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PEAK-LOAD SHIFTING UTILIZING LOAD FACTOR OPTIMIZATION: A CENTRALIZED MICROPROCESSOR-BASED SMART METERING DEMONSTRATION

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Physics

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AUTHOR’S DECLARATION

I, Mwewa Melody, do declare that this dissertation represents my own work and that it has neither in part nor in whole, been presented as substance for award of any degree at this or any other institution of learning or research. Where other people’s work has been used, acknowledgement has been made.

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APPROVAL

The University of Zambia approves the dissertation of Mwewa Melody as fulfilling part of the requirements for the award of the degree of Master of Science in Physics.

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ABSTRACT

In this work, a report is given of a centralized smart metering system intended to run an algorithm designed to address the problem of peak-hour energy deficit in Zambia. A survey study conducted in Lusaka to establish household power-usage patterns led to the development of the load-management software which was implemented on the Arduino Mega microcontroller. This system automatically regulated water heating and provided energy-usage information to the consumer at peak periods. These two interventions were enough to make a significant contribution to minimising peak-power usage, an outcome that could help to reduce the incidence of load shedding.

To my father, Mr. Douglas Mwewa, my mothers Jennipher Chabu and the late Evelyn Musonda and my sisters and brothers

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LIST OF SYMBOLS/ABBREVIATIONS

V_o-Output voltage

P_{max}-Maximum power

V_{max}-Maximum voltage

I_{max}-Maximum current

R_{shunt}-Shunt resistor

N-Neutral

L-Live

E-Total energy

T-Time

P_p-Peak power

P_{avg}-Average Power

AC-Alternating Current

ADC-Analogue Digital Converter

AMI-Advanced Metering Infrastructure

CPP-Critical Peak Period

CPU-Central Processing Unit

DC-Direct Current

DSM-Demand Side Management

EEPROM-Electrical Erasable Programmable Read Only Memory

IDMSS-Intelligent Decision Making Support System

I/O-Input/Output

RMS-Root Mean Square

RTC-Real Time Clock

SRAM-Static Random Access Memory

TOU-Time of Use

UN-United Nations

USD-United States Dollars

CHAPTER ONE

INTRODUCTION

1.0 Introduction

The problem of an energy deficit during peak hours is a serious one in Zambia. The country is rapidly developing and the development of generating capacity is seriously lagging behind and will continue to do so for the foreseeable future. This means that innovative methods of managing the power that is available are needed. In this thesis a system of load management through smart metering is proposed. By means of this system, electricity usage is rationalized by shifting non-essential consumption to off-peak hours. In this chapter the background to the problem of peak-hour energy deficit is provided. An outline of the importance of the load-management system proposed is given.

1.1 Background

When the first power system was commissioned in 1882 by Thomas Edison, the global population was much smaller than it is today [1]. The United Nations estimates that the world's population will grow from the current 6.7 to 9.2 billion by 2050 [2]. This rapid population growth will lead to a high demand for electricity. In countries like Zambia, electricity demand already outstrips supply, with consequent rolling blackouts.

In Zambia, the main consumers of electricity are the residential, commercial and industrial sectors. The biggest consumer is the residential sector mainly due to the rising number of newly electrified houses and increased energy usage. A presentation by the former Managing Director of Zesco Limited [3] showed that households consume 50 percent of total electricity produced. This means that more efficient use of existing supply by households can significantly reduce the number of new generators needed.

Non-essential appliances in a household cause strain to the electric grid if switched on at peak hours. Further strain is caused by using water-heating systems at peak hours, since 40 percent of domestic electricity consumption is attributed to household geysers [4].

One approach to mitigating the inefficient use of electricity is the use of systems such as the Advanced Metering Infrastructure (AMI). This is considered as a basic asset for linking the demand to the supply [5] and thereby managing the latter rationally. The smart metering system incorporates two way communications between the supplier and the consumer. The transition to smart meters is now underway and was heralded by the introduction of pre-paid meters which allow the consumer to monitor the total energy there are consuming. The disadvantage of pre-paid metering is that the consumer neither knows how much energy is being consumed at peak hour, nor being aware of when it is best to use certain appliances in their household in order to minimize the power demand. Modernizing the metering infrastructure and incorporating the consumer in the management of electrical energy leads to a significant reduction in the peak-hour load and may thus obviate the need for new infrastructure.

1.2 Statement of the problem

The electricity consumption in Zambia, as stated earlier, has grown significantly and the demand from 2006 has been running ahead of supply of installed power capacity. Zambia is facing an energy shortage of 11 percent with a peak deficit of 197MW. About 150MW to 200MW is curtailed at peak period to balance generation for the safety of generators and stable electricity supply chain. To balance the demand additional capacity is needed, but the cost involved for expanding and building new generation capacity is high [6]. This high cost of investment for additional capacity has forced the authority and the utility company to look into various energy conservation and energy management programmes. According to Bjork [7], load management is the process of scheduling the loads to reduce the electric energy consumption or the maximum demand. In [8] it is further stated that there are many methods of load management which can be followed by a utility company;

a) load shedding and restoring,
b) load shifting,
c) installing energy-efficient processes and equipment,
d) use of energy storage devices,

e) co-generation from non-conventional sources of energy,

In many Zambian households, the peak deficit is caused by switching on a significant number of appliances at the same time. This is termed as "peak-hour load" which pushes electricity demand beyond the maximum generated capacity. This forces the power company to implement load shedding. The Zesco director of generation stated that "load shedding management was being carried out in order to protect generating equipment, which would automatically shut down should there be an overload, a situation he termed would be costly" [4].

Load shedding is a load-management practice that forces the power company to shut down power in selected areas due to high power demand and then restore it when there is low power demand. This load shedding adversely affects and inconveniences consumers as a result the consumer resorts to environmental hazards as sources of energy; these include the use of burning wood for cooking, the use of kerosene lamps for lighting and so on. Another problem that arises from load shedding is the damage of household appliances due to switching power surges during sudden disconnection and connection of the power supply. The system proposed in this study seeks to address the problem of the "peak hour load", because this is the major cause of peak power deficit in the domestic sector.

1.3 Aim of the Study

The aim of this study was to develop a means of alleviating the problem of the peak-hour electricity deficit by reducing the peak-hour load. The method used employs an algorithm that provides power-usage information to the user and which can automatically suppress water-heating systems during peak hours.

1.4 Research Objectives

The main objectives of the project were to:

1. Establish the power-usage patterns for water heating and household-appliance use;

2. Develop a program for a centralised microprocessor-based electricity metering system; and

3. Designing of an electronic circuit for a centralised microprocessor-based electricity metering system.

1.5 Significance of the Study

The shortfall in electricity during peak hours in Zambia leads to load shedding. By reducing peak-hour load, load shedding can be significantly reduced without building new generators. Immediately shifting non-essential loads from the peak to the off-peak period would serve to level the load curve and ensure efficient use of the generation resource, which translates into financial savings of up to 40 percent by the utility company [6]. Clearly, there is significant scope for managing the consumption of domestic electricity.

1.6 Outline of the Thesis

This thesis is organized in the following way. In Chapter One the background to the study, the statement of the problem, the aims and the objectives of the research are presented. The importance of the study and the significance of the knowledge obtained from the study to the scientific community are explained. Chapter Two gives a review of the literature related to the study, with emphasis being placed on a detailed description of the different types of smart meters. Demand Side Management (DSM) program are briefly discussed and give some insight into the microcontroller. Furthermore analysis is given in detail about studies of load-shifting energy-efficiency algorithms.

In Chapter Three, methods and materials used in this work are explained. Individual sections elaborate on the steps involved in data collection and of the optimisation algorithm formulation. It is here that a detailed description of the hardware components of the smart metering system is given and of how the hardware and software are interfaced. Results are presented in Chapter Four, and the Discussion as well as the Research Findings in Chapter Five. A brief discussion of the limitations of the research and the impact on the research process and results were also given in this chapter. Finally the conclusion and recommendations for future work are given done in Chapter six.

1.7 Scope of the Thesis

In this thesis a centralized microprocessor-based smart-metering system is demonstrated. It implements an algorithm that reduces the electricity peak-hour load by alerting the consumer as to which non-essential usage of household appliances should be rescheduled. The model used to test the efficiency of the algorithm, it contained two houses, each with four household appliances. Only two houses were used for illustration because the results can be scaled up to a population of many houses.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter provides a review of the literature relevant to the research goals of this thesis. Particular emphasis is placed on research that has been carried out on DSM programs, their benefits and discussed load management as a DSM issue. This is preceded by first giving the background to three methods of load management, namely Peak Clipping, Load Shifting and Valley Filling. This is followed by a description of existing techniques for monitoring power consumption in households and of different types of current-sensing circuits. Microcontrollers play a vital role in smart meters, and hence an outline is given of their workings. Then a description is given of different types of existing smart meters, with an overview of how they operate.

Most smart meters have the same architecture but differ from one another only in the kind of algorithm they use. Studies that have been done on these different types of energy-efficiency algorithms are elaborated on. A survey on projects done for the implementation of smart-meter technology in different developed countries is also discussed.

2.1 A Brief Description of Demand Side Management (DSM)

DSM describes an intervention by the utility company, beyond the customer's meter, with the objective of altering the end use of electricity [9]. It is sometimes described as "a program implemented by the utility company to control energy consumption by the consumer" [10]. DSM explicitly refers to all deliberate interventions by the utility company to help the consumer to use electricity more efficiently by altering the consumer's load profile [11].

The first DSM programs were developed in the 1970s under the assumption that it was less expensive to reduce peak-hour loads through DSM than to build new power plants. Because of the energy crisis at that time, the programs were designed to achieve quick results and little time was devoted to monitoring and evaluating their impact [11]. At that time, the use of DSM programs was not widespread - a situation that prevailed until the early 1980s [12-14]. However, it is a fact that over the past three decades, DSM programs have had a significant impact on energy saving and these savings can only grow with improvements in the programs.

According to the literature [13-15], DSM programs come in many forms which include energy conservation, fuel substation programs, demand response programs and load management. The main focus in this research is on load management programs.

2.2 Load Management

Load management is the process of re-scheduling loads for the express purpose of reducing electricity consumption. The goal of any load-management program is to maintain, as nearly as possible, a constant level of load, thereby allowing the system load factor to approach 100 percent [16]. The important benefits of load management are reduction in maximum demand, reduction in power loss, better equipment utilization and savings through reduced maximum-demand charges.

There are three types of load-management methods. Figure 2.0 below shows an illustration of the three methods. Figure 2.0(a) demonstrates load shifting while Figures 2.0(b and c), illustrate peak clipping and valley filling respectively. Load shifting is one of the simplest methods for reducing customer demand during peak time; it works by shifting the use of appliances and equipment to partial-peak and off-peak periods. Here loads are not switched off, but only shifted or rescheduled, so that the total consumption is not affected [17]. The other methods of load management are peak clipping and valley filling, which are somewhat more difficult to implement. Peak clipping is where the demand peaks are "clipped" and the load is reduced at peak times. In valley filling, the demand valleys (low demand periods) are "filled" by building off-peak capacities i.e. switching on appliances at off-peak periods to minimize the margin between the peak and off-peak hour consumptions.

Load shifting is different to peak clipping in that the load is present in the overall demand whereas in clipping it is removed [11].

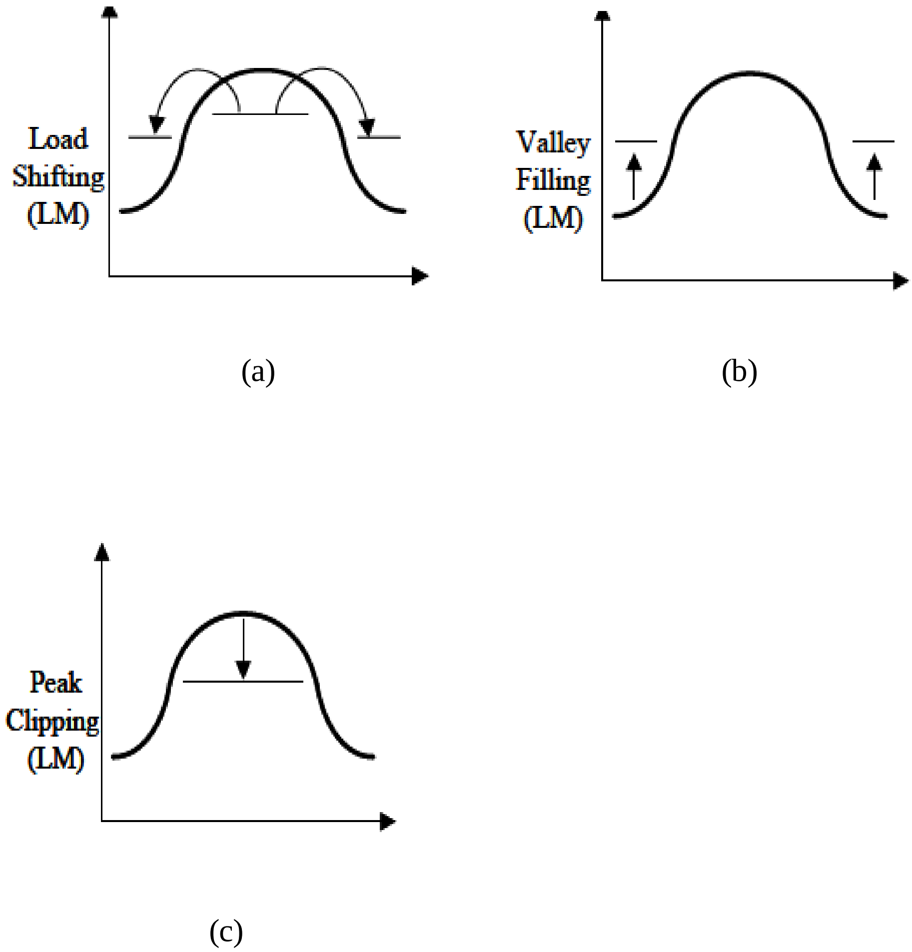


Figure 2.0: Three methods of load management [11]

2.3 Benefits of DSM Programs

According to [18], in 1999, 459 large electricity utilities in the United States had implemented DSM programs such as the one proposed in this study. This saved the utilities 50.6 billion kilowatt hours (kWh) of energy generation. This represented 1.5 percent of the annual electricity sales of that year. It was noted that New York had the potential to reduce demand by 1300MW through such techniques; this is enough power to be supplied to 1.3 million homes.

In South Africa, an initiative to improve energy efficiency in government buildings was carried out to determine potential energy savings. Because of the results from this, certain measures were implemented to reduce the energy consumption; these included the use of timers on electric geysers so that water can only be heated when needed, as well as the installation of energy- efficient lighting and solar water heaters. Resulting from this was 20 percent savings in electricity consumption, which was equivalent to a reduction in green house gas emissions of about 323 tons of CO_2 per year [19].

From [20], the quarterly report said that in 2004 South Africa saved 31.09 MW of power by the use of fluorescent lamps (CFL). Korea Electric Power Corporation reported that in 2008 by implementing DSM it avoided the financial expense of constructing three nuclear power plants with a total capacity of 1GW[21]. These are some of the benefits of DSM. From this information, it can be concluded that there can be huge savings if such systems are implemented. However the study did not look at the money which is saved if such a system was implemented.

2.3.1 Energy Savings from Household Appliances

a) Water Heating Systems

Research has shown that solar power can provide 60 percent to 70 percent of domestic water heating [21] energy and that it can deliver 2500kWh per year at a cost of US cents 4/kWh.

b) Appliances

Appliances such as refrigerators and air conditioners have become energy efficient. A 50 percent energy consumption savings is possible with LCD televisions using backlight modulations.

2.3.2 Ongoing Zesco Projects towards Improving the Peak Hour Load

In 2008 450MW was available from Zambia's generating infrastructure, leading to a peak-period deficit of 280MW. ZESCO required US$ 210 million just to rehabilitate the existing power plants and US$ 650 million for the construction of just one new plant. Load-management programs were introduced and have been used since in order to Maintain the balance of supply and demand.

Zesco embarked on a number of projects to reduce the peak hour load, which includes the following;

a) The installations of solar water heating systems
b) The introduction of pre-paid metering systems
c) The distribution of energy saving bulbs
d) Peak load shaving using Ripple control Equipment

2.4 Existing Techniques for Household Energy Measurements

In order to implement load-management programs, knowledge of consumer power usage is necessary. There are two main existing techniques for measuring this for households. These are **Survey Based Methods**, where the occupants provide information on household appliance- power usage and **Automated Methods**, where sensors are used to collect this information [22].

2.5 Current Sensing

The design of the sensing circuit is a critical part of the work. There are two different approaches to current sensing: indirect and direct sensing.

2.5.1 Indirect Sensing

This technique is based on Ampere's and Faraday's laws. Since there is no direct connection between the sensing circuitry and the system, the system is isolated. This method is typically used for sensing load currents of 100A-1000A [23].

2.5.2 Direct Sensing

This is based on Ohm`s law. By placing a shunt resistor in series with the system load, a voltage that is proportional to the system load current is generated across the shunt resistor. There are two types of direct current sensing – namely, low- and high-side sensing. Figure 2.1(a) and 2.1(b) illustrate the two types of direct current sensing. In low-side sensing, the shunt resistor is placed between the ground and the load while in high-side sensing, the shunt resistor is placed between the positive side of the power supply and the load [23].

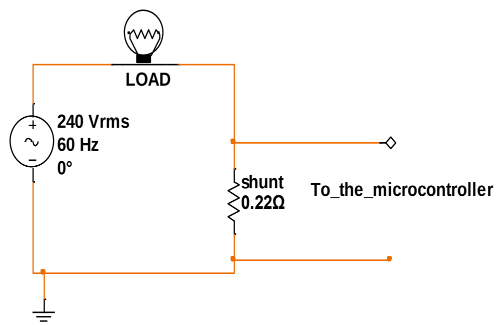


Figure 2.1(a) Low-side sensing

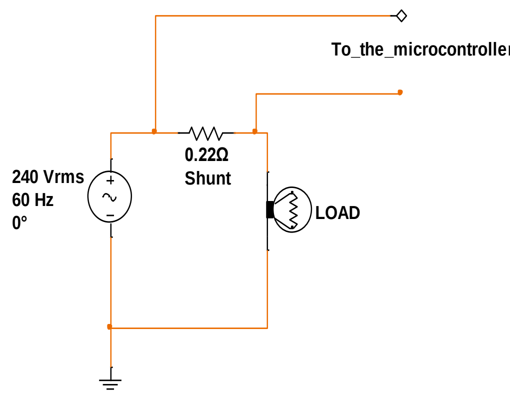


Figure 2.1(b) High-side sensing

2.5.3 Choosing a Shunt Resistor for Sensing

Firstly the maximum current that flows through the circuit is calculated using the equation;

$$I_{max} = \frac{P_{Max}}{V_{Max}} \tag{1}$$

where I_{max} : the maximum current

P_{max} : the maximum power

V_{max} : the maximum voltage

The shunt resistor value is calculated using the current and the desired output Voltage (V_o) using Ohms law;

$$R_{shunt} = \frac{V_O}{I_{Max}} \tag{2}$$

where R_{shunt} is the shunt resistor and V_O is the output voltage

The following equation is used to find the value of the power dissipated (P) in the resistor.

$$P = R_{shunt} I_{Max}^2 \quad (3)$$

2.6 The Microcontroller

Microcontrollers are the heart of most smart systems; the sensing circuits provide signals to the microcontrollers for calibration so that appropriate algorithms can be implemented and power is monitored. They are also responsible for controlling the appliance which can be switched on/off and what to display to the consumer at a particular period.

2.6.1 Microcontrollers and Microprocessors

The microprocessor is a CPU (Central Processing Unit) compacted into a single chip semiconductor device [24]. It is a general-purpose device, suitable for many kinds of applications. A microcontroller on the other hand is a programmable device which contains a microprocessor, a memory and input-output ports. It is a low cost programmable device which can also be defined as a single chip computer [24].

2.6.2 Choosing a Microcontroller for the System

When choosing an appropriate microcontroller for the system, the following have to be taken into consideration;

a) Memory space - After developing the algorithm, it is important to choose a microcontroller that has enough memory to suit the program.
b) Speed - The operational speed is needed in order to determined, how fast the instructions will be executed by the microcontroller.
c) Availability - The availability of the microcontroller on the market is very important.
d) Packaging - This is important for the purposes of designing space on the system.
e) Cost
f) Precision
g) Accuracy
h) Supply voltage and power dissipation
i) Voltage reference and real time clock facility
j) Input impedance and analogue range

k) Voltage range

The microcontroller development board used in this research was the Arduino Mega 2560.

2.6.3 The Arduino Mega 2560 Development Board

The development board is based on the ATmega 2560 microcontroller. Table 2.0 give a summary of the properties of the development board. Figure 2.2 shows a photo of the Arduino Mega Board taken from [25] with the components labeled. A brief explanation of each component is given in the appendix A.

Table 2.0: Summary of the microcontroller properties

Microcontroller	ATmega 2560
Operating Voltage	5V
Input Voltage	7-12V
Digital I/O Pins	54
Analogue Input	16
DC Current per I/O Pins	40mA
DC Current for 3.3V Pin	50mA
Flash Memory	256KB
SRAM	8KB
EEPROM	4KB
Clock Speed	16MHz

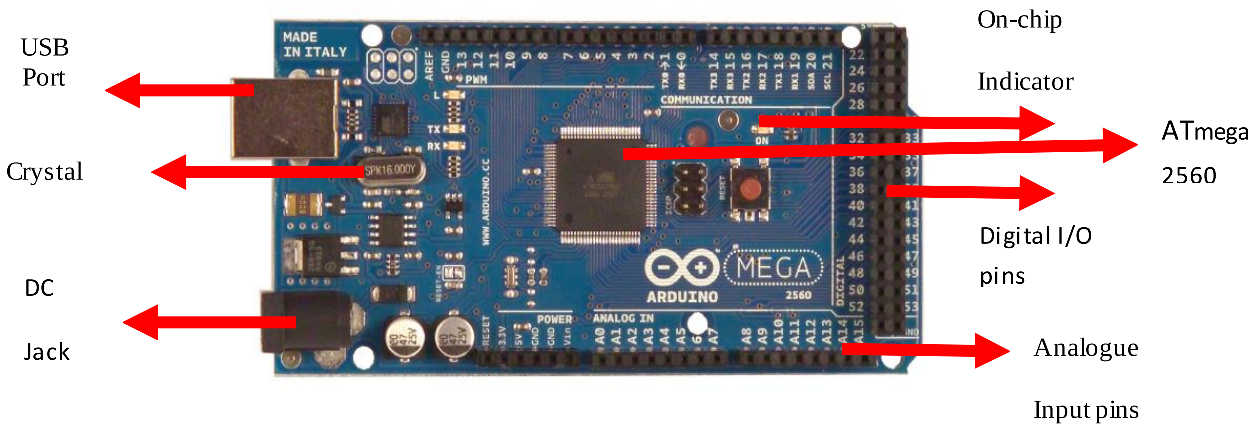


Figure 2.2: Arduino mega board with the names of the components on the board [26]

2.7 Load-shifting algorithm

The load-shifting algorithm is based on the nature and type of loads being controlled. It is not possible to reschedule all loads at once and certain types of loads cannot be shifted. That is why a load shifting algorithm has to be formulated.

Loads in the power system are classified into three groups [27]. These are:

a) Domestic loads
b) Commercial loads
c) Industrial loads.

The main focus of this research is domestic loads. According to the literature [28], this type of load can be further sub-grouped into the following:

a) Loads that cannot be rescheduled
b) Loads that can be shifted
c) Loads that can be curtailed

Examples of loads that cannot be shifted in a household are the stove and lighting. Those that can be shifted include the washing machine, pressing irons, dryers and dishwashing machine.

Load curtailing refers to loads that can be eliminated. Examples of such loads are the air conditioner and water-heating systems. In order to formulate an effective load-shifting algorithm, certain studies that have been conducted on the issue done are now presented in more detail.

2.7.1 Studies on the Load-Scheduling Algorithm

In [29], the authors proposed an optimal, autonomous, and distributed incentive-based algorithm, with the design based on the interactions among the end users. In this research, the algorithm used is different from other algorithms because the interaction was not only between the utility company and the user, but among the users as well. This proposed algorithm enables the users to inform each other of their respective schedule for hourly power usage, through a broadcast control message. The load-scheduling algorithm then optimally coordinates the timing of household energy consumption. The load factor calculated from the simulation of this algorithm was 55 percent.

Load shifting takes place through individual household appliances [30], which is why in this thesis a model was constructed using an agent-based approach. These individual agents were both the smart appliances and the non-smart appliances, which were grouped together as “other loads”. The proposed algorithm allowed all appliances in the household to be scheduled. The principle of this algorithm was the use of appliances with low start demand, scheduled at the low-load timeslots. It is shown in this work that load shifting by scheduling smart appliances is likely to produce more levelled demand patterns, and can reduce the peak load by 13 percent.

A national power centralized load control system is a system that automatically takes certain actions when specific conditions are met. One condition is the frequency [31]. If the system experiences a drop in frequency, this indicates high power demand, and the system automatically disconnects the load.

Another load-shifting algorithm in [32] works as described below;

> *Appliance scheduling is calculated in advance by the local scheduling agent given an input of maximum usage constraints for a time interval and the predicted load curve. The output of the algorithm is the new start times for all shifted appliances.*
>
> *Given the inputs, the algorithms operate on the set of loads that are currently planned to start during the time interval for which the*

constraint is in effect. For each of these loads a list of possible starting times is generated between the absolute start and end times, the times during the constraint are then removed from this list. A random number generator is then used to select from the remaining start times. The reason for randomly selecting the new start time is so that if many houses all shifted load in the same way a new peak would be formed where the shifting had occurred to, and using random selection in this way effectively spreads out the moved load around the peak. This was particularly important because multiple households would be shifting independently since otherwise shifting collision would be likely, causing new peaks.

Lee and Wilkins in 1983 [33] have presented a methodology for scheduling the use of water heaters. The water-heater load demand is modeled using data obtained by monitoring different uncontrolled residential water heaters. The approach of Lee and Wilkins is simple. A list with a fixed control strategy is defined, for example:

a) The appliance is switched off for 3 hours starting at 10AM
b) The appliance is switched off for 4 hours starting at 9:30AM
c) The appliance is switched off for 4 hours starting at 11AM.

Then, for a given number of controllable water heaters, the number that should be controlled in accordance with each control strategy was calculated. The optimization was based on peak reduction and was controlled by an algorithm using a linear program. Cohen and Wang [34] presented an optimal control scheduling method based on dynamic programming. The advantage of the scheme is that the candidate control schedules are not specified. The algorithm calculates the ON and OFF cycles for a selected number of appliance groups. Each group can be controlled more than once during the control period. The size and composition of the groups is supposed to be known in advance. During the execution of the algorithm each group of appliances is treated separately. The schedule for each group is calculated under the assumption that the load consumption of the rest of the groups is fixed, and that the obtained solution is not the optimal. This model can handle both peak reduction and production-cost minimization.

Kurucz, Brandt and Sim [35] have presented another optimization method based on linear programming. The approach is similar to that of Lee and Wilkins [33] but the list of predetermined candidate control schedules is more flexible. These schedules are of the type where the device will be switched OFF for four hours at a time. The flexibility is in the selection of the optimal starting time for the control action. The output from the algorithm is the number of appliances that are controlled at each time step following each candidate control action. The algorithm can be used with a mixture of appliances connected to two types of consumers: commercial and domestic. Each appliance type has its own list of candidate control actions based on contracts with consumers. The aim of this method was the reduction of peak load in Florida.

Popovic [36] has presented another optimization method based on linear programming. The main advantage of his approach compared to that of [35] is again flexibility in the candidate control action list. The controllable appliances are divided into two types: devices that can be turned OFF for a long period (water heaters) and appliances that can be switched ON/OFF for brief periods of time (air conditioners). This method assumes that water heaters can be controlled just once during the control period and that air conditioners can suffer more than one control action during the control period. The candidate control actions are of the type: The appliances will be turned OFF for 15 minutes and the minimum time interval between actions is one hour. The objective of the study was peak-load reduction.

A similar approach to [36] has been presented by Chu, Chen and Fu [37]. They target commercial buildings with air conditioning and apply dynamic programming techniques in order to schedule the OFF/ON cycles of groups of loads. The difference is that their objective is to reduce peak load by minimizing the amount of load controlled. The reasons for minimizing the amount of controlled load are to reduce income losses and to improve customer satisfaction.

Weller [38] has presented a method that helps to maintain system diversity. The method is based on the concept of distributed intelligence. Each water heater has a control device connected to it. Every time that device receives a control signal it generates a random number that produces a delay in the execution of the action. In this way the resulting system load curve is smoother.

Load shifting algorithms can only be effective in peak-load reduction if they are implemented through the smart-metering technologies.

2.8 Smart-Metering Technologies

Smart-metering technologies involve the use of a two-way communication system between the utility company and the supplier [39]. This technology deploys advanced information and communication to control the load on the electric grid [40].

Krishnan [41] has stated that smart-metering technologies play a very important role in the success of DSM. Advances in metering infrastructure have led to the implementation of Energy Consumption Scheduling (ECS) devices inside electrical smart meters [42].

2.8.1 Electrical Smart Meters

Literature in [43] defines the *smart meter* as *a microprocessor based device providing two-way communications capability and can help home owners to manage their electricity usage.*

According to Bean [44], *smart meters today are used to define a class of meters that have intelligence being built inside. This kind of intelligence allows the smart meter to record the energy usage (kWh) over the course of a day.* They are described as *meters that can measure consumption frequently thus providing two way information between the utility company and the consumer's premises".*

From these definitions it can be concluded that the main function of electricity smart meters is dual communication between the consumer and the supplier. This property of smart meters offers scope for expanding customer service functions. The system can also enable customers to better manage their own energy usage through different communication feedbacks.

2.8.2 Communication Feedbacks of the Smart Meters

Consumers are ready to change their energy consumption pattern if they are aware of their usage [45]. However, in this thesis, Bean [44] reports a shocking observation after deploying a Wattson smart meter in a consumer's home. In less than a month, the household became apathetic and stopped checking the meter reading. For this reason, Faruqui. etal [46] proposed a multiple tariff plan which included a Critical Peak Period (CPP) rate, a Peak Time Rebate (PTR) and a Time of Use (ToU) rate to determine how the consumer would respond based on rate design.

Sianaki.etal [43] argued that most such metering systems were not user friendly and has proposed an Intelligent Decision Making Support System (IDMSS) to assist the consumer in the decision-making process. In another paper, [47] had proposed a model which includes the use of cellular technology as a feedback channel to the consumer, especially for low-income countries. In her paper, Darby [48] concludes that domestic energy consumption is still invisible to millions of consumers and this is the prime cause of wastage. She shows in her results that 5 to15 percent of electricity can be saved if the consumer is given more insight into his or her energy usage pattern. That is why research is being done on smart meters: they have the capability of providing this function.

2.8.3 Types of Smart Meters

Many different types of smart meters are either in use or have been developed. Figure 2.3 illustrates block diagram of a typical smart meter.

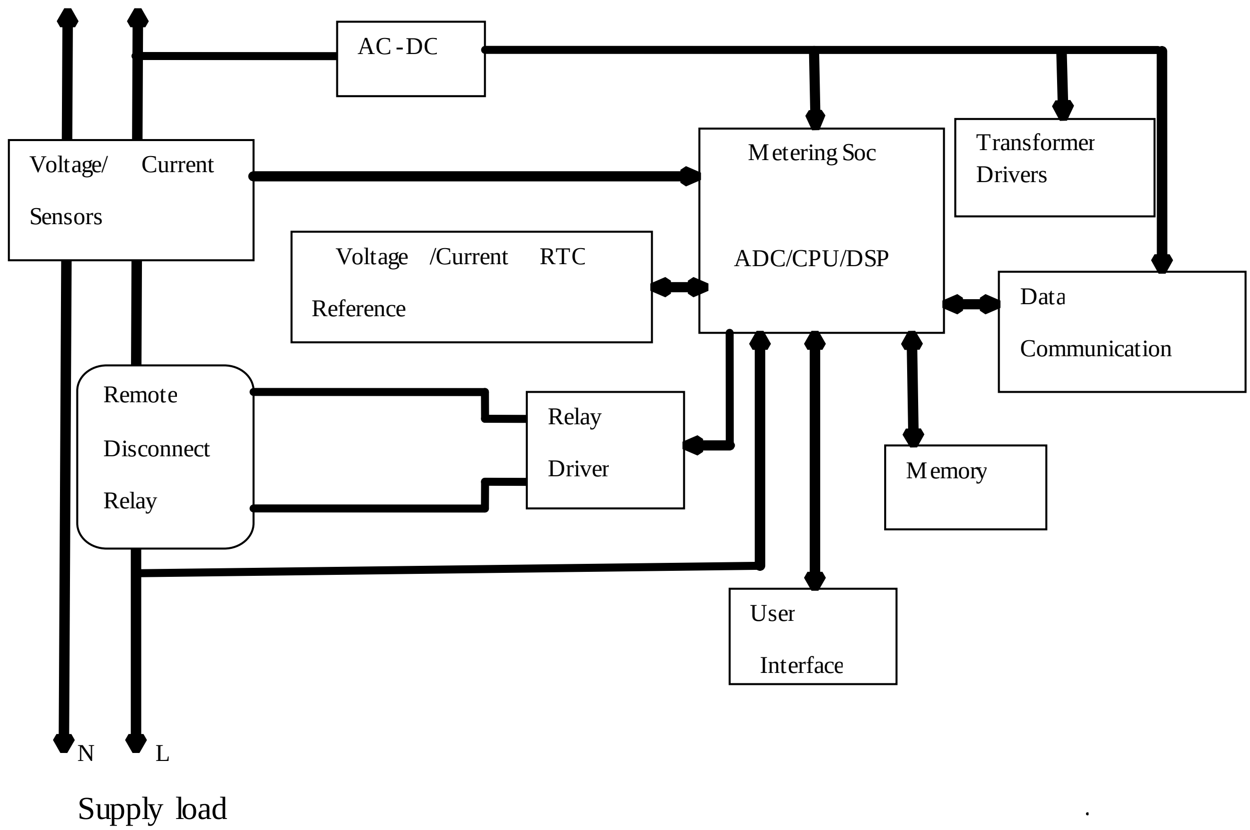


Figure 2.3: An example of a typical working smart meter [49]

The architecture of this smart meter is the basis for all smart meters surveyed during the literature review.

The heart of the smart meter is the Metering System on Chip (SoC) which includes (ADC/CPU/DSP) and is connected to several components, as illustrated in Figure 2.3. These components are:

1. **Voltage or Current Sensors** – these detect the instantaneous voltage and current from the power line.
2. **AC-DC** - feeds the inputs to the metering unit.
3. **Current or Voltage Reference** - ensures that power does not exceed the pre-determined limits.

4. **Transformer driver** - continously checks whether the power usage is still above or below the threshold.
5. **Relay driver** - If the power limit is exceeded, the relay driver is energized and disconnects power from the load.
6. **Memory** - feeds parameters to the processors.
7. **User interface** - checks if the user has disconnected the appliance.
8. **Data communication** - controls the transformer driver.

Though several kinds of smart meters have been developed, the research has considered only a few, because all smart meters work on the same principles.

The Google power-meter receives information from this utility smart meters and energy devices and provides consumers with access to their home electricity consumption on their personal Google homepage [50]. Figure 2.4 shows a graph of the typical data display from the Google meter.

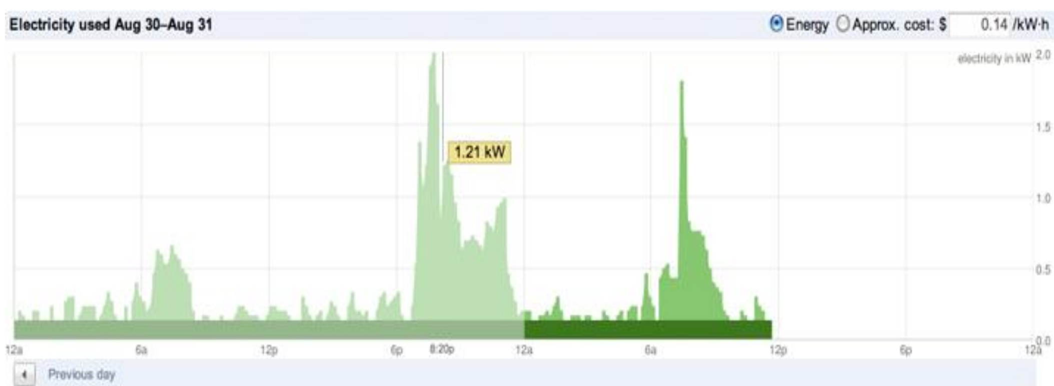


Figure 2.4: graphical data display for the google power meter

Similar to the Google power meter are the Echelon and Landis, Gyr meters [51]. These meters digitally post the consumer's power usage in kWh on the consumer's website. Figure 2.5 shows a picture of the Echelon meter.

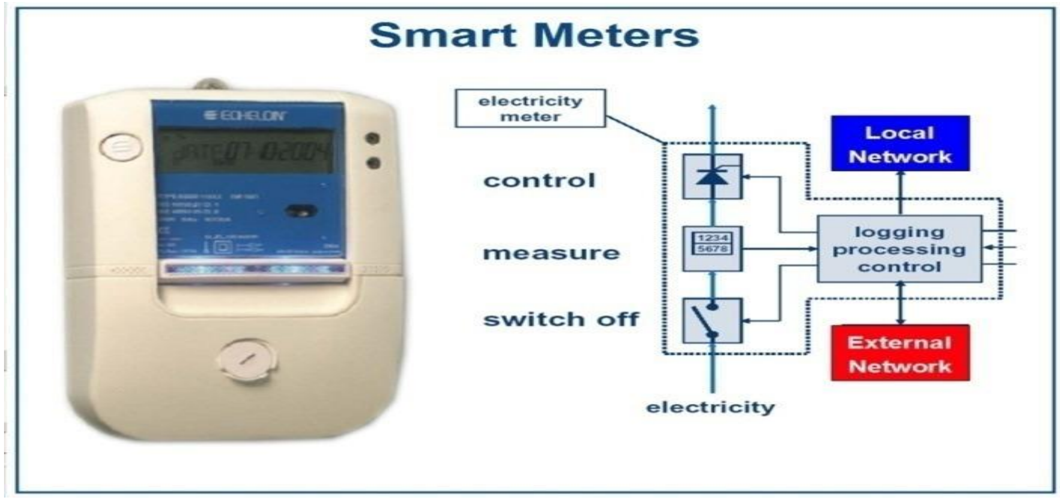


Figure 2.5: Echelon smart meter

The major disadvantage of these types of meters is that in most countries, not all users have access to the internet. This is certainly true of Zambia and it means that some consumers would not be able to receive the power-usage information.

The Wattson meter on the other hand measures power coming into a particular household; it can be located in a central position where all users can have access to it. The color-coded display produced by the meter is another advantage for alerting the user. Figure 2.6 below shows a picture of the Wattson meter [52].

Figure 2.6: Wattson Meter

The Wattson meter does not display the power consumption of individual loads in the household and the consumer can only see the total amount of energy used.

The Ecobee meter is a smart meter that controls appliances in a household in accordance with the consumer's preference and settings [53]. This kind of metering system has been adopted in Canada to automate heating systems based on the consumer's request, meaning the power company can be told to automatically switch off the geysers during peak hours [44]. Figure 2.7 shows a picture of the smart meter.

Figure 2.7: Ecobee Smart Meter

2.8.4 Global World Research Projects on Different Smart Metering Systems

Many smart metering projects are ongoing across the globe. Bean [44] describes the Grid Wise Project as one of the major ones being worked on in America; South America, Australia, Asia and South Africa are some of the places were projects are ongoing.

In the Ireland Smart Meter Project, over 10 000 meters were installed as part of a trial [54]. Enel in Italy to date has the largest number of installed smart meters. These number about 32 million, of which 24 million are remotely managed [55].

The Olympic Peninsula Project in America produced a 15 percent overall reduction in peak-hour energy usage through the implementation of smart metering. The decrease in consumer electricity bills was about 10 percent and there was a projected reduction of

$70 billion USD over 20 years in the costs of building new power plants [56]. This shows that smart metering systems benefit not only the suppliers, but the consumers as well. From the on-going projects, it is evident that more and more people across the globe are becoming aware of the benefits of incorporating smart meters into the electric grid. Such energy-efficiency systems would eventually reduce the impact and costs of blackouts and power shortages [56].

2.9 Types of Metering Systems in Zambia

Zambia currently has two types of metering systems for the management of electric power - the mechanical analogue system where the consumer is billed after using the power and the pre-paid system where the consumer pays for energy before using it [57]. The mechanical analogue system is time-consuming and tedious because it requires employees of the utility company to take readings of the consumers' meter, which can result in inaccuracy. The consumer is also not aware of how much power he or she is using, and so there is a tendency to misuse it. Due to these disadvantages, Zesco has introduced a pre-paid metering system which incorporates the use of digital technology in a dual communication system that links the consumer and the supplier, through the unit's sales points and not at the consumer meter location. The system has a pre-paid meter located at the consumer's home and he or she purchases electric energy from a vending station which is connected to the central control centre. Upon paying, the consumer is given a voucher with a 20-digit code to be keyed into the meter.

CHAPTER THREE

METHODS AND MATERIALS

3.0 Introduction

This chapter presents the research methods and materials used in the study. The chapter is organized under the following sections: the method used for data collection on household energy usage, load scheduling algorithm simulation flowchart, materials used for the models and the procedure followed in connecting the components to the Arduino Mega microcontroller.

3.1 Data Collection on Household Energy Usage Patterns

According to [22], there are two main methods for obtaining appliance energy usage. These are;

a) Automated methods.
b) Survey based methods.

3.1.1 Automated methods

These methods require sensors on household appliances and can provide accurate datasets. There are two types of such sensing systems. These are direct sensing and single-point sensing.

a) Direct sensing-This requires sensors at each device or appliance to measure consumption. The main advantage of this method is that it is very accurate, since it can sense and control the operations of various devices and appliances in the household. Though very accurate, it is very expensive and time consuming during to installation. Another disadvantage is that some appliances such as the stove are hard-wired and are difficult to reach.

b) Single point sensing- This approach requires sensing the household energy usage at a single point. A single sensor is used to sense and control the operations of household appliances; this method is still under research because no practical results have been obtained from it yet.

3.1.2 Survey Based Method

This approach uses the occupants to collect information on appliances use. This is done through questionnaires and interviews. This is also known as a descriptive survey design. A descriptive survey is a "…*method of collecting information by interviewing or administering questionnaires to a sample of individuals"* according to Orodho [58]; Orodho and Kombo[59] further state that, *"...a descriptive design can be used when collecting information about people's attitudes, opinions, habits or any of the variety of education or social issues"*. On the basis of this definition, despite the method not being very accurate in comparison to the automated methods, the descriptive design was used by the researcher to collect, analyze and present the household energy usage pattern. This method was forced on the research due to non-availability of sensing equipment on the Zambian market, the time frame allocated for the research, the high cost of the equipment and the fact of some appliances in the households being hard-wired.

3.1.3 Sample and Sampling Technique

A sample is a set of respondents selected from a larger population for the purpose of a survey [60].

Samples of five houses were purposely selected at Zamsure Garden Flats, Block A Thorn Park in Lusaka. They are in a low-density area, and the houses are connected to the same energy source. Only five houses were selected because this research is based on the premise that if the system worked or the algorithm worked for a sample of houses then it should work on a larger scale for houses connected to the same energy source. Information was collected for one day only, assuming that the power usage pattern generated depicted the weekly and eventually monthly usage.

Qualitative data were collected using questionnaires, interviews and observations. The questionnaire gave a brief background about the number of occupants, the monthly electricity bill, and the household appliances used in that house. The interview guide was used to collect basic information about the household power usage pattern and power ratings for the stated appliances were collected.

3.1.4 Household Profiling and Data processing

These generated graphs depicting the Power usage pattern for each house. The load profiles were built up by plotting the power consumption against the time, under the following assumptions;

1. A duty cycle of 50 percent (5minutes ON, 5minutes OFF) was considered for the following appliances in each household;
    a) Refrigerator
    b) Deep Freezer
2. The four-plate cooker in each house had the following elements: the four rounded solid plates, with 2 large plates, 2 small plates, the grill and oven and finally the warmer. These elements had different power ratings and it was assumed that they are not switched on at the same time.
3. In all the houses, energy saving bulbs and non-energy saving bulbs were used. There are three bedrooms, a kitchen with a storeroom, a living room, a toilet and bathroom, a dining room and a balcony with one security light.

The Energy and Power values of the households are shown in Appendix B and Appendix C. Appendix j shows the questionnaire and the interview guide. This information collected was used in formulating the load-shifting algorithm for the simulation.

3.2 Load Scheduling Algorithm Simulation Flowchart

The algorithm flow chart illustrates an energy rescheduling simulation of five houses with different numbers of household appliances. The first to be detailed when developing the algorithm was the objective.

3.2.1 Objective of the Algorithm

The main objective of the algorithm was to bring the total household consumption load profile as close as possible to the ideal load profile by increasing the load factor.

a) Load Factor

The load factor is a measure of the uniformity and efficiency with which electrical energy is being used. It is expressed as a percentage [61]. A high load factor implies that there is a more constant rate of electrical energy use, because power demand is held to a minimum relative to a total overall use. Load factor ratios are expressed as;

$$\text{Loadfactor } (\%) = \frac{E}{TP} 100 \tag{4}$$

where;

E: the energy used in the period of time under consideration

T: the time

P: the peak power consumed in the time period

In the electricity industry, the load factor describes a measure of the output of a power plant compared to the maximum output it can produce. Therefore a higher load factor usually means more output and a lower cost per unit, which implies more efficient electricity generation.

From the information collected from the household, the loadfactor was calculated as follows;

$$\text{Loadfactor } = \frac{P_{avg}}{P} \tag{5}$$

where: P_{avg} is the average power in the time period

$$P_{avg} = \frac{E}{T} \tag{6}$$

Household values were, for instance:

$$P_{avg} = \frac{298}{24} = 12\text{kW}; \qquad P = 47\text{kW};$$

$$\text{Hence Loadfactor } = \frac{12}{47} = 0.26 \tag{7}$$

The ideal load factor is 1.00. This is to be compared to the load factor calculated from the household; which is 0.26 hence a margin of 0.74. The objective of the algorithm is to make this margin as low as possible. Figure 3.0 shows the actual load profile from the houses with the peak power value at 47kW and Figure 3.1 shows the ideal case of the load profile.

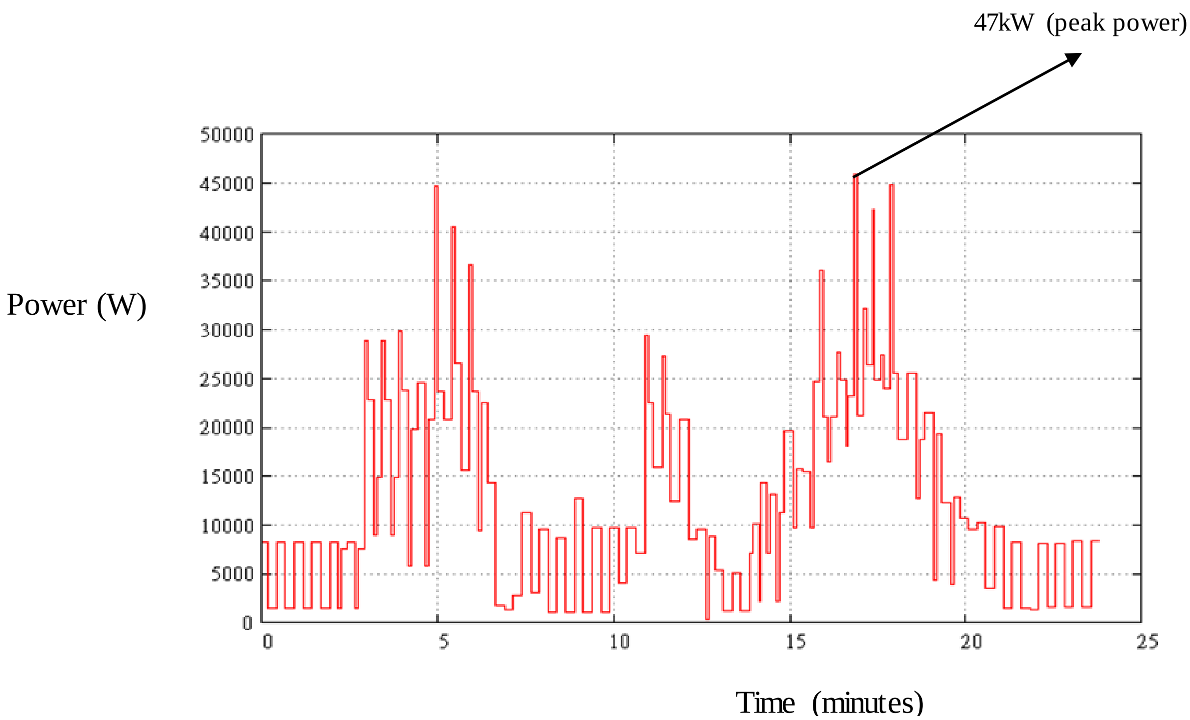


Figure 3.0: The actual household power usage pattern

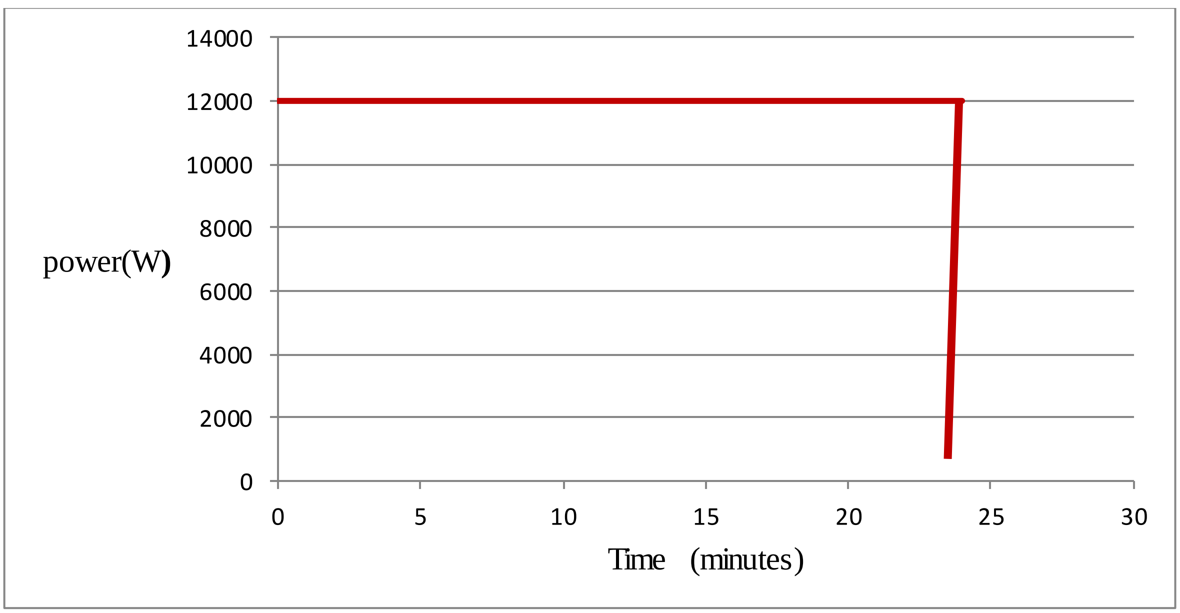


Figure 3.1: The ideal power household usage pattern

To obtain an effective algorithm, the household appliances were classified into three types of appliances. These were [62]:

a) Essentials Appliances

These appliances imposed constraints on the formulating of the algorithm, because they cannot be rescheduled to other times of usage from peak hours. Appliances such as refrigerators, deep freezers, lighting and security which lighting have known durations once they are switched on are found in this group.

b) Real-time Appliances

These are appliances that cannot be shifted to a later time slot if they are switched on at peak time; the stove is one such appliance. They are not switched on throughout the day, but they are essential appliances and the consumer cannot defer their use.

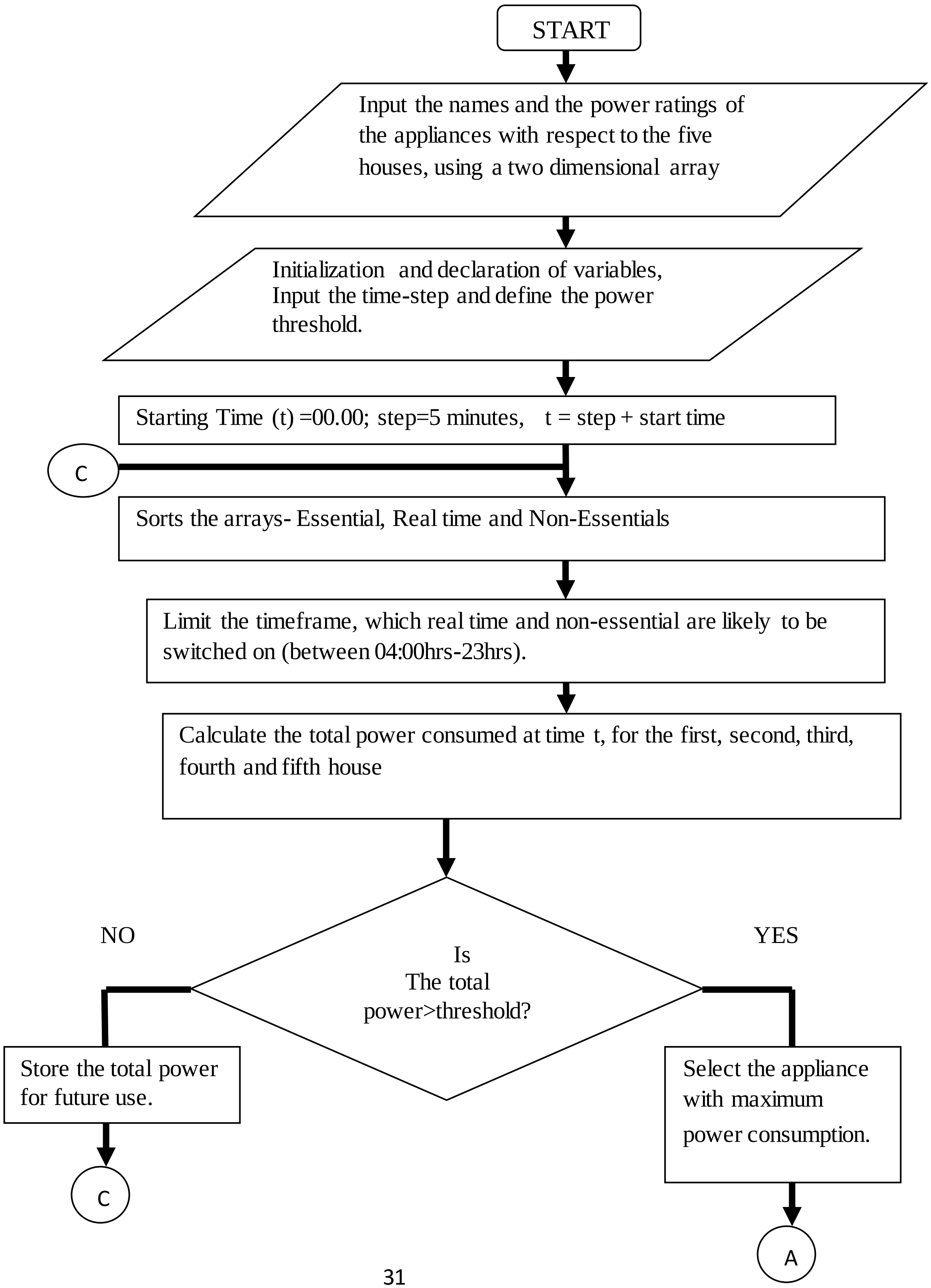
c) Non-Essential Energy Appliances (Shiftables)

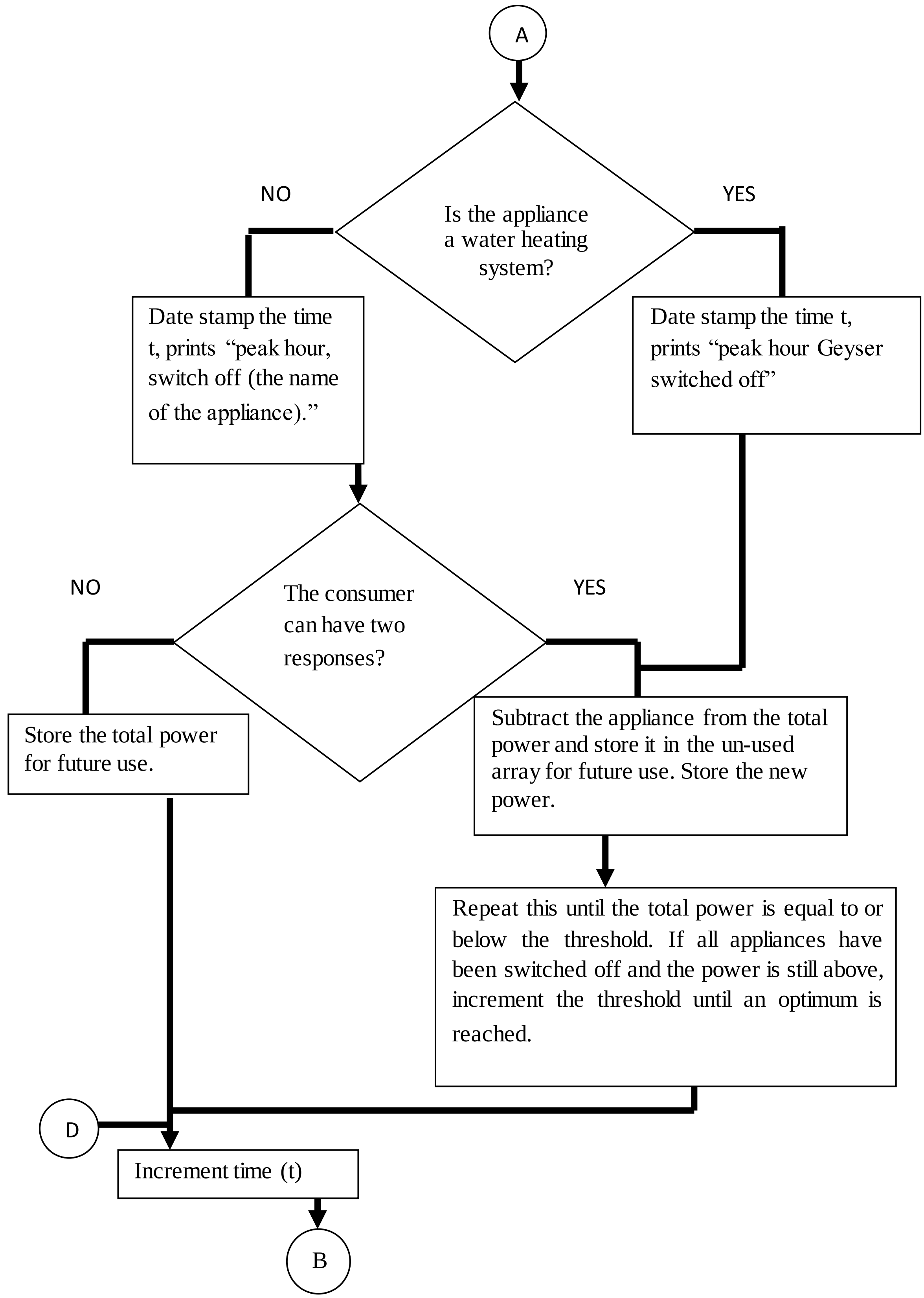
These are appliances that the consumer can use at some later period. These includes appliances such as pressing irons, video games, geysers, washing machines, clothes dryers, hair flatteners, dryers, electric kettles, microwaves, food blenders or mixers, toasters, sandwich makers, house hoovers, vacuum cleaners, and lawn mowers.

3.2.2 The Simulation Flow Chart

From the survey, it is found that most appliances in the households are switched on between 04:00hrs and 23:00hrs. This imposes a constraint on the formulation of the algorithm because a non-essential appliance cannot be shifted beyond 23:00hrs to before 04:00hrs.

The main goal of the simulation was not to change the total energy consumed by the households but to evenly distribute the household appliance usage, and hence reducing the peak power and increasing the load factor. The flow chart below describes the operation of the algorithm.


START
Input the names and the power ratings of the appliances with respect to the five houses, using a two dimensional array
Initialization and declaration of variables, Input the time-step and define the power threshold.
Starting Time (t) =00.00; step=5 minutes, t = step + start time
C
Sorts the arrays- Essential, Real time and Non-Essentials
Limit the timeframe, which real time and non-essential are likely to be switched on (between 04:00hrs-23hrs).
Calculate the total power consumed at time t, for the first, second, third, fourth and fifth house
NO
YES
Is The total power>threshold?
Store the total power for future use.
Select the appliance with maximum power consumption.
C
A


A
Is the appliance a water heating system?
NO
YES
Date stamp the time t, prints "peak hour, switch off (the name of the appliance)."
Date stamp the time t, prints "peak hour Geyser switched off"
The consumer can have two responses?
NO
YES
Store the total power for future use.
Subtract the appliance from the total power and store it in the un-used array for future use. Store the new power.
Repeat this until the total power is equal to or below the threshold. If all appliances have been switched off and the power is still above, increment the threshold until an optimum is reached.
D
Increment time (t)
B

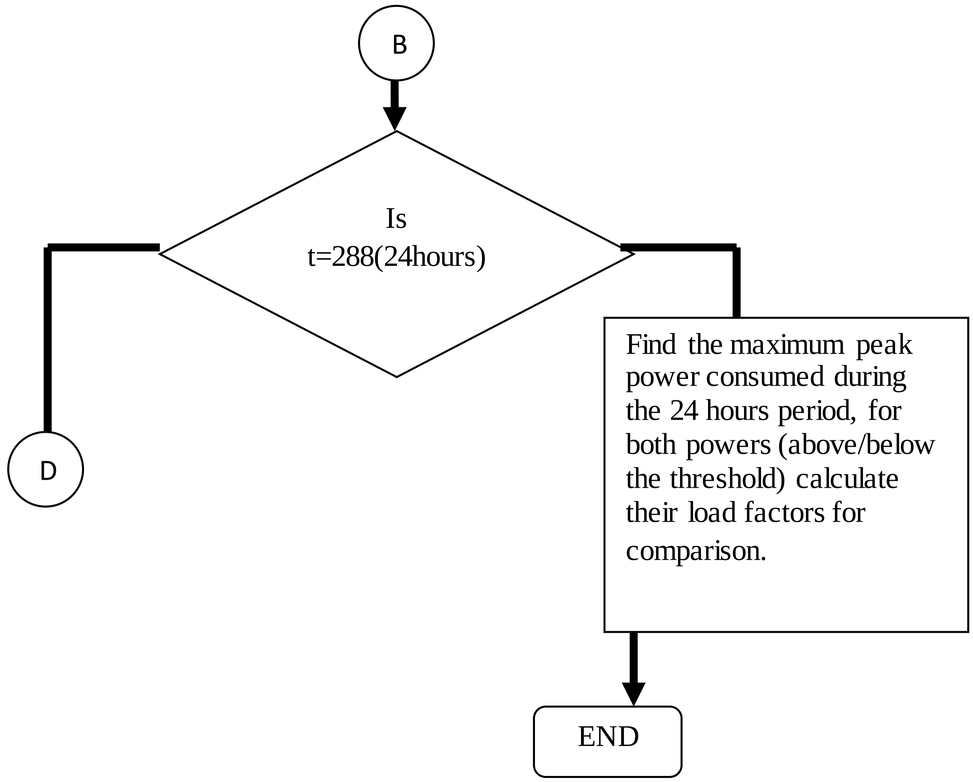


Figure 3.2: Algorithm flowchart

3.3 Materials and Methods for constructing the House Models.

Two models representing two houses were made using the following materials;

a) 100cm by 100cm wooden board.
b) Four 40-W bulb holders
c) Eight 13-A sockets
d) Two bulb switches
e) Eight 220-240V, 60 Hz single phase contactors.
f) Two 6.2Ω speakers.
g) Two Liquid Crystal Display (LCD) units.

Each model had all the materials listed above. House 1 is denoted by Model 1 and House 2 as Model 2. The wooden board was cut and shaped as illustrated in Figure 3.3. This figure shows all the measurements taken in order to provide slots for the materials to be put on the two boards.

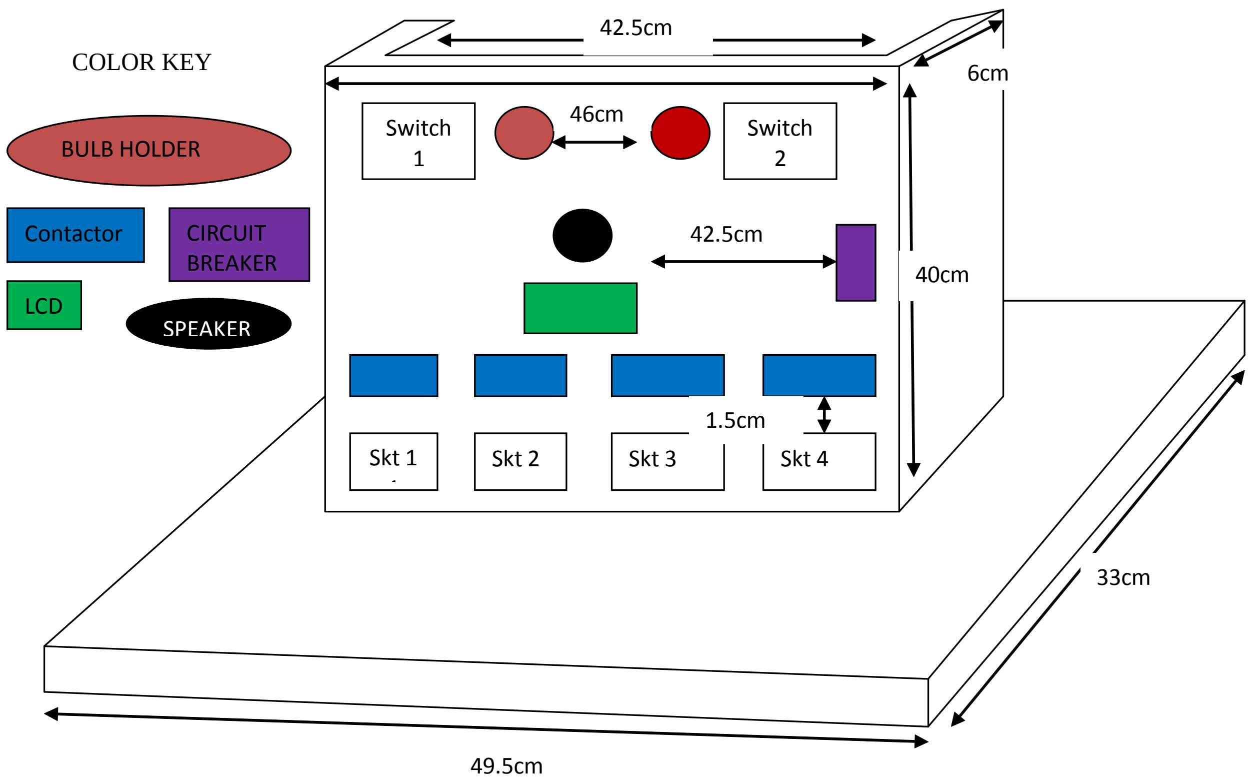


Figure 3.3: An illustration diagram for the board

The bulb holders with their respective switches were connected 42cm apart on the board. Bulbs were used to represent the lights in the household. A speaker was placed in the middle of the board for producing an alert when the peak hour load was high. A 16×2 inches LCD was placed 3.5cm from the speaker; this represents the screen on the electricity meter, which provides appropriate information to the consumer. Four sockets were placed 1cm from four contactors that are placed 1.5cm from the LCD. The four sockets were used for plugging in household appliances. The A.C and D.C relays are the major components of the control logic of the system. The control and sensor circuit boards were placed behind the boards.

3.3.1 The Control Logic

12V D.C SL relays were used to energize the contactors that were connected to the switches of the sockets. A BC108 transistor was used as a switch with the base being controlled by the microcontroller. When a logic high (5V) was sent from the microcontroller to the base of the transistor, the 12V DC supply energized the relay making the normally open contact to close. The common contact was connected to a 240V AC power supply and this line was connected to the coil of the contactor (AC relay), energizing it and allowing a complete the circuit. The components used in the control circuit were;

a) BC 108 transistor.

b) 12V D.C SL (240V AC).

c) Diode.

d) 220-240 ~60Hz, single phase contactor.

Figure 3.4 shows the Schematic diagram of the logic circuit as drawn from Multisim. The logic circuit was used to automatically switch off appliances during peak hour load.

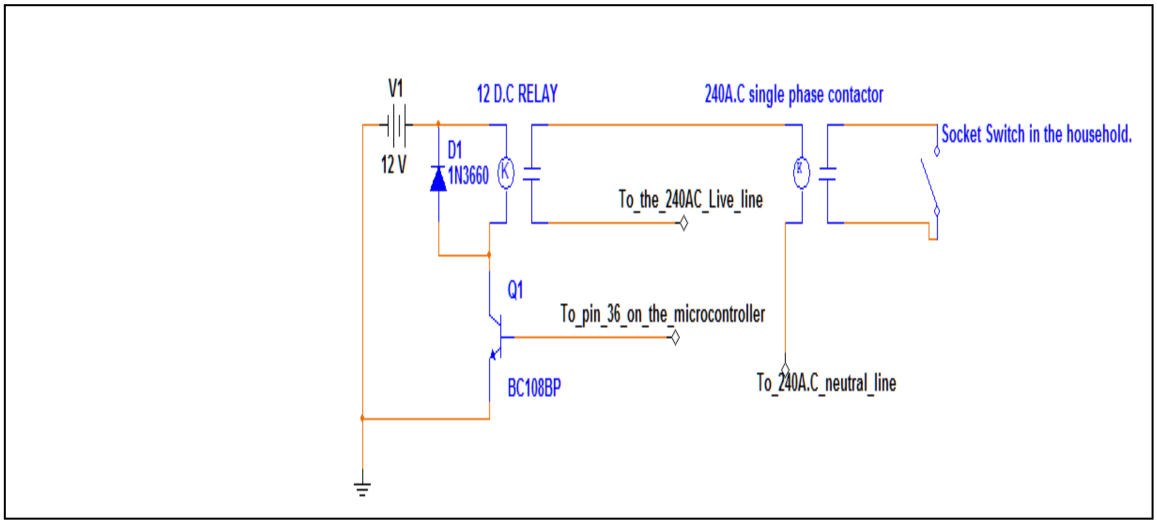


Figure 3.4: Control logic circuit

In order for the system to determine which appliances are switched on at a particular time of the day, a sensing circuit was necessary. This was done by using the low side current sensing method. The following were considered when choosing the appliances to be used in the model. A shunt resistor of 0.22Ω with power rating of 10W was used and the maximum current to flow in the system was limited to 5A. Table 3.0 shows the calculated AC values for the appliances.

Table 3.0: Calculated AC voltage values for the appliances

Model 1				Model 2			
Appliances	Power Ratings (W)	A.C Voltage (V)	Power Dissipated (W)	Appliances	Power Ratings (W)	A.C Voltage (V)	Power Dissipated (W)
Blower	1200	1.15	6.00	blower	900	0.741	3.37
Toaster	680	0.65	1.92	toaster	700	0.670	2.04
Philips Iron	1100	1.05	5.03	Kenwood iron	1200	1.148	6.00
Water heating element	1000	0.96	4.16	Water heating element	1000	0.956	4.16

The voltage across the shunt was then fed to the inverting pins of the LM324 Operational Amplifier (OPAMP), through a 120Ω resistor. The output line was connected to the microcontroller to sense the signal. The components used for this circuit are shown in table 3.1.

Table 3.1: Components used in the circuit

Component	Value	Quantity
Resistor	120Ω	16
Resistor	1000Ω	16
Resistor	0.22Ω	8
Capacitor	100µf	8
Power transistor(TIP4IC)[62]	-	8
LM324N[63]	-	2

Figure 3.5 shows the system circuit diagram as drawn from Multisim.

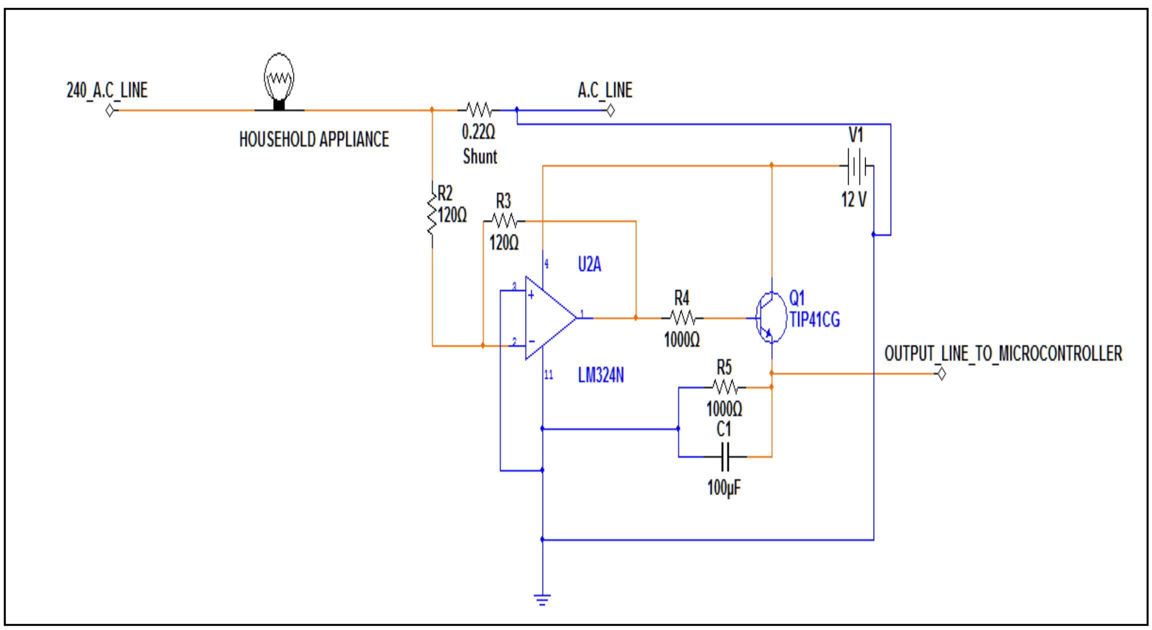


Figure 3.5: Sensor circuit diagram

The TIP4IC power transistor was used in the circuit for the speaker to send a pulse signal. This was done by connecting the base of the transistor to the microcontroller, the collector to one line of the speaker while the other line is connected to either a high logic for sound or to a low logic for no sound. Figure 3.6 shows the circuit diagram as drawn from Multisim.

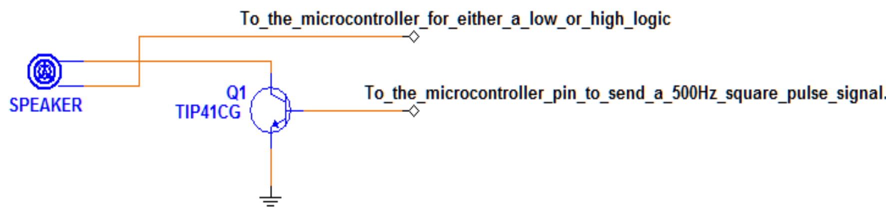
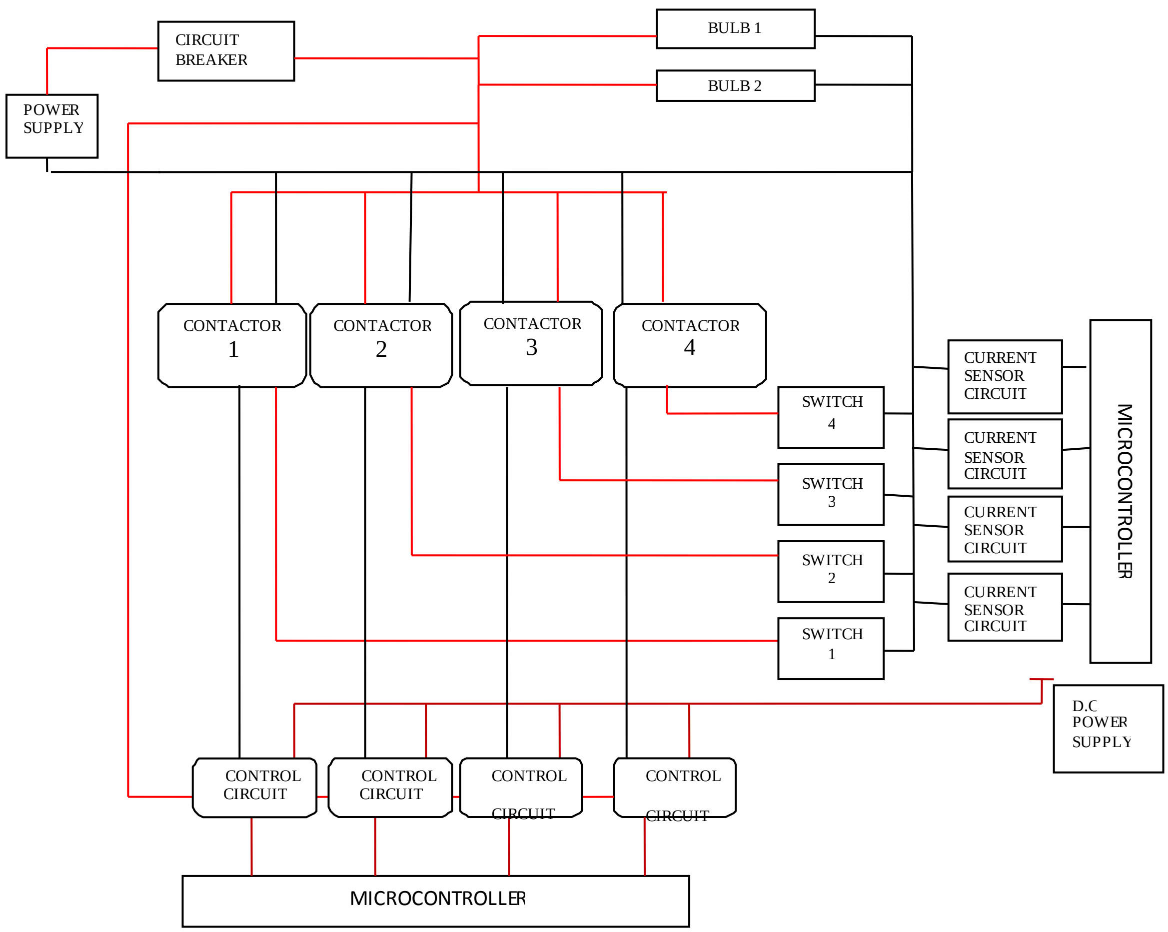


Figure 3.6: The circuit diagram for the speaker

3.3.2 The Full Block Diagram of the System

The figure below show the block diagram of the system and the full circuit diagram is shown appendix D.

THE SCHEMATIC BLOCK DIAGRAM



3.3.3 The Arduino Pin-Description for the Connected Lines

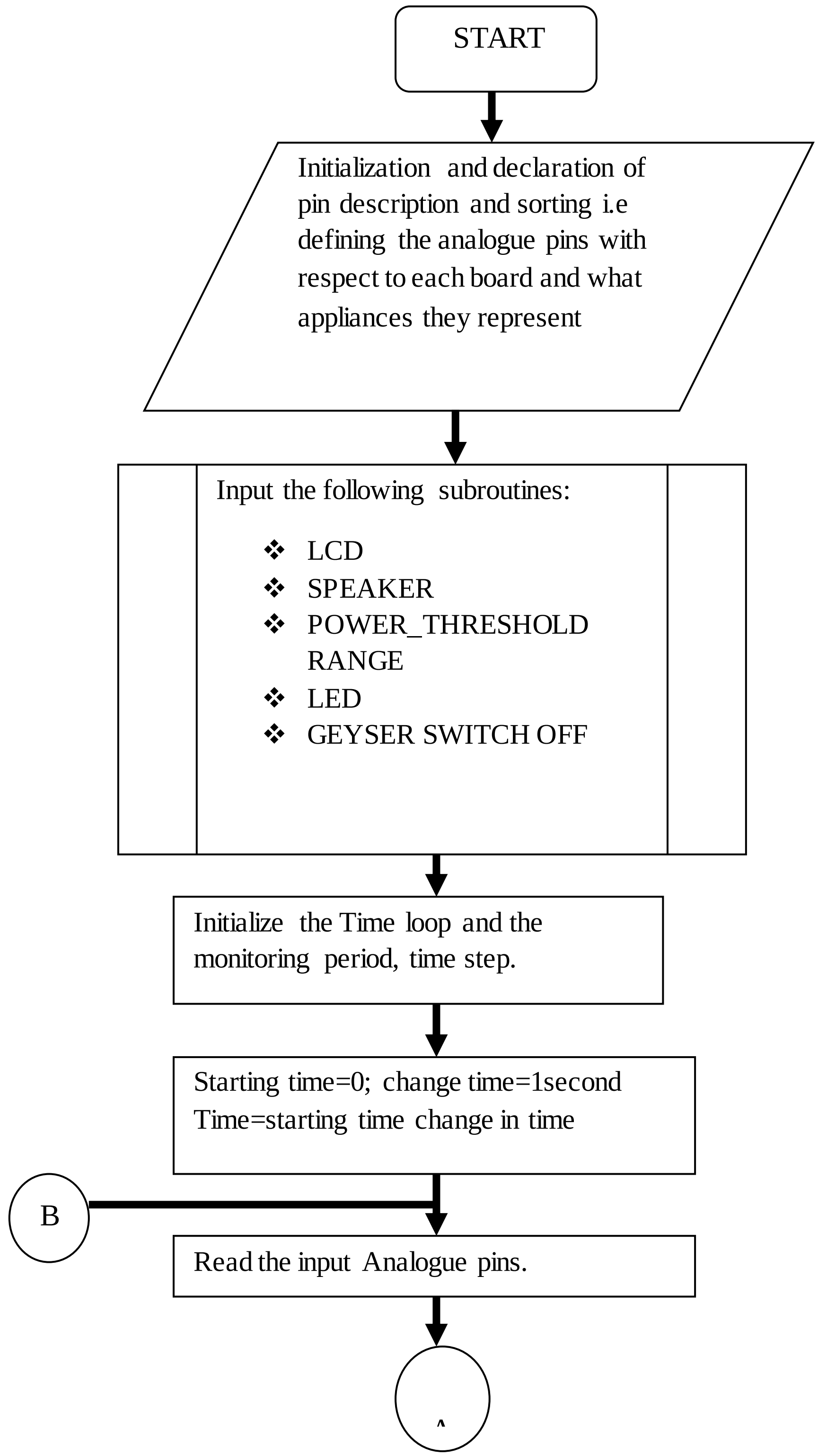
The pin description is summarized in Table 3.2 below.

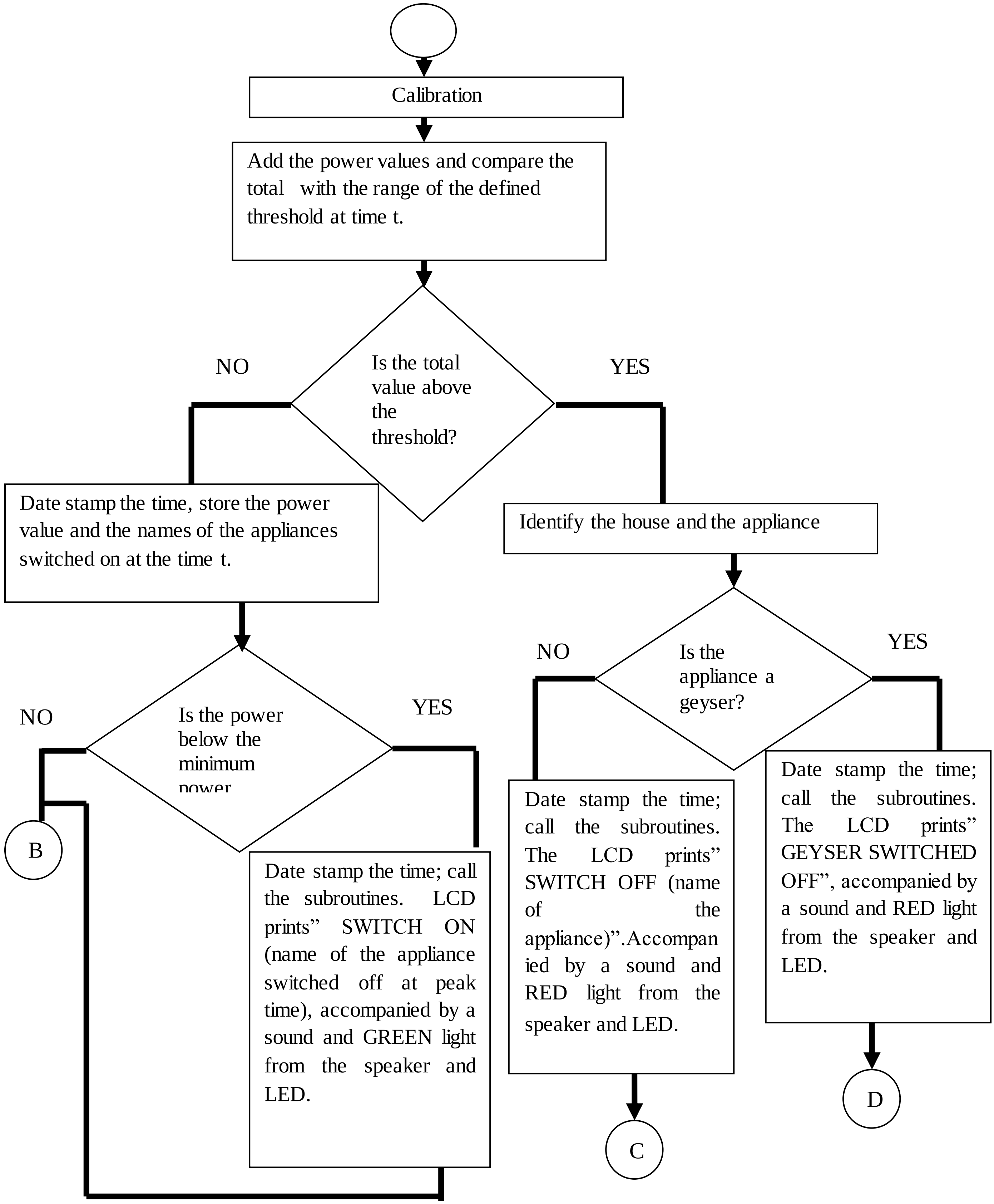
Table 3.2: Pin description on the Arduino Mega

PIN NUMBER	PIN DESCRIPTION	PIN FORMAT
A0-A7	SENSOR ANALOGUE INPUT	ANALOGUE INPUT
4-7	DATA LINES FOR THE LCDS	DIGITAL OUTPUT
10	ENABLE LINE 1-FIRST LCD	DIGTAL OUTPUT
9	ENABLE LINE 2-SECOND LCD	DIGITAL OUTPUT
8	REGISTER SELECT	DIGITAL OUTPUT
13	SPEAKER 1-LINE	DIGITAL OUTPUT
12	SPEAKER 2-LINE	DIGITAL OUTPUT
11	BASE FROM THE SPEAKER CIRCUIT	DIGITAL OUTPUT
16	LED	DIGITAL OUTPUT
36,38,40,50 24,26,28,32	LINES FROM THE BASE OF THE LOGIC CONTROL CIRCUIT	DIGITAL OUTPUT

3.3.4 The Flowchart for the Algorithm of the System

To test the efficiency of the simulation program, real household appliances were used to investigate how such an algorithm can work. The input analogue read pins informed the system what appliances were switched on. It was from this information that the system could determine if there was a high peak load or not. The flowchart below shows how the system worked using eight non-essential appliances from two houses.


START
Initialization and declaration of pin description and sorting i.e defining the analogue pins with respect to each board and what appliances they represent
Input the following subroutines:
LCD
SPEAKER
POWER_THRESHOLD RANGE
LED
GEYSER SWITCH OFF
Initialize the Time loop and the monitoring period, time step.
Starting time=0; change time=1second
Time=starting time change in time
B
Read the input Analogue pins.


Calibration
Add the power values and compare the total with the range of the defined threshold at time t.
Is the total value above the threshold?
NO
YES
Date stamp the time, store the power value and the names of the appliances switched on at the time t.
Identify the house and the appliance
Is the power below the minimum power
NO
YES
B
Date stamp the time; call the subroutines. LCD prints" SWITCH ON (name of the appliance switched off at peak time), accompanied by a sound and GREEN light from the speaker and LED.
Is the appliance a geyser?
NO
YES
Date stamp the time; call the subroutines. The LCD prints" SWITCH OFF (name of the appliance)".Accompanied by a sound and RED light from the speaker and LED.
C
Date stamp the time; call the subroutines. The LCD prints" GEYSER SWITCHED OFF", accompanied by a sound and RED light from the speaker and LED.
D

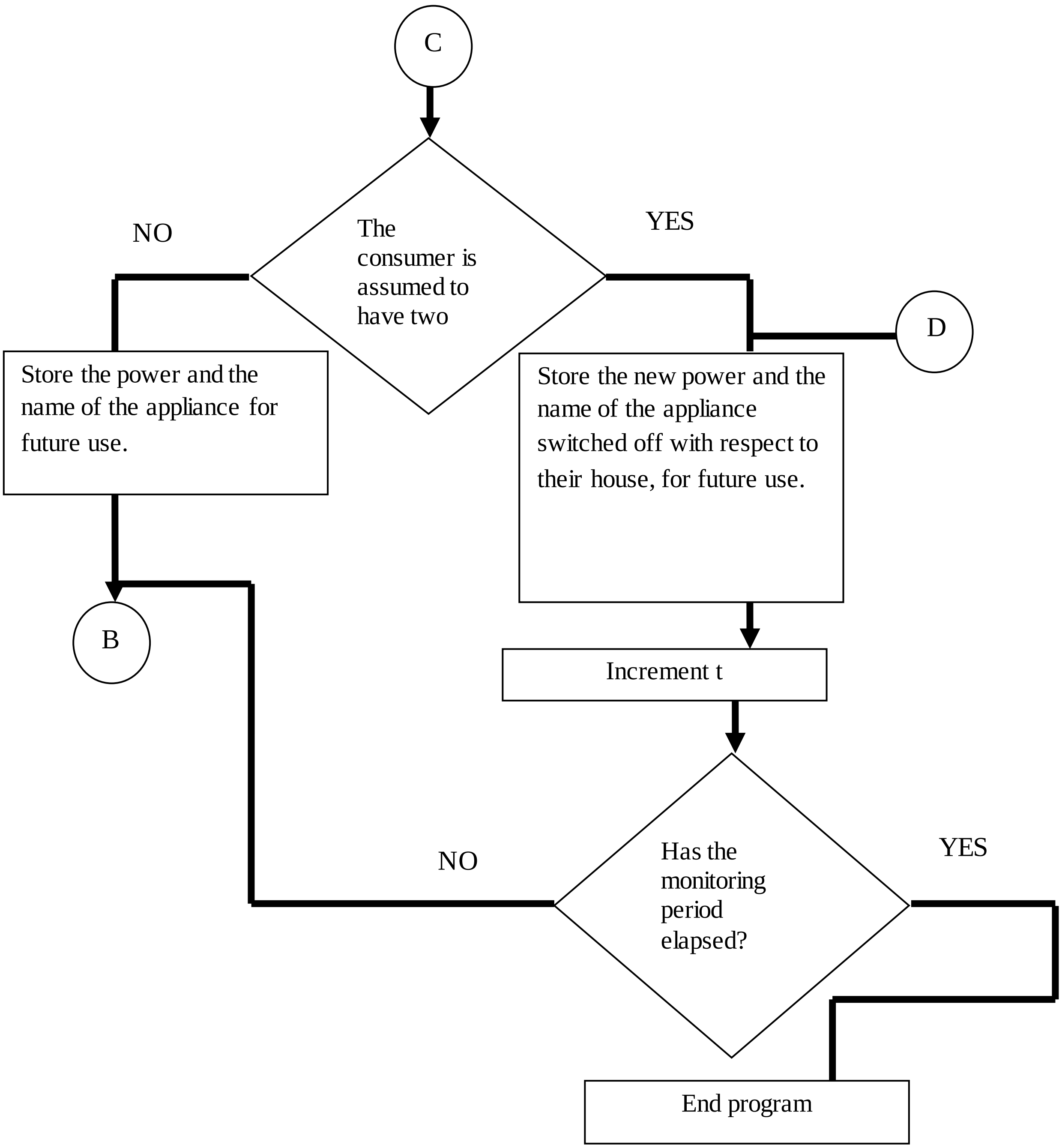


Figure 3.7: Simulation flowchart

CHAPTER FOUR

RESULTS AND DATA ANALYSIS

4.0 Introduction

This chapter presents the findings of the study and analyses the results.

The first part is a presentation of household load profiles for the five houses. The survey method was used to obtain the results presented in this section. The chapter further presents results as obtained from the computer simulation. The last section shows the results obtained by implementing the software using the Arduino-Mega microcontroller. This program monitored and controlled power consumption of household appliances using the two boards representing houses. Presentation of results is illustrated by description, by use of generated graphs and by means of tables

4.1 Generated Household Load Profile

Figures 4.0 and 4.1 below show the water-heating and power usage patterns for the households. These are shown as daily load profiles for each household studied.

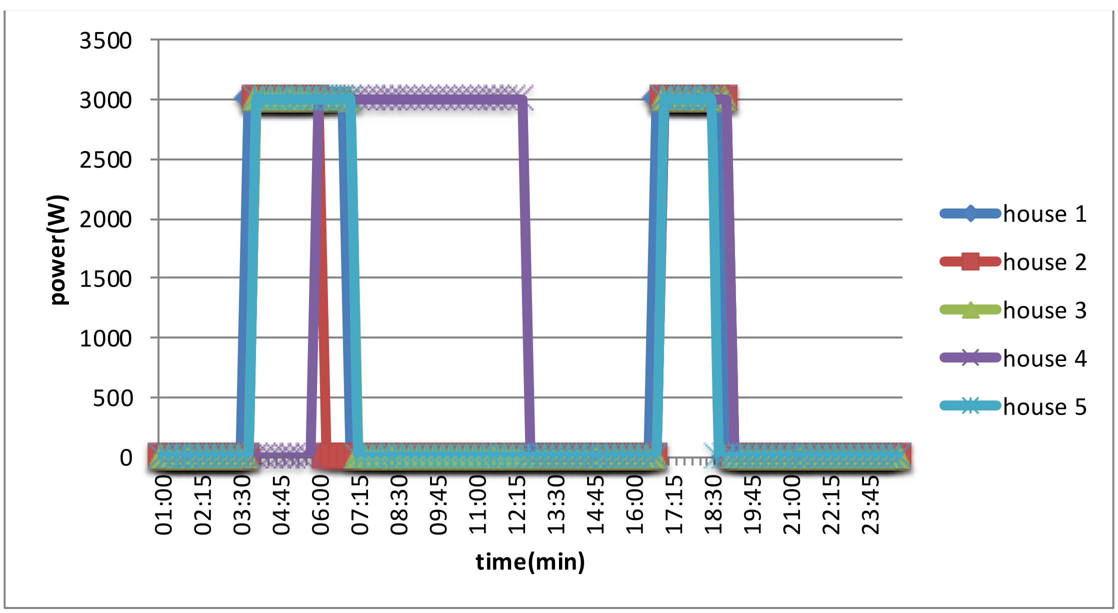


Figure 4.0: Water heating patterns for the five houses

It can be seen from the Figure 4.0 that the water heating patterns in all the five houses are very similar. In all the houses except for House 4, the heating systems are switched on from 03:00hrs to about 08:00hrs and again from 17:00 to about 19:00hrs. In house 4, the heating system is switched on from 06:00hrs to 13:00hrs and again from 16:00 to 19:00.

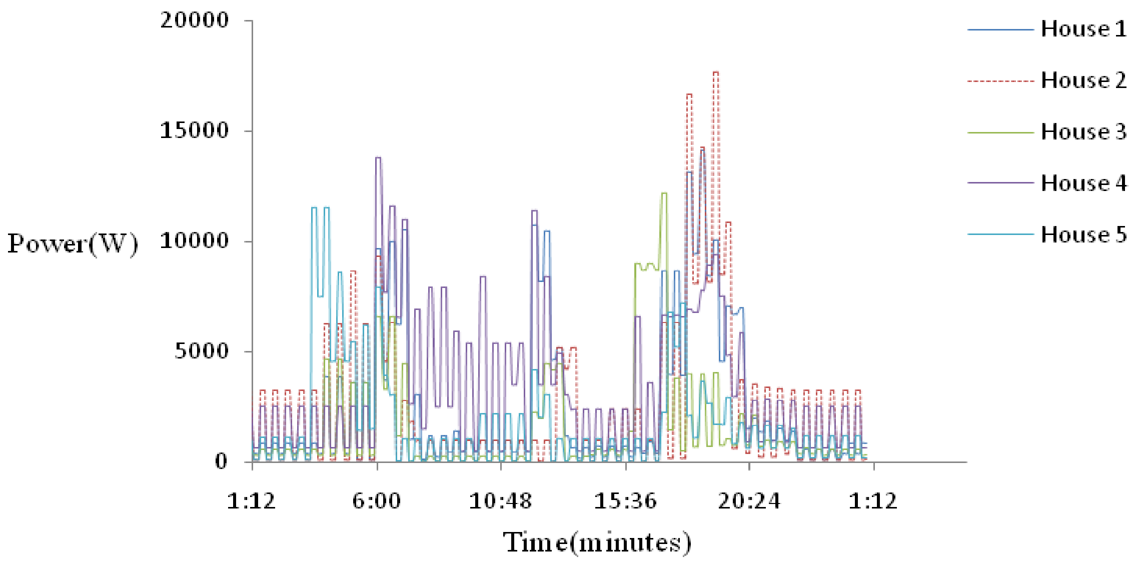


Figure 4.1: Household load profiles

From Figure 4.1, the peak hours for all the houses are between 17:00 and 20:30. These profiles were produced from the results of the surveys. Qualitative data were collected using questionnaires, interviews and observations. The questionnaire gave a brief background regarding the number of occupants, the monthly electricity bill, and the household appliances used in that house. The interview guide was used to collect basic information about the household power usage pattern and the power ratings of the appliances were recorded.

Figure 4.2 shows the total profile from the five houses and the peak time which falls at 18:00hrs. This corresponds to the highest power consumption for all the houses. This high power implies that most high-power consumption appliances were switched on at this time.

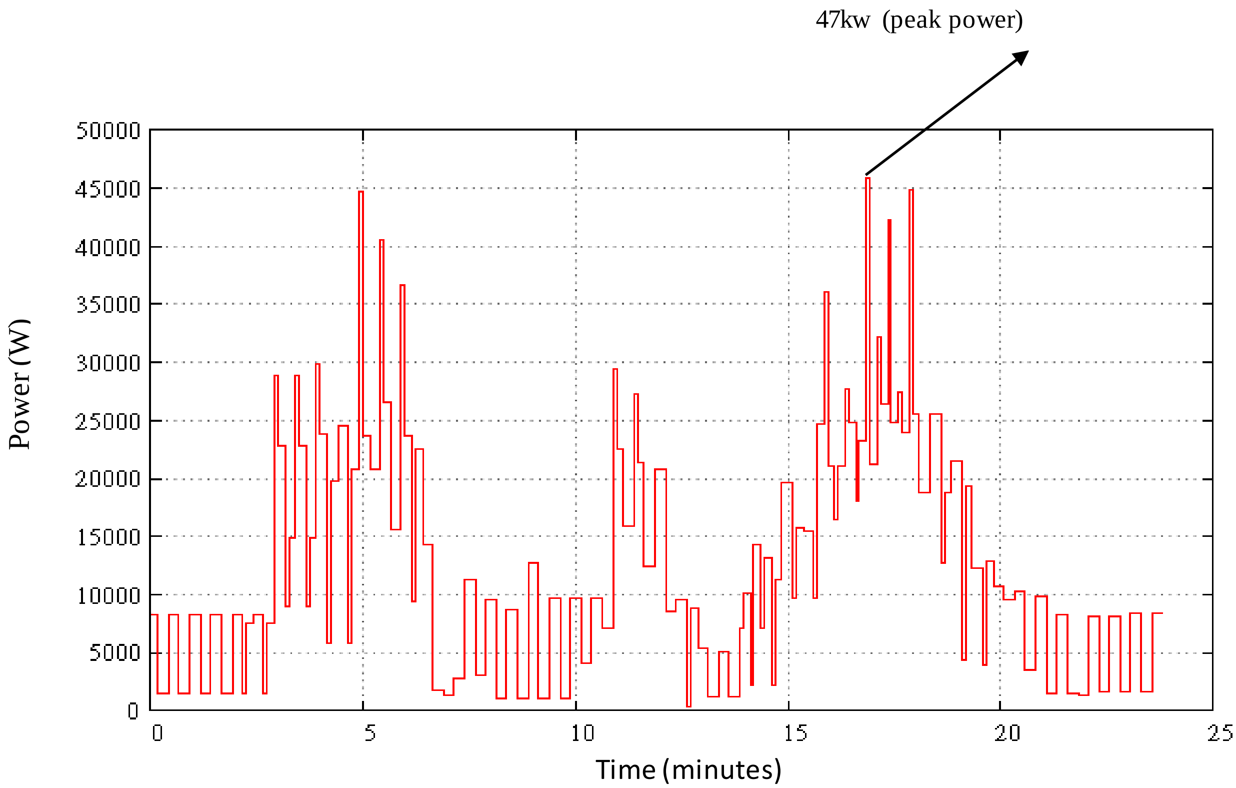


Figure 4.2: Total household power pattern usage from all the houses

Table 4.0 shows all the non-essential appliances that had been switched on for each house.

Table 4.0: Non-Essential Appliances Switched on at Peak Time

House 1	**House 2**	**House 3**	**House 4**	**House 5**
Geyser	Air conditioner1	Geyser	Geyser	Geyser
Tv1	Air conditioner2	TV1	TV1	Fan 1
Tv3	Electric kettle	Fan1	TV2	Fan 2
Pressing iron	Geyser	Fan 2	Pressing iron	DVD player
Fan 1	Fan1	Fan 3	Fan 1	
Fan 2		Fan 4	Fan 2	
			laptop	
			DVD PLAYER	

The highest power consuming appliance present in all the houses is the geyser (water heating). The power rating for this appliance is 3000W, meaning that the total power saved when it is switched off at this time is 15 000W, which reduces the peak power to 32 000W. The geysers can be switched on at 20:00hrs when there are fewer appliances switched on. This result in a new peak power of 44 802W at 19:00 and the load factor improves to 0.27. The shifting of non-essential appliances is repeated until the load factor reaches an optimum value. The load profile shown below in Figure 4.3 produces an optimum load factor of 0.45 and a peak time of 06:30hrs.

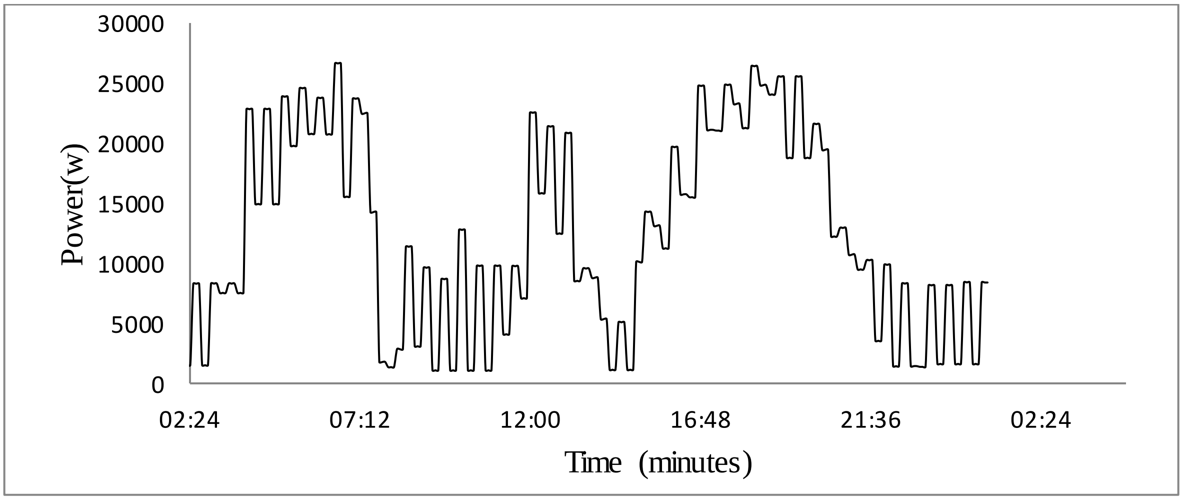


Figure 4.3: The load profile after non-essential appliances were shifted to off-peak times

It can be noted from Figure 4.3 that the load profile is more evenly distributed as compared to the one shown in Figure 4.2. Figure 4.4 shows this difference. The green line shows the load profile that gives a load factor of 0.25 while the red line gives a load factor of 0.45; the graph was produced Gnuplot.

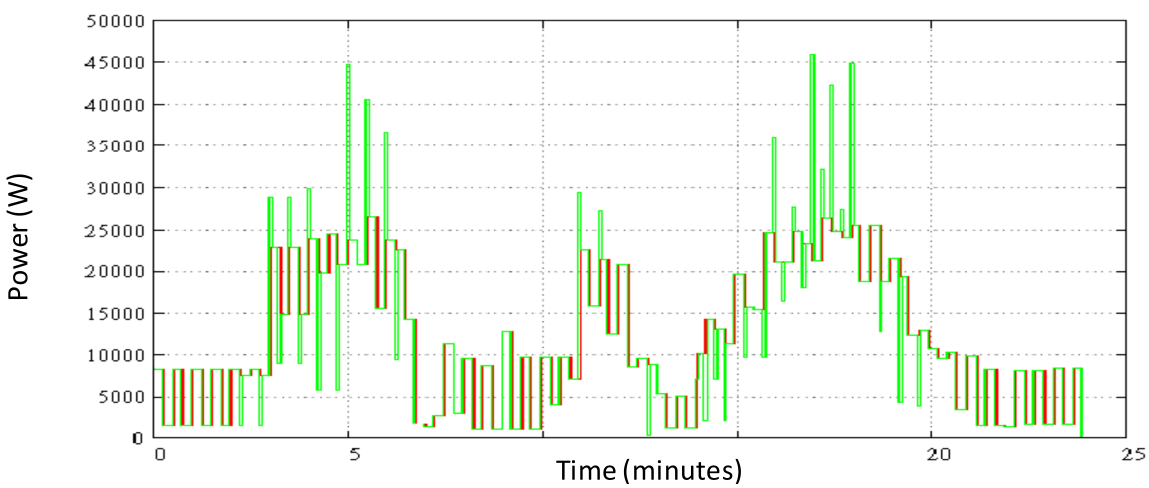


Figure 4.4: Comparison of the two load profiles

4.1.1 Analysis of load curves

Table 4.1: Derived information from the load curves

House	Peak time(hrs)	Total Energy (KWh)	Average Power(kW)	Load factor	Calculated bill (ZMK)	Stated bill (ZMK)
1	18:30	66	3	0.19	609 060	200 000
2	19:00	60	3	0.14	556 436	350 000
3	17:00	39	2	0.13	361 684	200 000
4	06:00	84	4	0.25	779 012	400 000
5	04:30	49	2	0.18	454 824	500 000

The load profiles from the five houses describe the load behavior for each house; this is the first step in implementing a load management program. The load factors calculated from the five houses were low, with House 3 having the lowest value of 0.13.The peak period for this house is between 16:00hrs to 17:15hrs. This house has the lowest load factor because all household loads are on during this short period compared to other times of the day. This information leads to the conclusion that an appliance switched on continuously throughout the day has a better load factor than one switched on intermediately. Despite House 3 having the least number of household appliances and the lowest electricity bill compared to the other four houses, it still has the lowest load factor. This clearly indicates that the load factor is highly dependent on how efficiently energy is consumed and how evenly appliance usage in a household is distributed. House 4 has the highest load factor of 0.25. As it is shown in Table 4.1 above, there is a big difference between the stated and the calculated bill; which can be attributed to the method used in collecting the information for the power usage pattern.

The peak time does not occur at the same time. This is a characteristic of good load management system. It is noted, however that peak power demand is high compared to the average power, meaning that appliances are switched on more or less at the same time. Applying the Zesco tariff rates [63] for residential loads, the following equation was used to calculate the electricity bill. Appendix E shows the Zesco limited tariff rates used.

$$C(ZMK) = \left(T(ZMK) \times E\,\frac{(kWh)}{1kWh}\right) \times 30days \qquad (10)$$

where:

C: the Electricity bill cost

E: Daily total energy for each house

T: the ZESCO tariffs as of May 2013 for metered residential one

The occupants of the five houses agreed that they experienced load shedding, but not very often.

4.1.2 Load Factor

Figure 4.5 shows the load factors for the five houses. As stated earlier House 4 had the highest load factor. The average load factor for the five houses was 0.25. This presented the possibility to investigate how the load factor can be improved for all five houses.

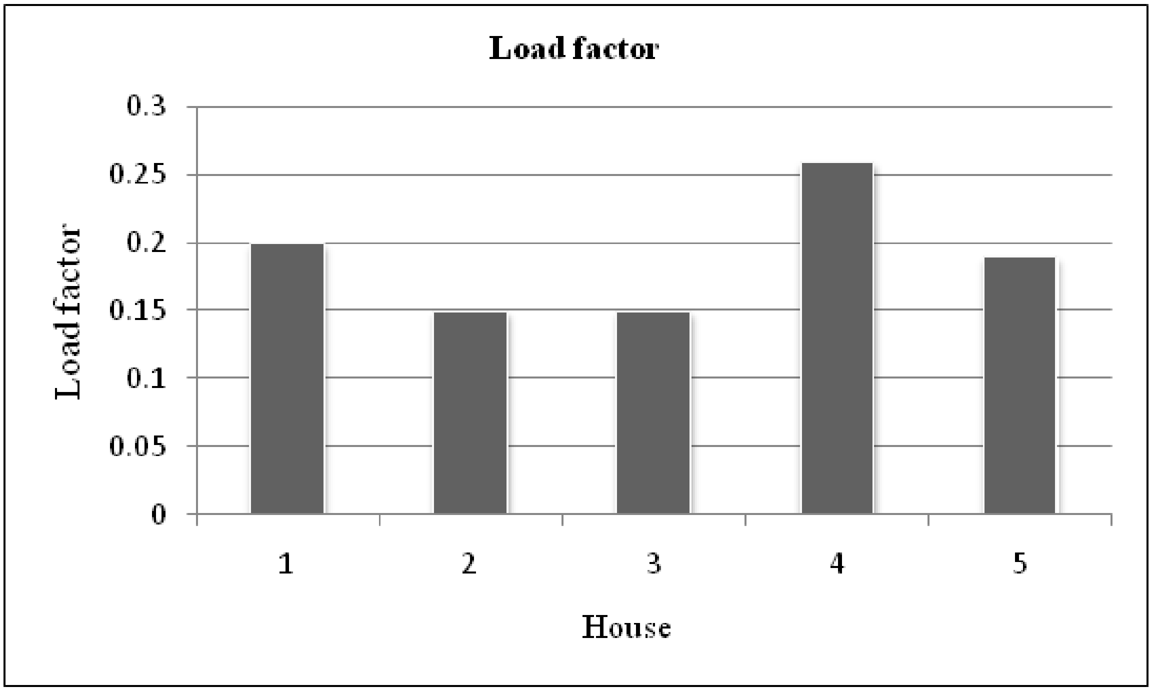


Figure 4.5: Graphical representation of the load factor.

It is important to remember that the findings of the study sought answers to the following hypothesis; the peak hour load can significantly reduce if non-essential appliances are shifted to other off-peak periods. It is also important to note that this study was conducted during the hot season when power usage was relatively low.

4.2 Results from the Simulation

The programming language C++ was used in coding the simulation. One of the tasks required for the program was the generation of pseudo-random numbers.

4.2.1 Pseudo-random Number Generation

One of the most important applications of computers is the *simulation* of real-world systems. Simulation requires the computer generation of *random numbers* to model the uncertainty of the real world. Most high-tech research and development is heavily dependent upon this technique for studying how systems work without actually having to interact with them directly [64]. Due to this aspect of the program, the C++ codes were executed seven times, to get the average results. The schedule for the usage of essential appliances was hard-wired into the program, because this could not be varied.

However, a random number generator was used to predict the usage patterns of the real-time and non-essential appliances.

Table 4.2 shows the appliances in each house from the data collected from the survey. House 1 had the highest number of appliances. These appliances in Table 4.2 are those defined as non-essential and they were randomly selected at different times from each house.

Table 4.2 Names of the non-essential appliances used in the simulation for each house.

House 1	**House 2**	**House 3**	**House 4**	**House 5**
Air Conditioner	Air Con1	Pressing Iron	Pressing Iron	Pressing Iron
Pressing Iron	Pressing Iron	Geyser	Washing Machine	Electric Kettle
Washing Machine	Electric Kettle	TV	Electric Kettle	Geyser
Electric Kettle	Geyser	Fan1	Geyser	TV
Geyser	Tv1	Fan2	Tv1	Fan1
Tv1	Fan 1	Fan3	Fan1	Microwave
Radio	Laptop	Fan4	Dish Washing Machine	Toaster
Fan	Microwave	DVD Player	Laptop	DVD Player
Laptop	Toaster		Hair Dryer	Headlamp
Microwave	Air Con2		Microwave	Fan2
Toaster	Tv2		Toaster	
Iron2	Fan2		DVD Player	
Iron3			Tv2	
Iron 4			Fan2	
Tv2			Blender	
Tv3				
Tv4				
Hair flattener				
Hair toner				
Sandmicker1				
Sandmicker2				

The following were the results using the power threshold of 21kW;

Table 4.3: Appliances switched off at the peak time

Peak Time	overload	house	Appliance
04:30	overload	house number four	hair dryer
07:06	overload	house number one	iron3
10:38	overload	house number one	tv1
13:27	overload	house number one	tv3
14:19	overload	house number four	DVD player
18.53	overload	house number five	Geyser
20:51	overload	house number two	Microwave

Table 4.3 shows all the appliances which were switched off at peak time to reduce the peak hour load. Figure 4.6a to 4.6e shows all the appliances that were switched on throughout the period and the numbers above the bar chart indicate how often they were on, from all five houses. These Figures show that despite these appliances given in Table 4.3 being switched off at peak time, they were switched on at some other off-peak time of the day. The numbers on the bar charts indicate the frequency of selection. This selection indicated that if an appliance was selected 19 times, its duration was then 19×5 minutes, giving a period of 1hour 35 minutes in which it consumed energy. There was no specific time set for the overload to occur; this was dependent on the number of appliances and the type of appliances selected. The total power was compared to the power threshold every 5 minutes.

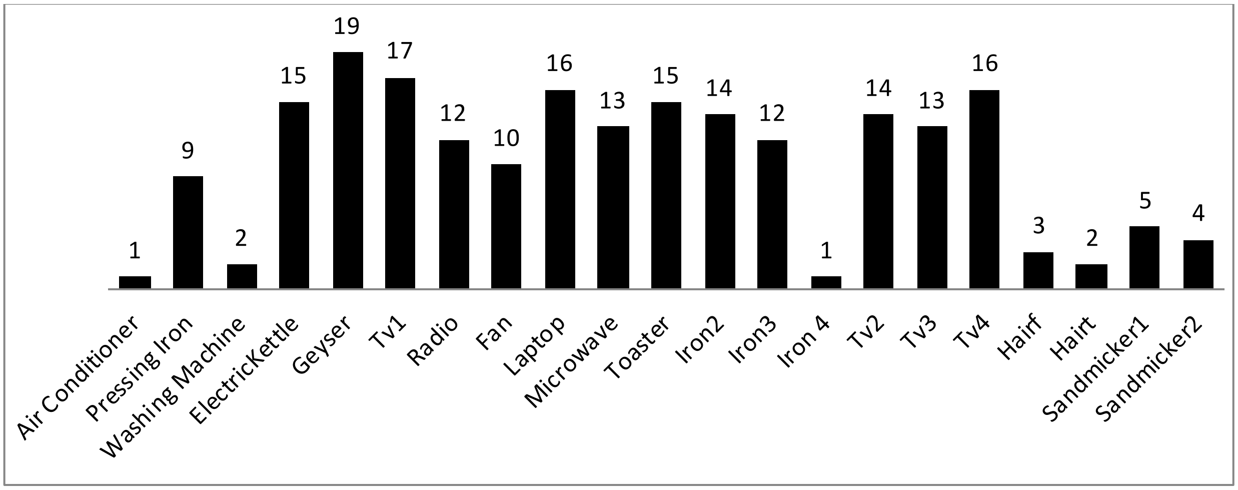


Figure 4.6(a): Appliances randomly selected in the whole period from House 1

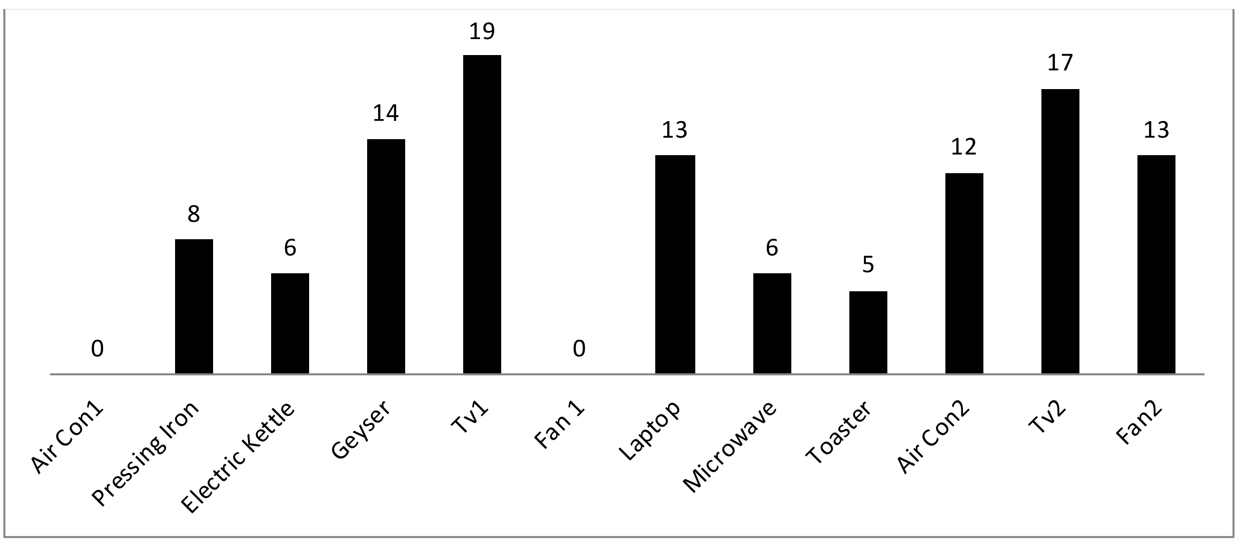


Figure 4.6(b): Appliances randomly selected in the whole period from House 2

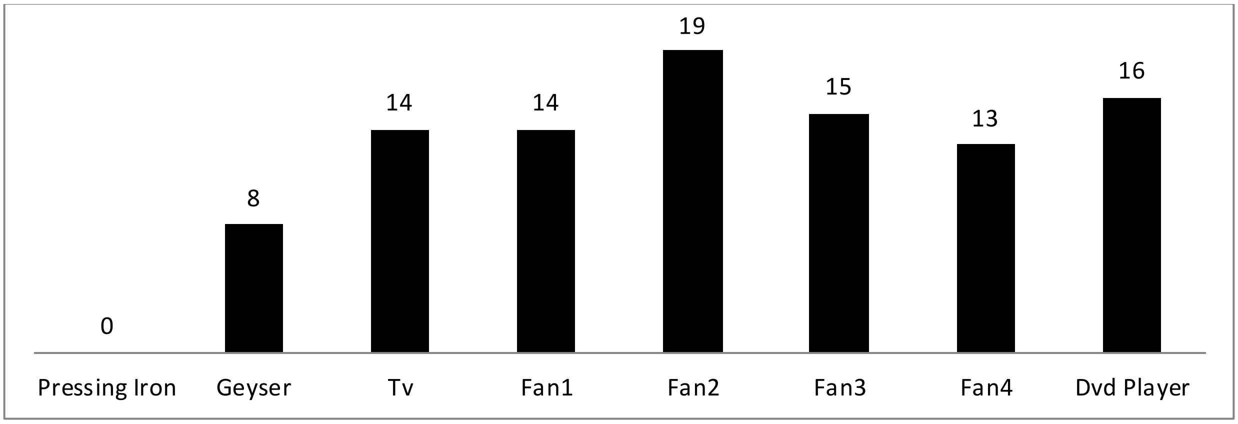


Figure 4.6(c): Appliances randomly selected in the whole period from House 3

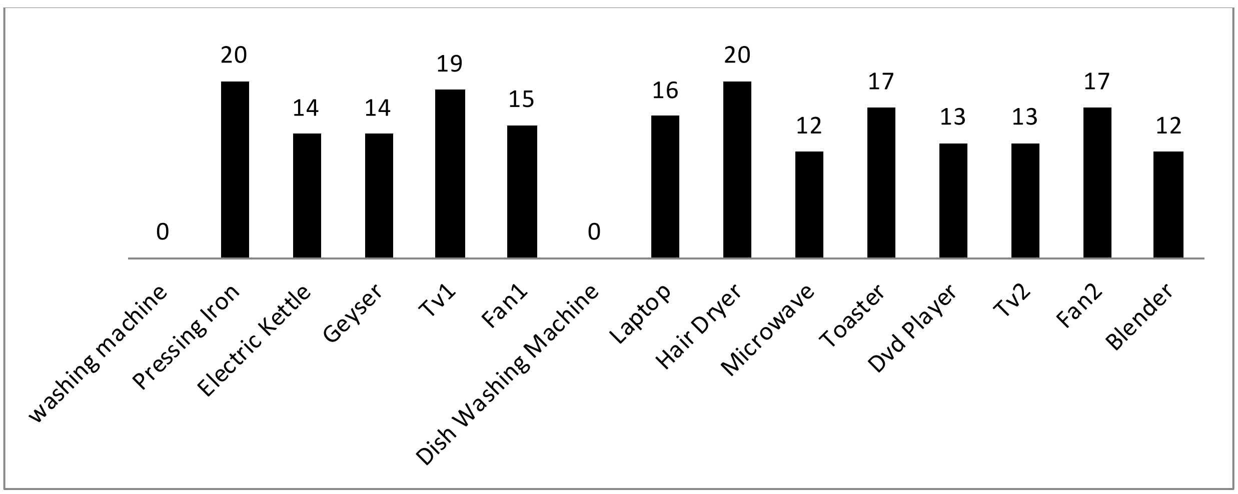


Figure 4.6(d): Appliances randomly selected in the whole period from House 4

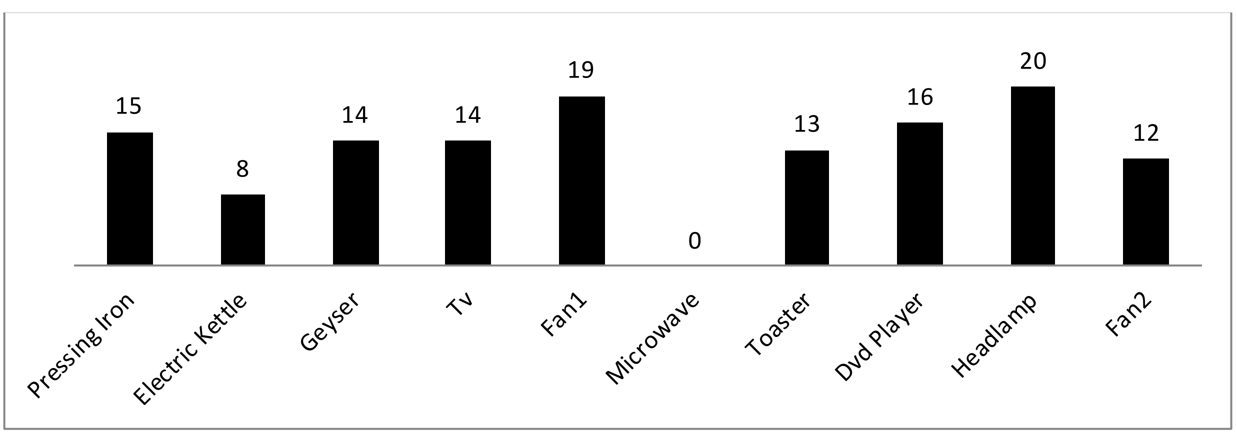


Figure 4.6(e): Appliances randomly selected in the whole period from House 5

Figure 4.7 shows two graphs indicating power value consumption at each time, before and after appliances were switched off at peak hour. The green line shows the time when there was an overload and the red line indicates how the peak reduces after the appliances are switched off.

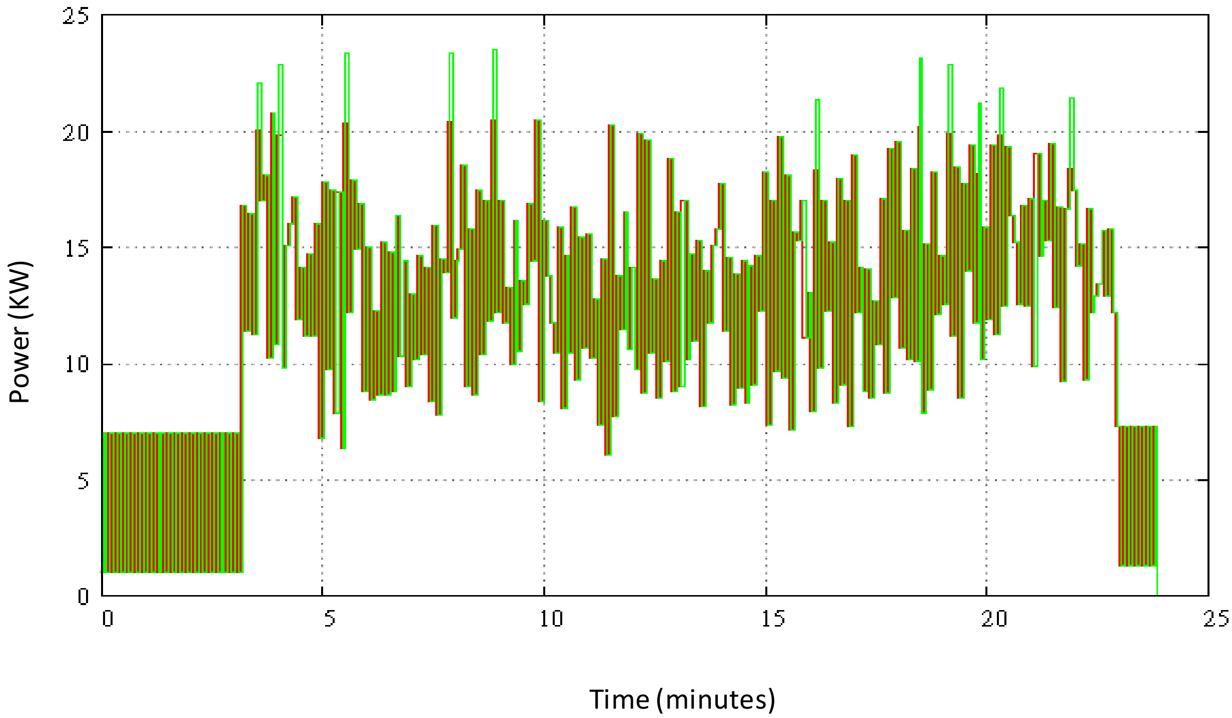


Figure 4.7: Simulation results of the comparison of the two load profiles

Figure 4.8 shows the results for the load factors. It compares the load factors from the ideal case and worst case from the households to the load factors calculated from the simulation.

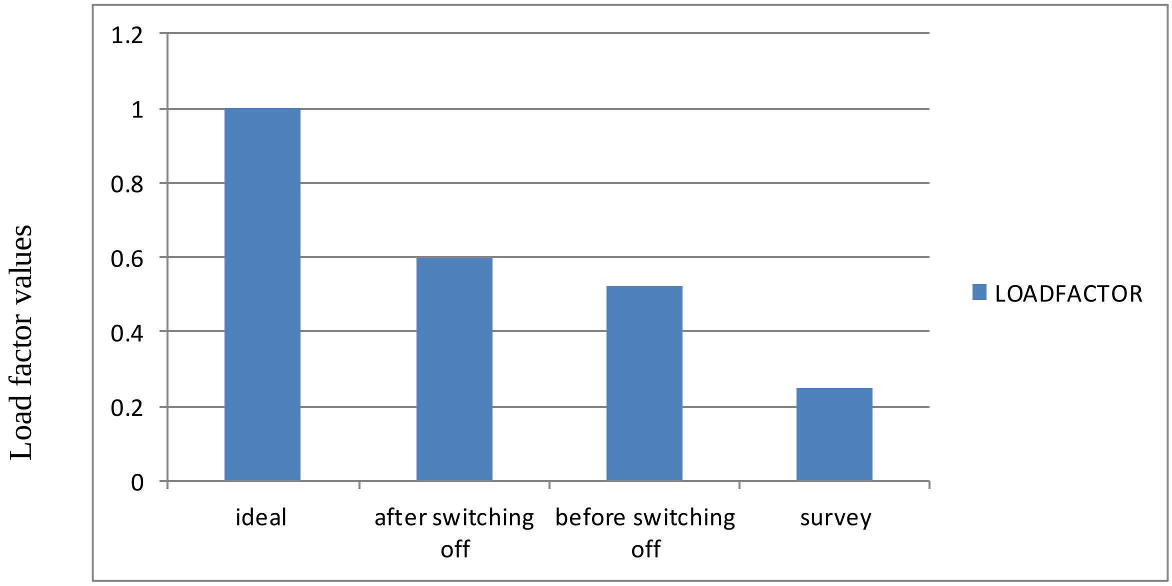


Figure 4.8: The load factors from different load profiles over a period of 24hrs.

As earlier stated, the ideal load factor is 1 and the load factor calculated from the household was 0.25. The load factor from the simulation results before the appliances were switched off was 0.52 and after the appliances were switched off was 0.60. This indicated that improved load factor can be achieved by evenly distributing the switching on and off of appliances in a household. Both the load factors from the simulation appear to be good, but the load factor can be further improved by switching off non-essential appliances to off-peak periods.

4.3 Results from the Model

The AC signal is rectified using an RC circuit whose time constant was 0.1seconds. Table 4.4 shows the AC and DC signal values from the sensing circuit.

Table 4.4: Sensing circuit signal values

Model 1				Model 2			
Appliances	Power Ratings (W)	A.C Voltage (RMS)	D.C Voltage (RMS)	Appliances	Power Ratings (W)	A.C Voltage (RMS)	D.C Voltage (RMS)
Blower	1200	1.093	0.850	Blower	900	0.893	0.617
Toaster	680	0.620	0.30	Toaster	700	0.695	0.387
Philips iron	1100	1.002	0.743	Kenwood iron	1200	1.093	0.850
Water heating element	1000	0.911	0.634	Water heating element	1000	0.911	0.634

The AC value is the effective voltage value across the shunt resistor and the DC value is the effective voltage after rectification. The main purpose of the sensing circuit is to read the signal across the shunt resistor. To make the sensor output suitable for the microcontroller, the signal has to be amplified and filtered. The half wave precision rectifier had an inverting operational amplifier with a gain of 1. This was to ensure a 1:1 ratio of the amplified and isolated signal. The power transistor acted as a buffer to charge the filter circuits. The inverting operational amplifier is used as a rectifier as in only the positive half of the AC signal is being amplified. Figures 4.9(a) and 4.9(b) show the graph of voltage values on the monitor screen of the Arduino microcontroller board. The microcontroller reads the effective D.C value (RMS). The graphs indicate that the values for each specific appliance were in a range. The instability of this value could be attributed to the ripple effect of the filter circuit.

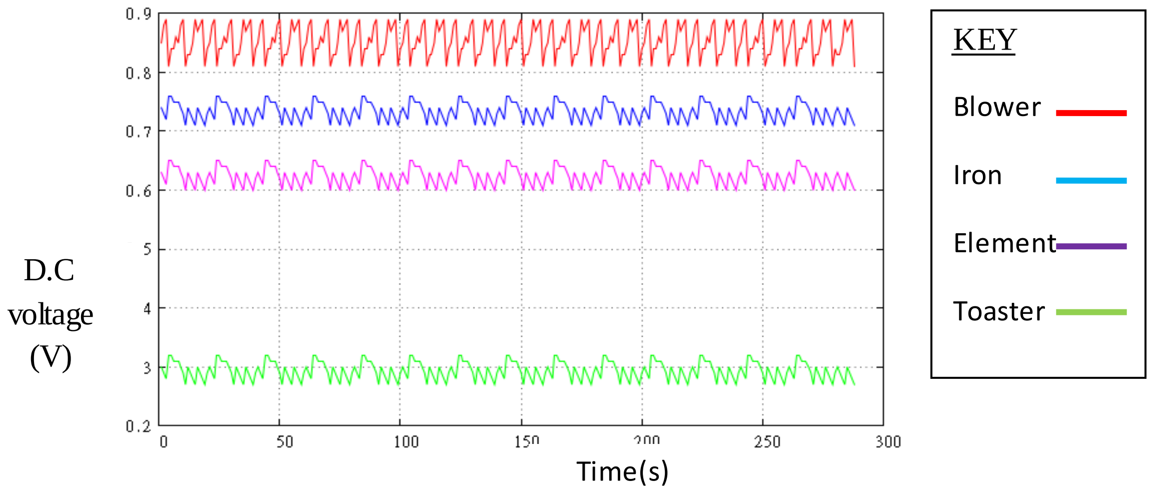


Figure 4.9(a): D.C voltage signals from Model 1

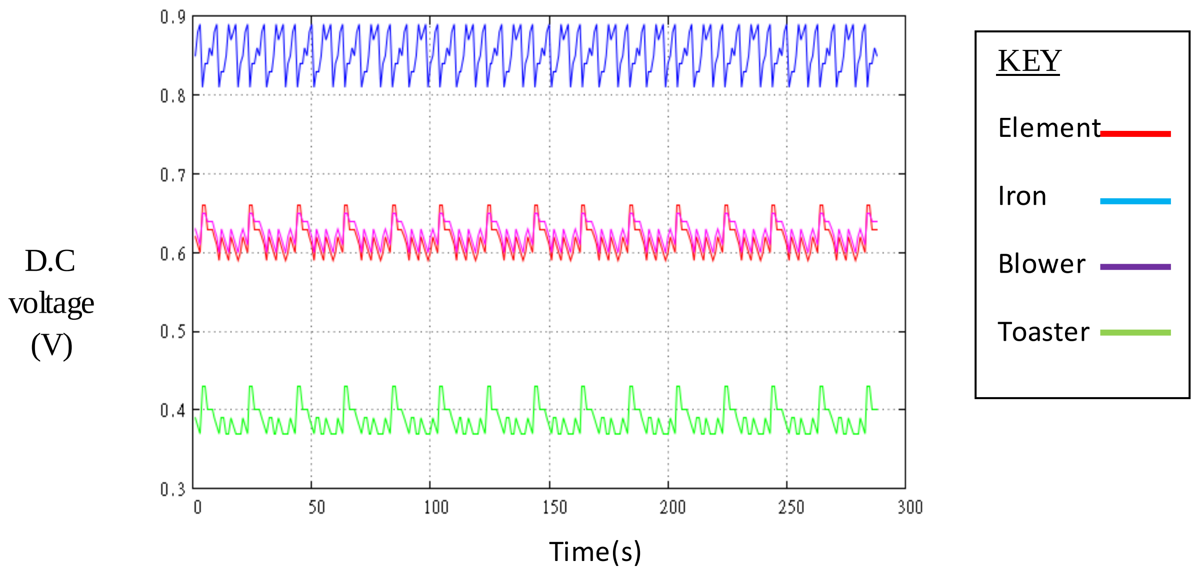


Figure 4.9(b): D.C voltage signals from Model 2

The program for the Arduino was written in the C language and is given in appendix F.

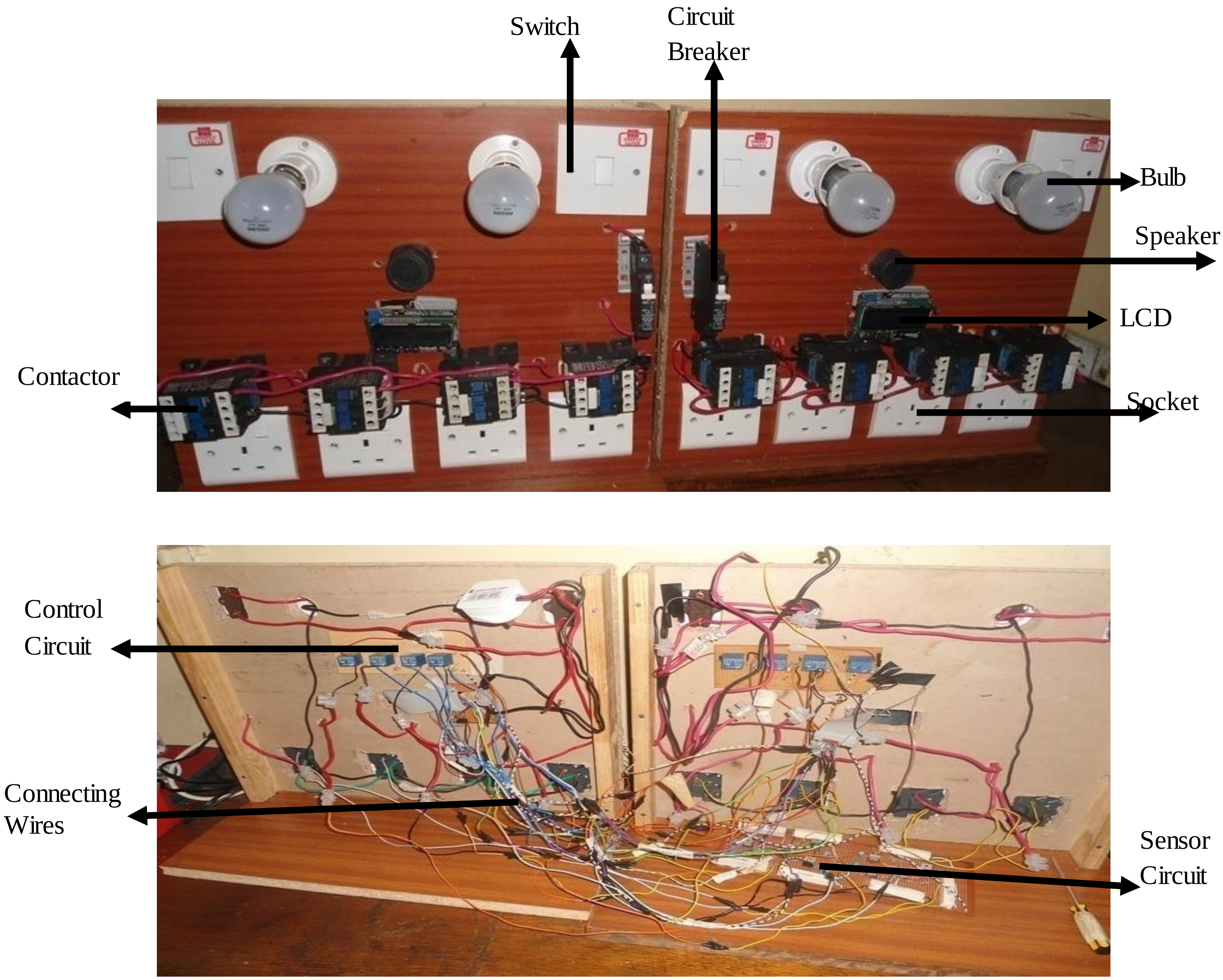


Figure 4.10: The complete set of the house models

Figure 4.10 shows the front and back view of the complete set of the house models. The laptop was connected to the Arduino-Mega microcontroller and it was used for loading the program. The signal values where monitored on the laptop screen. Other pictures on the complete set of the model are shown in Appendix G.

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CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter discusses the findings in relation to three main objectives of the research study, namely: To establish power usage patterns for household appliances and water heating; To develop a centralised microprocessor-based electricity monitoring system for optimised scheduling of household loads and; To design and construct an electronic circuit for this system.

5.1 Water Heating and Household Appliance Power Usage Pattern

The first objective was to establish household power-usage patterns. The load profiles showed that there was poor energy management in all the five households studied. The load factor calculated from the load profiles was 0.25, which is low compared to the ideal load factor of 1.00. The actual load factor value from the houses could have been slightly higher than the calculated value. This variation is due to some of the assumptions made when calculating and plotting the power-usage graphs.

The first assumption was a duty cycle of 50 percent on certain household appliances, but in reality this is not the case, as different appliances have different duty cycles. According to the literature [65], the temperature adjustment and the surrounding air temperature determine the refrigerator's duty cycle. It was also noted that most appliances in a household have a duty cycle of 30 -50 percent at room temperature, increasing to 90 percent at 38°C. Due to the use of the survey method, it was difficult to determine the exact duty cycles, and hence a duty cycle of 50 percent, obtained from the literature, was used. The other assumption made involved the electric cooker, which had six heating elements.

The survey results showed that the water-heating system consumes 40 percent of the total energy usage in a household, confirming what is stated in the literature [4]. This shows that switching off the water heating system at peak hour can result in a significant reduction in the peak load. This can also be confirmed from the results; by removing all the water heating systems switched on at peak time, the load factor improves to 0.27

from 0.25. It was also noted from the five households that only two households had energy saving bulbs in the entire house. It can be shown from Table 4.1 in the results section that the total energy consumed from these two houses was much lower than for the rest of the houses. According to [66] lighting makes up approximately 14 percent of the average household's electricity usage and 80 percent of that can be saved by replacing ordinary incandescent light bulbs with energy- efficient Compact Fluorescent Lamps(CFL). Ordinary bulbs are inefficient as they only use 10 percent of the power for lighting and 90 percent is wasted as heat. They only last 3-5 months, whilst CFLs last 3-5 years. The most utilized (i.e. switched on for a long period of time) appliance in all household was the Television set and all the houses had more than one set.

5.2 Simulation Results

It is not straight forward to evaluate most load shifting algorithms because most literature reviewed whether or not the amount of overload in the system has been reduced. In [63] a Peak Load Reduction (PLR) formula was expressed as;

$$PLR = 100 - \left(\frac{\mathrm{P_{new}}}{\mathrm{P_{old}}} \times 100\right) \tag{11}$$

where:

P_{new}: Peak Load New

P_{old}: Peak Load Old

A Percentage Overload (PO) was suggested in addition to the PLR in [16] and the result is

$$PO = \int \frac{O(L,T)dt}{L\,dt} \times 100 \tag{12}$$

where: O is the overload, L is the load and T is the threshold.

These two expressions were used to evaluate the load-shifting algorithms. The difference between them is that formula in (11) quantifies the reduction in peak load, but does not give an idea whether the system is continually overloaded, i.e., taking into consideration the local peak maximum. Formula (12) on the other hand takes into account the system overloading. In the present study, the power threshold was not fixed, and instead a range of a range of values was used for it. These fell between the ideal of

12kW and a maximum of 47kW. This peak maximum was suggested by the household load profiles.

As stated earlier it is difficult to have an ideal maximum peak because of power usage constraints, and so different power thresholds were used as inputs in the program. The use of 47kW as a threshold gave a low load factor as expected, and there was no overload indicated throughout the period. Running the program with 12kW as the threshold gave no solution, i.e., the executable result file gave an error. After running the program with different power thresholds, an optimum value of 21kW was arrived at. This value satisfied all the conditions implemented in the program. Therefore the method used to evaluate the algorithm was a comparison between the ideal load factor and the optimum load factor.

The main purpose of a load-shifting algorithm is to fill in the valleys by reducing the high peaks. This is illustrated in Figure 5.0, from the results given in [16].

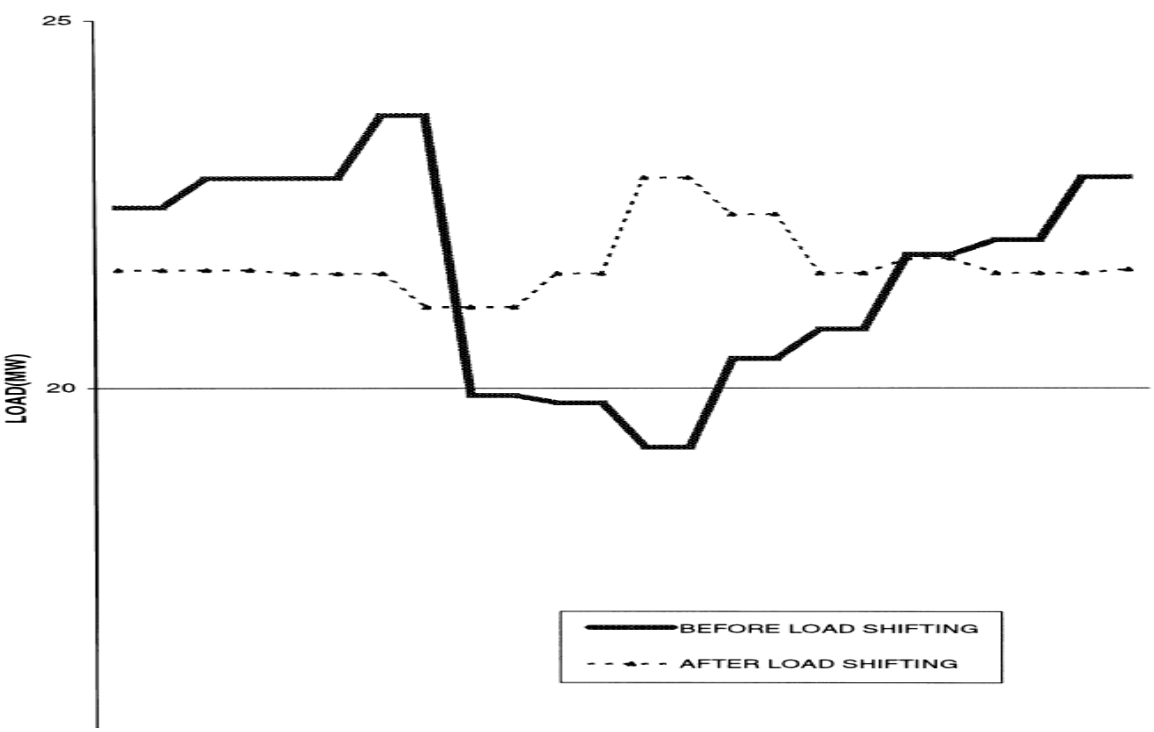


Figure 5.0: The main principle of a load-shifting algorithm [16]

Comparing this with the results presented in Figure 4.7 and obtained from the simulation, it is seen that the peaks have been reduced and valleys filled in due to the even distribution of the usage of appliances. It is seen that the load profiles are the same and they differ only during overload periods.

5.2.1 Data Input for the Simulation

In practice, non-essential appliances are not in use all the time. Therefore, the input values corresponding to them were set to zero sometimes, to represent when these appliances were off. Different algorithms have been formulated to implement the load-shifting technique; most of them have shown a significant peak reduction in peak power and a load factor in the range 0.40 to 0.60.

5.3 Results from the Model

The proposed algorithm was implemented. The two boards were used to illustrate how the program would run using real household appliances.

The first microcontroller proposed for the study was the Motorola 68 000 microprocessor which was first developed in 1975. Though it is good for educational purposes, it is difficult to interface with components. Another disadvantage is that compatible components are difficult to find on the market, because it is an old microprocessor. For this reason, the Arduino Mega, which was introduced in 2011, was used. The advantages of this microcontroller are that it is readily available, it has libraries for standard programs, such as the LCD interface, it is easy to program, the package is small, and it is of low cost compared to the 68 000.

The model was tested in the Electronics Laboratory, Department of Physics, School of Natural Sciences and in the Electrical and Electronics Laboratory in the School of Engineering at the University of Zambia.

5.3.1 Data Capture

Sampling of the voltage output of the sensor circuit was done using the ADC on the ATmega 2560. The Arduino IDE includes a family of functions for controlling and retrieving data from the ADC. An internal voltage reference option was set for the program and the function analogue read () returned a value between 0 and 1023, representing a voltage level on the specified analogue pin. The analogue read () took 100us to execute and return the converted value, which was fast.

As shown in Figure 4.9, the rectified signal could have been better if a full-wave bridge rectifier circuit was used, but due to the nature of the sensor circuit this was not possible. This could have also resulted in improved D.C voltage values. As shown in Table 4.5 the A.C values are higher than the D.C values. Time sampling was handled with the Arduino Millis () function, which returned the number of milliseconds from reset.

The system was successful in capturing voltage values, but difficulties were met in automatically detecting which appliances where switched off. Using the voltage range to identify the appliances was unreliable. This was so because some appliances used in the model had the same power rating, making it difficult to differentiate them. According to [67], parameters like harmonic distortion of the waveform for both current and voltage would be useful in identifying which appliances is on.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.0 Introduction

This chapter presents the conclusion and the recommendations of the study, based on the findings and the discussion. The first section establishes the importance of a high load factor, outlining how the proposed system can reduce load shedding through the reduction of the peak-hour load. The last section gives some recommendations arising from the study.

6.1 Conclusion

6.1.1 Establishing the Power-Usage Patterns for Water Heating and Household Appliances

The study of power-usage patterns showed that the water-heating system is one of the major contributor towards the high peaks seen on the load profiles. Water heating consumes 40 percent of the total energy used in the typical household and contributes to a high peak-hour load. The system proposed automatically switches off water-heating systems at peak hours, which can translate into energy savings. The most frequently used appliance in the household is the television set. Unfortunately, most consumers are not aware that changing from cathode-ray tube (CRT) television sets to those utilizing the more energy-efficient LCD screens may reduce power consumption. However it may increase viewing hours because of the greater attractiveness of the picture. This may lead to the television set being on practically throughout the day, significantly contributing to the peak-power consumption. Switching off this appliance at peak hour can help to reduce the peak hour load.

This study has shown that in a typical household, the peak periods for power usage are between 17:00 hrs and 19:30 hrs and between 04:00 hrs and 06:30 hrs. Such a pattern of use of electric power results in a load factor of 0.25. Use of the proposed system to regulate the power consumption improves the load factor to 0.45, indicating a substantial reduction in the peak-hour load.

6.1.2 Developing a Program for the Centralized Microprocessor-based Electricity Metering System

The importance of controlling the use of non-essential appliances has been demonstrated by this study. The simulation results showed a further improvement in the load factors as a result of adopting the practice of switching off non-essential appliances at peak hour. The value found from the simulation for the case when non-essential appliances were unregulated was 0.5. This could be improved further however: when these appliances were not used at peak time, the load factor rose to 0.62, which was a significant improvement.

The peaks and the valleys on the load curve do not differ by a large margin because of the limited threshold imposed in the algorithm; this ensured that the power consumption in all the households did not exceed 21kW and maintained the optimum situation in the system. It is important to note that the total energy consumed in each household however remained the same. It is clear that this technique does not change the total energy consumption of the consumer, but only modifies the appliance-usage pattern. This is enough to produce improvements in the value of the load factor.

The algorithm proposed in this study thus reduces the peak-hour load.

6.1.3 Design of an Electronic Circuit for the Centralized Microprocessor-based Electricity Metering System

In this study, the load-management algorithm was implemented in the microcontroller and tested on real household appliances. The microcontroller regulated the power usage of the appliances so that at peak period, a red light and a sound were produced to warn consumers to switch off the non-essential ones. The particular appliances recommended for switching off were displayed on the LCD. The algorithm proved itself and worked well.

The main objective of implementing such a load-management system was to maintain a near constant level of load, thereby allowing the household load factors to approach

1.00. The results indicate an improvement of 35 percent in the load factor. This was achieved through reduction of the peak-hour load.

The improved load factor values translate into a reduction in the maximum power demand, a reduction in the power loss, better equipment utilization and better management of maximum power demand. Thus the higher the load factor, the more constant the rate of electrical usage is and the better the usage of power. This means that the utility company can supply power to the consumer more efficiently. If the proposed system is implemented in a particular locality, the utility company can use smaller transformers and smaller transmitting cables, both of which result in significant financial savings. Since power demand can be held to a minimum, the occurrences of load shedding can be minimized.

In conclusion, all the measures dealt with in this work are cost effective and are of great potential impact to the economy. The high costs of rehabilitation and construction of power plants show that the system proposed in this study is an alternative to load shedding for reducing demand from the grid.

6.2 Recommendations

In view of the findings of the study, the following recommendations are being made:

6.2.1 Establishment of Power-Usage Patterns for Water Heating and Household Appliances

a) This study was carried out in the summer and in a low-density area. It is suggested that this study be done in winter in a high or medium density area in case there may are differences in the load profile.

b) As earlier stated, the particular method used in acquiring household power-usage patterns is important. It is therefore suggested that an automated method be used in order to ensure better results.

6.2.2 Developing a Program for a Centralized Microprocessor-based Electricity Metering System

a) Providing incentives to consumers to switch off appliances when alerted during peak hours can encourage their full participation in the task of regulating power consumption. It is therefore suggested that the algorithm in this study be improved further by incorporating the cost function.

b) In the simulation, random-number generation was used to predict when the consumer switches his/her appliances on and off. It is suggested that a program be developed that produces a schedule for appliance use by the consumer. This means that appliance use is no longer randomly determined. The flowchart in Appendix H describes another program that can be used as a way of selecting appliances. However, this algorithm would require the consumer to have full knowledge of the use of the smart system.

6.2.3 Designing of a Circuit for the Centralized Microprocessor-based Electricity Metering System

a) The use of harmonic distortion of the current and voltage waveform could be used in identifying which appliances are switched on.

b) The components used in the model are all low-current, low-power and low-voltage with the result that appliances with a current rating above 5A could not be handled. For actual implementation, high-current components should be used.

c) The first implementation of the Zesco limited pre-paid metering system was on 2nd December 2002, in Emmasdale Township in Lusaka. A total of 913 meters were installed. This was a pilot project to assess the response of the system. A total number of 116 respondents out of 180 expressed happiness and said that as a result of the meter, they now had the option of using power only when it was necessary [68]. Since this is a positive response, it is suggested that a similar pilot project be done for this system in order to determine the consumer's response.

REFFERENCES

[1] L. Sollecto, (2009) **Smart Grid: the road ahead**, Volume 02. Retrieved from http: //www.gedigitalenergy.com/multiline/journals/issues/Spring09/Smart_Grid_the Road Ahead.

[2] United Nations, (2007) **World population**. Retrieved from http: //www.un.org/ news/press/doc//2007/pop 952.

[3] R. P. Sisala, (2008) **Challenges and Possible Solutions in the Power Sector**. Published presentation report to the Economics Association of Zambia. Retrieved from http://www.fesnam.org/pdf/2008/events/No10_2008_PresentationSisala.pdf.

[4] K. Kasonkomona and M. Chinjila, (2011) **Solar water geyser project, impacts on the consumption profile of Electricity**, Published presentation on behalf of the managing director for Zesco at the ERB renewable energy forum. Retrieved from http://www.erb.org.zm/downloads/presentations/energyforum2011/Zesco%20Solar%20 Gyser%20Project.pdf.

[5] B. Ramanathan and V. Vittal, (2008) **A framework for evaluation of advanced direct load control with minimum disruption**, IEEE Trans. Power Systems, vol. 23, no. 4, pp. 1681–1688.

[6] IPA Energy consulting, (2007) **Revised ZESCO's cost of service**. A report to the Energy Regulation Board (ERB).

[7] C.O. Bjork, (1989) **Industrial load management theory practice & simulation**, Elsevier: New York.

[8] A.I Cochen and C.C Wang, (1988) **An optimisation method for load management scheduling**. IEEE Transactions on Power Systems; volume 3, pp 612-8.

[9] PACIFICORP, (2011) **Demand Side Management Study documents**, Retrieved from http: www.pacificorp.com/env/dsm./dtml.

[10] G.M. Masters, (2009) **Renewable and Efficient Electric Power Systems**. Hoboken, NJ: Wiley.

[11] Charles River Associates, (2005) **A primer on demand side management,** Prepared for the World Bank Washington, D.C.

[12] M. Fahrioglu and F. L. Alvardo, (2000) **Designing incentive compatible contracts for effective demand managements**, IEEE Trans. Power Systems, vol. 15, no. 4, pp. 1255–1260, November.

[13] B. Ramanathan and V. Vittal**,** (2008) **A framework for evaluation of advanced direct load control with minimum disruption,** IEEE Trans. Power Systems, vol. 23, no. 4, pp. 1681–1688, November.

[14] M. A. A. Pedrasa, T. D. Spooner, and I. F. MaxGill, (2009) **Scheduling of demand side resources using binary particle swarm optimization**, IEEE Trans. Power Systems, vol. 24, no. 3, pp. 1173–1181, August.

[15] C. W. Gellings and J. H. Chamberlin, (1993) **Demand Side Management: Concepts and Methods**, 2nd ed. Tulsa, OK: PennWell Books.

[16] S. Ashok and R. Banerjee, (2003) **Load-management applications for the industrial sector Energy System Engineering**, Indian Institute of Technology, Bombay, India.

[17] Sustainable Energy Regulation and Policy making for Africa, (2009) **Demand-Side Management**, 14th Module.

[18] Cogeneration News and Technologies, (2010) **Demand Side Management**: Retrieved from; www.cogeneration.net/Demand Side Management.

[19] **Energy Management News,** (2004) Volume 10, number 4, retrieved from www.erc.uct.ac.za

[20] **Eskom - Energy Audits,** (2006) Quarterly Report, Period: April to June.

[21] T. Harikrishnan and K.M Thayyib, (2010) **Green Energy Technology, Economics and Policy,** CRC press/balkena Taylor and Francis Group, London U.K.

[22] J. Froehlich, E. Larson and S. Gupta, (2011) **End-use Energy sensing for the smart grid,** published: IEEE 1536-1268.

[23] P. semig and C.wells,(2012) **current sensing tutorial—part 1: fundamentals**, An article on current sensing published by UBM technology.

[24] P. Horowitz and W. Hill, (1989) **The Art of Electronics** Cambridge University press.

[25] **Arduino Mega2560 datasheet**, retrieved from http: //www. Robotshop.com

[26] **Arduino board Uno**, retrieved from http: //www.arduino.cc/en/main

[27] W.Chardhurg and S. Andrews, (2002) **Payment mechanisms for micro-generation** DTI report KIEL/00282/REP.

[28] K.Ng and G.shele, (1998) **Direct load control, a profit based management using linear programming,** IEEE Transaction on power Systems Vol.13 number 2,pp 688-694.

[29] A. Mohsenian, W.S Vincent. Wong, J. Jatskevich and R. Schober, (2009) **Optimal and Autonomous Incentive-based Energy Consumption Scheduling Algorithm for Smart Grid,** IEEE Transaction on power Systems Vol.10 number 2, pp 688-694.

[30] M.J De Blecourt, (2012) **load-shifting in a new perspective: Smart Scheduling of smart household appliances using an agent based modeling approach,** published Master's thesis Delt University of technology.

[31]**Build Energy and Buildings**, (2011) retrieved from http:// www.elsevier.com /locate/ 39(2007)298-305.

[32] O.Ainsworth, M.Ristic and D.Brujic,(2005) **Agent-based Distributed Control framework with application in Demand-Side Management,** IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 3.

[33] H. Lee and C.L. Wilkins, (1983) **A practical approach to appliance load control analysis: a water heater case study**, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 4.

[34] A. Cohen and C. Wang, (1988) **An optimization method for load management scheduling IEEE Transactions on Power Systems**, Vol. 3, No. 2, pp 612-618.

[35] C.N Kurucz, D. Brandt, and S. Sim, (1996) **A linear programming model for reducing system peak through customer load control programs,** IEEE Transactions on Power Systems, Vol. 11, No. 4, pp 1817-1824.

[36] Z. Popovic, (1999) **Determination of optimal direct load control strategy using linear programming,** CIRED**.**

[37] W. Chu, B. Chen and C. Fu, (1993) **Scheduling of direct load control to minimize load reduction for a utility suffering from generation shortage,** IEEE Transactions on Power Systems, Vol. 8, No. 4, pp 1525-1530.

[38] G. Weller, (1988**) Managing the instantaneous load shape impacts caused by the operation of a large-scale direct load control system,** IEEE Transactions on Power Systems, Vol. 3, No. 1.

[39] E.millier, (2009) **Renewable and the smart grid,** Renewable Energy focus.vol 10 pp 67-69.

[40] J.Torriti, M.G Hassan, and M. Leach,(2009) **Demand response experience in Europe: policies, programs and implementation,** Energy vol. in press, corrected proof.

[41] R. Krishnan, (2008) **Meters of Tomorrow**, IEEE Power and Energy Magazine, pp. 92–94.

[42] A.H.Mohsenian-Rad, Member, Vincent W. S. Wong, J. Jatskevich, R. Schober, and A. L.Garcia,(2010) **Autonomous Demand-Side Management Based on Game-Theoretic Energy Consumption Scheduling for the Future Smart Grid,** IEEE Transactions on smart grid, vol. 1, no. 3,

[43] O. A. Sianaki , O. Hussain, T. Dillon, A. R. Tabesh, (2010) **Intelligent Decision Support System for Including Consumers' Preferences in Residential Energy Consumption in Smart Grid Digital Ecosystem and Business Intelligence** Institute Curtin University of Technology,Perth, Australia year,IEEE computer society.Vol 1,pp 84.

[44] T. Bean and J. McGrory, (2010) **The Integration of Smart Meters into Electrical Grids to Ensure Maximum Benefit for Consumers, Generators and Network Operators**, a published Dissertation, Dublin Institute of Technology

[45] L. H. Tsoukalas and R. Gao,(2008) **From Smart Grids to an Energy Internet: Assumptions, Architectures and Requirements**, Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT 2008), Nanjuing, 6-9, pp. 94-98. doi:10.1109/DRPT.2008.4523385

[46] A.Faraqui, R.Hledid and J. Tsoukalis, (2009) **The power of Dynamic pricing** The Electricity Journal , vol.22 pp 42-56.

[47] M. M. Abdullah and B. Dwolatzky, (2009) **Smart Demand-Side Energy Management Based on Cellular Technology - A way towards Smart Grid Technologies in Africa and Low Budget Economies.** Centre for Telecommunications Access and Services Johannesburg, South Africa.

[48] S. Darby, (2006**) The effectiveness of feedback on energy consumption a review for DEFRA of the literature on metering, billing and direct displays** retrieved from http://www.eci.ox.ac.uk/research/energy/electric -metering.php.

[49] **Smart Meter Block Diagram**, retrieved from: www.maxim-ic.com/smart meter.

[50] Google, (2009) **Power Meter** retrieved from http: //www.google.com/powermeter.

[51] Landis and Gyr, (2009) **Smart Meter** Product retrieved from http: www.landisgyr.com/en/pub/products_services.cfm.

[52] WattsonMeters, (2009) **Smartmeter** retrievedfrom http:www.electricity-monitor.com/wireless-energy monitors-Wattson-c-37_31.

[53] Ecobee meters, (2009) Ecobee product image, retrieved from http: www.treehugger.com/godgets/ecobee-smart meters.

[54] Pacific Northwest National Laboratories, (2007) **Gridwise Project Update**, retrieved from http://www.pnl.gov/topstory.asp?id=285.

[55] CER, (2009) **Smart Meter project Phase 1, Status update,** retrieved from http://www.cer.ie/en/information-centre-reports-andpublications.

[56] F.Borghese, (2006) **Evaluating the Leading-Edge Italian Telegestore Project**, February,retrievedfromhttp:www.05.ibm.com/cz/events/AMM/download/Borghes.

[57] Electrical Energy Management Guidelines Series No 102**, Improving Load Factor and Power Factor to Reduce Demand** a report by Tennessee Valley Authority and Distributors of TVA Electric power.

[58] A. J Orodho, (2003) **Essentials of Educational and Social Sciences Research Methods**. Masola Publishers: Nairobi.

[59] A. J. Orodho and, D. K. Kombo, (2005) **Research Methods**.Kenyatta University, Institute of Open Learning. Nairobi.

[60] S.Webster, (1985) **Educational Research: Competence for Analysis and Applications**, Macmillan: New Jersey.

[61] G.Ndumiso, (2012) **Implementing peak load reduction algorithms for household electrical appliances** Volume 44, pages 280-290. Energy policy, University of Kayota, School of Energy Science.

[62] K. Mets, M. Strobbe, T. Verschueren, T. Roelens, F. De Turck, C. Develder, (2012) **Distributed Multi-Agent Algorithm for Residential Energy Management in Smart Grids Ghent University** – IBBT Department of Information Technology Gaston Crommenlaan 8 bus 201, 9050 Gent, Belgium.

[63**] Zesco tarrif** datasheet as of 2010.

[64] J.R. Hubbard.Ph.D, (2000) **Shaum`s outlines programming with C++, second edition**, McGraw-Hill ,New York San Francisco Washington, D.C.

[65] J. Van den keybus and R. Belmans **Energy consumption of domestic refrigerators Using electronic energy saving devices** Published article from Katholieke universiteit leuven, dept. Esat, div. Electa.

[66] A. Moholkar, (2005) **Computer aided home management system,** published Ph.D dissertation,West Virginia University.

[67] C. McNally, (2010) **Arduino Based Wireless Power Meter,** a Design Project Report Presented to the Engineering Division of the Graduate School of Cornell University.

[68] I.K Chisanga, (2002) **An evaluation of the pre-payment Metering System a case of Zesco Lusaka Division** published master of business administration dissertation, Copperbelt University.

APPENDIX A: Component Definitions on the Arduino Mega

Analog Input Pins – These pins (A0-A15) take in analog values to be converted to digital form and thus to be represented by numbers in the range 0-1023 by means of an Analog to Digital Converter (ADC).

ATmega2560 Chip - A 16-bit microcontroller that runs the C-program that is programmed.

Crystal Oscillator -This is the clock with a frequency of 16MHz

DC Jack - This is where the power source (AC-to-DC adapter or battery) is connected. The supply voltage can vary between 6-20V and 7-12V is recommended.

Digital I/O pins -These are the input and output pins (0-13).

ON indicator - The LED that lights up when the board is connected to a power source.

Power Pins -These pins are used to supply the circuit with the values of the input voltage Vin from the DC jack, 3.3V and 5V.

Reset Button- This button is pressed whenever one needs to restart the C-program in the board.

USB Port -This allows the user to connect a USB cable to the board from a PC in order to upload C-programs or provide a voltage supply to the board.

APPENDIX B: Energy Consumption Values

TIME(h)	House 1	House 2	House 3	House 4	House 5	Total energy consumption for all houses
	Energy(kwh	Energy(Kwh)	Energy(kwh)	Energy(kwh)	Energy(kwh)	Energy(kwh)
0	0.215	0.8055	0.14225	0.6325	0.275	2.07025
0.25	0.0275	0.0275	0.07375	0.1675	0.02125	0.3175
0.5	0.215	0.8055	0.14225	0.6325	0.275	2.07025
0.75	0.0275	0.0275	0.07375	0.1675	0.02125	0.3175
1	0.215	0.8055	0.14225	0.6325	0.275	2.07025
1.25	0.0275	0.0275	0.07375	0.1675	0.02125	0.3175
1.5	0.215	0.8055	0.14225	0.6325	0.275	2.07025
1.75	0.0275	0.0275	0.07375	0.1675	0.02125	0.3175
2	0.215	0.8055	0.14225	0.6325	0.2785	2.07375
2.25	0.0275	0.0275	0.07375	0.1675	0.02475	0.321
2.5	0.215	0.8055	0.14225	0.6325	0.2785	2.07375
2.75	0.0275	0.0275	0.07375	0.1675	0.02475	0.321
3	0.965	1.5555	1.16725	0.6325	2.8785	7.19875
3.25	0.0275	0.0275	0.07375	0.1675	1.87475	2.171
3.5	0.965	1.5555	1.16725	0.6325	2.8785	7.19875
3.75	0.0275	0.0275	0.07375	0.1675	1.87475	2.171
4	0.965	2.1555	0.89225	0.6325	2.875	7.52025
4.25	0.0275	0.0275	0.07375	0.1675	1.14625	1.4425
4.5	0.965	1.5555	0.89225	0.6325	2.15	6.19525
4.75	0.0275	0.0275	0.07375	0.1675	1.14625	1.4425
5	2.47	2.323	1.64225	3.44375	1.3625	11.2415
5.25	0.92875	1.145	0.82375	1.92875	0.35875	5.185
5.5	2.55375	1.573	1.64225	2.89375	1.55	10.21275
5.75	1.5625	0	0.3	1.64175	0.38125	3.8855

6	2.685	0.69175	1.1185	2.7485	1.985	9.22875
6.25	0.2625	0.46375	0	0.6555	0.98125	2.363
6.5	0.83	0.24175	0.0685	1.7235	0.76	3.62375
6.75	0.0325	0.01375	0	0.3805	0.01875	0.4455
7	0.352	0.24175	0.0685	1.9735	0.26625	2.902
7.25	0.0545	0.01375	0	0.6305	0.0125	0.71125
7.5	0.352	0.24175	0.0685	1.9735	0.26625	2.902
7.75	0.0545	0.01375	0	0.6305	0.0125	0.71125
8	0.352	0.24175	0.0685	1.4735	0.26625	2.402
8.25	0.0545	0.01375	0	0.1305	0.0125	0.21125
8.5	0.242	0.24175	0.0685	1.3455	0.26625	2.164
8.75	0.0545	0.01375	0	0.1305	0.0125	0.21125
9	0.242	0.24175	0.0685	2.0955	0.54125	3.189
9.25	0.0545	0.01375	0	0.1305	0.0125	0.21125
9.5	0.242	0.24175	0.0685	1.3455	0.54125	2.439
9.75	0.0545	0.01375	0	0.1305	0.0125	0.21125
10	0.242	0.24175	0.0685	1.3455	0.54125	2.439
10.25	0.0545	0.01375	0	0.8805	0.0125	0.96125
10.5	0.242	0.24175	0.0685	1.3455	0.54125	2.439
10.75	0.0545	0.01375	0	0.1305	0.0125	0.21125
11	2.677	0.24175	0.5685	2.8455	1.04125	7.374
11.25	1.9895	0.01375	0.5	0.8805	0.5125	3.89625
11.5	2.677	0.24175	1.1185	2.0955	0.76625	6.899
11.75	1.1645	0.01375	1.05	0.8805	0.0125	3.12125
12	1.352	1.29175	1.1185	1.233	0.26625	5.2615
12.25	0.2895	1.06375	0	0.768	0.0125	2.13375
12.5	0.227	1.29175	0.0685	0.5955	0.26625	2.449

12.75	0.0395	0.01375	0	0.1305	0.0125	0.19625
13	0.227	0.24175	0.0685	0.5955	0.26625	1.399
13.25	0.0545	0.01375	0.075	0.1305	0.0125	0.28625
13.5	0.242	0.24175	0.1435	0.5955	0.26625	1.489
13.75	0.0545	0.01375	0.075	0.1305	0.0125	0.28625
14	0.242	0.59175	0.1435	0.5955	0.26625	1.839
14.25	0.0545	0.01375	0.35	0.1305	0.0125	0.56125
14.5	0.242	0.59175	0.1435	0.5955	0.26625	1.839
14.75	0.0545	0.01375	0.35	0.1305	0.0125	0.56125
15	0.4995	0.59175	2.2435	1.6455	0.26625	5.2465
15.25	0.037	0.01375	2.175	0.1305	0.0125	2.36875
15.5	0.4995	0.24175	2.2435	0.8955	0.26625	4.1465
15.75	0.037	0.01375	2.175	0.1305	0.0125	2.36875
16	2.437	1.574	3.05225	1.6675	0.56625	9.297
16.25	0.9245	0.046	0.365	1.6525	1.0625	4.0505
16.5	2.437	1.574	0.95225	1.6675	0.56625	7.197
16.75	0.9245	0.046	0.13375	1.6525	1.6875	4.44425
17	3.5555	4.154	0.99725	1.71375	1.306	11.7265
17.25	2.293	2.026	0.17875	1.69875	1.80225	7.99875
17.5	3.5305	3.554	1.00075	1.94725	0.531	10.5635
17.75	2.043	2.04475	0.18225	2.23225	0.27725	6.7795
18	2.76925	4.40725	1.00575	2.34975	0.9185	11.4505
18.25	1.08175	2.12925	0.18725	1.88475	0.66475	5.94775
18.5	2.01925	2.70375	0.25575	1.21225	0.4335	6.6245
18.75	1.61175	0.15575	0.18725	0.74725	0.42975	3.13175
19	2.04925	0.92	0.54075	1.46225	0.7285	5.70075
19.25	0.37325	0.102	0.19225	0.23225	0.20625	1.106

19.5	0.81075	0.88	0.53575	0.69725	0.445	3.36875
19.75	0.34325	0.062	0.18225	0.23225	0.16125	0.981
20	0.78075	0.84	0.24725	0.706	0.415	2.989
20.25	0.24825	0.057	0.16375	0.241	0.16125	0.87125
20.5	0.68575	0.835	0.23225	0.7025	0.415	2.8705
20.75	0.24825	0.087	0.16375	0.2275	0.16125	0.88775
21	0.65575	0.8175	0.23225	0.6925	0.3775	2.7755
21.25	0.0275	0.0275	0.08875	0.1675	0.04875	0.36
21.5	0.465	0.8055	0.15725	0.6325	0.3025	2.36275
21.75	0.0275	0.0275	0.08875	0.1675	0.04875	0.36
22	0.465	0.8055	0.14225	0.6325	0.3025	2.34775
22.25	0.0275	0.0275	0.07375	0.1675	0.04875	0.345
22.5	0.215	0.8055	0.14225	0.6325	0.3025	2.09775
22.75	0.0275	0.0275	0.07375	0.1675	0.04875	0.345
23	0.215	0.8055	0.14225	0.6325	0.3025	2.09775
23.25	0.0275	0.0275	0.07375	0.1675	0.04875	0.345
23.5	0.215	0.8055	0.14225	0.6325	0.3025	2.09775
23.75	0.0275	0.0275	0.07375	0.1675	0.04875	0.345
Total energy(kWh)	65.67425	60.38875	38.6505	84.03	49.027	297.7705

APPENDIX C: Power Consumption Values

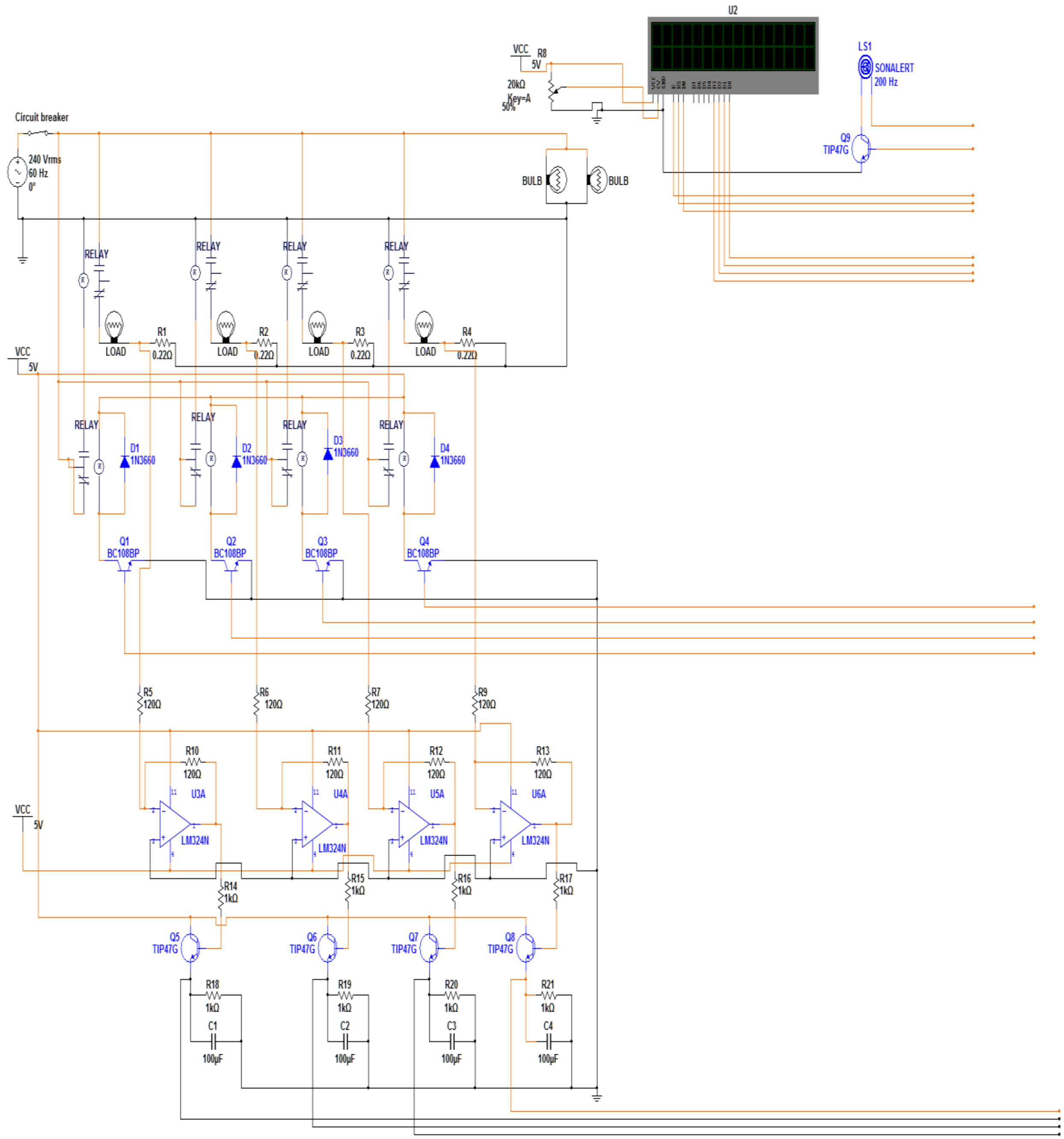
TIME	HOUSE 1	HOUSE 2	HOUSE 3	HOUSE 4	HOUSE 5	TOTAL POWER CONSUMPTION
Time(hours)	POWER (W)	POWER (W)	POWER (W)	POWER (W)	POWER (W)	POWER (W)
1:00	860	3222	569	2530	1100	8281
1:15	360	110	295	670	85	1520
1:30	860	3222	569	2530	1100	8281
1:45	360	110	295	670	85	1520
2:00	860	3222	569	2530	1100	8281
2:15	360	110	295	670	85	1520
2:30	860	3222	569	2530	1100	8281
2:45	360	110	295	670	85	1520
3:00	860	3222	569	2530	1114	8295
3:15	360	110	295	670	99	1534
3:30	860	3222	569	2530	1114	8295
3:45	360	110	295	670	99	1534
4:00	3860	6222	4669	2530	11514	28795
4:15	360	110	295	670	7499	8934
4:30	3860	6222	4669	2530	11514	28795
4:45	360	110	295	670	7499	8934
5:00	3610	8622	3569	2530	11500	29831
5:15	110	110	295	670	4585	5770
5:30	3610	6222	3569	2530	8600	24531
5:45	110	110	295	670	4585	5770
6:00	9630	9292	6569	13775	5450	44716
6:15	3715	4580	3295	7715	1435	20740
6:30	9965	6292	6569	11575	6200	40601
6:45	6250	0	1200	6567	1525	15542

7:00	10490	2767	4474	10994	7940	36665
7:15	1050	1855	0	2622	3925	9452
7:30	3070	967	274	6894	3040	14245
7:45	130	55	0	1522	75	1782
8:00	1158	967	274	7894	1065	11358
8:15	218	55	0	2522	50	2845
8:30	1158	967	274	7894	1065	11358
8:45	468	55	0	2522	50	3095
9:00	1408	967	274	5894	1065	9608
9:15	468	55	0	522	50	1095
9:30	968	967	274	5382	1065	8656
9:45	468	55	0	522	50	1095
10:00	968	967	274	8382	2165	12756
10:15	468	55	0	522	50	1095
10:30	968	967	274	5382	2165	9756
10:45	468	55	0	522	50	1095
11:00	968	967	274	5382	2165	9756
11:15	468	55	0	3522	50	4095
11:30	968	967	274	5382	2165	9756
11:45	468	55	0	522	50	1095
12:00	10708	967	2274	11382	4165	29496
12:15	8208	55	2000	3522	2050	15835
12:30	10458	967	4474	8382	3065	27346
12:45	4658	55	4200	3522	50	12485
13:00	5158	5167	4474	4932	1065	20796
13:15	1158	4255	0	3072	50	8535
13:30	658	5167	274	2382	1065	9546

13:45	158	55	0	522	50	785
14:00	658	967	274	2382	1065	5346
14:15	218	55	300	522	50	1145
14:30	718	967	574	2382	1065	5706
14:45	218	55	300	522	50	1145
15:00	718	2367	574	2382	1065	7106
15:15	218	55	1400	522	50	2245
15:30	718	2367	574	2382	1065	7106
15:45	218	55	1400	522	50	2245
16:00	648	2367	8974	6582	1065	19636
16:15	398	55	8700	522	50	9725
16:30	898	967	8974	3582	1065	15486
16:45	398	55	8700	522	50	9725
17:00	8648	6296	12209	6670	2265	36088
17:15	3948	184	1460	6610	4250	16452
17:30	8648	6296	3809	6670	2265	27688
17:45	3948	184	535	6610	6750	18027
18:00	13122	16616	3989	6855	5224	45806
18:15	9422	8104	715	6795	7209	32245
18:30	14122	14216	4003	7789	2124	42254
18:45	8422	8179	729	8929	1109	27368
19:00	10077	17629	4023	9399	3674	44802
19:15	4577	8517	749	7539	2659	24041
19:30	7077	10815	1023	4849	1734	25498
19:45	6697	623	749	2989	1719	12777
20:00	6947	3680	2163	5849	2914	21553
20:15	1493	408	769	929	825	4424

20:30	1993	3520	2143	2789	1780	12225
20:45	1373	248	729	929	645	3924
21:00	1873	3360	989	2824	1660	10706
21:15	993	228	655	964	645	3485
21:30	1493	3340	929	2810	1660	10232
21:45	993	348	655	910	645	3551
22:00	1373	3270	929	2770	1510	9852
22:15	110	110	355	670	195	1440
22:30	610	3222	629	2530	1210	8201
22:45	110	110	355	670	195	1440
23:00	610	3222	569	2530	1210	8141
23:15	110	110	295	670	195	1380
23:45	610	3222	569	2530	1210	8141
24:00:00	360	110	295	670	195	1630
24:15:00	860	3222	569	2530	1210	8391
24:30:00	360	110	295	670	195	1630
24:45:00	860	3222	569	2530	1210	8391
1:00	360	110	295	670	195	1630
Max power	14122	17629	12209	13775	11514	45806
Total power	248947	241555	154602	336120	196108	1177332
power in (kW)	248.95	241.555	154.602	336.12	196.108	1177.3

APPENDIX D: Circuit Diagram



APPENDIX E: Zesco Tariffs

ZESCO LIMITED
REVISION OF ELECTRICITY TARIFFS

Notice is hereby given that the Energy Regulation Board has approved revised electricity tariffs from 1 April 2005. The notice is being put in accordance with the requirements of section 8 subsection 2 of the Electricity Act CAP 433 of the Laws of Zambia. The fixed, energy, and demand charges will be as given below. The bills based on the new charges should therefore, be received by our customers in May 2005.

		Current Tariffs	**Approved Tariffs**
1. UNMETERED RESIDENTIAL TARIFFS			
L1-Consumption up to 2 Amps	Energy Charge/Month	K4,424.00	K4,911.00
L2-Consumption between 2 -15 Amps	Energy Charge/Month	K16,009.00	K17,770.00
2. METERED RESIDENTIAL TARIFFS	(Capacity 15kVA)		
R1-Consumption up to 300kWh	Energy Charge/kWh	K63.00	K70.00
R2-Consumption – 301 to 700kWh	Energy Charge/kWh	K90.00	K100.00
R3-Consumption above 700kWh	Energy Charge/kWh	K147.00	K163.00
	Fixed Monthly Charge	K5,266.00	K5,845.00
3. COMMERCIAL TARIFFS	(Capacity 15kVA)		
C1-Consumption	Energy Charge/kWh	K147.00	K163.00
	Fixed Monthly Charge	K26,331.00	K29,227.00
4. SOCIAL SERVICES TARIFFS			
Schools, Hospitals,Orphanages,	Energy Charge/kWh	K122.00	K135.00
Churches,Water pumping,Street Lighting	Fixed Monthly Charge	K21,065.00	K23,382.00
5. MAXIMUM DEMAND TARIFFS			
MD1-Capacity between 16 - 300kVA	MD Charge/kVA/Month	K6,255.00	K6,943.00
	Energy Charge/kWh	K90.00	K100.00
	Fixed Monthly Charge	K61,263.00	K68,002.00
MD2-Capacity between 301-2000kVA			
	MD Charge/kVA/Month	K11,703.00	K12,990.00
	Energy Charge/kWh	K77.00	K85.00
	Fixed Monthly Charge	K122,525.00	K136,003.00
MD3-Capacity between 2001-7500kVA			
	MD Charge/kVA/Month	K17,646.00	K19,587.00
	Energy Charge/kWh	K57.00	K63.00
	Fixed Monthly Charge	K245,050.00	K272,006.00
MD4-Capacity above 7500kVA	MD Charge/kVA/Month	K17,744.00	K19,696.00
	Energy Charge/kWh	K47.00	K52.00
	Fixed Monthly Charge	K490,101.00	K544,012.00

NOTE:
The above tariffs are:
(a) Exclusive of 5% Government excise duty
(b) Exclusive of 17.5% Value Added Tax (VAT)

20 May 2013 **R. P. SISALA**
MANAGING DIRECTOR

APPENDIX F: Arduino Program

```
#include <LiquidCrystal.h>
// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(8, 9, 4, 5, 6, 7);
LiquidCrystal lcd1(8, 10, 4, 5, 6, 7);
int led = 13;
int led2 = 12;
const byte ledGreen=16;
const byte ledRed=17;

int RelayControl[2][4]={
                    {50,46,38,36},
                    {30,22,24,26}
                   };
int Appliancesensor[2][4]={
                     {A0,A1,A2,A3},
                     {A4,A5,A6,A7}
                     };
float resistance=0.22;
float sval = 0;
int k;
double MaxAPPhouse1[4]={0};
double MaxAPPhouse2[4]={0};
```

```
float VoltageMaxApphse1;
float VoltageMaxApphse2;
float sum[288]={0};
int TIM[288]={0};
int sensorValue[2][4]={
                {A0,A1,A2,A3},
                {A4,A5,A6,A7}
                };
int voltage[2][4]={
                {A0,A1,A2,A3},
                {A4,A5,A6,A7}
                };
int current[2][4]={
                {A0,A1,A2,A3},
                {A4,A5,A6,A7}
                };
# define NTM 288
# define DT 0.08333
# define Pmax 7.00
#define Pmin 3.50
void setup() {
  pinMode(RelayControl[2][4], OUTPUT);
  pinMode(Appliancesensor[2][4], INPUT);
```

```
  pinMode(led, OUTPUT);

  pinMode(led2, OUTPUT);

  pinMode(ledGreen, OUTPUT);

  pinMode(ledRed, OUTPUT);

}

void loop(){

   for(int k=0;k<288;k++)/* Intializing the time array for 288 time steps*/

      TIM[k]=k*DT;

      {

  for(int i = 0; i < 2; i++){



for(int j = 0; j < 4; j++){



digitalWrite(RelayControl[i][j], HIGH);



delay(100);



 sensorValue[i][j] = analogRead(Appliancesensor[i][j]);

 voltage[i][j] = sensorValue[i][j] * (5.0 / 1023.0);

   current[i][j]=240*(voltage[i][j]/(resistance*(240-voltage[i][j])));

  float power = voltage[i][j]*current[i][j];



sval = sval + analogRead(Appliancesensor[i][j]);
```

```

}//close for i

}//close for j
sval=sum[k];

if(sval>Pmax){
lcd.setCursor(0,0);
lcd.print("OVERLOAD");
lcd1.setCursor(0,0);
lcd1.print("OVERLOAD");
blinkRed();
 tone(11,500,200);
do{
  for(int  j=0;j<4;j++)

                        {

                                    MaxAPPhouse1[j]=analogRead(Appliancesensor[0][j]);//this array stores the powers of the appliances  for each household
                                MaxAPPhouse2[j]=analogRead(Appliancesensor[1][j]);

                        }
```

```
int  shouse1=maxIndex(MaxAPPhouse1,4);
int  shouse2=maxIndex(MaxAPPhouse2,4);

VoltageMaxApphse1=maximium(MaxAPPhouse1,4);
VoltageMaxApphse2=maximium(MaxAPPhouse2,4);
if((VoltageMaxApphse1>1.046)&&(VoltageMaxApphse1<=1.051))
{
  lcd.setCursor(0,1);
    lcd.print("SWITCH  OFF BLOWER");
}
else  if((VoltageMaxApphse1>0.60)&&(VoltageMaxApphse1<=0.65))
{
  lcd.setCursor(0,1);
    lcd.print("SWITCH  OFF TOASTER");
}
else  if((VoltageMaxApphse1>0.952)&&(VoltageMaxApphse1<=0.957))
{
  lcd.setCursor(0,1);
    lcd.print("SWITCH  OFF IRON1");
}
else  ((VoltageMaxApphse1>1.042)&&(VoltageMaxApphse1<=1.050));
{
  digitalWrite(RelayControl[0][shouse1],  LOW);
```

```
  lcd.setCursor(0,1);
    lcd.print("GEYSER  SWITCHED  OFF");

}
if((VoltageMaxApphse2>1.046)&&(VoltageMaxApphse2<=1.051))
{
  lcd1.setCursor(0,1);
    lcd1.print("SWITCH  OFF BLOWER");
}
else  if((VoltageMaxApphse2>0.60)&&(VoltageMaxApphse2<=0.65))
{
  lcd1.setCursor(0,1);
    lcd1.print("SWITCH  OFF TOASTER");
}
else  if((VoltageMaxApphse2>0.952)&&(VoltageMaxApphse2<=0.957))
{
  lcd1.setCursor(0,1);
    lcd1.print("SWITCH  OFF IRON1");
}
else  ((VoltageMaxApphse2>1.042)&&(VoltageMaxApphse2<=1.050));
{
  digitalWrite(RelayControl[1][shouse2],  LOW);
  lcd1.setCursor(0,1);
```

```
   lcd1.print("GEYSER  SWITCHED  OFF");
}

      }while(sval>=Pmax);
}
      if(sval<=Pmin)
      {
        blinkGreen();
 tone(11,500,200);
      lcd.setCursor(0,1);
    lcd.print("low  power consumption");
  lcd1.setCursor(0,1);
    lcd1.print("low  power consumption");

      }

}
}
      double  maximium(double  a[], int  size)  {
    //assert(size  > 0);        // Note 1.
    double  maxVal  = a[0];      // Note 2.
    for  (int  i=1; i<size;  i++) {
       if  (a[i] > maxVal)  {
```

```
        maxVal = a[i];
      }
    }
    return maxVal;
}//end max
int maxIndex(double a[], int size) {
    //assert(size > 0);
    int maxIndex = 0;
    for (int i=1; i<size; i++) {
      if (a[i] > a[maxIndex]) {
        maxIndex = i;
      }
    }
    return maxIndex;
}//end maxIndex

void blinkRed(){
   // for (int i = 0; i < times, i++){
      digitalWrite(ledRed, HIGH);
      delay(1000);
      digitalWrite(ledRed, LOW);
      delay(1000);
    //}
```

}
void blinkGreen(){
//for (int i = 0; i < times, i++){
digitalWrite(ledGreen, HIGH);
delay(1000);
digitalWrite(ledGreen, LOW);
delay(1000);
// }
}//end of led function
void tone(){
digitalWrite(led, HIGH);
digitalWrite(led2, HIGH);
delay(1000);
}

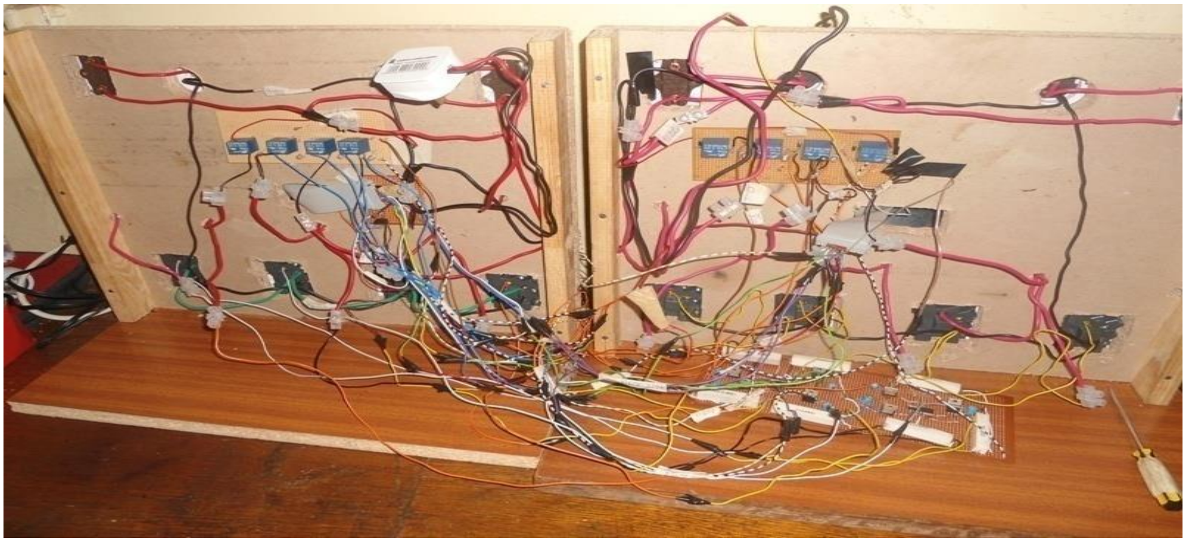
APPENDIX G: Pictures of the complete set of models

The following pictures show the complete set up model and different parts;

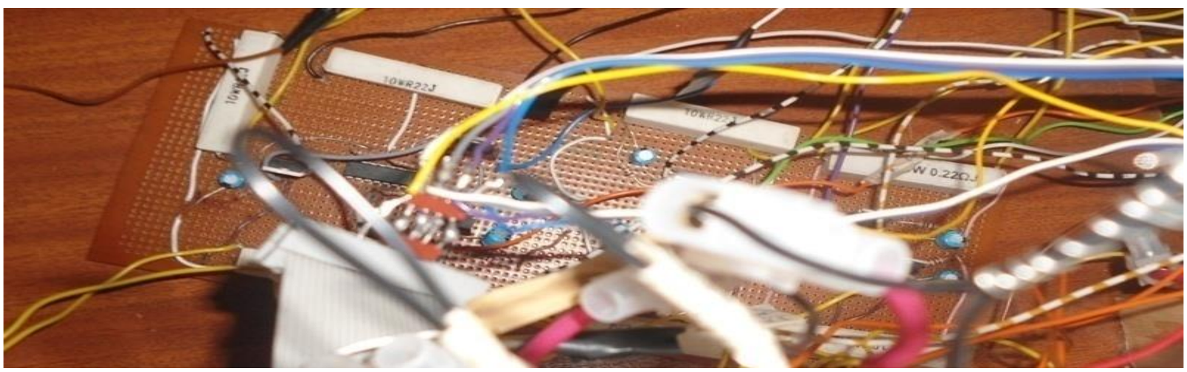
The two boards with the laptop where the microcontroller was connected and all the programs were written.

The two boards without the laptop and appliances, the picture shows the front view

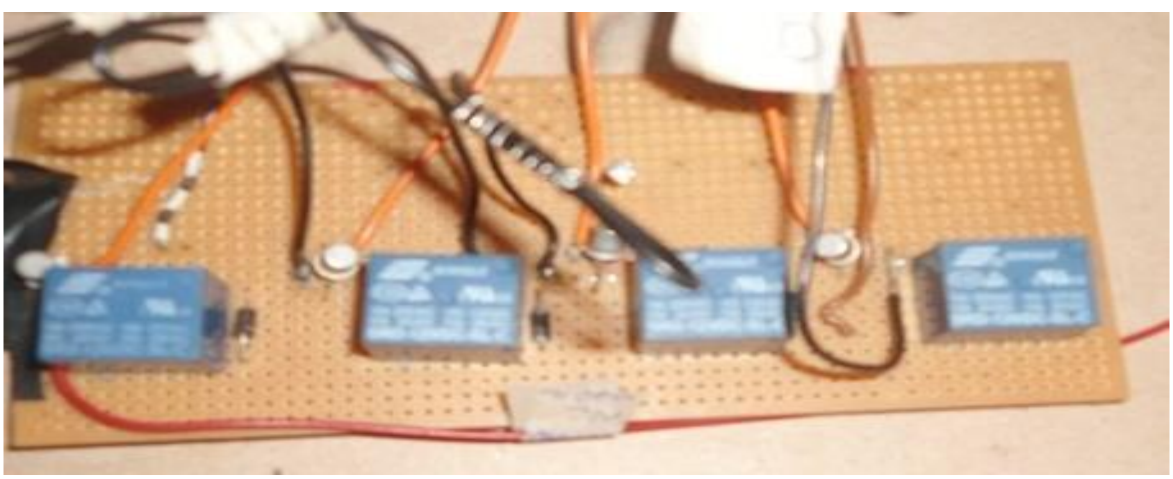
The picture shows the back view



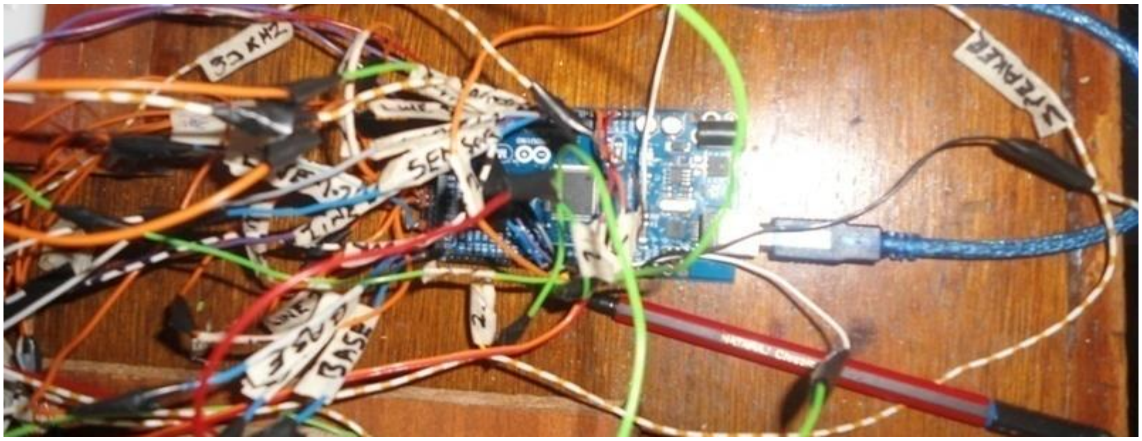
The picture shows the sensor circuit on the board



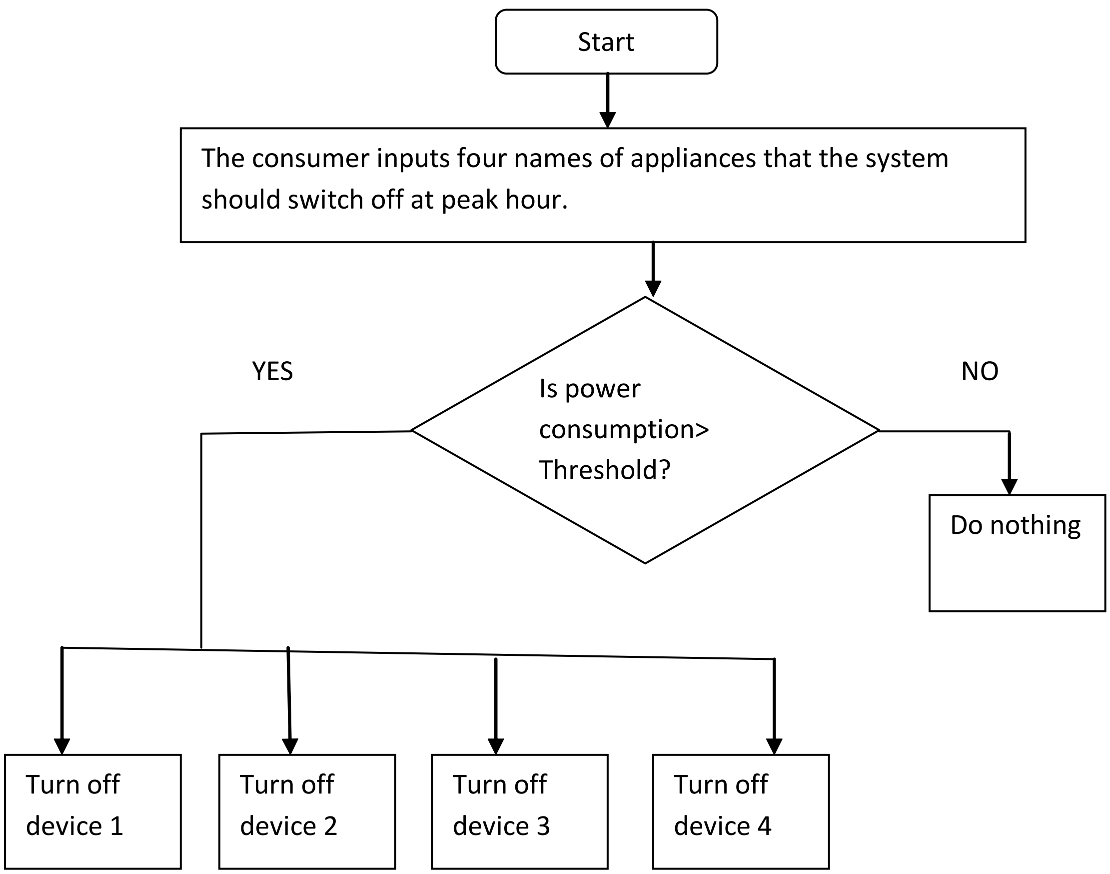
The picture shows the control logic circuit on the board



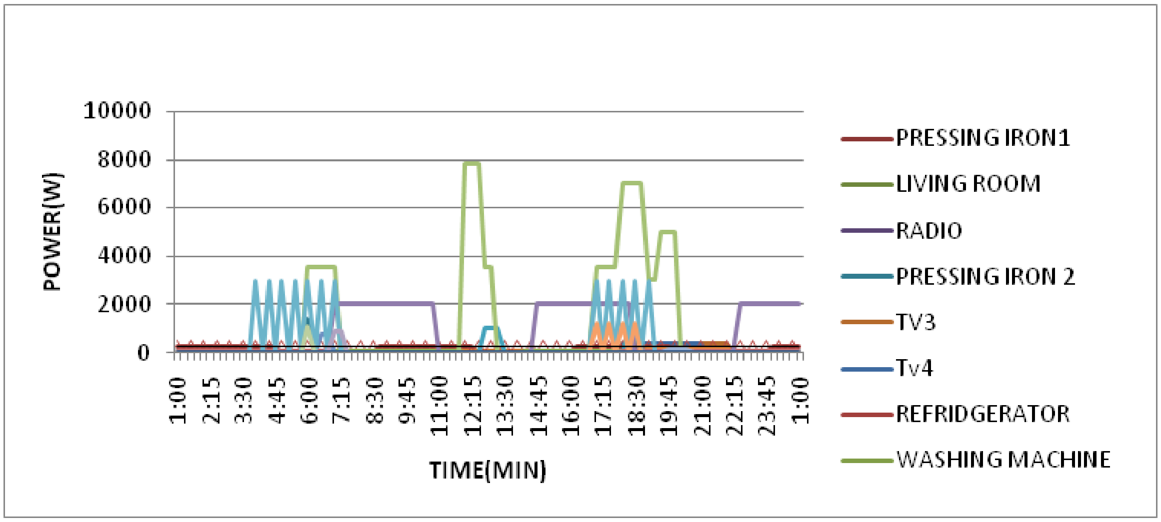
Lastly the picture below shows the Arduino connected to the lines from the circuits on the board.



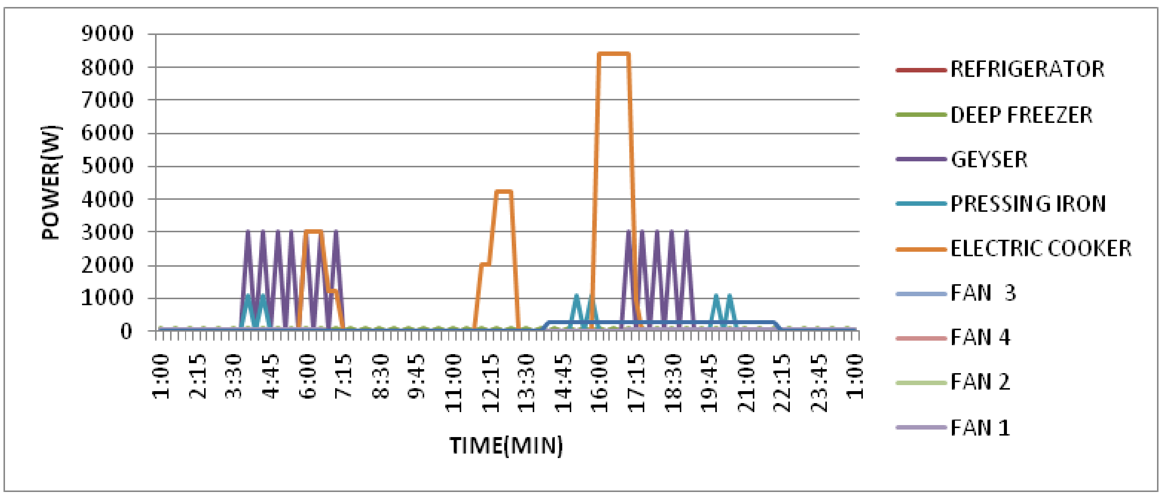
APPENDIX H: Suggested Flowchart for the system



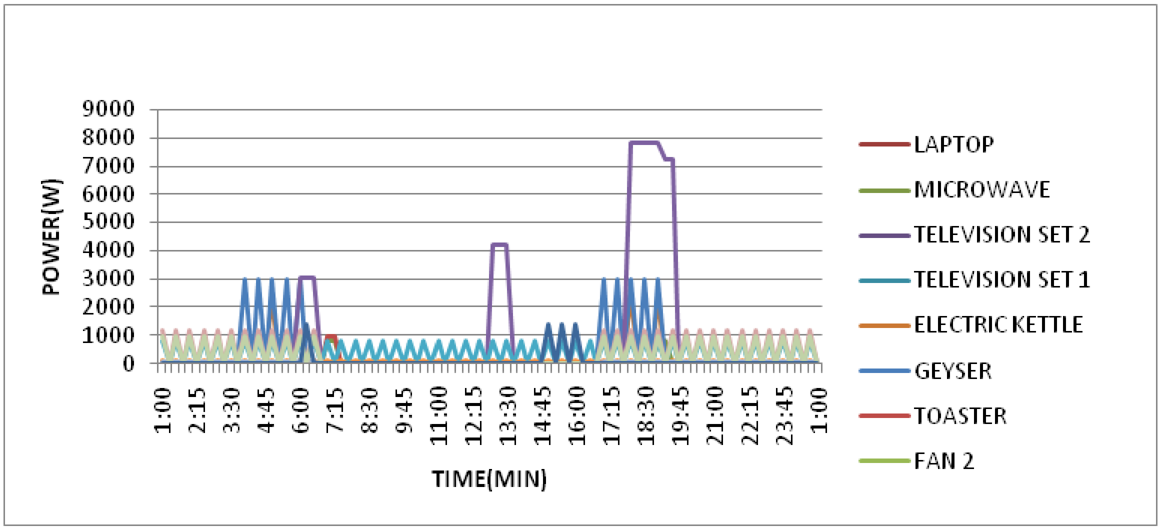
APPENDIX I: Profiles for the appliances in each household



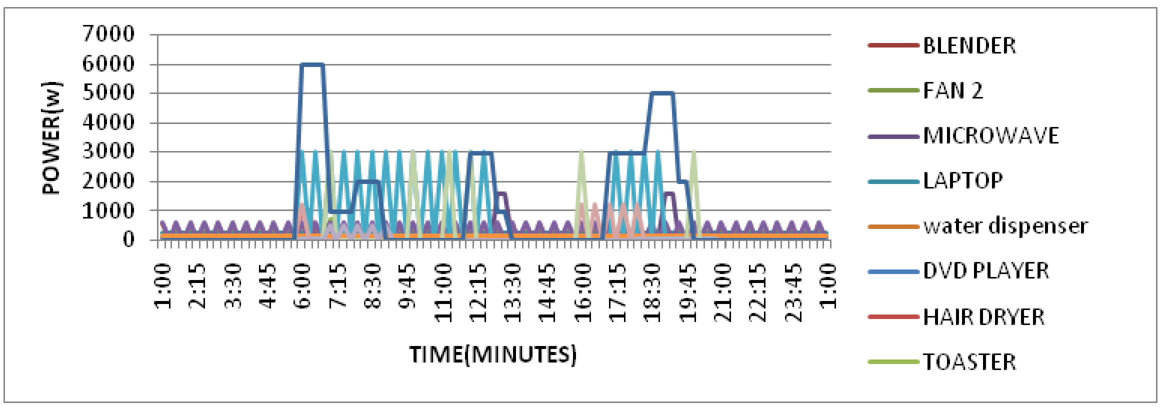
Appliance Load profiles for House One



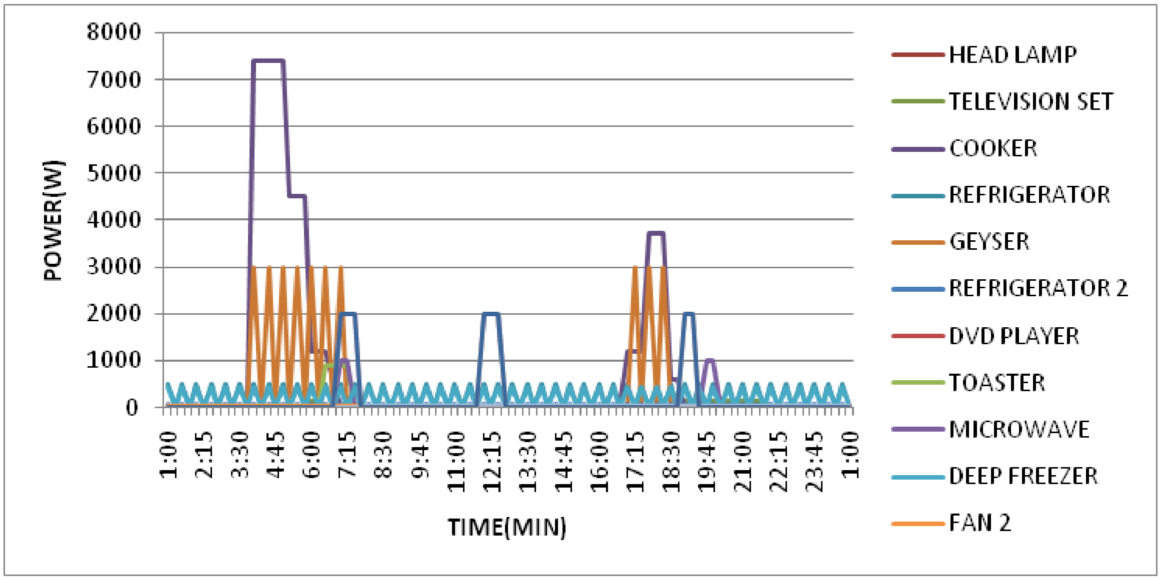
Appliance load profile for House Two



Appliance load profile for House Three



Appliance load profile for House Four



Appliance load profile for House Five

APPENDIX J: Program Codes for the Simulation

```
#include <iostream.h>
#include<stdlib.h>
#include<math.h>
#include<time.h>
#include <iomanip.h>
#include<fstream.h>
#include <assert.h>

#define Pmax 21

int randrange(int,int);
int maxIndex(double a[],int n);
```

double max(double a[], int size);
double Total(double a[],int n);
int nint(double);
int main(void)
{
double POWER[5][30]= {{0.750,0.060,0.214,2.5,2.5,1.0,1.0,2.0,0.8,1.0,1.1,0.440,2.0,3.0,0.088,0.070,0.050,0.060,1.0,0.920,1.4,1.2,1.1,0.175,0.380,0.380,0.085,0.020,0.750,2},
{2.152,0.060,0.214,3.0,3.0,1.2,1.2,2.0,0.6,1.0,1.4,2.4,3.0,0.070,0.050,0.075,0.8,1.0,1.9,0.048,0.055,0,0,0,0,0,0,0,0,0},
{0.162,0.060,0.116,3.0,3.0,1.2,1.2,2.0,0.6,1.1,3,0.3,0.060,0.055,0.60,0.060,0.030,0,0,0,0,0,0,0,0,0,0,0,0,0},
{1.860,0.060,0.254,2.0,2.0,1.0,1.0,2.0,1.0,1.2,0.512,3.0,3.0,0.147,0.088,1.201,0.240,1.0,1.550,0.700,0.085,0.045,0.050,0.400,0,0,0,0,0,0},
{1.015,0.060,0.254,2.5,2.5,1.2,1.2,2.0,0.6,1.1,2.0,3.0,0.150,0.050,1.0,0.900,0.030,0.014,0.025,0,0,0,0,0,0,0,0,0,0,0}};
char *Appliances[][30]={{"deep freezer_fridge","security lightining","ligthting","cooker plate1","cooker plate2",
"cooker plate3","cooker plate4","grill and oven","warmer", "Air con","pressing iron","washing machine","Electrickettle", "geyser","tv1","radio","fan","laptop","microwave","toaster",
"iron2","iron3","iron4","tv2","tv3","tv4","hairf","hairt","sandmicker1","sandmicker2"},

{"deep freezer_fridge","securitylightining","ligthting","cooker plate1","cooker plate2","cooker plate3","cooker plate4","grill and oven","warmer","Air con1",
"pressing iron","Electric kettle","geyser","tv1","fan1","laptop","microwave","toaster","air con2","tv2","fan2 "," "," "," "," "," "," ","","",""},
{"deep freezer_fridge","securitylightining","ligthting","cooker plate1","cooker plate2","cooker plate3","cooker plate4","grill andoven",
"warmer","pressingiron","geyser","tv",
"fan1","fan2","fan3","fan4","dvd player"," "," "," "," "," "," "," "," "," "," "," "," "},
{"deep freezer_fridge and water dispenser","security lightining","ligthting","cooker plate1","cooker plate2",
"cooker plate3","cooker plate4","grill and oven","warmer",
"pressing iron","washing machine","Electric kettle","geyser",
"tv1","fan1","dish washing machine","laptop","hair dryer",
"microwave","toaster","dvd player","tv2 ","fan2 ","blender"," "," "," "," "," "},
{"deep freezer_fridge","securitylightining","ligthting",
"cooker plate1",
"cooker plate2","cooker plate3","cooker plate4","grill and oven","warmer","pressing iron","Electric kettle","geyser","tv","fan1","microwave","toaster","dvd player","headlamp","fan2 "," "," "," "," "," "," "," "," "," ","",""}};
int RND,RND1,t,RND2;
double

```
pow_t[288],pow_t1[288],pow_t2[288],pow_t3[288],Maxload[288][5],MaxAPP[5];
int i,j,k,m,load,r;
double
Dt,sum,SUM,SUM1,sum1,sum2,PTOTAL,PMAX,ETOTAL,LOADFACTOR,PTOTAL
1,PMAX1,ETOTAL1,LOADFACTOR1,PTOTAL2,PMAX2,ETOTAL2,LOADFACTO
R2,Essential,Essential1,Essential2,non_essentials;

double T[288],Energy[288],Energy1[288],Energy2[288],E[5];

int number[5]={0};
double UNUSED_POWER[288]={0};
double USED_POWER[80];
ofstream output;
output.open("houses.txt");
ofstream output1;
output1.open("overload.txt");
ofstream output2;
output2.open("appliances.txt");
ofstream output3;
output3.open("power.txt");
ofstream output4;
output4.open("loadfactor.txt");

Dt=0.083;
srand(time(0));

```

```
cout<<"Time"<<setw(20)<<"power1"<<setw(20)<<"power2"<<'\n';


for(i=0;i<288;i++)
   T[i]=i*Dt;


for(i=0;i<288;i++)
 {
         sum=0;
  for(k=0;k<5;k++)
    {

           if((i%2)==0)
              Essential=0;
        else
              Essential=POWER[k][0];

       if((i>215)&&(i<=288))
         Essential1=POWER[k][1];
       else
                  Essential1=0;

       if(((i>215)&&(i<=288))||((i<72)&&(i<=288)))
         Essential2=POWER[k][2];
```

else
Essential2=0;
/*The assumption was made that appliances in each household can be switched on anytime of the day,
the duration of these appliances switched on is also not known and the number of appliances switched on at any
time is limited by Pmax*/
RND1=randrange(3,9);//assumption:these are appliances that are assumed, that when they are switched on they cannot be resheduled.
esc: RND=randrange(10,29);//These are appliances that can be switched on and can be resheduled.
Maxload[i][k]=RND;
cout<<RND<<setw(20)<<RND1<<setw(20)<<endl;
output<<setiosflags(ios::fixed)<<setprecision(2)<<T[i]<<setw(20)<<RND<<setw(20)<<RND1<<setw(20)<<Appliances[0][RND]<<setw(20)<<Appliances[0][RND1]<<setw(20)<<Appliances[1][RND]<<setw(20)<<Appliances[1][RND1]<<setw(20)<<Appliances[2][RND]<<setw(20)<<Appliances[2][RND1]<<setw(20)<<Appliances[3][RND]<<setw(20)<<Appliances[3][RND1]<<setw(20)<<Appliances[4][RND]<<setw(20)<<Appliances[4][RND1]<<endl;
if(i>38&&i<=276)//This is the time frame for the non-essentials.
non_essentials=POWER[k][RND]+POWER[k][RND1];
else

non_essentials=0;
sum=sum+non_essentials+Essential+Essential1+Essential2;//this is the sum of all the powers from all the five houses(am not sure here cause am getting wrong results, it is not the total power from all the houses)
}
pow_t[i]=pow_t1[i]=pow_t2[i]=sum;//at this point all the arrays contain the same values.
if(pow_t[i]>Pmax)// the condition that limits the total power at each time
{
//cout<<"overload\n";// if true it prints overload
for(m=0;m<5;m++)
{
load=Maxload[i][m];//this array stores the number of the randomly selected appliances at time t, from the five houses
MaxAPP[m]=POWER[m][load];//this array stores the powers of the appliances for each household
}
do
{

int s=maxIndex(MaxAPP,5);//The index for the maximium power value among the five appliances from five houses.This is done to identify the household with the highest power consumption appliance.
if (POWER[s][load] == 0)goto esc;//this condition is to prevent the maximium value from been a zero element.
//UNUSED_POWER[80]=POWER[s][load]; //this array stores all the un-used appliances this collected in order to compare whether they were selected at a time slot, if not all were selected Pmax is increased
cout<<Appliances[s][load]<<endl;
output1<<T[i]<<Appliances[s][load]<<endl;
pow_t1[i]=pow_t1[i]-MaxAPP[s];
MaxAPP[s]=0;
if(Appliances[s][load]=="geyser")
{
//cout<<"geyser switched off"<<endl;
}
/*This prints the name of the appliance to be switched off and the household if pow_t1 is still higher than Pmax this prints all the appliances to switched off from all the appliances*/
cout<<setiosflags(ios::fixed)<<setprecision(2)<<" overload"<<" "<<"HOUSE NUMBER "<<s<<" "<<Appliances[s][load]<<" "<<load<<" POWER= "<<POWER[s][load]<<endl;
output2<<setiosflags(ios::fixed)<<setprecision(2)<<T[i]<<" overload"<<setw(20)<<"HOUSE NUMBER "<<s<<setw(20)<<Appliances[s][load]<<setw(20)<<load<<setw(20)<<"POWER= "<<POWER[s][load]<<endl;

}while(pow_t1[i]>=Pmax);//this has to continue looping until the sum is either equal to /below threshold.
}//close the if condition loop
cout<<setiosflags(ios::fixed)<<setprecision(2)<<T[i]<<setw(20)<<pow_t1[i]<<setw(20) <<pow_t[i]<<endl;//then print the time, powt1 after the overload reduction, power before the reduction,power after the geyser is off.
output3<<setiosflags(ios::fixed)<<setprecision(2)<<T[i]<<setw(20)<<pow_t1[i]<<setw(20)<<pow_t[i]<<endl;
//selected for each household at time.
} keeping

track of this to compare with the actual set if all appliances in the array have been selected
/* finding the loadfactor*/
PTOTAL=Total(pow_t,288);//total power consumed in the 24hours period
PTOTAL1=Total(pow_t1,288);
PTOTAL2=Total(pow_t2,288);
PMAX=max(pow_t,288);//the maximum power in the 24hours period
PMAX1=max(pow_t1,288);
PMAX2=max(pow_t2,288);
cout<<" "<< PMAX1<<" "<<PMAX2<<" "<<PMAX<<endl;//prints the maximum power.
/*the total energy in the system as stated was 298kwh(all power values are in kw)*/
ETOTAL=298;
ETOTAL1=298;
ETOTAL2=298;
/* loadfactor calculated */
LOADFACTOR=(ETOTAL/(24*PMAX));
LOADFACTOR1=(ETOTAL1/(24*PMAX1));
LOADFACTOR2=(ETOTAL2/(24*PMAX2));
cout<<LOADFACTOR1<<" "<<ETOTAL1<<" "<<LOADFACTOR2<<" "<<LOADFACTOR<<" "<<ETOTAL<<endl;
output4<<LOADFACTOR1<<setw(20)<<ETOTAL1<<setw(20)<<setw(20)<<LOADFACTOR<<setw(20)<<ETOTAL<<endl;
output.close;
output1.close;
output2.close;

output3.close;
output4.close;
return 0;
}
/*____end of main program____*/
/*subroutines*/
int maxIndex(double a[], int size) {
//assert(size > 0);
int maxIndex = 0;
for (int i=1; i<size; i++) {
if (a[i] > a[maxIndex]) {
maxIndex = i;
}
}
return maxIndex;
}//end maxIndex
double Total(double a[],int size)
{ double Total=0;
for (int i=0; i<size; i++) Total+= a[i];
return Total; }
double max(double a[], int size) {

```
    //assert(size > 0);        // Note 1.
    double maxVal = a[0];      // Note 2.
    for (int i=1; i<size; i++) {
       if (a[i] > maxVal) {
          maxVal = a[i];
       }
    }
    return maxVal;
}//end max

int randrange(int min, int max)
{
    if(min>max)
    {
      return max+nint((min-max)*(double)rand()/RAND_MAX);
    }
    else
    {
      return min+nint((max-min)*(double)rand()/RAND_MAX);
    }
}


int nint(double x)
{
```

int nearest_int = (int)x;
double real_part = x - (int)x;
if(real_part >= 0.5) nearest_int++;
return nearest_int;
}

APPENDIX J: Questionnaire

The questionnaire

I am a student at the University of Zambia studying for the Master of Science degree. I am conducting my research on the construction of a centralized smart system with optimal energy usage as a response to the energy deficit currently been experienced in Zambia. As part of my system model in this research I need to gather basic information about the energy usage of the occupants in selected households. You have been purposely selected to fill in this questionnaire.

Kindly fill in this questionnaire. Your cooperation will be highly appreciated. Be assured that the information you will provide will highly be confidential and will only be used for academic research purposes.

SECTION A

Kindly tick in the appropriate box [ ]

Sex: female [ ] male [ ]

1. How many occupants reside at your home?

a) Stay alone [ ] b) three (3) [ ] c) other number (indicate the number)………..

2. State the number of:

a) Children (below the age of 18)…………….

b) Adults…………………….

c) Dependants…………………….

3. How many of those in part 2 (b) and (c) are in employment?

b) …………… c) ……………

4. How much money do you spend approximately on power every month?

a) K200 000 [ ] b) K500 000 [ ] c) other amount (specify amount)…………………..

5. How often do you experience power cuts (load shedding)?

a) Not very often [ ] b) very often [ ] c) never [ ]

6. Do you use household energy saving lighting appliances?

a) Yes [ ] b) No [ ] c) other (please specify)..............................

SECTION B

Tick in the suitable box in the table below for the appliances that are found in your household.

If your answer is yes state the quantity.

Appliance	**Tick**		**Quantity**
	YES	**NO**	
Refrigerator			
Air conditioner			
Pressing iron			
Washing machine			
Electric kettle			
Deep freezer			
Geyser			

Stove /cooker			
Heater			
Television set			
Radio			
Fan			
Dish washing machine			
Coffee making machine			
Computer			
Dryer			
Microwave			
Toaster			
Hair accessories equipment			
Borehole pumps			
DVD			
Video game			
Other electrical equipment:			
1. ……………………………			
2. …………………………….			

SECTION C

Interview Schedule

Name of Appliance	Time of Use

Thank you so much for your cooperation…..