Design and Development of An Energy Saving System for Nigerians

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***ABSTRACT*-This paper presents the design and development of an energy saving system which helps in resolving the problem of electrical energy conservation by reducing the amount of time spent on operating home appliances. This is achieved by the usage of a passive infrared sensor (PIR) to detect motion and a DS1621 thermostat for measuring temperature. The PIR sensor serves as the control switch for the lamp attached to the relay. The presence of motion activates the relay connecting the lamp while the DS1621thermostat act as a regulator switch controlling the speed of the fan at different intervals of temperature. A liquid crystal display (LCD) is used to display the PIR status and DS1621 temperature reading.**

The introduction of pre-paid meters by the utility providing company in Nigeria, i.e. Power Holding Company of Nigeria (PHCN) has made Nigerians to be more conscious of the amount of units (power in Watts) to be consumed per day. However, most Nigerians are still not used to switching off their appliances before leaving their houses and this results to wastage of units and money. Hence, a system like this is essential and thus recommended.

Keywords: passive infrared sensor (PIR), DS1621 digital thermostat, electrical energy conservation, energy saving system, microcontroller, relay, liquid crystal display (LCD).

1.0 INTRODUCTION

Research in the field of engineering has led to tremendous discoveries and inventions especially in the areas of automation and power control. Automation of mechanical systems and manual processes is one of the major breakthroughs of Electrical Engineering in the modern age. The discovery of solid state devices and integrated circuits (ICs) has made almost anything possible in terms of electronic control. The price of electricity and demand for power is predicted to increase exponentially in the next several years. In fact, the world's demand for electricity is rising faster than the demand can be met. Consequently, industries, businesses and homes are already taking energy saving measures to save money and to become more environmentally friendly. Energy saving methods is seen to have a small impact to each individual, but as the price and demand for electricity rises, the collective energy saving actions of everyone will make a significant difference. How many times have you forgotten to turn off the lights or TV when you stopped using them? How often does one turn on the kitchen lights to take dinner and then leave them on to be engaged in other domestic activities, like watching TV, reading in the library or cleaning the garden? The chances are that situations like this happen to everyone and re-occur on daily basis.

The main focus of this work is to conserve electrical energy consumption because electrical energy is a limited resource that requires huge investments for its generation. Consequently, it is necessary to make good use of electrical energy and avoid the unnecessary wastage of such resources so that the number of people who can benefit from its usage will be increased. Electrical energy conservation is the process of reducing the amount of electrical energy consumed by the end user in view of achieving an optimal result from the use of electrical energy at an optimized price [1].

However in this work, the two parameters that the basic signal processing acts on are the temperature and motion sensor. The control circuit is designed using a micro-controller. The outputs of these two parameters are read into the micro-controller and the micro-controller output is used to control the LCD display, so that the status of each parameter can be displayed. Also the micro-controller output is used to energize a relay. This relay energizes and de-energizes automatically according to the condition of he sensor's parameter. The simplified block diagram for the energy saving system is shown below in fig.1.

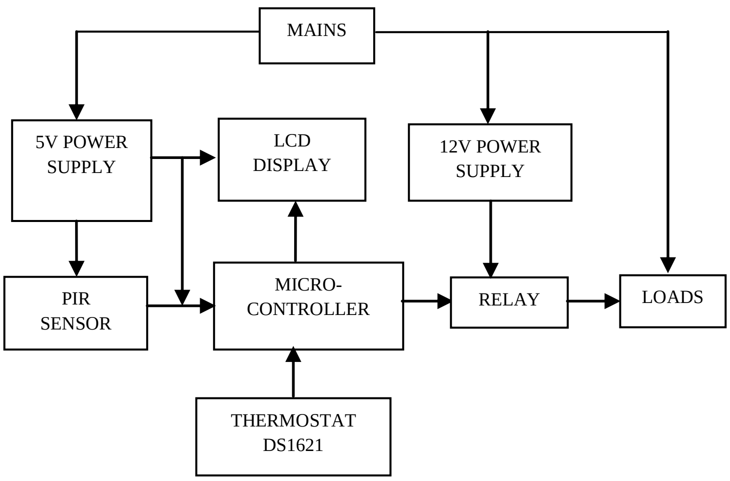

Fig. 1: The Simplified Block Diagram of the System.

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2.0 LITERATURE REVIEW

In 2007, some researchers, namely: N.Md. Saad, S.N.S.A. Rahman, M.F. Abas, M.S. Jadin and A.H.M. Hanafi of the University of Malaysia Pahang (UMP), carefully carried out a study and survey in the lecture hall on power consumption at DK13. The survey shows that there is a high usage of electricity based on the fact that after the end of lectures, the lighting system and the air-conditioning were usually left ON and unattended. Sometimes lecturers or students forget to switch OFF the lighting systems and the air-conditioning system which will result to an increase in the wastage of electricity in the university [2]. Thus, there is a great need to design a control system that will reduce the amount of electrical energy consumed by controlling the appliances while maintaining a comfortable and safe environment in the building.

There is an expanding strand of research work carried out on electrical appliance control and occupant behavior modeling for reducing energy consumption in residential, commercial and educational buildings. However, their main focus has been on reducing energy consumption while maintaining occupant comfort in terms of maintaining indoor temperature and air quality.

Mamidi et al. proposed an adaptive multiagent system that learns about occupants' behavior in order to optimize the appliance operation. They used machine learning technique to predict the occupancy of the rooms up to an hour in advance so as to allow the electrical appliance to minimize energy consumption while maintaining occupants' comfort. Their system only deals with temperature control, and they do not give any consideration to energy consumed by PCs and laptops in the laboratories. They also failed to include humans in the energy conservation loop [3].

More so, Wang proposed a system based on the approach of a hierarchical agent so as to minimize the conflict between occupants' comfort and energy consumption. The system was accounted for its ability in the management of lighting systems and environmental temperature without any regard to appliance level and device level energy monitoring and optimization [4].

In addition, Figureiredo and Costa implemented a predictive controller above a data acquisition platform for energy managements in buildings. This predictive controller optimizes the user preferences as a result of several distributed user interfaces while meeting constraints of minimizing energy waste [5].

3.0 METHODOLOGY

This section discusses the general overview of the design stages of some of the circuits used in accomplishing this work. These stages involve the PIR sensor stage, DS1621 thermostat stage, Microcontroller stage, switching stage, LCD stage and power supply stage.

3.1 PASSIVE INFRARED SENSOR (PIR)

A PIR sensor detects the physical movement in a given area or designated locations and then transforms motion into an electric signal. The PIR sensors are often fitted to security lights so that they will switch on automatically if approached. The sensor is passive because, instead of emitting a beam of light or microwave energy that must be interrupted by a passing person in order to "sense" that person, the PIR sensor is simply sensitive to the infrared energy emitted by every living thing. When an intruder walks into the sensor's field of vision, the sensor detects a sharp increase in infrared energy [6].

Fig. 2: A typical PIR sensor

3.2 DIGITAL THERMOMETER AND THERMOSTAT (DS1621)

The DS1621 digital thermometer and thermostat provides 9-bit temperature readings, which indicate the temperature of the device. User-defined temperature settings are stored in non volatile memory, so that parts may be programmed prior to insertion in a system. Temperature settings and temperature readings are all communicated to/from the DS1621 over a simple 2-wire serial interface [7].

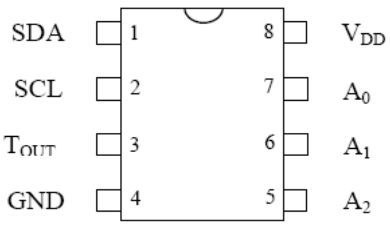

Fig. 4: Pin diagram for DS1621 thermostat

3.3 MICROCONTROLLER

A microcontroller is a computer control system on a single chip. It has many electronic circuits built into it, which can decode written instructions and convert them to electrical signals. The microcontroller will then step through these instructions and execute them one by one [8].

PIC16F72 is the microcontroller used in this system. It is a low-power, high performance, CMOS 8-bit microcomputer with a 2 kilobytes flash erasable and programmable read only memory (EPROM). PIC16F72 is a powerful microcomputer which provides a highly flexible and cost effective solution to many embedded control application [9].

The PIC16F72 receives signal from the PIR sensor and thermostat in the form of binary numbers and then convert it into electrical signals which can activate or deactivate the load. In activating the load, the PIC16F72 sends a high logic to the transistor that controls the relay and in deactivating the load, the PIC16F72 sends a low logic to the transistor controlling the relay. A 4MHz crystal XTAL is connected to port 9 and 10 of the PIC16F72 to generate the frequency required for the operation of the microcontroller. A 5V direct current (DC) supplies power to the microcontroller.

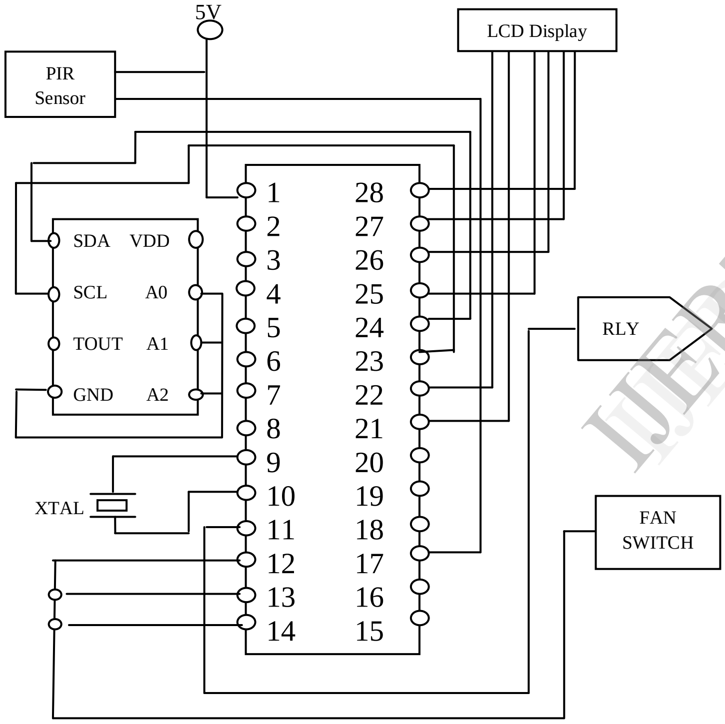

Fig. 5: Circuit diagram of the microcontroller section

3.4 LIQUID CRYSTAL DISPLAY (LCD)

Liquid Crystal Display (LCD) screen is an electronic display module that finds a wide range of applications.

A 16 × 2 LCD is used in this system and it has the capability of displaying 16 characters per line and there are 2 of such lines. In this LCD, each character is displayed in 5 × 7 pixel matrix. This LCD has two registers, namely, Command and Data.

The command register stores the command instructions given to the LCD. A command is an instruction given to the LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display, e.t.c.

The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD [10].

In this work, the Enable pin (E) is connected to the pin 22 of the PIC16F72, while the Register Selection pin (RS) of the LCD display to pin 21 of the PIC16F72. The Data registers (D4 – D7) connects to pins 25, 26, 27 and 28 of the PIC16F72 respectively. The VDD connects to the 5V supply while VSS and Read/Write (R/W) pins are grounded. The section of the LCD is shown fig. 6.

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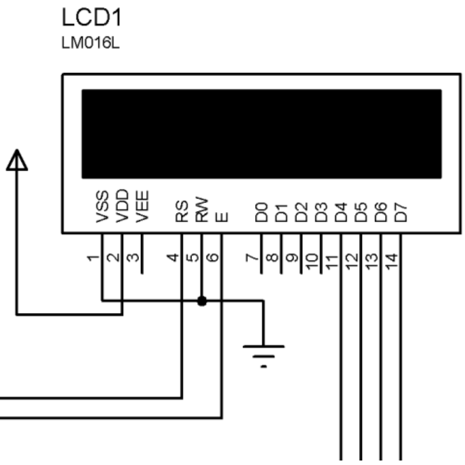

Fig. 6: Pin diagram of the 16 × 2 LCD display

3.5 RELAY

A relay is an electromagnetic switch that acts as a single-pole-double-throw (SPDT) switch. It consists of an electromagnet and a set of contacts. Relays find applications where it is needed to control a circuit by a low-power signal or where several circuits must be controlled by one signal.

In this work, the input to the relay is connected to the switching transistor which is in turn connected to pin 11 of the PIC16F72 that helps in controlling the switching of the lamp.

3.6 MATHEMATICAL MODELLING

This consists of all the mathematical analysis and breakdown of the circuits by adopting formulae that help in selecting the value of components being used.

3.6.1 SWITCHING TRANSISTOR STAGE

The switching transistor switches the relay which powers the load. The transistor operates in a class A mode as a switch. The relay is switched on when the PIC16F72 microcontroller gives a HIGH output. A base resistor is required to ensure perfect switching of the transistor in saturation [11].

In this paper, the collector resistance which is the resistance of the relay coil is represented as R_C. The value of R_C used in this work is 405Ω.

All the parameters used in this work are as follows:

V_{BE} is Silicon.

V_{CE} is when the transistor is switched off.

V_{IN} is from the multivibrator.

V^+ is the regulated voltage from the power supply stage.

h_{FE} is from the data sheet of P2N2222

$$\mathrm{R_C} = 405\Omega$$

$$\mathrm{V^+} = 17\mathrm{V}$$

$$V_{CE} = 0V$$

$$V_{IN} = 5V$$

$$V_{BE} = 0.7V$$

$$h_{FE} = 300$$

Since,

$$V^+ = I_C R_C + V_{CE} \qquad (1)$$

But,

$$V_{CE} = 0V \qquad (2)$$

Then,

$$V^+ = I_C R_C \qquad (3)$$

$$12V = 405 I_C$$

$$I_C = \frac{12}{405}$$

$$I_C = 3A$$

Also,

$$V_{IN} = I_B R_B + V_{BE} \qquad (4)$$

$$5 - 0.7 = I_B R_B \qquad (5)$$

But,

$$h_{fe} = \frac{I_C}{I_B} \qquad (6)$$

$$300 = \frac{3A}{I_B}$$

$$I_B = \frac{3}{300}$$

$$I_B = 0.01A$$

Thus,

From equation (5):

$$4.3V = I_B R_B \qquad (7)$$

$$R_B = \frac{4.3V}{0.01A}$$

$$R_B = 430\Omega.$$

The switching transistor stage is triggered by the output. The switching circuit is used since the PIC16F72 microcontroller output may not give enough current to drive the relay directly.

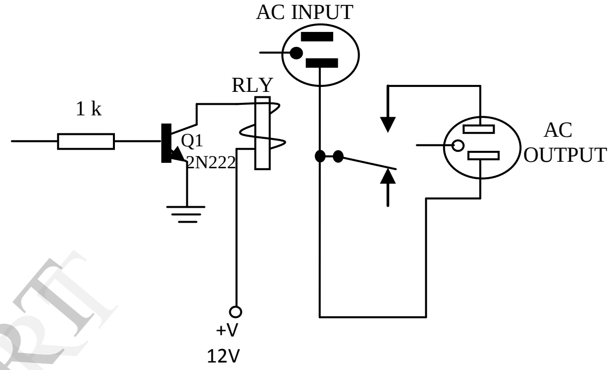

Fig. 7: Circuit diagram of the transistor switching stage

3.6.2 POWER SUPPLY STAGE

The power supply used here is a linear power supply type and it requires a step-down transformer, smoothening capacitor and a voltage regulator to supply the two voltages used in this work. The figure below shows the circuit diagram of the power supply stage.

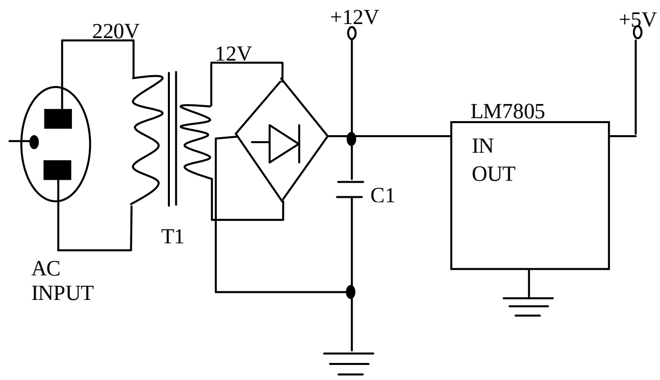

Fig. 8: Power supply circuit

$$Power = Voltage \times Current \qquad (8)$$

$$output\ voltage\ V_O = 12V$$

$$input\ voltage\ V_i = 220V$$

$$output\ current\ I_O = 0.47A$$

$$input\ current\ I_O = unknown$$

Since,

$$input\ power = output\ power \quad (9)$$

Then,

$$V_i I_i = V_O I_O \quad (10)$$

$$I_i = \frac{V_O I_O}{V_i} \quad (11)$$

$$I_i = \frac{12 \times 0.47}{220} = 0.026A$$

$$Peak\ Voltage\ V_P = V_O \times \sqrt{2} = 12 \times \sqrt{2} = 16.97V$$

$$Ripple\ voltage\ V_R = V_P - V_O = 16.97 - 12 = 4.97V$$

$$C = \frac{I_O}{(2 \times F \times V_R)} \quad (12)$$

Where,

C = Capacitance of the filtering capacitor

F = 50Hz

I_O = 0.47A

V_R = 4.97V

Hence,

$$C = \frac{0.47}{(2 \times 50 \times 4.97)}$$

$$C = 0.00095f = 950\mu f$$

3.7 PRINCIPLE OF OPERATION

When the circuit is connected to the mains supply, 220V alternating current (AC) flows into the step-down transformer T1 and it is then stepped down from 220V to 12V. This 12V is then passed through a bridge rectifier which transforms it to a direct current (DC) component. The resulting DC voltage is then filtered by a capacitor C1 to remove ripples and the flow is then directed to the voltage regulator which helps in the regulation of the voltage to 5V. This 5V is used to power the PIR sensor, LCD display and the microcontroller.

When an individual passes across the PIR sensor coverage view, the PIR sensor sends a signal in form of binary numbers to the PIC16F72 which then enables the activation of the first output by sending a high logic to the transistor connected to pin 11 of the microcontroller through the 1kΩ resistor and thus, activating the transistor. The transistor then triggers the relay RLY and thereby causing the 220V supply to flow to the lamp by closing the normally open contacts of the relay.

If motion exists, the speed regulation of the fan is made possible by the DS1621 thermostat. The thermostat helps in measuring the temperature of the room and then communicates it to the microcontroller. The microcontroller then sends three voltage signals to the three outputs at ports 12, 13 and 14 respectively. The microcontroller gives a high voltage signal at a temperature above 40°Celsius to the connected transistor at pin 12 of the microcontroller through a 100Ω resistor, causing the fan to be at its maximum speed. At a temperature above 30°C and below 40°C, the microcontroller gives a medium voltage signal to the transistor connected at pin 13 of the microcontroller through the 1kΩ resistor and hence the speed of the fan is regulated to its medium. The microcontroller gives a low voltage signal to the connected transistor through a 4.7kΩ when the measured temperature is above 18°C and below 30°C. This causes the fan's speed to be at its minimum.

The fan can be in its OFF state when the surrounding temperature is between 0°C - 18°C even while motion exists. The absence of motion within the confined space/room turns OFF the entire system by deactivating the relay and the fan outputs. Fig. 9 shows the complete circuit diagram of the energy saving system.

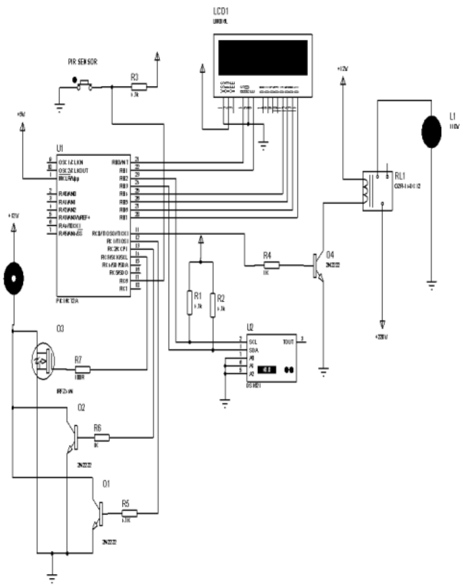

Fig. 9: Circuit diagram of the system

3.8 SOFTWARE DESCRIPTION

This section describes the flow chart of the design used in programming the microcontroller.

The software codes written into the microcontroller was written in PICBASIC programming language and was compiled by the aid of MPLAB integrated development environment. These compiled file was interfaced into the microcontroller by a hardware called a microcontroller programmer into the PIC16F72.

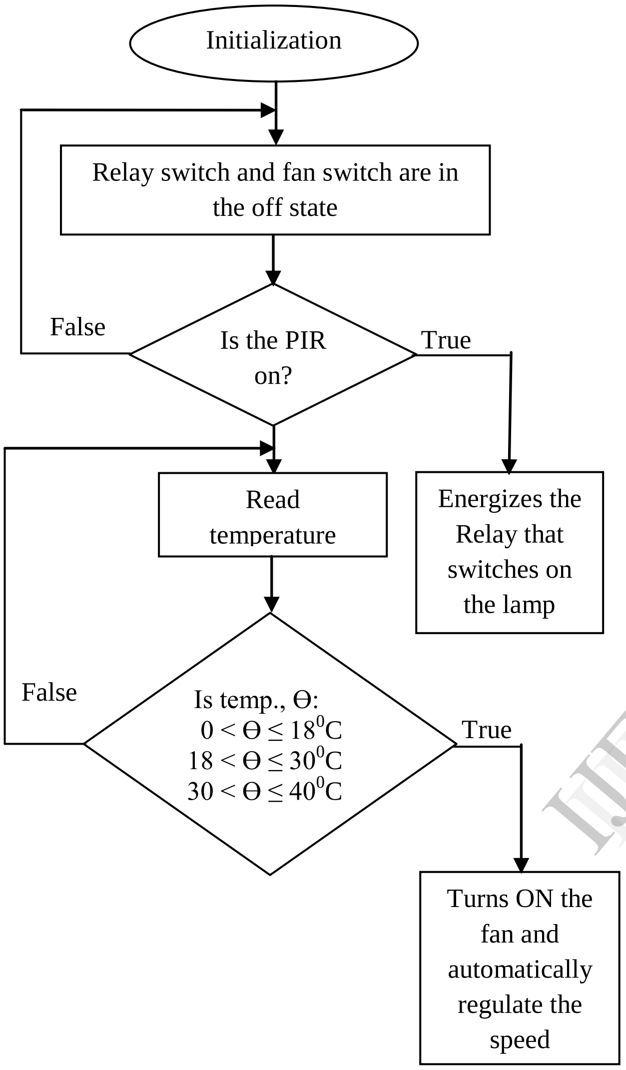

Fig. 10: A flow chart of the software procedures.

3.9 CONSTRUCTION

The circuit was first implemented on a breadboard to ensure it was working properly before it was transferred and soldered on a Printed Circuit Board (PCB). The microcontroller PIC16F72 was not soldered directly on the PCB, instead an IC socket of 28 pins were soldered before the Microcontroller IC was inserted into the socket. But the DS1621 thermostat was soldered directly onto the PCB. Wires were soldered at the point that a PIR sensor should connect and these wires extends to the PIR sensor protruding outside the system. Holes were fabricated at each sides of the system, so that the DS1621 thermostat can easily detect and measure the surrounding temperature. A 16 × 2 Liquid Crystal Display (LCD) was connected to the Microcontroller to display the status of the PIR sensor as well as the measured temperature.

The picture of the finished design is depicted in fig. 11 below.

Fig. 11: Picture of the finished design

4.0 TESTING

Various tests were carried out different section of the design. These tests range from hardware and software tests. Results were obtained to ensure that the system is working satisfactorily.

4.1 RESULT ANALYSIS

After the control system has been fabricated and tested, it was installed for further analysis in a residential building located in Lagos State of Nigeria, precisely, in a students' hostel of a block of twelve (12) flats located within Lagos State University, Epe Campus, Lagos. The energy consumed with and without the control system was compared by using a power meter. Based on the collection of data, the energy saving can be measured.

The data was collected within the 7 days of a week with and without the system and was taken on 3^{rd} February, 2014 to 9^{th} February 2014 without yet installing the control system and on the 10^{th} February, 2014 to 16^{th} February, 2014 after installing the system.

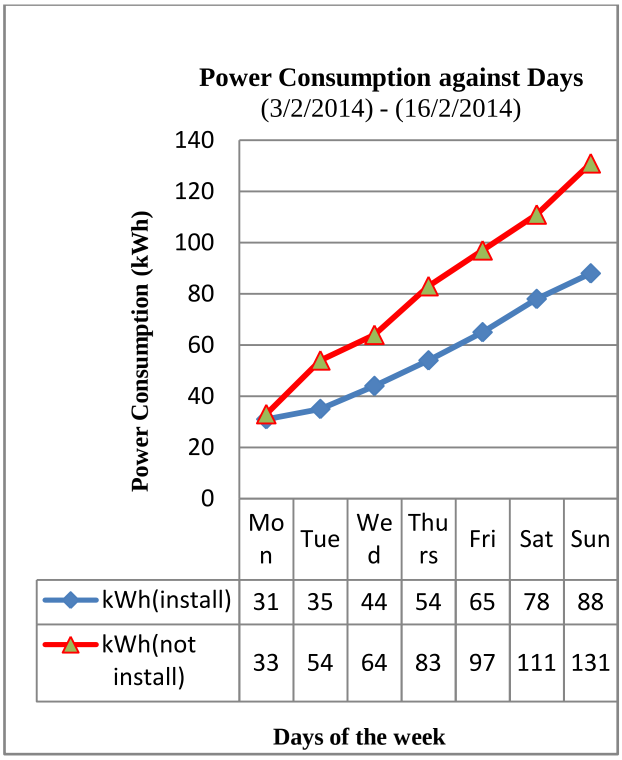

Fig. 12: Power consumption of a Lagos State residential building with and without the system

It can be deduced from the graph above, that:

$$Total\ kWh\ (when\ not\ installed) in\ a\ week = 573kWh.$$

$$Total\ kWh\ (when\ the\ system\ is\ installed) in\ a\ week = 395kWh$$

$$Percentage\ of\ energy\ saved = \frac{kWh(not\ install) - kWh(install)}{kWh\ (not\ install)} \qquad (13)$$

Hence,

$$Percentage\ of\ energy\ saved = \frac{573kWh - 395kWh}{573kWh} \times \frac{100}{1}$$

$$Percentage\ of\ energy\ saved = 31.06\%.$$

This results shows that power consumption rate was optimized to an approximate 31% in a week when the system was applied to automatically control the purposeful use of all electrical and electronic equipments in the residential building

5.0 CONCLUSION

Each of the components used in this work was tested independently and collectively to make sure the specifications meets the aim of the work.

This system helps an electric consumer to reduce the amount of electric power being consumed in the course of operating electrical and electronic equipment and hence, optimizes the cost of electrical power consumption.

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