DESIGN AND FABRICATION OF AN ENERGY EFFICIENT SMART AIR CONDITIONING SYSTEM

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MARCH, 2022

DECLARATION

This thesis is my original work and has not been presented for degree or other awards in any other university.

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DEDICATION

This work is dedicated to my Dad John Mwania, Mum Mary Kavita, my uncle Dr. Paul Mwania, my sister Alice Kavita and my wife Eunice Loko who gave me invaluable moral and material support throughout the period.

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AC	Air conditioning
ARM	Advanced RISC machine
BTU	British thermal units
CPU	Central processing unit
DC	Direct current
GND	Ground
GPIO	General power input and out
GPU	Graphics processing unit
GSM	Global system for mobile communication
HTML	Hypertext markup language
HVAC	Heating, ventilation and air conditioning
IC	Integrated circuit
OS	Operating system
PIR	Passive infra-red
PROLOG	Programming in logic
PWM	Pulse width modulation
RAM	Random access memory
RISC	Reduced instruction set computer
SD	Secure digital
SoC	System on chip

ABSTRACT

Residential and commercial space cooling demands are increasing steadily throughout the world. This has led to high growth in demand for air conditioning (AC) systems. Technology is playing a key role in digitization of these systems with sensors and microcontrollers being used extensively. Energy conservation remains the main focus of scientists and engineers. In line with working towards developing energy efficient systems, we carried out research to optimize the control of air conditioners for energy conservation purposes. This research was geared towards having an energy efficient system. In this research, temperature, proximity and a passive infrared sensor (PIR) were used as smart sensors. The system was designed such that when room occupants' approach a room, the system is activated and rapid cool down or warm up achieved within a predetermined time depending on the size of the room. As long as there is occupant in the room, the system settles quickly into the set conditions. When there is no one in the room, the system need not to be working and therefore it switches off. This ensures that the system only works when needed hence helps in energy conservation thus reducing bills paid by home owners and companies. The designed prototype is able to detect room occupancy, responds perfectly to temperature changes as well as human presence in the field of view of the PIR with an overall performance efficiency of 55.95% which is a good start towards actual implementation of an energy efficient A.C. system. We also recommend that utilization of more sensors like radiation detectors can be explored to diversify the working of this system.

CHAPTER ONE

INTRODUCTION

1.1 Background information

This chapter explains the working and evolution of air conditioners. The purpose of discussing air conditioners is to identify common problems that this research aims to solve.

An air conditioner (AC) is a system that controls the quality of air in a certain enclosed area through a refrigeration cycle. The essence of having an AC is to improve the comfort of occupants by providing the required room temperature.

The developing history of automatic air conditioners (ACs) is propelled by effectiveness, technology, societal needs and energy utilization. ACs have grown from windows type to split type then fixed frequency type and convertible frequency type. A smart type of AC was introduced recently which utilizes Wi-Fi for its control via a smartphone (Yang *et al*., 2016).

In 1990's, for noise reduction purposes, the windows model conditioner was advanced, by moving the compressor outside, to split type. As from 2000, factors such as oil prices and demand for energy conservation have led to modification to convertible frequency from fixed frequency on the control of compressors (Jacob, 2000).

ON and OFF output in compressors is achieved by use of full power in frequency control which leads to temperature changes as well as energy wastage. The compressor output and the rate of flow of the refrigerant are adjusted by use of an electronic expansion valve consistently based on the internal conditions (Nakayama, 1998).

As from 2010, smart phones, tablets and use of fourth generation (4G) communication technology were adopted for control of air conditioners and have led to great improvements. The user can control the operation of an air conditioner through a smartphone. They can switch it on and off as they please (Peter *et al*., 2013)

1.2 Statement of the problem

The indoor unit of an AC which is fitted in the building provides the conditioned air into the space. It has heat exchange coils, filters, remote signal receiver, fan and has an evaporator in which a temperature sensor is installed and used for feedback in traditional air conditioners. It enables the difference causing control by giving a sensor transfer function. The room control function of air conditioning sensor and controller are integrated to enhance the system. The use of feedback from temperature sensors causes control problems since the control output is dictated by the signal differences between setting point and actual signal fed back.

The existing systems can be transformed in such a way that it can use human intention feedback. It will cool or warm the space after sensing the temperature difference between the preset value and the room conditions thus utilizing the intention causing control. This can be achieved by having the temperature sensor outside the evaporator so that the temperature sensing is instantaneous. This will be a great deal towards improvement of air conditioning technology.

Energy conservation is also another consideration which has been made in redesigning ACs to ensure that their cost of operation reduces. For energy efficiency purposes;

i. A passive infrared (PIR) sensor was placed at the entrance of the building to enable the system to detect occupants as they approach it and thus activate the system prior to their entrance.

ii. A proximity sensor was used inside the building to detect room occupancy. This ensured that the system only works when there are occupants in the building and therefore reducing the running time of the air conditioner hence energy conservation is achieved.

1.3 Objectives

1.3.1 General objective

To design, fabricate and test a smart air conditioning system based on passive infrared sensor and temperature sensors.

1.3.2 Specific objectives

i) To design and fabricate a smart automatic air conditioner

ii) To monitor the presence of a person inside a room using proximity sensors to allow maintaining of the system working or to be put OFF in-case after the allowed delay time the occupants have not entered the building

iii) To detect the temperature by use of a thermal sensor and feed the information to a microcontroller so that either the heater or the fan can be switched on depending on the temperature level with reference to the system set temperature

iv) To obtain feedback information on the working of the system online from the microcontroller to make it be utilized as monitoring system since display of the system working would mean that there is an activity in that room.

1.4 Rationale of the study

With modernization, air conditioners are being used intensively to sustain the growing demand for comfort in the changing living standards. Methods for developing new energy efficient and cost effective ACs are being researched on and are considered a breakthrough to heating, ventilation and air conditioning (HVAC) technology advancement. Strategies that are applied in control are considered more cost effective.

Exploration in the world of microcontrollers has been a main activity in the recent past where systems are being automated to ease their operation and save on cost of operation. Intelligent systems remain the main focus by scientist and engineers for the benefit of future generations. Modifications on existing systems are being done to improve their efficiency and make them better and therefore their study becomes relevant and necessary in the field of technology.

This research was aimed at developing an energy efficient smart AC through developing an intelligent smart AC control unit based on smart sensors.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Air conditioners have existed for some time. In this chapter the history of air conditioners as well as the various researches done on smart air conditioners and the gaps identified in each one of them shall be discussed.

2.2 History of air conditioners

In 1758, Benjamin Franklin experimented on evaporation of alcohol to achieve low temperatures (Varrasi, 2011). Willis Carrier invented the modern air conditioner in 1902. He began experimenting on humidity laws to control an application challenge at a printing plant. Carrier used the same mechanical systems developed by Franklin. (Simha, 2012)

In 1933, an air conditioner was developed by carrier's company and it made use of a belt driven condensing unit and successfully managed to come up with a system which could maintain certain levels of temperature in a room (Simha, 2012).

2.3 Related researches on smart air conditioners

Peter *et al*., (2013) designed a smart air conditioning control utilizing wireless sensors. Wireless sensors are not restricted to wired installations and can be installed strategically near the various sources of thermal energy. Wireless sensors can be used to develop intelligent monitoring systems. Their research only considered a single sensor control setting and the main recommendation to develop it was on research in interaction between multi-input and multi-control systems in a networked setting which is an area considered in this research.

Smart phones, devices that can be worn, thermal and motion sensors were interlinked as smart sensors for control of air conditioners in a study by Cheng and Lee (2014). The system obtained feedback information from these devices. Their system was effective in providing conducive environment and achieved energy conservation goal and it utilized wireless devices.

Wireless devices have a promising potential, however, they introduce battery lifetime challenge. They have to operate for long periods and therefore being battery powered; the battery life span has to be maximized. The communication operation consumes a lot of energy and therefore it reduces the battery life time.

Control efficiency is also another area where a big challenge was met by Cheng and Lee (2014) due to energy consumption of the devices. Energy consumption is inversely proportional to efficiency (Riches, 1989). Sleeping of the device most of the time would lower energy consumption in-turn increasing battery life but would reduce the efficiency since the system will not be running hence sensing will not be taking place. Balancing energy consumption with efficiency is key to the usefulness of these devices more so for smart applications.

An energy saving controller for air conditioning in large buildings was designed and implemented by Liagh (2015). This system could also switch on and off the lights and switch on the systems when an occupant enters a room. However, it majorly controlled the level of humidity in the rooms.

A smart air conditioner system for adaptation to a smart home system was proposed by Yang *et al*. (2016). The system used sensors to control the levels of temperature and it was Wi-Fi controlled. Entirely, its control dependent on internet and it had limitations on the geographical areas to be used since not all areas have internet connections.

Mehmet and Hayrettin (2018) conducted a study on an internet of things-based air conditioner which could also control lighting in a house via a smart phone. Their emphasis was on the use of internet to come up with a smart home where the smartphone was used for control optimization. Their system could monitor temperature as well as humidity in various rooms in the house independently. The challenge they faced was on energy conservation which is one of the recommendations that they gave.

Another study which made use of wearable devices connected with multiple sensors for temperature and human movement was conducted by Nabil (2019). It enabled them to manipulate their environment in the different climatic states and obtain the necessary feedback especially on occupants of public places like companies and factories. The obtained information allowed for the adjustment of the air conditioner in advance prior to their arrival based on intentions. This was a great technological advancement.

However, the system faced some challenges; it did not provide means of switching them OFF in-case one had left and forgotten to switch them OFF. The information kept on being fed to the control system and this meant that the system remained working and if at all it was not needed still had to be switched off manually. They used a PIR inside the building for determining room occupancy and this could not be effective enough especially in-cases where there was limited physical activity of the occupants since the working principle of the PIR is based on motion. Their study was similar to that done by Cheng and Lee (2014), therefore still faced challenges of battery life time for those wearable devices not to mention the costs of the constant internet connectivity and that also meant that it could not be used in areas with poor internet connectivity.

Erham and Samudra (2020) designed an AC system which could be controlled remotely in the convenience of their houses. Similar to what Mehmet and Hayrettin (2018) did, they could switch it on prior to arrival and if they noticed that maybe they had left it on they could switch it off for purposes of energy conservation providing justification for any study towards methods of increasing energy conservation. The main challenge with their system was that it was not fast in its operation. It still had to be controlled manually via a smartphone or maybe a laptop. The system could not be implemented in areas without internet connectivity. If one leaves the AC running and only realizes after he/she gets home, we can think of how much energy will be consumed unnecessarily by the AC.

Our research showed that indeed we can be able to modify the existing air conditioning systems for energy conservation purposes. Placement of the PIR at the entrance of the building and the proximity sensor in the building to detect room occupancy proved that indeed there is a great hope in this line of research which was demonstrated by the working of the designed prototype.

2.4 Research gaps

There is need to develop a flexible system that is economical in-terms of power consumption, simple in design and yet very effective in its performance, taking into account that people behave differently due to culture, how they have been brought up and education exposure, making their influence on energy consumption highly variable. The system also needs to be flexible such that it can be adopted for other uses for the benefit of the society in which it would be used. This would help reduce the costs of operation since it will cut down the cost of installing parallel systems for the different tasks.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

Implementation of smart control for ACs requires integration of various devices. The theory of operation of these devices is discussed in this chapter which will also include a discussion of the hardware and software parts of the system

3.2 Theory

3.2.1 The passive infrared sensor (PIR)

It is a passive device which means it does not generate its own energy for detection purposes. It is a device that senses infrared radiation when objects cut across its field of view. All bodies whose temperature is above absolute zero radiate thermal energy. This radiation is not visible to the human eye since it is radiated at the infrared wavelengths. PIR sensors are used for the detection of these radiations.

A PIR sensor detects fluctuations in the intensity of radiation falling on it. The radiation intensity, changes based on the surface properties of the bodies in the field of view of the sensor and temperature. When a body like a human being cuts across the sensor’s field of view, the air temperature at that point will rise to the temperature of the body and then fall back. The resulting fluctuation in the detected radiation is converted by the sensor into variation in its corresponding output voltage and this enables the detection (Dereniak and Boremana, 1996).

When thermal energy flows to the sensor, it excites it. The excitation level depends on the energy received. The energy emitted by a black body per unit time per wavelength is given by

$$E_\lambda(T) = \frac{2\pi hc^2/\lambda^5}{e^{hc/\lambda kT} - 1} \quad (3.1)$$

where,

h – Planck's constant

k – Boltzmann constant

λ – Wavelength

c – Speed of light

T – Temperature (K)

Sensor elements are connected in pairs as contrasting inputs to a differential amplifier. Using this connection, the PIR detections counter-balance and the mean temperature of the area in-front of the sensor is obtained from the electric signal; raise in IR intensity to the sensor is self-neutralizing and cannot activate the system. This enables the system to reject false signals if exposed to short timed illuminations or in case of wide exposure of illumination. This configuration also helps reduce the common mode interference thus allowing resistance to trigger due to nearby electric fields. This mode is used for motion detection.

When a body motion is detected in the field of view of the PIR, as shown in Figure 3.1, equivalent pulses are produced in pairs by the sensor. The output signal is input to a converter and then to a relay circuit. The relay responds to the signals from the PIR, triggering the device connected to it.

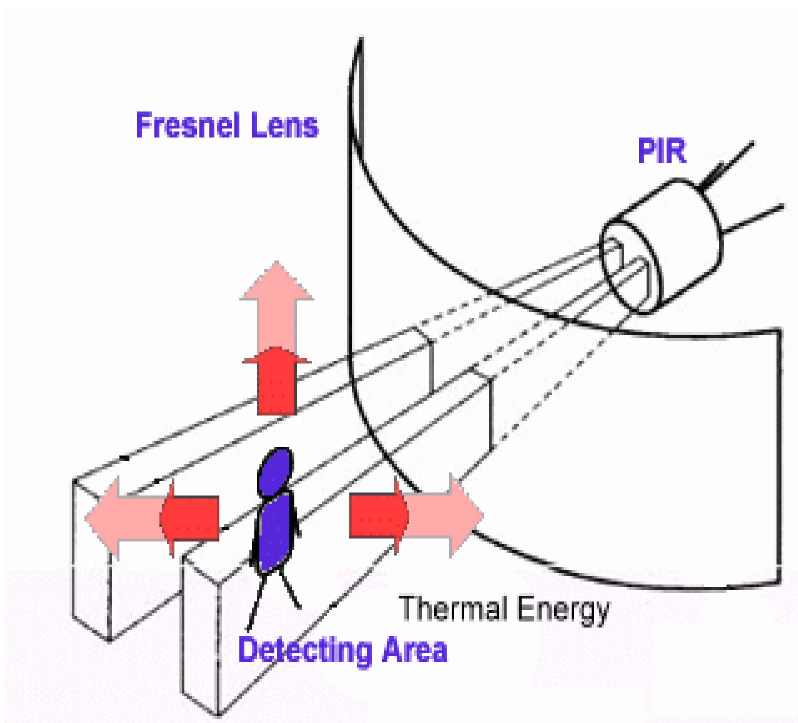

Figure 3.1: Diagram showing the operation of a PIR sensor.

The PIR sensor has two slots in it made of a material that is sensitive to IR and covered by a Fresnel lens. When the sensor is inactive, both slots receive uniform intensity of infrared radiation, the surrounding amount emitted within the room, walls or outdoors. If a warm body cuts across the field of view of the PIR, the thermal energy radiated first intercepts one half of the PIR sensor causing a positive differential change between the two halves (David and William, 1994).

The reverse happens when the warm body is out of the sensing area: the sensor gives a negative differential change. It is the change pulses that are detected.

The current generated is governed by equation 3.2.

$$i = \mathrm{b}T_a^3 \frac{2Pa\sigma\gamma}{\pi hc} \frac{[T_b - T_a]}{L^2} \qquad (3.2)$$

where,

i - Current generated by sensor

P- Sensor pyroelectric coefficient

a - Area of the lens

γ- Lens efficiency

h – Thickness of the lens

C - Specific heat capacity of the sensing material

b - Effective surface area of then subject

T_a - Temperature of the sensor

T_b - Surface temperature of the subject

L – Distance between subject and the sensor

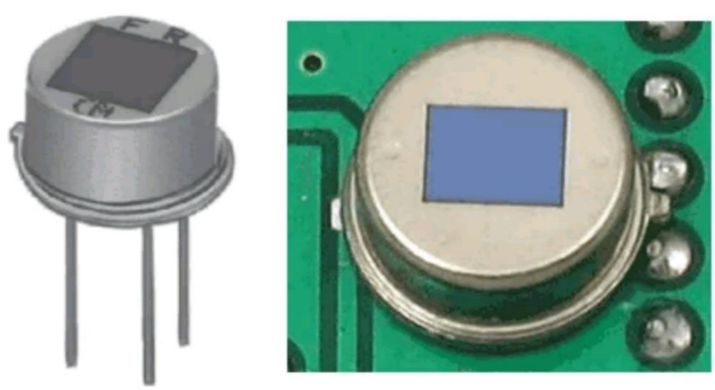

Figure 3.2: An overview of a PIR sensor.

As shown in Figure 3.2, the PIR sensor is enclosed in a waterproof housing to boost immunity to noise emanating from temperature of humidity. There is an opening made of IR transmitter material that shields the sensing element. Behind the opening are the two balanced sensors. To increase the detection area, a Fresnel lens is used. It concentrates light, giving a wider detection range the sensor as shown in Figure 3.3.

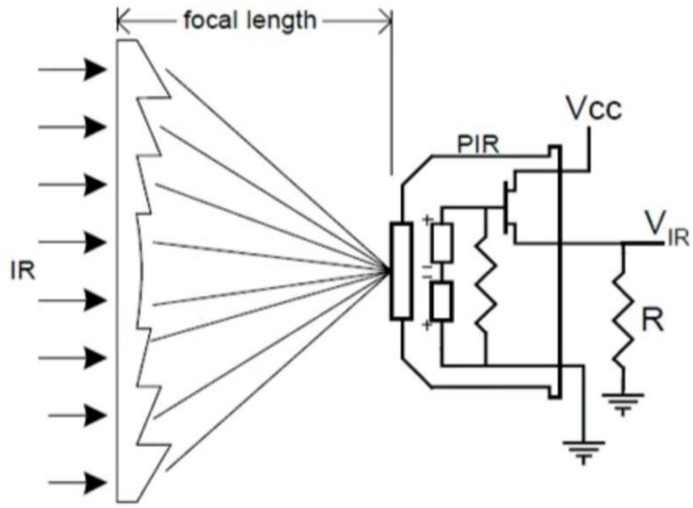

Figure 3.3: Diagram showing the working of a Fresnel lens.

3.2.2 DS18B20 Temperature sensor

It is a one wire programmable temperature sensor which operates at 3 V to 5 V with a temperature range of -55℃ to +125℃ with an output resolution of 9 bits to 12 bits. It has a unique 64 bit address which enables multiplexing and requires only the data pin connected to the microcontroller with a pull up resistor and the other two pins are used for power as in Figure 3.4

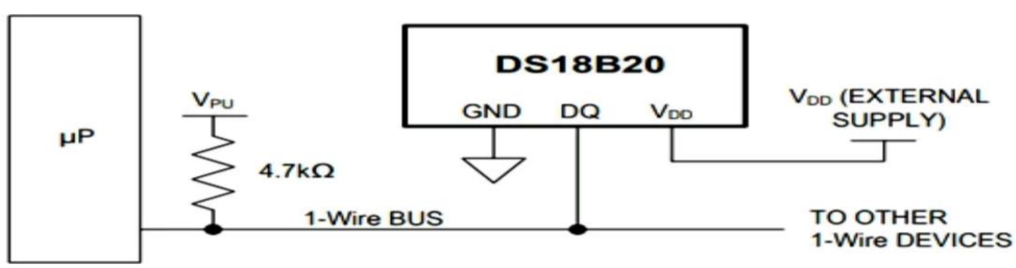

Figure 3.4: A schematic diagram showing the interfacing of the DS18B20 temperature sensor to other components

The line is kept high by the pull up resistor when the bus is inactive. Temperature at any point in a medium depends on the duration of heating and the sediment thermal conductivity (Guo *et al*., 2009). The change in temperature (ΔT), as a function of time (t) at a radial distance (r) from the line source is given by

$$\Delta T = \frac{q}{4\pi\lambda}\left[\ln t + \ln\frac{4\alpha}{r^2} - \gamma\right] \qquad (3.3)$$

where

$\Delta T = T - T_o$; T_o being the initial temperature

γ – Euler's constant (γ = 0.5772)

q – Heat input per unit area

$\boldsymbol{\alpha}$ – Thermal diffusity ($\alpha = \frac{\lambda}{\rho c}$) with λ, ρ and c being thermal conductivity, the density and the specific heat of the medium

3.2.3 Raspberry Pi 3

It is a small microcontroller which has ports to connect external peripherals like keyboards and audio devices as shown in Figure 3.5 together with its pin arrangement. As in Figure 3.6, it features a Broadcom system on a chip (SoC) with an advanced RISC machine (ARM) - compatible central processing unit (CPU) and on chip graphics processing unit (GPU) with a processor of 1.4 GHz and 1 GB random access memory (RAM). Secure Digital (SD) cards are used to store the operating system and program. It has an onboard Wi-Fi and Bluetooth.

Raspberry Pi 3 is a device that can be considered as a single board computer that works in the LINUX operating system (OS).

Figure 3.5: The raspberry Pi 3 and the microcontroller pin arrangement

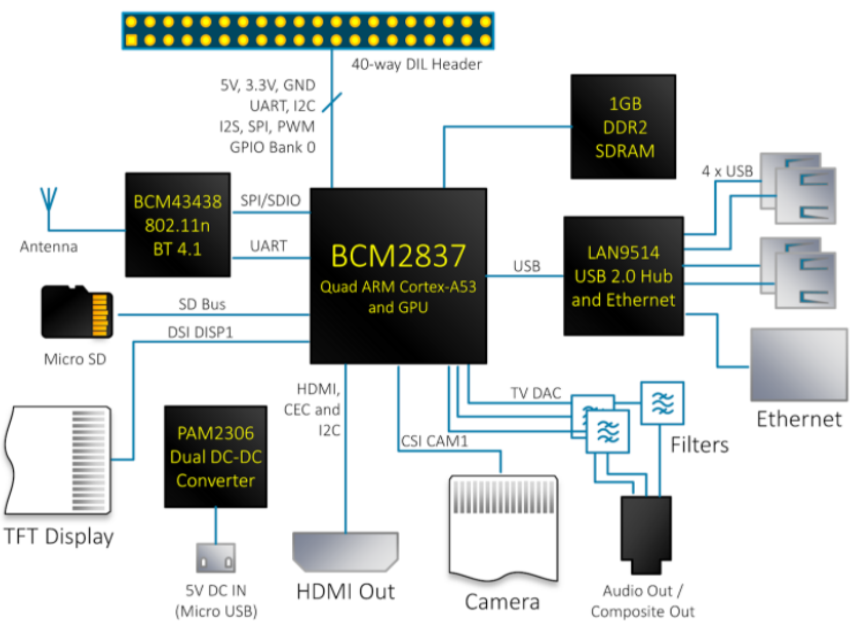

Figure 3.6: The internal architecture of the rasberry Pi 3

The internal archtecture of rasberry Pi 3 is shown in Figure 3.6 and its operation summarisied by the block diagram in Figure 3.7.

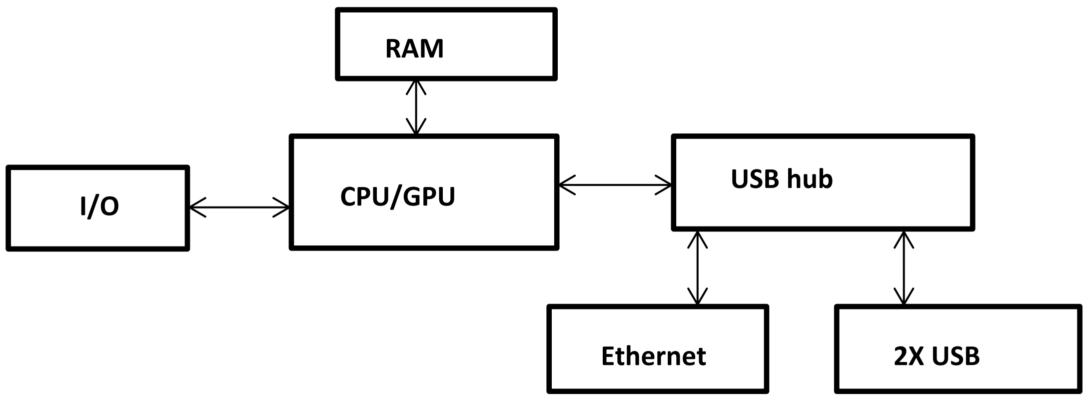

Figure 3.7: Operational block diagram of the raspberry Pi 3

The Pi needs the operating system to be installed first inorder to start working. It has dedicated OS; any other OS will not work. When programming the Pi, the steps followed are as follows;

a) A 16GB micro SD card is installed and specifically dedicated for Pi OS

b) OS software is chosen and downloaded from www.raspberrypi.org/downloads

c) After formatting the SD card, the OS is installed on it

d) The SD card is then inserted in the Pi board after OS installation

e) A monitor, keyboard and mouse are then connected

f) A micro USB connector is used to power the board

g) The Pi runs on the OS installed in the memory card when the power is turned ON and starts from boot.

h) The Pi asks for authorization after all the drivers are checked. This is set by default and can be changed

i) After authorization, the desktop is reached where all application program development starts

Application programs mandatory for use are downloaded directly and installed. The required program is developed and the Pi set to run the programs as required.

A Wi-Fi in the android needs to be activated inorder to create a connection between these devices with the Wi-Fi of the prototype. This connection allows comunication of the devices and hence the neccesary data corresponding to HVAC characterstics is obtained. In this research, three sensors were utilized. The Wi-Fi access enables a bi-directional communication among the sensors, the server and the actuators. For this reason, the first function is to identify and link up to the desired sensors. The microcontroller should accept to be fed with signals from the sensors after which it reads data from the input devices periodically and transmit the data to the cloud database. Figure 3.8 shows a flowchart representing these tasks of the raspberry Pi gateway application.

The application controls the temperature and sends instructions to turn ON/OFF the actuators. Whenever the application receives a signal, it checks if the value is within the range as per the set value and if not, it instructs the required actuator changing its state accordingly.

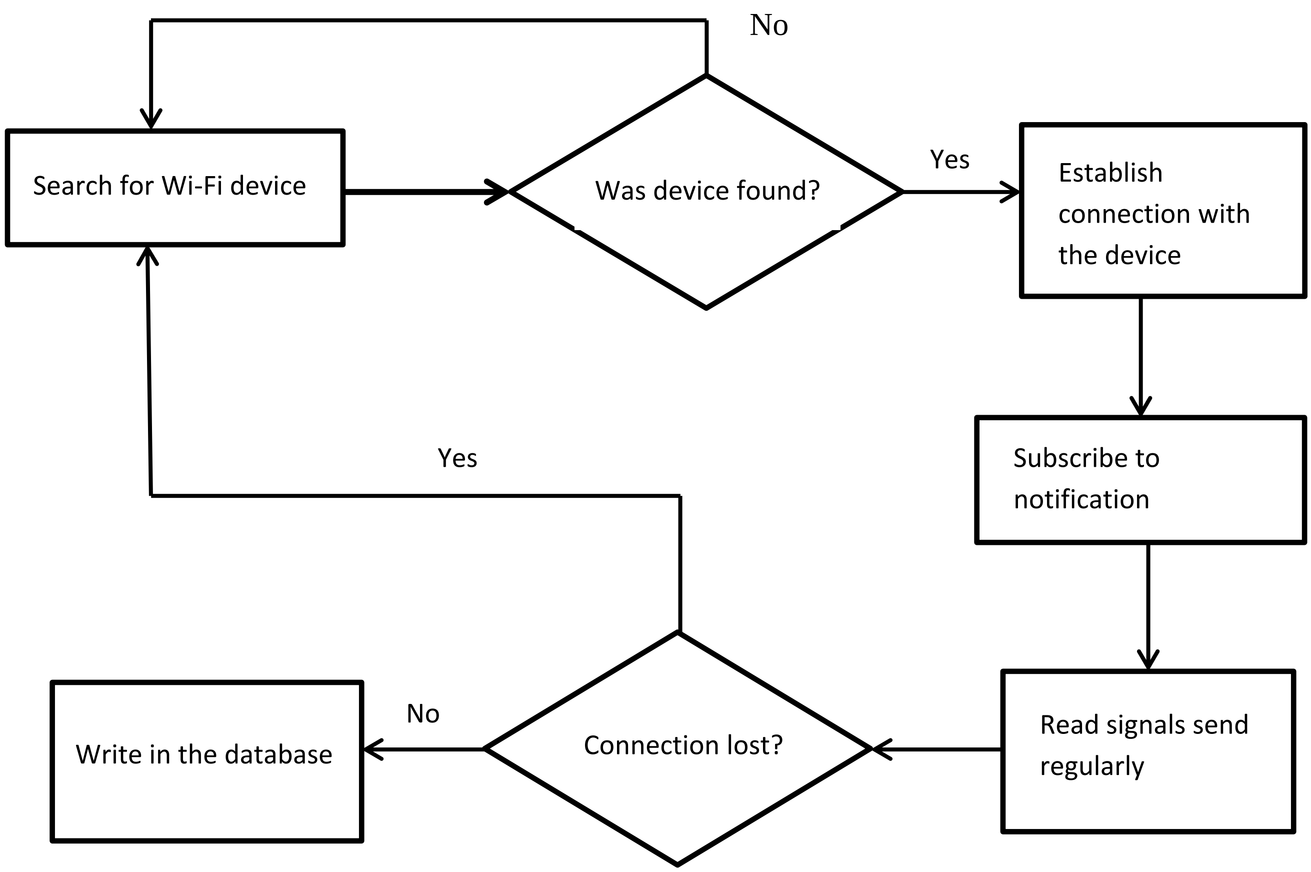

Figure 3.8: Flowchart showing data processing by the Pi 3 application.

3.2.4 HC-SR04 Ultrasonic sensor

It is a sensor which provides a non-contact measurement functionality of 2 cm to 450 cm with a ranging accuracy reaching up to 3 mm. It has four pins; V_{cc} (power), trig (trigger), echo (receive) and GND (ground). In this research, the HC-SR04 ultrasonic sensor was used for room occupancy detection which is vital for the functionality of the system since the system needs not to be working when no occupants are in the building for energy conservation.

The HC-SR04 Ultrasonic sensor has two ultrasonic transducers. One serves as a transmitter that changes electric signals into 40 KHz ultrasonic sound pulses. The other is the receiver and gives an output pulse whose wavelength is used to determine the distance the pulse travelled. At the beginning, a pulse with 10 µ periodic time is fed to the Trigger pin. The sensor in turn transmits eight pulse sonic bursts at 40 KHz. The 8-pulse order is the unique signature of the device, enabling the receiver to distinguish the transmitted signal from the ambient ultrasonic signal.

The pulses propagate via air progressively from the transmitter. The Echo back signal is initiated by the Echo pin going HIGH and times out after 38 mS (38 milliseconds) if the pulses are not reflected back and return LOW. Therefore, a 38 mS pulse shows that there is no blockage in the sensors' range.

The Echo pin will go LOW, upon reflection of the pulses, as soon as the signal is received. A pulse with a period oscillating between 150 µs to 25 ms is produced, based on the time taken by the signal to the receiver. The distance to the object is determined from the period to the signal using the equation below.

$$\text{Distance} = \text{speed} \times \text{time} \tag{3.4}$$

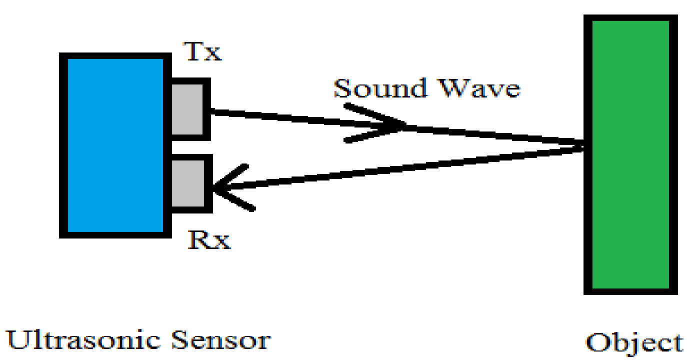

Figure 3.9: Diagram showing the working principle of the ultrasonic sensor

The universal speed for an ultrasonic wave is 330 m/s

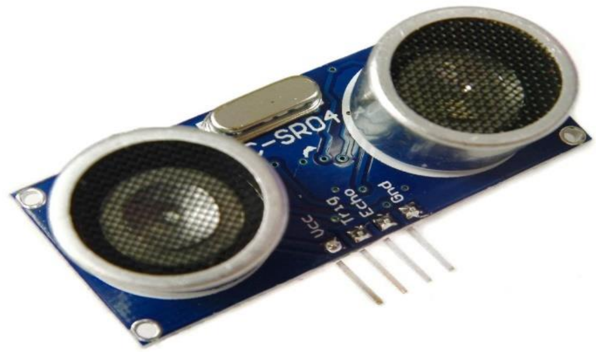

Figure 3.10: A HC-SR04 Ultrasonic sensor

3.3 Materials

The materials used are; a TIL38 passive infrared sensor, a 12 V DC servo motor, DS18B20 temperature sensor, L293D motor driver, HC-SR04 ultrasonic sensor, Raspberry Pi 3 micro-controller, a fan heater subsystem a computer and a smartphone.

3.4 Hardware

3.4.1 Detecting a person approaching a building

The PIR has three pins, the input, the ground and the output which are connected to a 5V, GND and GPIO pins of the micro-controller respectively. The range of the PIR is between 6-10 metres. When the PIR detects a person, it outputs a 5V signal to the microcontroller through its GPIO. The control program interprets this signal as an occupant coming in the room. The micro-controller therefore sets on either the fan or the heater depending on the temperature level of the room as measured by the thermal sensor.

3.4.2 Detecting the temperature inside a room

Having mounted the temperature sensor on the bread board, with the positive rail connected to a 3V pin of the micro-controller and the ground rail grounded too, a 4.7- kΩ resistor is connected across the positive lead and the output lead of the sensor. A wire is connected from the positive rail to the positive lead and from the ground rail to the ground lead. The temperature sensor will give a HIGH output when the temperature is high and this should trigger the micro-controller to switch ON the fan. In case the temperature is low, the sensor will give a LOW output and this should trigger the heater to be switched ON. In case of optimal temperature conditions, no action will be taken, thus the system will not be set ON.

3.4.3 Detecting the presence of occupant inside a room

The PIR having detected an occupant coming in to the room, and the signal from the temperature sensor having been fed to the microcontroller, the necessary action will be taken. The system will only go ON if the PIR has detected an occupant coming into the room and the temperature levels in the room are not optimal as per the control program. A timer is set such that after three minutes the system goes OFF if room occupancy is not detected.

When occupants enter into the room, the output signal from the proximity sensors installed in the room will give a HIGH output indicating room occupancy and this signal will maintain the system working until the required temperature conditions are achieved. The system continues to work if in addition to the sensor signal being LOW or HIGH, the signal from the proximity sensor is also HIGH. If the conditions are conducive, the micro-controller disconnects therefore the system stops working until again the temperatures fall or raise.

After the occupants leave the room, signal from the proximity sensor goes LOW and this is interpreted by the control program to mean that the occupants have left and this triggers the micro-controller to switch OFF the system.

3.4.4 Working of the motor to open and close the window

For the motor, there are two separate power sources;

a) Power for motor (provided by external power supply).

b) Power for the motor driver (which is provided by the GPIO pins of the micro-controller)

The revolution of the motor is varied using pulse width modulation (PWM). That is, control on the period voltage will be ON and by alternating between HIGH and LOW for a set period

The L293D motor integrated circuit (IC) is used. It has two inputs pins; one to give the required direction of the output and the other to sense ON/OFF. For the motor to spin forward (to open the windows), having the enable pin on, the input on pin one will be set to HIGH and that of pin two to LOW. To spin backwards (to close the windows), the input in pin two will be set to HIGH while that of pin one will be set to LOW. If both in puts are set to the same state, either LOW or HIGH, the motor does not run. The pulse modulation is applied on the enable pin.

On the micro-controller, one 3.3 V power supply and one grounding pin were used for the motor driver. Two of the output pins were used for the inputs on the IC and one for the enable.

The L293D chip is mounted on a bread- board. The wires need to be connected to the right slots: red for power connection, black for grounding, blue for inputs from the micro-controller and orange for the outputs of the motor. We note that the windows are only opened manually via a smart phone in situations when the AC may not be needed.

3.5 Software

3.5.1 Programming languages

A programing language is a formal language which comprises of a set of instructions used to produce various kinds of output. Programming languages are used to create programs that implement specific algorithms. They contain functions for deciding and executing data systems or organizing the execution procedure.

3.5.1.1 Python programming

Python a language which creates an object oriented approach to help programmers write logical code and is applicable for small and large scale projects. It has an advantage of supporting multiple programming standards.

Python works on different operating systems such as Windows, Mac, Linux, Raspberry Pi, etc. It utilizes syntax equivalent to the English language that enables developers to write shorter programs compared to other programming languages. It has an interpreter thus the program can run immediately it is written making prototyping easy.

It is a language which was designed for ease of use and is similar to English with some mathematical influence. Commands are completed using new lines, contrary to other programming languages which often use semicolons or parentheses. Python relies on indentation or use of whitespace, to define the range; such as the breadth of loops, functions and classes. Curly-brackets are mostly used in other languages for this purpose. In this research, python was used to program the Pi.

3.5.1.2 Java and Java script programming

Java is an object-oriented programming language. It is intended to let application developers "write one, run anywhere" program, meaning that compiled java code can run on all platforms that support java without the need for recompilation. In this research java was used in developing the android application.

JavaScript programming language is used on web pages to improve their usefulness. It is not similar or related to Java. The two have a C like syntax and are often used for client Web developments having only few similarities. JavaScript was used in this research to develop the system web page

3.5.2 System

3.5.2.1 Control system

Control systems are based on mathematical formulations and handle the control of consistent vital systems. The aim is to come up with a model to control such systems by use of a control trigger in a very effective way such that the system is stable.

To achieve this, a monitor having the required restorative behavior is utilized to monitor the variable controlled in the process and compare it with the point of reference. The contrast between the received signal and preset value of the system is applied as feedback to obtain a control action to bring the guarded system variable to desired value. This feedback is continuous and involves use of a sensor to take measurements and appropriately making adjustments to maintain the variable measured within a particular range using a controlling element such as a control valve.

A block diagram, as shown in Figure 3.11, is used to show how feedback is achieved in a system. In it is a system function, which is a replica of mathematics giving a connection between the input and output following the system processes.

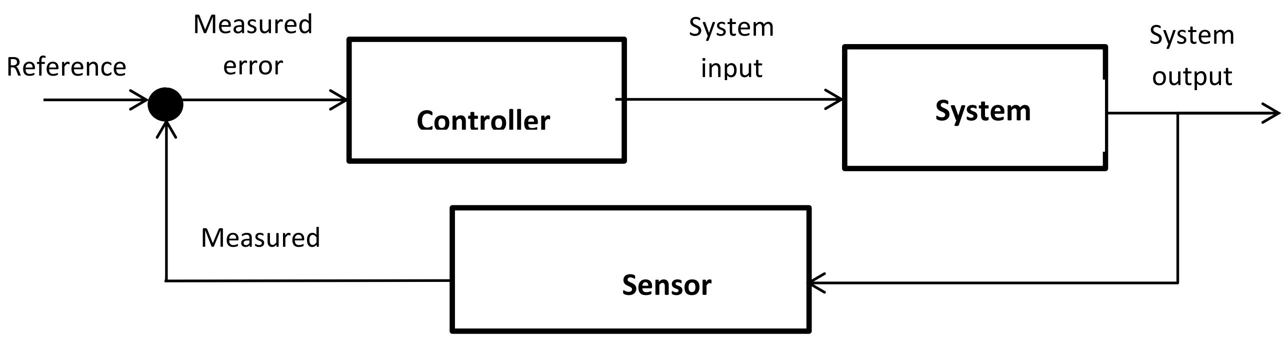

Fig 3.11: A schematic of a negative feedback control system block diagram

3.5.2.2: System operation

A passive infrared sensor measures infrared radiation emitted from objects that generate heat and therefore infrared radiation in its field of view. Basically, they detect the change in temperature in comparison with the surrounding temperature.

When a person enters in its field of view, infrared radiation is detected. Due to motion, there will be variation in the intensity of the infrared radiation. This causes a change in the output voltage generated. Having detected motion, the PIR outputs a HIGH signal on its output pin which switches ON the fan or the heater depending on the temperature state as measured by the temperature sensor in the building.

By the time occupants enter the room, the system will be working. To continue working, proximity sensors are integrated in the system to detect the presence of individuals in the room. The moment presence of occupants is confirmed; the output signal being HIGH maintains the system working. When optimal temperature conditions are achieved, the microcontroller switches OFF the air conditioning system.

If the temperature falls below or raises above the required level, the output of the temperature sensor will be LOW or HIGH respectively, which triggers the system to start working. When occupants leave the room, the proximity sensors will detect non availability of room occupants and thus give a LOW output which will switch OFF the system.

3.5.2.3 Virtualization of the system

The control program is designed in such a way that it is web based for the system can be virtualized (as in Figure 3.12). Owners will be able to access it online. This can act as a monitoring option since it will be showing which rooms have the system working and that would be interpreted to mean that we have occupants in those rooms. This is because the system is basically occupancy controlled and cannot work unless there is room occupancy in the building. Figure 3.13 shows the program execution flow chart.

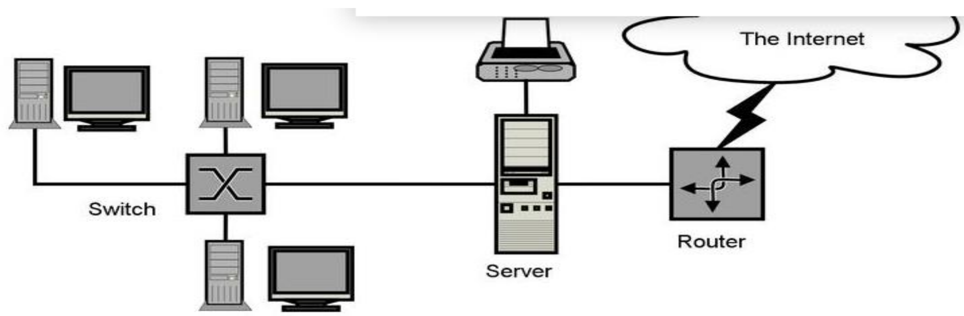

Figure 3.12: Diagram demonstrating the idea of virtualization

3.5.2.4 Program flow chart

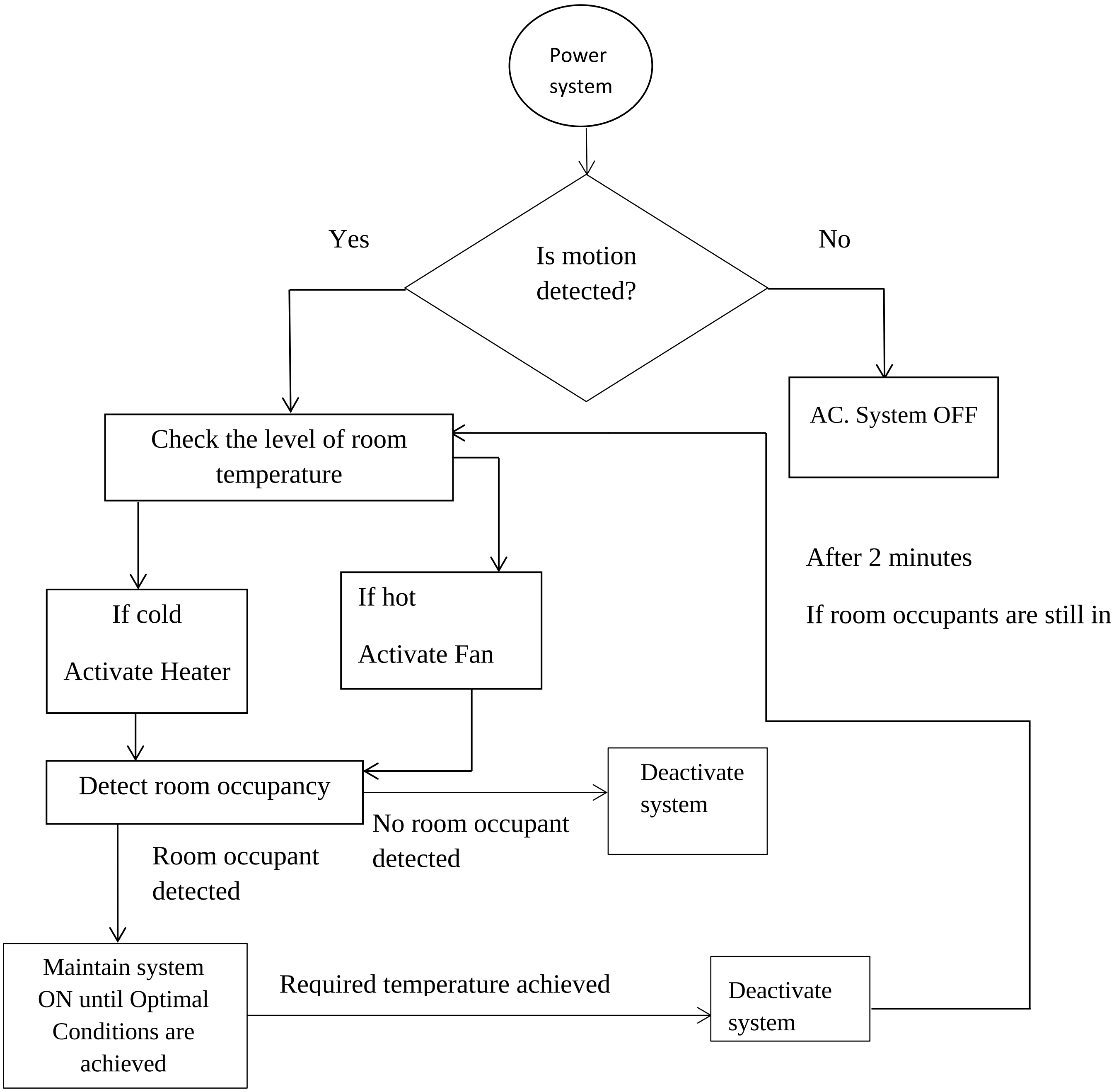

Figure 3.13: Program flow chart diagram.

3.5.2.5 Circuit diagram

The circuit diagram of the prototype is shown in Figure 3.14. It shows how the different devices were integrated and to which pins of the microcontroller they were connected to.

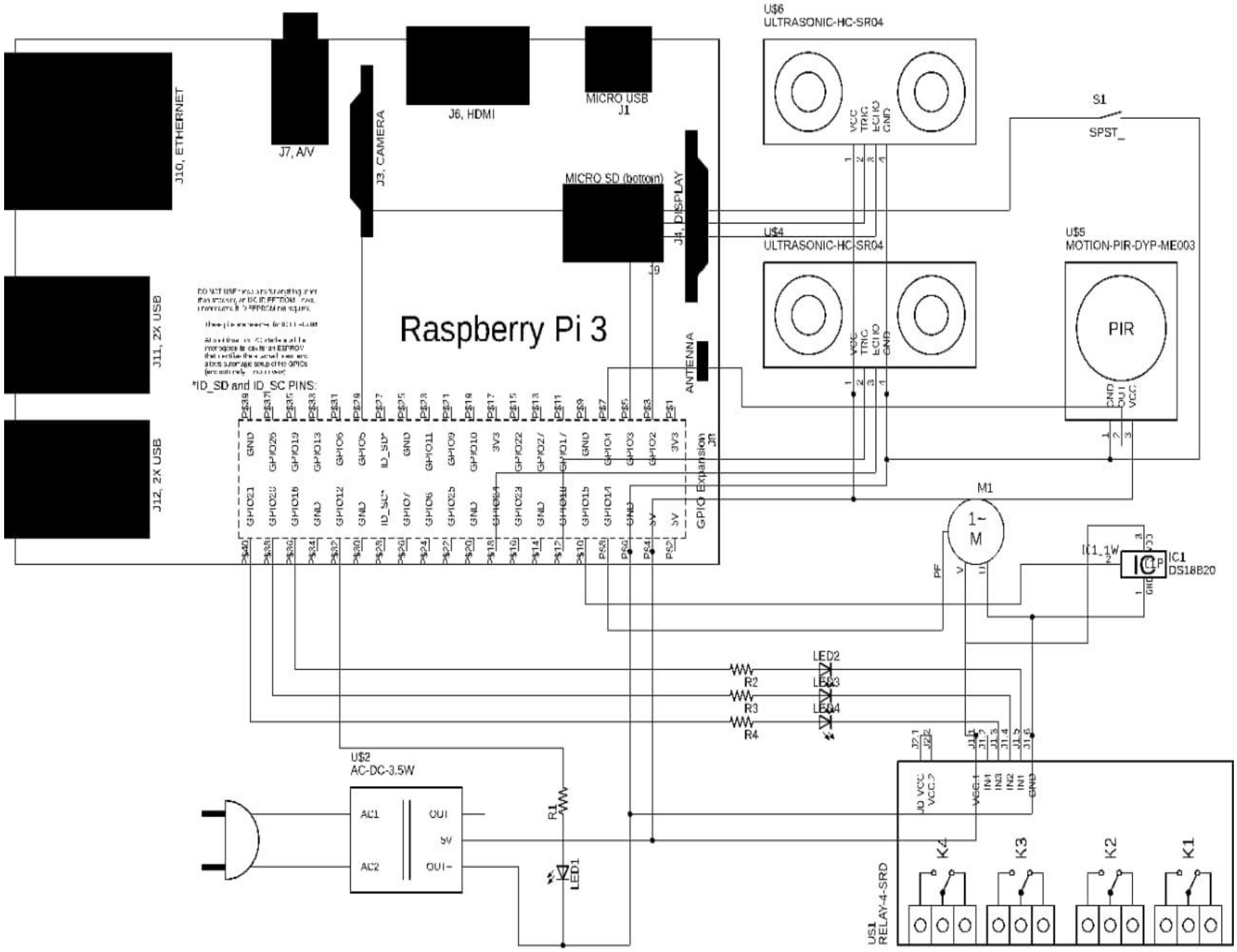

Figure 3.14: Circuit diagram of the prototype drawn using eagle CAD

CHAPTER 4

DATA ANALYSIS AND DISCUSSION

4.1 Introduction

Several factors determine how long it takes for an AC to create the required room conditions. One of these factors is the temperature and humidity outside since humidity cancels out cooling effect. The higher the temperature and humidity outside the longer it takes the AC (Alahmer *et. al.*, 2011). The size of the room is also another factor. Generally larger rooms take longer to be cooled or heated. Size of the air conditioner is also a major consideration when choosing an AC for your premises.

Air conditioners with large capacities take shorter time though this does not mean that one should install very large ACs. An oversize air conditioner will cycle on and off more frequently and this results to system breakdowns. Heat sources from inside the room also play a major role in determining the duration of time taken by an AC. Sources like electronic appliances as well as people raise the temperature inside a room and thus the AC takes longer. Air leaks and poor insulation allows heat into your home and cool air to escape outside which increases the air conditioning cooling time (Kohta *et. al.*, 2008).

In this chapter, test results are presented to show the working of the prototype as well as effects of some of the above mentioned factors.

4.2 Cooling capacity

Cooling capacity for a room can be explained as the heat pack in a place needs to be controlled for a certain room temperature and humidity to be achieved. The recommended conditions are 24℃ and 55% relative humidity (Percy *et. al.*, 2020).

To calculate the cooling capacity for an AC we follow a procedure of first determining the volume of the room to be cooled then multiply by six (whenever the ON/OFF type of compressor starts to run, the power consumed is 6 times more compared to when steadily running) (Charisis and Theoklitos, 2012). We also consider the number of occupants in that room (*N*). This will help us know the amount of heat to be generated by the occupants. Each person produces approximately 147 W of heat for normal office related activity. The amount of heat generated shall therefore be $147 \times N$.

Letting the volume of the room to be *V*, we multiply by 6 to get $6V = M$ and $147 \times N = K$. adding M and K gives us the simplified cooling capacity.

Hence the estimated cooling capacity = $M + K$ (4.1)

This equation holds on condition that heat from the other sources is negligible otherwise an allowance should be provided to accommodate that when designing an AC for a building.

4.3 Space Heat Gain (Heat Storage Effect)

Thermal energy entering a room from the various sources does not immediately get to heat the air in the room. Only part of it is taken by air in the room immediately resulting to a small change in its temperature. A lot of the radiant heat is mainly absorbed by the inner surfaces like ceiling, floor, internal walls and furniture. They have high thermal capacity hence their temperature raises slowly. The radiation introduces a time lag and also a reduction factor based on surface properties hence radiation effect will be evident after the radiation source is withdrawn (Ashrae, 2017).

This explains why the sensed temperature in a room may raise slightly above the required temperature and the reason cooling process has to begin instantly to stabilize the system shown in Figure 4.3.

4.4 Data presentation and analysis

In this research work, three sensors namely PIR, ultrasonic and temperature sensor were used to actualize the system and experimentation conducted. The sensors were mounted strategically to maximize their efficiency. The PIR is mounted at the entrance of the building such that the subject cuts across its field of view so that its two sensor elements are sequentially exposed to the infrared radiation. The response of the PIR was good up to a distance of 8 m (as shown in Table 1) beyond which the system could not respond to any motion.

Table 4.1: A table showing the response of the prototype with variation in subject distance from the PIR

Distance of subject from the PIR (m)	Did the system respond (Yes/No)
1	Yes
3	Yes
5	Yes
7	Yes
8	Yes
9	No

The ultrasonic sensor responded even when inclined at different angles. This test was necessary since in a room people can have different sitting positions. The maximum angle for its response was found to be 15°. Beyond that, room occupancy could not be detected (as shown in Table 2)

Table 4.2: A table showing the response of the prototype with variation in subject distance from the PIR

Distance from the ultrasonic sensor (m)	**System response (yes/no)**	**Response of the system due position Angle of the subject from the sensor (Yes/No)**			
		5	10	15	20
1	Yes	Yes	Yes	Yes	No
2	Yes	Yes	Yes	Yes	No
3	Yes	Yes	Yes	Yes	No
4	Yes	Yes	Yes	Yes	No
4.5	Yes	Yes	Yes	Yes	No
4.6	Yes	Yes	Yes	Yes	No
4.7	No				

The information in Table 4.2 would be useful to installers in that it would help them know where to mount the sensors for maximum effectiveness. Parameters like the sitting positions of the room occupants and the sensor placement from the sitting position can be determined from the table.

The fabricated prototype air conditioner worked and was effective in controlling the temperature in a room. It has a dashboard where users can monitor the temperature inside the room as shown in Figure 4.1. It is through the same dashboard where users can operate manually the designed air conditioner. It displays the temperature level at any particular instant with an accuracy of 0.001℃. The Wi-Fi range of the raspberry was tested and found to be 10 m in open space, distance which reduced slightly to 8 m when kept in a room as a result of obstruction of the waves by the walls of the room and the equipment in it.

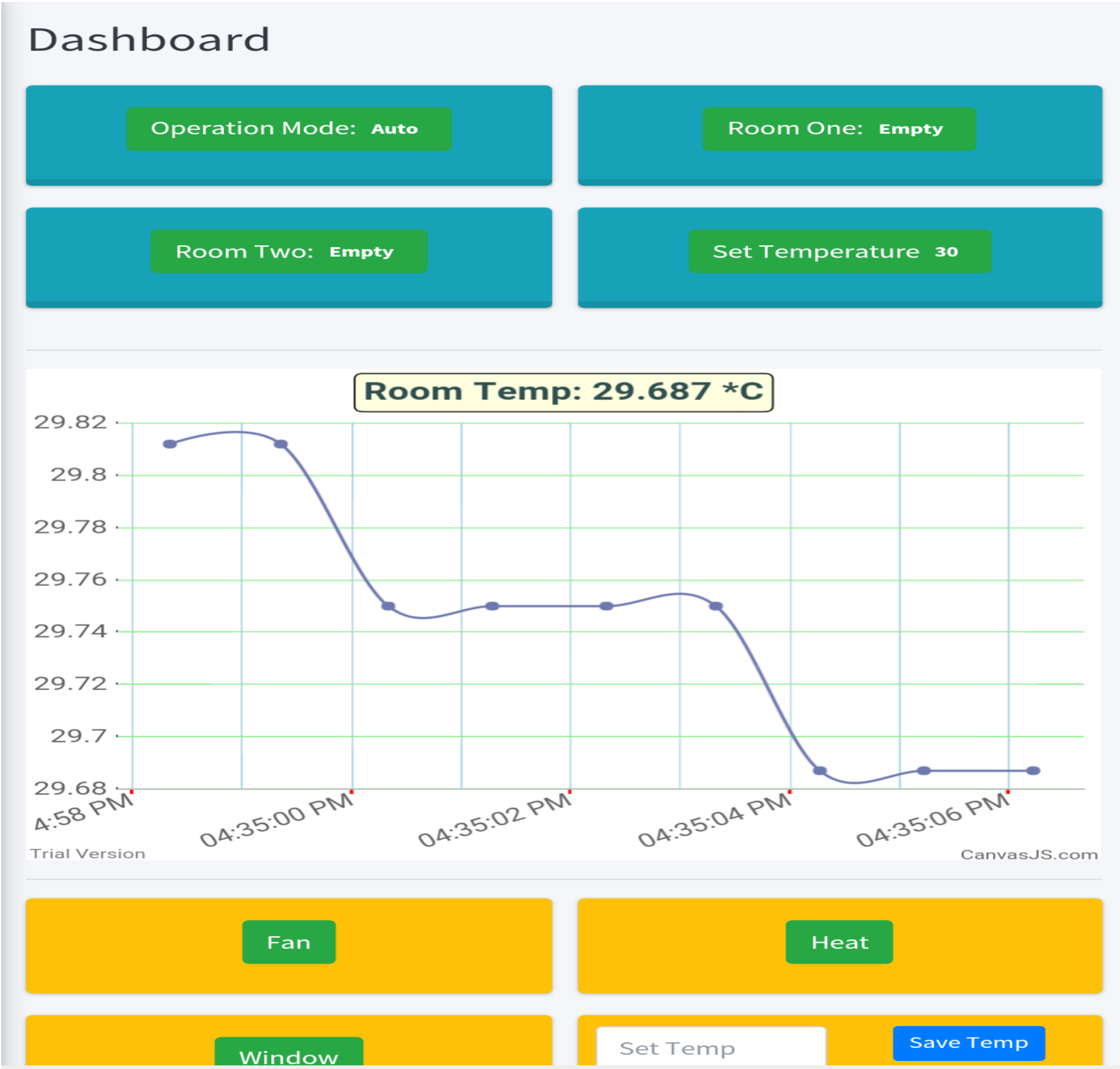

Fig. 4.1: A picture of the dashboard for the designed prototype working.

The dashboard, as seen in Fig. 4.1, has various icons to switch on the various devices. Clicking the FAN and HEAT will switch on the fan and heater respectively while clicking WINDOW will trigger the servo motor to open the window. SAVE TEMP is the icon to be clicked when temperature is being adjusted. It allows one to enter the values and save them for execution. The room temperature as displayed on the dashboard is 29.687 °C while the set temperature is 30°C.

From Figure 4.2, it is observed that the temperature was not steady. This was due to interference from the weather conditions outside. The blowing wind blew away some of the heat from the sun as well as bringing in some cold air into the room and that led to fluctuations in the temperature as detected by the temperature sensor and observed on the graph.

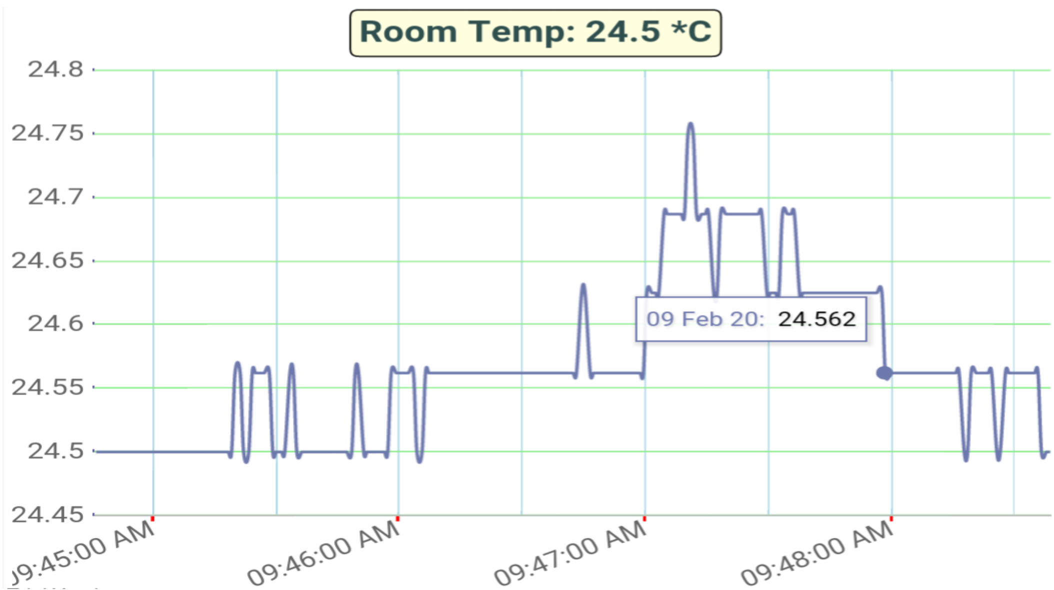

Fig. 4.2: Picture of a dashboard showing warming up of room by AC (windows and doors were open)

Experimental results showed that it took three and a half minutes (as shown in Figure 4.3) to raise the temperature of a room, under moderate weather conditions, whose volume was 9.6 m^3 by 4°C. The fan heater used has a power rating of 500 watts. If a fan with a rating of 1,000 watts would be used, then the expectation is that the time taken by the AC to warm up the room would reduce proportionately. The time taken by an AC and the power rating of the AC are inversely proportional. We can therefore use the obtained results to determine the approximate time it would take, under moderate conditions, to cool a particular room with this prototype smart AC.

From Figure 4.3, after proper sealing of the room, the temperature stabilized as seen in the system response graph. This showed that an AC works well in a properly insulated room.

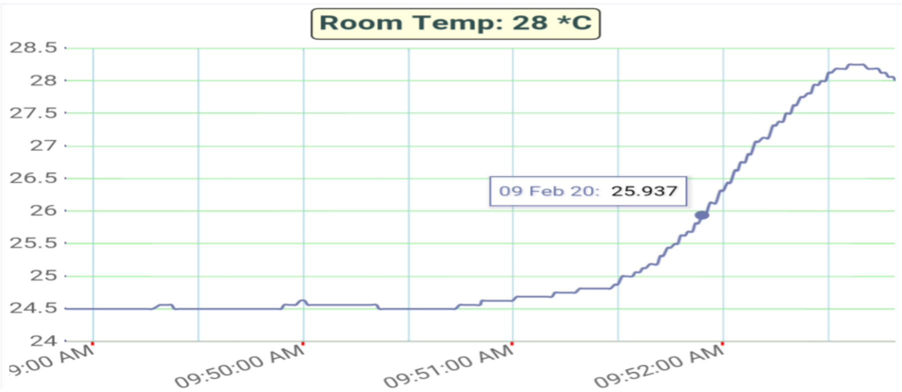

Fig. 4.3: a picture showing the warming up of a room (windows and doors were closed)

A closer look at the $3\frac{1}{2}$ minutes time taken by the system in raising the temperature of a room during experimentation by 4°C is actually considerate.

This can be proved by calculating the energy required (U_1) to warm up that room.

$$(U_1) = mc\Delta T \qquad (4.2)$$

Where: m – Mass of air in the room (ρV) ($\rho = 1.275\ kgm^{-3}$)

c – Specific heat capacity of air(c = 1.2 $kJkg^{-1}k^{-1}$)

ΔT – change in temperature

$U_1 = 1.2 \times 1275 \times 4 \times 2.4 \times 4$

$= 58{,}752 \pm 0.18\, J$

The energy (U_2) dissipated by the heater in the prototype AC can also be calculated

$$(U_2) = Power \times Time \tag{4.3}$$

$= 500 \times 3.5$

$= 105{,}000 \pm 0.014\, J$

The difference in the values can be accounted for in-terms of entropy based on the second law of thermodynamics which states that in any closed system, the entropy of the system will remain constant or increase (Boles *et al*., 2011)

The efficiency (E) of the prototype is given below

$$(E) = \frac{work\ output\ (U_1)}{work\ input (U_2)} \times 100\% \tag{4.4}$$

$$= \frac{58{,}752}{105{,}000} \times 100\%$$

$$= 55.95 \pm 0.65\ \%$$

Most of the existing systems have efficiencies ranging between 10.0 -17.0 with a few going as high as 23.45% (Yang *et al*., 2016). The expectation is that the higher the efficiency the more the energy consumption of the AC unit is reduced. That is to say high efficiency air conditioners drastically reduce energy costs.

The results can be used to approximate the time it would take the system when used in different rooms or even the time it would take to bring the room to a preset temperature.

In-case the temperature rises above the desired value, the cooling process begins automatically as shown in Figure 4.4

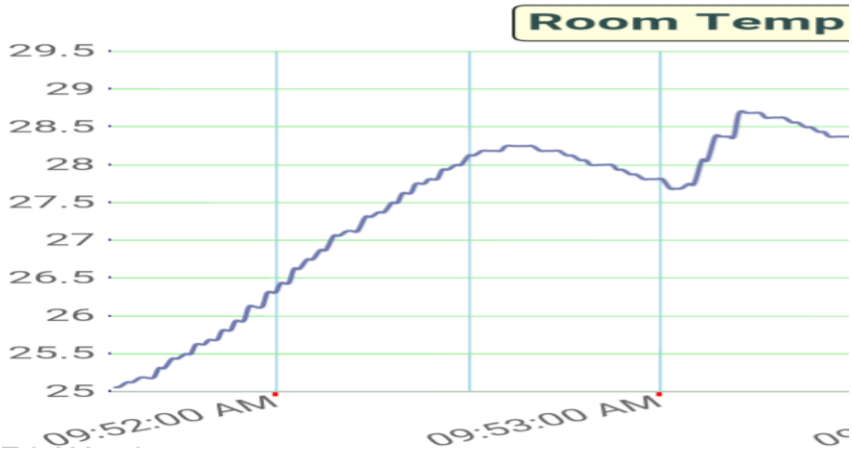

Figure 4.4: A picture showing the automatic start of the cooling process after the desired temperature has been attained

The prototype operates in the auto mode with an option of manual mode via a smart phone or a computer platform which still performs all the tasks as required. The system was able to detect room occupancy as shown in Figure 4.5 and Figure 4.6 and this enabled the system to respond appropriately in triggering the system.

Figure 4.5: Dashboard display of room occupancy in room two

Figure 4.6: Dashboard display of room occupancy in room one and room two

Figure 4.5 shows that only room two was occupied and Figure 4.6 shows that both rooms were occupied. This shows that room occupancy in any of the rooms can be determined independently and therefore the working of the AC in either of the rooms will not be affected by the other.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the findings of my research and the recommendations made towards improvement of the project.

The benefit of making ACs smart is to enable remote control rather than have manual control of them. Having them programmed so that they can accommodate our current schedule and lifestyle too would be an added advantage for convenience purposes (Chien and Lih, 2019). Of importance is energy conservation to save on bills creating the need to have not only smart but intelligent systems which will only run at the required times and this also means that its lifespan is enhanced. This research aimed at achieving energy conservation as well as automation of the AC system.

5.2 Cost analysis

The purchasing cost of an AC starts as low as Kshs. 50,000 with the smart ones going for as low as Kshs. 75,000 depending on their sizes. This research sought to achieve a smart AC for energy conservation purpose by developing a smart control unit which would reduce the running time of the ACs and hence reduce power consumption.

The cost of developing the smart control unit for the AC is Kshs. 26,000. Large scale production of these units would lower their production cost. Their integration in the smart AC systems would in turn increase their purchasing cost but the recurrent expenditure will be lowered at the end in that when the running time of the ACs is lowered, the operational costs reduce and hence significant savings are made. From the energy consumption perspective, the smart ACs with the intelligent control units will result to economical systems due to reduced operational costs and hence energy saving is achieved.

5.3 Conclusions

i) A smart air conditioner control system was designed and fabricated and it proved to be energy efficient in its working.

ii) The system is able to detect a person approaching a building and respond effectively.

iii) It is also able to detect room occupancy

iv) Temperature levels inside the room are detected by this system

v) The working of the system can be monitored online through an android app as well as a web platform in a computer

The main focus of intelligent air conditioners includes human comfort and energy conservation and should be evaluated by;

1. Human comfort

This is determined by the response of system during the specified time to attain the required temperature in indoor which is basically a numerical value that varies with climatic conditions. The response of this system is actually fast and therefore human comfort is assured.

2. Energy consumption

Switching ON of the system only when needed then back to sleep mode when not needed is a great way of conserving energy rather than having a system that runs all through. This was taken care of by having three sensors in the control of the intelligent prototype and these aids in energy conservation.

It would therefore be in order to conclude that implementation of this system would be a great boost in automation of air conditioners since we would have a system which would serve two purposes at the same time and a system which is cost effective both in operation and installation.

The efficiency of the prototype was found to be 55.95% which is higher than the 23.45% HVAC efficiency recorded so far. This shows that there is room for improvement on the existing systems to enhance energy conservation.

5.4 Recommendations

Several modifications can be made to this system to have a more advanced and more efficient system.

i. A camera can be introduced for face recognition at the entrance in place of the PIR thus enhancing security for home owners and prevent the system from being triggered by false signals like passers-by.

ii. Access to the system through its Wi-Fi is currently within the premises in which it has been installed. Any improvement to have it accessed at different places far from the area it is installed would increase its efficiency since, like in situations where it is used as a monitoring system, it can be used in different branches of the firm with centralized monitoring. This would also enable activation of the system even at a distance through the manual mode.

iii. The possibility of having other sensors on the system can still be explored to increase its utility. Example: we can have sensors to detect radiations emitted by the electronic components in buildings and hence raise alarm in case they rise above the recommended exposure.

iv. In line with covid-19 ministry of health protocols, a thermal gun can be installed at the entrance to monitor temperature of occupants entering the room. The system can be modified such that it can even open doors. If the temperature of the subject is above the recommended level it doesn't open the door.

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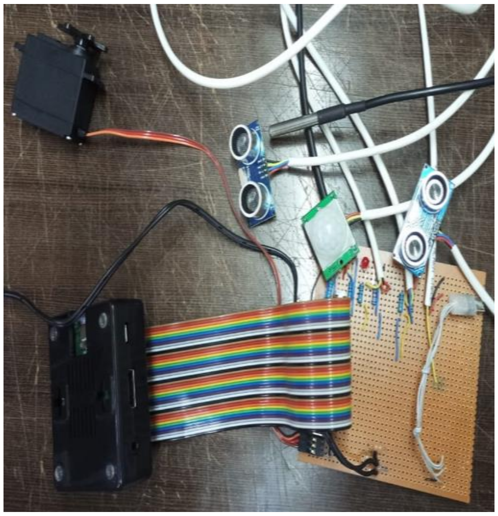
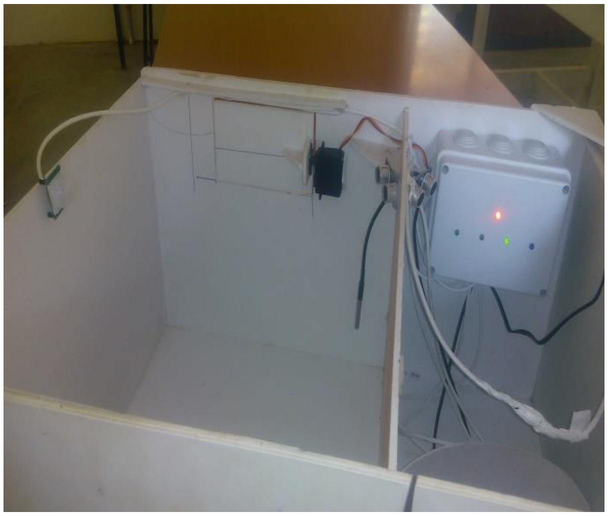
APPENDIX 1: Photos showing connections of various devices

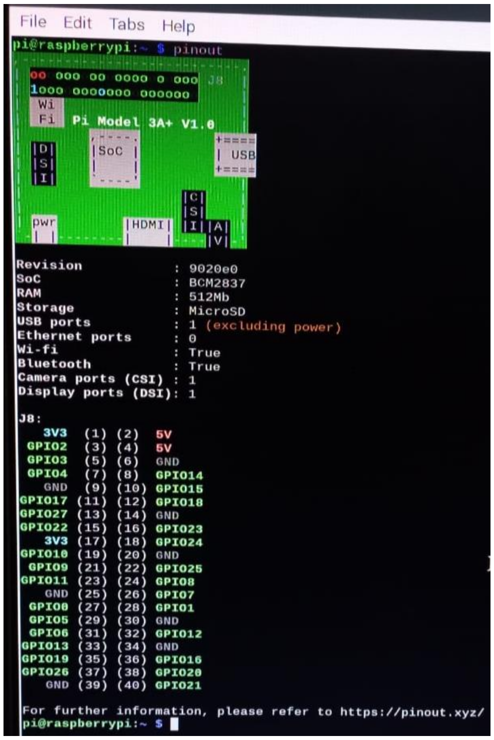


A picture showing the connection installed of the various components



A picture showing the prototype AC

A picture showing the wiring of system state LEDs



A picture showing access of the microcontroller via a computer for pin designation and programing

APPENDIX 2: Control programs

```
WebViewClientImpl - Notepad
File  Edit  Format  View  Help
package com.journaldev.webview;import android.app.Activity;import
android.content.Intent;import android.net.Uri;import
android.webkit.WebView;import android.webkit.WebViewClient;public class
WebViewClientImpl extends WebViewClient {    private Activity activity
= null;    public WebViewClientImpl(Activity activity) {
this.activity = activity;    }    @Override    public boolean
shouldOverrideUrlLoading(WebView webView, String url) {        if
(url.indexOf("192.168.43.102/dashboard/") > -1 ) return false;
Intent intent = new Intent(Intent.ACTION_VIEW, Uri.parse(url));
activity.startActivity(intent);        return true;    }}
```

Java code for web view of the system response

```
temperature_sensor_code - Notepad
File  Edit  Format  View  Help
# Import Librariesimport osimport globimport time # Initialize the GPIO Pinsos.system('modprobe w1-gpio')  # Turns on the GPIO
moduleos.system('modprobe w1-therm') # Turns on the Temperature module # Finds the correct device file that holds the temperature
database_dir = '/sys/bus/w1/devices/'device_folder = glob.glob(base_dir + '28*')[0]device_file = device_folder + '/w1_slave' # A
function that reads the sensors datadef read_temp_raw():  f = open(device_file, 'r') # Opens the temperature device file  lines =
f.readlines() # Returns the text  f.close()  return lines # Convert the value of the sensor into a temperaturedef read_temp():  lines
= read_temp_raw() # Read the temperature 'device file'   # While the first line does not contain 'YES', wait for 0.2s  # and then
read the device file again.  while lines[0].strip()[-3:] != 'YES':    time.sleep(0.2)    lines = read_temp_raw()   # Look for the
position of the '=' in the second line of the  # device file.  equals_pos = lines[1].find('t=')   # If the '=' is found, convert the
rest of the line after the  # '=' into degrees Celsius, then degrees Fahrenheit  if equals_pos != -1:    temp_string = lines[1]
[equals_pos+2:]    temp_c = float(temp_string) / 1000.0    temp_f = temp_c * 9.0 / 5.0 + 32.0    return temp_c, temp_f # Print out
the temperature until the program is stopped.while True:  print(read_temp())  time.sleep(1)
```

Temperature sensor code in python language servo - Notepad

File Edit Format View Help

```
import RPi.GPIO as GPIOimport timeservoPIN = 3GPIO.setmode(GPIO.BCM)
GPIO.setup(servoPIN, GPIO.OUT)p = GPIO.PWM(servoPIN, 50) # GPIO 17 for
PWM with 50Hzp.start(2.5) # Initializationtry:  while True:
p.ChangeDutyCycle(5)    time.sleep(0.5)    p.ChangeDutyCycle(7.5)
time.sleep(0.5)    p.ChangeDutyCycle(10)    time.sleep(0.5)
p.ChangeDutyCycle(12.5)    time.sleep(0.5)    p.ChangeDutyCycle(10)
time.sleep(0.5)    p.ChangeDutyCycle(7.5)    time.sleep(0.5)
p.ChangeDutyCycle(5)    time.sleep(0.5)    p.ChangeDutyCycle(2.5)
time.sleep(0.5)    p.start(0)except KeyboardInterrupt:  p.stop()
GPIO.cleanup()p.stop()
```

The servo motor code in python

ultrasonic_distance - Notepad

File Edit Format View Help

```
#Librariesimport RPi.GPIO as GPIOimport time #GPIO Mode (BOARD / BCM)
GPIO.setmode(GPIO.BCM) #set GPIO PinsGPIO_TRIGGER = 22GPIO_ECHO =  24
#set GPIO direction (IN / OUT)GPIO.setup(GPIO_TRIGGER, GPIO.OUT)
GPIO.setup(GPIO_ECHO, GPIO.IN) def distance():    # set Trigger to HIGH
   GPIO.output(GPIO_TRIGGER, True)     # set Trigger after 0.01ms to
LOW    time.sleep(0.00001)    GPIO.output(GPIO_TRIGGER, False)
StartTime = time.time()    StopTime = time.time()     # save StartTime
  while GPIO.input(GPIO_ECHO) == 0:        StartTime = time.time()
# save time of arrival    while GPIO.input(GPIO_ECHO) == 1:
StopTime = time.time()     # time difference between start and arrival
  TimeElapsed = StopTime - StartTime    # multiply with the sonic speed
(34300 cm/s)    # and divide by 2, because there and back    distance =
(TimeElapsed * 34300) / 2     return distance if __name__ ==
'__main__':    try:        while True:            dist = distance()
       print ("Measured Distance = %.1f cm" % dist)
time.sleep(1)         # Reset by pressing CTRL + C    except
KeyboardInterrupt:        print("Measurement stopped by User")
GPIO.cleanup()
```

The ultrasonic sensor code in python

FINAL - Notepad

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```
#Librariesimport RPi.GPIO as GPIOimport timeimport osimport globimport threadingfrom multiprocessing import Queuefrom flask import
requestfrom flask_cors import CORS , cross_origin#GPIO Mode (BOARD / BCM)GPIO.setmode(GPIO.BCM)#set GPIO Pins for ultrason Sensor 1
Room1P = 0GPIO_TRIGGER = 18GPIO_ECHO =  24#set GPIO Pins for ultrason Sensor 2Room2P = 0GPIO_TRIGGER1 = 15GPIO_ECHO1 =  23 #set GPIO
direction (IN / OUT)GPIO.setup(GPIO_TRIGGER, GPIO.OUT)GPIO.setup(GPIO_ECHO, GPIO.IN)GPIO.setup(GPIO_TRIGGER1, GPIO.OUT)GPIO.setup
(GPIO_ECHO1, GPIO.IN)#FAN = 16 #G3FAN = 16pwrc = 0GPIO.setmode(GPIO.BCM)GPIO.setup(FAN,GPIO.OUT)#HEAT_LOW = 20 #G2HEAT_LOW = 20pwrh1
= 0GPIO.setmode(GPIO.BCM)GPIO.setup(HEAT_LOW,GPIO.OUT)#HEAT_HIGH = 21 #G1HEAT_HIGH = 21pwrh2 = 0GPIO.setmode(GPIO.BCM)GPIO.setup
(HEAT_HIGH,GPIO.OUT)#WHATCHDOG BLUE LEDLED = 12GPIO.setmode(GPIO.BCM)GPIO.setup(LED,GPIO.OUT)#MOTION SENSORPIR = 17activate = 0
Run_Sys = 0StartT = 0StopT = 0GPIO.setmode(GPIO.BCM)GPIO.setup(PIR, GPIO.IN) #PIR# Initialize the GPIO Pins for tempos.system
('modprobe w1-gpio')  # Turns on the GPIO moduleos.system('modprobe w1-therm') # Turns on the Temperature module # Finds the correct
device file that holds the temperature database_dir = '/sys/bus/w1/devices/'device_folder = glob.glob(base_dir + '28*')[0]device_file
= device_folder + '/w1_slave'servoPIN = 3new_angle = 0GPIO.setmode(GPIO.BCM)GPIO.setup(servoPIN, GPIO.OUT)p = GPIO.PWM(servoPIN, 50)
# GPIO 3 for PWM with 50Hzp.start(2.5) # InitializationState = 1Set_temp = 26pwrc = 0pwrh1 = 0pwrh2 = 0def cool(pwrc):    if pwrc:
    print("FAN ON")        GPIO.output(FAN,True)     else:        print("FAN OFF")        GPIO.output(FAN,False)     return FANdef
warm(pwrh1):    if pwrh1:        print("HEAT_LOW ON")        GPIO.output(HEAT_LOW ,True)    else:        print("HEAT_LOW OFF")
GPIO.output(HEAT_LOW ,False)    return HEAT_LOWdef heatT(pwrh2):    if pwrh2:        print("HEAT_HIGH ON")        GPIO.output
(HEAT_HIGH,True)    else:        print("HEAT_HIGH OFF")        GPIO.output(HEAT_HIGH,False)    return HEAT_HIGHdef blink(LED):
GPIO.output(LED,True)    time.sleep(0.5)    GPIO.output(LED,False)    time.sleep(0.5)    return LEDdef detectMotion(PIR):
time.sleep(0.02) # to stabilize sensor    if GPIO.input(PIR):        # print("Motion Detected...")        time.sleep(0.02) #to avoid
multiple detection        return True    else :        #print("No Motion Detected...")        time.sleep(0.01) #loop delay, should be
less than detection delay        return Falsedef moveServo(dir):    if dir:        p.ChangeDutyCycle(7.5)        time.sleep(0.01)
else:        p.ChangeDutyCycle(2.5)        time.sleep(0.01)        return Truedef distance(GPIO_TRIGGER,GPIO_ECHO):    # set Trigger
to HIGH    GPIO.output(GPIO_TRIGGER, True)    # set Trigger after 0.01ms to LOW    time.sleep(0.00001)    GPIO.output(GPIO_TRIGGER,
False)    StartTime = time.time()    StopTime = time.time()    # save StartTime    while GPIO.input(GPIO_ECHO) == 0:
StartTime = time.time()    # save time of arrival    while GPIO.input(GPIO_ECHO) == 1:        StopTime = time.time()    # time
difference between start and arrival    TimeElapsed = StopTime - StartTime    # multiply with the sonic speed (34300 cm/s)    # and
divide by 2, because there and back    distance = (TimeElapsed * 34300) / 2    return distance# A function that reads the sensors
datadef read_temp_raw():  f = open(device_file, 'r') # Opens the temperature device file  lines = f.readlines() # Returns the text
f.close()  return lines # Convert the value of the sensor into a temperaturedef read_temp(pir):  lines = read_temp_raw() # Read the
temperature 'device file'   # While the first line does not contain 'YES', wait for 0.2s  # and then read the device file again.
while lines[0].strip()[-3:] != 'YES':    time.sleep(0.2)    lines = read_temp_raw()  # Look for the position of the '=' in the
```

Part of the Main control code