UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

Title: Development of A Smart Monitoring System for Rwandan Hospitals Cold Rooms.

(case study: King Faisal Hospital)

By:

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by:

Dr. Alexander NGENZI

Dr. Kizito NKURIKIYEYEZU

DECLARATION

I, Alice UWONKUNDA declare that this dissertation entitled “Development of a Smart Monitoring System for Rwandan Hospital Cold Rooms, a Case Study of King Faisal Hospital” is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

UNIVERSITY of RWANDA

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Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

CERTIFICATE

This is to certify that the project entitled **"Development of a Smart Monitoring System for Rwandan Hospital Cold Rooms, a case study of King Faisal Hospital"** is a record of original work done by Alice UWONKUNDA, reference number: 220020272, a MSc. Degree student in Biomedical Engineering.

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ACKNOWLEDGMENTS

I want to thank my Supervisors Dr. Alexander NGENZI and Dr. Kizito NKURIKIYEYEZU for the great work done during my research. Your guidance, contribution, input, and corrections were of great value. I appreciate your cooperation and contribution.

I would like to thank the East African Regional Center of Excellence in Biomedical Engineering and E-Health (CEBE) for initiating this great program. The program will benefit Biomedical Engineering in Rwanda greatly, and quality health care will be available to all of us.

I sincerely appreciate the University of Rwanda for hosting this program. The knowledge gained will help us to improve biomedical Engineering, especially in Rwanda.

I am grateful to King Faisal Hospital for allowing me to research in the hospital's cold room.

I thank my classmates for their wonderful cooperation during this journey. Your support and encouragement were of great significance.

ABSTRACT

Medicine and vaccines are the most important parts of disease treatment and prevention. Some temperature-sensitive medicines and vaccines must be stored in cold rooms under the WHO's recommended range of 2°C and 8°C. Because of a failure to have effective and well-monitored medicine systems, medicines lose their quality and efficacy, causing people to die and negatively impacting the economies of individuals and the country as a whole. Presently, these medicines and vaccines are monitored manually in Rwandan hospitals, for instance, King Faisal Hospital, which is untrustworthy and makes it impossible to know if their effectiveness has been negatively impacted by the time they are implanted into individuals. This study aimed to develop a smart monitoring system using IoT technology for cold rooms in Rwandan hospitals to store temperature-sensitive medicines and vaccines within the recommended range. The qualitative method was used to gather information about the cold room systems currently used at King Faisal Hospital. It required improvements to rapidly explore concepts and develop a smart monitoring system for the cold room storage of medicines and vaccines. The content analysis method was used to analyze the collected data. The study found that there are currently no remote monitoring systems and that stored medical products were damaged due to abnormal environmental temperatures and humidity.

A prototype was created using microcontroller units, sensors, GSM, wireless communication technology, a relay module, and a user interface. The results demonstrated that the prototype can collect data, send it to a cloud-hosted database, display real-time data on the LCD, and send an SMS to the cold room's operator in the event of an abnormal value. The main contribution of this work is that the staff remotely monitors the cold room of medicines and vaccines rather than manually using thermometers, which presents some challenges in minimizing medicine quality loss. The designed system relied on only three parameters to detect the status of a cold room, even though many factors influence the quality of medicines. As a result, future researchers will investigate other environmental factors that can cause medicines stored in cold rooms to lose their quality.

Keywords: Development, Smart Monitoring System, Hospitals, Cold Rooms.

LIST OF ACRONYMS

RFID: Radio Frequency Identification

API: Application Programming Interface

IDE: Integrated Development Environment

FDA: Food and Drug Administration.

GPRS: General Packet Radio Services

GSM: Global System for Mobile Communications

HTML5: Hypertext Markup Language revision

HTTP: Hypertext Transfer Protocol

IoT: Internet of Things

KFH: King Faisal Hospital

LCD: Liquid Crystal Display

LDR: Light Dependent Resistor

MATLAB: Matrix Laboratory

MCU: microcontroller unit

I/O: Input/ Output

MQTT: Message Queuing Telemetry Transport

RTM: Real-Time Monitoring

SIM: Subscriber Identity Module

SMS: Short Message Service

UML: Unified Modeling Language

WHO: World Health Organization

Wi-Fi: Wireless Fidelity

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

Medicines and vaccines are important for preventing and treating different diseases [1]. However, their success is dependent on well-monitored cold storage, which keeps medicines and vaccines within the World Health Organization's recommended temperature range of 2 to 8 degrees Celsius from the time they are manufactured to the time they are given. So, health facilities are required to maintain cold storage to ensure that temperature-sensitive medicines and vaccines reach consumers in good quality. Various environmental parameters, such as temperature, humidity, and light, must be strongly monitored regularly. Failure to do so will result in the loss of medicine potency, which may result in an increased disease burden, higher medical costs for patients, and a waste of supplies [2]. Temperature variations in cold rooms for drugs and vaccines are common in both developed and developing countries, according to several studies [3]. It has been discovered that 37% of vaccines in low-income countries are exposed to temperatures that are outside of the acceptable range, making this an important issue to address [4]. In a survey that was also performed in the cold room of the KFH located in Kigali, Rwanda, some problems with the cold room's functioning were observed, like the temperature and humidity becoming out of range, which leads medicines to lose their quality. They still use the thermometer to detect the temperature inside the cold room, and there is also no real-time system to monitor the storage, especially during the holidays.

These convincing guidelines of the FDA and surveys taken indicate that medicines or vaccines may become damaged due to the inability to track the environmental parameters (temperature, humidity, light, and so on) at the right time. To combat product loss, a smart monitoring system for pharmacy cold rooms is being developed to track environmental parameters such as temperature, humidity, and light intensity.

The pharmaceutical cold room is a type of refrigeration chamber or insulated space designed to maintain an artificially generated temperature or range of temperatures. It is generally designed for storing pharmaceutical products like medicines and vaccines in an environment below the outside temperature.

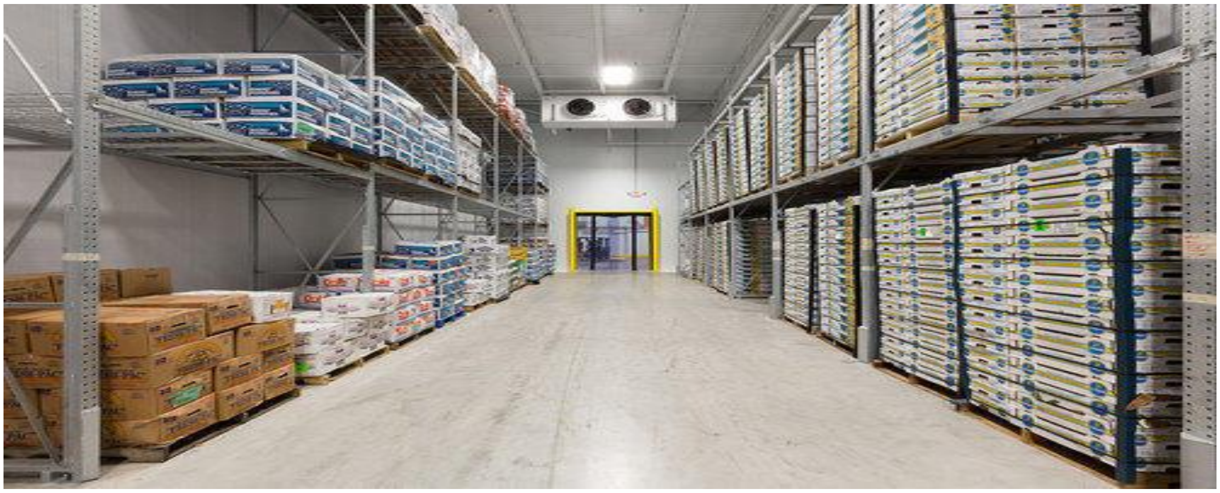


Figure 1.1: cold room

The cold room contains an air conditioner that exchanges hot air for cold air. It consists of four main parts: a refrigerant compressor that compresses the refrigerant into the system, a condenser that removes warm air to the outside, an expansion valve that changes the state from hot refrigerant to cold refrigerant, and an evaporator that generates cool air on the inside [5]. The developed system for monitoring the cold storage of medicines and vaccines is shown below.

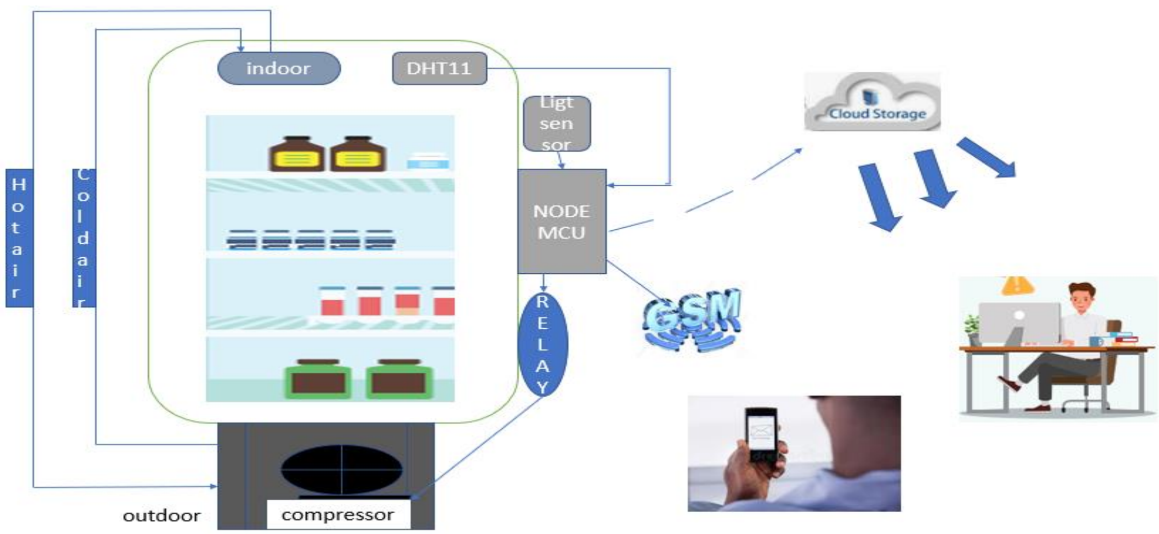


Figure 2.1: Proposed Cold room monitoring system

The temperature and humidity (DHT 11) sensor will be connected to the microcontroller to sense a degree of coldness and heat. In this case, if the microcontroller detects that the temperature or humidity has reached the set upper or lower limit, it either stops or runs the compressor by turning on or off the relay module. If the temperature and humidity continue to be abnormal after the compressor is turned on or off, or if there is light in the room, then the device sends the message to the pharmacist or technician’s mobile phone using GSM. An online web application is used to help Cold Room operators retrieve the stored data at any time and from anywhere by using any user interface machine. The system also saves the current state of internal temperature to the cloud, which you can access or save for later use. In this project, the algorithms used are usually smaller and faster for IoT-based software implementation according to the existing system.

The above project can transform people's lives by significantly increasing the perseverance of healthcare systems, saving limited resources, and providing access to life-saving treatment methods.

1.2 Problem statement

In the cold room, many factors such as heat, air, light, and moisture can damage medicines due to the inability to measure vital ambient environmental parameters. Moreover, keeping medicines in inappropriate temperature and humidity conditions may cause medicines and vaccines to lose their potency, which may lead to an increased disease burden, higher medical costs for patients, and the waste of supplies. Medicine control is manual and ineffective; cold room operators are required to monitor temperature and humidity with a thermometer at least twice a day, which is unfair, especially during holidays. So, it is difficult to know whether a drug's effectiveness has been compromised by the time it reaches the patient, resulting in unnecessary deaths and medical expenses. To overcome this problem, a real-time monitoring system is proposed and developed that will track environmental parameters such as temperature, humidity, and light intensity to help cold room operators monitor the room wherever they are, which will reduce the number of medicines that can lose their quality and efficacy.

1.3 Research Hypotheses

An IoT solution can be developed to address the current challenges in cold room storage, resulting in improved drug efficacy, reduced drug waste, and ultimately, the saving of lives and significant cost savings.

1.4 Research Questions

- How to reduce the loss rate of medicines in the cold room?
- What are the primary environmental parameters that should be computed?

- How to facilitate personnel to take timely necessary action according to medicines status in cold storage?
- What is the way of reducing human error and the possible loss of the manually filled form?
- How the power energy should be saved in a cold room?

1.5 Objectives

1.5.1 General Objective

The main objective of this system is to track the environmental parameters of the cold room continuously as well as communicate with the cold room operators to obtain the current changes in these parameters, such as temperature, humidity, and light intensity.

1.5.2 Specific Objectives

- To collect, analyze, and compute the temperature, humidity, and intensity of light.
- To send the message to the cold room operator when the temperature or humidity has reached the set upper or lower limit.
- To visualize temperature, humidity, and light intensity values in an online web application called ThingSpeak.
- To start or stop the compressor when the measurement value is above or below the limit value.
- To store the processed data in ThingSpeak storage for future use.

1.6 Study Scope

This study was conducted to develop a prototype of a smart remote monitoring system for the efficient storage of temperature-sensitive medicines and vaccines in cold rooms. Therefore, it will be based in Rwandan hospitals' cold rooms and mainly focus on the KFH's cold room. The system can record medicines and vaccines' temperatures (between 2 and 8 degrees Celsius), humidity, and light intensity inside a cold room, send the recorded values to an online platform for remote monitoring, and notify end users whenever the temperature and humidity go above or below the recommended range.

1.7 Significance of the Study

After this research, the system is of great significance to the KFH and other organizations with cold rooms because it will facilitate their ability to get the real-time status of medicines from anywhere at any time and minimize the number of medicines damaged due to uncontrolled environmental parameters at the right time. It also minimizes the human effort for manual monitoring and saves time. This system will also save money on energy by controlling the working of the compressor. Following the implementation of this system, patients benefited from this research by receiving high-quality medications.

1.8 Research Organization

This study is organized as follows: Chapter One presents a general introduction, which contains the introduction of the study, the problem statement, the research questions, the objectives (general and specific objectives), the study scope, the significance of the study, the organization of the study, and the summary. In chapter two, the existing literature, the gaps in this literature, and how to solve them are presented. Next, the research process and research design method that is used in the implementation of the project are summarized in chapter three. Chapter four discusses system implementation, chapter five represents project results and analysis. Finally, the conclusion and recommendations of this study are provided in Chapter 6.

1.9 Summary

The above chapter gives a general introduction to the developed system. It shows the background and problem of the developed system, the objectives, and the significance and organization of the research. The developed system is an IoT project that controls the temperature, humidity, and light intensity in the cold room according to the WHO recommended range. In addition, it helps the personnel receive the message in case of emergency issues and visualize the current value of these parameters remotely.

CHAPTER 2. STATE OF THE ART

2.1 Introduction

This chapter discusses related works, identifies limitations, and proposes contributions for incorporating them for efficient monitoring of medicines and vaccines using IoT. This chapter provides an overview of the research area's background. This chapter presents related work. The similarities and differences between conferences and journal papers are also discussed. Some of the parameters, technologies, and materials that previous researchers did not consider are highlighted, and our scientific contributions are identified.

Many research projects have been undertaken over the years to develop online, web-based, and mobile-based applications that can aid in increasing drug coverage and controlling the cold room. Most of the mobile applications created are mainly responsible for collecting information on drug coverage in difficult-to-reach areas of developing countries [6]. Additionally, some researchers focused on only monitoring the temperature parameter in a cold room, while other parameters such as humidity and light were completely ignored.

2.2 current system used in KFH cold room

According to a survey, the cold room contains an air conditioner that exchanges hot air for cold air. The digital thermometer is put inside the room to detect the temperature inside the cold room and then displays the result on the LCD. The cold room operators have regular tasks to enter the cold room at least twice per day to check the environment parameters, such as temperature and humidity, and then record the information for future use. In this case, they do not have a reliable real-time system that they use to monitor the cold room remotely. This means they are not able to monitor their cold room remotely without having someone physically check on the above-mentioned devices.

2.3. Existing cold room monitoring system

Regarding the cold room monitoring shown in this part, a great deal of work has been done by different researchers. However, there is a study gap in the area of real-time environmental parameter monitoring in a cold room, and research is needed in this area to reduce the quality loss of pharmaceuticals and vaccines in a cold room. The contribution of the researchers regarding real-time monitoring of environmental factors that affect the quality of medicines and vaccines in cold rooms is described herein. Their gaps and how to overcome them are presented here.

The Kenya team conducted and implemented research to determine whether using remote temperature monitoring (RTM) devices, as well as a structured problem-solving and action-oriented data utilization strategy, will aid in vaccine management. As part of the system, over 50 vaccine fridges were built across 18 sub-country vaccine storage facilities and 18 high-volume health facilities. When the temperature went above or below the recommended temperature range for the vaccine, the system devices sent an SMS alert to the employees [5].

Xiuying et al. [7] built a temperature and humidity monitoring system for small cold storage of fruits and vegetables using Arduino. Moreover, it is shown as a system that can manage the status of the cold room, including temperature and humidity, and do so with remote control access. In addition, the data collected by the temperature and humidity sensor can be sent to the main control board and then uploaded to the Internet of Things platform, which displays the curve of the output. As a result, it can display the change in environmental temperature and humidity on the terminal display in real time and output the digital signal.

Sergio et al. [8] designed a smart cold chain system based on the Internet of Things that uses 2G-RFID-Sys temperature monitoring in the medicine cold chain to address medical challenges Cold chain management is related to temperature monitoring. They observed that combining RTM technology with a structured data review procedure carried out by a management team is an efficient way of improving cold chain outcomes.

Asif et al. [9] presented an IoT system to monitor food storage humidity and temperature. It was developed to mitigate manual monitoring and to develop an internet-based, real-time temperature and humidity monitoring system using sensors and a microcontroller. Furthermore, the sensor detects the temperature and humidity in the storage and sends them to the microcontroller to be processed, then sends them to the cloud platform to be visualized by the administrator anywhere and anytime.

Alinafe et al. [10] designed and implemented a real-time, web-based temperature monitoring system for cold chain management to monitor both fixed and mobile cold chains. This system has demonstrated huge potential for tackling issues that arise due to poor monitoring solutions. It allowed users to log in at any time, anywhere, to check the condition of their assets.

Monitoring of the Medication Distribution and the Refrigeration Temperature in a Pharmacy-Based on the Internet of Things (IoT), technology was designed to monitor a pharmacy store. The method was based on electronic sensors connected to an Intel Galileo board to perform a medication search and control the refrigeration temperature within pharmacy shelves. The temperature of the room was sensed, and the relay was triggered for the fan motor to be on, and its speed was controlled to obtain a preset temperature. The cloud also provides the room temperature report, allowing the manager to access and monitor data remotely [11].

Flávio et.al [12] presented a system called a Low-Cost Temperature and Humidity Monitoring System in Hospital Ambiance. It was proposed to check and show the climatic variances of the hospital's ambiance continuously. The project was built in two stages, the first one contemplating the prototype development (hardware and software) and the second including the data collection. For the hardware development, the Arduino was used, which is an open platform for electronic prototyping with a microcontroller whose simple interface allows information acquisition and device control.

The Department of Immunization, Vaccines, and Biologicals has released a document developed by the Expanded Programme on Immunization that explains how to monitor temperatures in the vaccine supply chain in the World Health Organization (WHO) Management Handbook [13]. Among the methods described is the use of an electronic freeze indicator, a small device placed with freeze-sensitive vaccines during transportation. It has a visual display that indicates whether it has been exposed to cold temperatures.

Rajani et al. [14] proposed an Internet of Things-based blockchain for temperature monitoring and counterfeit pharmaceutical prevention. Their primary focus was on improving traditional blockchain systems to make them suitable for IoT-based supply chain management, with a secondary focus on leveraging these new promising technologies to enable a viable smart healthcare ecosystem via a drug supply chain.

2.4 Summary of identified weaknesses and the scientific contribution of the developed system

Medicines and vaccines have been monitored using various techniques, according to the above-mentioned literature. However, weaknesses have been identified, and this research makes a scientific contribution to improving the cold room system.

2.4.1 summary of existing systems and gaps identified

After reviewing and analyzing the literature, the table below summarizes the existing systems for displaying the authors, topic, techniques, methods, and identified gaps.

Table 1.2: summary of existing systems

S/N	Authors	Topic	Techniques	Method	Gaps
1	Sergio et. al	A novel deployment of a smart Cold Chain system using 2G-RFID-Sys temperature monitoring in medicine Cold Chain based on the Internet of Things.	RFID application model named 2G-RFIDSys.	Conducted a literature survey on temperature monitoring in the medicine Cold Chain then developed of conceptual model.	No carrying out: a field study to validate the conceptual model qualitatively in the medicine and vaccine Cold Chains.
2	Xiuying et al.	Design and implementation of temperature and humidity monitoring system for small cold storage of fruit and vegetables based on Arduino.	IoT technology	This paper designed an Arduino-based temperature and humidity monitoring system.	Ignores other important environmental parameters that can affect cold storage. A slow response time, which is not good for monitoring the cold room for medications
3	Asif et al.	Monitoring food storage humidity and temperature data using IoT.	IoT	The connection between the microcontroller and the temperature sensor was done using conventional methods.	Other essential ecological variables that can affect cold storage are ignored.
4	Flávio et al.	Low-Cost Temperature and Humidity Monitoring System in Hospital Ambience	IoT	Data collection and prototype development.	The system was designed to monitor only two environmental variables (temperature, and humidity) which are insufficient to monitor the status of the

					cold room. In areas with no internet connectivity, the method of notifying staff in the case of an emergency is unfavorable.
5	Elie et al.	Monitoring of the Medication Distribution and the Refrigeration Temperature in a Pharmacy based on Internet of Things (IoT) Technology.	IoT	Made a connection between the microcontroller and sensors (prototype).	The system was only concerned with temperature, which is not the only environmental variable that can affect medicines.
6	Rajani et al.	Internet of Things-Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention.	Blockchain and IoT technology.	->Building a scalable and high throughput blockchain distribution network. ->Building an Internet of Things (IoT) and blockchain-based supply.	It is expensive and has no mechanism to control the working of the compressor.

After reviewing and analyzing the literature, the smart monitoring system is proposed to overcome the existing challenges. The following table describes a comparison of existing cold room monitoring solutions and the developed system based on technology, purpose, parameters controlled, notification process, cost, and energy savings.

Table 2.2:comparison of existing systems and developed system

S/N	Topic	Purpose	Temperature	Humidity	Light.	Web app	Notify (GSM)	Saving energy (compressor control)	Cost (cheap)
1	Temperature and humidity monitoring system for small cold storage of fruit and vegetable-based on Arduino	manage the status of the cold room including temperature and humidity	✓	✓	x	✓	x	x	✓
2	IoT system to monitor food storage humidity and temperature	to mitigate the man monitoring and to develop an internet-based real-time temperature and humidity monitoring	✓	✓	x	✓	✓	x	x
3	Monitoring of the Medication Distribution and the Refrigeration	designed to monitor a pharmacy store	✓	✓	x	✓	✓	x	x

	Temperature in a Pharmacy based on Internet of Things (IoT) Technology								
4	Smart Cold Chain system using 2G-RFID-Sys temperature monitoring in medicine Cold Chain based on the Internet of Things	to address challenges of the medicine Cold Chain related to temperature monitoring	✓	x	x	✓	✓	x	x
5	Internet of Things-Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceu	Improving traditional blockchain systems to make them suitable for IoT-based supply chain management	✓	x	x	✓	✓	x	x

	tical Prevention								
6	Low-cost temperature and humidity monitoring System in hospital ambiance	to check and show the climatic variances of the hospital's ambiance continuously.	✓	✓	x	✓	✓	x	✓
7	Developed system	To create a low-cost remote monitoring system for the cold room to reduce the number of drugs that lose their quality.	✓	✓	✓	✓	✓	✓	✓

2.4.2 Scientific contribution of the developed system

Cold storage is an effective strategy for preserving the quality of medicines and vaccines. The main concern here is to perform real-time monitoring of environmental parameters (temperature, humidity, and light) inside the cold room to reduce the loss of quality of medicines and vaccines and alert personnel. Moreover, the system is made of low-cost hardware components, resulting in an affordable solution for Rwandan hospital cold rooms. It also controls the working of the compressor by turning it on or off when the temperature becomes abnormal to save energy. In addition, the developed system sends an automatic SMS to staff when these parameters reach dangerous limits, allowing them to take the necessary action to prevent the loss of medicines and save time.

2.3 Summary

The above chapter gives an overview of related research. It includes the previous researchers' investigation of the problem, the suggested technical solution, the methodology used, and the results discovered. Eventually, gaps in earlier similar and related research were identified, which provided justification and motivation for the current study. The developed system is a low-cost remote monitoring system to monitor the cold room of medicines and vaccines to address the existing gaps.

CHAPTER 3. RESEARCH METHODOLOGY

In this chapter, the methods and approaches used to conduct the study are outlined. This includes the steps undertaken to complete the study, the system design methodology, and the methods used in data collection, and analysis.

3.1 Research Process

The below diagram provides an overview of the steps involved in research and system development, from idea generation to prototype development and results.

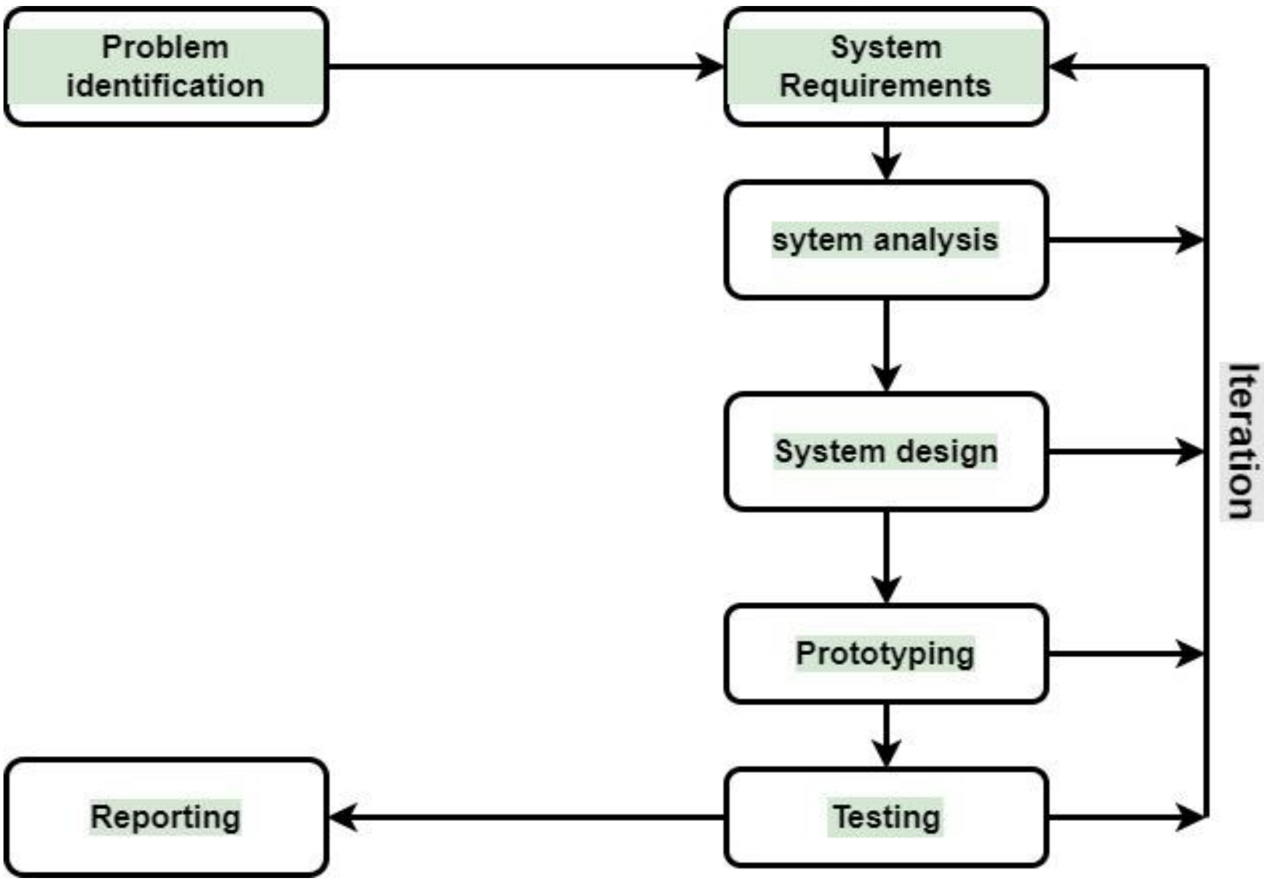


Figure 3.1: Research process

To begin, the idea generation and problem statement for this research deviated from a field survey and a review of the literature to identify the problems and limitations of previous works. I proposed a system to address the gaps after analyzing the existing system and identifying the gaps. Second, I set the requirements and created the system architecture, flowcharts, and algorithms for the developed system. Finally, I built a prototype and tested it in KFH's cold room to see if it met the requirements.

3.2 Research Design Method

3.2.1 Data collection

In this study, qualitative research was used with primary and secondary data from the existing cold room monitoring system. The goal was to investigate the existing system and identify its strengths and weaknesses to improve it using technology.

3.2.1.1 Primary data

During this phase, the questionnaire and interviews were used to gather primary data, and the questionnaire was given to the King Faisal Hospital's chosen pharmacy director or biomedical technician who could accurately report on the monitoring of cold room conditions in their respective storage to gather sufficient information about how existing cold room monitoring systems are used, their challenges, and the improvements that are required.

3.2.1.2 Secondary data

In this research, previous records on temperature were collected for analysis and comparison with the recommended acceptable limits. Documentary reviews on other reports and publications about the same topic or related subject were consulted to collect useful information for gaining an understanding of the existing research and debates relevant to a particular topic or area of study and to present that knowledge in the form of a developing system.

3.2.2 Location of the study

King Faisal Hospital's cold room was the study area.

3.2.3 Target and study population

The study's population was divided into two groups. The first group of study participants was biomedical technicians. Biomedical technicians are full-time hospital employees who maintain cold rooms. Cold-room operators were the second target audience.

3.2.4 Ethical consideration

I received a recommendation letter from the College of Science and Technology/Regional Center of Excellence in Biomedical Engineering and e-Health, which helped me to apply for approval of KFH's IRB. This approval helped me to be able to conduct research in any hospital's department.

To approach my respondents, I assured them that the information gathered would be used only for this research and that their participation was entirely voluntary.

3.2.5 Data analysis

Different questions were set to collect information on monitoring tools and cold room equipment. Each question had a Yes/No option and a space to provide additional information if any. The content analysis method is used to analyze the collected data. Therefore, the data obtained showed that 2–8 degrees Celsius is the temperature range that is recommended by the WHO in cold rooms for the storage of medicines and vaccines. The recommended humidity range is between 50 and 70%. Temperatures become abnormal during the day, and stored medical products are damaged due to abnormal environmental temperatures and humidity. I also discovered that the cold rooms where medicines and vaccines are stored have built-in thermometers with a display that provides current temperature readings. So, there is no remote monitoring system used to control the cold room.

3.2.6 System prototype design and development

Regarding the assessment of cold room operators' needs, the next step was to design and develop a prototype in which both physical and logical components required for the overall system's proper functioning were simulated, and developed, to produce a complete cold room IoT remote monitoring system using IoT technology.

3.2.6.1 Components of the proposed system

To design and create the prototype, various hardware and software tools such as NodeMCU, temperature and humidity sensor (DHT11), LDR light sensor, relay module, LCD, PCB prototype board, buzzer, GSM SIM 800 L, resistors, and LED, Arduino IDE, proteus, ThingSpeak were used. The block diagram below depicts the interconnection of the system's components.

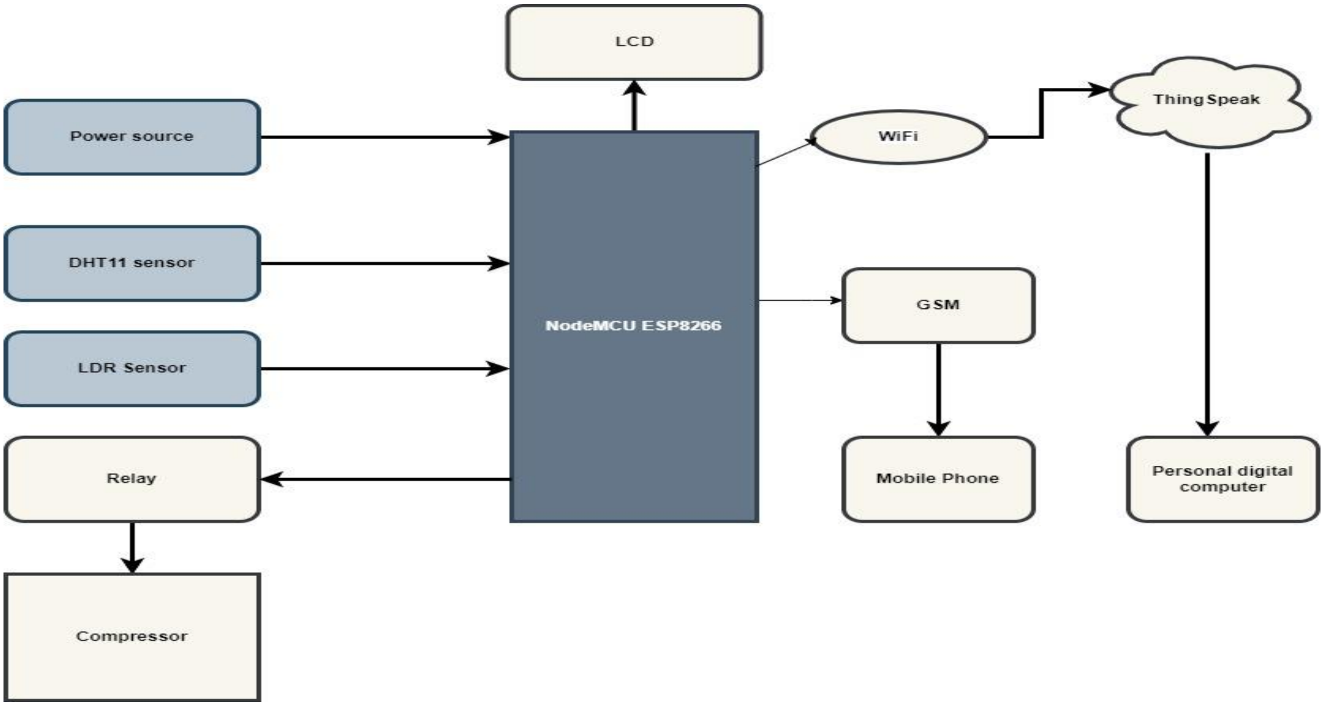


Figure 4.3: System block diagram

The block diagram above describes the various phases from collecting temperature, humidity, and light intensity to the data visualization point. The DHT11 sensor is used to capture temperature and humidity; the LDR is used for recording data about the intensity of light; the control unit is used to process the data; the relay module is used to command the compressor to be on or off when the temperature and humidity become abnormal, which is controlled by a NodeMCU ESP8266; and an LCD is attached to the outside of the room to display the temperature, humidity, and light intensity value in the storage. Wi-Fi is used to send data to the server, and the cloud storage that is used in this project is ThingSpeak, which is an IoT platform used to store and visualize the collected data before performing the analysis through MATLAB.

3.2.7 system testing

The developed system was tested in KFH's cold room to determine whether it met all objectives and how accurate and connected it was over a given period. Data was collected, including comparison tests, to determine the accuracy and durability of various types of sensors to be used in the final system.

CHAPTER 4. SYSTEM DESIGN AND DEVELOPMENT

4.1 Introduction

The method of establishing the architecture, components, modules, interfaces, and data for a system to meet specified requirements is known as systems design. The application of systems theory to product development could be viewed as systems design. The design goals are identified during system design by breaking down the system into subsystems and modifying the subsystem decomposition until all design goals are met. however, this section describes the architecture of the system prototyped throughout this project. It describes the system's design and implementation.

4.2 Architecture-designed system

The system architecture is an important step in the design process. The process of creating the physical layer design describes how the system will be distributed across the computers and what hardware and software will be used for each computer. In addition, the structure of structured information is typically composed of entities and their externally visible properties, as well as the relationships between them [20]. The following figure shows the architecture of the developed system.

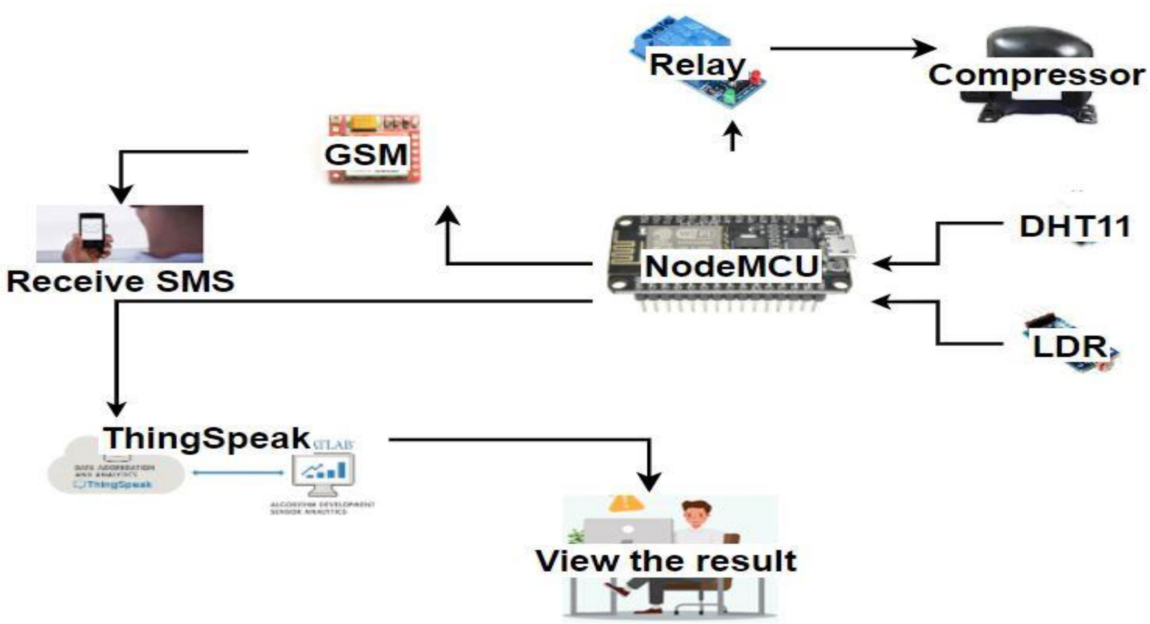


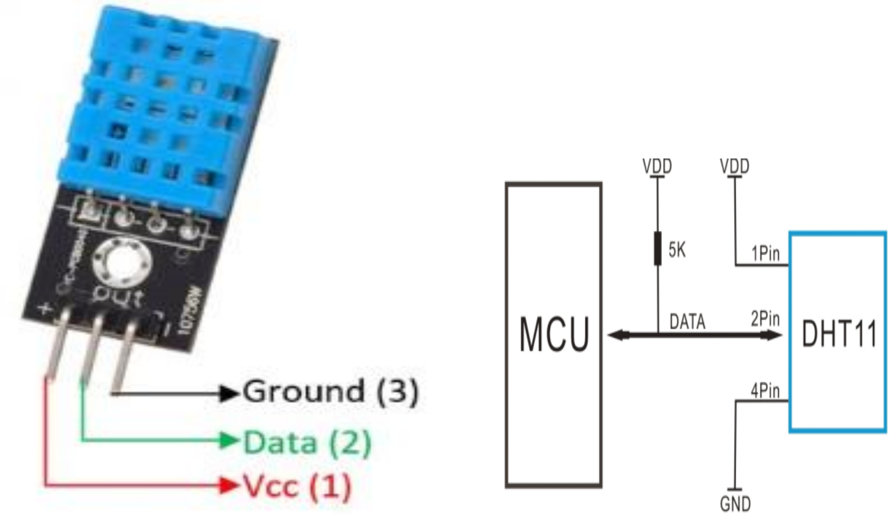
Figure 5.4: system architecture

The above figure shows the sensors that collect environmental parameters and send them to the NodeMCU board. At this point, NodeMCU receives that data to be processed and sends information to cloud storage and GSM. The cloud storage used here is ThingSpeak, which stores information and helps the user visualize the updated information (temperature, humidity, and light intensity) as well as the data analysis through MatLab. It also shows the user interface, which runs on the user's computer and mobile phone and receives messages in emergencies. Moreover, GSM was used to send SMS to the user, whereas collected temperature, humidity, and light intensity were sent to an online database via Wi-Fi and will be viewed on a web application using computers and smartphones. Therefore, a web-based user interface allows the user to view and monitor the collected environmental parameters.

The controlling side is made up of a NodeMCU ESP8266 for processing the data, a cloud platform for data analytics, and an actuating module made up of one relay to control the working of the compressor controlled by a NodeMCU ESP8266. The communication side is made up of Wi-Fi and GSM for sending data to the cloud and sending SMS to cold room staff in case of emergency issues. The components are detailed in the following paragraphs.

4.2.1 Humidity and Temperature Sensor

In this study, the temperature and humidity must be measured to obtain an accurate expression of the hotness and coldness of the cold room. A DHT11 sensor is used in this system to measure temperature and humidity because it can measure temperature from 0°C to 50°C and humidity from 20% to 90% and has an operating voltage of 3.5V to 5.5V. It is also a low-cost device with automatic climate control that is compatible with the NodeMCU ESP8266 and has a faster response time of 2 seconds [15].



source: DHT11 datasheet

Figure 6.4: DHT11- Temperature and humidity sensor

As you can see, the data pin is connected to an MCU I/O pin via a 5K pull-up resistor. This data pin serially outputs the temperature and humidity values.

4.2.2 Light sensor

For this study, the LDR (Light Dependent Resistor) was chosen to record data about the intensity of light in the medicines and vaccines' cold rooms. An LDR, also known as a photoresistor, photocell, or photoconductor, is a light-dependent resistor. It is a resistor whose resistance varies with the amount of light falling on its surface [16]. When light shines on the resistor, the resistance changes. It is also used in the developed system to check the presence of light in the medicines' storage because it is automatic, low-cost, and quick to respond.

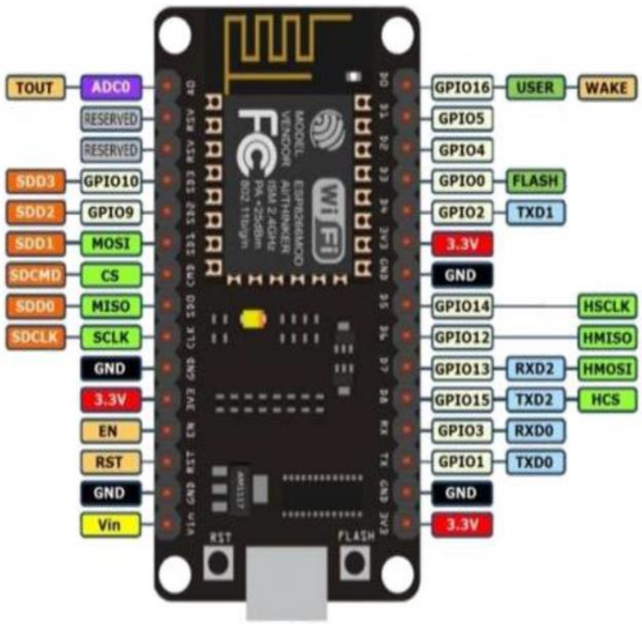
Light Resistance at 10Lux (at 25℃)	8～20KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gamma value at 100-10Lux	0.7
Power Dissipation(at 25℃)	100mW
Max Voltage (at 25℃)	150V
Spectral Response peak (at 25℃)	540nm
Ambient Temperature Range:	- 30～+70℃

Source: LDR datasheet

Figure 7.4: Light Dependent Resistor

4.2.3 Node MCU ESP8266

The NodeMCU is an open-source Internet of Things platform. It is an open-source firmware and development kit that is used to prototype the developed system with just a few lines of Arduino code. The board can be programmed using the Arduino IDE. As a result, it is programmed to process sensor data and upload it to the internet. Furthermore, the compressor automatically turns on and off by using the relay module. It was chosen because of its Wi-Fi capability, analog and digital pins that connect the sensors and other components, serial communication protocols, Arduino IDE compatibility, low current consumption, lightweight, and small size. Low cost. It operates at 3.3 volts, can be powered by USB, has 17 GPIOs, is powered by a Tensilica L106 32-bit processor, and draws 10 to 170 mA of current at a processor speed of 80 to 160 MHz [17].



Source: NodeMCU datasheet

Figure 8.4: Node MCU ESP8266

4.2.4 GSM SIM 800 L

The SIM800L GSM/GPRS module is a small GSM modem that can be used in a variety of IoT projects [18]. It sends and receives messages or makes voice calls using the GSM library. Due to its compatibility with NodeMCU, it is used to send SMS to the user in case of emergencies.

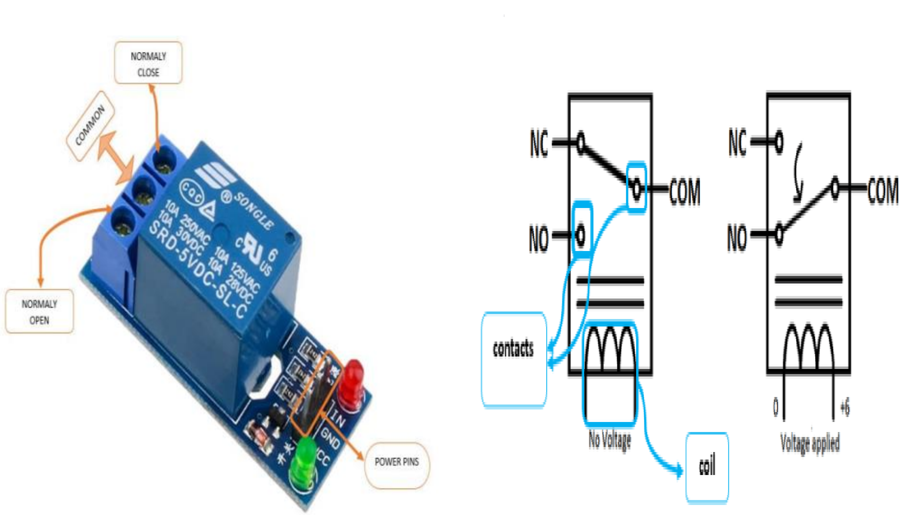
Feature	Implementation
Power supply	3.4V ~4.4V
Power saving	typical power consumption in sleep mode is 0.7mA (AT+CFUN=0)
Frequency bands	● Quad-band: GSM 850, EGSM 900, DCS 1800, PCS 1900. SIM800L can search the 4 frequency bands automatically. The frequency bands can also be set by AT command "AT+CBAND". For details, please refer to document [1]. ● Compliant to GSM Phase 2/2+
Transmitting power	● Class 4 (2W) at GSM 850 and EGSM 900 ● Class 1 (1W) at DCS 1800 and PCS 1900
GPRS connectivity	● GPRS multi-slot class 12 (default) ● GPRS multi-slot class 1~12 (option)
Temperature range	● Normal operation: -40°C ~ +85°C

Source: GSM datasheet

Figure 9.4: GSM 800 L

4.2.5 Relay

Relays are made up of three pins: a normally open pin, a normally closed pin, a common pin, and a coil [19]. A magnetic field is generated when the coil is turned on, which connects the contacts, as the following figure shows.



Source: relay datasheet

Figure 10.4: relay module

As the above figures show, the relay module has one NC (normally closed), one NO (normally open), and one COM (common) terminal. As a result, the channel relay has two NCs, two NOs, and two COMs in total. NC stands for "normal close port contact" and the state of being powerless. NO denotes the normally open port contact and the power state. COM stands for "common port." This channel relay interface board requires a driver current of 15-20 mA and at least 3.3V. It has a standard interface that can be directly controlled by a microcontroller. That is why it was used in the developed system to turn on and off compressors when the temperature value exceeded the threshold (2-8^{0}C).

4.3 Working principle of the designed system.

The working principle of the designed system is depicted in the algorithm, flow chart diagram, circuit diagram, and codes**.**

4.3.1 Algorithm of the developed system

An algorithm is any well-defined computational procedure that takes some value or set of values as input and produces some value or set of values as output [21]. The following procedures were used in this research:

```
Start
Set Wi-Fi connection
If Wi-Fi_status! = connected then
   Wi-Fi connection failed
Else
    Display Wi-Fi connected
   Read sensors: temperature(T), humidity(H), light(L)
End if
If T, H, or L is not found then
  Display sensors not found
Else
 If L and H! =range then
   Turn on relay
   Turn on the red LED
   Warning buzzer
   Send SMS
Else if T and H == range then
    Turn off relay
```

Turn on blue LED

Else if L! = range then

Send SMS

End if

4.3.2 Flow chart of the developed system

A flow chart (also known as a process flow diagram or process map) is a diagram that depicts the steps in a process and their sequence [22]. The flow chart below depicts the steps taken to create the developed system.

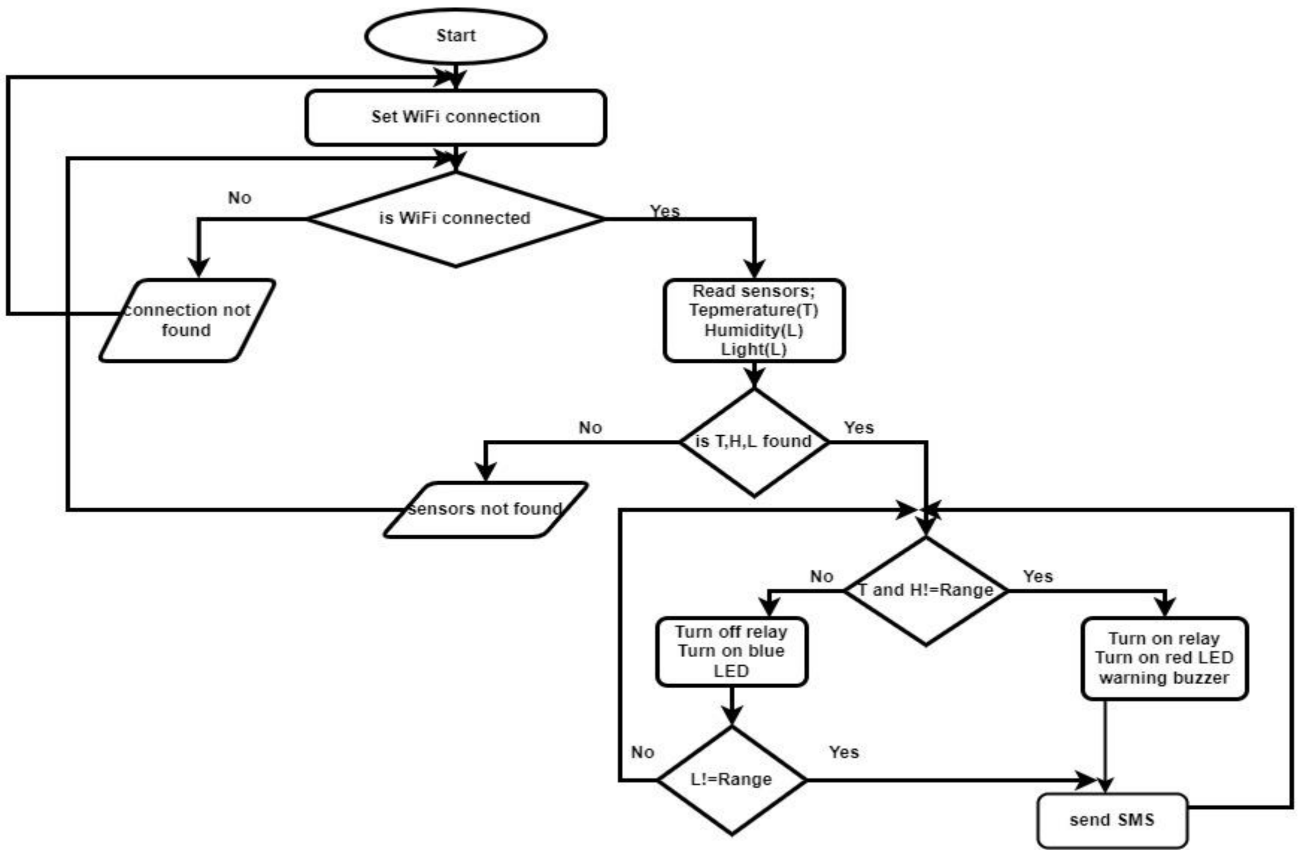


Figure 11.4: developed system Flowchart

4.4 Circuit diagram

A circuit diagram is a simplified representation of an electrical circuit's components that uses either images of the distinct parts or standard symbols. It depicts the relative positions of all the elements as well as their connections. It is frequently used to show an electrician the circuit visually [23]. The developed system's circuit diagram is shown in the figure below.

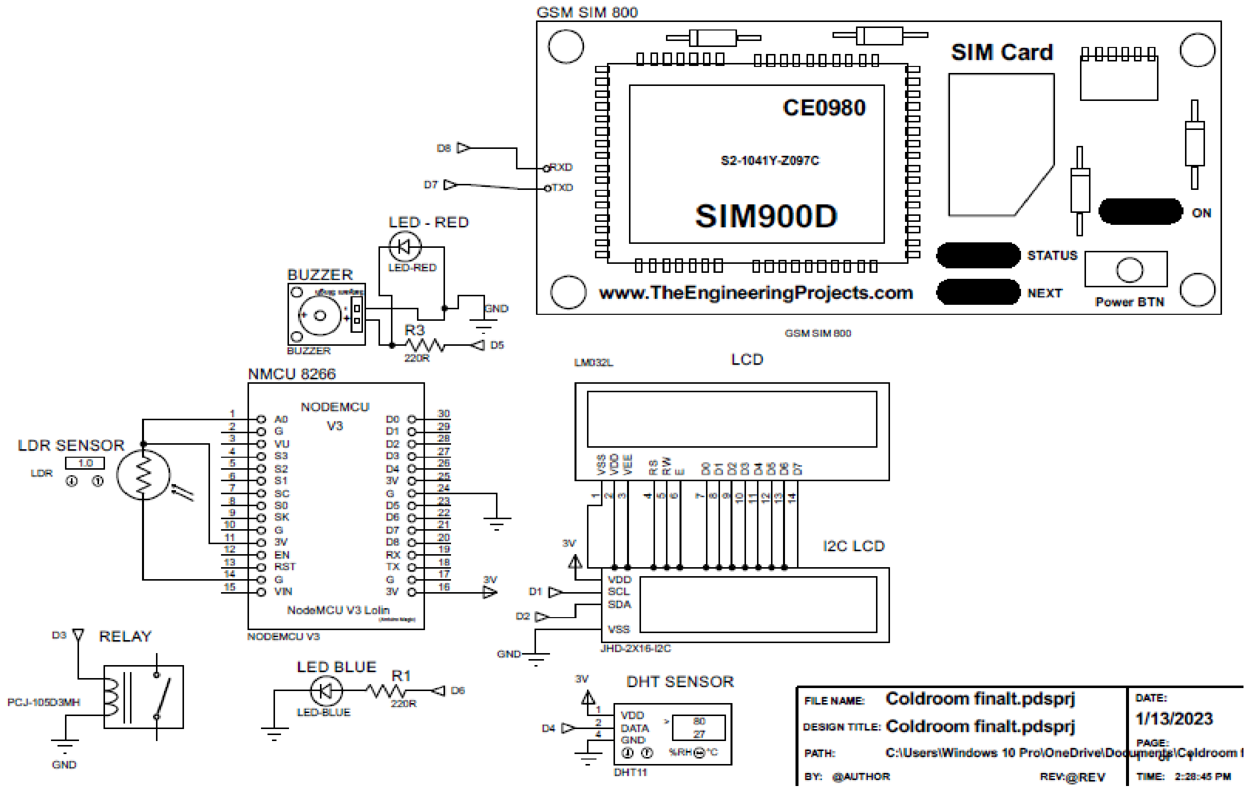


Figure 12.4: Circuit Diagram of the Developed system

The central controlling unit is a NodeMCU, which communicates with other components and modules via its digital and analog pins. As can be seen, the used digital and analog pins are A0, D1, D2, D3, D4, D5, D6, D7, and D8. Both D7 and D8 are used as TxD and RxD, respectively, for serial communication with the GSM SIM800 L to send messages to personnel. D5 and D6 are configured as output pins, with D3 causing the relay to switch on or off. On the other hand, it was used to bias the transistor that switches ON/OFF to allow the corrector current to flow, causing the relay to be on or off. D1 and D2 pins are used for the I2C LCD, whereas D4 is for the DHT 11 sensor to send the collected temperature and humidity. D1 and D2 pins are used for the I2C LCD, whereas D4 is for the DHT 11 sensor to send the collected temperature and humidity. I2C LCD is used to reduce the number of pins on the LCD so that it only takes two pins to connect to the NodeMCU rather than seven. As the diagram shows, all components are connected to a power source of 3 volts and ground.

4.5 System prototype

A prototype is a basic real-world model of a product or information system that is typically built for demonstration or as part of the development process. In addition, it is a tool for making connections to solve design problems. The following picture is the prototype of the developed system.

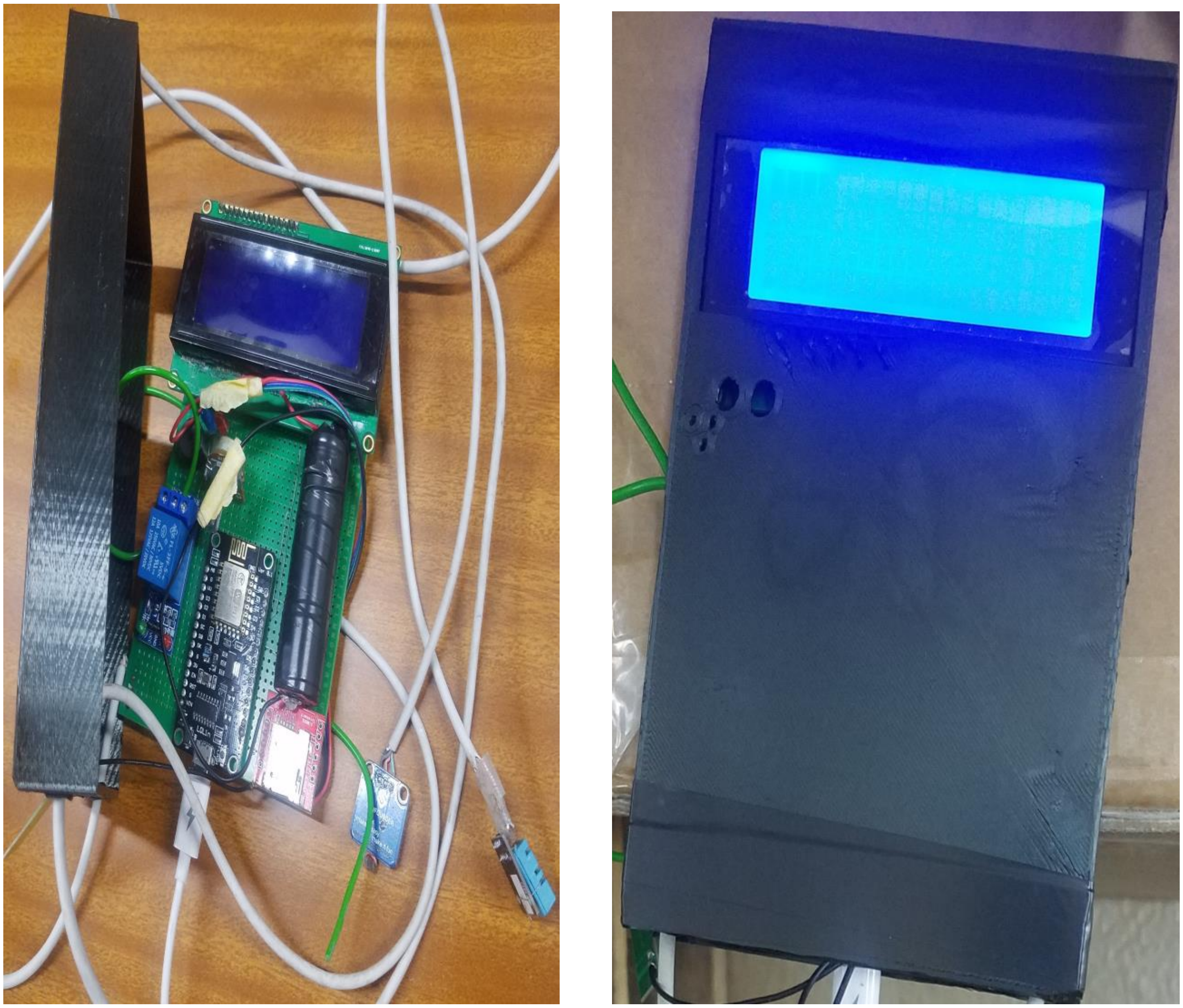


Figure 13.4: System prototype

4.6 Technologies Used During the System Implementation

The following technologies and tools were used to create this developed system:

Proteus: The Proteus Design Suite is a closed-source software tool suite primarily used for electronic design automation. Electronic design engineers and technicians primarily use the software to create schematics and electronic prints for the production of printed circuit boards [24]. In this study, Proteus was used to design the circuit diagram of the developed system.

- **Draw.io:** It is a cross-platform graph drawing software written in HTML5 and JavaScript that is free and open source. Its interface allows you to create flowcharts, wireframes, UML diagrams, organizational charts, and network diagrams [25]. In this research, it was used to design the research process, block diagram, and flowchart of the developed system.

- **Arduino IDE:** The Arduino Integrated Development Environment (IDE) is a cross-platform application written in C and C++ functions. It is used to write and upload programs to Arduino-compatible boards, but it can also be used to write and upload programs to third-party cores and other vendor development boards [26]. The Arduino 1.8 version is used in this study to connect the sensors and other components to NodeMCU and the microcontroller to ThingSpeak to store the processed data. The following image is the interface of the Arduino IDE with some codes from the developed system.

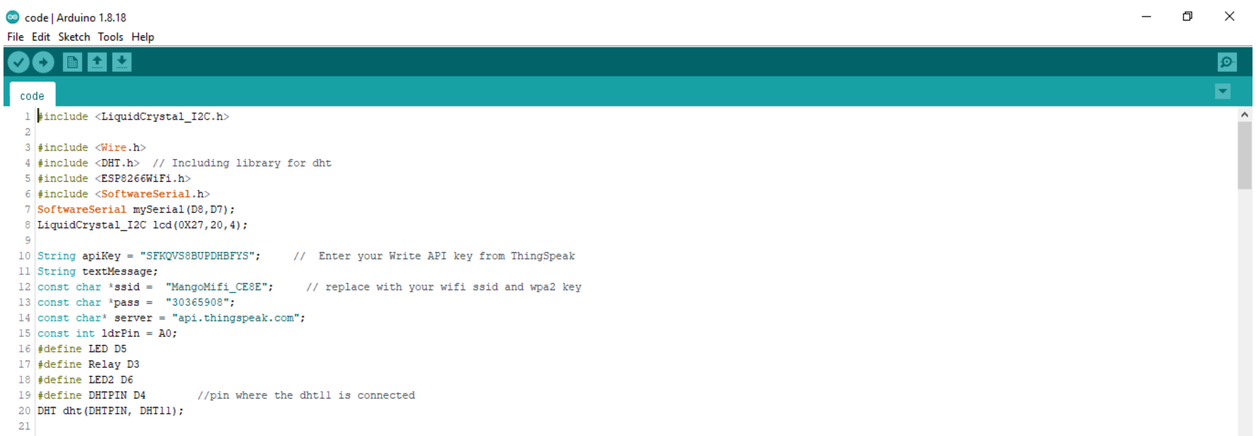


Figure 14.4: Arduino IDE interface

For this research, the three rules were used to monitor the cold room state based on the temperature, humidity, and light intensity values. These rules are set based on the threshold values that are the normal values of the cold room to store medicines and vaccines. As of [27] the normal ranges for temperature and humidity to store medicines and vaccines in the cold room are respectively 2-8^0C and 50-70% and if they are satisfied, the cold room is in a normal state.

Rule 1: if the temperature is 2^0C<=t<=8^0C and humidity is 50%<=h<=70%, then switch off the relay, and turn the blue LED.

Rule 2: if the temperature is 8^0C<=t<=2^0C and humidity 70%<=h<=50%, then switch on the relay, turn on the red LED, buzzer warns, and send an SMS which tells the personnel that the temperature and humidity are out of range.

Rule 3: if the light intensity li>2000, then send an SMS that tells personnel that there is a light in the cold room

- **Cloud platform**: Cloud computing is the process of storing and accessing data and programs via the internet rather than your computer's hard drive. The cloud is also not about having dedicated network-attached storage hardware or It is provided as a service, with all of the various data stored on the cloud's computers. Data mining and analysis are required to gain intelligent access to that information [28]. In this research, the ThingSpeak platform was used to store, visualize, and analyze data streams in the cloud. In addition, it is an open-source Internet of Things application and API to store and retrieve data from things using the HTTP and MQTT protocols over the Internet. For using ThingSpeak, creating an account is required to get access before creating a channel.

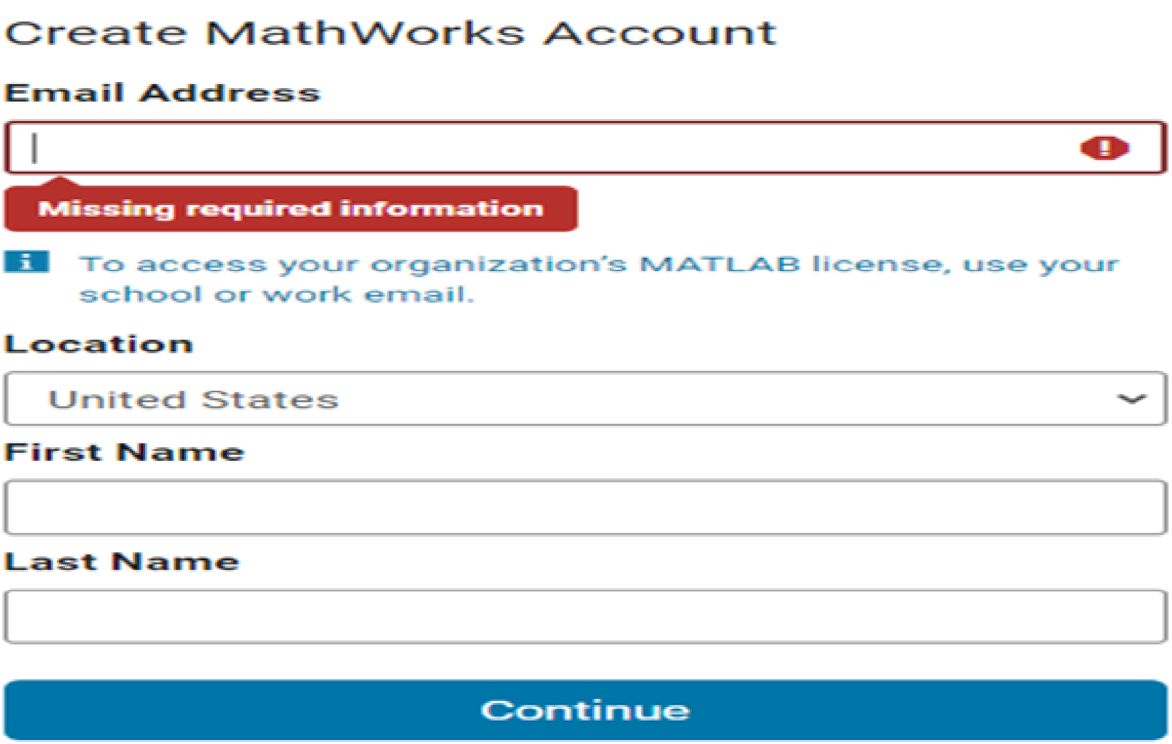
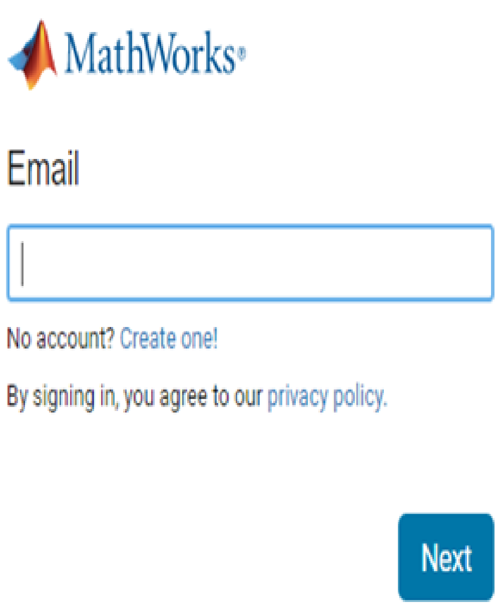
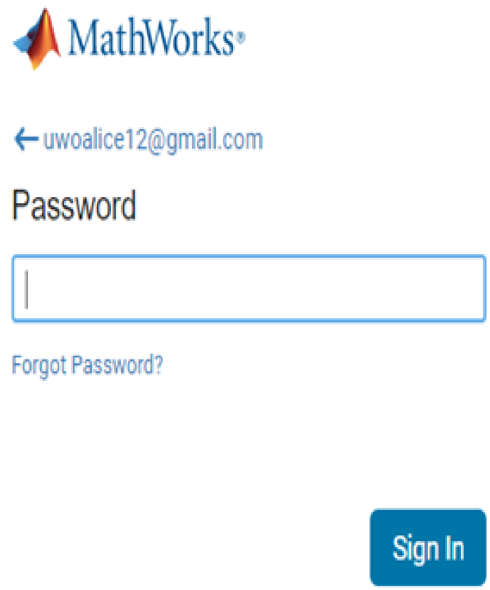
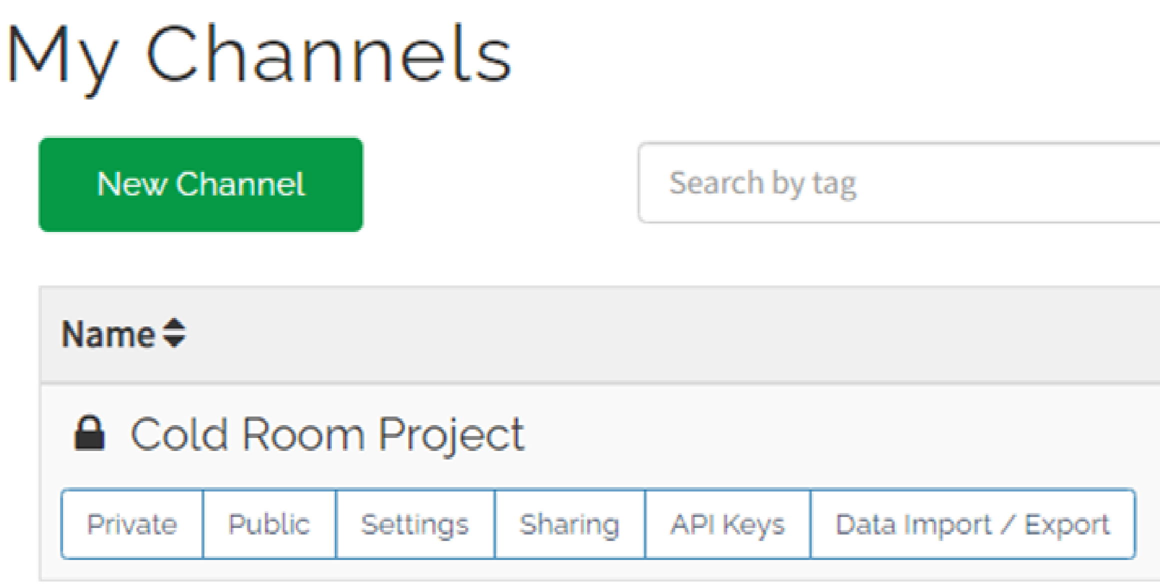


Figure 15.4: ThingSpeak account creation interface





The above pictures, show the interface of the registration and signing form that should be performed before creating the channel. The next step is to create a channel called cold room with API keys which are written in Arduino IDE to connect the board and ThingSpeak.



source: ThingSpeak application

This channel also helps the personnel visualize the temperature, humidity, and light intensity values.

4.7 Summary

This research activity has been carried out in a variety of ways. In general, a technological IoT solution has been developed that integrates people's needs directly related to cold room monitoring. The system consists of two components: the embedded system and a web application (ThingSpeak) that can view the data collected by Arduino and send messages via GSM to personnel in the event of an abnormal condition. This is a good technology that helped in the development of a smart monitoring system capable of responding to local challenges such as loss of quality in medicines, limited connectivity, less energy, and user interaction patterns. The data was collected using qualitative methods at King Faisal Hospital, and the collected data was analyzed to design the developed system before building the prototype. After prototyping, the device was tested in King Faisal Hospital’s cold room to check if all objectives were achieved. This research project followed the steps and methods outlined above.

CHAPTER 5. RESULTS AND ANALYSIS

5.1 Introduction

This chapter describes the data visualization and system accuracy analysis, which includes data analysis and comparisons between the current system used in KFH and the developed system. It was performed by using the graphs and the table as shown below.

5.2 System testing

The prototype was tested in KFH Hospital's cold room to control the system's accuracy, power management, and connectivity over a given period, where the research was conducted, which has one cold room in the laboratory department. As the following picture shows, the sensors are put into the cold room to sense the temperature, humidity, and light. The board and LCD are taken out of the room to process and display the results. The system achieves all objectives as they were set.

Figure 16.5: developed system testing

The following tasks were tested and proved successful. A temperature and humidity sensor measures the precise temperature and humidity levels.

- The light sensor detects the light intensity in the cold room.
- It sends an SMS to the cold room operator when the temperature and humidity are out of range or if a light is found in the cold room.
- When the temperature falls outside of 2-8 degrees Celsius, the system activates or deactivates the relay, causing the compressor to turn on or off.
- It stores the processed data in cloud storage for future use.
- It visualizes temperature, humidity, and light intensity values in an online web application called ThingSpeak.
- In a few words, it monitors the cold room remotely.

The following results are discovered:

- When a temperature and humidity sensor is placed in a cold room, it takes the current value after 30 seconds.
- To open the cold room door, raise the temperature by 1 or 2 degrees Celsius above the current temperature.

- The temperature difference between the designed and current systems is one or 0.5 degrees Celsius.

5.3 Data visualization

The two sensor nodes are deployed in the cold room of King Faisal Hospital during the prototype implementation. Data was collected from the various sensor devices and visualized on the ThingSpeak dashboard.

The figure below depicts data entries made over time. The graph is a ThingSpeak visualization showing the status of sensor values over a given period. The data from sensors sent to the cloud from different entries differ, which explains the graphs' up-and-down lines.

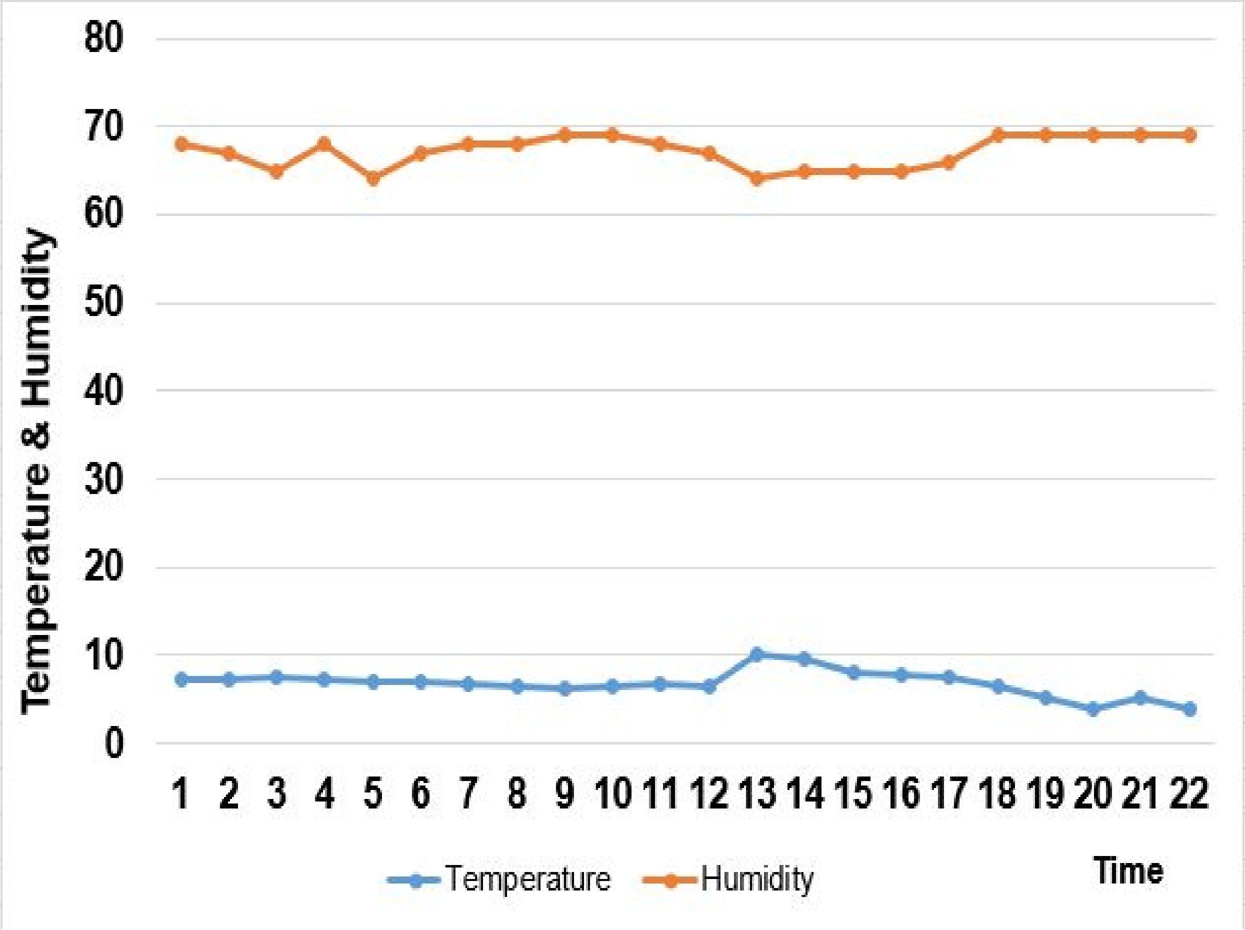


Figure 17.5: Temperature chart *Figure 18.5: Humidity chart*

As seen in the graphs, temperature, and humidity values are indicated on the vertical axis, while the time intervals at which the temperature and humidity are indicated on the horizontal axis. The figure shows a range of temperatures, mostly between 4 and 10 degrees Celsius.

When the temperature rises above 8 degrees Celsius, the relay module is activated to regulate the temperature, and the user receives an appropriate notification via mobile phone message. The temperature threshold was set to 2 and 8 degrees Celsius for temperature control.

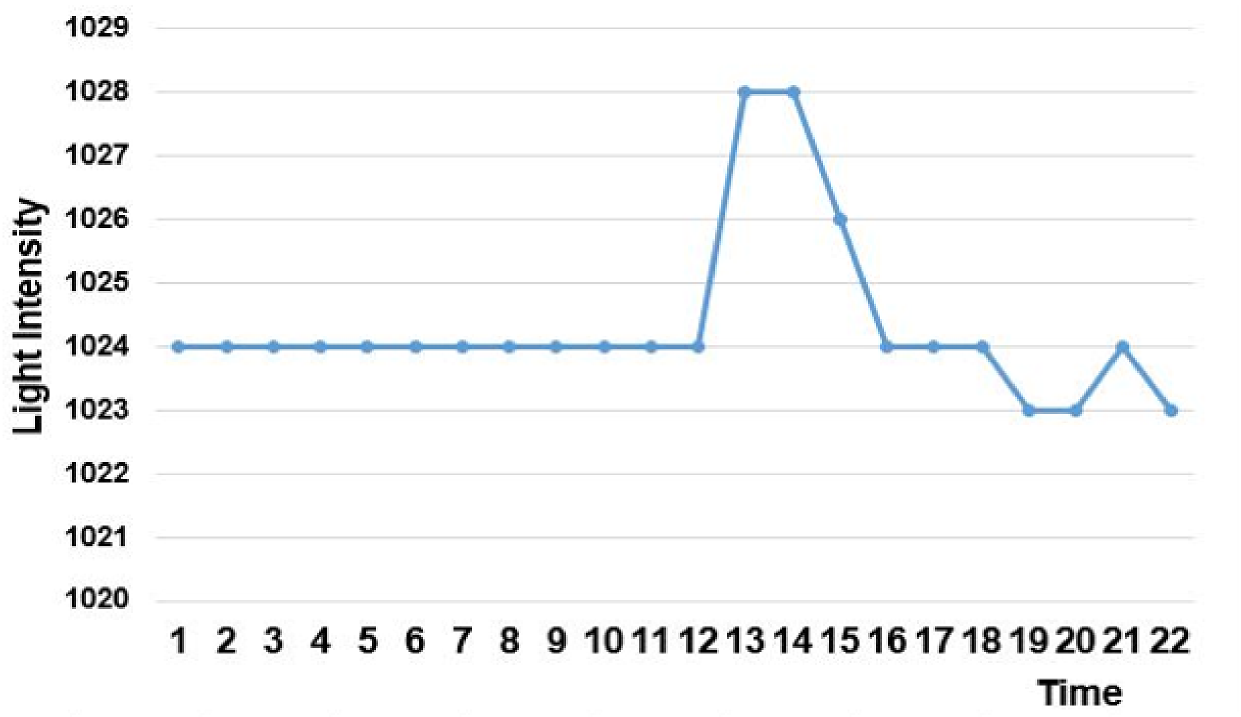


Figure 19.5: light chart

The figures above show the results displayed on the ThingSpeak platform. The variation shown is based on sensor values collected at various environmental conditions. We can conclude from the output that the humidity is high when the temperature is low. The LDR shows the amount of light that is unaffected by the other two parameters.

The system also allows users to generate a daily report on the temperature and humidity variations at a specified time interval, as the following table shows.

Table 3.5: Result record

Time	Temperature(oC)	Humidity(%)	Light Intensity(Lux)
1	7.3	68	1024
2	7.3	67	1024
3	7.4	65	1024
4	7.2	68	1024
5	7.1	64	1024
6	7	67	1024
7	6.8	68	1024
8	6.5	68	1024
9	6.3	69	1024
10	6.5	69	1024
11	6.7	68	1024
12	6.4	67	1024
13	10	64	1028
14	9.5	65	1028
15	8	65	1026
16	7.8	65	1024
17	7.4	66	1024
18	6.5	69	1024
19	5.1	69	1023
20	4	69	1023

5.4 System Accuracy Analysis

5.4.1 Comparison

Several studies have been conducted to address the challenges of storing medicines and vaccines in a cold room, as discussed in chapter two of this report. Although they can be used to monitor the temperature of medicines, they have a relatively long history of neglecting to monitor other parameters and using unfavorable techniques to deliver data to the user interface. They also rely on traditional monitoring, which presents a significant challenge to maintaining the quality of the medicine and vaccines. The table below compares the existing cold room monitoring system used in KFH to the system designed in this thesis project.

Table 4.5: Comparison of the current and existing system

Procedures	Current system	developed system
Monitoring method	Use a thermometer to monitor the cold room.	It is an IoT Real-time monitoring system.
Data communication:	Immediate reading of the temperature value. The cold room operators must go to the cold room at least twice per day to check the temperature and humidity rate and write the temperature value which is impossible on holidays and weekends.	web-based requests and SMS. The user can visualize the temperature and humidity variations without leaving their current locations.
Storage:	local	online
Human error	When the cold room operators open the door of the cold room, the temperature changes immediately before they can read the temperature. So, they can make an error by reading an unreal temperature.	No human error
Power energy saving	The compressor runs continuously, wasting power and energy.	The compressor works based on the temperature value.

5.4.2 Data analysis

Based on the findings presented in the preceding section, medication monitoring and temperature control in cold storage can be accomplished with a simple and dependable IoT-based system. The implementation costs of such a system are lower than those of existing systems. Additionally, because all transactions are saved on the cloud, it reduces paper-based work. It also reduces the unnecessary temperature changes caused by the frequent opening of the cold room door. The users can see the current temperature wherever they go, which reduces the loss of medicine quality, especially on weekends or holidays. So the accuracy of the data generated by the designed system was compared to that of the KFH's current system. Considering the efficiency of the developed system, the data generated does not show many changes. Therefore, the developed system has high accuracy.

5.5 Summary

This chapter provides and discusses the anticipated outcomes of the smart monitoring system by using the IoT solution for the efficient storage of temperature-sensitive medicines and vaccines in Rwanda. It describes the results obtained from sensors and displayed on the system's user interface during prototype implementation, as well as temperature variation graphs where sensors are deployed.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

The conclusion is based on the discovered results from the documents approached and the proposed methodology was discussed in this chapter. Therefore, make recommendations for future cold room monitoring research.

6.1 Conclusion

In this research, An IoT Smart monitoring system was developed to monitor medicines and vaccines in cold rooms between 2°C and 8°C, by controlling temperature, humidity, and light intensity, all of which affect the quality of medicines and vaccines based on their value. This study focused on using IoT-based technology to overcome the challenges that the existing system presents as the previous chapters have shown.

This research was done in different phases, namely requirements gathering and analysis, system design, system prototyping, and testing. The King Faisal Hospital visited and observed the method used to monitor the cold room of medicines and vaccines to collect data about the requirements.

The results of this research demonstrated that the current cold room monitoring method has several flaws. These include manual medicine and vaccine temperature recording, which makes it impossible for the staff to control the storage remotely, drugs that lose quality and efficacy, and high power consumption. An online web application has been created to assist cold room technicians in viewing temperature and humidity data at any time and from any location. A GSM module has also been provided to send messages to cold storage technicians in the event of a temperature deviation. The testing process was also carried out in this hospital to ensure that the system met all of its objectives. Moreover, it shows that when a temperature and humidity sensor is placed in a cold room, it takes the current value after 30 seconds, opening the cold room door leads to the temperature rising by 1 or 2 degrees Celsius above the current temperature, and the temperature difference between the designed and current systems is one or 0.5 degrees Celsius.

According to the results of real-time data analytics, the designed system efficiently controlled the medicines and vaccines' cold room, provided reliable data about the interior indoor environmental ambiance, applied electrical current and energy consumption, and sent the necessary notifications in the case of an emergency. It is intended to save many medicines and vaccines thrown away because it can collect temperatures and humidity, detect temperature changes, check the presence of light in the storage, and alert users whenever the detected temperature exceeds or falls below the WHO recommended range. It also generates a continuous report to minimize human effort for manual monitoring. It also saves energy by controlling the operation of the compressor. The patients will also have benefited from this research by receiving high-quality medications.

The designed system relied on only three parameters to detect the status of a cold room, even though many factors influence the quality of medicines. It cannot also control the cold room door, which affects the temperature value. It is required to investigate other environmental factors that cause medicines stored in cold rooms to lose their quality.

6.2 Recommendations

Based on the findings, the following recommendations are suggested:

- ✓ Cold rooms should be fitted with remote monitoring systems since they are still using manual temperature monitoring devices, which makes temperature monitoring impossible on weekends and holidays. This will help staff monitor the cold storage everywhere they are and get the message in case of an emergency.

- ✓ The research was primarily focused on one hospital, KFH. A similar study in other hospitals is required to collect more data and compare the findings.
- ✓ Future researchers will investigate other environmental factors that can cause medicines stored in cold rooms to lose their quality and control the door of the cold room to determine the cause of the abnormal temperature.
- ✓ It is suggested that the researchers use another kind of temperature sensor and GSM module to improve the system's accuracy.

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APPENDICES

Appendix 1: Approval letters for data collection

UNIVERSITY of RWANDA

Regional Centre of Excellence in Biomedical Engineering and E-Health (CEBE)

To: The Director General/ CEO

Kigali-Rwanda

Dear Director General

Subject: Data Collection's Introductory Letter for Biomedical Engineering Master's Degree Student, Ms UWONKUNDA Alice

CEBE is referring to the MoU between the Centre (CEBE) and the Ministry of Health; we are also referring to the operation of CEBE which is based on innovation, consultancy, and service ecosystem to achieve high-impact results in support of key health sector initiatives.

Therefore, this is to introduce Ms **UWONKUNDA Alice.**

A Master's Degree Student with reference number **220020272**,

who is doing the master's degree research works under the East African Regional Center of Excellence in Biomedical Engineering and E-Health (CEBE), Biomedical Engineering programme.

Her research topic is: **DEVELOPMENT OF A SMART MONITORING SYSTEM FOR RWANDAN HOSPITALS COLD ROOMS.**

She, therefore, needs to collect data for the related Master's degree dissertation; however, the management of CEBE declares that no publications of the data can be made without an ethical clearance to do so.

Your support in this regard will be highly appreciated

for

Prof. Celestin Twizere

Director of CEBE

UNIVERSITY OF RWANDA CEBE

KING FAISAL HOSPITAL RWANDA

INSTITUTIONAL REVIEW BOARD

Patient Centered Care

IRB Notification of Approval

Ref: KFH/2022/ 025/IRB

Date: November 22, 2022
Protocol Title: Development of Smart Monitoring System for Rwandan Hospitals Cold Rooms
Principal Investigator(s):
Name: Alice Uwonkunda
Email: uwoalice12@gmail.com
Tel: +250783726614
Protocol Reference #: KFH/2022/ 025/IRB
Date of IRB Initial Review: November 15, 2022
Review Type: Full review
IRB Review Decision: Approved
Date of Effectiveness: November 23, 2022
Date of Expiry: November 23, 2023

Dear Alice

King Faisal Hospital Rwanda's Institutional Review Board (KFH IRB) reviewed your protocol submission. This letter is to notify you that the KFH IRB approved your submission, and this approval is valid for one (1) year and then must be renewed according to the KFH IRB Standard Operating Procedures.

Please note the following considerations:

1. Please review the KFH IRB Standard Operating Procedures and ensure compliance with all requirements, including participant content, changes or amendments to the protocol, and reporting requirements.
2. All project materials, including signed consent forms, must be retained and are subject to review in case of a routine audit.
3. Notify the KFH Directorate of Research once data collection is completed.
4. The Principal Investigator is requested to submit a hard copy of his/her final manuscript to the Directorate of Research upon completion.
5. Principal Investigators must follow the appropriate study continuing review and closure procedures as indicated in the Standard Operating Procedures Manual.

Please contact us at [illegible] in case of any questions or clarifications.

Sincerely,

Dr. Jean Marie Vianney Dus[illegible]
Consultant ENT Surgeon
Chair, Institutional Review Board

Appendix 2: Questionnaire

Department / Unit of work: *

- ◯ Pharmacy
- ◯ Biomedical
- ◯ Other: __________

While storing pharmaceutical products in the cold room, do you strictly check and consider the labeled storage conditions of temperature? *

- ◯ Yes
- ◯ No

If yes, please tick recommended conditions: *

- ☐ 2 °C – 8 °C
- ☐ -5 °C and -20 °C
- ☐ Other: __________

What is recommended humidity range in the cold room? *

Your answer __________

Are environmental conditions, primarily temperature, monitored on an ongoing basis in which medical products are stored? *

- ◯ Yes
- ◯ No

Is there any negative effect of light (for example sunlight) on the medicines and vaccines stored in the cold room? *

- ◯ Yes
- ◯ No

If yes, describe them

what are the monitoring devices(for example Thermometer, etc) that you use to monitor the environmental parameters (temperature and humidity) level?

Your answer

Is the environmental temperature (maximum and minimum) monitored daily, at a specified time by a designated staff member by using these monitoring devices (manual or automatic device)?

◯ Yes

◯ No

If yes, how many times the temperature must be checked during a day

Your answer

Is there any real-time system that helps the staff to control the cold room without leaving his/her current place)? *

◯ Yes

◯ No

If yes, show me how it works

Your answer

Are environmental temperature and humidity results becoming outside of the required condition range? *

◯ Yes

◯ No

If yes, how many times does the temperature become abnormal during a day or a week?

Appendix 3: The Utilized Codes

```
#include <LiquidCrystal_I2C.h>

#include <Wire.h>
#include <DHT.h>  // Including library for dht
#include <ESP8266WiFi.h>
#include <SoftwareSerial.h>
SoftwareSerial mySerial(D8,D7);
LiquidCrystal_I2C lcd(0X27,20,4);

String apiKey = "T1P9R8Y0DST566X5";     //  Enter your Write API key from ThingSpeak
String textMessage;
const char *ssid =  "MangoMifi_CE8E";     // replace with your wifi ssid and wpa2 key
const char *pass =  "30365908";
const char* server = "api.thingspeak.com";
const int ldrPin = A0;
#define LED D5
#define Relay D3
#define LED2 D6
#define DHTPIN D4          //pin where the dht11 is connected
DHT dht(DHTPIN, DHT11);

WiFiClient client;

void setup()
{       Serial.begin(9600);
        mySerial.begin(9600);
        delay(10);
        pinMode(LED, OUTPUT);
        pinMode(LED2, OUTPUT);
```

```
        pinMode(Relay, OUTPUT);
        pinMode(ldrPin, INPUT);
       Wire.begin(D2, D1);   //Use predefined PINS consts
        lcd.begin(20,4);
        lcd.backlight();      // Turn on the backlight.
        lcd.home();
        Serial.println("Connecting to ");
        Serial.println(ssid);


        WiFi.begin(ssid, pass);

       while  (WiFi.status() != WL_CONNECTED)
      {
              delay(500);
              Serial.print(".");
      }
       Serial.println("");
       Serial.println("WiFi connected");
       //--------------------------------------
 Serial.print("Serial ready...");// things written in serial monitor
  mySerial.print("AT+CMGF=1\r"); // things written in serial monitor
  delay(100);
  // Set module to send SMS data to serial out upon receipt
  mySerial.print("AT+CNMI=2,2,0,0,0\r");// things written in serial monitor
  delay(100);
}

```

```
  if(mySerial.available()>0){
   textMessage = mySerial. readString();
   Serial.print(textMessage);  //send sms to ohone
   delay(10);
 }
     int ldrStatus = analogRead(ldrPin);
     if (ldrStatus <=300) {
Serial.println(ldrStatus);
Serial.println("Light present in cold room");
sendmessage();
}

else {

Serial.println(ldrStatus);
Serial.println("Cold room has not presence of light");

}
     float h = dht.readHumidity();
     float t = dht.readTemperature();

             if (isnan(h) || isnan(t))
                {
                    Serial.println("Failed to read from DHT sensor!");
                     return;
                }
```

```

                     if (client.connect(server,80))   //   "184.106.153.149" or api.thingspeak.com
                   {

                         String postStr = apiKey;
                         postStr +="&field1=";
                         postStr += String(t);
                         postStr +="&field2=";
                         postStr += String(h);
                         postStr +="&field3=";
                         postStr += String(ldrStatus);
                         postStr += "\r\n\r\n";

                         client.print("POST /update HTTP/1.1\n");
                         client.print("Host: api.thingspeak.com\n");
                         client.print("Connection: close\n");
                         client.print("X-THINGSPEAKAPIKEY: "+apiKey+"\n");
                         client.print("Content-Type: application/x-www-form-urlencoded\n");
                         client.print("Content-Length: ");
                         client.print(postStr.length());
                         client.print("\n\n");
                         client.print(postStr);
                         //lcd.setCursor(2,0);
                         Serial.println("%. Send to Thingspeak.");
                         lcd.println("T:" );
                         lcd.println(t);
                         lcd.print("H:");
                         lcd.println(h);
```

```
                             lcd.print("Lux:");
                             lcd.println(ldrStatus);
                             delay(2000);
                             lcd.clear ();
                             }
          client.stop();

          Serial.println("Waiting...");

  // thingspeak needs minimum 15 sec delay between updates
  delay(1000);
  if ((t>=2)&&(t<= 8))
{
  digitalWrite(LED2, HIGH);
  delay(700);
  digitalWrite(LED2, LOW);
  delay(700);
  digitalWrite(LED, LOW);
  digitalWrite(Relay, LOW);
}
else
{
  digitalWrite(LED, HIGH);
  delay(500);
  digitalWrite(LED, LOW);
  delay(500);
  digitalWrite(Relay, HIGH);
  digitalWrite(LED2, LOW);
```

```
 textMessage = "";
 Send_SMS();}}
void Send_SMS(){
   mySerial.println("AT");
   delay(10);// akanya gacamo
  mySerial.println("AT+CMGF=1");
  delay(10);// akanya gacamo
  mySerial.println("AT+CMGS=\"0783726614\"");//

  delay(10);// akanya gacamo
  mySerial.print("cold room Temp is out of Range");//send sms
  delay(10);// akanya gacamo
  mySerial.write(26);
  delay(100);// akanya gacamo

}
void sendmessage(){
   mySerial.println("AT");
   delay(10);
  mySerial.println("AT+CMGF=1");
  delay(10);
  mySerial.println("AT+CMGS=\"0783726614\"");
  delay(10);
  mySerial.print("Cold room Temp detected light");
  delay(10);
  mySerial.write(26);
  delay(100);
}
```

-;