DESIGN AND DEVELOPMENT OF TEMPERATURE AND HUMIDITY WEATHER CHAMBER

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

Faculty of Electronics and Computer Technology and Engineering
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ABSTRACT

Numerous facets of life, ecosystems, and technical systems are impacted by temperature and humidity levels. The complex interplay between temperature and humidity gives rise to phenomena like dew point, evaporation, and condensation. Weather phenomena including clouds, rain, and atmospheric stability are all impacted by this interplay. For the comfort of the people and the durability of the structure, interior spaces must maintain a balance between temperature and humidity. Many health problems are emerging at the moment, including respiratory infections, dry skin and irritation, physical discomfort, dehydration, and among many others. Thus, the consumer ends up spending more money and taking up more space by buying both humidifiers and electric heater. The "Temperature and Humidity Weather Chamber" is the project name that is currently under development. Controlling the humidity and temperature in a particular area can help prevent a number of health issues. The project's goal is to control a location's humidity and temperature as needed while reducing costs for the user. This initiative might result in a reduction in the cost of buying electric heater and humidifiers by ensuring correct regulation of environmental conditions. It is directed to make the equipment more efficient through automatic adjustment of changing environmental conditions, such as temperature and humidity within Weather Chamber. Consequently improving user satisfaction, promoting or encouraging environmental control systems automats to be implemented. In order to accomplish such a goal, it was designed and built an automated system based on Arduino. The sensors for Arduino system monitor the temperature and humidity within the Weather Chamber. It makes use of the elements to change different components based on environmental data that it collects. The Arduino reads the data that is created by these temperature and humidity

sensors and contrasts that information with ideal values set in advance. Contrasted with ideal values, the system actuate the chamber's ambient parameters. In summary, the current study outlines how the temperature and humidity weather chamber system enhances performance and how this equipment would work under varying environmental conditions.

ABSTRAK

Pelbagai aspek kehidupan, ekosistem dan sistem teknikal dipengaruhi oleh tahap suhu dan kelembapan. Interaksi kompleks antara suhu dan kelembapan menimbulkan fenomena seperti takat embun, penyejatan dan pemeluwapan. Fenomena cuaca termasuk awan, hujan dan kestabilan atmosfera semuanya dipengaruhi oleh interaksi ini. Untuk keselesaan orang ramai dan ketahanan struktur, ruang dalaman mesti mengekalkan keseimbangan antara suhu dan kelembapan. Banyak masalah kesihatan yang timbul pada masa ini, termasuk jangkitan pernafasan, kulit kering dan kerengsaan, ketidakselesaan fizikal, dehidrasi, dan banyak lagi. Oleh itu, pengguna akhirnya membelanjakan lebih banyak wang dan mengambil lebih banyak ruang dengan membeli kedua-dua pelembap dan pemanas elektrik. "Kebuk Cuaca Suhu dan Kelembapan" ialah nama projek yang sedang dalam pembangunan. Mengawal kelembapan dan suhu di kawasan tertentu boleh membantu mencegah beberapa isu kesihatan. Matlamat projek adalah untuk mengawal kelembapan dan suhu lokasi mengikut keperluan sambil mengurangkan kos untuk pengguna. Inisiatif ini mungkin mengakibatkan pengurangan kos pembelian pemanas elektrik dan pelembap dengan memastikan peraturan keadaan persekitaran yang betul. Ia diarahkan untuk menjadikan peralatan lebih cekap melalui pelarasan automatik perubahan keadaan persekitaran, seperti suhu dan kelembapan dalam Ruang Cuaca. Akibatnya, meningkatkan kepuasan pengguna, mempromosikan atau menggalakkan sistem kawalan alam sekitar untuk dilaksanakan. Untuk mencapai matlamat sedemikian, ia telah direka bentuk dan membina sistem automatik berdasarkan Arduino. Penderia untuk sistem Arduino memantau suhu dan kelembapan dalam Ruang Cuaca. Ia menggunakan elemen untuk menukar komponen berbeza berdasarkan data persekitaran yang dikumpulnya. Arduino membaca data yang

dicipta oleh penderia suhu dan kelembapan ini dan membezakan maklumat tersebut dengan nilai ideal yang ditetapkan terlebih dahulu. Berbeza dengan nilai ideal, sistem menggerakkan parameter ambien ruang. Ringkasnya, kajian semasa menggariskan bagaimana sistem ruang cuaca suhu dan kelembapan meningkatkan prestasi dan cara peralatan ini akan berfungsi dalam keadaan persekitaran yang berbeza-beza.

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δ	-	Voltage angle
%	-	Percentage
+	-	Positive
-	-	Negative
×	-	Multiply
=	-	Equal
>	-	Bigger than
<	-	Smaller than

LIST OF ABBREVIATIONS

V	-	Voltage
A	-	Ampere
RH	-	Relative Humidity

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter provides the background information of the project, description of the problem, objectives of the study, and work scope. The said project is to design a temperature and humidity weather chamber in which all environmental conditions could be changed to enhance equipment efficiency.

1.1 Background

As part of an overall effort to optimize the environment globally, more attention is focused on developing the systems that control efficiently the temperature and humidity levels with minimum energy consumption. Among all such devices, weather chambers or the chambers controlling humidity and temperature have drawn the most interest. These are rooms that are meant for a kind of environment control to be utilized in the testing research and even storage where defined sections of the humidity and temperature control becomes mandatory. Weather chambers, for instance-which basically require high technology in order to provide the most stable controlled condition of all-have increasingly gained popularity across the globe both in research laboratories and industries over the last 10 years. The sophisticated sensors and actuators monitor the temperature and humidity level in such rooms and thus control them to provide the perfect environment to be used for research, testing of products and storage purposes. The Weather Chambers have automated control systems which play the most important role in building up the right atmosphere of humidity and temperature. These are managed by exact sensors and Controllers. They can instantaneously change the climate and, hence, provide a controlled and stable climate for sensitive products and machinery, and even processes. But, as a matter of fact, while Weather Chambers do control the environment to a large extent, their large-scale systems may not be appropriate for residential purposes. The ideas and techniques that have been applied to the Weather Chambers in the course of years can be used in the future to come up with better and more user-friendly solutions for domestic temperature control systems. [1]

1.2 Problem Statement

Integrating advancements in sensor and actuator technologies into Weather Chambers can significantly enhance their responsiveness and precision. These advanced control systems will enable more accurate and reliable maintenance of desired environmental conditions, supporting a wider range of applications and improving overall performance. [2]

Cost is so much a factor in the development and implementation of advanced climate control features as into a Weather Chamber. The cost of Initial start-up may be more disproportionate or even unaffordable to maintain the equipment bringing these new features, especially for nowadays many contender smaller labs, research institutes, or as a private user. Weather Chambers should always be affordable and available by seeking cost-effective methodology, that shall ensure absolute uniformity in temperature and humidity. [3]

Eventually, new concepts to reduce the production time, improve its performance with regard to energy efficiency and require less maintenance may bring down the exorbitant price and make the broader application of Weather Chambers possible. The construction and operation of the Weather Chamber will demand maximum possible energy efficiency so that its operational costs are minimized and there is less environmental degradation. The reason to incorporate the methods of energy management in these chambers has embarked on minute size and continuous running mode so that there will be less misuse of electricity and corresponding carbon emission. Energy efficiency allows Weather Chambers to cut down on their costs and achieve sustainability goals while minimizing environmental impacts. [4]

1.3 Project Objective

Below are the main objectives of "Temperature and Humidity Weather Chamber" project.

i) To design and simulate a weather chamber by using Proteus software.

ii) To fabricate a weather chamber that is effective in regulating humidity and temperature precisely.

iii) To benchmark to key parameters and design with the existing works and current trends.

1.4 Scope of Project

This is the project scope for the design of an efficient weather chamber:

i) A comprehensive and detailed accommodation of the design specifications of the Weather Chamber as it relates to size, materials, and components.

ii) The climate control system, involving heating/ cooling components, humidity, temperature sensors, and a control algorithm that ensures the very best in terms of regulation.

iii) Weather chamber sub-systems, involving ventilation ducts, and erection of the chamber based on designated parameters from the previous scope.

iv) Test the weather chamber to ensure that it produces and sustains the environmental conditions as per the need.

v) The collected environmental information will be provided by the sensors.

vi) The temperature and humidity will be controlled by a software application.

vii) The voltage supply to the weather chamber will be from 12V to 18V and the power consumption will lie between 10W to 50W.

viii) Take stakeholder and test user input to get what should be changed and/or improved upon for the weather chamber operation and its ease of use.

1.5 Importance of Project

i) The weather chamber is a much-needed project to help establish a controlled environment for conducting very accurate tests and experiments, and most importantly, to ensure reliable research results.

ii) The project aims to reduce the cost of operation and mitigate concomitant damage to the environment due to improved efficiencies in energy utilization and temperature regulation along the established sustainable standards.

iii) The project will foster more innovation thinking and teamwork since it will make advanced weather chamber equipment more cost-friendly for the small or few organizations and individual users.

iv) The purpose is to improve the occupational health and safety requirements and availably of conditions in which the users and occupants can feasibly operate in a comfortable and safe environment summons with it the need to ventilate and manage the air quality through the weather chamber.

1.6 Report Outline

An overview of earlier recommendations for improving the quality and efficiency of temperature and humidity weather chambers is provided in Chapter 2. The project's benefits and drawbacks are also covered in this chapter.

The steps and procedure for building a weather chamber are described in Chapter 3. The flow chart diagram illustrates each stage of the goal-achieving design process, which is covered in great detail in this chapter. Furthermore, the top-level system is illustrated by the block diagram, and this chapter also includes Gantt charts.

The implementation and verification of the proposed system—a functional design for the weather chamber—are covered in Chapter 4. Sensors and the data they provide are used to develop the system. This chapter covers the performance analysis and display of the suggested system.

Chapter 5 of this report provides a summary of the project's findings. There are also suggestions for future lines of inquiry and potential commercialization strategies.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Environmental conditions, such as those of temperature and humidity, constitute a very important area of study in very many fields, from agriculture to industry and even scientific research. This has given rise to very important tools, such as the Temperature and Humidity Weather Chamber, which offer different controlled environments for experimentation and testing. The paper aims to use available literature to highlight past experiences on the evolution, application, and advancement in the temperature and humidity chambers to understand their contribution to sustainable practices, improving research capacities for different research, and climate-resilient technologies. This shall be established through conducting a literary review of published literature that will try to argue that, indeed, those kinds of chambers have been of much importance to sustaining environmental precision, offering energy efficiency optimization, and innovation facilitates in many fields. [5] Furthermore, this review shall present emerging trends, technological integrations towards IoT and automation, and future directions of research and development allowing maximum exploitation of these temperature and humidity chambers. This review is expected to give an understanding of how these environmental chambers have been transforming environmental management, scientific exploration, and sustainable development initiatives. [6]

2.2 Understanding Temperature and Humidity issue in the Literature

This section looks exhaustively at Temperature and Humidity Weather Chambers, their effects on research information about climate and, hence, their role in boosting our understanding of global warming and hence our effort at mitigation. In fact, the chambers are used basically to create artificial control environments where scientists study the effects of fluctuating high and low temperatures as well as humidity levels- key indicators for global warming trends. Through such precise simulation and monitoring of the parameters, researchers can come to know the response of the ecosystems, agriculture, and materials under the proper climate change scenarios. In effect, Temperature and Humidity Weather Chambers have made it evident that rising global temperatures and altered precipitation patterns are leading to much more frequent, intense weather events, such as heatwaves, droughts, and heavy rainfall. [7]

Integrated approaches to analyze observed temperature and humidity data collected in the weather chambers with the support of other available environmental as well as socio-economic datasets provide a much more substantial realization on the study of climate change impacts. This integrated approach will help both researchers as well as policy framers to formulate informed strategies about adaptation and mitigation under the complexity of interrelationships between climate change, human activities, and health of the ecosystems. Therefore, Temperature and Humidity Weather Chambers have a hard core role to play in the results of climate change research that is the provision of accurate and reliable data that may be used by the globe at large; in battling climatic changes. With their ability to mimic or simulate environmental conditions, they become an indispensable component in the study and development of mitigants to climate variability and an enhancer of resilience in different fields across the world. [8]

2.3 Temperature and Humidity Control System

2.3.1 Temperature and Humidity Control System for Laboratory Medicine Cabinet

The temperature and humidity control system for the embedded biological laboratory medicine cabinet, designed based on the STM32F103RCT6 chip, is developed for efficient management of the storage of medicines, vaccines, and reagents requiring different temperatures and humidity. The system comes with a central control screen where a user can set accurate temperature and relative humidity values for every storage zone of the cabinet. It records and stores the data for both temperature and humidity periodically, in case of remote notification, if the threshold exceeds it for five minutes. It is divided into two major parts for design strategy: hardware and software. Hardware design includes mainly a module for the detection of temperature and humidity inside all cabinet partitions, which collects and then converts this data into digital kind of signals that are transmitted to the key control module. This module incorporates the STM32F103RCT6 chip primarily to serve the purpose of controlling the temperature with the air-cooled condenser and the evaporator depending on the threshold that is set. A touch screen, actual buttons, and emergency switches provide the human-machine interface and control at the central console of the system. The zigbee sends data to the equipment outlined for remote management and monitoring by the laboratory staff. It means such a comprehensive system will offer the highest level of accuracy with respect to the control of the temperature and humidity levels inside a biological laboratory medicine cabinet, which will create an ideal environment for the storage of pharmaceuticals and ensure smooth management as well as monitoring of the storage environment. [9]

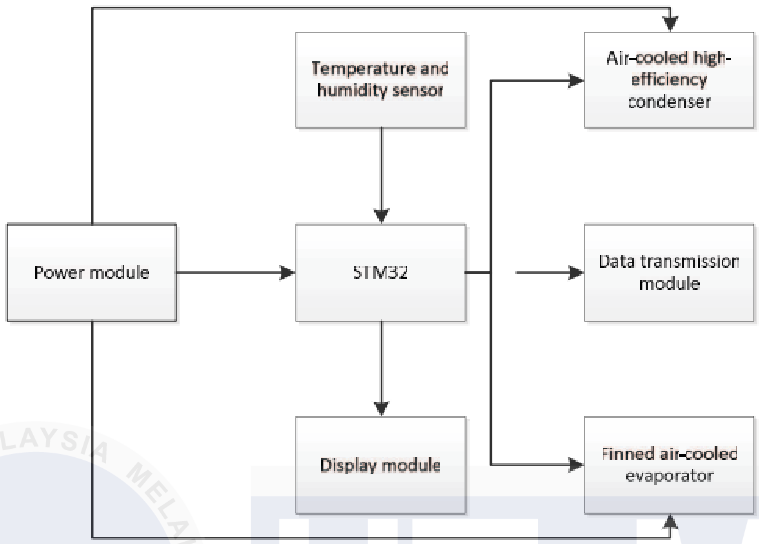

Figure 2.1 : Hardware system design framework figure

2.3.2 Temperature, Humidity, and Light Control System for Indoor Flowers

The automatic control system is centered around the STC89C52 as the main control CPU, with a range of input and output devices forming its peripheral circuit. Input devices include a keyboard button, temperature sensor (DS18B20), humidity sensor, and illuminance sensor. Output devices consist of an exhaust fan, temperature compensation lamp, water pump, fill light, OLED display, alarm system, and others. The system operates as follows: the DS18B20 temperature sensor converts environmental temperature into digital data, sent to the STC89C52 microcontroller. The YL-69 soil moisture sensor and a photosensitive resistance detect soil moisture and light intensity, respectively, with their signals converted to digital through an A/D converter (XPT2046) and then transmitted to the microcontroller for display on an OLED screen. The microcontroller compares these values to preset maximum and minimum thresholds. If the temperature falls below the minimum, the warming lamp activates; if it exceeds the maximum, the microcontroller triggers the exhaust fan for cooling. Low soil moisture activates an alarm for watering, with the microcontroller controlling the water pump. When humidity surpasses the maximum, watering stops. Additionally, if ambient light is insufficient, the fill light is activated. This system integrates sensors, microcontroller logic, and relay circuits to automate environmental monitoring and control, offering efficient management of temperature, humidity, soil moisture, and light intensity for optimized plant care and environmental conditions. [10]

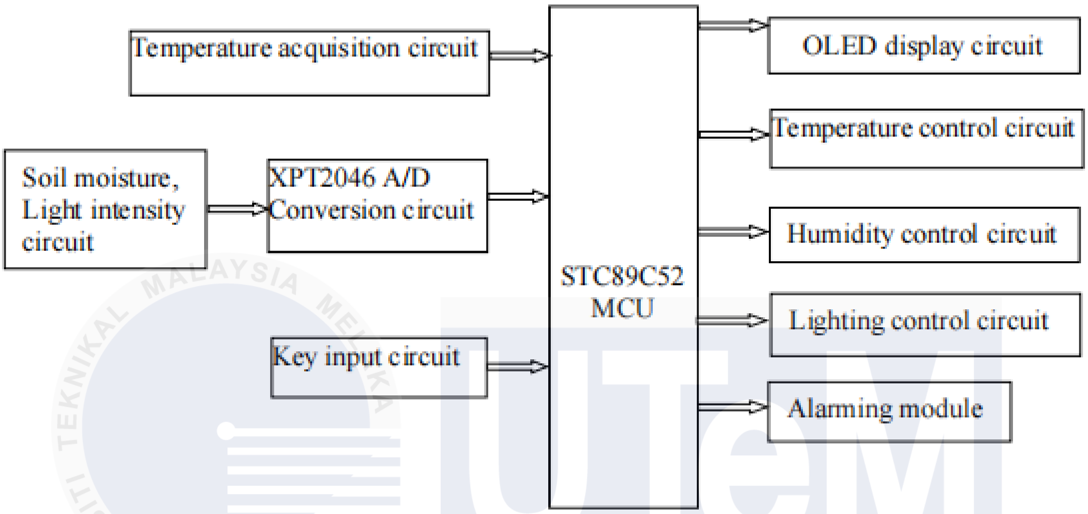

Figure 2.2 : Overall frame structure of the system

2.3.3 Development of Temperature and Humidity Controller for Sprout Cultivation

In an engineering design process, programs were used in plant growth to engineer a temperature and relative humidity controller. A prototype was given with features and dimensions determined. The provided prototype aimed at stabilizing its temperature and humidity to allow the growth of plants inside it. It had some sprout shelves, a water filling slot, and acrylic sliding doors. It involved seven components namely the control system, which consisted of the temperature and humidity sensor; ultrasonic humidifier; water container; humidity-increasing and decreasing fans; and growing shelves. The microcontroller used is an Arduino MEGA 2560 with a relay switch, LCD screen, and ON/OFF switch for environmental factors control such as humidity and temperature. The temperature range of -40°C to 125°C and relative humidity of 0-100% RH were sensed by

DHT22, turning on the ultrasonic humidifier and the fans in turning on the appliances to achieve its optimum growth for the corns. It is carried out by comparing the readings taken from the controller against the wet-dry bulb hygrometer benchmark for five days, recording the results in plant growth when compared to the typical method. In general, the controller kept high accuracy and efficiency in automating environmental parameter control needed for the growth of sprouts in a closed system. [11]

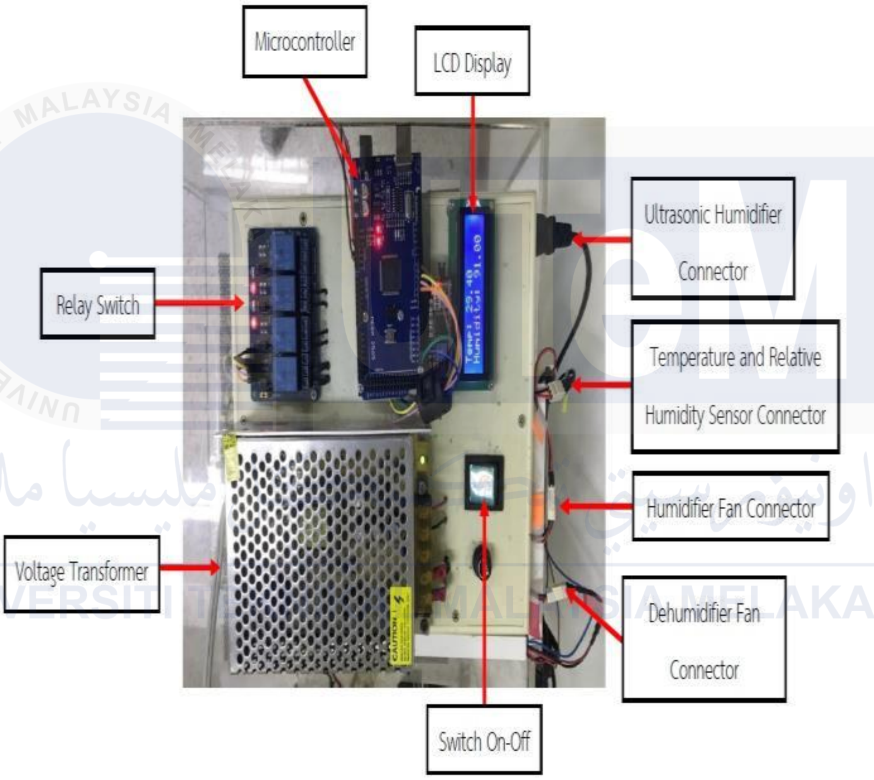

Figure 2.3 : The control system of the temperature and relative humidity controller

2.3.4 Heating and Cooling Fresh Air Using Exhaust Air from HVAC Systems

This study presents experimental setups and the economics in performance analysis on a heat recovery system under conditions of hot and cold day. The experimental setups for simulation of hot day and cold day were made using the same heat exchanger effectiveness in heat recovery, varying the cold air flow rate in the exhaust and hot air flow in the exchanger. Results suggest, the higher the flow rate of air; the transfer rate will be on the higher side. The system will reach an average effectiveness of 87% to 89%. In the same way cold day simulation has depicted heat transfer rates with varying hot air flow rates and the cold air flow rate of the exchanger; the phenomenon shows a constant rise in rates of heat transfer and 42.5% to 89 % average effectiveness. Comparing the two scenarios of the hot and cold day, high efficiency is shown by the system for cold days where more recovery is detected without any ambiguity; this again sharpens its prospects to bring about energy efficiency.

Economic and environmental analysis confirms the cost-effectiveness and sustainability of the system. The levels of heat recovery realized between 60 W and 196 W are equivalent to a rate of energy saving oscillating from 2.4 to 190 kWh a month. Especially on hot days, the system's electric energy-saving capacity and cost reduction will be only more obvious, up to $6 a month in comparison with cold days' savings of $2. Similarly, all dependent factors and running hours or heat recovery rates result in a payback period ranging from 1.5 years to even more than 6 years. Besides, it can also decrease up to 1 ton of CO_2 emissions per year, considering that the system is more environmentally friendly. From the overall effect study, it can therefore be shown with high potential in achieving energy efficiency and cost savings and a positive effect on the environment when the operating conditions are optimally designed and have higher airflow rates. [12]

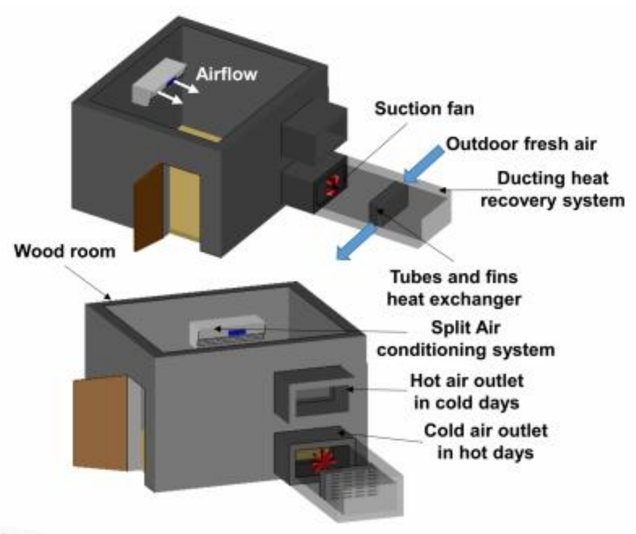

Figure 2.4 : Schematic of the experimental prototype.

2.3.5 Temperature and Humidity Control with Nextion 3.2 HMI in a Natural Greenhouse

This research mainly involves the monitoring and control of microclimate conditions both outside and inside the greenhouse with a very strong emphasis on temperature and humidity parameters. It starts from the external climate where the Automatic Weather Station employs devices fabricated on the 2nd floor deck of the Fatepa Building and begins transmission to other apparatus inside the greenhouse in real-time. The data available from the ecowitt.net website shows trend day wise and week wise for both temperature and humidity. From the trend, it is shown that the temperature is peaking at noon and humidity is inversely proportional to the temperature, which complies with previous research works. Also, IoT-based microclimate monitoring has been designed using ESP8266 and SHT10 sensors, connects the data logger and results are demonstrated on a Nextion 3.2 HMI LCD. It enables real-time monitoring of the inside temperature and humidity of the greenhouse with automated fan and water pump controls depending on set threshold values of temperature and humidity to give the best conditions for plants to grow including the red spinach plant.

The microclimate monitoring system is thus realized in this greenhouse showing proper mechanisms in place for data collection and control. That is to say, the readings show variation with time in an alternating manner, with the resulting appropriate reaction in the enabling of fans and pumps in the regulation of the condition. The data visualization grievance on the Nextion LCD provides insight into changes of environmental conditions that can lead to timely adjustments of the conditions to guarantee the temperature stays within the desired range for plant growth. All in all, IoT technology taken into greenhouse climate management ensures higher accuracy and efficiency of the process, which leads to higher plant productivity. [13]

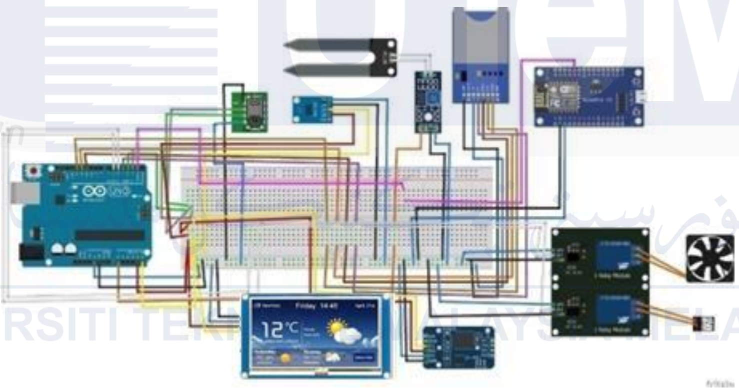

Figure 2.5 : Nextion circuit

2.3.6 Smart Indoor Temperature and Humidity Control System

The system design for the indoor climate control is broadly classified into three major sections, namely the mobile application, the main control board, and the executive board. The main control board consists of modules of sensors, communication management, central control, interaction locally, and modules of communication. It includes body temperature, humidity, and PM2.5 sensors for data collection; a microcontroller for data integration; a display for feedback; buttons for setting parameters;

and Bluetooth and infrared modules for wireless communication. The infrared/WIFI communication-linked executive board includes an infrared receiver and a microcontroller to receive and interpret the execution command coming from the main control board. There would also be a software design, programming the microcontroller to perform various functions such as Bluetooth, infrared communication, the implementation of the PID algorithm, and then designing user interface remote controls through the mobile app.

The tests are simulated once the system has been designed in order to understand and investigate the working of the whole system and all its benefits. The local interactive testing is performed to check the functionality of this main control board under the category of high-end testing, it involves the function of showing real-time sensor data on the LCD display, for setting the control parameters, buttons are used and through an LCD display, interaction is given to the user. With these, the checking of the system's performance and robustness will be done. [14]

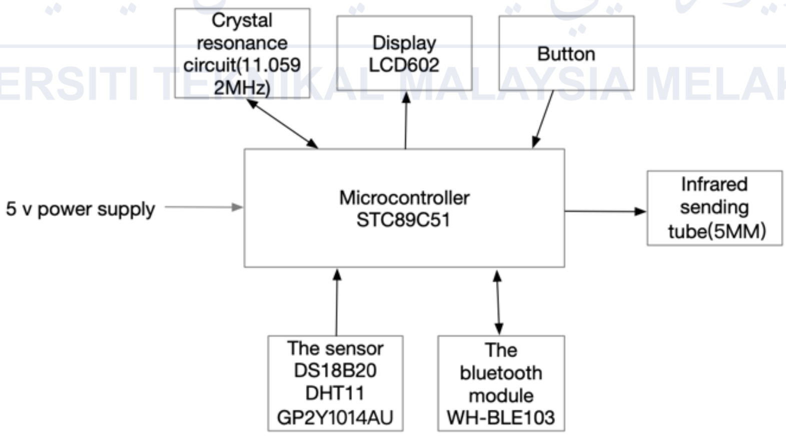

Figure 2.6 : Design of the main control board

2.3.7 ARM-Based Temperature and Humidity Control System Design

In PID control technology, the controlling of temperature and humidity aims to offer optimum conditions for warehouse storage. Proportional, integral, and derivative are the algorithms that have been implemented in order to minimize system errors and enhance speed in the response of the control system. Depending upon the monitored real values of temperature and humidity, the controller adjusts the control parameters with the purpose of making the warehouse environment ideal. It works on the principle of reading the detected value and comparing it with the set value, thus generating a control signal. Actual PID control constantly regulates system parameters toward a balanced state, where all requirements imposed by the warehouse environment are satisfied.

Programming on the system The module involved in programming for the warehouse temperature and humidity monitoring system are: main program, data acquisition subprograms, display subprograms, and relay output control subprograms. This system becomes initialized with power-up, which sets up the parameter readings through ARM11 main control. The temperature and humidity scale data are read through acquisition boards, processed to the system, and therefore proclaims action, e.g., window pusher and fan in excess of temperature beyond limits will automatically turn on, likewise when it is more humid than required; it will turn on a dehumidifier. Another feature of this system is also to set their upper and lower limits for each of these variables through a display interface and, through a WiFi network, remote monitoring and adjustments. [15]

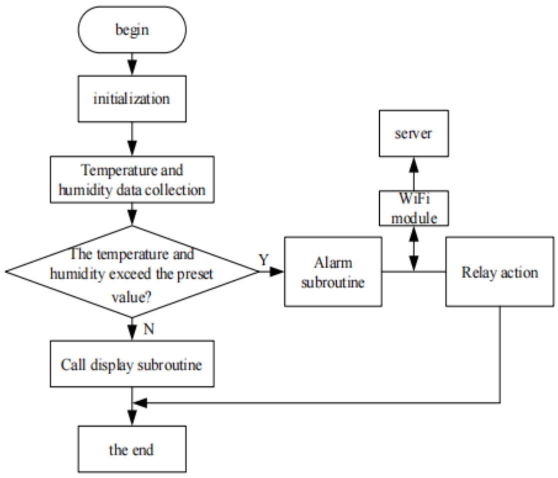

Figure 2.7 : Software Design Flow Chart

2.3.8 Experimental Study on Cooling and Dehumidification Performance of an Ice Storage Air Conditioner in an Underground Refuge Chamber

From the impact factors analysis on the influence factors of ISACS cooling and dehumidifying performance, it is found that IAT, IAV and IARH have a significant influence on ISACS. Experimental results enhance that IAV has the most significant influence on OAAT and OAMC followed by IAT with the least impact by IARH. Through orthogonal experiments, it was found that the optimal cooling and dehumidification conditions were 30°C IAT, 5 m/s IAV, and 70% inlet air humidity. Based on this, the ISACS performs best at these conditions, and IAV is the most dominant of them all for ensuring optimal temperature and humidity regulation.

Comparative performance evaluation of various kinds of ice storage air conditioning systems shows that ISACS can effectively meet its cooling and dehumidification needs for a refuge chamber accommodating not more than 15 persons for not more than 96 hours. Moreover, its design enhancements, which include multiple round tube heat exchange bundles and even utilization of mine-pressurized air to provide power in it, enhance its efficiency and lead to more energy savings. It recommends that the distribution of the cooling capacity of the high-temperature refuge chamber can be optimized so as to extend the effective temperature control time and to improve thermal comfort by pre-cooling surrounding rock during the periods of non-refuge and by admixing cold air from ISACS with mine compressed air. These shall make the ISACS practical and efficient under emergency situations in maintaining safe and comfortable conditions. [16]

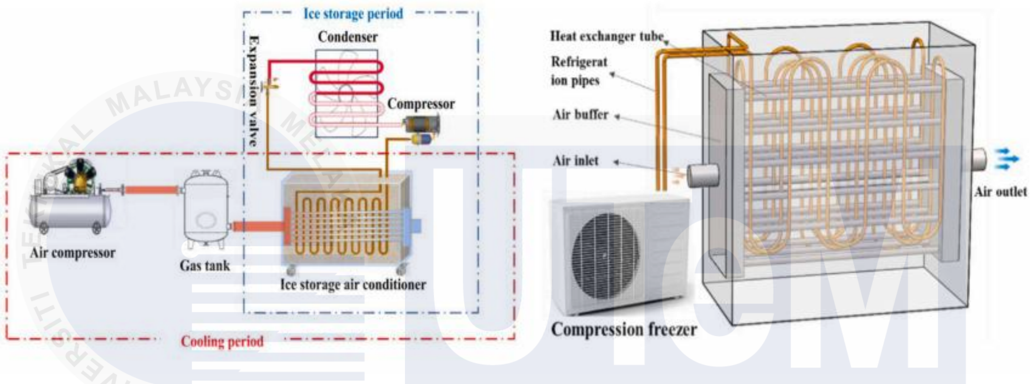

Figure 2.8 : Working Principle and ISACS Structure Schematic

2.4 Temperature and Humidity Monitoring

2.4.1 Assessment of Low-Cost Arduino-Based Temperature, Humidity, and CO2 Sensors for Indoor Environments

This research paper critically compares some selected temperature, relative humidity, and CO2 sensors. It compares these selected sensors on certain aspects like accuracy, cost, availability, compatibility with Arduino, ease in programming, and minimum number of extra components required. The temperature sensor section will include comparisons in terms of measuring range, resolution, and compatibility with the EN–ISO–7726 standards. For the relative humidity sensors, the comparison will be based on the factors of accuracy and EN 16242 standards. The CO2 sensors are tested based on the requirements for good accuracy within well-defined concentration ranges set forth by the California Title 24 Standard. The experimental setup is carried out in order to test the sensors in controlled environments and consequently log their performance with data loggers and other components, including but not limiting to Arduino boards, SD card modules, Wi-Fi shields, among others. Temperature and humidity sensors were tested in the climatic chamber with controlled temperature and humidity levels, while CO2 sensors were tested in an acrylic box injected with CO2 and monitored with a reference sensor CM-0001. This setup enables one to ensure the evaluation of the sensor conditions with respect to accuracy, response time, and reliability at standardized conditions and gives important information on the applicability of the sensors in monitoring environments. [17]

2.4.2 Temperature and Humidity Monitoring System Using DHT11 Sensor and NodeMCU

This paper addresses the design and testing of a tool for monitoring temperature and humidity. Development of a desktop application was accomplished using Visual Basic.Net, while tools were programmed with the Arduino IDE. The software interface showed the result of the temperature and humidity. It first showed the result of the normal room temperature and humidity; after bringing a hot object near the DHT11 sensor, the software demonstrated the operation of the system in case of changes. The hardware setup was based on one NodeMCU module that monitored the room temperature. The test was made by contrasting the values read by the DHT11 sensor, comparing them with the data obtained through the readings taken from a digital thermometer. Once this was performed, leaving both devices exposed to a temperature of high degrees for 5 minutes, the difference in thermal value was of 0.94 degrees centigrade, and for the case of humidity, the difference was 5.9, as opposed to what it had read on the thermometer. All these tests documented the differences of measurements between the tool's own sensors and one made by a digital thermometer, proving that this tool could be used for general and ordinary temperature and humidity monitoring but with some gaps in terms of precision compared with more accurate measuring devices. [18]

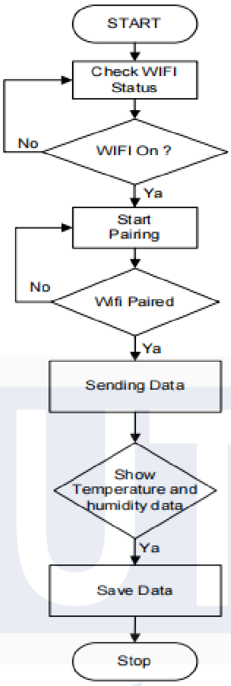

Figure 2.9 : Flow chart of the project

2.4.3 SmartHatch: An IoT-Based Temperature and Humidity Monitoring System for Poultry Egg Incubation and Hatchability

This is a study to develop and validate solar powered egg incubator with IoT applications more efficient in production, enhancing quality and profitability of agribusiness production. In this study, the researchers will closely collaborate with the following major stakeholders, namely; veterinaries, farmers, farm owners, IT experts and engineers, all of whom have practical and technical knowledge of designing and testing a prototype. The temperature sensor DHT11 is tested for functionality using the incubator and 50 eggs for 21 days, which evaluates the accuracy against the gold standard provided by the use of an analog thermostat. Results show that the sensor is efficient at maintaining the incubator at the required temperature levels for optimal hatchability, hence proving effective in the prototype test.

The incubation process has been monitored closely where the temperature and humidity control are kept critically under check for the hatching to facilitate the chicks. The relative humidity of the incubator is also controlled during the incubation periods depending on the varying ranges proposed at different stages to provide maximum hatchability. Hatchability rates are also used in estimating the efficiency of the prototype in the study, which has a success rate of approximately 95.24% based on fertile eggs. Usability assessments also uphold the prototype's functionality, and the satisfaction level of the major stakeholders has been high regarding the prototype performance on temperature management and humidity regulation. The all-inclusiveness of such an approach not only ensures that the eggs will hatch successfully but helps identify the role of IoT-enabled solutions in such modernization of agricultural practices, including the ones that lead to increased productivity and sustainability. [19]

Figure 2.10 : Actual Prototype Setup and Testing

2.4.4 Design of Indoor Temperature and Humidity Monitoring System Using Kalman Filter

This system design has an STM32 microcontroller that uses a DHT11 sensor to collect data regarding the temperature and humidity, uses the Kalman filtering algorithm to make optimum estimates, and uses an HC-05 Bluetooth module for wireless communications. The compliance circuit for the power supply has been realized through the use of a DC-5V voltage regulator AMS1117-3.3 module for the STM32 microcontroller. The temperature and humidity acquisition module circuit is the composition of DHT11 sensor with simple serial communication with the microcontroller. If the data exceeds the threshold set, then alert through the alarm module that comprises a buzzer and 8050 triode, while on the other side, wireless communication module with Bluetooth allows mobile APP control. The optimal estimation of temperature and humidity is obtained using the Kalman filtering algorithm and, therefore, hardware debugging allows obtaining a validation test run of the system operation in both manual and automatic modes.

The system architecture is basically threefold: key power management, precise data acquisition, efficient alarm triggering, and reliable wireless communication-all of which are coordinated by the STM32 microcontroller. Multiplexing with Kalman filtering accrues more accuracy to the data and allows the setting of mechanisms for retention of optimal indoor conditions. The hardware debugging phase validates that the system would appropriately act upon set thresholds by triggering the alarm and engaging appropriate components responsible for regulating the humidity. Such a system design spends, therefore in general, ignores a sophisticated yet very accessible means of indoor climate monitoring and control that exists in a host of real-time data analyzing and interjecting applications. [20]

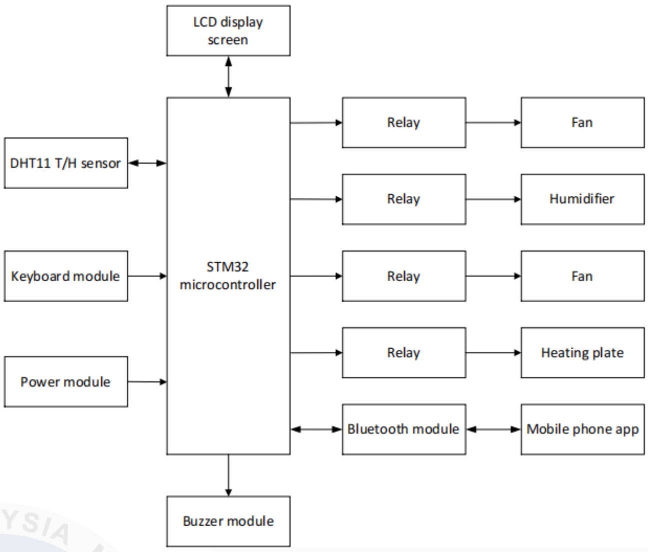

Figure 2.11 : Control system structure block diagram

2.4.5 Remote Temperature and Humidity Measurement System Using IoT and WSN for Smart Homes and Warehouses

Data is stored for analysis purposes as well as other reasons in the use of cloud storage, especially environmental parameters such as temperature and humidity that are stored in rooms. In our case, regarding the parameters mentioned, they are monitored through the use of sensors such as the BME680. It's a very versatile sensor used for other things, too - especially measuring home air quality, or for that matter, making predictions regarding what the weather might do. The system is connected to the cloud using Wi-Fi communication. Data is analyzed using similar platforms such as "ThingSpeak" or tools like MATLAB where detailed data analysis will be done based on pre-defined metrics and error checks.

The factors that determine the operation algorithm of such a system include the initialization of startup routines, oversampling to attain accurate data from sensors, error checking, transmission to the cloud, and notably response mechanisms, either by actuating actuators or pid controllers depending on sensor reading. Also, the system could be integrated with other devices or not as it is in the case of networks like ZigBee or MQTT-SN, which are low power, stretch flexibility, and easy adaptability in different IoT environments like home automation, medical systems, industry automation, ultimately providing efficient intelligent control of environmental parameters and system operations. [21]

2.5 Comparison of Literature Review

Table 2.1 : Comparison Table

No.	Title	Authors	Methods/Devices	Types of Components	Features	Advantages	Disadvantages
i)	Design of Temperature and Humidity Control System for Medicine Cabinet in Biological Laboratory Based on Embedded System	Meng Chao	Uses microcontrollers for sensor integration and data logging	Temperature sensors (DS18B20), humidity sensors (DHT22), CO_2 sensors (MH-Z19)	Real-time monitoring, data logging, low-cost implementation	Cost-effective, easy to implement, suitable for real-time applications	Limited long-term reliability, potential accuracy issues under varying conditions
ii)	Design of temperature humidity and illumination control system for indoor flowers	Haidong Liu, Xiaosong Wang	Automatic control system based on STC89C52 microcontroller	STC89C52 microcontroller, DS18B20 temperature sensor, YL-69 soil moisture sensor, photosensitive	Monitors and controls temperature, humidity, and light intensity for indoor flowers, displays results on OLED, alarms, and	Low cost, strong environmental adaptability, safe and reliable, low power consumption, stable function	Manual presetting required, dependent on sensor accuracy

				resistor, OLED display module	automatic watering system		
iii)	Low-cost Arduino-based temperature, relative humidity and CO2 sensors - An assessment of their suitability for indoor built environments	Pedro F. Pereira, Nuno M.M. Ramos	Uses Arduino-based sensors for temperature, humidity, and CO2 measurements	Temperature sensors (SHT85), humidity sensors, CO2 sensors (K30, T6713-5K)	High accuracy with low-cost sensors, long-term and short-term performance assessment	Low-cost, high accuracy, compliance with standards, suitable for large-scale deployment	Some sensors lose accuracy over long-term use, not all sensors meet stringent standard limits
iv)	Monitoring System for Temperature and Humidity Measurement with DHT11 Sensor Using NodeMCU	Muhammad Syahputra Novelan, Muhammad Amin	Monitoring system using NodeMCU and DHT11 sensor	NodeMCU, DHT11 temperature and humidity sensor, Visual Basic Net, Firebase	Measures temperature and humidity, real-time data transmission to Firebase, visual monitoring via desktop application	Remote monitoring, real-time data access, stable communication	Dependent on internet connectivity for data access, limited to specific sensors
v)	Study and Development of Temperature and Humidity Controller	Khongdet Phasinam, Thanwamas Kassanuk	Temperature and humidity controller	Arduino MEGA 2560 ATmega 2560, AC to DC adapter, 220 V 10 A relay switch, LCD	Controls temperature and humidity for sprout cultivation,	Enhances growth conditions for sprouts, potentially improving yield and quality	Specific to sprout cultivation, may not be applicable to other crops

	for Sprout Cultivation			screen, DHT22 temperature and humidity sensor	enhancing growth conditions		
vi)	SmartHatch: An Internet of Things–Based Temperature and Humidity Monitoring System for Poultry Egg Incubation and Hatchability	Ronaldo C. Maaño, Roselyn A. Maaño, Pedro Jose De Castro, Enrico P. Chavez, Susana C. De Castro, Cielito D. Maligalig	IoT-based system with Arduino MKR1000, DHT11 sensor	Arduino MKR1000, DHT11 sensor, LCD, sensors for temperature and humidity monitoring	Real-time temperature and humidity monitoring, Wi-Fi connectivity, cost-effective solution, suitable for agricultural use	Cost-effective, practical, suitable for IoT applications, improved agricultural productivity	Requires long-term energy sources for optimal performance, dependency on consistent internet connectivity for IoT functions
vii)	Heating/Cooling Fresh Air Using Hot/Cold Exhaust Air of Heating, Ventilating, and Air Conditioning Systems	Mahmoud Khaled, Samer Ali, Hassan Jaber, Jalal Faraj, Rabih Murr and Thierry Lemenand	IoT-based system with STM32 microcontroller, DHT11 sensor, Kalman filter, LCD1602, HC-05 Bluetooth module	STM32 microcontroller, DHT11 sensor, LCD1602, HC-05 Bluetooth module	Real-time monitoring and control, stable and reliable data processing, accurate results with Kalman filter, Bluetooth connectivity	Stable, reliable, easy to implement, accurate data processing	Limited flexibility in handling varied temperature condition, complexity in installation and maintenance

viii)	Temperature and Humidity Control using Nextion 3.2 HMI in the Natural Greenhouse	Sirajuddin Haji Abdullah, Joko Sumarsono, Gagassage Nanaluih De Side, Asih Priyati	Microclimate monitoring with ESP8266, SHT10 sensor, Nextion 3.2 HMI LCD	ESP8266, SHT10 sensor, Nextion 3.2 HMI LCD, relay for fan and water pump control	IoT-based monitoring, data logging, internet connectivity, smartphone access via Cayenne application, control of fans and water pump	Easy access via smartphone, reduced workload for GUI design, efficient data logging	Relies on SHT10 sensor, which has a slightly higher error margin, Depends on WiFi for data transmission, which may be less stable in areas with poor internet connectivity
ix)	Design of indoor temperature and humidity monitoring system based on Kalman Filter	Weixu Huang, Qing Wang, Feng Jiang	STM32 microcontroller, DHT11 sensor, Kalman filter, HC-05 Bluetooth module, LCD1602	STM32 microcontroller, DHT11 sensor, Kalman filter, HC-05 Bluetooth module, LCD1602	Real-time monitoring and control, Kalman filtering for accurate data, Bluetooth connectivity, mobile app for monitoring	Stable, reliable, convenient, accurate data processing, widely applicable	Utilizes Bluetooth for mobile app connection, potentially limiting range and stability compared to WiFi, Needs a specific power module (AMS1117-3.3) for voltage regulation, which could add complexity to the design
x)	Intelligent Indoor Temperature and Humidity Control System	Shuo Sun, Yukun Ma	Divided into modules (Management, Communication, Hollow, Sensor, Execution). Uses	Temperature sensors, humidity sensors, PM2.5 sensors, Bluetooth module,	Real-time monitoring and automatic adjustment of indoor temperature and	Improved indoor climate control, user-friendly, real-time adjustments.	Poor penetration of infrared signals, multi-room communication

			sensors, wireless modules, single-chip microcomputers, Bluetooth, infrared transmitters, microcontrollers.	infrared transmitter, microcontroller.	humidity, centralized control.		issues, lacks sensors on the executive board.
xi)	Remote temperature and humidity measurement system with the use of IoT and WSN for intelligent homes and warehouses	Stanyo Kolev	The system design includes a power supply unit, ESP32 microcontroller with built-in Wi-Fi module, and BME680 sensor for measuring temperature and humidity. Data is processed and sent to cloud storage via Wi-Fi	ESP32 with built-in Wi-Fi, BME680 for temperature, humidity, air quality, and pressure measurements	Real-time monitoring of temperature, humidity, and air quality, data transmission to cloud storage for analysis, remote activation of actuators based on sensor readings	Cost-effective, high accuracy, easy integration and implementation, can be used for various applications such as home automation, healthcare, and industrial automation	Potential issues with sensor placement affecting accuracy, significant costs for large-scale implementation, need for regular calibration which can be time-consuming and require specialized equipment
xii)	Design of temperature and humidity control system based on ARM	ZhanPeng Huang, XinHua Du, YangKe Gou, Qin Li	ARM Cortex-M3 microcontroller, DHT11 temperature and humidity sensor	Microcontroller, sensor, LCD display	Real-time monitoring, user interface via LCD	Cost effective, precise control and scalable	Limited to specific sensors, potential compatibility issues with other sensors

							Limited to specific sensors, potential compatibility issues with other sensors
xiii)	Experimental study on cooling and dehumidification performance of an ice storage air conditioner used in underground refuge chamber	Weishuang Guo, Zujing Zhang, Hongwei Wu, Liang Ge, Xing Liang, Ruiyong Mao	Arduino Uno, DHT11 temperature and humidity sensor, soil moisture sensor, Wi-Fi module	Microcontroller, sensors, Wi-Fi module	Remote monitoring, data logging, automated irrigation control	Remote access, integration with IoT, improves crop yield	Requires stable internet connection, initial setup cost

2.6 Summary

Moreover, this literature review concerns the different systems developed for the control of temperature and humidity within a wide range of fields-scopes, including, but not limited to: biological laboratory medicine cabinets, indoor flowers, weather stations, greenhouses. The most significant technologies involved are: microcontrollers' usage - STM32F103RCT6, Arduino, STC89C52; sensors integration such as DHT22, DS18B20, SHT75 for environment monitoring with high precision. These systems comprise IoT, wireless communication, and advanced algorithms like PID control and Kalman filtering to achieve a higher degree of accuracy and efficiency. The applications range from optimum laboratory storage to agricultural growth chambers and hence are new advancements in the embedding of sensors, transfer of data, and automation mechanisms. The research work clearly depicts that optimum maintaining conditions are a must for sensitive environments. The advent of advanced technology plays a vital role in efficient monitoring, environmental sustainability, and energy efficiency.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is a systematic and theoretical analysis of the methods applied to a field of study. It can embrace a theoretical analysis of the principles and methods of enquiry applicable to that branch of knowledge. We have prepared a detailed plan to be able to convert this project into a fully functional and safe product. Each step can be planned in a flow from data gathering to mechanical design, circuit design, and testing with verification, so that the project is ensured to finish on time. Represented below is a total system and a series of steps under the "Temperature and Humidity Weather Chamber" in this comprehensive plan.

3.2 Sustainable Development

Within the concerns of sustainable development, the Temperature and Humidity Weather Chamber project greatly converges with SDG 13: Climate Action. It provides a way to enhance climate resilience through controlled testing of technologies reacting to a wide range of environmental conditions. To do so, it simulates and optimizes the parameters of temperature and humidity, thus helping research into the areas of reducing greenhouse gas emissions and enhancing energy efficiency in various sectors of industries. It further encourages the sustainable use of climate-responsive technologies or methods relevant to mitigating impacts on the environment and using fewer resources. Education and awareness in enhancing capacities and knowledge on the strategies in mitigating climate change mean contributing to reinforcing global efforts on SDG 13 objectives. This holistic approach underscores the chamber's potential as a vital tool for fostering climate resilience and promoting sustainable development practices.

3.3 Description of Methodology

Methodology explains detail about the whole system and flow of step that used in “Temperature and Humidity Weather Chamber”. Then, it also describes furthermore the planning of the whole project we do in semester 6 & 7. This is the attachment that explains my project.

i) Flowchart of project
ii) Block diagram
iii) Project software

3.3.1 Flowchart of project

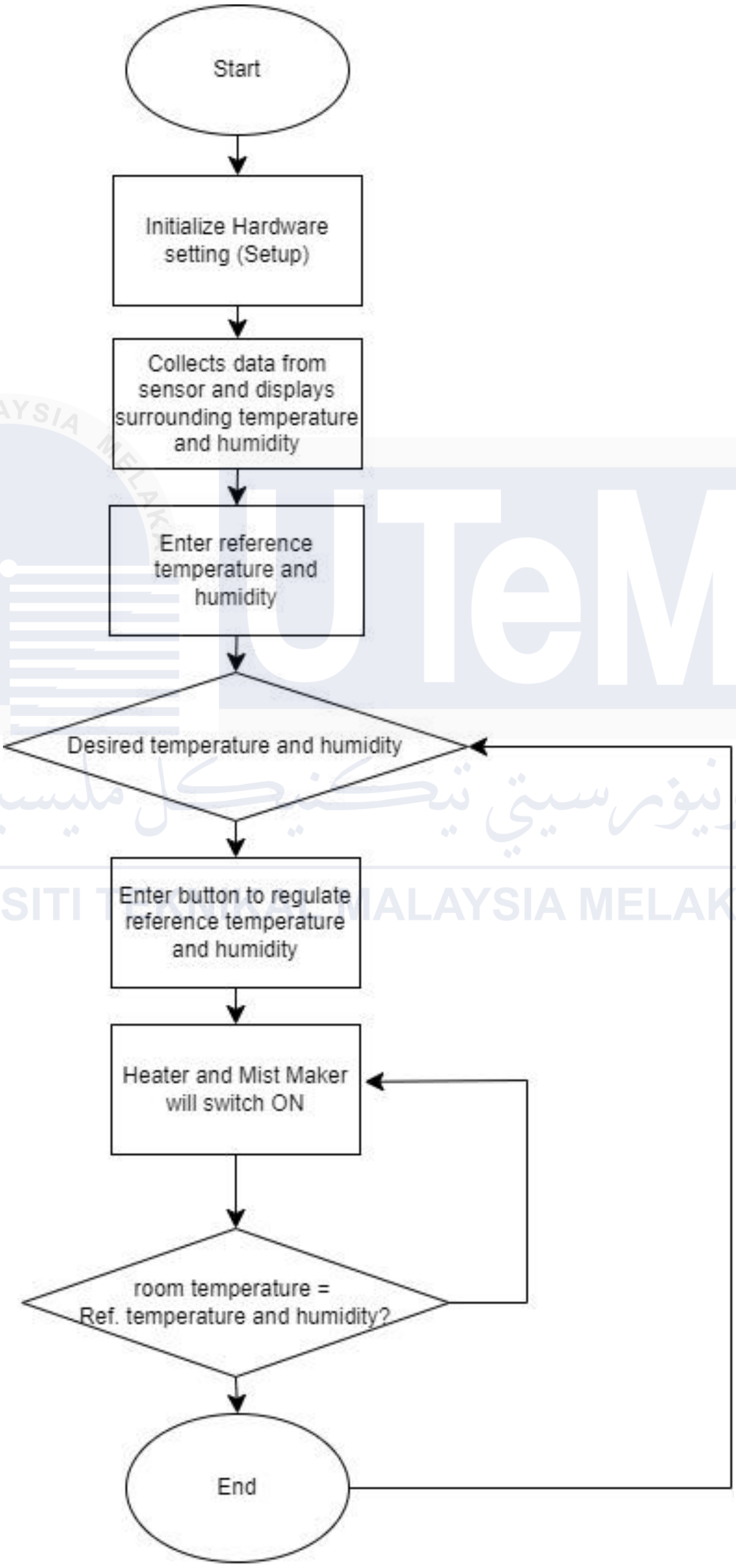

Figure 3.1 : Flow Chart of the project

3.3.2 Flowchart Explanation

The first step is to initialize the hardware settings, or the apparatus that includes the sensors, heating element , and mist producers, etc. Upon informing the hardware to initialize, the user can now set the reference temperature and humidity of the chamber or, in other words, the environment desired. These reference values thus set up will establish the expected goal conditions of the environment. Then it starts to receive the inputs from the sensors to determine the current temperature and humidity of the room and present it to the user.

Then it compares this with the reference values input by the user, after which all the current conditions were shown. After it has determined what needed to do next, if the reference values are equal to the current conditions, the software will sit idle and keeps notifying the user to track it if he wants to track. But if these values are not equal the user proceeds by starting the control sequence with a press of the button. The heating element and mist maker then come on as an effect and then alter the environmental conditions. The mist maker alters the humidity adding it or subtracting the same and the heating element changes the temperature. The user interface, in the meantime, queries the current condition of the room although the control sequence is still on.

On the other hand, if the results are still divergent, the software will proceed to alter the conditions until they are exactly coincident with the reference values. This loop repeats itself until the user requirements are met by the continuing check and alteration of the surroundings. By now, the weather room should be able to hold enough Humidity and

Temperature for a myriad of tests to be conducted inside it, achieving the purpose of the whole project in the process.

3.3.3 Block Diagram of Project

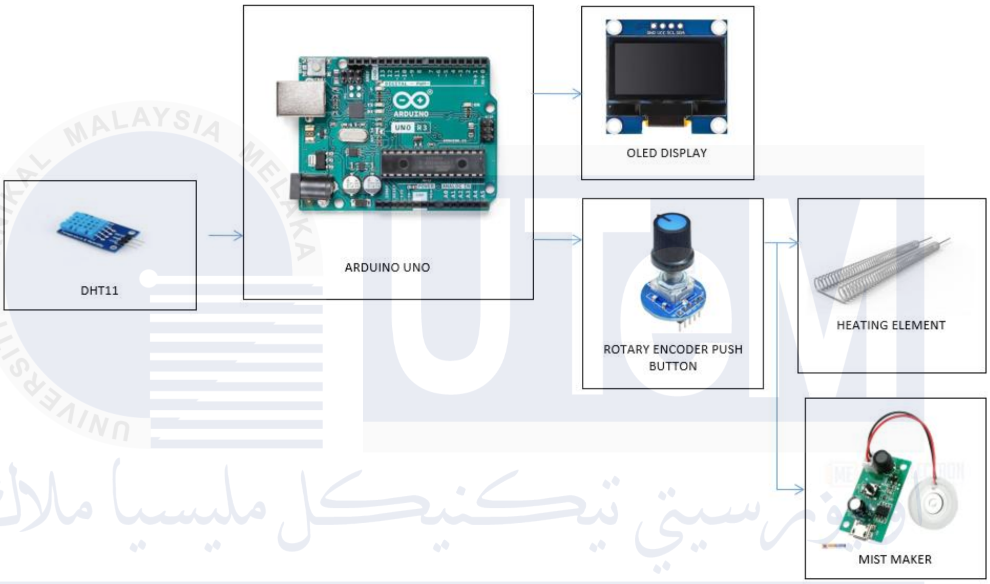

Figure 3.2 : Block Diagram of the system

The DHT22 sensor measures the temperature and humidity levels and sends this data to the Arduino Uno. The Arduino Uno acts as the central control unit, processing the sensor inputs and managing the outputs. The LCD display connected to the Arduino Uno shows the temperature and humidity readings, along with other relevant information. A rotary encoder push button allows the user to set the desired temperature and humidity levels, which the Arduino Uno then uses to adjust the system's parameters. The Arduino Uno controls the heating element for adjusting the temperature and a mist maker for controlling the humidity by creating mist inside the weather chamber. This system constantly monitors, adjusts the temperature and humidity to maintain the desired condition written in the code inside the weather chamber.

3.3.4 Block Diagram Explanation

3.3.4.1 Power Supply

Figure 3.3 : DC supply

The power supply unit serves the dispensing of DC power among this arduino system's various component parts. This is how all devices that are used from sensors, microcontrollers, to pumps - get exactly the amount of electricity that they need. A reliable power supply is very crucial to maintaining the stability of the system and avoiding problems associated with power.

3.3.4.2 DHT22

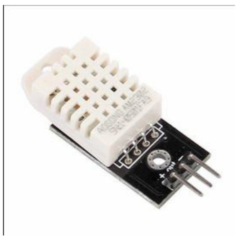

Figure 3.4 : DHT22

This is the very common and cheap digital sensor for measurement of temperature and humidity. DHT22 measures the temperature from 0°C to 100°C with an accuracy of ±2°C, and the relative humidity from 20% to 100% RH, with an accuracy of ±5%. The sensor is single-wire digital and hence is easier to connect and interface with any microcontroller including Arduino. But the DHT22, though spuriously simpler and cheaper, does find great use in hobbyist projects and simple environmental monitoring. This type of simplicity and cost-effectiveness is hard to beat.

3.3.4.3 Arduino UNO

Figure 3.5 : Arduino UNO

The Arduino Uno is based on the ATmega328P microcontroller board. It serves as the main control unit for the entire system by processing all the inputs developed by the DHT22 sensor along with controlling the power to multiple output devices. In other words, the Arduino Uno takes sensor data and user inputs from the rotary encoder push button and uses it to arrive at decisions that will control and operate the heating element and mist maker in such a way that the desired environment is achieved.

3.3.4.4 Arduino Coding Configuration

Main_Coding_PSM.ino

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "DHT.h"

// LCD setup
LiquidCrystal_I2C lcd(0x27, 16, 2);  // Adjust I2C address if needed

// DHT sensor setup
#define DHTPIN A0
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

// Rotary encoder pins
const int clkPin = 10;
const int dtPin = 11;
const int swPin = 9;

// Hardware pin definitions
const int Heater = 13;    // Heater
const int Motor = 12;     // Motor (Humidifier)

// Control mode variables
int controlMode = 0;  // 0 = Adjust humidity, 1 = Adjust temperature
int humiditySetting = 50;  // Default target humidity
int temperatureSetting = 22;  // Default target temperature

// Rotary encoder state
int currentStateCLK;
int previousStateCLK;
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 50;  // milliseconds

// Timing for sensor read interval
unsigned long previousMillis = 0;
const long interval = 2000;

void setup() {
  // Initialize LCD and DHT sensor
  lcd.init();
  lcd.backlight();
  dht.begin();

  // Initialize rotary encoder and hardware pins
  pinMode(clkPin, INPUT);
  pinMode(dtPin, INPUT);
  pinMode(swPin, INPUT_PULLUP);
  pinMode(Heater, OUTPUT);
  pinMode(Motor, OUTPUT);

  // Initial display message
  lcd.setCursor(0, 0);
  lcd.print("Weather Chamber");
  delay(1500);
  lcd.clear();

  // Set initial states
  digitalWrite(Heater, LOW);
  digitalWrite(Motor, LOW);

  // Initialize rotary encoder state
  previousStateCLK = digitalRead(clkPin);

  // Display initial settings
  updateLCD();
}

void loop() {
  // Rotary encoder control for setting adjustments
  adjustSettings();

  // Read current temperature and humidity at intervals
  unsigned long currentMillis = millis();
  if (currentMillis - previousMillis >= interval) {
    previousMillis = currentMillis;
    readAndDisplaySensorData();
  }

  // Check the SW button for mode change
  if (digitalRead(swPin) == LOW && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();
    controlMode = (controlMode + 1) % 2;  // Toggle between 0 and 1
    updateLCD();
  }
}

// Function to handle rotary encoder adjustments
void adjustSettings() {
  currentStateCLK = digitalRead(clkPin);

  if (currentStateCLK != previousStateCLK && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();
    if (digitalRead(dtPin) != currentStateCLK) {
      // Adjust upwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting + 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting + 1, 20, 100);
      }
    } else {
      // Adjust downwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting - 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting - 1, 20, 100);
      }
    }
    updateLCD();
  }
```

```
  previousStateCLK = currentStateCLK;
}

// Function to read sensor data and update the display
void readAndDisplaySensorData() {
  float T = dht.readTemperature();
  float RH = dht.readHumidity();

  if (isnan(T) || isnan(RH)) {
    Serial.println("Failed to read from DHT sensor!");
    lcd.setCursor(0, 0);
    lcd.print("Sensor Error");
    delay(2000);
    lcd.clear();
    return;
  }

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Temp: ");
  lcd.print(T);
  lcd.print("C");

  lcd.setCursor(0, 1);
  lcd.print("Hum: ");
  lcd.print(RH);
  lcd.print("%");

  // Control motor (humidifier) based on humidity readings and setpoint
  if (RH >= humiditySetting) {
    digitalWrite(Motor, HIGH);  // Turn on motor (humidifier)
  } else {
    digitalWrite(Motor, LOW);   // Turn off motor (humidifier)
  }

  // Control heater based on temperature readings and setpoint
  if (T >= temperatureSetting) {
    digitalWrite(Heater, HIGH); // Turn on heater
  } else {
    digitalWrite(Heater, LOW);  // Turn off heater
  }
}

// Function to update the LCD with the current mode and settings
void updateLCD() {
  lcd.clear();

  if (controlMode == 0) {
    lcd.setCursor(0, 0);
    lcd.print("Set Humidity:");
    lcd.setCursor(0, 1);
    lcd.print(humiditySetting);
    lcd.print("%");
  } else if (controlMode == 1) {
    lcd.setCursor(0, 0);
    lcd.print("Set Temperature:");
    lcd.setCursor(0, 1);
    lcd.print(temperatureSetting);
    lcd.print("C");
  }
}
```

Figure 3.6 : Arduino Coding

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "DHT.h"
```

Figure 3.7 : Import Libraries

The command “**Wire.h**” enables communication with I2C devices. It was used here for the I2C LCD. “**LiquidCrystal_I2C.h**” is a library to control an LCD via I2C, simplifying the setup and use of the display. “**DHT.h**” library is for interfacing with the DHT sensor, which reads temperature and humidity.

```
// LCD setup
LiquidCrystal_I2C lcd(0x27, 16, 2);  // Adjust I2C address if needed
```

Figure 3.8 : LCD Setup

The command **“lcd(0x27, 16, 2)”** defines the LCD object with “**0x27**” which is the I2C address of the and “**16, 2**” is the dimensions of the LCD (16 characters wide, 2 lines).

```
// DHT sensor setup
#define DHTPIN A0
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);
```

Figure 3.9 : DHT Sensor Setup

The command “**DHTPIN A0**” is defined to mention where the DHT sensor’s data pin is connected. “**DHTTYPE DHT11**” specifies the sensor type DHT22 that we use. “**DHT dht(DHTPIN, DHTTYPE)**” command creates a DHT object to read sensor data.

```
// Rotary encoder pins
const int clkPin = 10;
const int dtPin = 11;
const int swPin = 9;
```

Figure 3.10 : Rotary Encoder Pins

The command “**clkPin**, **dtPin**” defines the rotary encoder’s data pins used for detecting rotation direction. “**swPin**” is the button pin on the rotary encoder for toggling modes.


```
// Hardware pin definitions
const int Heater = 13;   // Heater
const int Motor = 12;    // Motor (Humidifier)
```

Figure 3.11 : Hardware Pin

Pins 13 and 12 are used to control the heater and humidifier.

```
// Control mode variables
int controlMode = 0;  // 0 = Adjust humidity, 1 = Adjust temperature
int humiditySetting = 50;  // Default target humidity
int temperatureSetting = 22;  // Default target temperature
```

Figure 3.12 : Control Mode Variables

The command “**controlMode**” tracks whether the user is adjusting humidity (0) or temperature (1). “ **humiditySetting**” command is to set Default target humidity to 50% and “**temperatureSetting**” to set default target temperature to 22°C.

```
// Rotary encoder state
int currentStateCLK;
int previousStateCLK;
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 50;  // milliseconds
```

Figure 3.13 : Rotary Encoder State

This command tracks the rotary encoder's state to detect changes and avoid false signals caused by bouncing. "**debounceDelay**" command ensures stable input processing.

```
// Timing for sensor read interval
unsigned long previousMillis = 0;
const long interval = 2000;
```

Figure 3.14 : Timing for Sensor Reading

"**interval**" is used to define a 2-second delay between sensor readings to avoid excessive updates.

```
void setup() {
  // Initialize LCD and DHT sensor
  lcd.init();
  lcd.backlight();
  dht.begin();

  // Initialize rotary encoder and hardware pins
  pinMode(clkPin, INPUT);
  pinMode(dtPin, INPUT);
  pinMode(swPin, INPUT_PULLUP);
  pinMode(Heater, OUTPUT);
  pinMode(Motor, OUTPUT);

  // Initial display message
  lcd.setCursor(0, 0);
  lcd.print("Weather Chamber");
  delay(1500);
  lcd.clear();
```

Figure 3.15 : Setup Function

"**lcd.init, lcd.backlight, dht.begin**" command initializes the LCD, turns on its backlight, and starts the DHT sensor. "**pinMode**" sets up pins for the rotary encoder and hardware controls. "**lcd.setCursor, lcd.print, delay, lcd.clear**" command displays "Weather Chamber" for 1.5 seconds and then clears the LCD.

```
void loop() {
  // Rotary encoder control for setting adjustments
  adjustSettings();

  // Read current temperature and humidity at intervals
  unsigned long currentMillis = millis();
  if (currentMillis - previousMillis >= interval) {
    previousMillis = currentMillis;
    readAndDisplaySensorData();
  }

  // Check the SW button for mode change
  if (digitalRead(swPin) == LOW && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();
    controlMode = (controlMode + 1) % 2;  // Toggle between 0 and 1
    updateLCD();
  }
}
```

Figure 3.16 : Loop Function

"**adjustSettings**" command calls a function to check the rotary encoder's state and adjust humidity/temperature settings. "**readAndDisplaySensorData**" command reads sensor data every 2 seconds and updates the display. The command "**digitalRead**" checks if the encoder button is pressed to toggle between humidity and temperature adjustment modes.

```
// Function to handle rotary encoder adjustments
void adjustSettings() {
  currentStateCLK = digitalRead(clkPin);

  if (currentStateCLK != previousStateCLK && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();
    if (digitalRead(dtPin) != currentStateCLK) {
      // Adjust upwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting + 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting + 1, 20, 100);
      }
    } else {
      // Adjust downwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting - 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting - 1, 20, 100);
      }
    }
    updateLCD();
  }

  previousStateCLK = currentStateCLK;
}
```

Figure 3.17 : Rotary Encoder Adjustments

"**digitalRead**" command here detects rotation direction by comparing the clkPin and dtPin states. The settings can be adjusted using command (**humiditySetting or temperatureSetting**) based on the current control mode.

```
// Function to read sensor data and update the display
void readAndDisplaySensorData() {
  float T = dht.readTemperature();
  float RH = dht.readHumidity();

  if (isnan(T) || isnan(RH)) {
    Serial.println("Failed to read from DHT sensor!");
    lcd.setCursor(0, 0);
    lcd.print("Sensor Error");
    delay(2000);
    lcd.clear();
    return;
  }

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Temp: ");
  lcd.print(T);
  lcd.print("C");

  lcd.setCursor(0, 1);
  lcd.print("Hum: ");
  lcd.print(RH);
  lcd.print("%");

   // Control motor (humidifier) based on humidity readings and setpoint
   if (RH >= humiditySetting) {
     digitalWrite(Motor, HIGH);  // Turn on motor (humidifier)
   } else {
     digitalWrite(Motor, LOW);   // Turn off motor (humidifier)
   }

   // Control heater based on temperature readings and setpoint
   if (T >= temperatureSetting) {
     digitalWrite(Heater, HIGH); // Turn on heater
   } else {
     digitalWrite(Heater, LOW);  // Turn off heater
   }
 }
```

Figure 3.18 : Sensor Data and Display

The command "**dht.readTemperature, dht.readHumidity**" will read temperature and humidity from the DHT sensor. "**isnan**" command displays an error message if the readings fail. "**lcd.print**" displays the current temperature and humidity on the LCD. "**digitalWrite**" command activates the motor if humidity is below the target and activates the heater if the temperature is below the target.

```
// Function to update the LCD with the current mode and settings
void updateLCD() {
  lcd.clear();

  if (controlMode == 0) {
    lcd.setCursor(0, 0);
    lcd.print("Set Humidity:");
    lcd.setCursor(0, 1);
    lcd.print(humiditySetting);
    lcd.print("%");
  } else if (controlMode == 1) {
    lcd.setCursor(0, 0);
    lcd.print("Set Temperature:");
    lcd.setCursor(0, 1);
    lcd.print(temperatureSetting);
    lcd.print("C");
  }
}
```

Figure 3.19 : Update LCD

"**lcd.print**" command displays either the humidity or temperature setting, depending on the active control mode.

3.3.4.5 LCD Display

Figure 3.20 : LCD Display

This means a very small screen with various visual information being presented to the user. Since it is attached to the Arduino Uno, in our implementation, it thus live-updates a lot of temperature and humidity readings but also other interesting information or settings. Therefore, reading off from currently inside the weather chamber is pretty straightforward, as well as checking if everything functions according to expectations.

3.3.4.6 Rotary Encoder Push Button

Figure 3.21 : Rotary Encoder Push Button

The control input to this system is the rotary encoder push button. The user inputs make interactions with the system: he would rotate the encoder and, hence, set the temperature desired, and similarly, the percentage of humidity he desires to see in the atmosphere. He may use the functions of the push button to enable selections or to confirm settings. This input by the user is relayed to the Arduino Uno, and these system parameters are suitably altered.

3.3.4.7 Heating Element

Figure 3.22 : Heating Element

This heating element works based on the conversion principle of electrical energy to heat. The thermometer or the temperature control system controls this. When the temperature of the chamber goes below the Setpoint, it turns on and heats the air for maintaining the atmosphere. It serves to help with controlled or, in other words, constant conditions for accurate testing. At the same time, indirectly, it influences the conditions of the relative humidity. In most industrial applications, it serves to convey highly accurate and credible environmental situations.

3.3.4.8 Mist Maker

Figure 3.23 : Mist Maker

This device, depending on the need, turns the mist maker into action or not. It produces a very fine kind of mist. In this work, Arduino Uno controlled the mist maker depending on the data on the humidity of the air received from the DHT22 sensor and depending on the desired ending level set by the user. So, the Arduino turns the mist maker on or off depending on the need to keep the humidity of the air within the weather chamber at a desired level.

3.4 Project Software

3.4.1 Proteus Professional 8

In this project, Proteus Professional 8 is used to simulate the Temperature and Humidity Weather Chamber before implementing the actual hardware. The circuit will consist of an

Arduino Uno microcontroller, a DHT22 sensor for temperature and humidity, a two-channel relay module to switch on or off the heater and humidifier, and an LCD with I2C interface that will display in real time. The DHT22's data pin is connected to one of the Arduino's digital inputs. The input pins of the relay module are connected to digital pins 13 and 12 and drive simulated loads, like LEDs, representing a heater and humidifier, respectively. The LCD is connected using the I2C interface with pins A4 (SDA) and A5 (SCL). The Arduino is programmed by a sketch to read data from sensors, drive relays on/off based on the threshold, and show the readings on the LCD. Testing of the system against various responses for proper functioning is achieved by running the simulation.

3.4.2 Arduino IDE (Integrated Development Environment)

Arduino IDE is an open-source programming software designed for writing and compiling code using Arduino modules. This official programming software simplifies the code compilation process, making it accessible for individuals with varying levels of expertise. It is compatible with multiple operating systems such as MAC, Windows, and Linux, and supports a range of Arduino modules including Arduino Mega, Arduino Uno, and more. Below is the code in the "Arduino IDE" for the Temperature and Humidity Weather Chamber to handle the sensors, heater, and humidifier controls, and real-time data presentation. This project uses the "DHT library" for the DHT22 sensor to measure temperature and humidity and the "LiquidCrystal_I2C library" to handle the LCD display. The code begins with the initialization of the sensor, LCD, and relay control pins. In the `setup()` function, the LCD is initialized using `lcd.init()` and displays a start-up message while setting up the sensor and the relays for operation. The continuous reading from DHT22 temperature and humidity is done in the "loop()" function, comparing them against threshold values. If the temperature or humidity falls out of the desired range, it turns on the heater or humidifier by triggering or deactivating the relays. The real-time readings and system status are displayed on the LCD so that users can monitor the chamber conditions directly. This structure of coding ensures smooth integration of components and accurate control of environmental conditions.

3.5 Hardware Setup

The casing of the Temperature and Humidity Weather Chamber is solid, made from 4 sheets of aluminum (2mm thick) for the sides and bottom, which provide rigidity and good thermal retention. The front and top are made of acrylic sheets, allowing users to view inside. Inside, a DHT22 sensor measures temperature and humidity with high precision. The environmental control is implemented by means of a heater and a humidifier, controlled through a two-channel relay module connected with Arduino's digital pins 13 and 12. Arduino acts as the controller of the system, reading from sensors and giving the actuating signal to devices in need. In real time, the readings will be displayed on an LCD with an I2C interface connected with A4 and A5 pins of Arduino. Integrated system to provide real accurate monitoring and control, with condition systems in this chamber, ideal for applications with consistency sought at temperature and humidity.

3.6 Summary

In developing a temperature and humidity weather chamber, emerging technologies are integrated to create a controlled environment with as much precision as possible for a variety of applications. It collects real-time data from the temperature and humidity sensors, and then the same is communicated to the central processing unit using wireless protocols for real-time monitoring and control. This will ensure real-time, accurate, and continuous data collection. The data will be processed and analyzed in the cloud for real-time decision and adjustment. The sensors are well calibrated to measure temperature and humidity to very accurate values, offering reliable data to the operator to maintain the desired set point of the environmental conditions within the chamber. The machine learning models are used to enhance and eliminate errors within the accuracy. These models scrutinize the patterns of data, and in-line adjustment of the system's parameters is done to keep the condition optimal. With the latest signal processing techniques being applied on the data, the system can now distinguish between many factors that might lead to a change in temperature and humidity, such as a change in the outer environment. This contributes to effective energy consumption and a streamlined process that minimizes the overall costs within a climate chamber. With the employment of appropriate advanced control technology and regular maintenance, the chamber runs with high efficiency at a long life cycle, consequently making use of it very cost beneficial over time. Such an integrated approach will develop an efficient, accurate, and cost-effective solution for controlled environment conditions in various applications.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The environmental monitoring temperature and humidity weather chamber in this paper is made from control systems to ensure that it is sustainable. In its turn, the scientific experiment and industrial processes call for stable, strict, or well-regulated conditions. The means of achieving the control and monitoring of these occur actively or traditionally and are mostly cumbersome to execute, power hungry, and involve extensive use of human workforce.

In this project we would design, construct and build a weather chamber, which incorporated the technologies and measurements of temperatures and humidity. Sophisticated control systems allow one to maintain environmental conditions that can be manipulated in the first order, thus offering the prospects of both repeatability and confirmation. Here, I merely provide an overview of some outcomes of the design and use of this system that has begun to emerging.

4.2 Results and Analysis

4.2.1 Results

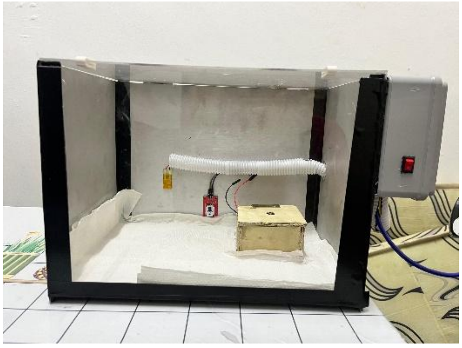

Figure 4.1 : Overall view of the project

Figure 4.2 : Exterior of the project

4.2.2 Output of the Project

Figure 4.3 : Current Detection of Humidity & Temperature

Figure 4.4 : Desired Humidity

Figure 4.5 : Output after Humidifier powered On

Figure 4.6 : Desired Temperature

Figure 4.7 : Output after Heater powered On

The Temperature and Humidity Weather Chamber is a compact and efficient system designed to regulate environmental conditions with precision. As shown in (Figure 4.1 and Figure 4.2), the chamber's design ensures ease of use and adaptability for various applications. Using a (DHT22 sensor), the system accurately detects real-time temperature and humidity levels, which are displayed on an LCD for user monitoring (Figure 4.3). The setpoint of the temperature and the humidity can be changed through the rotary encoder as shown in (Figure 4.4 and Figure 4.6), respectively. Once the setpoints are identified, the system will automatically turn on either the humidifier (Figure 4.5) or heater (Figure 4.7) to sustain the best environment. This immediate way of sustaining will make sure that the chamber will be running reliably and constantly for scientific research, product testing, and other agricultural purposes. Overall, the project is an integrated and user-friendly solution for controlled environments where accurate climate control is achieved.

Summary

This chapter presents outlines the development and results of the Temperature and Humidity Weather Chamber designed to regulate environmental conditions with precision. The results show promise, evidencing how the system can effectively maintain the environment at desired levels. It reacts dynamically to changes in temperature and humidity due to the precise integration of the DHT22 sensor, robust control via Arduino Uno, and a LCD displays current and target values, while a heating element and a motorized humidifier maintain desired levels.. Simulation testing gives consistent performance with guaranteed parameters that keep the environment within the bounds of design. The proposed maintenance policy ensures the minimum loss of time and efficiency in the long run. The expected real implementation of the system in the real world shows that it will fulfill all its objectives and it will be able to provide a reliable and efficient weather chamber solution for a wide range of usages.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In summary, the Temperature and Humidity Weather Chamber can be highlighted with regards to sustainable and environmental management techniques. Indeed, through proper temperature and humidity levels control, this chamber helps maintain a controlled atmosphere, which consequently forms ground for many industries such as research, manufacture, and agriculture. Techniques of energy efficiency and resource management are also improvised, along with climate-resilient technologies, due to the capacity to simulate and streamline circumstances. Also, the ancillary educational features incorporated in the chamber orient awareness and knowledge about the implications of change in temperature and humidity, eliciting proactive actions sited in sustainability.

Moreover, the relationship of the project to SDG 13: Climate Action with other sustainable development goals puts emphasis on its role in curbing the climate threat and linking interaction practices to environmental stewardship. The Temperature and Humidity Weather Chamber is a company that has fixed its core agenda on using innovation and research as a means of advancing sustainable practices-linking interaction behavior with changing environmental concerns. As such, it represents progress toward a more sustainable future where technological innovation and careful environmental management work together to support global initiatives aimed at advancing sustainability and climate resilience.

5.2 Future Works

Further development in the future in this area brings along several possible lines of upgrading for the Temperature and Humidity Weather Chamber : more sophisticated sensors within the chamber will mean finer monitoring and control of the relevant levels of temperature and humidity. This may include more accurate ranges of such sensors, if coupled with automation technologies and smart control systems. It would read the real-time data, provided by the identification and usage of AI algorithms or machine learning models, and predict, adjust against environmental parameters for maximizing the operational efficiency and responsiveness. Furthermore, the energy efficiency improvements also need to be face-lit. Another approach of research works can be the optimization of heating, cooling, and ventilation systems in order to consume least energy and at the same time maintaining exact environmental conditions. Further, strategy embedding renewable sources like solar power, wind power, etc., shall provide scope for sustainability, show reduction in operational cost and also ensure operation/functioning at off-grid or remote locations

Making it implement the Blynk software inside it would make such a system remote access in terms of change in its settings and also reading the data from it that would get updated in real time from anywhere. Advanced data analytics along with intuitive user interface would present intuitive operation and insightful data visualization permitting informed decision making along with process optimization. Indeed, such joint research efforts between academia and associated industry players would render interdisciplinary knowledge that would further widen the applications of this chamber, from average pharmaceutical storage to complex crop conditioning. All these combined makes the Temperature and Humidity Weather Chamber project a truly leading subject in environmental control technology, with wide-ranging implications for sustainable development and innovation in many other fields.

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APPENDICES

Appendix A

Rancangan Kerja	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pendaftaran tajuk PSM 1														
Penghantaran Synopsis														
Menentukan objektif dan Gantt chart														
Penulisan Bab 1 pengenalan														
Penghantaran Bab1														
Penulisan Bab 2 kajian literartur														
Penghantaran Bab2														
Penulisan Bab 3 Metodologi														
Penghantaran Bab3														
Pembetulan Bab 1, 2, dan 3														
Perbincangan dan semakan terakhir berkaitan format laporan PSM 1														
Penghantaran penulisan lengkap kepada penyelia														
Membuat pembetulan akhir sebelum menghantar ke penilai														
Presentation														

Gantt Chart PSM 1

Appendix B

Rancangan Kerja	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pengumpulan data awal	■													
Pembangunan sistem	■	■												
Pengujian awal sistem			■	■										
Pengujian lanjut sistem				■	■									
Analisis data dan keputusan					■									
Penulisan Bab 4: Analisis Data						■	■							
Penulisan Bab 5: Kesimpulan dan Cadangan							■							
Penghantaran laporan penuh kepada penyelia								■	■					
Penghantaran laporan penuh kepada penyelia									■					
Pembetulan laporan akhir										■	■			
Pembetulan Bab 1 hingga Bab 5										■	■			
Penyediaan poster												■		
Penyediaan untuk pembentangan													■	
Pembentangan akhir PSM2														■

Gantt Chart PSM 2

Appendix C

Coding

~~~
`````
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "DHT.h"

// LCD setup
LiquidCrystal_I2C lcd(0x27, 16, 2);  // Adjust I2C address if needed

// DHT sensor setup
#define DHTPIN A0
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

// Rotary encoder pins
const int clkPin = 10;
const int dtPin = 11;
const int swPin = 9;

// Hardware pin definitions
const int Heater = 13;   // Heater
const int Motor = 12;    // Motor (Humidifier)

// Control mode variables
int controlMode = 0;  // 0 = Adjust humidity, 1 = Adjust temperature
int humiditySetting = 50;  // Default target humidity
int temperatureSetting = 22;  // Default target temperature

// Rotary encoder state
int currentStateCLK;
int previousStateCLK;
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 50;  // milliseconds

// Timing for sensor read interval
unsigned long previousMillis = 0;
const long interval = 2000;

void setup() {
  // Initialize LCD and DHT sensor
  lcd.init();
  lcd.backlight();
  dht.begin();
~~~

```
  // Initialize rotary encoder and hardware pins
  pinMode(clkPin, INPUT);
  pinMode(dtPin, INPUT);
  pinMode(swPin, INPUT_PULLUP);
  pinMode(Heater, OUTPUT);
  pinMode(Motor, OUTPUT);

  // Initial display message
  lcd.setCursor(0, 0);
  lcd.print("Weather Chamber");
  delay(1500);
  lcd.clear();

  // Set initial states
  digitalWrite(Heater, LOW);
  digitalWrite(Motor, LOW);

  // Initialize rotary encoder state
  previousStateCLK = digitalRead(clkPin);

  // Display initial settings
  updateLCD();
}

void loop() {
  // Rotary encoder control for setting adjustments
  adjustSettings();

  // Read current temperature and humidity at intervals
  unsigned long currentMillis = millis();
  if (currentMillis - previousMillis >= interval) {
    previousMillis = currentMillis;
    readAndDisplaySensorData();
  }

  // Check the SW button for mode change
  if (digitalRead(swPin) == LOW && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();
    controlMode = (controlMode + 1) % 2;  // Toggle between 0 and 1
    updateLCD();
  }
}

// Function to handle rotary encoder adjustments
void adjustSettings() {
  currentStateCLK = digitalRead(clkPin);

  if (currentStateCLK != previousStateCLK && (millis() - lastDebounceTime) >
debounceDelay) {
```

```
    lastDebounceTime = millis();
    if (digitalRead(dtPin) != currentStateCLK) {
      // Adjust upwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting + 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting + 1, 20, 100);
      }
    } else {
      // Adjust downwards
      if (controlMode == 0) {
        humiditySetting = constrain(humiditySetting - 5, 0, 95);
      } else if (controlMode == 1) {
        temperatureSetting = constrain(temperatureSetting - 1, 20, 100);
      }
    }
    updateLCD();
  }

  previousStateCLK = currentStateCLK;
}

// Function to read sensor data and update the display
void readAndDisplaySensorData() {
  float T = dht.readTemperature();
  float RH = dht.readHumidity();

  if (isnan(T) || isnan(RH)) {
    Serial.println("Failed to read from DHT sensor!");
    lcd.setCursor(0, 0);
    lcd.print("Sensor Error");
    delay(2000);
    lcd.clear();
    return;
  }

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Temp: ");
  lcd.print(T);
  lcd.print("C");

  lcd.setCursor(0, 1);
  lcd.print("Hum: ");
  lcd.print(RH);
  lcd.print("%");

  // Control motor (humidifier) based on humidity readings and setpoint
  if (RH >= humiditySetting) {
    digitalWrite(Motor, HIGH);  // Turn on motor (humidifier)
```

```
  } else {
    digitalWrite(Motor, LOW);   // Turn off motor (humidifier)
  }

  // Control heater based on temperature readings and setpoint
  if (T >= temperatureSetting) {
    digitalWrite(Heater, HIGH); // Turn on heater
  } else {
    digitalWrite(Heater, LOW);  // Turn off heater
  }
}

// Function to update the LCD with the current mode and settings
void updateLCD() {
  lcd.clear();

  if (controlMode == 0) {
    lcd.setCursor(0, 0);
    lcd.print("Set Humidity:");
    lcd.setCursor(0, 1);
    lcd.print(humiditySetting);
    lcd.print("%");
  } else if (controlMode == 1) {
    lcd.setCursor(0, 0);
    lcd.print("Set Temperature:");
    lcd.setCursor(0, 1);
    lcd.print(temperatureSetting);
    lcd.print("C");
  }
}
```

````
````

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