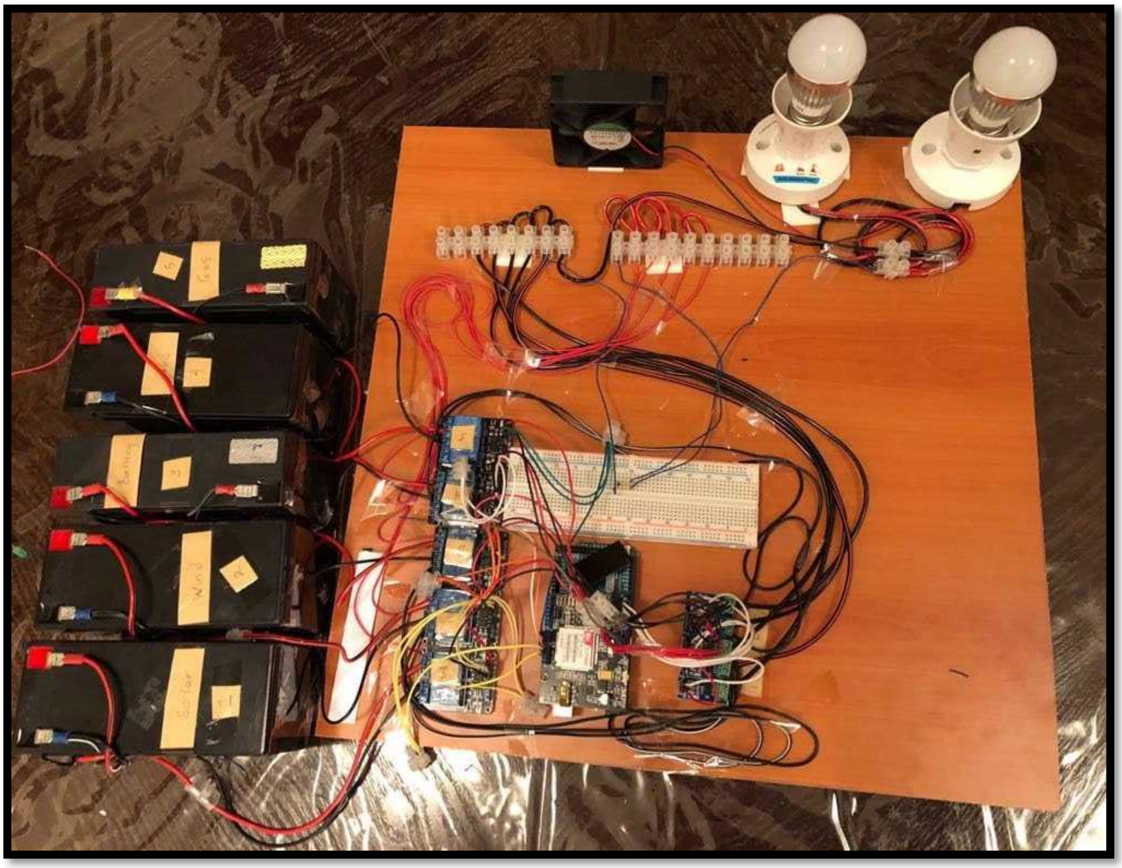


Figure 23. Hardware Prototype

3.6.1 Hardware Logic

The logic behind the hardware is as follow: Five batteries were chosen to represent the five sources of energy: solar, wind, battery bank, grid and gas. The solar, wind and grid are represented by 12V with 7 amps. Meanwhile, the battery and gas are represented by 6 V batteries with 12 amps. This was done to represent that different sources will have different power capacities. Each of the batteries are connected to two relays in which the positive side of the battery is connected to the com of the first relay and the negative side is connected to the normally open of the second relay. The normally open of the first relay is then connected to the positive of the loads (2 light bulbs and a fan) in which the three loads were combined together with two junctions one for the positive and one for the ground. The com of the second relay is then connected to the current sensor. Two relays were used for each battery to avoid a reverse movement of the current back to the batteries since one ground is done for all the loads. The relays are used to trigger a certain source (battery) to open at a certain time and supply current. Now, the other side of the current sensor is connected to the common ground of the loads. The current sensors are used to measure how much current was drawn from each source; the current sensors do not have polarity.

Both the current sensors and the relays were connected to the Arduino microcontroller in which it will read the data from the current sensors. Based on these values of the currents sensors and the index variable from the MATLAB (index is a variable that contains the arrangement of the sources that should be used at a certain time to save cost); signals will be sent from the Arduino microcontroller to the relays to trigger the cheapest source at a certain time. A GSM modem was placed on the Arduino microcontroller; where it will send the user a text message every time a different source is used. In this hardware prototype, all sources and loads are represented as DC. However, in real life only the solar and battery bank are DC and 90% of the loads in the houses will be AC. Thus these two sources should be connected to DC/AC converter in real life.

The main idea of the system will be when MATLAB sends the index values, the Arduino Microcontroller will use the current sensors to check the power capacity of the sources. If enough power exists in the cheapest source the Arduino microcontroller will send a signal to the relay of that battery to trigger it. Otherwise, it will move to the second cheapest source and so forth. When then relay triggers a battery the light bulbs will go on and the fan as well. Moreover, a text message will be sent to the user mentioning which source is currently being used.

3.6.2 Functionality Testing of the Components

Testing #1: Before connecting the hardware, the current sensors were tested by connecting it to the Arduino microcontroller, a battery and a variable load resistor. The main aim here is to see if the current drawn from the battery changes based on changing the load. Therefore, an Arduino code was used with varying the load where it showed that the sensor is working properly. The Arduino code used is shown in Appendix 4.

Testing #2: Another testing was done for the relay. The test started by uploading a code to the Arduino to trigger the relay. The code is shown in Appendix 5. Afterwards, the relay was connected to the Arduino and a 5v power supply. The relay was triggering on and off continuously. Then, the code was edited to include only the high signal where no action was shown from the relay. Last step, the code was updated to include only the low signal and the relay got triggered here. It was found that the relay is triggered at the low signal.

3.6.3 Hardware Performance Criteria

According to ISO 50001 (a standard that helps you manage energy policy and usage) an energy management system should have the following criteria: (Indian Register Quality Systems, 2017)

- Reduce energy costs.
- Improve overall performance to reduce energy consumption and bills.
- Reduce carbon emissions.

Based on our developed energy management system; the following criteria are implemented in the system. The system works on optimizing energy based on cost which is basically satisfying the first and second criteria. Moreover, the system works on implementing renewable sources of energy which are solar energy and wind energy. Thus, satisfying the third criterion, which is reducing carbon emissions.

3.8 Testing and Evaluating the Hardware Prototype

The hardware was tested and evaluated in six iterations; these iterations are as follow:

Iteration one: it consisted of the three loads, battery [1], relay [1] and current sensor [1] connected to the Arduino microcontroller. A code was written only for this part, which consisted of triggering the relay to test if the current will flow and the loads will turn on. As well as reading the current sensor values. It was found that calibration shall be done for the sensors to be able to get the correct values.

Iteration two: it consisted of the three loads, battery [2], relay [2] and current sensor [2] connected to the Arduino microcontroller. Similar code used in iteration one will be used here to test if the second set of components is working properly.

Iteration three: it consisted of the three loads, battery [3], relay [3] and current sensor [3] connected to the Arduino microcontroller. Similar code used in iteration one and two will be used here to test if the third set of components is working properly.

Iteration four: it consisted of the three loads, battery [4], relay [4] and current sensor [4] connected to the Arduino microcontroller. Similar code used in iteration one, two and three will be used here to test if the fourth set of components is working properly.

Iteration five: it consisted of the three loads, battery [5], relay [5] and current sensor [5] connected to the Arduino microcontroller. Similar code used in the previous iterations will be used here to test if the fifth set of components is working properly.

Iteration six: it consisted of combining all components together to test the whole system; the full code was used here to see if the system will function as intended. The main issue faced in this iteration was when to switch from one source to another because of the current sensors values. After many trials in the code and doing multi-calibration for the current sensors the system worked properly and it will only switch from the first cheapest source to the second when the power capacity of the source is reduced and sensed by the current sensors.

CHAPTER 4: RESULTS & DISCUSSION

This section will describe the results obtained based on the methodology described in chapter 3. A main focus of this section will be on implementing the data estimated in the algorithm in Matlab and analyzing these results to show how different sources will reduce cost. Different figures and table will be used to describe the data obtained and to clarify the importance of implementing this system in Qatar. The algorithm will run for 365 days of a full year.

4.1 Household Power Consumption

- Power consumption for each electrical appliance/device. This will be used in calculating the electrical consumption that occurs in an hour or a day. Table (9) shows this data.

Table 9

Power consumption of devices (Watt)

Electrical Appliance	Power Consumption (Watt)
Air Conditioner	2500
Television	200
Vacuum Cleaner	1400
Fridge	800
Oven	3000
Washing Machine	2200
Clothes Dryer	3000
Microwave	1200
Blender	600
Kettle	1800
Dishwasher	2400
Toaster	1400
Hair Dryer	1500
Hair Iron	300
Clothes Iron	2200
Water Heater	4500
Water Cooling system	5000

- An example of electricity consumption at different timings of the day in June. This is shown in figure (24). Days in June are determined to have the highest electricity consumption in the year. The hourly consumption is based on the power consumption of the electrical devices. This graph mainly shows that the consumption will vary from one hour to another and usually there is no pattern.

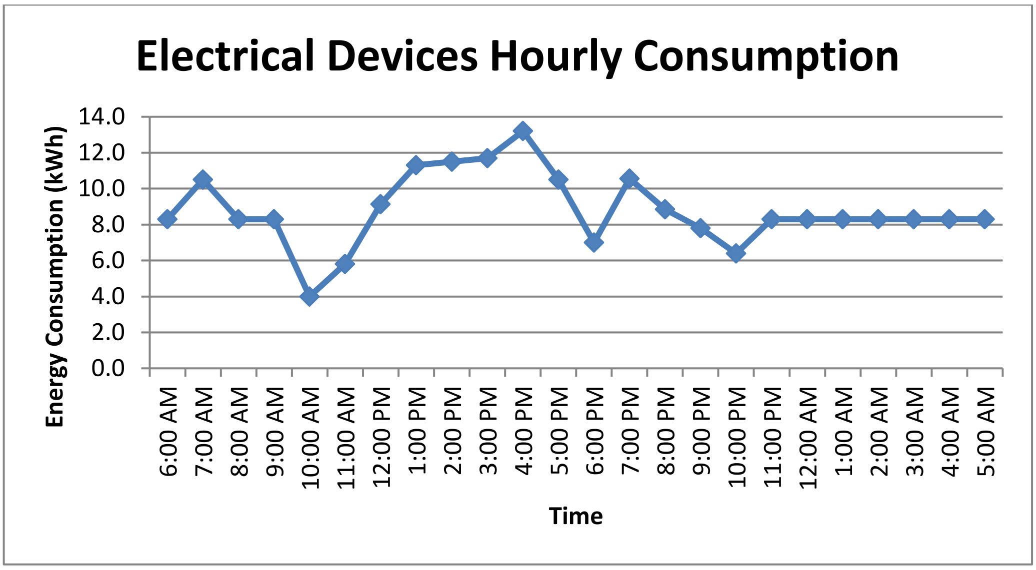


Figure 24. Electrical Devices Hourly Consumption in One Day

- Maximum Household Electricity Consumption. The data is represented in table (10).

Table 10

Average Household Electricity Consumption

Household Electricity Consumption	Unit
211	KWh/ day
6,330	KWh/ month
75,960	KWH/ year

- The tarrif of AC current (KWH) in Qatar. This is shown in table (11).

Table 11

Electricity Tariff in QAR

	Electricity	
From (KWH)	To (KWH)	Tariff in QAT
1	2000	0.08
2001	4000	0.09
4001	6000	0.1
6001	8000	0.12
8001	15000	0.18
15001	Maximum	0.22

The grid power capacity that is from Kahramaa is known to have no limitations on the electricity supplied to the households.

4.2 Results of the Selection of Solar Panels, Wind Turbines and Battery Bank

4.2.1 Solar Panels

The factor rating method steps are shown in table (12). The table clarifies the weights and the grades given for the criteria and the alternatives. The weights are given based on judgment considering the most important criteria for the state of Qatar. While, the grades are given based on the data of each criteria.

Table 12. Factor Rating Method for Solar Selection

Criteria/ Type	Weight 0 to 1.00	Grades for Alternative (0 to 100)		
		Monocrystalline	Polycrystalline	Amorphous
Typical module efficiency	0.30	80	60	50
Area required for 1 kWp	0.15	80	75	50
Typical length of warranty	0.10	90	90	75
Lowest price	0.20	60	80	70
Temperature resistance	0.25	80	70	90

After completing the weights and grades, the following calculation is done to accomplish an overall score for each type:

- **Monocrystalline** = 0.3(80) + 0.15(80) + 0.10(90) + 0.2(60) + 0.25(80) = 77
- **Polycrystalline =** 0.3(60) + 0.15(75) + 0.10(90) + 0.2(80) + 0.25(70) = 71.75

- **Amorphous** = 0.3(50) + 0.15(50) + 0.10(75) + 0.2(70) + 0.25(90) = 66.50

From the results obtained, it is clear that monocrystalline solar panels are the best thus this type will be selected and more specifically the Trina 240 watt monocrystalline solar panel.

Qatar has set a target to supply 20% of energy through renewable energy sources, by 2030 (International Renewable Energy Agency, 2016). In this project, this percentage was divided between solar and wind as 15 % and 5% respectively since relatively less power is expected from the wind resource in Qatar . This distribution was selected according to Qatar's yearly weather since solar has higher availability than wind. Calculating 15% of energy based on the maximum annual consumption per household which is 75,960 KWH; the maximum amount required from is 11,394 KWH per house. Based on this, the 10 KW system should be selected with 40 panels. The size of one solar panel is 1.64 m^2; accordingly the total space required will be 65.6 m^2. On the other hand, the weight of one solar panel is 10 kg per m^2.According to the villas specification; the 10 KW system can be handled by the house roof.

4.2.2 Wind Turbines

Based on the rating of the wind turbines, WINDMILL 1500W is considered the best with a rating of 4.1 and will be selected for this project. After deciding the type; the next step is to select the number of wind turbines required. Table (13) was generated based on the wind speed (m/s) and the power of the selected wind turbine; and it contains the number of hours of wind availability per month. An assumption is made that wind will be available all month. The final column shows the amount of wind energy generated in KWh/month as well as the annual wind energy.

Table 13

Wind Energy Production

Month	Wind speed (m/s)	Wind Power (w)	Wind (hrs/month)	Wind energy (KWh/month)
January	4	90	720	64.8
February	4	90	720	64.8
March	4	90	720	64.8
April	4	90	720	64.8
May	5	130	720	93.6
June	5	130	720	93.6
July	4	90	720	64.8
August	4	90	720	64.8
September	3	40	720	28.8
October	3	40	720	28.8
November	4	90	720	64.8
December	4	90	720	64.8
Annual wind energy (Kwh/year)				763.2

Now in order to find the number of wind turbines required; the selected distribution of solar and wind discussed previously takes place which is only 5% of the total annual household energy should be covered by wind energy; which is equivalent to 3,798 KWh. According to this value, 5 wind turbines are required. The area required for one wind turbine is 2 m^2 and the weight of one wind turbine is 15 kg. Equivalently, a wind turbine weighs 7.5 kg per m^2 and the total space required for five wind turbines is 10 m^2. Accordingly, the five wind turbines can be handled by the rooftop in addition to the solar panels.

4.2.3 Battery Bank

Table (14) was generated based on the criteria and the alternatives of the batteries using factor rating method.

Table 14

Factor Rating Method for Battery Selection

Criteria/ Type	Weight 0 to 1.00	Grades for Alternative (0 to 100)		
		Flooded lead-acid	AGM	Gel-cell
Efficiency	0.35	50	100	50
Maintenance	0.20	60	100	100
Durability	0.20	70	70	100
Cost	0.25	90	70	70

The weights and grades are completed now; the following calculation is done to accomplish an overall score for each type:

- **Flooded lead-acid** = 0.35(50) + 0.20(60) + 0.20(70) + 0.25(90) = 66
- **AGM =** 0.35(100) + 0.20(100) + 0.20(70) + 0.25(70) = 86.5
- **Gel-cell =** 0.35(50) + 0.20(100) + 0.20(100) + 0.25(70) = 75

According to the above results, AGM will be selected. The next step is to select the size of the battery bank. The size of the battery bank is found based on the following data:

1. The daily electrical energy consumption (KWh/day) from renewable resources which is 42.2 KWh/day.
2. The number of days the system should work without sun. Since most of days in Qatar are sunny thus 2 days can be selected.
3. The maximum depth of discharge (DoD). 50% is selected as an average.
4. The lowest temperature the battery will adhere in Qatar, which is set to be 10 °C on average.
5. A 12V with 400 Ah will be selected according to the market.

The result of the online calculator shows that the battery bank should have a capacity of 231 KWh and 4,813 amp hours. In order to find the number of batteries the total amperes is divided by the amperes of the selected battery; giving us a total of 12 batteries required.

The costs of the different sources were based on published researches for Qatar state. Table (15) shows these costs with certain assumptions.

Table 15

Cost of each Source in QAR/KWh

Resource	Source	Assumption	Cost
Solar	A research by Al-Fakhri, Mohandes & Sanfilippo (2016) done in Qatar studied Solar PV and showed that a rooftop solar PV costs 0.4263 QAR/KWh.	The government gives an incentive of paying 30% for every KWh.	0.2984 QAR/KWh
Wind	Al-Kuwari & Rao (2013) calculated wind energy cost to be 0.1784 QAR/KWh	___	0.1784 QAR/KWh
Battery	The 12 V batteries with 400 Ah are sold approximately for 45	The battery is recharged from the renewable resources	0.3027 QAR/KWh

	QAR in many commercial websites. The cost of recharging the battery is 0.2384 QAR/KWh. The battery is assumed to have a lifecycle of 7 years.	having their average cost. To calculate the battery cost its equivalent to the average cost + (45/(365*7))	
Grid	According to Al-Fakhri, Mohandes & Sanfilippo (2016) the cost of the electricity coming from the grid without subsidy is much higher than the tariff Kahramaa is charging. This is equivalent to 0.3139 QAR/KWh.	The government does not provide any subsidy to the electricity coming from the grid.	0.3139 QAR/KWh
Gas	WOQOOD mentions that the cost of a 12 kg gas cylinder is 150 QR. Meanwhile, refilling the cylinder is 15 QR. In which 12 Kg is equivalent to 163 KWh. The gas cylinder is having a life cycle of 5 years.	The gas cylinder will be refilled once every month. The cost can be calculated as (15QAR/163 KWh) + (350/ (365 days * 5 years))	0.3047 QAR/KWh

4.3 Main Results and Findings

The data discussed above will be used as input for the algorithm that was described in the section 3.5. The output will be the arrangement of which source to use; and how much kWh/day will be used from each source to satisfy the daily consumption with the optimized cost based on the selection. The actual cost of main grid was used for comparison. It will also calculate the savings that will occur in each day. An assumption was made here the total daily consumption required is AC since 90% of the home appliances and electrical devices use AC current. Since solar, and battery do not supply ac directly; the conversion factors were included the algorithm to adjust the losses that occur when they are converted to AC current.

According to the costs and the amount of power available from each source; the following arrangement was obtained after running the algorithm: wind, solar, battery, gas and lastly grid. The rest of the results are written in appendix 7.

A column chart is used to show how the consumption of the five sources varies at each day for every month in the year. A line chart was used to represent the actual and optimized costs on the same graph and to show if a trend exists.

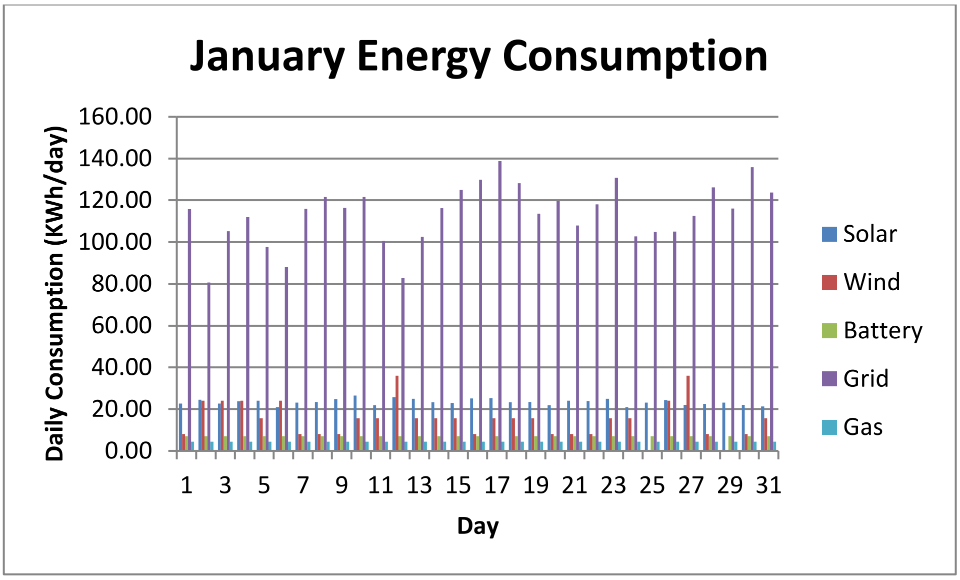


Figure 25. January Energy Consumption using Five Sources

Figure 25 shows the January energy consumption using Five Sources. The consumption of sources varies over the days according to the sources availability. In January, solar is produced and consumed the least at day 6 and the highest in day 10. On the other hand, from the graph wind energy is zero at days 25 and 29 which shows that some days may not have wind thus eliminating wind energy. In addition, wind energy is highly available and consumed on day 27 showing high wind speed was at that day. For the grid, it is consumed the most on 17th of January. Furthermore, it is clear that the usage of the battery and the gas does not vary over the month. This is because the gas is dedicated cooking, while the battery is used to store energy that may be used to supplement energy from other sources when the instantaneous demand is high. Additionally, it can be noticed that solar energy production does not vary much as wind energy does.

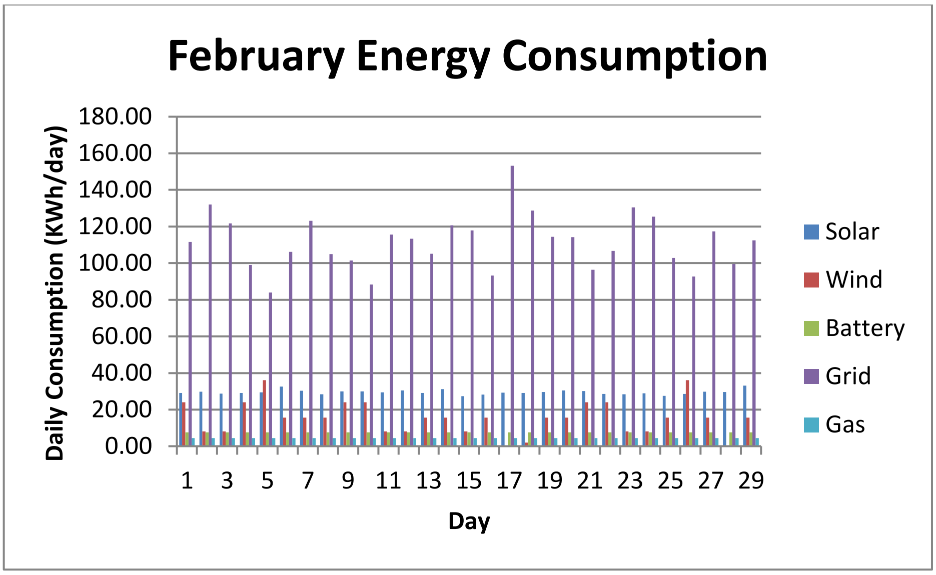


Figure 26. February Energy Consumption using Five Sources

Figure 26 shows the energy consumption in February, solar is produced and consumed the most at day 6 and the least at day 15. However, wind energy is produced and consumed the most at day 5 but oppositely on days 17 and 18 wind energy is eliminated. The grid is highly consumed on day 17 while battery and gas do not vary.

In March, solar is produced and consumed the least at day 7 and the most at day 24. While, wind energy is eliminated on several days 7, 11, 12 and 23 but it is highly consumed on day 14. On day 2; a high consumption of the grid is occurring. Battery and gas do not vary as mentioned before. This is shown in figure (27).

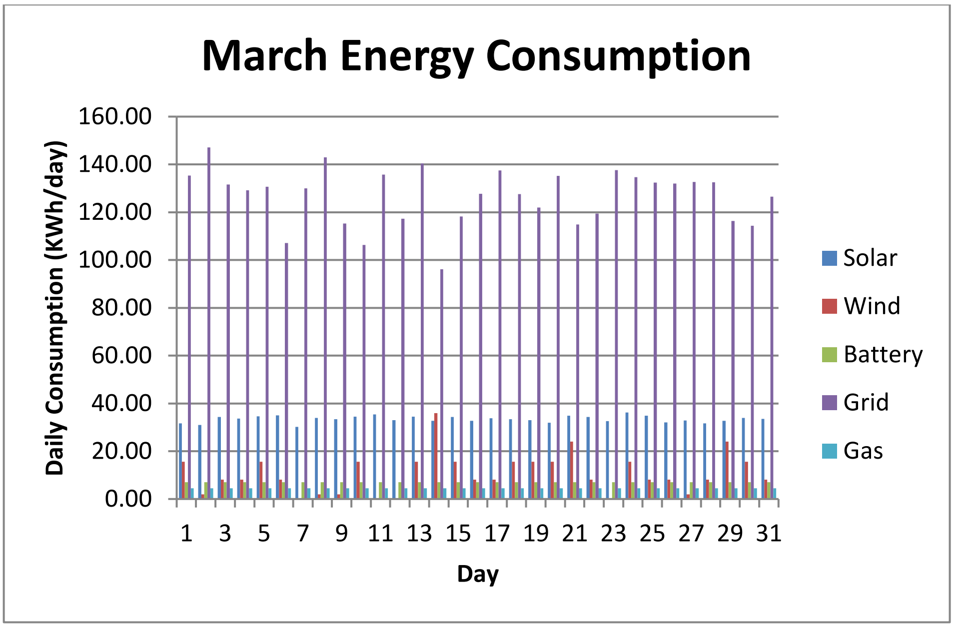


Figure 27. March Energy Consumption using Five Sources

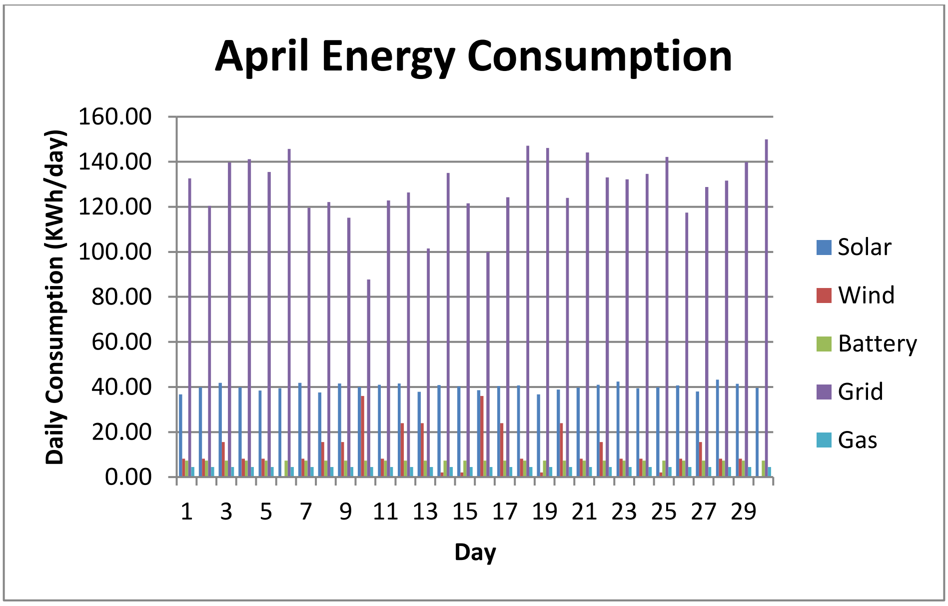


Figure 28. April Energy Consumption using Five Sources

Figure (28) shows the energy consumption in April, solar has minimum production and consumption at day 1 of the month. Meanwhile, the maximum is occurring at day 28. Wind energy is produced highly on days 10 and 16 and does not exist on days 6 and 30. The grid is consumed the highest at the last day of the month. Again, battery and gas do not vary. In May, solar is produced the least on day 19 and the highest on day 23. On the other hand, wind energy is highly produced in this month and exists every day; days 1, 5, 9, 11, 14, 15, 21, 23, 27, and 28 are considered the highest. The grid is used the most on day 18. Meanwhile, battery and gas do not vary. This is shown in figure (29).

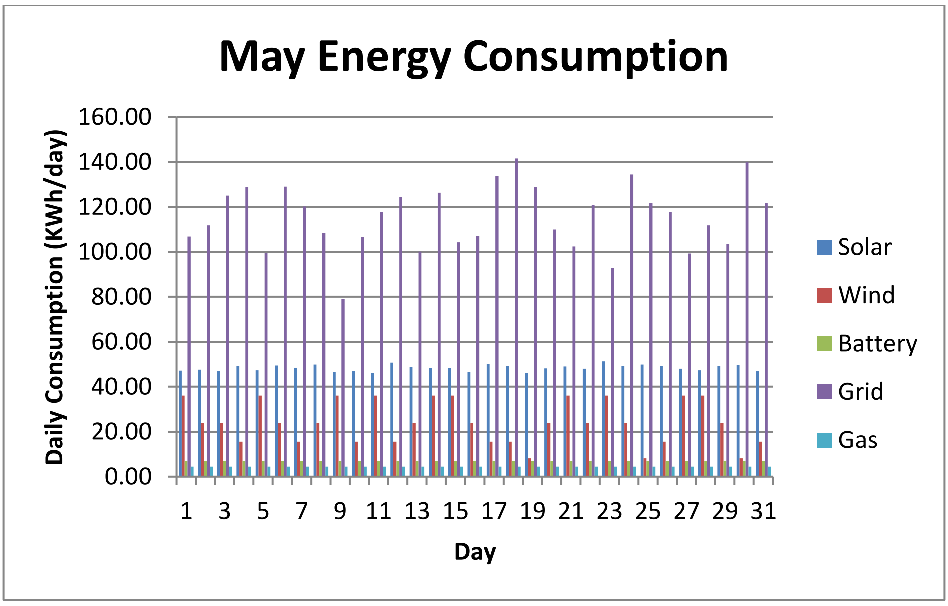


Figure 29. May Energy Consumption using Five Sources

Figure (30) shows the energy consumption in June, days 21 and 24 are considered the lowest and the highest in terms of solar production and consumption. Meanwhile, days 4, 17, 19, 22, 28 and 29 are the lowest in terms of wind energy production and consumption oppositely days 1, 5, 6, 14, 16, 18, 23 and 27 are the highest in terms of wind energy production and consumption. The grid is consumed mostly on day 4. The consumption battery and gas do not change.

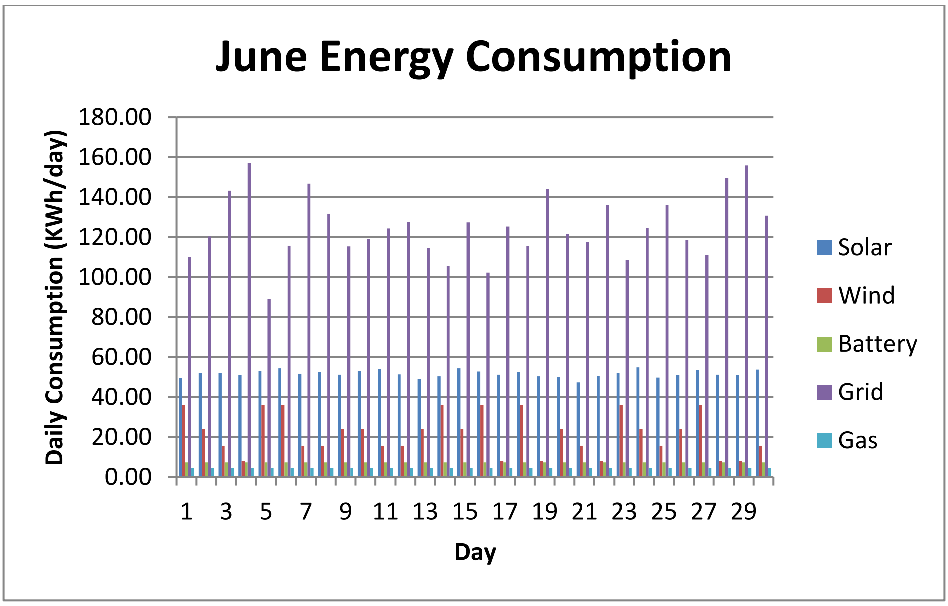


Figure 30. June Energy Consumption using Five Sources

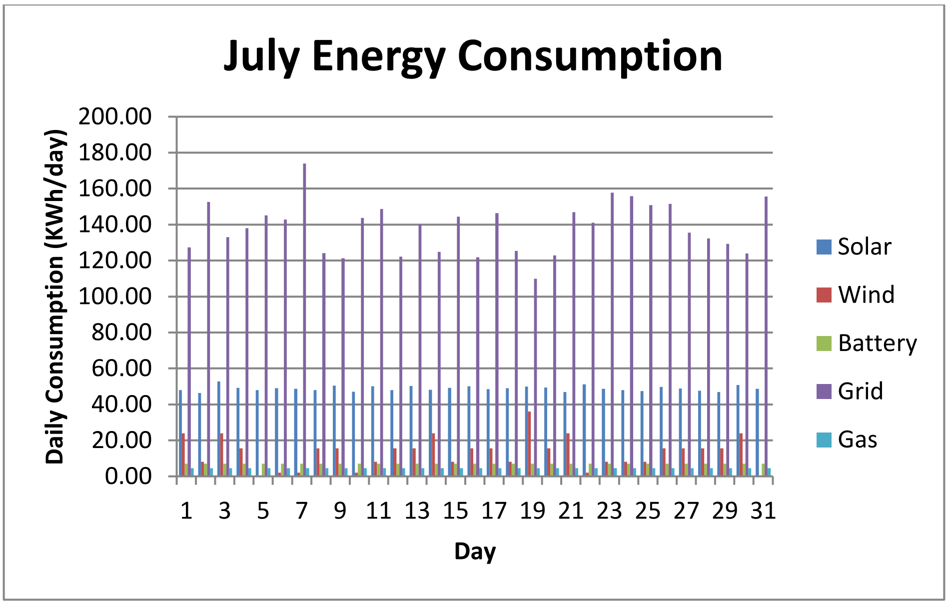


Figure 31. July Energy Consumption using Five Sources

Figure (31) shows the energy consumption in July, days 2 and 3 are significant for solar forming the lowest and highest production and consumption. Wind energy is at peak on day 19 and eliminated on day 31. Day 7 is significant for the grid where high consumption occurred. Finally battery and gas do not vary.

In August, solar energy is produced and consumed the least on day 4 and the highest on day 7. In addition, wind energy is eliminated on day 22 and produced highly on days 8, 9 and 18. High consumption of the grid is occurring at day 27. Consumption of battery and gas is constant throughout the month. This is shown in figure (32).

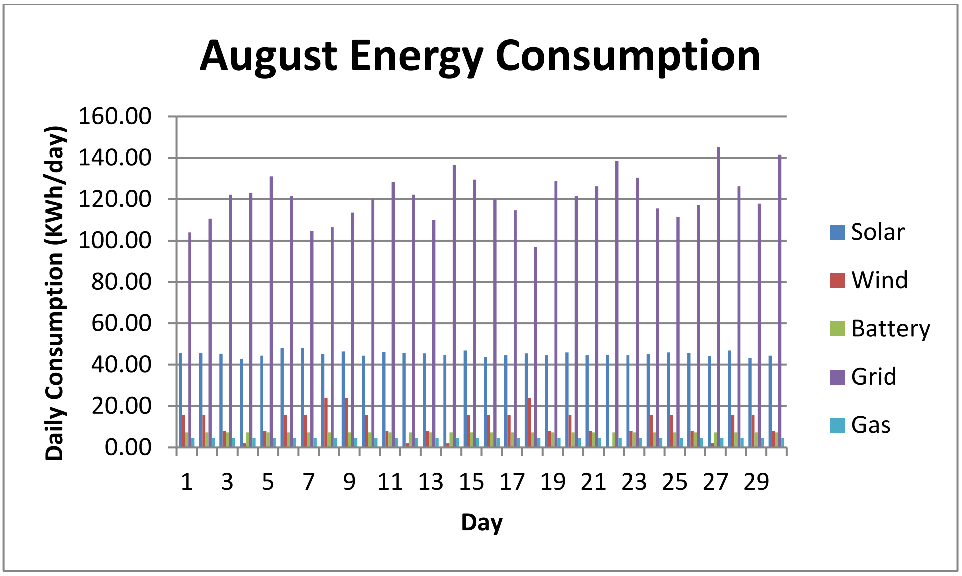


Figure 32. August Energy Consumption using Five Sources

In September, solar energy is consumed the least on the 8th of the month and the highest on the 29th of the month. Wind energy production through this month is very minimal and eliminated on 2nd, 3rd, 4th, 8th, 13th, 15th, 16th, 22nd, 23rd, 25th, 27th and 29th. The highest occurred on the 12th, 20th, and 28th of the month. The grid is consumed the highest on the 4th meanwhile the consumption of both the battery and gas do not vary. This is shown in figure (33).

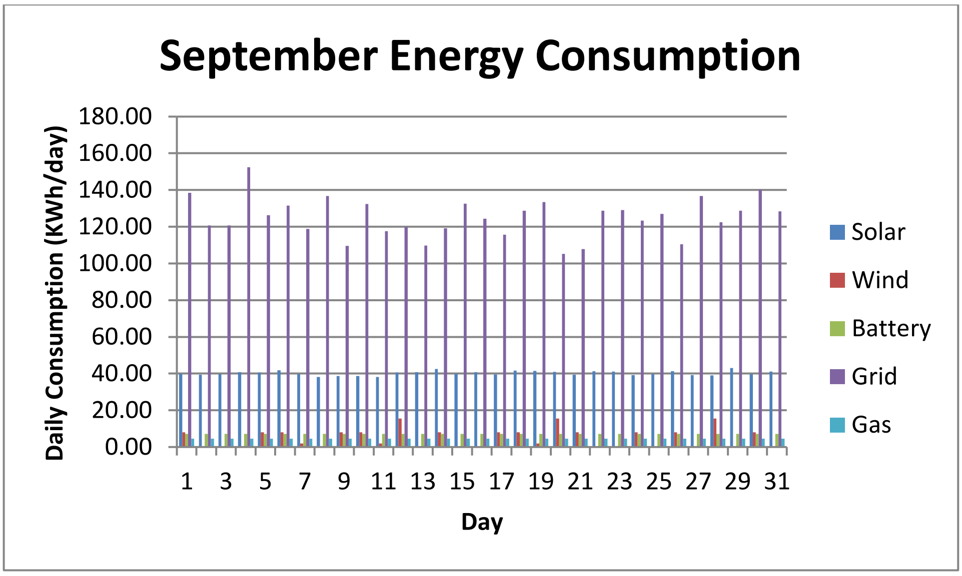


Figure 33. September Energy Consumption using Five Sources

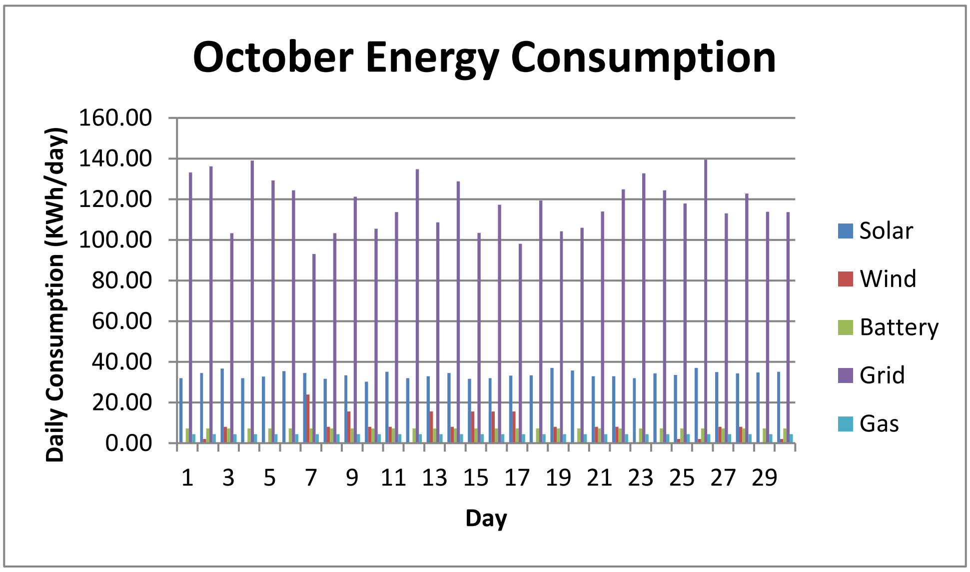


Figure 34. October Energy Consumption using Five Sources

Figure (34) shows the energy consumption in October, solar energy has the highest consumption on day 10 and the lowest consumption on 26. While, wind energy is eliminated on 1st, 4th, 5th, 6th, 12th, 18th, 20th, 23rd, 24th and 29th and produced highly on the 7th. The grid is highly consumed on the 26th. The other two sources: battery and gas are consumed constantly.

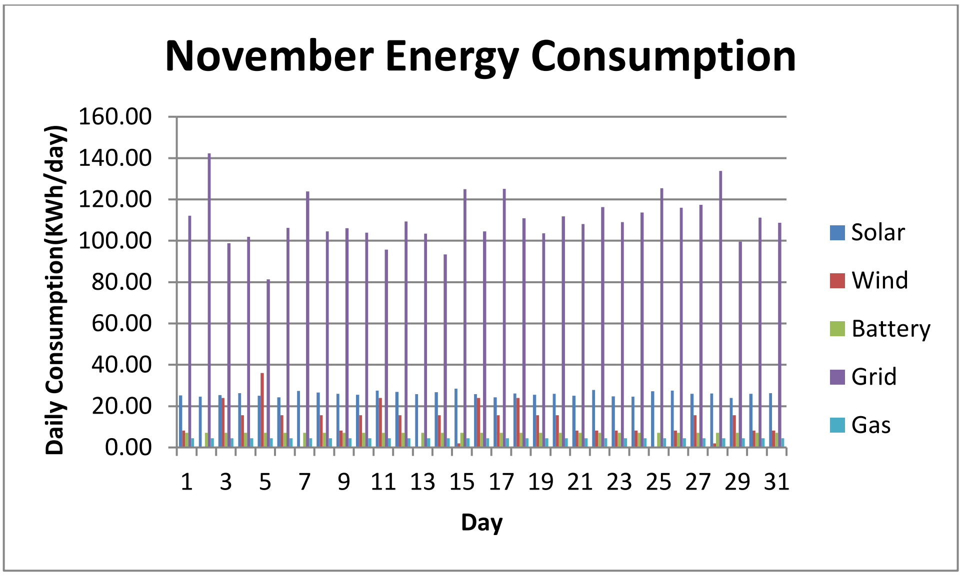


Figure 35. November Energy Consumption using Five Sources

Figure (35) shows the energy consumption in November, solar energy is consumed and produced the highest on day 15 and the least on day 29. On the other hand, wind energy is highly available on day 5 and does not exist on days 2, 7, 13 and 25. On day 2, the grid is highly consumed. Battery and gas usage are stable throughout the month. This is shown in figure (35).

In December, solar is consumed the least on day 14 and highest on day 10, wind is eliminated on days 3, 12 and 28 and highest on day 25. Grid is consumed the highest on day 3. Meanwhile, battery and gas consumption is still stable. This is shown in figure (26).

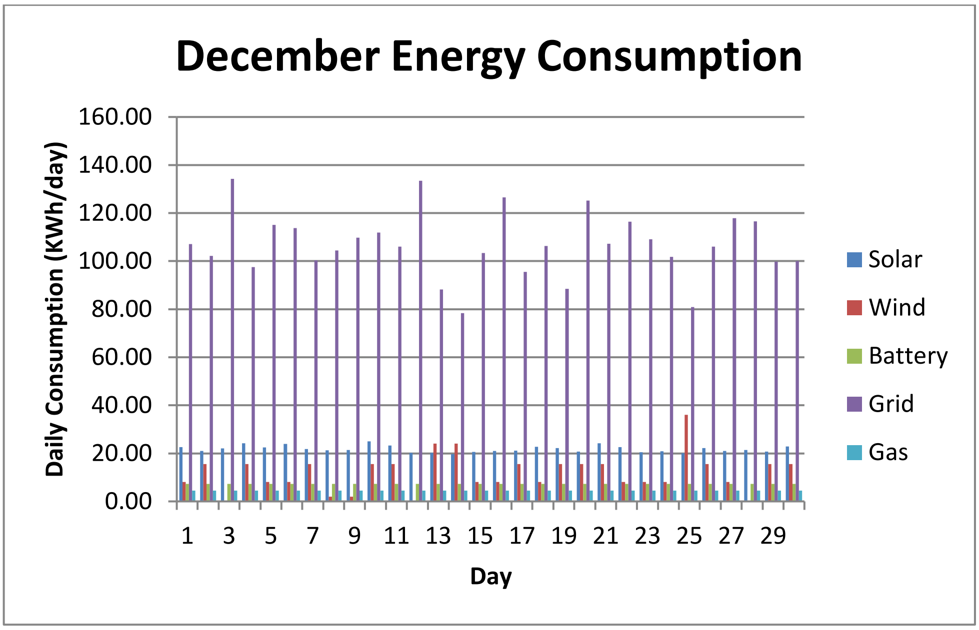


Figure 36. December Energy Consumption using Five Sources

Previously the energy consumption of the five different sources at different days for all months was discussed; in this part the actual and the optimized costs for the different days of every month will be discussed.

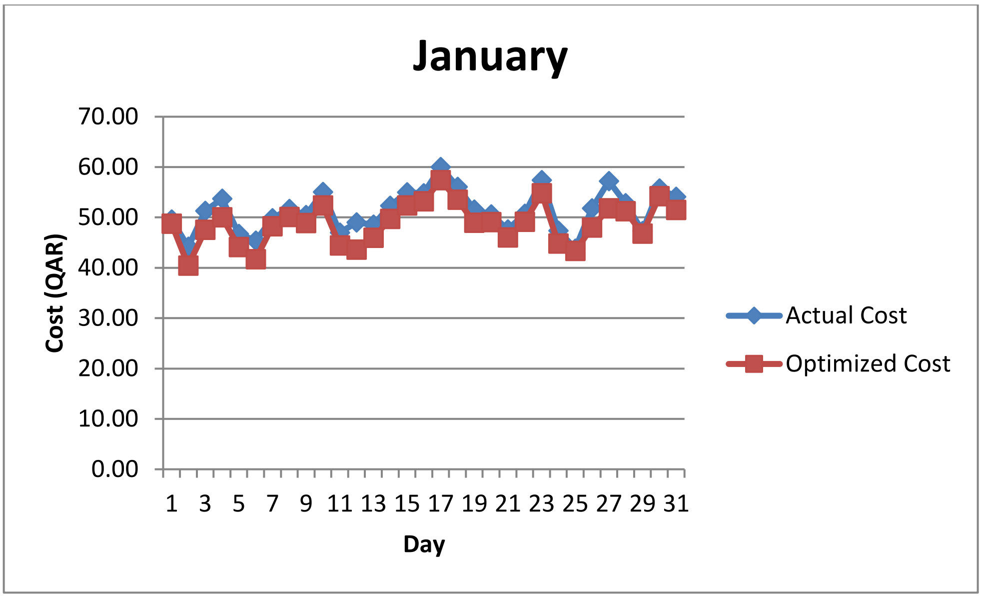


Figure 37. January Actual and Optimized Costs

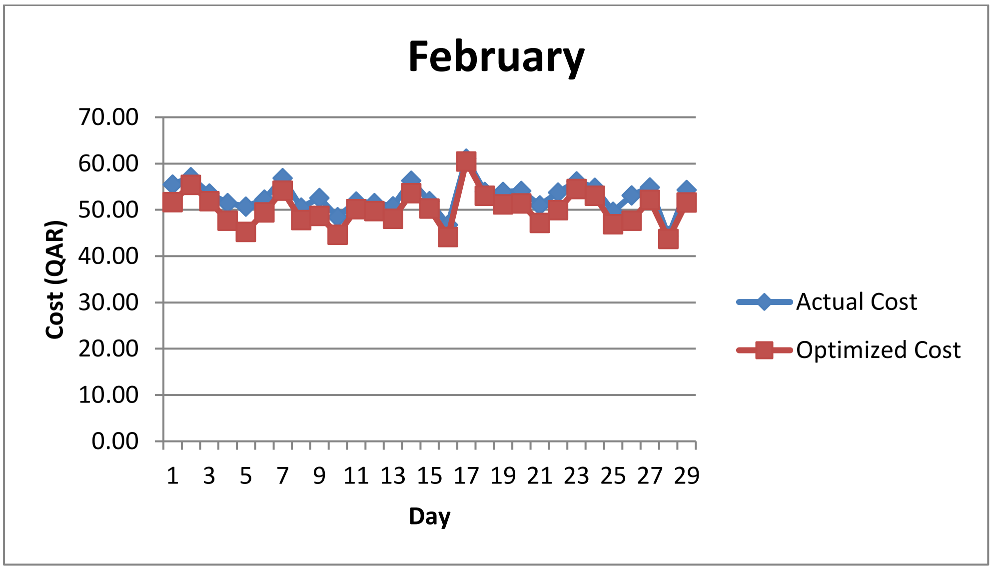


Figure 38. February Actual and Optimized Cost

Figure (40) shows actual and optimized costs in January, the costs are represented by dots and it is clear that the costs vary up and down from one day to another and there is no obvious trend. This is due to the different capacities of the sources each day and the difference in their cost per KWh. It is clear from the graph that the actual cost is the highest at day 17 so is the optimized cost.

It can be called the peak time of the month. Relating this to the January energy consumption; in day 17 grid usage was the highest and since grid is the most expensive it led to high actual cost. Meanwhile, the lowest actual cost is occurring at day 25 and the lowest actual optimized is at day 2. From the graph, the savings are represented by the gap between the two curves and it can be seen that at day 12 the highest gap occur which means the highest saving.

In February, the highest actual and optimized costs are occurring at day 17 meanwhile the lowest actual and optimized costs are occurring at day 28. Again, this is related to the grid consumption where it's the highest on day 17 and the lowest on day 28. The maximum is occurring on day 5 because about 78% of the energy on that day is used from renewable resources. This is shown in figure (38).

In March, costs reach to the peak on day 13 and reach the minimum on day 6. Meanwhile, the maximum savings are occurring on day 14 because solar energy and wind energy were highly available on this day. This is shown in figure (39).

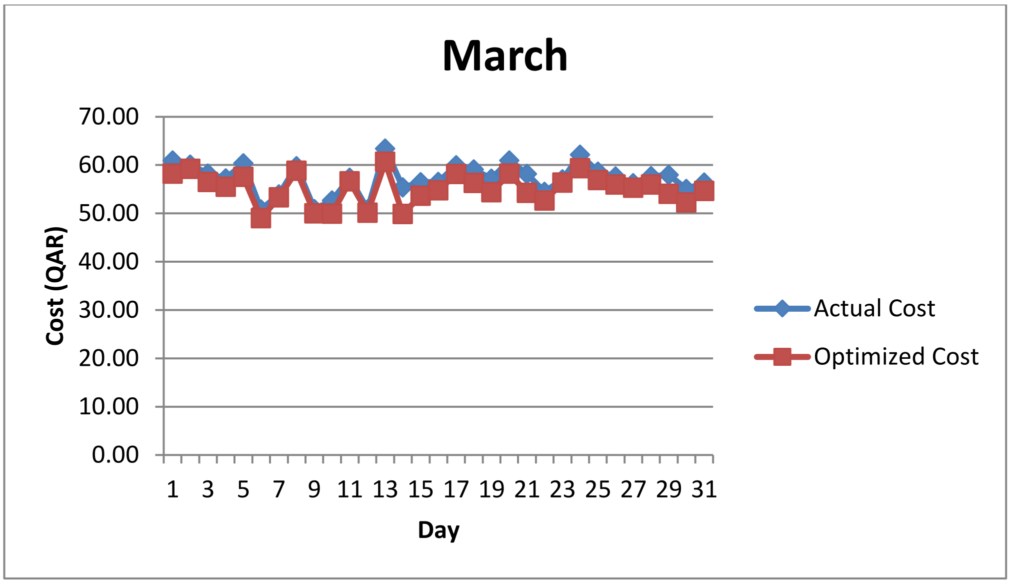


Figure 39. March Actual and Optimized Costs

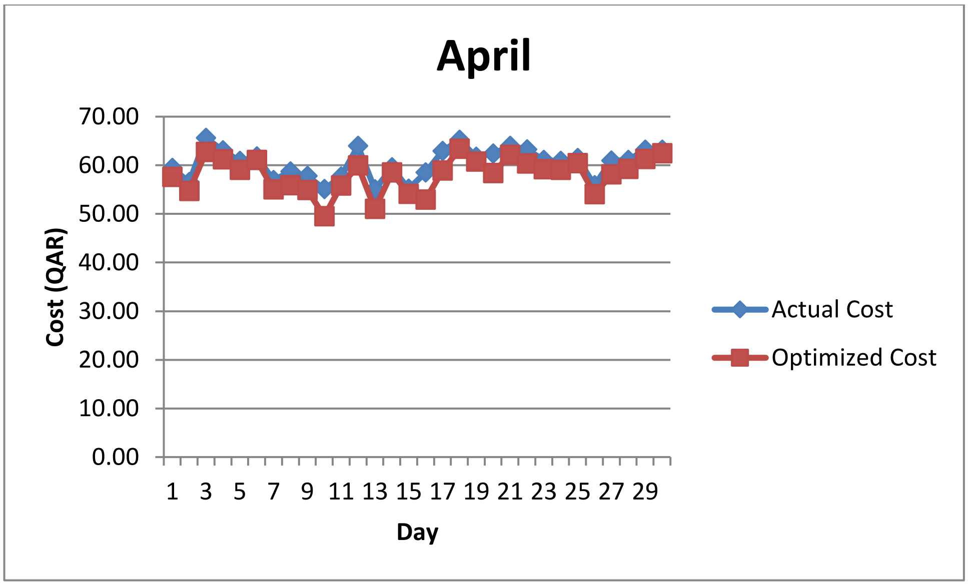


Figure 40. April Actual and Optimized Costs

In April, the actual cost and the optimized cost extremes differ. The actual cost is the highest on day 3 and lowest on day 13. Meanwhile, the optimized cost is the highest on day 18 and the lowest on day 10. The reason behind having the lowest optimized cost because the summation of solar energy and wind energy is the highest in this day. This is show that the actual and the optimized costs are not always proportional. Day 16 has the highest savings. This is shown in figure (40).

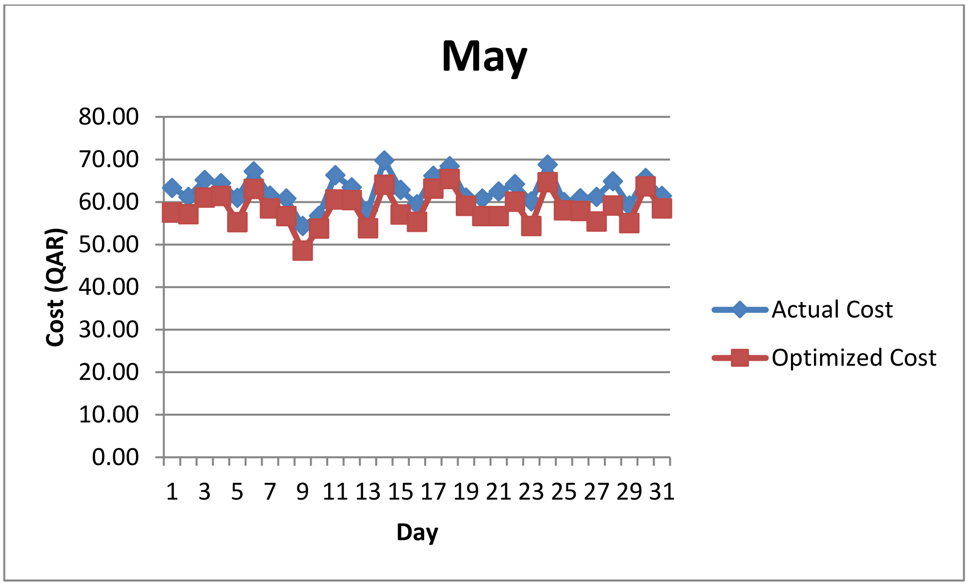


Figure 41. May Actual and Optimized Costs

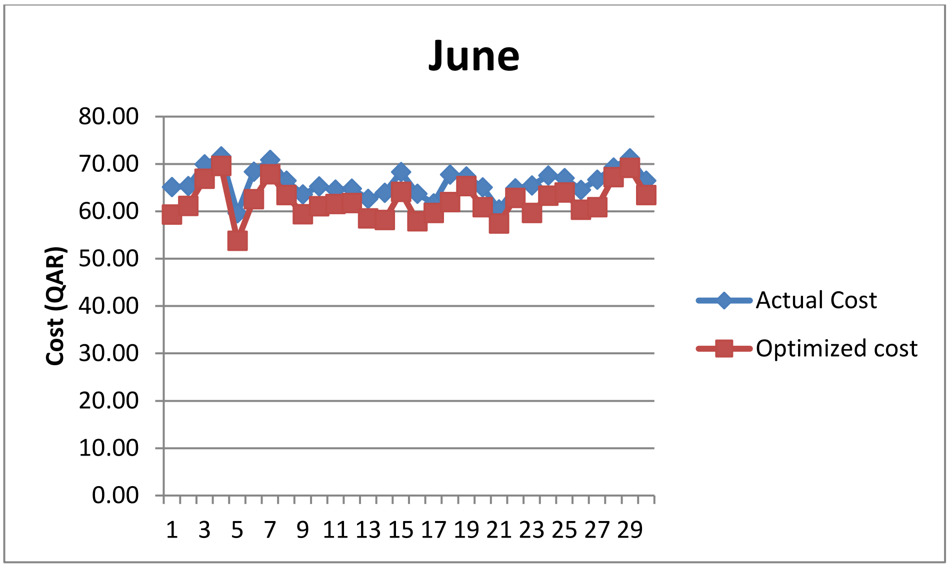


Figure 42. June Actual and Optimized Costs

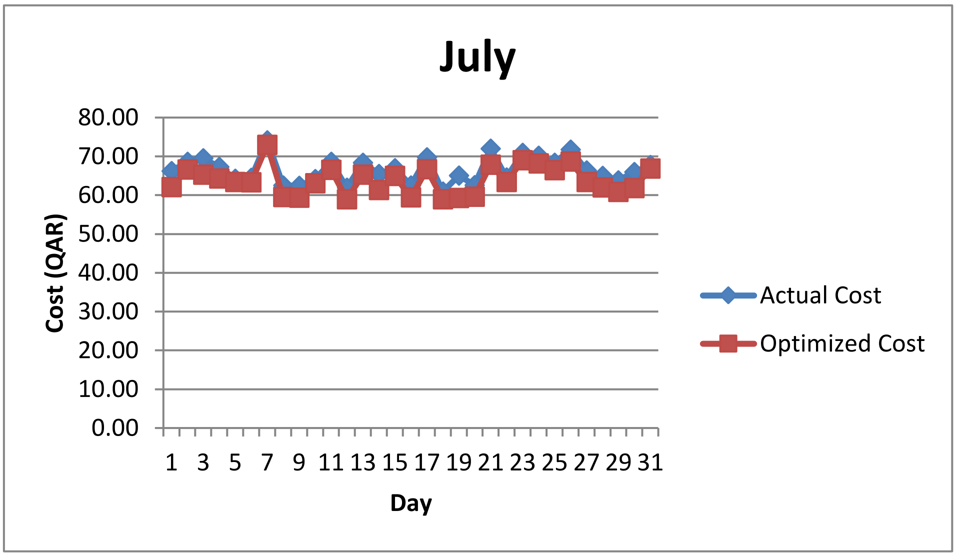


Figure 43. July Actual and Optimized Costs

Figure (41) shows the actual and the optimized costs in May, the actual cost is the lowest on day 9 and the highest at day 14. The optimized cost is the lowest on day 9 as well but the highest on day 18. This is another example to show that the actual and the optimized costs do not always meet. Finally, the savings are high this month and specially on day 23.

Figure (42) shows the actual and the optimized costs in June, day 4 is recorded to have the highest actual and optimized costs while day 5 is recorded to have the lowest actual and optimized costs. In addition, day 6 is recorded to have the highest savings.

Figure (43) shows the actual and the optimized costs n July, day 18 has the highest actual and optimized costs and day 7 has the lowest actual and optimized costs. The highest savings are occurring at day 19. The two lines of the actual cost and the optimized cost are almost overlaying each other showing the savings are very minimal in this month.

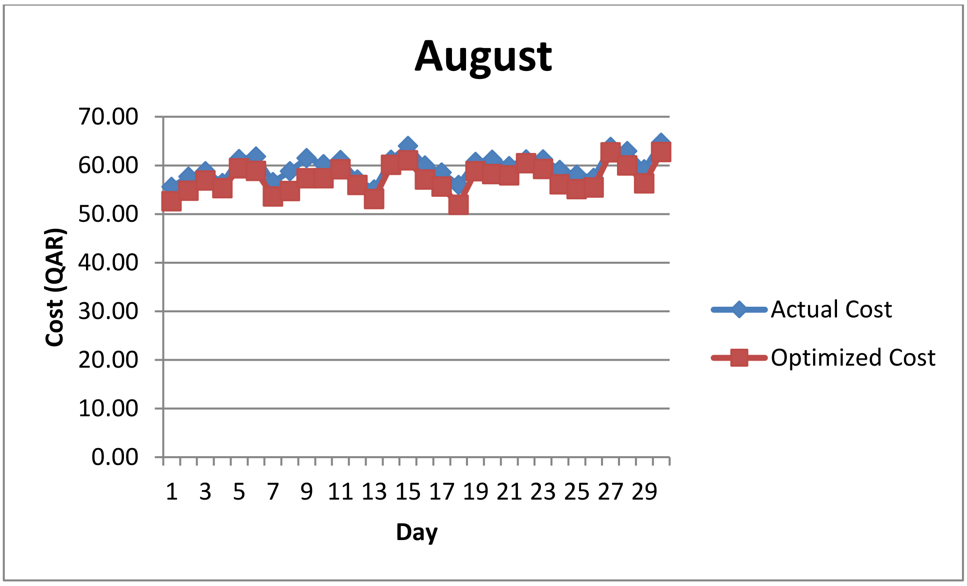


Figure 44. August Actual and Optimized Costs

In August, the highest actual and optimized costs are occurring at the last day of the month, the lowest actual cost is occurring on day 13, the lowest optimized cost is occurring at day 18 and the maximum savings are occurring at day 9. This is shown in figure (44).

In September, day 4 and day 13 have the highest and the lowest actual and optimized costs respectively. The savings are minimal since the two lines are very close and the maximum saving is occurring at day 20. This is shown in figure (45).

In October, the highest costs are occurring at day 26. Meanwhile, the lowest actual cost occurring at day 20 and the lowest optimized cost at day 8. At day 7, maximum savings are occurring. This is shown in figure (46).

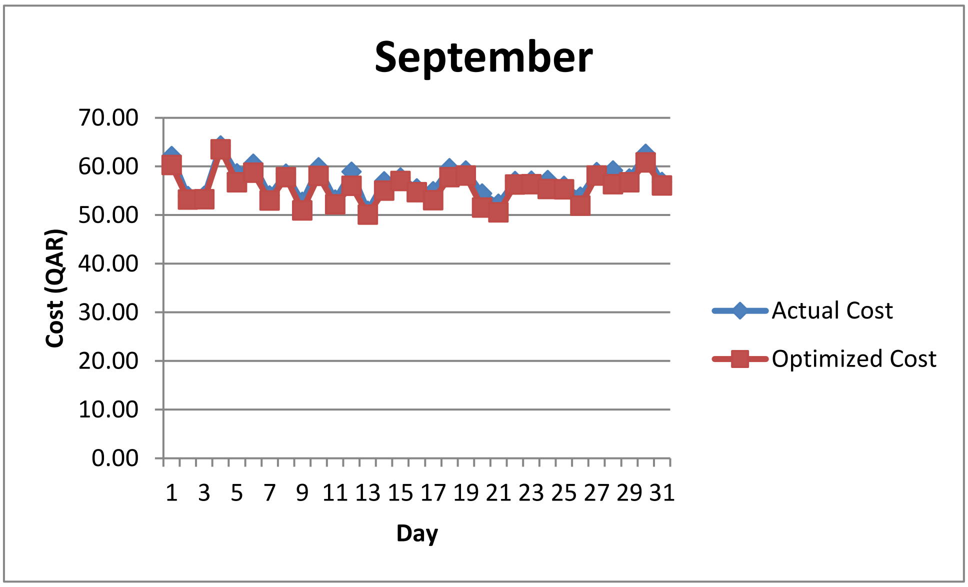


Figure 45. September Actual and Optimized Costs

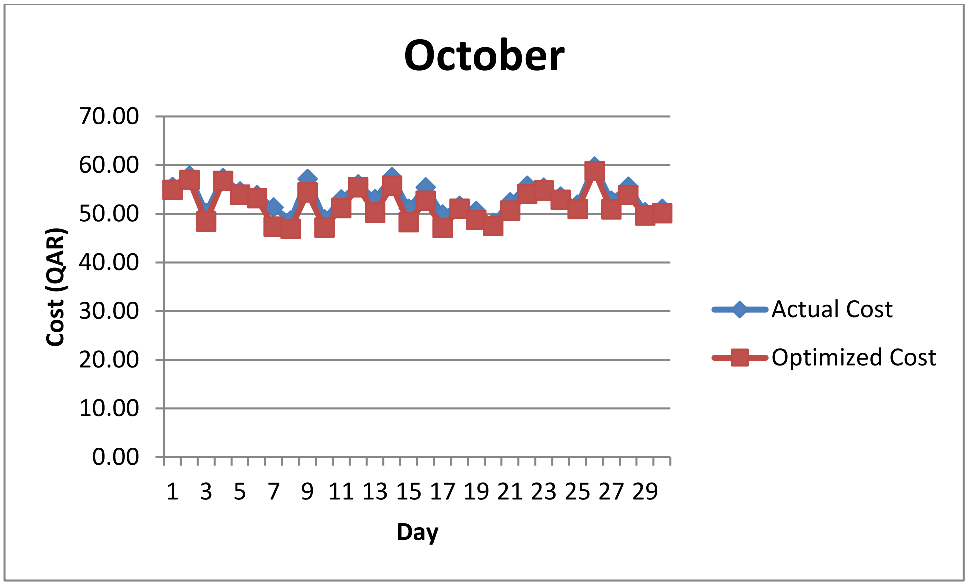


Figure 46. October Actual and Optimized Costs

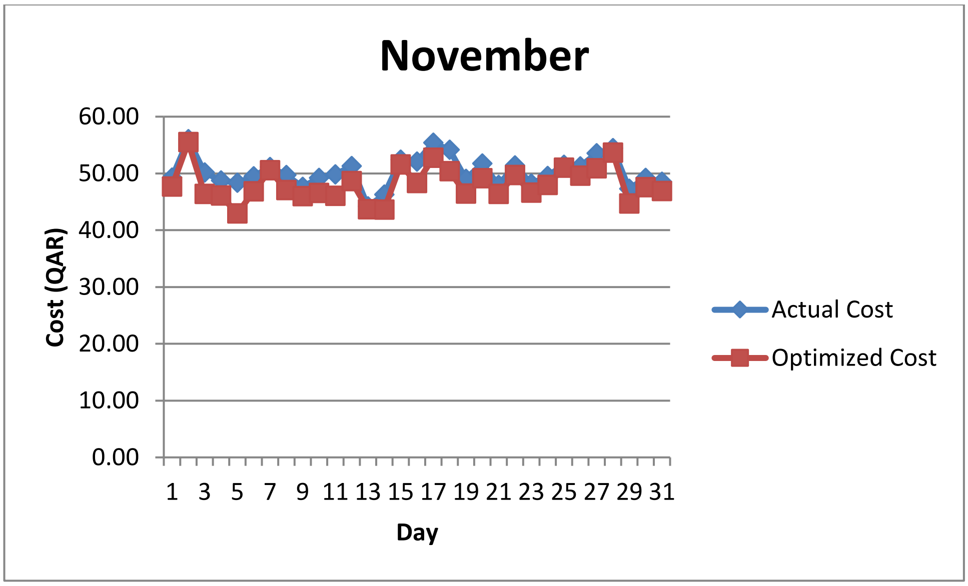


Figure 47. November Actual and Optimized Costs

Figure (47) shows the actual and the optimized costs in November, day 2 has the highest costs, day 5 has the lowest optimized cost and day 13 has the lowest optimized cost. Maximum savings are at day 5. In December, day 14 has the lowest costs, day 3 has the highest optimized cost, and day 20 has the highest actual cost. Maximum savings are occurring at day 25. This is shown in figure (48).

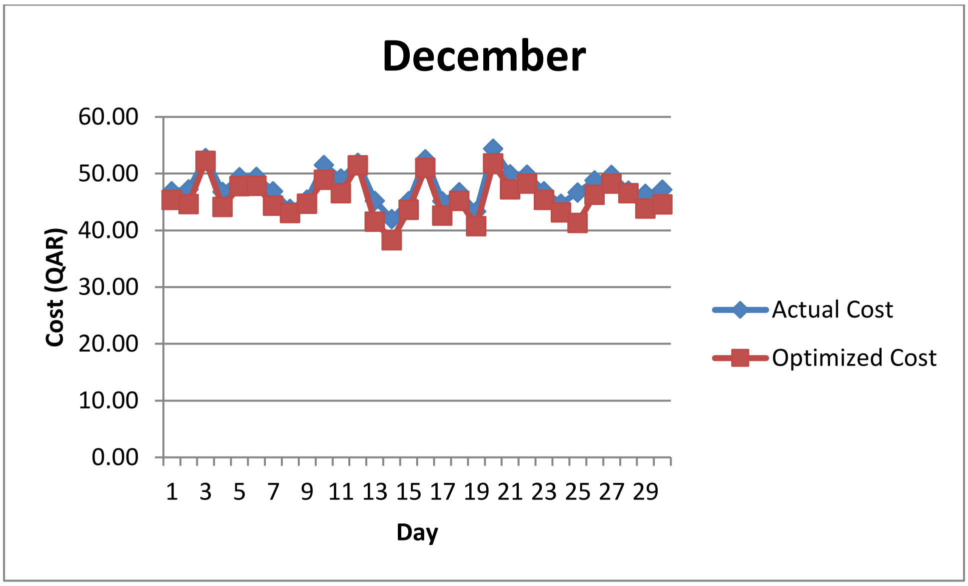


Figure 48. December Actual and Optimized Cost

A summary based on the above results is shown in two tables; table (16) summarizes daily consumption into monthly and yearly consumption for each of the five sources. Table (17) summarizes the daily optimized cost, daily actual cost, and daily savings into monthly and yearly data for one villa. The same parameters were also calculated for all houses in Qatar in order to visualize the impact of savings at national level. The calculations for national level were based on the number of total houses in

Qatar, i.e. 201,432 (Ministry of Development Planning and Statistics, 2016). As assumption was made that all villas are equal to the total number of houses in Qatar.

Table 16

Monthly and Yearly Consumption of each of the five sources

Month	Consumption	Solar	Wind	Battery	Grid	Gas
January	5061.28	726.71	460.2	231.00	3516.2	163.00
February	4883.83	855.72	460.2	231.00	3232.6	163.00
March	5650.15	1036.67	219.45	231.00	4038.7	163.00
April	5774.12	1198.62	359.3	231.00	3862.5	163.00
May	6181.14	1499.12	749.1	231.00	3574.8	163.00
June	6305.39	1552.42	653.4	231.00	3745.9	163.00
July	6569.95	1514.83	407.9	231.00	4289.1	163.00
August	5703.77	1358.69	355.7	231.00	3635.7	163.00
September	5633.13	1247.85	150.0	231.00	3877.1	163.00
October	5096.53	1013.00	191.0	231.00	3538.8	163.00
November	4966.49	804.22	380.5	231.00	3423.6	163.00
December	4567.31	653.84	356.2	231.00	3096.5	163.00
Yearly	66393.10	13461.68	4743.0	2772.0	43831.5	1956.0

Table 17

Actual Cost, Optimized Cost and Savings of One House & All Houses

Month	One Villa			All Villas		
	Actual Cost	Optimized Cost	Savings	Actual Cost	Optimized Cost	Savings
January	1588.74	1512.09	76.65	320022280.4	304583121.8	15439158.6
February	1533.03	1455.64	77.39	308802088	293213459.1	15588628.91
March	1773.58	1709.20	64.38	357256017.3	344287432.8	12968584.49
April	1812.50	1741.54	70.96	365094820.8	350801886.3	14292934.48
May	1940.26	1811.79	128.47	390830728.7	364952070.6	25878658.09
June	1979.26	1862.97	116.29	398686922.5	375262180.5	23424741.97
July	2062.31	1979.82	82.48	415414888.6	398799898.6	16614989.92
August	1790.41	1717.46	72.95	360646761.3	345952305.3	14694455.97
September	1768.24	1724.84	43.40	356179905.3	347437598	8742307.255
October	1599.80	1554.53	45.27	322251207.6	313131399	9119808.552
November	1558.98	1491.22	67.76	314028590.7	300380118.7	13648472.07
December	1433.68	1371.59	62.09	288788893.2	276281472.9	12507420.28
Yearly	20840.80	19932.70	908.10	4198003104	4015082944	182920160.6

In table (16), the highest electricity consumption is occurring in July; this is also shown in figure (49) where the consumption starts increasing from January and from one month to another until it reaches a peak in July and then the consumption starts decreasing. This is can be related to the temperature increase during the year; where the higher the temperature the higher the consumption since it is mainly influenced by the demand for cooling energy. On the other hand, table (16) and figure (50) shows how the consumption varies each month using the five different sources. Moreover, table (16) shows how solar availability and production changes from one month to another; increasing from January until it reaches a peak in May and then starts decreasing again. This is related to how solar irradiance changes from one month to another throughout the year. This trend can also be observed in figure (51). Furthermore, table (16) shows that there’s no exact pattern of how wind energy changes throughout the year. This is due to the different availability of wind which is not stable. This is also shown in figure (52).

In table 17, the highest saving occurs in May. It can be observed that for one villa, the saving is 128 QAR. This translates to a total of 25,878,658 QAR savings per month for all villas in Qatar. The savings may appear little when it is only calculated for one villa; however it becomes significant and clear when it is calculated for all villas. It is also clear from the table that there’s no clear pattern in the savings occurring from one month to another and this is mainly due to the variation of the sources availability from one month to another. The total yearly saving for one villa is 908 QAR, meanwhile for all villas the saving is 182,920,160 QAR. In order to show these comparisons clearly; figures (53 and 54) show the actual cost and the optimized cost in a column chart for one villa and all villas respectively. The difference in the elevation of the columns shows the savings. All of the above results prove the importance of the proposed system and its huge effect on the savings that will occur for Qatar State.

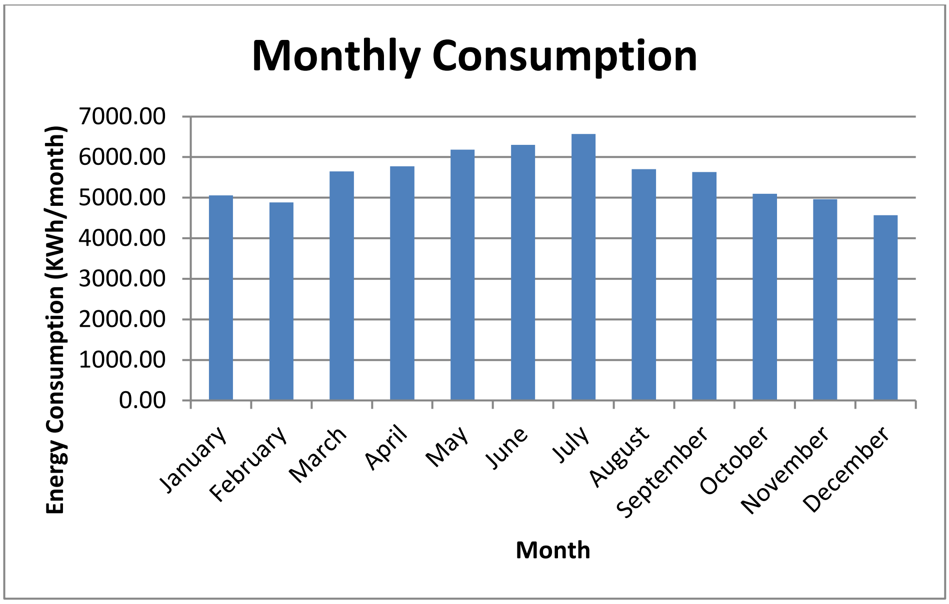


Figure 49. Monthly Consumption using only One Source

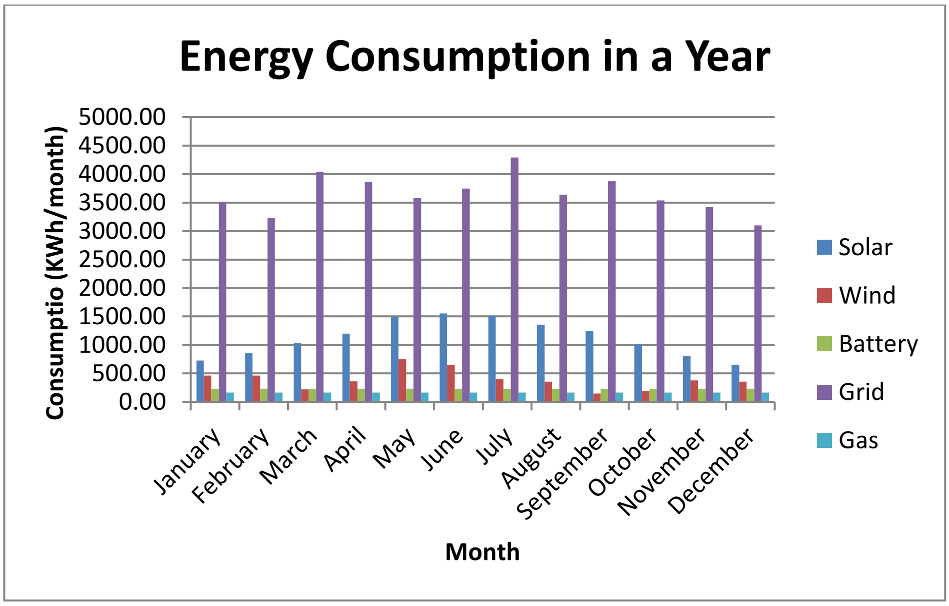


Figure 50. Monthly Consumption using Five Sources

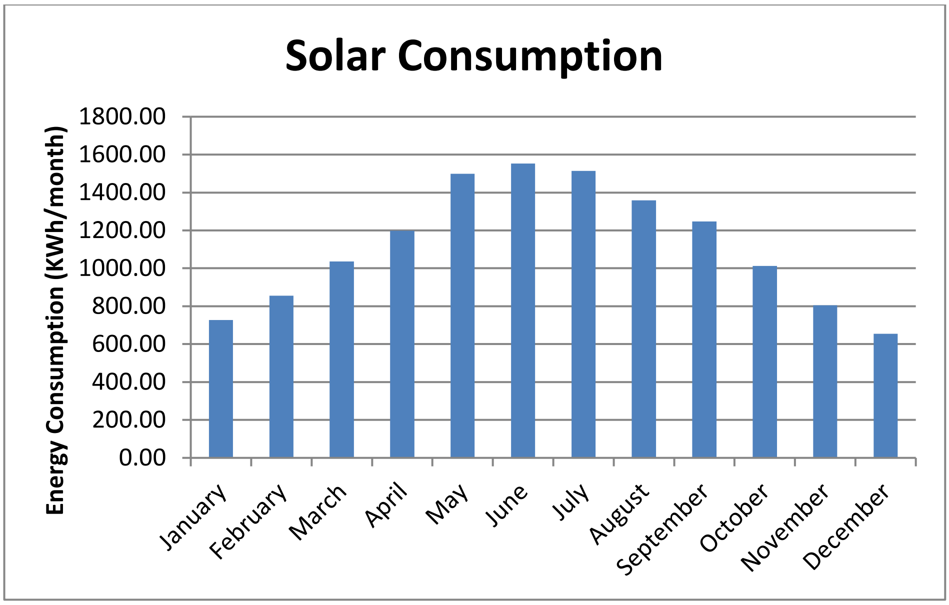


Figure 51. Solar Consumption based on its availability

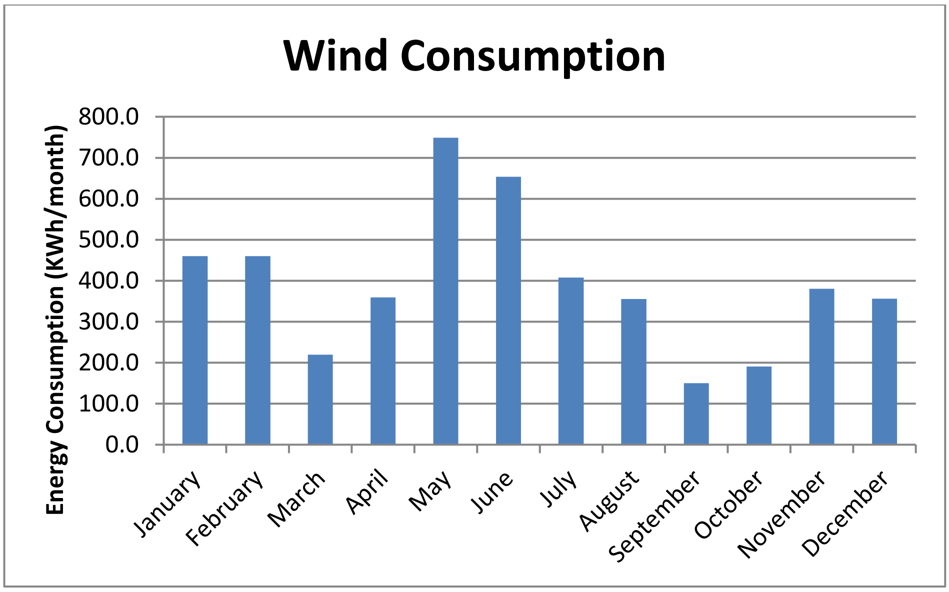


Figure 52. Wind Consumption based on its availability

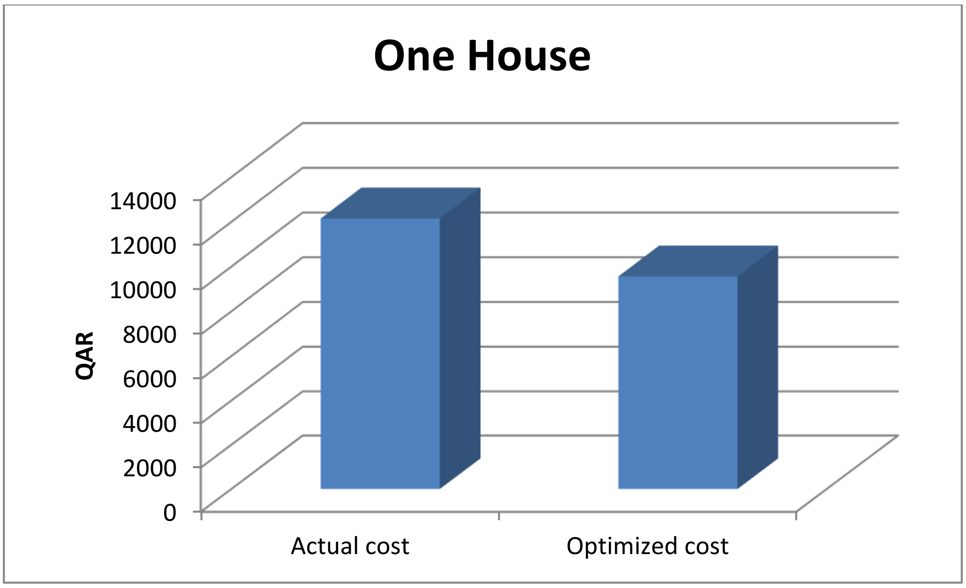


*Figure 53.*Comparison of the Total Actual Cost and the Total Optimized Cost of One House

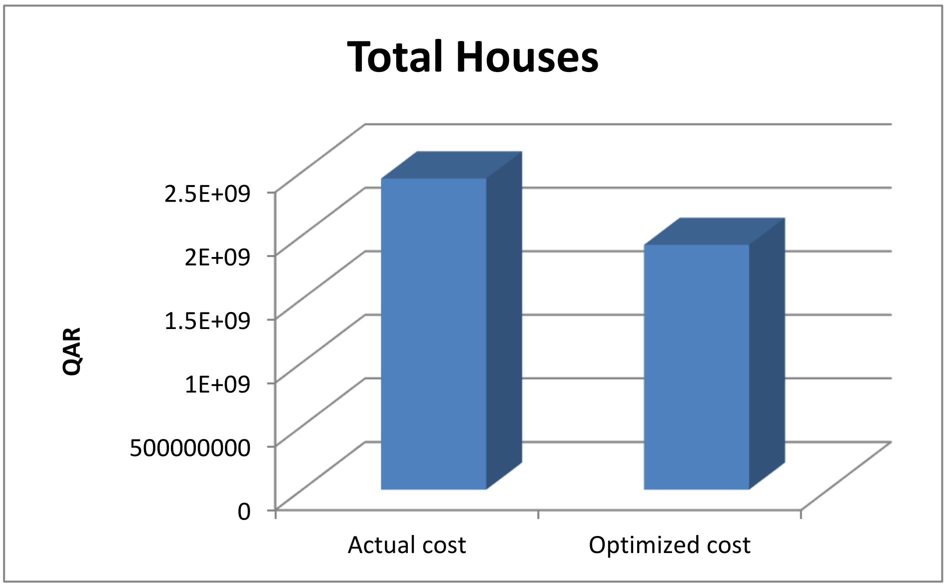


Figure 54. Comparison of the Total Actual Cost and the Total Optimized Cost of All Houses

CHAPTER 5: CONCLUSION

The population of the State of Qatar has been increasing very rapidly in the past few years, according to the economic growth that has been in the country. People have been migrating to the country to fulfill the positions required for completing the projects of World Cup FIFA 2022. The increase in the population leads to the increase of electricity consumption in the country; as well as the increase in the country expenses. This introduces the concept that an energy management system must be established in the country; and more specifically a “Home Energy Management System (HEMS)”.

Qatar is known to have only one source of energy to be supplied to the houses, which is the conventional power grid. Natural gas is basically used to produce this energy. Natural gas is a non-renewable source of energy and it must be consumed in a sustainable manner. However, the country aims by 2030 to start producing 20% of the total energy from renewable sources of energy such as solar and wind. This aspiration can be supported by introducing a “Home Energy Management System (HEMS)” that will help to conserve energy, reduce consumptions, and reduce dependency on conventional energy by integrating different sources of energy”.

In this project, two sources of renewable energy were investigated for use in Qatar, i.e., solar and wind. Their applicability to Qatar was also explored. A review of different home energy management systems applied in other countries were also investigated. A Smart Home Energy Management System was proposed for use in Qatar. The operations of the SHEM system was discussed with reference to a case study villa in Qatar. Case study analysis showed that a SHEM system is a potential inclusion into Qatar’s quest for using available energy sources in a sustainable manner. In order to demonstrate the functionality of the proposed SHEM system, a prototype was designed, constructed and tested. The main features of the prototype were demonstrated through the inclusion of a GSM Modem and Arduino Microcontroller. The focus of the prototype was to implement a Home Energy Management System that uses different sources with the aid of GSM Modem and Arduino Microcontroller to minimize the cost.

The project was carried out in different stages. The first stage was selecting a "House" as a case study to be able to implement the system and characterize all the electrical devices/ appliances in the house. The second stage consisted of data collection from Kahramaa based on the classified electrical devices/appliances and in order to find the electrical consumption in KWh per day. The third stage consisted of selecting the type of solar panels, wind turbines and battery bank that shall be used in the system. As well as; their sizes.

The fourth stage consisted of estimating how much each source will produce and how much the electrical consumption will be per day per house. As well as, discovering the costs of the different sources in QAR per KWh.

The fifth stage consisted of developing two algorithms: the first algorithm was written in Matlab and will take the data mentioned in the last stage as an input. The output will be which energy source to use and the savings that will occur. The second algorithm was written in Arduino 1.8.3 and was used to give signals to the hardware to switch from one source to another and to turn on the GSM Modem to send messages to the user to update the user about the energy system status.

The main results can be summarized as follow. In order to implement the system to the villa that was selected as a case study, a 10 KW solar system is required with 40 panels that are made from monocrystalline material. 5 wind turbines rated at e 1500W are required. 12 AGM batteries with 12 V and 400 Ah are required in addition to an LPG cylinder dedicated for cooking purposes.

Obtained results show that the highest electricity consumption occurs in July, the highest production of solar energy occurs in May and the production of wind energy varies randomly throughout the year.

The results also showed that the yearly consumption of energy for one house is about 66,393 KWh per year and the actual cost when only one source was used (current situation in Qatar) is 20,841 QAR per year. The optimized cost after using the different sources of energy that are managed by selecting the least cost energy option is 19,933 QAR per year. This leads to a total saving of 908 QAR per year for one villa. On the other hand, the actual cost for all villas in Qatar was calculated to be 4,198,003,104 QAR per year. The optimized energy cost for all villas was found to be 4,015,082,944 QAR per year. This leads to a total saving of 182,920,161 QAR per year.

These results show that SHEM systems are an essential component of energy management issues since these system can be implemented to (a) reduce energy consumption of main grid electricity, (b) reduce energy costs, (d) reduce electricity bills for consumers, and (e) reduce the total budget for energy for a national economy.

5.1 Future Work

Upon completing the research and understanding the importance of implementing a Smart Home Energy Management System in Qatar. The future work is to install the system in a villa in Qatar and collect real time data and actual results of the savings that will occur. This will give the ability to test the difference between results obtained based on research and results obtained based on real testing.

5.2 Recommendations

To implement the Smart Home Energy Management System in Qatar stage by stage and not at once. In other words, to implement the system to one district and test the results, then move forward to the next district. This will give the ability to check the differences that might occur from one district to another. After investigating the differences between the districts and completing them, this will allow testing the differences between the seven different zones in Qatar and see if there are differences in terms of savings.

5.3 Limitations

There are several limitations in this project which can be summarized as follow:

1. The data taken from Kahramaa is for one day in June which is general. This may affect the calculation that was done for finding the monthly and the yearly consumption for one villa.
2. The prototype that was done in this project has no scale which means it can be enlarged to be implemented on an actual villa directly. The prototype was just for proof of concept.
3. Kahramaa does not vary the tariff with respect to time, in which this did not allow to an hourly analysis. Thus daily analysis was done in this project.

REFERENCES

1. Worldometers. (2017). Qatar Population (2017). Worldometers. Retrieved 19 April 2017, from http://www.worldometers.info/world-population/qatar-population/
2. World Bank. (2014). Electric power consumption (kWh per capita). Data world bank. Retrieved 19 March 2017, from http://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?locations=EU
3. Gulf Times. (2015). Qatar electricity consumption: Domestic usage more than half. Gulf-Times. Retrieved 4 April 2017, from http://www.gulf-times.com/story/458141/Qatar-electricity-consumption-Domestic-usage-more-
4. Bojanczyk, K. (2013). Redefining Home Energy Management Systems. Green Techmedia. Retrieved 8 March 2017, from https://www.greentechmedia.com/articles/read/home-energy-management-systems-redefined
5. Sustainable Energy Authority of Ireland. (2017). Home Energy Management Systems. SEAI. Retrieved 8 March 2017, from http://www.seai.ie/Renewables/Smart_Grids/The_Smart_Grid_for_the_Consumer/Home_Consumer/Home_Energy_Management_Systems
6. World Commission on Environment and Development. (2017). World Commission on Environment and Development. Public WSU. Retrieved 9 May 2017, from http://public.wsu.edu/~susdev/WCED87.html
7. Solar Energy Industries Association. (2017). Solar Photovoltaic. SEIA. Retrieved 9 March 2017, from http://www.seia.org/policy/solar-technology/photovoltaic-solar-electric

8. Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. Renewable And Sustainable Energy Reviews, 15(3), 1625-1636. http://dx.doi.org/10.1016/j.rser.2010.11.032
9. New Dawn Energy Solutions,. New Dawn Energy Solutions. Newdawn-es.com. Retrieved 10 March 2017, from http://www.newdawn-es.com/info-center/how-solar-works
10. Horgan, N. Solar panel installer for London, Bucks, Herts, UK - Kewsolar. Kewsolar.co.uk. Retrieved 10 March 2017, from http://www.kewsolar.co.uk/techinfo/panels.aspx
11. Renewable Energy World. Advantages and disadvantages of Solar Photovoltaic – Quick Pros and Cons of Solar PV. Renewableenergyworld.com. Retrieved 10 March 2017, from http://www.renewableenergyworld.com/ugc/articles/2012/12/advantages-and-disadvantages-of-solar-photovoltaic--quick-pros-and-cons-of-solar-pv.html
12. Global Foot Prints,. What is sustainability. Globalfootprints.org. Retrieved 11 March 2017, from http://www.globalfootprints.org/sustainability
13. Conserve Energy Future,. How Sustainable is Renewable Energy? - Conserve Energy Future. Conserve Energy Future. Retrieved 11 March 2017, from http://www.conserve-energy-future.com/isrenewableenergysustainable.php
14. Rossell, A., & Soler, J. (2011).Towards Efficient Energy Management : Defining HEMS and Smart Grid Objectives. International Journal of Advances in Technology, 4(3), 249–263.
15. Zhou, B., Li, W., Chan, K. W., Cao, Y., Kuang, Y., Liu, X., & Wang, X. (2016). Smart home energy management systems: Concept, configurations, and scheduling

strategies. Renewable and Sustainable Energy Reviews, 61, 30–40. https://doi.org/10.1016/j.rser.2016.03.047

16. Missaoui, R., Joumaa, H., Ploix, S., & Bacha, S. (2014). Managing energy Smart Homes according to energy prices: Analysis of a Building Energy Management System. Energy And Buildings, 71, 155-167. http://dx.doi.org/10.1016/j.enbuild.2013.12.018
17. ABS Alaskan,. (2017). AC and DC Electrical Loads. Absak.com. Retrieved 25 March 2017, from http://www.absak.com/diagram/text/load.htm
18. Zhao, C., Dong, S., Li, F., & Song, Y. (2015). Optimal home energy management system with mixed types of loads. CSEE Journal Of Power And Energy Systems, 1(4), 29-37. http://dx.doi.org/10.17775/cseejpes.2015.00045
19. Office of Energy Efficiency & Renewable Energy. (2017). How Do Wind Turbines Work? | Department of Energy. Energy.gov. Retrieved 6 July 2017, from https://energy.gov/eere/wind/how-do-wind-turbines-work
20. Wind Energy Development Programmatic EIS. (2017). Wind Energy Basics. Windeis.anl.gov. Retrieved 6 July 2017, from http://windeis.anl.gov/guide/basics/
21. Conserve Energy Future. (2017). 7 Pros and Cons of Wind Energy - Conserve Energy Future. Conserve Energy Future. Retrieved 6 July 2017, from http://www.conserve-energy-future.com/pros-and-cons-of-wind-energy.php
22. TechTarget. (2017). What is GSM (Global System for Mobile communication)? - Definition from WhatIs.com. SearchMobileComputing. Retrieved 7 July 2017, from http://searchmobilecomputing.techtarget.com/definition/GSM

23. Singh, P., Chotalia, K., Pingale, S., & Kadam, S. (2016). A Review Paper on Smart GSM Based Home Automation System. International Research Journal of Engineering and Technology (IRJET), 03(04).
24. Singh, S., & Ray, K. K. (2017). HOME AUTOMATION SYSTEM USING INTERNET OF THINGS. International Journal of Computer Engineering and Applications, Special Edition.
25. Vinay sagar, K. N., & Kusuma, S. (2015). Home Automation Using Internet of Things. International Research Journal of Engineering and Technology (IRJET),2(3).
26. Dwivedi, A. K., Narayan Y., & Shimi S. L. (2015) Home Automation and Energy Management Using Smart Phone. International Journal for Research in Applied Science & Engineering Technology (IJRASET).
27. Patil, A., Potnis, P., & Katkar, K. (2017). SMS Based Home Automation System using Arduino ATMEG328 with GSM. International Journal of Engineering Trends and Technology (IJETT), 47(7), 369-374.
28. Effah E., Aryeh F. L., & Kehinde W. K. (2016). GSM-Based Home Appliances Control System (HACS) for Domestic Power Users in Ghana. Ghana Journal of Technology, 1(1), 25 - 31.
29. Shawki, F., Dessouki, M., Elbasiouny, A., Almazroui, A., & Albeladi, F. (2015). MICROCONTROLLER BASED SMART HOME WITH SECURITY USING GSM TECHNOLOGY. International Journal of Research In Engineering And Technology, 04(06), 20-28. http://dx.doi.org/10.15623/ijret.2015.0406003.
30. Hassan A. (2015). Enhancement of a GSM Based Control System. Advances in Circuits, Systems, Signal Processing and Telecommunications.

31. Trade Arabia. (2017). Qatar to start work on major solar power plant in June. Tradearabia.com. Retrieved 20 July 2017, from http://www.tradearabia.com/news/OGN_321642.html
32. Home Wind Turbines. (2017). Home wind turbines - Which?. Which.co.uk. Retrieved 20 July 2017, from http://www.which.co.uk/reviews/wind-turbines/article/installing-a-wind-turbine/home-wind-turbines
33. Norton Rose Fulbright. (2017). Renewable energy in Qatar. Nortonrosefulbright.com. Retrieved 20 July 2017, from http://www.nortonrosefulbright.com/knowledge/publications/48660/renewable-energy-in-qatar
34. Pipattanasomporn, M., Kuzlu, M., & Rahman, S. (2012). An Algorithm for Intelligent Home Energy Management and Demand Response Analysis. IEEE Transactions On Smart Grid, 3(4), 2166-2173. http://dx.doi.org/10.1109/tsg.2012.2201182
35. Boynuegri, A., Yagcitekin, B., Baysal, M., Karakas, A., & Uzunoglu, M. (2013). Energy Management Algorithm for Smart Home with Renewable Energy Sources. POWERENG, pp. 1753-1758.
36. Fabio. (2011). *What is Arduino, Why we choose it, what can we do with it? | Varesano.net*. *Varesano.net*. Retrieved 26 July 2017, from http://www.varesano.net/blog/fabio/what%20arduino%20why%20we%20choose%20it%20what%20can%20we%20do%20it
37. McDonnell, S. (2017). *Advantages Of GSM*. *It Still Works*. Retrieved 26 July 2017, from http://itstillworks.com/advantages-gsm-28848.html

38. *Maehlum, M. (2013).* Solar Cell Comparison Chart – Mono-, Polycrystalline and Thin Film - Energy Informative. Energy Informative. *Retrieved 22 September 2017, from http://energyinformative.org/solar-cell-comparison-chart-mono-polycrystalline-thin-film/*

39. *Maehlum, M. (2013).* Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film?. Energy Informative. *Retrieved 22 September 2017, from http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/*

40. *Tarbi, L. (2017).* How Many Solar Panels Do I Need For My Home in 2017? | EnergySage. EnergySage Solar News Feed. *Retrieved 22 September 2017, from http://news.energysage.com/how-many-solar-panels-do-i-need/*

41. *Kinnear, J. (2017).* Choosing a Battery Bank for Your Solar System | Solar Power Authority. Solar Power Authority. *Retrieved 23 September 2017, from https://www.solarpowerauthority.com/choosing-battery-bank-solar-pv/*

42. *Leading Edge. (2016).* Battery Bank Size Calulations - Leading Edge Turbines & Power Solutions. Leadingedgepower.com. *Retrieved 23 September 2017, from* https://www.leadingedgepower.com/shop/help-advice-faq/help-with-batteries/battery-bank-size-calulations.html

43. Alternative Energy Store Inc. (2016). *Off Grid Calculator | altE. Stories of Awesome People Going Solar from altE.* Retrieved 23 September 2017, from https://www.altestore.com/store/calculators/off_grid_calculator/

44. Tiny House Huge Ideas. (2017). *Small Wind Turbine Guide 2017: What's the Best System?. Tiny House, Huge Ideas*. Retrieved 27 September 2017, from https://tinyhousehugeideas.com/best-wind-turbine-reviews/

45. Beckers, R. *The Truth About Small Wind Turbines - Solacity Inc.*. *Solacity Inc.*. Retrieved 28 September 2017, from https://www.solacity.com/small-wind-turbine-truth/
46. Al-Kuwari, M., & Rao, p. (2013). *ASSESSMENT OF SOLAR AND WIND ENERGY POTENTIAL IN QATAR*. Retrieved 28 September 2017, from https://www.jccp.or.jp/international/conference/docs/14assessment-of-solar-and-wind-energy-potential-in.pdf
47. Indian Register Quality Systems. (2017). *Energy Management System EMS Certification. Indian Register Quality Systems*. Retrieved 30 September 2017, from http://www.irqs.co.in/energy-management-system.html
48. International Renewable Energy Agency. (2016). *RENEWABLE ENERGY MARKET ANALYSIS - The GCC Region (p. 12).* Abu Dhabi: IRENA. Retrieved from http://www.irena.org/DocumentDownloads/Publications/IRENA_Market_GCC_2016.pdf
49. Sun Force Products. (2017). *WINDMILL 1500W Kit User's Manual.* Retrieved from https://www.northerntool.com/images/downloads/manuals/40091.pdf
50. World Weather & Climate Information. (2016). *CLIMATE: AVERAGE MONTHLY WEATHER IN DOHA, QATAR*. Word Weather & Climate Information. Retrieved 1 November 2017, from https://weather-and-climate.com/average-monthly-rainfall-temperature-sunshine,doha,qatar
51. Solar Irradiance Calculator - Useful Sun power tool. (2017). Efficientenergysaving.co.uk. Retrieved 6 November 2017, from http://www.efficientenergysaving.co.uk/solar-irradiance-calculator.html

52. Woqod. (2017). *Shafaf*. Woqod.com. Retrieved 10 November 2017, from http://www.woqod.com/EN/Gas/SHAFAF/Pages/default.aspx

53. Trina Solar TSM-240DA05 | Trina Solar TSM-240DA05 Solar Panel | Trina Solar TSM-240DA05 Solar Module

54. Al Fakhri, M., Mohandes, N., & Sanfilippo, A. (2016). Modeling Residential Adoption of Solar PV in Qatar. Doha: Qatar Environment & Energy Research Institute, HBKU. Retrieved from http://ae2016.it/public/ae2016/files/AE_2016_paper_21.pdf

APPENDIX 1: MATLAB CODE

```
clc
clear all


%  Current AC and DC loads in kWh (instantaneous) // will be automatically selected
based
% on the varibale t (time)

Lac_ofp=158.01;
Lac_medp=158.01;
Lac_onp=158.01;

Ldc_ofp=0;
Ldc_medp=0;
Ldc_onp=0;

Lthermal_ofp=0; % kBTU /hour
Lthermal_medp=0;
Lthermal_onp=0;

Lac_array=[Lac_ofp,Lac_medp,Lac_onp];
Ldc_array=[Ldc_ofp,Ldc_medp,Ldc_onp];

% Time :

t=0;

% Available power capacity at different energy sources in kWh (Power profile)

Spv=23.78;
Swt=8.1;
Sbattery=7.45;
Sgrid=100000000;
Sgas= 5.26;

Ssource_matrix=[Spv Swt Sbattery Sgrid Sgas];% Source Power Capactiy (SPC)
Ssource_matrix_cost=[Spv Swt Sbattery Sgrid Sgas];

% Energy conversion factors

AC_DC=0.85;
AC_thermal=1;

DC_AC=0.95;
DC_thermal=1;

Gas_AC=0.85;
```

```
Gas_DC=Gas_AC*AC_DC;
Gas_thermal=0.85;

if (t>=19 && t<=24 || t>=0 && t<=7)
    Lac=Lac_ofp;
    Ldc=Ldc_ofp;
    Lthermal=Lthermal_ofp;
    'OFF-PEAK'
else if (t>=11 && t<=17)
    Lac=Lac_medp;
    Ldc=Ldc_medp;
    Lthermal=Lthermal_medp;
    'MED-PEAK'
    else
    Lac=Lac_onp;
    Ldc=Ldc_onp;
    Lthermal=Lthermal_onp;
    'ON-PEAK'
    end
end


% Prices of different energy sources in Qatari Riyal per kWh
Cpv_dc=0.2984;
Cpv_ac=Cpv_dc*(1/DC_AC);
Cpv_thermal=Cpv_dc/3.412; For immersed heating elements, 3.412 kBTU / KWh

Cwt_ac=0.1784;
Cwt_dc=Cwt_ac*(1/AC_DC);
Cwt_thermal=Cwt_ac/3.412;

% Energy Prices

Cgrid_ofp=0.3139; % per kWh
Cgrid_medp=0.3139;
Cgrid_onp=0.3139;
Cgrid_dc_ofp=Cgrid_ofp*(1/AC_DC);
Cgrid_dc_medp=Cgrid_medp*(1/AC_DC);
Cgrid_dc_onp=Czgrid_onp*(1/AC_DC);
Cgrid_thermal_ofp=Cgrid_ofp/3.412;
Cgrid_thermal_medp=Cgrid_medp/3.412;
Cgrid_thermal_onp=Cgrid_onp/3.412;


Cbattery_dc=0.3027;
Cbattery_ac=Cbattery_dc*(1/DC_AC);
Cbattery_thermal=Cbattery_dc/3.412;
```

```
Cgas=0.2547;
Cgas_ac= 0.2547+0.05; %0.05 QAR per kWh is added to cover the price of generator
and maitenance
Cgas_dc=Cgas_ac*(1/AC_DC);
Cgas_thermal=Cgas/35*(1/Gas_thermal);

Cmatrix_ac_onp=[ Cpv_ac Cwt_ac Cbattery_ac Cgrid_onp Cgas_ac]; % cost array
Cmatrix_ac_medp=[ Cpv_ac Cwt_ac Cbattery_ac Cgrid_medp Cgas_ac];
Cmatrix_ac_ofp=[ Cpv_ac Cwt_ac Cbattery_ac Cgrid_ofp Cgas_ac];
Cmatrix_dc_onp=[ Cpv_dc Cwt_dc Cbattery_dc Cgrid_dc_onp Cgas_dc];
Cmatrix_dc_medp=[ Cpv_dc Cwt_dc Cbattery_dc Cgrid_dc_medp Cgas_dc];
Cmatrix_dc_ofp=[ Cpv_dc Cwt_dc Cbattery_dc Cgrid_dc_ofp Cgas_dc];
Cmatrix_thermal_onp=[Cpv_thermal Cwt_thermal Cbattery_thermal
Cgrid_thermal_onp Cgas_thermal];
Cmatrix_thermal_medp=[Cpv_thermal Cwt_thermal Cbattery_thermal
Cgrid_thermal_medp Cgas_thermal];
Cmatrix_thermal_ofp=[Cpv_thermal Cwt_thermal Cbattery_thermal
Cgrid_thermal_ofp Cgas_thermal];



if (t>=19 && t<=24 || t>=0 && t<=7)
   Cmatrix_ac=Cmatrix_ac_ofp;
   Cmatrix_dc=Cmatrix_dc_ofp;
   Cmatrix_thermal=Cmatrix_thermal_ofp;
   Lac=Lac_ofp;
   Ldc=Ldc_ofp;
   Lthermal=Lthermal_ofp;
   'OFF-PEAK'
else if (t>=11 && t<=17)
   Cmatrix_ac=Cmatrix_ac_medp;
   Cmatrix_dc=Cmatrix_dc_medp;
   Cmatrix_thermal=Cmatrix_thermal_medp;
   Lac=Lac_medp;
   Ldc=Ldc_medp;
   Lthermal=Lthermal_medp;
   'MED-PEAK'
   else
   Cmatrix_ac=Cmatrix_ac_onp;
   Cmatrix_dc=Cmatrix_dc_onp;
   Cmatrix_thermal=Cmatrix_thermal_onp;
   Lac=Lac_onp;
   Ldc=Ldc_onp;
   Lthermal=Lthermal_onp;
   'ON-PEAK'

   % Load correction coeffecients (Energy losses) [ kwh kwh kwh kwh kBTU]
```

```
   Lac_matrix=[Lac*1/(DC_AC) Lac Lac*1/(DC_AC) Lac*1/(DC_AC)
Lac*1/(Gas_AC)*3.412]*1/Lac;
   Ldc_matrix=[Ldc Ldc+1/(AC_DC) Ldc Ldc*1/(AC_DC)
Ldc*1/(Gas_DC)*3.412]*1/Ldc;
   Lthermal_matrix=[Lthermal/3.412 Lthermal/3.412 Lthermal/3.412 Lthermal/3.412
Lthermal*1/Gas_thermal]*1/Lthermal; % equivelant load matrix
   end
end

% Sorting the energy sources by price
[Cmatrix_ac_asc,Index_ac]=sort(Cmatrix_ac); %Carray_ac(Index_ac(1)) -> Lowest
price , Carray_ac(Index_ac(1)) -> Highest price
[Cmatrix_dc_asc,Index_dc]=sort(Cmatrix_dc);
[Cmatrix_thermal_asc,Index_thermal]=sort(Cmatrix_thermal);
[Cmatrix_acdc_asc,Index_cost_acdc]=sort([Cmatrix_ac Cmatrix_dc
100*Cmatrix_thermal]) % cost matric with consideration of losses - This matrix is the
one which orders the listed resources
                                                              % the Cmatrix_thermal is
multiplied by 100 to move the thermal loads to the end and to give the priority to AC
and DC
ff=' +++++++++++++ Min Cost Algorithm  +++++++++++++++++++++++'

Total_cost_ac_sum_grid=Lac*Cmatrix_ac(4);
Total_cost_dc_sum_grid=Ldc*Cmatrix_dc(4);
Total_cost_thermal_sum_gas=Lthermal*Cmatrix_thermal(5);
xlswrite('D://Low running cost controller.xlsx',[Lac Ldc, Lthermal],'Based on AC
Cost','B13');
xlswrite('D://Low running cost controller.xlsx',Ssource_matrix,'Based on AC
Cost','B10');

Lac_rem= Lac;
Ldc_rem= Ldc;
Lthermal_rem= Lthermal;
for i=1:15
   kk=i
   Lac=Lac_rem
   Ldc=Ldc_rem
   Lthermal=Lthermal_rem
   Ssource_matrix_cost
   Ssource_matrix_cost_record(i,:)=Ssource_matrix_cost;
   if (Index_cost_acdc(i)>=0 && Index_cost_acdc(i)<=5) % AC loads - based on the
order of resources in the sorted matrix
         if
Ssource_matrix_cost(Index_cost_acdc(i))<=Lac*(Lac_matrix(Index_cost_acdc(i))) %
Lac_matrix includes all power supply conversion factors.
            Lac_rem=Lac*(Lac_matrix(Index_cost_acdc(i)))-
Ssource_matrix_cost(Index_cost_acdc(i));
```

```
            Lac_rem=Lac_rem/(Lac_matrix(Index_cost_acdc(i)));
            % total_cost_ac from column 1 to 5 -> AC loads drawn off source 1 to 5,
from column 6 to10 -> DC loads and from column 11 to 15 -> thermal loads

Total_cost_ac(i,Index_cost_acdc(i))=Ssource_matrix_cost(Index_cost_acdc(i))*Cmat
rix_ac(Index_cost_acdc(i));
            %output power ( to control power inverters)

Output_power(1,Index_cost_acdc(i))=Ssource_matrix_cost(Index_cost_acdc(i));
            Ssource_matrix_cost(Index_cost_acdc(i))=0;
         else
            Lac_rem=0;

Ssource_matrix_cost(Index_cost_acdc(i))=Ssource_matrix_cost(Index_cost_acdc(i))-
Lac*(Lac_matrix(Index_cost_acdc(i)));
            Total_cost_ac(i,Index_cost_acdc(i))=Lac*Cmatrix_ac(Index_cost_acdc(i));

Output_power(1,Index_cost_acdc(i))=Lac*(Lac_matrix(Index_cost_acdc(i)));

         end
   else if (Index_cost_acdc(i)>=6 && Index_cost_acdc(i)<=10) % DC loads - based
on the order of resources in the sorted matrix
         if Ssource_matrix_cost(Index_cost_acdc(i)-
5)<=Ldc*(Ldc_matrix(Index_cost_acdc(i)-5))
            Ldc_rem=Ldc*(Ldc_matrix(Index_cost_acdc(i)-5))-
Ssource_matrix_cost(Index_cost_acdc(i)-5);
            Ldc_rem=Ldc_rem/(Ldc_matrix(Index_cost_acdc(i)-5));
            % from column 1 to 5 -> AC loads drawn off source 1 to 5, from column 6
to10 -> DC loads and from column 11 to 15 -> thermal loads
            Total_cost_dc(i,Index_cost_acdc(i)-
5)=Ssource_matrix_cost(Index_cost_acdc(i)-5)*Cmatrix_dc(Index_cost_acdc(i)-5);
            Output_power(2,Index_cost_acdc(i)-
5)=Ssource_matrix_cost(Index_cost_acdc(i)-5);
            Ssource_matrix_cost(Index_cost_acdc(i)-5)=0;

         else
            Ldc_rem=0;
            Ssource_matrix_cost(Index_cost_acdc(i)-
5)=Ssource_matrix_cost(Index_cost_acdc(i)-5)-
Ldc*(Ldc_matrix(Index_cost_acdc(i)-5));
            %Output(i,Index_cost_acdc(i)-5)=Ldc*(Ldc_matrix(Index_cost_acdc(i)-
5));
            Total_cost_dc(i,Index_cost_acdc(i)-
5)=Ldc*Cmatrix_dc(Index_cost_acdc(i)-5);
            Output_power(2,Index_cost_acdc(i)-
5)=Ldc*(Ldc_matrix(Index_cost_acdc(i)-5));

         end
```

```
    else if (Index_cost_acdc(i)>=11 && Index_cost_acdc(i)<=15)  % Thermal loads
i=11 to15
            if Ssource_matrix_cost(Index_cost_acdc(i)-
10)<=Lthermal*(Lthermal_matrix(Index_cost_acdc(i)-10)) % convert to electrical
kwh
                Lthermal_rem=Lthermal*(Lthermal_matrix(Index_cost_acdc(i)-10))-
Ssource_matrix_cost(Index_cost_acdc(i)-10);
                Lthermal_rem=Lthermal_rem/(Lthermal_matrix(Index_cost_acdc(i)-10));
                Total_cost_thermal(i,Index_cost_acdc(i)-
10)=Ssource_matrix_cost(Index_cost_acdc(i)-
10)*Cmatrix_thermal(Index_cost_acdc(i)-10);
                Output_power(3,Index_cost_acdc(i)-
10)=Ssource_matrix_cost(Index_cost_acdc(i)-10);
                Ssource_matrix_cost(Index_cost_acdc(i)-10)=0;
                FF=' Themal load > source +++++++++++++++'
            else
                Lthermal_rem=0;
                Ssource_matrix_cost(Index_cost_acdc(i)-
10)=Ssource_matrix_cost(Index_cost_acdc(i)-10)-
Lthermal*(Lthermal_matrix(Index_cost_acdc(i)-10));
                Output_power(3,Index_cost_acdc(i)-
10)=Lthermal*(Lthermal_matrix(Index_cost_acdc(i)-10));
                Total_cost_thermal(i,Index_cost_acdc(i)-
10)=Lthermal*Cmatrix_thermal(Index_cost_acdc(i)-10);
                FF=' Themal load <= source +++++++++++++++'
            end
        end
      end
    end

    ff= ' next loop +++++++++++'
end
Total_cost_ac_sum=sum(Total_cost_ac)
%Total_cost_ac_sum_grid=Lac*Cmatrix_ac(4)
Total_cost_ac_sum_grid

Total_cost_dc_sum=sum(Total_cost_dc)
%Total_cost_dc_sum_grid=Ldc*(1/AC_DC)*Cmatrix_ac(4)
Total_cost_dc_sum_grid

Total_cost_thermal_sum=sum(Total_cost_thermal)
%Total_cost_thermal_sum_gas=Lthermal*(1/Gas_thermal)*Cmatrix_ac(5)
Total_cost_thermal_sum_gas

xlswrite('D://Low running cost controller.xlsx',Total_cost_ac_sum,'Based on AC
Cost','B3:F3');
xlswrite('D://Low running cost controller.xlsx',Total_cost_ac_sum_grid,'Based on AC
Cost','H3');
```

```
xlswrite('D://Low running cost controller.xlsx',Total_cost_dc_sum,'Based on AC
Cost','B4:F4');
xlswrite('D://Low running cost controller.xlsx',Total_cost_dc_sum_grid,'Based on AC
Cost','H4');
xlswrite('D://Low running cost controller.xlsx',Total_cost_thermal_sum,'Based on AC
Cost','B5:F5');
xlswrite('D://Low running cost controller.xlsx',Total_cost_thermal_sum_gas,'Based
on AC Cost','H5');
xlswrite('D://Low running cost controller.xlsx',Output_power,'Based on AC
Cost','H9');
```

APPENDIX 2: SERIAL COMMUNICATION CODE

```
/*
Serial Communication Added in Matlab

*/
disp(Index_ac);

arduino=serial('COM6','BAUD',9600); % create serial communication object on port

COM4

fopen(arduino); % initiate arduino communication

pause(30);

ardRead = fscanf(arduino);

disp(ardRead);

fprintf(arduino,'%d',Index_ac); % send answer variable content to ardui

fclose(arduino);



Serial.print(Voltage,3); // the '3' after voltage allows you to display 3 digits after
decimal point
 Serial.print("\t Amps = "); // shows the voltage measured
 Serial.println(Amps,3); // the '3' after voltage allows you to display 3 digits after
decimal point
 delay(2500);

}
```

APPENDIX 3: ARDUINO CODE

```
// Header library for Software Serial Communication with GSM Sheild
#include<SoftwareSerial.h>

//Defining the GSM Sheild Comunication via PWM pins 7 = Rx & 8 = Tx
SoftwareSerial GSMComm(7,8);

// for reading Current Sensor Output and keeping the Volt Results.
// Sample += 0.0049 * analogRead(Pin) Where 0.0049 is 5.0/1024 & Pin is A0 - A5
Pins where sensors are connected.
float sample1 = 0.0;
float sample2 = 0.0;
float sample3 = 0.0;
float sample4 = 0.0;
float sample5 = 0.0;

String Temp = ""; // Storing temporary priority coming from matlab
int TempLen; // Getting the Length of the String
char MyData[5] = {}; // Storing charachter of priority

int i = 0;
int k = 0;
void setup() {
// put your setup code here, to run once:
Serial.begin(9600);
GSMComm.begin(19200);
delay(1000);

//Defining the Mode of Pins
// These pins are used for Tiggering the Relay
/*
Pin 13 - Solar Relay
Pin 12 - Wind Relay
Pin 11 - Battery Relay
Pin 10 - Grid Relay
Pin 09 - Gas Relay
*/
pinMode(13, OUTPUT);
pinMode(12, OUTPUT);
pinMode(11, OUTPUT);
pinMode(10, OUTPUT);
pinMode(9, OUTPUT);
pinMode(0, INPUT);
pinMode(1, INPUT);
pinMode(2, INPUT);
```

```
pinMode(3, INPUT);
pinMode(4, INPUT);

// Relay Pins from pin 13 to 9. These pins are initially high to disable all the relays
initially.

digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);

Serial.print("Waiting for data from MATLAB : ");

// Reading Data From Matlab.
ReadPriority();

// Variable i is used for moving through the Array (MyData[ ]) where the priorities are
stored after reading from Matlab or Serial Communication.
i = 0;

// For Reading Data from Current Sensor
ReadValues();
ReadValues();
ReadValues();
ReadValues();

// Function is to trigger Relay based on what value is supplied to the parameter i. If i =
0, What ever value present in MyData[0] is present, it will trigger that relay.
/*
For example From matlab we receive 52341
Then at MyData[0] = 5
MyData[1] = 2
MyData[2] = 3
MyData[3] = 4
MyData[4] = 1

So TriggerRelayFirst(0)
will trigger 5th Source.
*/
TriggerRelayFirst(i);
}
void loop() {
// put your main code here, to run repeatedly:

//This if will not let i's value to go more than 4, since our Array only has length of 5
i.e. 0 - 4. If its greater than 4, it will make it 0
if(i>4)
```

```
{
i = 0;
}

// Checking the Array for Priority
// If priority matched, then will check for the voltage available.
// if both the conditions are satisfied i.e. priority and it's respective reference voltage then that particular source is used by triggering that perticular relay.
// If it does not matches the reference volts then it will go to the next relay by making i++ and Trigger that relay. And then read its voltage by ReadValue();
if (MyData[i] == '1')
{
ReadValues();
ReadValues();
ReadValues();
ReadValues();


if (sample1 >= 2.47 && sample1 < 2.49)
{
TriggerRelay(i);
}
else
{
i++;
TriggerRelay(i);
delay(1000);
ReadValues();
ReadValues();
ReadValues();
ReadValues();
delay(3000);
}
}
else if (MyData[i] == '2')
{
ReadValues();
ReadValues();
ReadValues();
ReadValues();
if (sample2 <= 2.49)
{
TriggerRelay(i);
}
else
{
i++;
TriggerRelay(i);
```

```
delay(1000);
ReadValues();
ReadValues();
ReadValues();
ReadValues();
delay(3000);
}
}
else if (MyData[i] == '3')
{
ReadValues();
ReadValues();
ReadValues();
ReadValues();
if (sample3 <= 2.50)
{
TriggerRelay(i);
}
else
{
i++;
TriggerRelay(i);
delay(1000);
ReadValues();
ReadValues();
ReadValues();
ReadValues();
delay(3000);
}
}
else if (MyData[i] == '4')
{
ReadValues();
ReadValues();
ReadValues();
ReadValues();
if (sample4 <= 2.49)
{
TriggerRelay(i);
}
else
{
i++;
TriggerRelay(i);
delay(1000);
ReadValues();
ReadValues();
ReadValues();
```

```
ReadValues();
delay(3000);
}
}
else if (MyData[i] == '5')
{
ReadValues();
ReadValues();
ReadValues();
ReadValues();
if (sample5 <= 2.50)
{
TriggerRelay(i);
}
else
{
i++;
TriggerRelay(i);
delay(1000);
ReadValues();
ReadValues();
ReadValues();
ReadValues();
delay(3000);
}
}
}

// Reading values form serial communication either from serial moniter or MATLAB
void ReadPriority()
{
while (!Serial.available())
{
// Waiting for Index Value to Come from MATLAB
}
if (Serial.available()>0)
{
// Reading string from serial communication
Temp = Serial.readString();
}
delay(100);
// calculating the length of the string
TempLen = Temp.length() + 1;
// Converting the string into Character array
Temp.toCharArray(MyData, TempLen);
// displaying the string to the serial moniter or matlab
Serial.print(Temp);
}
```

```
// Taking one thousand samples from the current sensor in sample variables which is
going to be used to trigger the source
void ReadValues()
{
for (int i = 0; i<1000; i++)
{
sample1 += 0.0049 * analogRead(0);
sample2 += 0.0049 * analogRead(1);
sample3 += 0.0049 * analogRead(2);
sample4 += 0.0049 * analogRead(3);
sample5 += 0.0049 * analogRead(4);
delay(1);
}

// Taking the average volts
sample1 = sample1 / 1000;
sample2 = sample2 / 1000;
sample3 = sample3 / 1000;
sample4 = sample4 / 1000;
sample5 = sample5 / 1000;
Serial.print("Solar Volt: ");
Serial.print(sample1);

Serial.print("   Wind Volt: ");
Serial.print(sample2);

Serial.print("   Battery Volts: ");
Serial.print(sample3);

Serial.print("   Grid Volt: ");
Serial.print(sample4);


Serial.print("   Gas Volt: ");
Serial.print(sample3);

Serial.println("");
}

// Triggering the Relays
void TriggerRelay(int val)
{
if(val > 4)
{
loop();
}
```

```
// To trigger next relay
if (MyData[val] == '1')
{
digitalWrite(13, LOW);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);
SendSMS("Resource Used: Solar","Solar");
digitalWrite(6, HIGH);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
}

if (MyData[val] == '2')
{
digitalWrite(13, HIGH);
digitalWrite(12, LOW);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);
SendSMS("Resource Used: Wind","Wind");
digitalWrite(6, LOW);
digitalWrite(5, HIGH);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
}

if (MyData[val] == '3')
{
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, LOW);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);
SendSMS("Resource Used: Battery","Battery");
digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, HIGH);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
}

if (MyData[val] == '4')
{
```

```
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, LOW);
digitalWrite(9, HIGH);
SendSMS("Resource Used: Grid","Grid");
digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, HIGH);
digitalWrite(2, LOW);
}

if (MyData[val] == '5')
{
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, LOW);
SendSMS("Resource Used: Gas","Gas");
digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, HIGH);
}
}

void TriggerRelayFirst(int val)
{
if (MyData[val] == '1')
{
digitalWrite(13, LOW);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);
//LED Pins
digitalWrite(6, HIGH);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
```

```
GSMComm.println("Resource Used: Solar");
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
}

if (MyData[val] == '2')
{
digitalWrite(13, HIGH);
digitalWrite(12, LOW);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);

digitalWrite(6, LOW);
digitalWrite(5, HIGH);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
GSMComm.println("Resource Used: Wind");
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
}

if (MyData[val] == '3')
{
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, LOW);
digitalWrite(10, HIGH);
digitalWrite(9, HIGH);

digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, HIGH);
digitalWrite(3, LOW);
digitalWrite(2, LOW);
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
```

```
GSMComm.println("Resource Used: Battery");
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
}

if (MyData[val] == '4')
{
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, LOW);
digitalWrite(9, HIGH);

digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, HIGH);
digitalWrite(2, LOW);
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
GSMComm.println("Resource Used: Grid");
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
}

if (MyData[val] == '5')
{
digitalWrite(13, HIGH);
digitalWrite(12, HIGH);
digitalWrite(11, HIGH);
digitalWrite(10, HIGH);
digitalWrite(9, LOW);

digitalWrite(6, LOW);
digitalWrite(5, LOW);
digitalWrite(4, LOW);
digitalWrite(3, LOW);
digitalWrite(2, HIGH);
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
```

```
GSMComm.println("Resource Used: Gas");
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
}
}
void SendSMS(String MSG, String CurrSource)
{
if(PrevSource == CurrSource)
{

}
else
{
GSMComm.print("AT+CMGF=1\r");
delay(100);
GSMComm.println("AT+CMGS = \"+97466093759\"");
delay(100);
GSMComm.println(MSG);
delay(100);
GSMComm.print((char)26);
delay(100);
GSMComm.println();
PrevSource = CurrSource;
}

}
```

APPENDIX 4: CURRENT MEASURING CODE

```
/*
Measuring Current Using ACS712
*/
const int analogIn = A0;
int mVperAmp = 185; // use 100 for 20A Module and 66 for 30A Module
int RawValue= 0;
int ACSoffset = 2500;
double Voltage = 0;
double Amps = 0;

void setup(){
 Serial.begin(9600);
}

void loop(){

 RawValue = analogRead(analogIn);
 Voltage = (RawValue / 1024.0) * 5000; // Gets you mV
 Amps = ((Voltage - ACSoffset) / mVperAmp);


 Serial.print("Raw Value = " ); // shows pre-scaled value
 Serial.print(RawValue);
 Serial.print("\t mV = "); // shows the voltage measured
```

APPENDIX 5: RELAYS TESTING CODE

```
/*
Testing the Relays Functionality
*/

void setup()
{
    pinMode(12, OUTPUT);
}

void loop()
{
    digitalWrite(12,HIGH);
    delay(1000);
    digitalWrite(12,LOW);
    delay(1000);
}
```

APPENDIX 6: DAILY CONSUMPTION AND SOURCES CAPACITY

Month	Day	Daily Consumption	Solar KWh/day	Wind KWh/day	Battery KWh/day	Grid KWh/day	Gas KWh/day	Solar irradiance	Wind speed (m/s)	Wind Power (...)	Wind ...
January	1	158.01	23.78	8.1	7.45	Unlimited	5.26	3.225	3.850	90	18
	2	140.72	25.82	24.0	7.45	Unlimited	5.26	3.503	5.358	200	24
	3	163.41	23.91	24.0	7.45	Unlimited	5.26	3.243	5.468	200	24
	4	171.20	24.94	24.0	7.45	Unlimited	5.26	3.383	5.106	200	24
	5	148.85	25.27	15.6	7.45	Unlimited	5.26	3.427	4.465	130	24
	6	144.62	22.12	24.0	7.45	Unlimited	5.26	3.000	5.607	200	24
	7	158.77	24.36	8.1	7.45	Unlimited	5.26	3.303	3.980	90	18
	8	164.67	24.61	8.1	7.45	Unlimited	5.26	3.337	3.035	90	18
	9	160.87	26.17	8.1	7.45	Unlimited	5.26	3.549	3.520	90	18
	10	175.29	27.93	15.6	7.45	Unlimited	5.26	3.789	4.301	130	24
	11	149.70	23.11	15.6	7.45	Unlimited	5.26	3.134	4.605	130	24
	12	156.15	27.11	36.0	7.45	Unlimited	5.26	3.677	6.338	300	24
	13	154.68	26.30	15.6	7.45	Unlimited	5.26	3.567	4.136	130	24
	14	166.68	24.47	15.6	7.45	Unlimited	5.26	3.319	4.964	130	24
	15	175.11	24.17	15.6	7.45	Unlimited	5.26	3.278	4.975	130	24
	16	174.59	26.42	8.1	7.45	Unlimited	5.26	3.583	3.827	90	18
	17	191.19	26.60	15.6	7.45	Unlimited	5.26	3.608	4.823	130	24
	18	178.68	24.51	15.6	7.45	Unlimited	5.26	3.324	4.884	130	24
	19	164.21	24.63	15.6	7.45	Unlimited	5.26	3.341	4.289	130	24

	20	161.28	23.10	8.1	7.45	Unlimited	5.26	3.133	3.106	90	18
	21	151.68	25.33	8.1	7.45	Unlimited	5.26	3.435	3.709	90	18
	22	161.58	25.09	8.1	7.45	Unlimited	5.26	3.403	3.325	90	18
	23	182.86	26.23	15.6	7.45	Unlimited	5.26	3.557	4.133	130	24
	24	150.97	22.14	15.6	7.45	Unlimited	5.26	3.003	4.214	130	24
	25	139.56	24.39	0.0	7.45	Unlimited	5.26	3.309	7.588	0	24
	26	164.94	25.64	24.0	7.45	Unlimited	5.26	3.477	5.059	200	24
	27	182.15	23.15	36.0	7.45	Unlimited	5.26	3.140	6.488	300	24
	28	168.30	23.66	8.1	7.45	Unlimited	5.26	3.209	3.213	90	18
	29	150.64	24.28	0.0	7.45	Unlimited	5.26	3.293	2.014	0	0
	30	177.67	23.27	8.1	7.45	Unlimited	5.26	3.156	3.365	90	18
	31	172.26	22.47	15.6	7.45	Unlimited	5.26	3.048	4.251	130	24
February	1	176.75	30.67	24.0	7.97	Unlimited	5.26	4.160	5.059	200	24
	2	181.90	31.29	8.1	7.97	Unlimited	5.26	4.244	3.392	90	18
	3	170.60	30.17	8.1	7.97	Unlimited	5.26	4.092	3.288	90	18
	4	164.07	30.63	24.0	7.97	Unlimited	5.26	4.154	5.194	200	24
	5	161.49	31.03	36.0	7.97	Unlimited	5.26	4.209	6.813	300	24
	6	166.41	34.26	15.6	7.97	Unlimited	5.26	4.647	4.368	130	24
	7	181.08	31.82	15.6	7.97	Unlimited	5.26	4.316	4.096	130	24
	8	160.92	29.87	15.6	7.97	Unlimited	5.26	4.052	4.248	130	24
	9	167.45	31.53	24.0	7.97	Unlimited	5.26	4.277	5.250	200	24
	10	154.33	31.54	24.0	7.97	Unlimited	5.26	4.277	5.018	200	24
	11	165.17	30.97	8.1	7.97	Unlimited	5.26	4.201	3.066	90	18

	12	163.97	32.08	8.1	7.97	Unlimited	5.26	4.351	3.498	90	18
	13	161.84	30.69	15.6	7.97	Unlimited	5.26	4.163	4.970	130	24
	14	179.44	32.85	15.6	7.97	Unlimited	5.26	4.455	4.387	130	24
	15	165.36	28.78	8.1	7.97	Unlimited	5.26	3.904	3.433	90	18
	16	149.04	29.62	15.6	7.97	Unlimited	5.26	4.017	4.151	130	24
	17	194.47	30.77	0.0	7.97	Unlimited	5.26	4.174	2.407	0	0
	18	171.76	30.59	2.0	7.97	Unlimited	5.26	4.149	2.880	40	10
	19	171.73	31.24	15.6	7.97	Unlimited	5.26	4.238	4.635	130	24
	20	172.40	32.13	15.6	7.97	Unlimited	5.26	4.358	4.531	130	24
	21	162.46	31.67	24.0	7.97	Unlimited	5.26	4.295	5.325	200	24
	22	171.32	30.07	24.0	7.97	Unlimited	5.26	4.079	5.629	200	24
	23	179.03	29.94	8.1	7.97	Unlimited	5.26	4.061	3.287	90	18
	24	174.44	30.42	8.1	7.97	Unlimited	5.26	4.125	3.131	90	18
	25	157.98	28.89	15.6	7.97	Unlimited	5.26	3.919	4.233	130	24
	26	169.30	30.01	36.0	7.97	Unlimited	5.26	4.070	6.099	300	24
	27	174.83	31.36	15.6	7.97	Unlimited	5.26	4.253	4.065	130	24
	28	141.20	31.10	0.0	7.97	Unlimited	5.26	4.219	2.085	0	0
	29	173.09	34.76	15.6	7.97	Unlimited	5.26	4.714	4.662	130	24
March	1	194.16	33.33	15.6	7.45	Unlimited	5.26	4.521	4.419	130	24
	2	191.54	32.56	2.0	7.45	Unlimited	5.26	4.416	2.710	40	10
	3	185.53	36.10	8.1	7.45	Unlimited	5.26	4.897	3.390	90	18
	4	182.48	35.46	8.1	7.45	Unlimited	5.26	4.809	3.944	90	18
	5	192.33	36.39	15.6	7.45	Unlimited	5.26	4.936	4.147	130	24

6	161.79	36.91	8.1	7.45	Unlimited	5.26	5.006	3.054	90	18
7	171.72	31.82	0.0	7.45	Unlimited	5.26	4.316	1.141	0	0
8	190.35	35.67	2.0	7.45	Unlimited	5.26	4.838	2.927	40	10
9	162.20	35.15	2.0	7.45	Unlimited	5.26	4.768	2.865	40	10
10	167.90	36.22	15.6	7.45	Unlimited	5.26	4.912	4.592	130	24
11	182.71	37.22	0.0	7.45	Unlimited	5.26	5.048	2.190	0	0
12	161.84	34.72	0.0	7.45	Unlimited	5.26	4.710	2.142	0	0
13	202.08	36.32	15.6	7.45	Unlimited	5.26	4.926	4.354	130	24
14	176.42	34.50	36.0	7.45	Unlimited	5.26	4.680	6.178	300	24
15	179.75	36.20	15.6	7.45	Unlimited	5.26	4.909	4.448	130	24
16	180.08	34.42	8.1	7.45	Unlimited	5.26	4.668	3.924	90	18
17	190.97	35.63	8.1	7.45	Unlimited	5.26	4.832	3.951	90	18
18	188.19	35.19	15.6	7.45	Unlimited	5.26	4.773	4.213	130	24
19	182.08	34.71	15.6	7.45	Unlimited	5.26	4.708	4.954	130	24
20	194.21	33.55	15.6	7.45	Unlimited	5.26	4.551	4.172	130	24
21	185.26	36.69	24.0	7.45	Unlimited	5.26	4.977	5.458	200	24
22	173.41	36.17	8.1	7.45	Unlimited	5.26	4.906	3.904	90	18
23	181.71	34.26	0.0	7.45	Unlimited	5.26	4.646	2.309	0	0
24	198.01	38.11	15.6	7.45	Unlimited	5.26	5.169	4.497	130	24
25	186.91	36.74	8.1	7.45	Unlimited	5.26	4.983	3.396	90	18
26	183.74	33.79	8.1	7.45	Unlimited	5.26	4.584	3.711	90	18
27	179.11	34.60	2.0	7.45	Unlimited	5.26	4.694	2.839	40	10
28	183.89	33.38	8.1	7.45	Unlimited	5.26	4.527	3.062	90	18

	29	184.70	34.47	24.0	7.45	Unlimited	5.26	4.675	5.069	200	24
	30	175.41	35.67	15.6	7.45	Unlimited	5.26	4.838	4.744	130	24
	31	179.68	35.29	8.1	7.45	Unlimited	5.26	4.786	3.994	90	18
	1	189.23	38.62	8.1	7.70	Unlimited	5.26	5.239	3.350	90	18
	2	180.12	41.90	8.1	7.70	Unlimited	5.26	5.683	3.464	90	18
	3	209.05	44.10	15.6	7.70	Unlimited	5.26	5.981	4.075	130	24
	4	200.83	41.91	8.1	7.70	Unlimited	5.26	5.685	3.343	90	18
	5	193.89	40.49	8.1	7.70	Unlimited	5.26	5.492	3.846	90	18
	6	196.84	41.44	0.0	7.70	Unlimited	5.26	5.621	1.284	0	0
	7	181.28	44.06	8.1	7.70	Unlimited	5.26	5.976	3.358	90	18
	8	187.07	39.59	15.6	7.70	Unlimited	5.26	5.369	4.792	130	24
	9	184.00	43.70	15.6	7.70	Unlimited	5.26	5.927	4.055	130	24
	10	175.51	42.07	36.0	7.70	Unlimited	5.26	5.706	6.005	300	24
April	11	183.69	43.13	8.1	7.70	Unlimited	5.26	5.849	3.634	90	18
	12	203.76	43.74	24.0	7.70	Unlimited	5.26	5.933	5.642	200	24
	13	175.18	39.83	24.0	7.70	Unlimited	5.26	5.402	5.538	200	24
	14	189.75	43.01	2.0	7.70	Unlimited	5.26	5.834	2.731	40	10
	15	175.60	42.34	2.0	7.70	Unlimited	5.26	5.742	2.832	40	10
	16	186.40	40.62	36.0	7.70	Unlimited	5.26	5.509	6.172	300	24
	17	200.40	42.54	24.0	7.70	Unlimited	5.26	5.770	5.088	200	24
	18	207.70	42.78	8.1	7.70	Unlimited	5.26	5.802	3.773	90	18
	19	196.61	38.65	2.0	7.70	Unlimited	5.26	5.242	2.766	40	10
	20	198.67	40.92	24.0	7.70	Unlimited	5.26	5.550	5.435	200	24

	21	203.72	41.76	8.1	7.70	Unlimited	5.26	5.664	3.810	90	18
	22	201.39	43.09	15.6	7.70	Unlimited	5.26	5.844	4.617	130	24
	23	194.46	44.57	8.1	7.70	Unlimited	5.26	6.045	3.443	90	18
	24	193.94	41.52	8.1	7.70	Unlimited	5.26	5.632	3.717	90	18
	25	195.76	41.91	2.0	7.70	Unlimited	5.26	5.684	2.721	40	10
	26	177.99	42.82	8.1	7.70	Unlimited	5.26	5.807	3.836	90	18
	27	194.21	39.95	15.6	7.70	Unlimited	5.26	5.419	4.183	130	24
	28	194.65	45.46	8.1	7.70	Unlimited	5.26	6.166	3.418	90	18
	29	201.16	43.62	8.1	7.70	Unlimited	5.26	5.917	3.749	90	18
	30	201.26	41.57	0.0	7.70	Unlimited	5.26	5.639	1.880	0	0
May	1	201.51	49.62	36.0	7.45	Unlimited	5.26	6.730	6.972	300	24
	2	194.95	50.06	24.0	7.45	Unlimited	5.26	6.790	5.358	200	24
	3	207.55	49.42	24.0	7.45	Unlimited	5.26	6.703	5.186	200	24
	4	205.19	51.90	15.6	7.45	Unlimited	5.26	7.040	4.062	130	24
	5	194.21	49.73	36.0	7.45	Unlimited	5.26	6.745	6.186	300	24
	6	214.03	52.07	24.0	7.45	Unlimited	5.26	7.063	5.330	200	24
	7	195.89	51.05	15.6	7.45	Unlimited	5.26	6.924	4.800	130	24
	8	193.79	52.51	24.0	7.45	Unlimited	5.26	7.122	5.566	200	24
	9	173.01	48.86	36.0	7.45	Unlimited	5.26	6.627	6.491	300	24
	10	180.68	49.36	15.6	7.45	Unlimited	5.26	6.694	4.643	130	24
	11	211.28	48.53	36.0	7.45	Unlimited	5.26	6.582	6.407	300	24
	12	202.12	53.35	15.6	7.45	Unlimited	5.26	7.236	4.769	130	24
	13	184.58	51.42	24.0	7.45	Unlimited	5.26	6.974	5.327	200	24

	14	222.20	50.89	36.0	7.45	Unlimited	5.26	6.902	6.225	300	24
	15	200.13	50.80	36.0	7.45	Unlimited	5.26	6.890	6.933	300	24
	16	189.38	49.12	24.0	7.45	Unlimited	5.26	6.663	5.597	200	24
	17	210.80	52.60	15.6	7.45	Unlimited	5.26	7.135	4.967	130	24
	18	217.87	51.79	15.6	7.45	Unlimited	5.26	7.024	4.262	130	24
	19	194.40	48.43	8.1	7.45	Unlimited	5.26	6.569	3.700	90	18
	20	193.66	50.70	24.0	7.45	Unlimited	5.26	6.877	5.365	200	24
	21	198.96	51.62	36.0	7.45	Unlimited	5.26	7.001	6.169	300	24
	22	204.49	50.50	24.0	7.45	Unlimited	5.26	6.850	5.868	200	24
	23	191.59	53.96	36.0	7.45	Unlimited	5.26	7.319	6.180	300	24
	24	219.17	51.73	24.0	7.45	Unlimited	5.26	7.017	5.424	200	24
	25	191.10	52.48	8.1	7.45	Unlimited	5.26	7.118	3.758	90	18
	26	193.91	51.73	15.6	7.45	Unlimited	5.26	7.016	4.382	130	24
	27	194.82	50.59	36.0	7.45	Unlimited	5.26	6.862	6.182	300	24
	28	206.67	49.80	36.0	7.45	Unlimited	5.26	6.755	6.256	300	24
	29	188.36	51.80	24.0	7.45	Unlimited	5.26	7.026	5.919	200	24
	30	209.14	52.21	8.1	7.45	Unlimited	5.26	7.082	3.962	90	18
	31	195.70	49.38	15.6	7.45	Unlimited	5.26	6.697	4.118	130	24
	1	207.39	52.15	36.0	7.70	Unlimited	5.26	7.074	6.131	300	24
	2	208.08	54.72	24.0	7.70	Unlimited	5.26	7.421	5.534	200	24
June	3	222.69	54.77	15.6	7.70	Unlimited	5.26	7.429	4.608	130	24
	4	228.10	53.79	8.1	7.70	Unlimited	5.26	7.296	3.371	90	18
	5	189.92	56.01	36.0	7.70	Unlimited	5.26	7.596	6.901	300	24

6	217.86	57.25	36.0	7.70	Unlimited	5.26	7.765	6.054	300	24
7	225.81	54.35	15.6	7.70	Unlimited	5.26	7.372	4.269	130	24
8	211.81	55.47	15.6	7.70	Unlimited	5.26	7.523	4.352	130	24
9	202.48	53.94	24.0	7.70	Unlimited	5.26	7.316	5.410	200	24
10	207.84	55.77	24.0	7.70	Unlimited	5.26	7.565	5.875	200	24
11	205.81	56.83	15.6	7.70	Unlimited	5.26	7.708	4.348	130	24
12	206.42	54.12	15.6	7.70	Unlimited	5.26	7.341	4.202	130	24
13	199.51	51.75	24.0	7.70	Unlimited	5.26	7.020	5.735	200	24
14	203.68	53.07	36.0	7.70	Unlimited	5.26	7.198	6.296	300	24
15	217.63	57.21	24.0	7.70	Unlimited	5.26	7.760	5.828	200	24
16	202.94	55.58	36.0	7.70	Unlimited	5.26	7.539	6.050	300	24
17	196.50	53.90	8.1	7.70	Unlimited	5.26	7.311	3.376	90	18
18	215.86	55.26	36.0	7.70	Unlimited	5.26	7.495	6.665	300	24
19	214.51	53.07	8.1	7.70	Unlimited	5.26	7.198	3.381	90	18
20	207.18	52.59	24.0	7.70	Unlimited	5.26	7.134	5.653	200	24
21	192.40	49.87	15.6	7.70	Unlimited	5.26	6.765	4.035	130	24
22	206.52	53.28	8.1	7.70	Unlimited	5.26	7.227	3.950	90	18
23	208.56	54.84	36.0	7.70	Unlimited	5.26	7.438	6.403	300	24
24	215.18	57.73	24.0	7.70	Unlimited	5.26	7.831	5.757	200	24
25	213.46	52.41	15.6	7.70	Unlimited	5.26	7.108	4.969	130	24
26	205.53	53.78	24.0	7.70	Unlimited	5.26	7.295	5.462	200	24
27	212.50	56.47	36.0	7.70	Unlimited	5.26	7.659	6.182	300	24
28	220.50	53.86	8.1	7.70	Unlimited	5.26	7.305	3.850	90	18

	29	226.86	53.72	8.1	7.70	Unlimited	5.26	7.286	3.939	90	18
	30	211.87	56.54	15.6	7.70	Unlimited	5.26	7.669	4.548	130	24
	1	210.89	50.47	24.0	7.45	Unlimited	5.26	6.845	5.534	200	24
	2	218.52	48.72	8.1	7.45	Unlimited	5.26	6.609	3.685	90	18
	3	221.46	55.61	24.0	7.45	Unlimited	5.26	7.543	5.471	200	24
	4	214.32	51.77	15.6	7.45	Unlimited	5.26	7.022	4.016	130	24
	5	204.69	50.48	0.0	7.45	Unlimited	5.26	6.847	1.708	0	0
	6	205.35	51.58	2.0	7.45	Unlimited	5.26	6.996	2.539	40	10
	7	236.18	51.27	2.0	7.45	Unlimited	5.26	6.953	2.798	40	10
	8	199.22	50.43	15.6	7.45	Unlimited	5.26	6.839	4.221	130	24
	9	198.85	53.02	15.6	7.45	Unlimited	5.26	7.192	4.014	130	24
	10	204.45	49.64	2.0	7.45	Unlimited	5.26	6.732	2.644	40	10
July	11	218.43	52.65	8.1	7.45	Unlimited	5.26	7.142	3.859	90	18
	12	197.28	50.45	15.6	7.45	Unlimited	5.26	6.843	4.197	130	24
	13	217.63	52.92	15.6	7.45	Unlimited	5.26	7.178	4.146	130	24
	14	208.54	50.70	24.0	7.45	Unlimited	5.26	6.877	5.151	200	24
	15	213.39	51.87	8.1	7.45	Unlimited	5.26	7.035	3.499	90	18
	16	199.04	52.75	15.6	7.45	Unlimited	5.26	7.154	4.000	130	24
	17	222.09	51.11	15.6	7.45	Unlimited	5.26	6.932	4.065	130	24
	18	194.07	51.70	8.1	7.45	Unlimited	5.26	7.012	3.769	90	18
	19	207.32	52.48	36.0	7.45	Unlimited	5.26	7.118	6.020	300	24
	20	199.35	51.97	15.6	7.45	Unlimited	5.26	7.049	4.928	130	24
	21	229.32	49.38	24.0	7.45	Unlimited	5.26	6.698	5.389	200	24

	22	205.73	53.89	2.0	7.45	Unlimited	5.26	7.309	2.896	40	10
	23	226.02	51.19	8.1	7.45	Unlimited	5.26	6.943	3.304	90	18
	24	223.46	50.57	8.1	7.45	Unlimited	5.26	6.859	3.735	90	18
	25	217.88	49.91	8.1	7.45	Unlimited	5.26	6.770	3.126	90	18
	26	228.49	52.42	15.6	7.45	Unlimited	5.26	7.109	4.606	130	24
	27	211.50	51.47	15.6	7.45	Unlimited	5.26	6.982	4.233	130	24
	28	207.09	50.13	15.6	7.45	Unlimited	5.26	6.800	4.556	130	24
	29	203.32	49.41	15.6	7.45	Unlimited	5.26	6.701	4.119	130	24
	30	210.21	53.42	24.0	7.45	Unlimited	5.26	7.245	5.033	200	24
	31	215.88	51.18	0.0	7.45	Unlimited	5.26	6.942	1.237	0	0
	1	177.04	48.13	15.6	7.70	Unlimited	5.26	6.528	4.774	130	24
	2	183.81	48.25	15.6	7.70	Unlimited	5.26	6.544	4.644	130	24
	3	187.35	47.70	8.1	7.70	Unlimited	5.26	6.470	3.124	90	18
	4	179.61	44.98	2.0	7.70	Unlimited	5.26	6.101	2.704	40	10
	5	195.20	46.67	8.1	7.70	Unlimited	5.26	6.330	3.920	90	18
	6	196.88	50.51	15.6	7.70	Unlimited	5.26	6.850	4.898	130	24
August	7	180.22	50.67	15.6	7.70	Unlimited	5.26	6.872	4.412	130	24
	8	187.37	47.61	24.0	7.70	Unlimited	5.26	6.457	5.051	200	24
	9	195.79	48.84	24.0	7.70	Unlimited	5.26	6.625	5.495	200	24
	10	191.95	46.66	15.6	7.70	Unlimited	5.26	6.328	4.245	130	24
	11	194.62	48.70	8.1	7.70	Unlimited	5.26	6.606	3.522	90	18
	12	181.77	48.12	2.0	7.70	Unlimited	5.26	6.526	2.935	40	10
	13	175.23	47.83	8.1	7.70	Unlimited	5.26	6.487	3.776	90	18

	14	194.91	46.97	2.0	7.70	Unlimited	5.26	6.371	2.724	40	10
	15	203.74	49.41	15.6	7.70	Unlimited	5.26	6.701	4.192	130	24
	16	191.02	46.10	15.6	7.70	Unlimited	5.26	6.252	4.333	130	24
	17	186.49	46.83	15.6	7.70	Unlimited	5.26	6.352	4.541	130	24
	18	178.37	47.92	24.0	7.70	Unlimited	5.26	6.500	5.100	200	24
	19	193.28	46.94	8.1	7.70	Unlimited	5.26	6.367	3.094	90	18
	20	194.76	48.43	15.6	7.70	Unlimited	5.26	6.569	4.724	130	24
	21	190.62	46.93	8.1	7.70	Unlimited	5.26	6.365	3.739	90	18
	22	195.07	47.02	0.0	7.70	Unlimited	5.26	6.378	2.309	0	0
	23	194.93	46.93	8.1	7.70	Unlimited	5.26	6.366	3.895	90	18
	24	188.13	47.61	15.6	7.70	Unlimited	5.26	6.458	4.981	130	24
	25	184.98	48.43	15.6	7.70	Unlimited	5.26	6.569	4.961	130	24
	26	182.77	47.99	8.1	7.70	Unlimited	5.26	6.510	3.884	90	18
	27	203.09	46.41	2.0	7.70	Unlimited	5.26	6.295	2.817	40	10
	28	200.39	49.27	15.6	7.70	Unlimited	5.26	6.682	4.110	130	24
	29	188.51	45.57	15.6	7.70	Unlimited	5.26	6.181	4.510	130	24
	30	205.86	46.79	8.1	7.70	Unlimited	5.26	6.346	3.896	90	18
	1	197.99	41.92	8.1	7.45	Unlimited	5.26	5.686	3.509	90	18
	2	171.70	41.52	0.0	7.45	Unlimited	5.26	5.631	1.965	0	0
September	3	172.00	41.81	0.0	7.45	Unlimited	5.26	5.670	1.982	0	0
	4	204.78	42.93	0.0	7.45	Unlimited	5.26	5.823	1.666	0	0
	5	186.59	42.78	8.1	7.45	Unlimited	5.26	5.802	3.585	90	18
	6	192.99	43.99	8.1	7.45	Unlimited	5.26	5.967	3.058	90	18

7	172.10	41.79	2.0	7.45	Unlimited	5.26	5.669	2.889	40	10
8	186.37	40.15	0.0	7.45	Unlimited	5.26	5.445	0.785	0	0
9	167.99	40.80	8.1	7.45	Unlimited	5.26	5.534	3.067	90	18
10	190.70	40.75	8.1	7.45	Unlimited	5.26	5.528	3.126	90	18
11	169.35	40.21	2.0	7.45	Unlimited	5.26	5.454	2.923	40	10
12	187.63	42.69	15.6	7.45	Unlimited	5.26	5.790	4.406	130	24
13	162.07	43.00	0.0	7.45	Unlimited	5.26	5.832	1.539	0	0
14	181.36	44.70	8.1	7.45	Unlimited	5.26	6.063	3.871	90	18
15	183.99	42.03	0.0	7.45	Unlimited	5.26	5.700	2.273	0	0
16	176.74	42.92	0.0	7.45	Unlimited	5.26	5.821	1.661	0	0
17	174.86	41.55	8.1	7.45	Unlimited	5.26	5.636	3.058	90	18
18	190.02	43.83	8.1	7.45	Unlimited	5.26	5.945	3.859	90	18
19	188.41	43.62	2.0	7.45	Unlimited	5.26	5.916	2.828	40	10
20	173.31	43.04	15.6	7.45	Unlimited	5.26	5.838	4.435	130	24
21	166.77	41.37	8.1	7.45	Unlimited	5.26	5.611	3.482	90	18
22	181.66	43.51	0.0	7.45	Unlimited	5.26	5.902	1.751	0	0
23	181.88	43.35	0.0	7.45	Unlimited	5.26	5.880	1.964	0	0
24	182.18	41.20	8.1	7.45	Unlimited	5.26	5.588	3.115	90	18
25	178.44	41.91	0.0	7.45	Unlimited	5.26	5.685	2.186	0	0
26	171.40	43.54	8.1	7.45	Unlimited	5.26	5.906	3.733	90	18
27	187.54	41.22	0.0	7.45	Unlimited	5.26	5.591	1.921	0	0
28	188.51	41.02	15.6	7.45	Unlimited	5.26	5.564	4.263	130	24
29	183.32	45.35	0.0	7.45	Unlimited	5.26	6.151	2.438	0	0

	30	199.48	41.75	8.1	7.45	Unlimited	5.26	5.663	3.568	90	18
	31	181.01	43.28	0.0	7.45	Unlimited	5.26	5.870	1.787	0	0
	1	176.94	33.69	0.0	7.70	Unlimited	5.26	4.569	2.386	0	0
	2	184.44	36.27	2.0	7.70	Unlimited	5.26	4.919	2.528	40	10
	3	159.84	38.58	8.1	7.70	Unlimited	5.26	5.233	3.549	90	18
	4	182.74	33.63	0.0	7.70	Unlimited	5.26	4.561	1.546	0	0
	5	173.82	34.43	0.0	7.70	Unlimited	5.26	4.670	1.960	0	0
	6	171.62	37.36	0.0	7.70	Unlimited	5.26	5.067	2.423	0	0
	7	163.34	36.37	24.0	7.70	Unlimited	5.26	4.933	5.599	200	24
	8	154.84	33.39	8.1	7.70	Unlimited	5.26	4.529	3.524	90	18
	9	182.06	35.22	15.6	7.70	Unlimited	5.26	4.777	4.577	130	24
	10	155.63	31.85	8.1	7.70	Unlimited	5.26	4.320	3.145	90	18
October	11	168.59	36.91	8.1	7.70	Unlimited	5.26	5.006	3.999	90	18
	12	178.57	33.67	0.0	7.70	Unlimited	5.26	4.567	1.526	0	0
	13	168.80	34.57	15.6	7.70	Unlimited	5.26	4.689	4.399	130	24
	14	183.24	36.37	8.1	7.70	Unlimited	5.26	4.933	3.757	90	18
	15	162.51	33.40	15.6	7.70	Unlimited	5.26	4.530	4.206	130	24
	16	176.58	33.63	15.6	7.70	Unlimited	5.26	4.561	4.492	130	24
	17	158.81	35.05	15.6	7.70	Unlimited	5.26	4.753	4.209	130	24
	18	164.55	35.15	0.0	7.70	Unlimited	5.26	4.768	2.500	0	0
	19	161.09	39.00	8.1	7.70	Unlimited	5.26	5.289	3.805	90	18
	20	153.44	37.65	0.0	7.70	Unlimited	5.26	5.107	2.399	0	0
	21	166.79	34.72	8.1	7.70	Unlimited	5.26	4.709	3.376	90	18

	22	177.77	34.73	8.1	7.70	Unlimited	5.26	4.710	3.202	90	18
	23	176.43	33.59	0.0	7.70	Unlimited	5.26	4.556	1.770	0	0
	24	170.56	36.20	0.0	7.70	Unlimited	5.26	4.911	1.303	0	0
	25	165.24	35.24	2.0	7.70	Unlimited	5.26	4.780	2.586	40	10
	26	190.30	39.04	2.0	7.70	Unlimited	5.26	5.295	2.802	40	10
	27	167.82	36.73	8.1	7.70	Unlimited	5.26	4.982	3.881	90	18
	28	177.11	36.19	8.1	7.70	Unlimited	5.26	4.908	3.371	90	18
	29	160.40	36.69	0.0	7.70	Unlimited	5.26	4.976	1.825	0	0
	30	162.66	37.00	2.0	7.70	Unlimited	5.26	5.019	2.619	40	10
	1	157.01	26.56	8.1	7.45	Unlimited	5.26	3.602	3.278	90	18
	2	178.40	25.85	0.0	7.45	Unlimited	5.26	3.507	1.486	0	0
	3	159.73	26.75	24.0	7.45	Unlimited	5.26	3.628	5.836	200	24
	4	155.25	27.60	15.6	7.45	Unlimited	5.26	3.743	4.100	130	24
	5	153.97	26.42	36.0	7.45	Unlimited	5.26	3.583	6.142	300	24
	6	157.61	25.51	15.6	7.45	Unlimited	5.26	3.459	4.143	130	24
November	7	162.87	28.87	0.0	7.45	Unlimited	5.26	3.916	2.199	0	0
	8	158.39	28.04	15.6	7.45	Unlimited	5.26	3.803	4.687	130	24
	9	151.71	27.34	8.1	7.45	Unlimited	5.26	3.708	3.617	90	18
	10	156.68	26.89	15.6	7.45	Unlimited	5.26	3.647	4.710	130	24
	11	158.81	28.97	24.0	7.45	Unlimited	5.26	3.929	5.405	200	24
	12	163.38	28.38	15.6	7.45	Unlimited	5.26	3.849	4.301	130	24
	13	140.75	27.14	0.0	7.45	Unlimited	5.26	3.681	1.997	0	0
	14	147.37	28.15	15.6	7.45	Unlimited	5.26	3.819	4.586	130	24

	15	166.96	29.89	2.0	7.45	Unlimited	5.26	4.054	2.857	40	10
	16	165.93	27.15	24.0	7.45	Unlimited	5.26	3.682	5.024	200	24
	17	176.45	25.50	15.6	7.45	Unlimited	5.26	3.459	4.129	130	24
	18	172.63	27.51	24.0	7.45	Unlimited	5.26	3.732	5.517	200	24
	19	156.25	26.76	15.6	7.45	Unlimited	5.26	3.630	4.416	130	24
	20	164.90	27.26	15.6	7.45	Unlimited	5.26	3.697	4.423	130	24
	21	152.82	26.32	8.1	7.45	Unlimited	5.26	3.570	3.102	90	18
	22	163.71	29.26	8.1	7.45	Unlimited	5.26	3.969	3.205	90	18
	23	153.52	26.10	8.1	7.45	Unlimited	5.26	3.540	3.903	90	18
	24	157.88	25.84	8.1	7.45	Unlimited	5.26	3.504	3.407	90	18
	25	164.20	28.59	0.0	7.45	Unlimited	5.26	3.878	1.986	0	0
	26	163.19	28.95	8.1	7.45	Unlimited	5.26	3.927	3.710	90	18
	27	170.51	27.38	15.6	7.45	Unlimited	5.26	3.714	4.239	130	24
	28	173.52	27.50	2.0	7.45	Unlimited	5.26	3.729	2.675	40	10
	29	150.67	25.19	15.6	7.45	Unlimited	5.26	3.417	4.533	130	24
	30	156.76	27.28	8.1	7.45	Unlimited	5.26	3.700	3.131	90	18
	31	154.65	27.60	8.1	7.45	Unlimited	5.26	3.743	3.608	90	18
December	1	149.57	23.82	8.1	7.70	Unlimited	5.26	3.231	3.681	90	18
	2	150.52	22.10	15.6	7.70	Unlimited	5.26	2.997	4.120	130	24
	3	168.12	23.29	0.0	7.70	Unlimited	5.26	3.159	2.183	0	0
	4	149.06	25.40	15.6	7.70	Unlimited	5.26	3.445	4.367	130	24
	5	157.42	23.63	8.1	7.70	Unlimited	5.26	3.205	3.170	90	18
	6	157.56	25.22	8.1	7.70	Unlimited	5.26	3.421	3.264	90	18

7	149.53	22.94	15.6	7.70	Unlimited	5.26	3.112	4.658	130	24
8	139.53	22.42	2.0	7.70	Unlimited	5.26	3.041	2.858	40	10
9	144.87	22.46	2.0	7.70	Unlimited	5.26	3.046	2.853	40	10
10	164.28	26.33	15.6	7.70	Unlimited	5.26	3.571	4.737	130	24
11	156.73	24.45	15.6	7.70	Unlimited	5.26	3.317	4.991	130	24
12	165.39	21.26	0.0	7.70	Unlimited	5.26	2.884	2.107	0	0
13	144.18	21.21	24.0	7.70	Unlimited	5.26	2.876	5.651	200	24
14	133.77	20.72	24.0	7.70	Unlimited	5.26	2.810	5.329	200	24
15	143.88	21.64	8.1	7.70	Unlimited	5.26	2.935	3.070	90	18
16	167.44	22.16	8.1	7.70	Unlimited	5.26	3.005	3.471	90	18
17	143.98	22.22	15.6	7.70	Unlimited	5.26	3.014	4.108	130	24
18	149.02	23.96	8.1	7.70	Unlimited	5.26	3.250	3.969	90	18
19	138.11	23.37	15.6	7.70	Unlimited	5.26	3.169	4.766	130	24
20	173.33	21.79	15.6	7.70	Unlimited	5.26	2.955	4.329	130	24
21	158.94	25.52	15.6	7.70	Unlimited	5.26	3.462	4.244	130	24
22	158.84	23.76	8.1	7.70	Unlimited	5.26	3.223	3.938	90	18
23	149.48	21.51	8.1	7.70	Unlimited	5.26	2.918	3.588	90	18
24	142.55	21.92	8.1	7.70	Unlimited	5.26	2.973	3.233	90	18
25	148.70	21.13	36.0	7.70	Unlimited	5.26	2.866	6.648	300	24
26	155.65	23.43	15.6	7.70	Unlimited	5.26	3.178	4.344	130	24
27	158.71	22.04	8.1	7.70	Unlimited	5.26	2.990	3.766	90	18
28	149.78	22.57	0.0	7.70	Unlimited	5.26	3.061	1.682	0	0
29	147.97	21.87	15.6	7.70	Unlimited	5.26	2.966	4.458	130	24

30	150.39	24.12	15.6	7.70	Unlimited	5.26	3.271	4.212	130	24

APPENDIX 7: OPTIMAL SOURCES CONSUMPTION WITH THE OPTIMAL COSTS AND SAVINGS

Month	Day	Solar KWh/day	Wind KWh/day	Battery KWh/day	Grid KWh/day	Gas KWh/day	Actual Cost	Optimized Cost	Savings
January	1	23.78	8.1	7.45	113.4	5.26	49.60	48.00	1.60
	2	25.82	24.0	7.45	78.2	5.26	44.17	40.39	3.78
	3	23.91	24.0	7.45	102.8	5.26	51.30	47.54	3.75
	4	24.94	24.0	7.45	109.5	5.26	53.74	49.97	3.77
	5	25.27	15.6	7.45	95.3	5.26	46.72	44.09	2.64
	6	22.12	24.0	7.45	85.8	5.26	45.40	41.67	3.73
	7	24.36	8.1	7.45	113.6	5.26	49.84	48.23	1.61
	8	24.61	8.1	7.45	119.2	5.26	51.69	50.08	1.61
	9	26.17	8.1	7.45	113.9	5.26	50.50	48.86	1.64
	10	27.93	15.6	7.45	119.0	5.26	55.02	52.34	2.68
	11	23.11	15.6	7.45	98.3	5.26	46.99	44.39	2.60
	12	27.11	36.0	7.45	80.3	5.26	49.02	43.59	5.43
	13	26.30	15.6	7.45	100.1	5.26	48.55	45.90	2.65
	14	24.47	15.6	7.45	113.9	5.26	52.32	49.70	2.62
	15	24.17	15.6	7.45	122.6	5.26	54.97	52.35	2.62
	16	26.42	8.1	7.45	127.4	5.26	54.80	53.16	1.64
	17	26.60	15.6	7.45	136.3	5.26	60.01	57.36	2.66
	18	24.51	15.6	7.45	125.9	5.26	56.09	53.46	2.63
	19	24.63	15.6	7.45	111.3	5.26	51.54	48.92	2.63
	20	23.10	8.1	7.45	117.4	5.26	50.62	49.04	1.59
	21	25.33	8.1	7.45	105.5	5.26	47.61	45.99	1.62
	22	25.09	8.1	7.45	115.7	5.26	50.72	49.10	1.62
	23	26.23	15.6	7.45	128.3	5.26	57.40	54.75	2.65
	24	22.14	15.6	7.45	100.5	5.26	47.39	44.80	2.59
	25	24.39	0.0	7.45	102.4	5.26	43.81	43.30	0.51
	26	25.64	24.0	7.45	102.6	5.26	51.78	47.99	3.78
	27	23.15	36.0	7.45	110.3	5.26	57.18	51.81	5.37
	28	23.66	8.1	7.45	123.8	5.26	52.83	51.23	1.60
	29	24.28	0.0	7.45	113.6	5.26	47.29	46.78	0.51
	30	23.27	8.1	7.45	133.6	5.26	55.77	54.18	1.59
	31	22.47	15.6	7.45	121.5	5.26	54.07	51.48	2.59
February	1	30.67	24.0	7.97	108.5	5.63	55.48	51.61	3.87
	2	31.29	8.1	7.97	128.9	5.63	57.10	55.38	1.72
	3	30.17	8.1	7.97	118.7	5.63	53.55	51.84	1.71
	4	30.63	24.0	7.97	95.9	5.63	51.50	47.64	3.87
	5	31.03	36.0	7.97	80.9	5.63	50.69	45.19	5.50

	6	34.26	15.6	7.97	102.9	5.63	52.23	49.45	2.79
	7	31.82	15.6	7.97	120.1	5.63	56.84	54.09	2.75
	8	29.87	15.6	7.97	101.9	5.63	50.51	47.79	2.72
	9	31.53	24.0	7.97	98.3	5.63	52.56	48.68	3.88
	10	31.54	24.0	7.97	85.2	5.63	48.44	44.56	3.88
	11	30.97	8.1	7.97	112.5	5.63	51.85	50.13	1.72
	12	32.08	8.1	7.97	110.2	5.63	51.47	49.73	1.74
	13	30.69	15.6	7.97	102.0	5.63	50.80	48.07	2.73
	14	32.85	15.6	7.97	117.4	5.63	56.33	53.56	2.76
	15	28.78	8.1	7.97	114.9	5.63	51.91	50.22	1.68
	16	29.62	15.6	7.97	90.2	5.63	46.78	44.07	2.71
	17	30.77	0.0	7.97	150.1	5.63	61.04	60.43	0.62
	18	30.59	2.0	7.97	125.6	5.63	53.92	53.03	0.89
	19	31.24	15.6	7.97	111.3	5.63	53.91	51.17	2.74
	20	32.13	15.6	7.97	111.1	5.63	54.12	51.36	2.75
	21	31.67	24.0	7.97	93.2	5.63	51.00	47.11	3.88
	22	30.07	24.0	7.97	103.7	5.63	53.78	49.92	3.86
	23	29.94	8.1	7.97	127.4	5.63	56.20	54.49	1.70
	24	30.42	8.1	7.97	122.3	5.63	54.76	53.05	1.71
	25	28.89	15.6	7.97	99.9	5.63	49.59	46.89	2.70
	26	30.01	36.0	7.97	89.7	5.63	53.14	47.66	5.48
	27	31.36	15.6	7.97	114.3	5.63	54.88	52.14	2.74
	28	31.10	0.0	7.97	96.5	5.63	44.32	43.70	0.62
	29	34.76	15.6	7.97	109.1	5.63	54.33	51.54	2.79
	1	33.33	15.6	7.45	132.5	5.26	60.95	58.18	2.76
	2	32.56	2.0	7.45	144.3	5.26	60.12	59.22	0.91
	3	36.10	8.1	7.45	128.6	5.26	58.24	56.45	1.79
	4	35.46	8.1	7.45	126.2	5.26	57.28	55.50	1.78
	5	36.39	15.6	7.45	127.6	5.26	60.37	57.56	2.81
	6	36.91	8.1	7.45	104.1	5.26	50.79	48.99	1.80
	7	31.82	0.0	7.45	127.2	5.26	53.90	53.28	0.63
	8	35.67	2.0	7.45	140.0	5.26	59.75	58.79	0.96
	9	35.15	2.0	7.45	112.3	5.26	50.91	49.97	0.95
March	10	36.22	15.6	7.45	103.4	5.26	52.70	49.90	2.81
	11	37.22	0.0	7.45	132.8	5.26	57.35	56.64	0.71
	12	34.72	0.0	7.45	114.4	5.26	50.80	50.13	0.67
	13	36.32	15.6	7.45	137.4	5.26	63.43	60.62	2.81
	14	34.50	36.0	7.45	93.2	5.26	55.38	49.83	5.54
	15	36.20	15.6	7.45	115.2	5.26	56.42	53.62	2.81
	16	34.42	8.1	7.45	124.8	5.26	56.53	54.76	1.76
	17	35.63	8.1	7.45	134.5	5.26	59.95	58.16	1.78
	18	35.19	15.6	7.45	124.7	5.26	59.07	56.28	2.79
	19	34.71	15.6	7.45	119.1	5.26	57.15	54.37	2.78
	20	33.55	15.6	7.45	132.3	5.26	60.96	58.20	2.77

	21	36.69	24.0	7.45	111.9	5.26	58.15	54.20	3.95
	22	36.17	8.1	7.45	116.4	5.26	54.43	52.64	1.79
	23	34.26	0.0	7.45	134.7	5.26	57.04	56.38	0.66
	24	38.11	15.6	7.45	131.6	5.26	62.16	59.32	2.84
	25	36.74	8.1	7.45	129.4	5.26	58.67	56.87	1.80
	26	33.79	8.1	7.45	129.1	5.26	57.68	55.92	1.75
	27	34.60	2.0	7.45	129.8	5.26	56.22	55.28	0.94
	28	33.38	8.1	7.45	129.7	5.26	57.72	55.98	1.75
	29	34.47	24.0	7.45	113.5	5.26	57.98	54.06	3.92
	30	35.67	15.6	7.45	111.4	5.26	55.06	52.26	2.80
	31	35.29	8.1	7.45	123.6	5.26	56.40	54.62	1.78
	1	38.62	8.1	7.70	129.4	5.43	59.40	57.57	1.83
	2	41.90	8.1	7.70	117.0	5.43	56.54	54.66	1.88
	3	44.10	15.6	7.70	136.2	5.43	65.62	62.69	2.93
	4	41.91	8.1	7.70	137.7	5.43	63.04	61.16	1.88
	5	40.49	8.1	7.70	132.2	5.43	60.86	59.00	1.86
	6	41.44	0.0	7.70	142.3	5.43	61.79	61.01	0.78
	7	44.06	8.1	7.70	116.0	5.43	56.90	54.99	1.92
	8	39.59	15.6	7.70	118.7	5.43	58.72	55.86	2.86
	9	43.70	15.6	7.70	111.6	5.43	57.76	54.83	2.93
	10	42.07	36.0	7.70	84.3	5.43	55.09	49.43	5.67
	11	43.13	8.1	7.70	119.3	5.43	57.66	55.76	1.90
	12	43.74	24.0	7.70	122.9	5.43	63.96	59.89	4.07
	13	39.83	24.0	7.70	98.2	5.43	54.99	50.98	4.01
	14	43.01	2.0	7.70	131.6	5.43	59.56	58.49	1.07
	15	42.34	2.0	7.70	118.1	5.43	55.12	54.06	1.06
April	16	40.62	36.0	7.70	96.6	5.43	58.51	52.87	5.64
	17	42.54	24.0	7.70	120.7	5.43	62.90	58.86	4.05
	18	42.78	8.1	7.70	143.7	5.43	65.20	63.30	1.90
	19	38.65	2.0	7.70	142.8	5.43	61.72	60.71	1.01
	20	40.92	24.0	7.70	120.6	5.43	62.36	58.34	4.02
	21	41.76	8.1	7.70	140.7	5.43	63.95	62.07	1.88
	22	43.09	15.6	7.70	129.6	5.43	63.22	60.30	2.92
	23	44.57	8.1	7.70	128.7	5.43	61.04	59.12	1.92
	24	41.52	8.1	7.70	131.2	5.43	60.88	59.00	1.88
	25	41.91	2.0	7.70	138.7	5.43	61.45	60.39	1.06
	26	42.82	8.1	7.70	113.9	5.43	55.87	53.97	1.90
	27	39.95	15.6	7.70	125.5	5.43	60.96	58.09	2.87
	28	45.46	8.1	7.70	128.0	5.43	61.10	59.16	1.94
	29	43.62	8.1	7.70	136.3	5.43	63.14	61.23	1.91
	30	41.57	0.0	7.70	146.6	5.43	63.18	62.40	0.78
	1	49.62	36.0	7.45	103.2	5.26	63.25	57.47	5.78
May	2	50.06	24.0	7.45	108.2	5.26	61.19	57.03	4.16
	3	49.42	24.0	7.45	121.4	5.26	65.15	61.00	4.15

	4	51.90	15.6	7.45	125.0	5.26	64.41	61.36	3.05
	5	49.73	36.0	7.45	95.8	5.26	60.96	55.18	5.78
	6	52.07	24.0	7.45	125.2	5.26	67.19	62.99	4.19
	7	51.05	15.6	7.45	116.5	5.26	61.49	58.45	3.04
	8	52.51	24.0	7.45	104.6	5.26	60.83	56.63	4.20
	9	48.86	36.0	7.45	75.4	5.26	54.31	48.54	5.77
	10	49.36	15.6	7.45	103.0	5.26	56.72	53.71	3.01
	11	48.53	36.0	7.45	114.0	5.26	66.32	60.56	5.76
	12	53.35	15.6	7.45	120.5	5.26	63.45	60.37	3.07
	13	51.42	24.0	7.45	96.4	5.26	57.94	53.76	4.18
	14	50.89	36.0	7.45	122.6	5.26	69.75	63.95	5.80
	15	50.80	36.0	7.45	100.6	5.26	62.82	57.02	5.80
	16	49.12	24.0	7.45	103.5	5.26	59.45	55.30	4.15
	17	52.60	15.6	7.45	129.9	5.26	66.17	63.11	3.06
	18	51.79	15.6	7.45	137.8	5.26	68.39	65.34	3.05
	19	48.43	8.1	7.45	125.2	5.26	61.02	59.04	1.98
	20	50.70	24.0	7.45	106.2	5.26	60.79	56.62	4.17
	21	51.62	36.0	7.45	98.6	5.26	62.45	56.64	5.81
	22	50.50	24.0	7.45	117.3	5.26	64.19	60.02	4.17
	23	53.96	36.0	7.45	88.9	5.26	60.14	54.29	5.85
	24	51.73	24.0	7.45	130.7	5.26	68.80	64.61	4.19
	25	52.48	8.1	7.45	117.8	5.26	59.99	57.94	2.04
	26	51.73	15.6	7.45	113.9	5.26	60.87	57.82	3.05
	27	50.59	36.0	7.45	95.5	5.26	61.15	55.36	5.79
	28	49.80	36.0	7.45	108.2	5.26	64.87	59.09	5.78
	29	51.80	24.0	7.45	99.8	5.26	59.13	54.94	4.19
	30	52.21	8.1	7.45	136.1	5.26	65.65	63.61	2.04
	31	49.38	15.6	7.45	118.0	5.26	61.43	58.42	3.01
	1	52.15	36.0	7.70	106.1	5.43	65.10	59.28	5.82
	2	54.72	24.0	7.70	116.2	5.43	65.32	61.08	4.24
	3	54.77	15.6	7.70	139.2	5.43	69.90	66.80	3.10
	4	53.79	8.1	7.70	153.1	5.43	71.60	69.53	2.07
	5	56.01	36.0	7.70	84.8	5.43	59.62	53.73	5.88
	6	57.25	36.0	7.70	111.5	5.43	68.39	62.49	5.90
	7	54.35	15.6	7.70	142.7	5.43	70.88	67.79	3.09
June	8	55.47	15.6	7.70	127.6	5.43	66.49	63.38	3.11
	9	53.94	24.0	7.70	111.4	5.43	63.56	59.33	4.22
	10	55.77	24.0	7.70	114.9	5.43	65.24	60.99	4.25
	11	56.83	15.6	7.70	120.3	5.43	64.60	61.47	3.13
	12	54.12	15.6	7.70	123.6	5.43	64.80	61.71	3.09
	13	51.75	24.0	7.70	110.6	5.43	62.62	58.43	4.19
	14	53.07	36.0	7.70	101.5	5.43	63.94	58.10	5.84
	15	57.21	24.0	7.70	123.3	5.43	68.31	64.04	4.28
	16	55.58	36.0	7.70	98.2	5.43	63.70	57.83	5.88

	17	53.90	8.1	7.70	121.4	5.43	61.68	59.61	2.07
	18	55.26	36.0	7.70	111.5	5.43	67.76	61.89	5.87
	19	53.07	8.1	7.70	140.2	5.43	67.34	65.28	2.06
	20	52.59	24.0	7.70	117.5	5.43	65.03	60.83	4.20
	21	49.87	15.6	7.70	113.8	5.43	60.39	57.37	3.02
	22	53.28	8.1	7.70	132.0	5.43	64.83	62.77	2.06
	23	54.84	36.0	7.70	104.6	5.43	65.47	59.60	5.86
	24	57.73	24.0	7.70	120.3	5.43	67.54	63.26	4.28
	25	52.41	15.6	7.70	132.3	5.43	67.01	63.94	3.06
	26	53.78	24.0	7.70	114.6	5.43	64.51	60.29	4.22
	27	56.47	36.0	7.70	106.9	5.43	66.70	60.81	5.89
	28	53.86	8.1	7.70	145.4	5.43	69.22	67.15	2.07
	29	53.72	8.1	7.70	151.9	5.43	71.21	69.14	2.07
	30	56.54	15.6	7.70	126.6	5.43	66.51	63.38	3.13
	1	50.47	24.0	7.45	123.7	5.26	66.20	62.03	4.17
	2	48.72	8.1	7.45	149.0	5.26	68.59	66.61	1.98
	3	55.61	24.0	7.45	129.1	5.26	69.52	65.27	4.25
	4	51.77	15.6	7.45	134.2	5.26	67.27	64.23	3.05
	5	50.48	0.0	7.45	141.5	5.26	64.25	63.34	0.91
	6	51.58	2.0	7.45	139.1	5.26	64.46	63.26	1.20
	7	51.27	2.0	7.45	170.2	5.26	74.14	72.94	1.20
	8	50.43	15.6	7.45	120.5	5.26	62.53	59.51	3.03
	9	53.02	15.6	7.45	117.5	5.26	62.42	59.35	3.07
	10	49.64	2.0	7.45	140.1	5.26	64.18	63.00	1.17
	11	52.65	8.1	7.45	145.0	5.26	68.56	66.52	2.05
	12	50.45	15.6	7.45	118.5	5.26	61.93	58.90	3.03
	13	52.92	15.6	7.45	136.4	5.26	68.31	65.25	3.07
	14	50.70	24.0	7.45	121.1	5.26	65.46	61.29	4.17
July	15	51.87	8.1	7.45	140.7	5.26	66.98	64.95	2.03
	16	52.75	15.6	7.45	118.0	5.26	62.48	59.41	3.06
	17	51.11	15.6	7.45	142.7	5.26	69.71	66.68	3.04
	18	51.70	8.1	7.45	121.6	5.26	60.92	58.89	2.03
	19	52.48	36.0	7.45	106.1	5.26	65.08	59.25	5.82
	20	51.97	15.6	7.45	119.1	5.26	62.58	59.53	3.05
	21	49.38	24.0	7.45	143.2	5.26	71.98	67.84	4.15
	22	53.89	2.0	7.45	137.1	5.26	64.58	63.34	1.24
	23	51.19	8.1	7.45	154.0	5.26	70.95	68.92	2.02
	24	50.57	8.1	7.45	152.1	5.26	70.14	68.13	2.01
	25	49.91	8.1	7.45	147.1	5.26	68.39	66.39	2.00
	26	52.42	15.6	7.45	147.8	5.26	71.72	68.67	3.06
	27	51.47	15.6	7.45	131.7	5.26	66.39	63.35	3.04
	28	50.13	15.6	7.45	128.6	5.26	65.01	61.98	3.02
	29	49.41	15.6	7.45	125.6	5.26	63.82	60.81	3.01
	30	53.42	24.0	7.45	120.1	5.26	65.98	61.77	4.21

	31	51.18	0.0	7.45	152.0	5.26	67.76	66.84	0.93
August	1	48.13	15.6	7.70	100.2	5.43	55.57	52.58	3.00
	2	48.25	15.6	7.70	106.8	5.43	57.70	54.70	3.00
	3	47.70	8.1	7.70	118.4	5.43	58.81	56.84	1.97
	4	44.98	2.0	7.70	119.5	5.43	56.38	55.28	1.10
	5	46.67	8.1	7.70	127.3	5.43	61.27	59.32	1.96
	6	50.51	15.6	7.70	117.6	5.43	61.80	58.77	3.03
	7	50.67	15.6	7.70	100.8	5.43	56.57	53.53	3.04
	8	47.61	24.0	7.70	102.6	5.43	58.82	54.69	4.13
	9	48.84	24.0	7.70	109.8	5.43	61.46	57.31	4.15
	10	46.66	15.6	7.70	116.6	5.43	60.25	57.28	2.97
	11	48.70	8.1	7.70	124.7	5.43	61.09	59.10	1.99
	12	48.12	2.0	7.70	118.5	5.43	57.06	55.90	1.15
	13	47.83	8.1	7.70	106.2	5.43	55.01	53.03	1.98
	14	46.97	2.0	7.70	132.8	5.43	61.18	60.05	1.14
	15	49.41	15.6	7.70	125.6	5.43	63.95	60.94	3.02
	16	46.10	15.6	7.70	116.2	5.43	59.96	57.00	2.96
	17	46.83	15.6	7.70	110.9	5.43	58.54	55.56	2.98
	18	47.92	24.0	7.70	93.3	5.43	55.99	51.86	4.13
	19	46.94	8.1	7.70	125.1	5.43	60.67	58.71	1.96
	20	48.43	15.6	7.70	117.6	5.43	61.14	58.14	3.00
	21	46.93	8.1	7.70	122.5	5.43	59.84	57.87	1.96
	22	47.02	0.0	7.70	134.9	5.43	61.23	60.37	0.87
	23	46.93	8.1	7.70	126.8	5.43	61.19	59.23	1.96
	24	47.61	15.6	7.70	111.8	5.43	59.05	56.07	2.99
	25	48.43	15.6	7.70	107.8	5.43	58.06	55.06	3.00
	26	47.99	8.1	7.70	113.5	5.43	57.37	55.39	1.98
	27	46.41	2.0	7.70	141.5	5.43	63.75	62.62	1.13
	28	49.27	15.6	7.70	122.4	5.43	62.90	59.89	3.01
	29	45.57	15.6	7.70	114.2	5.43	59.17	56.22	2.96
	30	46.79	8.1	7.70	137.8	5.43	64.62	62.66	1.96
September	1	41.92	8.1	7.45	135.3	5.26	62.15	60.27	1.88
	2	41.52	0.0	7.45	117.5	5.26	53.90	53.12	0.78
	3	41.81	0.0	7.45	117.5	5.26	53.99	53.21	0.78
	4	42.93	0.0	7.45	149.1	5.26	64.28	63.48	0.80
	5	42.78	8.1	7.45	123.0	5.26	58.57	56.68	1.89
	6	43.99	8.1	7.45	128.2	5.26	60.58	58.67	1.91
	7	41.79	2.0	7.45	115.6	5.26	54.02	52.97	1.05
	8	40.15	0.0	7.45	133.5	5.26	58.50	57.75	0.75
	9	40.80	8.1	7.45	106.4	5.26	52.73	50.87	1.86
	10	40.75	8.1	7.45	129.1	5.26	59.86	58.00	1.86
	11	40.21	2.0	7.45	114.4	5.26	53.16	52.13	1.03
	12	42.69	15.6	7.45	116.6	5.26	58.90	55.99	2.91
	13	43.00	0.0	7.45	106.4	5.26	50.87	50.08	0.80

	14	44.70	8.1	7.45	115.8	5.26	56.93	55.01	1.92
	15	42.03	0.0	7.45	129.3	5.26	57.76	56.97	0.78
	16	42.92	0.0	7.45	121.1	5.26	55.48	54.68	0.80
	17	41.55	8.1	7.45	112.5	5.26	54.89	53.02	1.87
	18	43.83	8.1	7.45	125.4	5.26	59.65	57.74	1.91
	19	43.62	2.0	7.45	130.1	5.26	59.14	58.06	1.08
	20	43.04	15.6	7.45	101.9	5.26	54.40	51.49	2.91
	21	41.37	8.1	7.45	104.6	5.26	52.35	50.48	1.87
	22	43.51	0.0	7.45	125.4	5.26	57.02	56.22	0.81
	23	43.35	0.0	7.45	125.8	5.26	57.09	56.29	0.80
	24	41.20	8.1	7.45	120.2	5.26	57.19	55.32	1.87
	25	41.91	0.0	7.45	123.8	5.26	56.01	55.23	0.78
	26	43.54	8.1	7.45	107.0	5.26	53.80	51.90	1.90
	27	41.22	0.0	7.45	133.6	5.26	58.87	58.10	0.77
	28	41.02	15.6	7.45	119.2	5.26	59.17	56.29	2.88
	29	45.35	0.0	7.45	125.3	5.26	57.54	56.71	0.83
	30	41.75	8.1	7.45	136.9	5.26	62.62	60.74	1.88
	31	43.28	0.0	7.45	125.0	5.26	56.82	56.02	0.80
	1	33.69	0.0	7.70	130.1	5.43	55.54	54.88	0.66
	2	36.27	2.0	7.70	133.0	5.43	57.90	56.93	0.97
	3	38.58	8.1	7.70	100.0	5.43	50.17	48.34	1.83
	4	33.63	0.0	7.70	136.0	5.43	57.36	56.70	0.66
	5	34.43	0.0	7.70	126.3	5.43	54.56	53.89	0.67
	6	37.36	0.0	7.70	121.1	5.43	53.87	53.16	0.72
	7	36.37	24.0	7.70	89.8	5.43	51.27	47.32	3.95
	8	33.39	8.1	7.70	100.2	5.43	48.61	46.85	1.75
	9	35.22	15.6	7.70	118.1	5.43	57.15	54.35	2.80
	10	31.85	8.1	7.70	102.5	5.43	48.85	47.12	1.73
	11	36.91	8.1	7.70	110.4	5.43	52.92	51.11	1.81
	12	33.67	0.0	7.70	131.8	5.43	56.05	55.39	0.66
	13	34.57	15.6	7.70	105.5	5.43	52.99	50.20	2.79
October	14	36.37	8.1	7.70	125.6	5.43	57.52	55.72	1.80
	15	33.40	15.6	7.70	100.4	5.43	51.01	48.24	2.77
	16	33.63	15.6	7.70	114.2	5.43	55.43	52.66	2.77
	17	35.05	15.6	7.70	95.0	5.43	49.85	47.06	2.79
	18	35.15	0.0	7.70	116.3	5.43	51.65	50.97	0.68
	19	39.00	8.1	7.70	100.9	5.43	50.57	48.73	1.84
	20	37.65	0.0	7.70	102.7	5.43	48.17	47.45	0.72
	21	34.72	8.1	7.70	110.8	5.43	52.36	50.58	1.77
	22	34.73	8.1	7.70	121.8	5.43	55.80	54.03	1.77
	23	33.59	0.0	7.70	129.7	5.43	55.38	54.72	0.66
	24	36.20	0.0	7.70	121.2	5.43	53.54	52.84	0.70
	25	35.24	2.0	7.70	114.9	5.43	51.87	50.91	0.95
	26	39.04	2.0	7.70	136.1	5.43	59.74	58.72	1.01

	27	36.73	8.1	7.70	109.9	5.43	52.68	50.88	1.80
	28	36.19	8.1	7.70	119.7	5.43	55.60	53.80	1.79
	29	36.69	0.0	7.70	110.6	5.43	50.35	49.64	0.70
	30	37.00	2.0	7.70	110.5	5.43	51.06	50.08	0.98
November	1	26.56	8.1	7.45	109.6	5.26	49.29	47.65	1.64
	2	25.85	0.0	7.45	139.8	5.26	56.00	55.47	0.53
	3	26.75	24.0	7.45	96.3	5.26	50.14	46.34	3.80
	4	27.60	15.6	7.45	99.3	5.26	48.73	46.06	2.67
	5	26.42	36.0	7.45	78.8	5.26	48.33	42.91	5.42
	6	25.51	15.6	7.45	103.8	5.26	49.47	46.83	2.64
	7	28.87	0.0	7.45	121.3	5.26	51.13	50.55	0.58
	8	28.04	15.6	7.45	102.0	5.26	49.72	47.04	2.68
	9	27.34	8.1	7.45	103.5	5.26	47.62	45.97	1.65
	10	26.89	15.6	7.45	101.5	5.26	49.18	46.52	2.66
	11	28.97	24.0	7.45	93.1	5.26	49.85	46.02	3.83
	12	28.38	15.6	7.45	106.7	5.26	51.29	48.60	2.69
	13	27.14	0.0	7.45	100.9	5.26	44.18	43.63	0.55
	14	28.15	15.6	7.45	90.9	5.26	46.26	43.58	2.68
	15	29.89	2.0	7.45	122.4	5.26	52.41	51.54	0.87
	16	27.15	24.0	7.45	102.1	5.26	52.09	48.28	3.80
	17	25.50	15.6	7.45	122.6	5.26	55.39	52.75	2.64
	18	27.51	24.0	7.45	108.4	5.26	54.19	50.38	3.81
	19	26.76	15.6	7.45	101.2	5.26	49.05	46.39	2.66
	20	27.26	15.6	7.45	109.3	5.26	51.76	49.09	2.67
	21	26.32	8.1	7.45	105.7	5.26	47.97	46.33	1.64
	22	29.26	8.1	7.45	113.6	5.26	51.39	49.71	1.68
	23	26.10	8.1	7.45	106.6	5.26	48.19	46.56	1.63
	24	25.84	8.1	7.45	111.2	5.26	49.56	47.93	1.63
	25	28.59	0.0	7.45	122.9	5.26	51.54	50.97	0.58
	26	28.95	8.1	7.45	113.4	5.26	51.23	49.55	1.68
	27	27.38	15.6	7.45	114.8	5.26	53.52	50.85	2.67
	28	27.50	2.0	7.45	131.3	5.26	54.47	53.64	0.83
	29	25.19	15.6	7.45	97.2	5.26	47.30	44.66	2.64
	30	27.28	8.1	7.45	108.7	5.26	49.21	47.55	1.65
	31	27.60	8.1	7.45	106.2	5.26	48.55	46.89	1.66
December	1	23.82	8.1	7.70	104.5	5.43	46.95	45.35	1.60
	2	22.10	15.6	7.70	99.7	5.43	47.25	44.66	2.59
	3	23.29	0.0	7.70	131.7	5.43	52.77	52.28	0.50
	4	25.40	15.6	7.70	94.9	5.43	46.79	44.15	2.64
	5	23.63	8.1	7.70	112.6	5.43	49.41	47.81	1.60
	6	25.22	8.1	7.70	111.1	5.43	49.46	47.83	1.62
	7	22.94	15.6	7.70	97.9	5.43	46.94	44.33	2.61
	8	22.42	2.0	7.70	102.0	5.43	43.80	43.04	0.75
	9	22.46	2.0	7.70	107.3	5.43	45.48	44.72	0.76

10	26.33	15.6	7.70	109.2	5.43	51.57	48.91	2.66
11	24.45	15.6	7.70	103.5	5.43	49.20	46.57	2.63
12	21.26	0.0	7.70	131.0	5.43	51.92	51.45	0.47
13	21.21	24.0	7.70	85.8	5.43	45.26	41.54	3.72
14	20.72	24.0	7.70	75.9	5.43	41.99	38.28	3.71
15	21.64	8.1	7.70	101.0	5.43	45.17	43.60	1.57
16	22.16	8.1	7.70	124.1	5.43	52.56	50.98	1.58
17	22.22	15.6	7.70	93.0	5.43	45.20	42.60	2.59
18	23.96	8.1	7.70	103.8	5.43	46.78	45.17	1.61
19	23.37	15.6	7.70	86.0	5.43	43.35	40.74	2.61
20	21.79	15.6	7.70	122.8	5.43	54.41	51.82	2.59
21	25.52	15.6	7.70	104.7	5.43	49.89	47.24	2.65
22	23.76	8.1	7.70	113.8	5.43	49.86	48.26	1.60
23	21.51	8.1	7.70	106.7	5.43	46.92	45.35	1.57
24	21.92	8.1	7.70	99.4	5.43	44.75	43.17	1.57
25	21.13	36.0	7.70	78.4	5.43	46.68	41.34	5.34
26	23.43	15.6	7.70	103.5	5.43	48.86	46.25	2.61
27	22.04	8.1	7.70	115.4	5.43	49.82	48.24	1.58
28	22.57	0.0	7.70	114.1	5.43	47.02	46.53	0.49
29	21.87	15.6	7.70	97.4	5.43	46.45	43.86	2.59
30	24.12	15.6	7.70	97.5	5.43	47.21	44.59	2.62