DESIGN AND DEVELOPMENT OF COST EFFECTIVE ENVIRONMENTAL CONTROL SYSTEM FOR PROTECTIVE CULTIVATION WITH GSM

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra (India)

In the partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in

IRRIGATION AND DRAINAGE ENGINEERING

by

MR. SONAWANE RUSHIKESH NITIN

(Regd. No. ENDPM 2019 / 164)

B. Tech (Agricultural Engineering)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING,
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH,
DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA).

October, 2021

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Approved by the advisory committee

(U. S. Kadam)
Chairman and Research Guide
Professor and Head,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology, Dapoli

Members

(S. T. Patil)
Assistant Professor,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology,
Dapoli

(P. M. Ingle)
Agricultural Engineer,
AICRP on Water Management,
Wakawali

(H. T. Jadhav)
Assistant Professor,
Department of Farm Structure,
College of Agricultural Engineering and Technology, Dapoli

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted
by me or any other person to any other
University or Institute
for award of Degree or
Diploma.

(Sonawane Rushikesh Nitin)

Place : Dapoli

Date :

Prof. Dr. U. S. Kadam

B. Tech. (Agril. Engg.), M. Tech. (A.E.) IDE, Ph.D. (U.K)
Chairman and Research Guide,
Professor and Head,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712
Dist. Ratnagiri, Maharashtra (India)

CERTIFICATE

This is to certify that the thesis entitled **“Design and Development of Cost Effective Environmental Control System for Protective Cultivation with GSM”**, submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.) in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Irrigation and Drainage Engineering**, embodies the record of a piece of bonafide research work carried out by **Mr. Sonawane Rushikesh Nitin (Regd. No. ENDPM 2019 / 164)** under my guidance and supervision and that no part of this thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

(U. S. Kadam)

Place : Dapoli

Date :

Prof. Dr. U. S. Kadam

B. Tech. (Agril. Engg.), M. Tech. (A.E.) IDE, Ph. D. (U.K)
Professor and Head,
Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712
Dist. Ratnagiri, Maharashtra (India)

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Place : Dapoli

Date : **(U. S. Kadam)**

Dr. Y. P. Khandetod

M. Tech. (P.H.E.), Ph. D. (AGFE), IIT Kharagpur

Dean,

Faculty of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli – 415 712
Dist. Ratnagiri, Maharashtra (India)

CERTIFICATE

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The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place : Dapoli

Date : **(Y. P. Khandetod)**

ACKNOWLEDGEMENT

Although the words hardly suffice at this moment, I avail this opportunity to express my deep sense of gratitude and indebtedness to my research guide and Chairman of the Advisory Committee ***Prof. Dr. U. S. Kadam****, Professor and Head, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli for his valuable inspiration, scholastic guidance, generous treatment and constant encouragement throughout this research work. He was always beside me during the happy and hard moments to push me and motivate me and help in final shaping of this manuscript in the present form.*

I take this opportunity to express sincere reverence, a deep sense of gratitude and grateful thanks to ***Dr. Y. P. Khandetod,*** *Dean, Faculty of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli for his encouragement and providing necessary facilities for prosecuting the study.*

I am especially indebted to ***Dr. S. T. Patil,*** *Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli for his encouragement and provision of necessary laboratory and technical assistance for prosecuting the study.*

I am deeply obliged to ***Dr. P. M. Ingle,*** *Agricultural Engineer, AICRP on Irrigation Water Management, CES, Wakawali, Dr. BSKKV, Dapoli for giving me time to time valuable guidance and directions.*

Grateful thanks are extended to ***Dr. H. T. Jadhav****, Assistant Professor, Department of Farm Structure, College of Agricultural Engineering and Technology, Dapoli for his timely valuable guidance, encouragement, and motivation in the research work.*

It's my fortune to gratefully acknowledge the support of my dear friends ***Tejas Sir, Sampada Mam, Rawat Sir, Ramesh Sir, Ajay, Nita, Ranjit Sir, Deepak, Suraj Sir, Sainath, Jaypal, Vicky sir, Prashant Dada, Uday Kaka, Aniket Dada and Sawant Kaki,*** *for their constant support and timely help during this project work.*

Finally, I acknowledge the people who mean a lot to me, my parents, ***Mr. Nitin Sonawane (Papa)*** *and* ***Mrs. Madhuri Sonawane (Mummy)*** *for showing faith in me and giving me liberty to choose what I desired. I salute you all for the selfless love, care, pain and sacrifice you did to shape my life. I would never be able to pay back the love and affection showered upon by my parents. With their blessing and support. I could complete this study.*

I am extremely obliged to acknowledge the respect and affection of my sisters ***Vaishnavi and Janhavi.*** *No words are enough to describe their efforts in building up my educational career and my all-round development.*

I express my sincere thanks to those who directly and indirectly extended help during the research work.

Place : Dapoli

Date :

(Sonawane Rushikesh Nitin)

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LIST OF SYMBOLS

Symbol	Description
%	Per cent
^{0}C	Degree Celsius
^{0}F	Degree Fahrenheit
®	Registered trademark symbol
™	Trade Mark
µs	Microseconds
$	Dollar

LIST OF ABBREVATIONS

Abbreviation	Meaning
A	Ampere
AC	Alternating current
AM	Anti Meridiem
AT	Attention
ADC	Analog to digital convertor
AMC	Available Moisture Content
App	Application
ARM	Advanced Reduced instrument set computer Machine
ASEE	American Society for Engineering Education
Cm	Centimeters
DC	Direct Current
E	East
etc.	Etcetera
et al.	and others
FC	Field Capacity
FIE	Frontiers in Education
Fig.	Figure
gm	Gram
Ha	Hectare
Hz	Hertz
GB	Giga Byte
Gmail	Google mail
GOI	Government of India
GPRS	General Packet Radio Services
GND	Ground
GSM	Global System for Mobile Communication
Hr	Hour
Ha	Hectare
IDE	Integrated development environment
Inc	Incorporated

IO	Input Output
iOS	iphone Operating System
IoT	Internet of Things
LCD	Liquid Crystal Display
LED	Light Emmiting Diode
LDR	Light dependent resistor
Lit	Liter
Ltd	Limited
M	Meter
MCU	Micro Computer Unit
Mha	Million hectare
Min	Minutes
Mm	Millimeters
Mv	Megavolt
N	North
no.	Number
PAR	Personal Animation Recorder Parallel
PC	Personal computer
PIC	Peripheral Interface Controller
PIR	Passive Infrared Sensor
PM	Post Meridiem
Ppm	Parts per million
PWM	Pulse Width Modulation
Pvt	Private
PWP	Permanent Wilting Point
RH	Relative Humidity
SCADA	Supervisory Control and Data Acquisition
SD	Storage Device
Sec	Seconds
SIM	Subscriber identity module
SMS	Short Message Service
USB	Universal Serial Bus
V	Volt

VB	Visual Basic
viz.	Namely
Vs	Versus
VWC	Volumetric water content
Wi-Fi	Wireless Fidelity
WSN	Wireless sensing network

ABSTRACT

DESIGN AND DEVELOPMENT OF COST EFFECTIVE ENVIRONMENTAL CONTROL SYSTEM FOR PROTECTIVE CULTIVATION WITH GSM

by

Mr. Sonawane Rushikesh Nitin

Regd. No. : ENDPM 2019 / 164

Department of Irrigation and Drainage Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

Project guide	:	**Prof. Dr. U. S. Kadam**
Department	:	**Irrigation and Drainage Engineering**

The present study entitled, "Design and Development of Cost Effective Environmental Control System for Protective Cultivation with GSM'' was carried out during the year 2019-20 and 2020-21 at the Laboratory and the Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

The different commercial environmental control systems like Priva Compass, Growtronix Automation System, Growlink System, Autogrow IntelliClimate Controller, iGrow 800 Greenhouse Controller are available in the market are having certain merits and demerits, some of them may be working well but costing is high and require skill manpower. Some systems required frequent maintenance. The system is difficult to understand, problem in its operations, not serviceable locally and spares are not available easily. Therefore, to overcome limitation of available systems in the market, the unit of the automatic environmental control system coupled with real time irrigation system was developed by assembling the various hardware components such as Arduino Mega 2560 (controller), DHT 22 sensor, soil moisture sensors, solid state relays, GSM module, Bluetooth module, solenoid valve, wires and other accessories. The programming required for controlling the exhaust fan, solenoid

valve and electric motor was done using C and C++ in the Arduino IDE. DHT 22 sensor was used to record temperature and relative humidity inside the protective cover and Dual probe conductance based and anticorrosive soil moisture sensors were used to record the real time soil moisture content from the pot.

The field testing of the system was done by installing the system in the greenhouse prototype. Under calibration, the temperature and relative humidity sensors were calibrated by comparing DHT 22 sensor readouts in ^{o}C and % with the respective temperature and relative humidity readouts determined by Thermometer and Masons Hygrometer respectively. After getting readouts, the average error in measurement of temperature and relative humidity sensors was obtained and used later for setting of LSP and HSP to minimize the error and to get reliable and most accurate readout for further processing. While the soil moisture sensor was calibrated by comparing moisture content readout with gravimetric moisture content. The non-linear polynomial equation of degree 3 in terms of ‘x’ and ‘y’ was developed and the other values of corresponding moisture content were determined using interpolation.

The value of 32 ºC temperature was given as higher set point to ON the exhaust fan, solenoid valve for fogger and pump. While, 28 ºC temperature was given as lower set point to OFF the exhaust fan, solenoid valve for fogger and pump. The lower set point for relative humidity of 55% was given to ON solenoid valve for fogger and pump. Higher set point for relative humidity of 65% was given to OFF solenoid valve for fogger and pump. Along with it the value of the field capacity of the soil was given as the higher set point to the system in order to OFF the solenoid valve and pump. The value of the desired depletion of available moisture (50 percent AMC) was given as the lower set point to the system to ON the solenoid valve and pump.

The field performance and testing of sensors includes the temperature, relative humidity and soil moisture sensor readout which was compared with the thermometer, Masons Hygrometer and moisture content by gravimetric method respectively. According to that, two DHT 22 sensors and three soil moisture sensors were installed in the greenhouse prototype by adopting a standard procedure. The controller was tested for the one month period on daily basis for temperature and relative humidity and on weekly basis for soil moisture content from 28/12/2020 to 27/01/2021 at fixed time intervals of four hours starting from 8.30 am followed by 12.00 pm and 4.30 pm respectively.

The results of the study revealed that during temperature measurement, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. The developed unit of automatic environmental control system has maximum variation in temperature readings of about 3.33 %. The average readout of relative humidity shown by RHS-I and RHS-II has close match with the actual relative humidity shown by Masons Hygrometer. The developed unit of automatic environmental control system has maximum variation in relative humidity readings of about 10.28 %. The average readout of available soil moisture shown by SMS-I, SMS-II and SMS-III nearly matches with the actual available soil moisture content shown by Gravimetric method. The developed unit of automatic environmental control system has maximum variation in available moisture content readings of about 5.10 %. Hence, it is revealed from the study that with the use of an automatic environmental control system coupled with real time irrigation system, the temperature and relative humidity inside the protective cover and available soil moisture content inside the pot was always maintained within predetermined limits.

The total cost incurred for the design and development of the controller along with accessories for prototype greenhouse is Rs. 11,781/- and estimated cost for the greenhouse of size 20 × 28 m^2 is Rs. 24,996/-.

Therefore, the designed and developed automatic environmental control system for protective cultivation with GSM is found cost effective and working efficiently for controlling environment and irrigation in protective cover along with saving water and energy.

I. INTRODUCTION

The total geographical area of India is 328.7 Mha out of which 200.9 Mha is the gross cropped area of the country (61.11 % of total geographical area) (Anonymous, 2017). The population of India is 16.5 % (1.22 billion) of the world's population (Mane, 2019). The increasing demand for the food is growing due to the constantly growing population. There is already tremendous pressure on the available natural resources like soil, water and land, etc. to fulfill the demand of food like grains and vegetables of growing population. It is a challenge to meet the ever growing demand of food. Therefore, it is essential to shift our farming system from conventional to advance to meet this challenge.

Climatic change is a significant challenge in front of the farmers. Most of the farmers are doing traditional farming in India and are facing problems like abrupt variation in climate change, high temperature, cyclones and other which is hampering the productivity. Again the farmers are facing the problems of rate for their agricultural produce as there are chances to have the tremendous supply in the market as there is no any control, planning and strategy to grow any specific crop by the farmers. Therefore, sometimes there may be surplus and shortage of agricultural produce irrespective of the demand. Therefore to tackle with the danger of climate change there is a need to alter the environmental parameters suit to the growing crops which is only possible under the protective cover. This leads to bring the agricultural produce in off season to fetch the higher prices in the market. Therefore, the option goes to modern farming techniques such as Greenhouse / Shednet house cultivation, hydroponic farming, etc. Many farmers are now switching over from open cultivation to protective cultivation to cultivate the off season crop to fetch the higher price in the market by creating the congenial environment inside the protective cover. Area under protected cultivation of horticulture crops was reported to be about 40,000 ha in 2014 (Singh, 2014).

All plants and vegetation requires certain climatic conditions for their proper growth. Therefore, it is necessary to create the favourable environmental conditions as close to the ideal or as per requirement of the crops to be grown under the protective cover. To create an optimal environment, the major climatic and environmental parameters such as light, temperature and humidity need to be alter to create congenial environment for the plant growth (Kolhe and Annadate, 2012).

Temperature and humidity are the most important and influencing parameter among the others, needs to be taken care of which by default taking care of soil conditions/ media in production of crops cultivated under protective cover. Lack of control over any of them will ultimately lead to unpleasant growth of crops, attracts more and severe pests and diseases which results in the loss in production. Temperature and relative humidity influences the load of airborne viruses, bacteria, fungi and etc. Temperature and relative humidity plays an important role in the lifecycle of the plants along with light. When plants have the right humidity and temperature they thrive, because they open their pores completely and so breathe deeply without threat of excessive water loss (Kale, 2016).

It is proven fact that the light, temperature and humidity requirement is different for different types of crops. Tomatoes yield best with ideal temperature and relative humidity range of 28-30 °C and 55-65 %, respectively. For peppers ideal temperature and relative humidity is 30 °C and 55-65 %, respectively. (https://www.commercial-hydroponic-farming.com/ideal-temperature-humidity-greenhouse-crops/). Also, crop like gerbera requires ideal temperature of 23°C for flower initiation and 25-27 °C for leaf unfolding. The flowering of Gerbera is harmed below 12°C (Bud initiation will stop) and above 35°C and relative humidity during day time inside the greenhouse should be 70 %, (De and Kumar, 2019) which will maintain the good health of the plants. Thus, controlling temperature and humidity plays an important role to grow high valued crops under protective cover.

Though the plants are in need of different climatic conditions to have the better quality and quantity, however it is difficult to manage these environmental conditions manually even though the plants are grown under protective cover. Therefore, the option goes to automation of the system. Along with the automation of climate control system again there is need to take care for supply of required amount of water and fertilizers as and when required by the growing plants to keep them more active for longer active period to get better quality and maximum yield from the unit area.

Automation for environmental control system is one of the prudent technology to control environment inside the greenhouse to create the congenial environment in order to suit to high valued crops are to be grown under protective cover. An automatic environmental control system means the operation of the system with no or minimal manual intervention except the surveillance. Along with the climate control system the real time soil moisture based irrigation system which irrigates field according to the requirement of crop is needed. The real time soil moisture based automatic irrigation system is taking care of congenial soil moisture condition all the while which will favour to the root environment and always try to maintain the soil moisture condition to the field capacity.

In market the climate control system and the automatic irrigation system based on time, volume, etc. are available, however they are having certain limitations some important of them are as follows;

i. High Cost
ii. Requirement of skilled manpower
iii. Continuous energy supply
iv. High maintenance
v. Recalibration after energy failure
vi. Installation and etc.

There are various manufacturers of the environmental control system worldwide viz., Raiseon Automation and Control Engineering Pvt. Ltd., Climate Control System Inc., Plantech Control System Inc., etc. However, the cost of existing environmental control system in the market is expensive and beyond the reach of marginal farmers. The cost of the system ranges from 1 to 5 lakh for 560 m^2 area of polyhouse (https://www.indiamart.com/agriplastprotected-cultivation/polyhouse-automation-system.html). Not only this, but it also requires frequent maintenance and calibration which requires skill manpower and again adding the cost. This problem can be tackled by designing and development of user friendly, cost effective, sensor based automatic climate control system with GSM.

Therefore, it was felt necessary to develop environmental control system with GSM module to fulfill the following requirements of marginal farmer(s) combined with real time automatic irrigation system;

i. User-friendly management of temperature, humidity and irrigation
ii. Cost effective
iii. No need to recalibrate even after energy failure
iv. Minimum or nil maintenance
v. The operational details of system should be received to mobile through SMS

Therefore, it was decided to develop such an accurate and integrated automatic environmental control system including real time soil moisture based automatic irrigation system which will be cost effective, maintain temperature and humidity of the polyhouse according to requirement of crop, deliver water as per crop water requirement, with digital display of temperature, humidity and soil moisture content status on mobile/ PC and that to with GSM, data storage and transfer facility etc.

This proposed technology will helps in maintaining temperature and humidity within the threshold limits suitable for optimum plant growth. When the temperature of the greenhouse shall cross the limit then the sensor will sense temperature and send to the controller, controller shall process the readout and pass the order to relay to start the exhaust fan, then the exhaust fan will automatically start to bring temperature within the set limits. When temperature reaches upto set limits the fan will be stopped automatically by following the same steps and procedure. If the humidity of the greenhouse fall down than the set limit then again sensors shall sense the humidity, pass to the controller, controller process the readout and issues order to relay to start the pump and solenoid valve for fogger and automatically stop when reaches the desired and or the set limit of humidity. Also, the proposed system is consisting the real time soil moisture based automatic irrigation system which work on the same working principle by the upper limit i.e. field capacity and lower limit i.e. 50 % available soil moisture content of field capacity. Whenever, moisture content in the soil falls below the lower limit pump automatically starts, open the solenoid to deliver the water and when the soil moisture reaches to the upper limit the system gets stopped. Thus, it was proposed to develop combine system for automatic management of climatic parameters and irrigation and which will operate 24 × 7.

The research study was undertaken on “Design and Development of Cost-Effective Environmental Control System for Protective Cultivation with GSM” with the following objectives;

1. Survey and study of different climate control system available in the market
2. Design and development of cost-effective system for temperature and humidity control with GSM
3. Performance evaluation of developed system for temperature and humidity control with GSM
4. Cost analysis

II. REVIEW OF LITERATURE

This chapter deals with the review of the research work done related and relevant to the title and objectives of the present study. This chapter describes the reviews related to automatic environmental control systems, automatic irrigation systems, application of GSM module in automation systems, use of Arduino as a microcontroller in automation systems and placement of sensor to fulfill the title of the present study and accordingly the objectives. The reviews are classified into different sections as give below:

1. Automatic climate control systems
2. Automatic Irrigation systems
3. Application of GSM module in automation systems
4. Arduino as a microcontroller in automation systems
5. Placement of sensors

2.1 Automatic climate control systems

It was necessary to know the different existing automatic climate control system, there merits and demerits, working principles, material availability for development of such types of devices and cost, etc. to finalize the design and development consideration to overcome with limitations with the existing devices developed by the earlier scientists. Therefore the survey and study of such devices are described in this section.

Kolhe and Annadate (2012) developed ARM7 controller based greenhouse automation using temperature sensor (LM 35), LDR (light dependant resistor), humidity sensor (SY-HS-220) and soil moisture sensor. They connected all these sensors to LPC2148 microcontroller, which was used as the main processing unit of their system. They observed that the sensors sense different conditions and provide data to microcontroller for further processing. Further they found that according to the data obtained from the sensors, the program controlled the actuator components like heater, blower, humidifier and pump inorder to achieve the system requirements. They had also provided facility to set the limits according to the crop type via PC interface. They reported that more accurate a sensor is, better will be performance of system. Further they concluded that relays worked properly at any set temperature, humidity, light intensity and soil moisture value.

Waykole and Agrawal (2012) comparatively studied different wireless technologies viz., ZigBee, bluetooth and wifi and developed greenhouse automation system. They selected PIC16F877A microcontroller as their main processing unit and connected temperature sensor (LM35), LDR (Light dependent resistor) and a humidity sensor to it. They observed that LDR ON/ OFF the light bulbs to maintain light inside greenhouse. Also they found that, humidity level was maintained by system around a predefined value by opening/ closing solenoid valve to flow water through network of pipelines (which had small drilled holes for fine jet) installed inside the greenhouse floor. They reported drawback during temperature controlling that since every time the system was switched ON, the user needs to get user mode and set the desired temperature value once again. Finally they concluded applying ZigBee technology to greenhouse was revolutionary for protected agriculture to overcome limitations of wire connection system.

Deshmukh and Deshmukh (2016) worked on greenhouse monitoring and controlling using GSM and Android. In their system they controlled four main parameters of greenhouse like humidity, temperature, light intensity, soil moisture. They used LM35 and HIH4000 sensors to sense temperature and humidity respectively and the sensor output was amplified and was given to ADC. In their study they stated that, microcontroller controlled these parameters and kept them at some predefined values using relay interface. They also used GSM Module to send the status of system via SMS to the user. Their results showed that the system developed by them closely monitored and controlled the micro parameters which were required for green house. Also they suggested that further improvements can be made to make their system less expensive and more reliable sensors can be used for agriculture production.

Anju and Kumar (2017) proposed greenhouse automation using Zigbee and smart phone. They monitored and controlled parameters viz., Light, Soil Moisture, Temperature and Humidity using ARM microcontroller. They reported different values of sensors were monitored and transmitted through the Zigbee to the VB based web server and then to the android mobile phone via internet connection and real time information access was available to user. They proposed new approach using team viewer software so that user can view data anywhere from the world on their android phone via internet. Also they reported limitation of not getting message due to low signal. Their results showed that system saved labour, has accuracy and low cost.

Elaydi (2017) developed an automated irrigation system for greenhouses, with monitoring and control features using SCADA technology. The system designed by them controlled humidity, temperature and irrigation. To complete the objective of their study they provided irrigation based on the plant's needs using PIC microcontroller for automation. They used model greenhouse as a prototype for their experiment and several sensors like GP2D12, LM35, etc. were connected to an acquisition and their system was controlled using a PC. They provided heater and fan for controlling temperature and foggers and humidifier were used to control humidity inside the greenhouse. Also they observed that system periodically generates alarms and automatically sends emails to notify users about the conditions inside greenhouse. They concluded that system could be used as stand-alone control and monitoring system by farmer with no technical background.

Shah and Bhatt (2017) designed and implemented greenhouse automation and monitoring system prototype. Their system had three sections; temperature and humidity sensor node, soil moisture sensor node and PC or mobile app to control system. They interconnected every section to one central server (raspberry pi) directly or indirectly (via the Internet). They observed that server sent and received information from user end using internet connectivity. They also provided three modes of operation of the system; time-based mode, sensor-based mode and manual mode. They reported that in a time based and sensor-based mode, the system made calculative decisions based on the plantation specific conditions and controlled the actuation actions whereas in manual mode the user was able to control the operations simply using an android app or a desktop application. They reported issue with data security using IoT technology for their system. Further they concluded that system developed by them could increase yield of crop and was affordable to majority of agricultural community but need to be modified to install in real world.

Omar and Qaqos (2019) worked on real-time implementation of greenhouse monitoring system based on wireless sensor network. They used Arduino MEGA 2560 to control and monitor the different environmental parameters viz., concentration of gas, temperature, light and humidity of greenhouses in realtime along with WSN and ZigBee protocol. They distributed group of sensors uniformly in the greenhouse and placed one coordinator node to manage all sensors and control actuators which were connected to microcontroller. They reported under normal conditions, the sensor node read data from sensors every few minutes and the node sent real-time data to the coordinator node. They observed that when detected value of a parameter was found more or lower from the standard limit, the coordinator turned ON/ OFF one of the actuators. Their results showed that system had good stability, low power consumption and low cost. Also quoted that the system was efficient, easy to install and maintenance.

Hoque *et al.* (2020) developed an automated greenhouse monitoring and controlling system using sensors and solar power. They used various sensors such as temperature sensor (LM35), humidity sensor (HSU-07), light sensor and soil moisture sensor to collect environmental parameters of greenhouse. Also they used Arduino Uno R3 (to store and process data), GSM module (to send the measured value of the various parameters to the user cell phone via SMS to ensure efficient growth of plants) and solar power system with rechargeable battery (for continuous power supply). Moreover, Internet of Things (IoT) was used by them to store data to a database and process the collected data and finally send the information to the android apps which was developed for monitoring and controlling of greenhouse by the user. They also compared the proposed greenhouse model with some recent works and found that the system proposed by them was cost effective, efficient and effective by analyzing major environmental parameters. Hence they concluded that the developed cost effective greenhouse model could be used to monitor and control greenhouse parameters in order to increase productivity in farming especially in countries like Bangladesh where there is ample risk of insect infestation, harsh climate and increasing demand of food with the decrease of fertile land. However, they suggested that some future work need to be done such as exact determination of soil texture and use of fertilizer.

The brief summary of the review drawn in the Section 2.1 is presented in Box No. 2.1

Box No. 2.1: The brief summary of the reviews drawn in the Section 2.1

Sr. no.	Year	Name	Location of research	Accessories or methods used	Remark
1	2012	Kolhe and Annadate	Department of Electronics and Telecommunication Engineering, JNEC	ARM7 controller, LM35, SY-HS-220, LDR and soil moisture	• Sensor sense the temperature, humidity, light and soil moisture sensor. • Controller process the readout and pass the order to relay and solenoid valve to ON and OFF the system as

			Aurangabad	sensor	per set limit automatically.
2	2012	Waykole and Agrawal	Shrisant Gadgebaba College of Engg. And Technology, Bhusawal, MH, India	ZigBee PIC16F877A controller, LM35 and LDR	• System maintains humidity level around a predefined value by opening/ closing solenoid valve • Reported drawback during temperature controlling since every time system was ON, user has to set desired limits
3	2016	Deshmukh and Deshmukh	SGB Amravati University	LM35, HIH4000 GSM and Android Application	• Sensors sense temperature and humidity respectively and gives output to ADC by amplifying it. • Microcontroller controlled these parameters and kept them at some predefined values using relay interface.
4	2017	Anju and Kumar	Ganga Institute of Technology and Management Kablana, Haryana	ARM micro controller, Zigbee and Smart Phone	• Controlled light, soil moisture, temperature and humidity. • Different values of sensors monitored and transmitted through the Zigbee to the VB based web server and then to the android mobile phone via internet connection and real time information access available to user.
5	2017	Hatem Elayde	Islamic University of Gaza, Palestine	GP2D12, LM35, PIC micro controller and SCADA Technology	• Provided heater and fan for controlling temperature and foggers and humidifier to control humidity inside the greenhouse. • System periodically generates alarms and automatically sends emails to notify users about the conditions inside greenhouse.
6	2017	Shah and Bhatt	GH Patel College of Engineering and Technology, VV Nagar, Anand, India	Raspberry Pi and IOT	• Provided three modes of operation of the system. • In time based and sensor-based mode, the system made calculative decisions based on the plantation specific conditions and controlled the actuation

					actions whereas in manual mode the user was able to control the operations simply using an android app or a desktop application.
7	2019	Omar and Qaqos.	Duhok Polytechnic University, Duhok, Iraq	Arduino Mega 2560, WSN and Zigbee Protocol	• Distributed group of sensors uniformly in the greenhouse and placed one coordinator node to manage all sensors and control actuators. • When detected value of a parameter is found more or less than the standard limit, then coordinator turned ON/ OFF one of the actuators.
8	2020	Hoque *et al.*	International Islamic University Chittagong, Bangladesh	Arduino uno, GSM, IOT LM35 sensor and HSU-07 sensor	• Sensor collect environmental parameters and Arduino Uno R3 store and process data • Internet of Things (IoT) store data to a database and process the collected data and finally send the information to the android apps

Critique of review

Based on the literatures reviewed, it is observed that scientists worked on the automatic environmental control system based on various controllers coupled with temperature, humidity and soil moisture sensors such as DHT 11, DHT 22, LM35, HSU07, etc. In their studies, some of the scientists reported some serious problems associated with these automatic environmental control system such as every time when the system is switched on then the user has to set the desired set limits once again, etc. Further some automatic climate control systems available in market are working on time basis and have high cost ranging from Rs.1 lakh to Rs.5 lakhs which is beyond the reach of marginal farmers and made hurdles to its promotion. However during the use of temperature, humidity and soil moisture sensors in automatic environmental control system, the calibration of the sensors and their durability have not been covered combinely or very few scientists worked on this. Therefore to deliver water as per crop water requirement and to control and maintain environment favourable for crop inside the greenhouse the study of design and development of automatic environmental control system is undertaken.

2.2 Automatic irrigation systems

It was necessary to know the workdone on development of different automatic irrigation systems by earlier scientists and limitations faced by them while designing the automation system so that these limitations can be tackled by our system. The work done by the earlier scientists on designing of automatic irrigation system is described in this section

Munoz-Carpena *et al.* (2008) designed a new controller for soil water based irrigation. They have developed the controller with a custom circuit board and a commercially available capacitance soil water probe. The controller was tested on plastic mulched tomato field in south Florida with drip irrigation. In their studies, they stated that up to 61% water was saved in a comparison with evapotranspiration based water application. They obtained nearly the same saving with switching tensiometers. Also they found that intrinsic uncertainty in soil and water relationships, soil water-probes and thermal effects could introduce uncertainty in the controller response resulting in water application variability. In spite of these result, the new controller developed by them proved reliable, simple to use and cost effective. Further they concluded that the high variability in water application was due to combined variability of soil and water probe, although the resulting variability in yield was less.

Ooi *et al.* (2010) developed a real-time feedback automated irrigation system based on soil moisture. They tested the system at Pink Lady^{TM} apple orchard, Dookie campus, University of Melbourne, Australia by using soil moisture sensors, actuators and wireless network to develop closed-loop irrigation system. They observed that controller turns ON the motor and solenoid valve when the soil moisture level was below the lower limit and turn OFF when soil moisture level reaches above the upper level. From their study they stated that the real-time closed-loop system substantially improved water productivity i.e. 73 % increase in water use efficiency compared with manual irrigation. So, they quoted that the adoption of this technology would lead to labour and time-saving. They found that automated orchard saves more than 1/3 water than that the manually operated orchard requires to achieve this income. Hence, they revealed that real time feedback based automation would dramatically improve economic efficiency with low water efficiency.

Prathyusha and Suman (2012) designed an embedded system for the automation of drip irrigation which precisely monitors and control the humidity and temperature of plants. They used LM3S5T36 as a microcontroller and connected timer to it which operated the pump and solenoid valve according to the sensors. They observed that once the active root zone area of the plant reached a threshold moisture level then the sensor sends a signal to the microcontroller to turn OFF relays, which control the valves and pump. Similarly, the solenoid valve was controlled by using relays and the case of the sensor failure, the timer turns OFF the valves after the threshold level of time to prevent further disaster. They reported that, the system applied the right amount of water at the right time, regardless of the availability of labour. They concluded that, the system reduces runoff over watering saturated soils, avoid irrigating at the wrong time of the day, improved crop performances and helped in time-saving and revealed that the design of microcontroller-based drip irrigation was a real-time feedback control system.

Sanjukumar and Krishaniah (2013) developed the intelligent agriculture monitoring system which had sensor nodes to obtain the soil moisture, temperature, humidity information in real time. In their study, they sensed water level and information was transmitted over the GSM module and at the base station the data was received by the receiver module and transferred to PC through RS232 interface. Further they observed that the data was processed by the microcontroller and then was transmitted to farmer's mobile phone using GSM module. Then they provided provision that commands were given by the farmer through GSM which initiated or terminated the irrigation process via relay controlled motor in the field depending on the moisture conditions of the soil. They reported that system had useful characteristics of low power consumption, low cost, large network capacity, flexible deposition and minor influence on the natural environment. Finally they concluded that the proposed technology was tested and validated numerically in the field, so the system can control the soil moisture content of the soil in a cultivated field.

Shiraz and Yogesha (2014) developed a microcontroller based automatic irrigation system for nursery irrigation system which consisted of soil moisture sensors, analog to digital converter, microcontroller (PICI6F877A), relays, solenoid valve, solar panel and battery. During their study they observed that, when the moisture content in soil was getting reached to lower threshold limit, then the signal was generated from the microcontroller to ON the relay and after coming to upper threshold limit, the soil moisture sensor gave a signal to microcontroller and relay was turned OFF. Further they concluded that the microcontroller based irrigation system control the drip irrigation efficiently and effectively. Also they reported that the system saved time, remove human error in adjusting soil moisture levels and maximize the net profits.

Abdurrahman *et al*. (2015) developed sensor based automatic irrigation management system with the help of low-cost sensors, simple circuitry and PIC16F887 microcontroller for decision making. They connected LCD to the microcontroller, which displayed the soil moisture level and they also provided switches to set the limits of humidity for switching the individual solenoid valves. In their study they used relays for controlling solenoid valves, which controlled the flow of water entering to different parts of the field. They used another relay to shut-off the main motor which was used to pump the water to the field. They studied the performance of sensors in terms of energy consumption and finally reported that the system reduced electric power consumption significantly.

Kansara *et al.* (2015) reviewed sensor based automated irrigation system with IoT with objective to provide an automatic irrigation system to save time, money and power of the farmer, thereby reducing the human intervention. They studied the rain gun system which was installed in the field and was connected to the water pump. They controlled flow with the help of the solenoid valve using the data obtained from sensor and hence valve used by them maintained the desired amount of moisture. They used two mobiles which were connected using GSM. They observed that when the moisture level was low, micro-controller gave the signal to the mobile to activate the buzzer, which indicated that the valve needs to be opened by pressing the button and the signals were sent back to the micro-controller. They also studied another broad-based methodology having windows application to monitor the field and was found an efficient system. In this system, they connected sensors by wireless communication to cover wider field area, having five in-field sensing stations, an irrigation control station and a base station. They provided all the in-field stations with user friendly wireless transmission. Thus, they concluded that micro-controller reduced power consumption, saved time and led to the removal of human errors.

Bowlekar (2017) designed and tested a low cost automatic irrigation system using Raspberry pi as a microcontroller at the Laboratory and the Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. He placed four sensors in the field, two were placed at 5 cm and remaining two at 10 cm depth. He observed that any of the 2 sensors showed nearly 50 per cent depletion of water than available water, then solid state relay automatically opened the solenoid valve and also the pump was started automatically. Also, when any of the two sensors read moisture content near to field capacity, the motor was automatically closed OFF with the help of solid state relay and then the solenoid valve was also closed. He reported water saving of 7.99 m^3 for the entire crop period by adopting an automatic irrigation system. Therefore he revealed that this system was cost effective, working efficiently with 0-10 % error and user friendly.

The brief summary of the review drawn in the Section 2.2 is presented in Box No. 2.2

Box No. 2.2: The brief summary of the reviews drawn in the Section 2.2

Sr. no.	**Year**	**Name**	**Location of research**	**Accessories or methods used**	**Remark**
1	2008	Munoz-Carpena *et al.*	Agricultural and Biological Engineering Department, University of Florida	Capacitance based soil water probe	• New controller proved reliable, simple to use and cost effective • Saves 61 % water in comparison with evapotranspiration based irrigation
2	2010	Ooi *et al.*	University of Melbourne, Australia	Soil moisture sensors, Wireless network	• Controller turns ON the motor and solenoid valve when the soil moisture level was below the lower limit and turn OFF when soil moisture level reaches above the upper level • 73 % increase in water use efficiency obtained over manual irrigation
3	2012	Prathyusha and Suman	K.L. University, Vaddeswaram, Guntur, Andhra Pradesh, India	LM3S5T36 microcontroller, soil moisture sensor, timer	• Once the active root zone area of the plant reached a threshold moisture level then the sensor sends a signal to the microcontroller to turn OFF relays, which control valves and pump. • In case of the sensor failure, the timer turns OFF the valves after the threshold level of time to prevent further disaster.

4	2013	Sanjukumar and Krishaniah	Dept of ECE, D.R.K. Institute of Science and Technology, Hyderabad, India	Soil moisture sensor, Temperature and humidity sensor and GSM module	• Sensor sense water level and transmit information by GSM to receiver module and then to PC through RS232 interface. Data is processed by microcontroller and then transmitted to farmer's mobile phone using GSM • Farmers had provision to give command via GSM to start or stop the irrigation process depending on soil moisture conditions
5	2014	Shiraz and Yogesha	Dept. of Mechanical Engineering MCE, Hassan	PICI6F877A, soil moisture sensor, Solar panel, Ni- Cd Battery	• Microcontroller based irrigation system control the drip irrigation effectively and efficiently also it reduces human error in adjusting soil moisture levels
6	2015	Abdurrahman *et al.*	Ethiopian Institute of Technology - Mekelle University, Ethiopia	PIC16F887, soil moisture sensor, etc.	• Studied the performance of sensors in terms of energy consumption and reported that the system reduced electric power consumption significantly
7	2015	Kansara *et al.*	Uka Tarsadia University, Bardoli, Gujarat, India	IoT technology, GSM, soil moisture sensors, etc.	• Sensor sense soil moisture when it is low, controller give the signal to the mobile to activate the buzzer, which indicated that the valve needs to be opened by pressing the button and the signals are sent back to the controller
8	2015	Nallani and Hency	VIT University, Chennai, TN, India	SHT_1X soil moisture sensor, Arduino, GPRS SIM 900 Module	• Sensors sense parameters and send the information to Arduino and then Arduino compares this values with predefined threshold value. • If the value was found greater than the threshold value then the control

					unit activated the solenoid valve and status of the valve was sent to the authorized person through Gmail and SMS.
9	2017	Bowlekar *et. al.*	CAET, DBSKKV Dapoli, MH, India	Raspberry Pi, soil moisture sensor, etc.	• Reported 7.99 m^3 water saving for entire crop period using real time automatic irrigation system over the manual irrigation method.

Critique of reviews

After reviewing the literature placed in this section it was revealed that, for automation of irrigation many scientists have worked based on time based or volume based systems. Few scientists have also worked on real time moisture based irrigation system. But very few of them were able to suggest actual threshold limits for irrigating field. However a comprehensive study of design and development of cost effective environmental control system attached with real time irrigation system have not been attempted or very few scientists worked on it. Therefore it felt necessity to develop the cost effective environmental control system for protective cultivation which will control irrigation in any type of soil along with temperature and humidity.

2.3 Application of GSM module in automation system

There was need to get detailed information of the most effective and user friendly technology for communicating with user to provide him information of the status of the system. Thus, various literatures showing comparative study of communication technology and application of GSM technology and its benefits are described under this section.

Chanda *et al.* (2012) did a survey of automated GSM based irrigation systems and comparatively studied the five recent approaches of incorporating GSM technology and Bluetooth with mobile devices into a wireless adaption of the farm irrigation system. They observed that GSM increases efficiency of automation system by giving it more user friendly interface using SMS (Short Message Service) coupled with missed called services and incorporation of Bluetooth for further controlling the system from the farmer’s side. From their study they reported that the GSM technology is readily available, simple in use, less signal deterioration makes it better for sending control signals and receiving updates over long distances. Additionally, they observed that the system incorporated with Bluetooth for remote monitoring reduces the problem of range with GSM networks and saves the cost of SMS.

Anusha *et al.* (2015) proposed GSM based automation system. In this system, they used LDR (Light dependent resistor), humidity, temperature, PIR (Passive infrared sensor) and water sensor to control the agricultural parameters and all these sensors were interfaced with the microcontroller through the relay. They used simple logic as if any one of them generate a low signal, then controller activates the GSM module to send the information about parameters. Further, they provided provision to send this information in the form of SMS to the user with the help of GSM modem to the registered mobile number by using AT commands. Finally they concluded that all the sensors were giving low bit data to controller and the controller was responding according to data and giving information in the form of SMS through GSM modem.

Soni *et al.* (2016) developed greenhouse monitoring system using GSM. They controlled temperature, humidity, light and soil moisture using microcontroller of 8051 family along with fan, water pump, lamp and sprinkler. They observed that microcontroller received the value from sensors and values were analysed by comparing it with the threshold value, based on this value the microcontroller use to take the appropriate decision and controlled the output device. Simultaneously they made provision so that microcontroller sent the report by the GSM modem to the farmer’s phone. Also they reported as soon as the change of temperature or humidity for instance was detected, GSM modem sent SMS on a number provided in the GSM code, which kept user aware about conditions inside the greenhouse. Further they concluded that greenhouse monitoring system using GSM was far better than the same system using the different technologies and the system would increase productivity.

Aprajita *et al.* (2017) designed arduino based agriculture monitoring system operating on GSM network. They connected Arduino board to GSM modem in which transmitter of Arduino was connected to the receiver of GSM modem and receiver of Arduino was connected to the transmitter of GSM modem. They reported that the data sensed by soil moisture sensor and temperature sensor was transmitted to microcontroller in which threshold values were programmed initially. Then the values received from sensors were compared with threshold values. Further they observed that if the readings from the temperature sensor were more than the threshold value and the soil moisture reading was lesser than the threshold value then a SMS alert was sent to the user by GSM/GPRS module. Then the motor pump was switched ON by the user as soon as the message ON was received. They concluded that the developed embedded system would help in monitoring agricultural field.

Sipani *et al.* (2017) worked on wireless sensor data communication using Arduino, DHT11, SIM900A GSM module, etc. They used DHT 11 for temperature and humidity monitoring. In the system developed by them, information obtained from sensors was given to the GSM Module which was interfaced as serial communication peripheral with Arduino. They used GSM Module to transmit data to the mobile device via SMS. They also reported limitation that if the mobile device is out of network coverage area, then there are chances of loosing information sent over SMS to the mobile. Further they concluded that developed system would effectively monitor temperature and humidity in real time and the developed system was compact and cost effective.

The brief summary of the review drawn in the Section 2.3 is presented in Box No. 2.3

Box No. 2.3: The brief summary of the reviews drawn in the Section 2.3

Sr. no.	**Year**	**Name**	**Location of research**	**Accessories or methods used**	**Remark**
1	2012	Chanda *et al.*	UIT University TN, India	GSM Technology survey	• Reported GSM increases efficiency and Bluetooth enables controlling the system from the farmer's side. • Bluetooth for remote monitoring reduces the problem of range with GSM networks and saves the cost of SMS
2	2015	Anusha *et al.*	Mallareddy Engg. Clg. For Women JNTU, Hyderabad, India	GSM Module, PIR sensor, LDR and temp. and humidity sensor	• Sensors sense data and if any one of them generate low signal, then controller activates the GSM module to send the information about parameters to the user
3	2016	Soni *et al.*	Gujarat Technical University, Gujarat, India	GSM Module	• Microcontroller receives data from sensors, then analyses and takes the appropriate decision to control the output device and sends the report to the farmer's phone using the GSM. • Reported GSM is better than same system using different technologies

4	2016	Aprajita *et al.*	Dept. of ENTC Engg. BVDUCOE, Pune, MH, India	Atmega 328, GSM SIM 900, LM35 temperature and soil moisture sensor	• Controller receives data from sensor, if temperature is more and the soil moisture is lesser than that of threshold value then a SMS alert is sent to the user by GSM/GPRS module. • User switched ON pump as soon as receives message ON.
5	2017	Sipani *et al.*	Chandubhai S. Patel Insti. of Tech., Charusat, Changa, India	Arduino and GSM 900 Shield	• Information obtained from sensors was given to the GSM Module. • Used GSM to transmit data to the mobile device via SMS. • Reported limitation that if the mobile device is out of network coverage area, then there are chances of losing information sent over SMS to mobile.

Critique of reviews

From the above reviews, it is inferred that most of the attention is given on only intimation of automation operation and remotely operation of automation system by using GSM and Bluetooth technology. However very few scientists worked on the use of android mobile application for automatic climate control system. The use of Bluetooth is not only limited up to intimate the user about climate control operations but it can be also used as interface to connect the android mobile with automatic environmental control system at free of cost. Also there is chance of losing information sent over SMS due to improper network. Therefore there is need to work combinely to monitor the operation of an automatic environmental control system and keep be in touch with greenhouse operations with the help of mobile. Hence the GSM module + Bluetooth technology is selected for this research work.

2.4 Arduino as a microcontroller in automation systems

It was necessary to know the application of Arduino as a microcontroller in various fields of automation. The work done by the earlier scientists on designing of Arduino based automation systems is described in this section.

Krishnamurthi *et al.* (2015) developed arduino based weather monitoring system. For the development of system they used arduino, DHT11 sensor, LM35 sensor and LDR (light dependent resistor). Through this system they automatically collected the information about humidity and temperature. The details collected by them were stored in a database and according to current and previous data they produced the results in graphical manner in the system. They formulated the weather and forecasted the weather without human error. They concluded that the system developed by them was successful and would provide a competent method for recording real time weather readings and would help farmers whose livelihood depends on the weather in a country like India to produce better quality crops.

Subhankar Chattoraj (2015) developed smart home automation using Light Detecting Resistors, Temperature sensor (LM35), LPG and Smoke sensor (MQ2), Temperature and Humidity sensor (DHT11) and arduino as a master controller. The system developed by him consisted of two main hardware components: the computer which runs the Matlab, Visual Basic, and the Arduino Uno microcontroller board which was flexible, inexpensive, offered a variety of digital and analog inputs, serial interface and digital and PWM outputs. They observed arduino takes required actions like controlling the speed of fan, switching the LED and turning ON/OFF the alarm according to the data obtained from sensors. Finally they concluded that developed system was cost effective and affordable to common person.

Kale and Kulkarni (2016) worked on wireless sensor network (WSN) technology for temperature and humidity monitoring using Arduino microcontroller, Xbee S2, DHT11 sensor and PC. They quoted that, the traditional wired systems fail for parameter measurement at remote places so there was a need of next generation technology like wireless technology. They used Arduino microcontroller to make complex computation of the parameters and then to transmit the data wirelessly by using Xbee S2 module to the receiver. Further during performance evaluation, they recorded temperature and humidity in two sets one for night and other during day time in summer at Nashik. They observed that temperature variation in day and night was less as compared to humidity. More variation of humidity was found in night time as compared to day time. Finally they concluded that the developed system was stable, compact, easy to use and cost effective.

Manghnani *et al.*, (2017) developed arduino based wireless system for temperature and humidity monitoring using Arduino uno, nRF24L01 wireless transceiver module, temperature and humidity sensor, etc. They divided system in two parts viz., data acquisition and system control. The data acquisition part of the system developed by them consisted of ATMEGA328 MCU based on Arduino platform, DHT 11 sensor and wireless transceiver module nRF24L01. While the control system was single-chip microcomputer ATMEGA328 which controlled the nRF24L01 module. They provided flexibility of setting the upper and lower limits of temperature and humidity data at any time in control system. They observed that received data was checked for the upper and lower limits and if the received values were not within the original data range, the buzzer was sounded for alarming the people's attention, to make a timely dispose. Further they concluded that developed system was having small size, low cost, less power consumption, high accuracy, superior anti-interference performance and easy Man Machine Interface.

Mohammed (2017) reviewed the embedded systems education in the Arduino age with objective to study challenges faced in embedded systems education, to analyse different Arduino teaching integration methodologies and to study whether Arduino successfully addresses embedded education challenges or not. He reported the advantages of Arduino such as low cost, cross-platform, the simplicity of programming, and open-source extendable software and hardware. He not only found Arduino board can be easily interfaced with external components for data acquisition and control applications but also the popularity of the Arduino is increasing day by day due to it is an open source electronics platform based on easy to use software and hardware. According to Fig.2.1 he illustrated the results extracted by Google Trends regarding searches for three microcontrollers, namely: Arduino, Raspberry Pi and the PIC microcontroller. Which clearly revealed Arduino became more and more popular among academics and researchers. Fig. 2.2 illustrates the number of Arduino-related publications in the following engineering education conferences: American Society for Engineering Education (ASEE), Frontiers in Education (FIE), IEEE Teaching, Assessment, and Learning for Engineering (TALE), and IEEE Global Engineering Education Conference (EDUCON). Also, he reported 19% of the surveyed professionals were considering the use of Arduino in their next embedded projects according to market survey carried out by UBM4 in 2014. Finally he concluded that Arduino was gaining interest from the students, academics, researchers and industry as well.

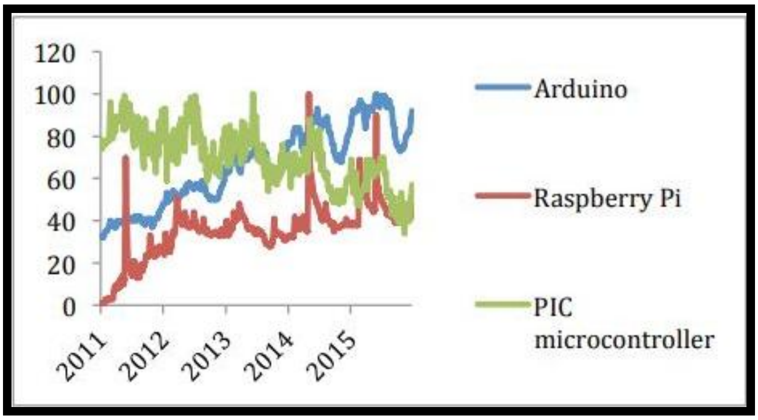


Fig. 2.1 Google trends regarding searches for 3 microcontroller

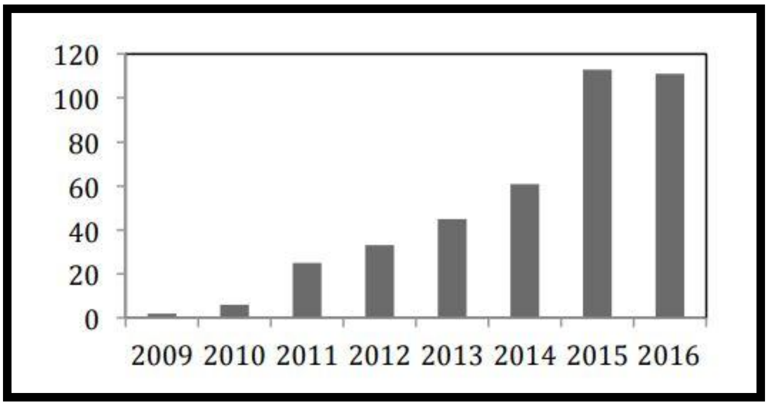


Fig. 2.2 Number of Arduino related publications

Saha *et al*., (2017) developed automated greenhouse system using soil moisture sensor, temperature sensor, humidity sensor, light sensors and Arduino uno as a microcontroller. They maintained desired temperature and humidity by turning ON/ OFF the heater/cooler. They controlled moisture level within soil by turning the water valve ON/ OFF. Further they used emergency lights to maintain desired light intensity whenever necessary. They reported a few µs delay in systems reaction time for restoration of variations of microclimatic parameters because of the program scan cycle. However, they found efficiency and accuracy of the system to be more accurate than manual systems. Further they concluded that the developed system was suitable for both large scale agribusiness as well as small agriculture farms.

Shirsat *et al*., (2017) worked on IoT based smart greenhouse automation using arduino uno along with soil moisture sensor, light sensor (LDR), Humidity sensor (DHT11), Temperature sensor (LM35), etc. They used IoT technology as it enables farmer to control greenhouse from remote locations. They observed that if the temperature exceeds beyond the set limit then a fan was automatically switched ON and when it reaches the desired temperature the fan was switched OFF automatically with the help of a relay. Also when the temperature decreased below the optimum temperature, bulb as a heater was switched ON to set the temperature within the desired range. They concluded system was cost effective and saved labour cost.

Negrete *et al.*, (2018) reviewed status of Arduino board in the automation of agriculture in Mexico. They studied the 25 different systems in which Arduino was used as a microcontroller and found that Arduino is used for automation in irrigation, livestock production, agricultural machines, photovoltaic energy, biotechnology, agricultural education, agro-meteorology, greenhouses, robotics, fruit classification and dehydration. They reported the use of Arduino in various countries as per following chart –

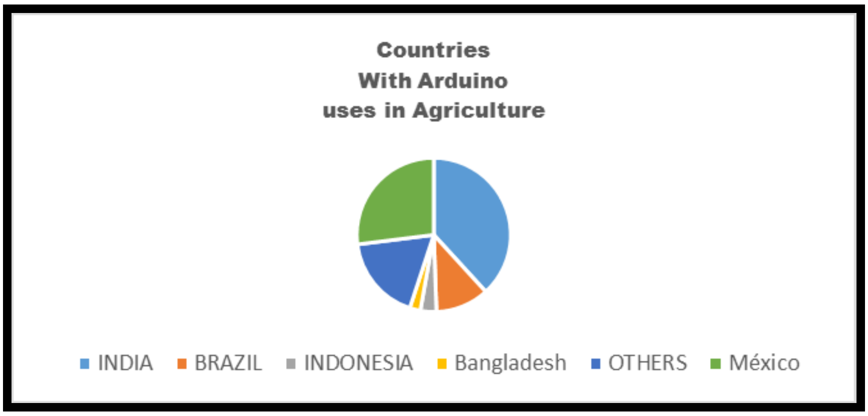


Fig. 2.3 Country wise use of Arduino in Agriculture

In their study they found that India is a leading country to use Arduino as a microcontroller in agriculture and not only irrigation but also fertigation could be automated by using Arduino. Finally, they revealed that the Arduino had novel application in the various fields with minimum cost and power consumption and higher efficiency.

Shrivastava *et al.*, (2018) worked on measurement of temperature and humidity by using arduino tool and DHT 11. They studied system using EEH110 and EEH210 Humidity sensor and found drawbacks in that system. Then they developed system consisting of three sections one that senses the humidity and temperature by using humidity and temperature sensor DHT11. The second section of their system was reading the DHT sensor module’s output and extracting temperature and humidity values into a suitable number in percentage and Celsius scale. The third part of their system was displaying humidity and temperature on LCD. They made system connections based on single wire serial communication. They recommended to use 5k pull up resistor while placing DHT sensor at distance less than 20 m and for placing

DHT at distance longer than 20 m they suggested to use appropriate value pull up resistor. Finally they concluded that proposed system can provide a convenient method for effective monitoring of temperature and humidity in real time.

The brief summary of the review drawn in the Section 2.4 is presented in Box No. 2.4

Box No. 2.4: The brief summary of the reviews drawn in the Section 2.4

Sr. no.	**Year**	**Name**	**Location of research**	**Accessories or methods used**	**Remark**
1	2015	Krishnamurthi *et al.*	Christ University, Bangalore, India	Arduino, DHT 11, LM 35 and LDR	• Automatically collected information about humidity and temperature and stored it in a database and according to current and previous data produced the results in graphical manner in the system. • Formulated and forecasted the weather without human error.
2	2015	Subhankar Chattoraj	Techno India University	Arduino uno, Light Detecting Resistor (LDR), LM35, (MQ2) LPG and smoke sensor, DHT 11	• System consisted of two main hardware components: the computer (which runs Matlab, Visual Basic) and the Arduino uno microcontroller • Arduino takes required actions like controlling the speed of fan, switching the LED and turning ON/OFF the alarm according to the data obtained from sensors.
3	2016	Kale and Kulkarni	KTHM College, Nashik, MH, India	DHT 11, Arduino and Xbee S2	• Collected data using WSN and transmitted it using Xbee S2 module. • Simplified temperature and humidity monitoring system was developed with least number of components and less complexity.
4	2017	Manghnani *et al.*	Spoorthy Engg. College,	Atmega 328, Arduino	• Controller received data from sensor and checked for the upper and lower

			Hyderabad, India	uno, DHT 11, wireless transmitor module-nRF24L01	limits and if the received values were not within the original data range, the buzzer was sounded for alarming people's attention, to make a timely dispose.
5	2017	Mohammed al-Abd	American University of Kuwait	Surveyed Arduino based embedded system	• Reported 19% of the surveyed professionals were considering the use of Arduino in their next embedded projects according to market survey carried out by UBM4 in 2014. • Concluded arduino was gaining interest from students, academics, researchers and industry as well.
6	2017	Saha *et al.*	Islamic University Kushtia, Bangladesh	Arduino uno, Temperature, humidity, LDR and soil moisture sensor	• Maintained desired temperature and humidity inside the greenhouse by turning ON heater/cooler and soil moisture using irrigation valve ON/ OFF. • Maintained desired light intensity with the help of emergency lights whenever necessary.
7	2017	Shirsat *et al.*	Padma bhushan Vasantrao dada Patil Insti. of Technology	Arduino, IoT Technology, DHT 11, LM 35, LDR and soil moisture sensor	• Sensor sense temperature and if it exceeds set limit then a fan was switched ON and when it reaches desired temperature the fan was switched OFF automatically with the help of a relay. • Also when the temperature decreased below the optimum temperature, bulb as a heater was switched ON to set the temperature within the desired range.
8	2018	Negrete *et al.*	Agragian Autonomous Antonio Nano Univ.	Reviewed use of Arduino	• Studied 25 different systems in which Arduino was used as a microcontroller and found

			Brazil		that Arduino is used for automation in irrigation, livestock production, agricultural machines, photovoltaic energy, biotechnology, agricultural education, agro-meteorology, greenhouses, robotics, fruit classification and dehydration.
9	2018	Shrivastava *et al.*	JSS Academy of Techni. Edu. Noida, India	Arduino, DHT 11, LCD	• System had 3 sections: first senses data by DHT11, second was reading DHT 11 module's output and extracting values and third part of system was displaying humidity and temperature on LCD. • Recommended use 5k pull resistor while DHT placed <20 m

Critique of reviews

The above reviewed literature of this section highlighted the research work and design proposals for systems based on Arduino microcontroller in the world. Based on the reviews, it was inferred that Arduino is used as a microcontroller in various fields as like irrigation, livestock production, agricultural machines, photovoltaic energy, biotechnology, agricultural education, agro-meteorology, greenhouses, robotics, fruit classification and dehydration with minimum cost and low power consumption as compare to other two. In spite of that a very few attempts were made by scientists to automize the environmental control system with the help of Arduino as a microcontroller. It is an open source electronic platform based on easy to use software and hardware. Hence, Arduino was implemented as a microcontroller for automation of the environmental control system.

2.5 Placement of sensor

There was need to study work done by different scientists to get appropriate position for the placement of temperature, humidity and soil moisture sensor to get best results of the performance evaluation of the developed system. The work done by the earlier scientists on placement of sensors is described in this section.

Kennedy *et al.* (2003) evaluated the dielectric constant based soil moisture sensor. They carried out study at USDA-ARS Walnut Gulch Experimental Watershed. They measured soil moisture by using soil moisture sensors over a 12 month period and reported that the probes accurately measured soil moisture after applying a linear regression to closely match volumetric water content with gravimetrically sampled VWC. In their study, they placed sensors at 5 cm, 15 cm and 30 cm depth respectively. They observed that sensors at 5 cm and 10 cm were responding quickly and another one showed a delayed response and analyzed during summer a rapid response to precipitation can be seen at 5 cm and 15 cm. From their study they revealed that sensors at 5 cm and 15 cm responded very quickly after precipitation as compared to the sensor at depth 30 cm. Finally they concluded that a dielectric constant based soil moisture sensor offers several advantages over other techniques for measuring soil moisture content.

Dukes *et al.* (2015) explained how the soil moisture sensors works and provided general rules for placement of sensors. They reported that the soil moisture sensors estimate soil volumetric water content based on the dielectric constant of the soil. In general rules they stated to install the sensor in the root zone area of the plants and with the good contact of the soil avoiding the air gaps. Further they suggested to place sensors at least 5 ft from irrigation heads toward the center of an irrigation zone and 3 ft from a planted bed area. They calibrated the sensor as per the method to determine the field capacity of the soil by field method. They tested these sensors for the different controls available such as Acclima Digital TDT® RS500, AquaBlu®, Moisture Clik™ IL200-MC and WaterTec™ S100 by doing programming as per the desired irrigation events.

Nallani and Hency (2015) developed low power, cost-effective automatic irrigation system using SHT1X soil moisture sensor which gives soil temperature and humidity. They placed sensor at the depth of 8 cm and was powered 5V using Arduino microcontroller. They connected the wireless sensing unit to a solar power unit. They observed that control unit received the data of sensor through Zig-bee and was connected to the Arduino receiver and values were compared with the predefined threshold value. They reported that if the value was found to be greater than the threshold value then the control unit activated the solenoid valve. They provided provision to send status of the valve to the authorized person through Gmail and SMS connected through GPRS. They also observed that whenever the received data value was less than the threshold value then the control unit would display the status of the solenoid valve on the display screen. Finally, they concluded that the system was helpful to the farmers and could be extended by using the database to store the data at the field and the camera to monitor the growth of the plant.

Lee *et al.* (2019) studied optimal sensor placement for monitoring and controlling greenhouse internal environments in greenhouse of width of 34.4 m, length of 30 m, eave height of 4.5 m and a ridge height of 5.7 m. They determined the optimal sensor placement for monitoring and controlling the internal environment accurately by measuring internal air temperature of the greenhouse at nine locations. They worked out all the combinations of sensor locations to determine which combinations would best reflect the overall environment of the greenhouse using the error-based method. They used entropy based method to detect optimal sensor locations for areas with significant air temperature variations. They further performed statistical analysis to evaluate the accuracy of the data measured at selected sensor locations by comparing with the average data measured by all of the sensors. They mentioned typically, single sensor at the center of greenhouse is to be installed according to the experience of the designer or grower. Further they concluded, that the sensors located at both sides of the greenhouse, which were more affected by heat gain from the heat pumps and heat loss from the greenhouse cladding, had showed the areas with significant air temperature variations.

Mane *et al.* (2019) developed “Cost effective real time soil moisture based automatic irrigation system with GSM” using Arduino Mega. They had done programming required for controlling solenoid valve and motor in Arduino IDE. They used dual probe conductance based and anti-corrosive soil moisture sensors to record real time soil moisture content of the field. They did comparative study for three depths of placement of sensor i.e. 7.5 cm, 10 cm and 12.5 cm. They performed field testing of sensor by comparing sensor readouts with moisture content by gravimetric method. In their study they found that biometric parameters, yield parameters, water use efficiency and B:C ratio was maximum for 7.5 cm depth of sensor over 10 cm and 12.5 cm depth of sensors. Hence, they revealed that use of automation irrigation system with 7.5 cm depth of placement of sensor was working efficiently and effectively. Finally they concluded that low cost automatic irrigation system was effectively developed.

The brief summary of the review drawn in the Section 2.5 is presented in Box No. 2.5

Box No. 2.5: The brief summary of the reviews drawn in the Section 2.5

Sr. no.	Year	Name	Location of research	Accessories or methods used	Remark
1	2003	Kennedy *et al.*	Walnut Gulch Experiment al watershed, Tombstan, A2	Dielectric constant based soil moisture sensor	• Soil moisture sensor at 5 cm and 10 cm depth provided a quick response
2	2015	Dukes *et al.*	Deptt. of Agril. and Biological Engg, UF/ IFAS Extension Gainesville	Soil moisture sensor	• Sensor should be placed at 5 ft. from Irrigation head and towards center of irrigation zone and 3 ft. from potted bed area from
3	2015	Nallani and Hency	VIT University TN, India	Arduino, SHT1X sensor	• Soil Moisture sensor was placed at 8 cm depth
4	2019	Lee *et al.*	West Coast of south east korea in Jugyo- myeon Boryeong city, Chungcheong nam province	Temperatur e sensor placement study	• Single sensor should be located at center typically. • When two sensors, then they should be located at both sides of greenhouse, which were most affected by heat gain from heat pump and heat loss from greenhouse cladding
5	2019	Mane *et al.*	CAET, DBSKKV Dapoli, MH, India	Arduino Mega, soil moisture sensor, GSM module, Bluetooth module, etc.	• Comparatively studied three depths of placement of sensor i.e. 7.5 cm, 10 cm and 12.5 cm. • Biometric parameters, yield parameters, water use efficiency and B:C ratio was maximum for 7.5 cm depth of sensor over 10 cm and 12.5 cm depth of sensors.

Critique of reviews

Based on the reviews, it was inferred that sensor positioning affects temperature, humidity and irrigation efficiencies. Typically temperature sensor is installed at the center of greenhouse as per experience of designer. While sometimes two sensors at the sides of greenhouse which are more affected by heat gain from heat pumps and heat loss from the greenhouse cladding are selected for more accuracy. Hence, two temperature and humidity sensors at the two sides of greenhouse representing entire temperature and humidity of the greenhouse prototype are selected for study. Also for irrigation, the effective root depth is giving precise information about water uptake depth of roots. This depth includes maximum numbers of thinner roots and which acquire maximum water from the soil. So sensors should be placed in between 5 to 15 cm depth from soil surface which responds very quickly as compared to 30 cm depth. However, it was found that sensor positions 20 cm from the soil surface or deeper were related to noticeably lower irrigation efficiencies. Hence there is need to study the proper depth of sensors placement for the study. For this 7.5 cm depth of placement of soil moisture sensor from the soil surface is selected for study.

2.6 Overall Critique of review

After reviewing the literature it was revealed that, most of the scientists have worked and focused on development of controller for automation of the greenhouse. It was revealed that various sensor based environmental systems were designed by various scientists such as LM35, DHT 11, DHT 22 and HSU07 sensor, etc. They reported some serious problems associated with these automatic systems such as every time the system is switched on the user needs to get user mode and set the desired set limits once again, etc, However in case of automatic irrigation systems, the system available in market are not delivering exact water as per crop water requirement because they are either time base or volume base and the cost of automatic irrigation system is also beyond the reach of marginal farmer. In spite of that the use of temperature, humidity and soil moisture sensor and their calibration, solenoid valve, use of GSM + Bluetooth module, storage of data and its suitability in different environmental conditions and soils have not been covered comprehensively or very few scientists worked on it. Further it is found that the existing automatic environmental systems or automatic irrigation systems require frequent recalibration. Therefore there is need to develop user friendly system with minimum cost. In addition to this, from reviewed literature it is inferred that environmental parameters plays vital role in growth and yield of crop inside the greenhouse. Hence, to maintain optimum temperature and humidity inside the greenhouse and deliver water as per crop water requirement the research work of design and development of cost effective environmental control system for protective cultivation with GSM was undertaken.

III. MATERIALS AND METHODS

The present study entitled "Design and Development of Cost-Effective Environmental Control System for Protective Cultivation with GSM" was conducted at the Laboratory and Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. This chapter describes materials, location, climatic and weather conditions, materials used for development of environmental control system. Further under the section methodology, the design details of controller, functions of component, automation of environmental control system, installation and performance evaluation of the developed environmental control system, placement of sensor, etc. are described. In addition to this chapter includes survey and study of different available climate control systems available in the market.

3.1 Study Area

The experiment was conducted during 2019-20 and 2020-21 at the Instructional Farm and in Laboratory of the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli.

3.2 Location

Cost-Effective Environmental Control System for Protective Cultivation with GSM was designed, developed and tested at the laboratory and Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli (Dr. BSKKV, Dapoli). The experimental site is situated at 17^0 45' 12" N latitude and 73^0 10' 48" E longitudes and altitude of 250 m. The location comes under coastal belt of Konkan region of Maharashtra state.

3.3 Climate and Weather Condition

The location comes under hot and humid climate region with average annual rainfall of about 3542 mm. The average minimum and maximum temperatures are 7.5 ^{0}C to 38.5 ^{0}C, respectively. The relative humidity ranges from 46 to 99 % (Mane 2019).

3.4 Survey and study of available systems in market

After reviewing the literature, it is revealed that there are different environmental control systems available in the market like Priva compass, Growtronix automation system, Growlink system, Autogrow IntelliClimate controller, iGrow 800 Greenhouse controller, etc. Therefore, it was felt necessary to conduct the survey to know the different devices/ systems/ controllers available in the market and then study of them regarding what type of environmental control systems are available in the market, its cost, technical specification, merits and demerits, maintenance, availability of spares in the market, etc. to enable, to design and development of the cost effective system for environmental control to overcome with the demerits of available systems, etc. The survey and study of environmental control system available in the market was undertaken and described as given below under this section.

There are various environmental control systems available in the market. Some of the related systems to the present study under consideration are as follows:

- Priva Compass
- Growtronix Automation System
- Growlink System
- Autogrow IntelliClimate Controller
- iGrow 800 Greenhouse Controller

3.4.1 Priva Compass

Priva Compass as shown in Plate 3.1, allows to control three different areas: Photosynthesis, climate and irrigation. The photosynthesis modules allows to control and optimize light and CO_2 to ensure the best crop growth. With the climate modules temperature, air humidity and airflow are adjusted easily. The irrigation modules ensure the right amount of water at right time and as per crop water requirement to prevent temporary water logging conditions in the root zone due to excess amount of water and scarce of water due to less amount of water for proper root development and optimum water and nutrient uptake for better growth and yield of crop.

Plate 3.1 Front View of Priva Compass Controller

(Source: https://www.indiamart.com/agriplastprotected-cultivation/polyhouse-automation-system.html)

1. **Technical Specifications:** The Priva Compass is available in 2 basic versions: Priva Compass 2S and Priva Compass 4S with the same working principles and technical features. However, Priva Compass 4S is the advance version of 2S which is being used for more zones of different crops. Depending on number of crop zones, we can select the version most suited to our situation.

   Every Priva Compass 2S or 4S comes with following features:

   - Priva Gateway (only in Compass 2S/4S)
   - Priva Blue ID C4 controller(s)
   - Small I/O modules
   - Multi-voltage power 100-230 Vac 50-60 hz
   - Separate power supply to Priva Compass and field devices (two 24 V DC supplies)
2. **Parameters are to be controlled:** Temperature, humidity, soil moisture, light
3. **Sensor used :** Temperature sensor, humidity sensor, soil moisture sensor and light sensor
4. **Access:** Wireless based operable from any device with mobile with android system/ PC via the Cloud
5. **Data Transfer:** Priva Compass system alarms to operator via Mobile/ PC.
6. **Suitability:** To control temperature, humidity, soil moisture and light under the protective cover.
7. **Special feature**: Priva Compass automatically generates predefined graphs and reports. Once you have insight into your process and you're able to analyze it, your job suddenly becomes a lot easier.
8. **Cost:** 5 lakh (Source: https://www.indiamart.com/agriplastprotected-cultivation/polyhouse-automation-system.html)

3.4.2 Growtronix Automation System

The Growtronix Automation System as shown in Plate 3.2, allows for precision control over every aspect of the growing environment. The base system of the Growtronix Automation contains all the essential hardware and software for setting up a basic control system for controlling temperature and humidity to create congenial environment for plant growth under protective cover.

Plate 3.2 Front view of Growtronix Automation System

(Source: https://www.postscapes.com/greenhouse-climate-and-control-systems/)

1. **Technical Specifications:** Basic controller includes a Humidity/ Temperature Sensor and Controllable power outlets unit (provides the software control of 2 devices)
2. **Parameters are to be controlled:** Temperature, Humidity, Soil Moisture, Light
3. **Sensor used :** Temperature sensor, humidity sensor, soil moisture sensor and light sensor
4. **Access:** Wireless based access from any mobile with android system/ PC
5. **Data transfer:** Growtronix automation system alerts operator via email or text message
6. **Suitability:** To control temperature, humidity, soil moisture and light under protective cover.
7. **Special feature:** Advance Time Lapse Movie Maker, Advanced Charting System
8. **Cost:** $599 for basic package

3.4.3 Growlink System

The Growlink system as shown in Plate 3.3, easily identifies microclimates and equipment impact using real-time heat maps for all sensor data including temperature, humidity, VPD, CO_2 and PAR. The system enables user to select any data range and add hundreds of wireless sensors to know exactly what is going on inside the greenhouse. It works well in greenhouses, single level and multi-level vertical farms.

Plate 3.3 Growlink Automation System

(Source: https://www.postscapes.com/greenhouse-climate-and-control-systems/)

1. **Technical Specifications:** Basic Controller includes four sensor inputs and four relays (Can control other equipment with power control extension) and control up to 1000 controllers per grow operation.
2. **Parameters are to be controlled:** Relative Humidity, Air temperature, CO_2, Barometric pressure, Vapour Pressure, Light
3. **Sensor used:** EE160 humidity and temperature sensor, EE820 CO_2 sensor, Barometric pressure sensor, vapour pressure sensor and light sensor
4. **Access:** Wireless based from any device with mobile with android system/ PC via wifi
5. **Data transfer:** Growlink Automation System has data transfer to alert operator using Mobile/ PC
6. **Suitability:** These thermostats are suited for single or multi-stage heating, cooling and ventilation binary output control applications such as RTU or AHU
7. **Special feature:** Advanced data analytics, artificial intelligence, user management, long-term data storage (on optional subscription)
8. **Cost:** $899 for basic

3.4.4 Autogrow IntelliClimate Controller

The IntelliClimate controller from Autogrow as shown in Plate 3.4, is an intelligent grow room controller that automates the tasks of the user. It runs the room to exact specifications set by the user making calculated decisions to maintain the set points of various climatic parameters. IntelliClimate controls fans, AC, lights, heaters, CO_2 and dehumidifiers and it sends text or email to the user if something goes wrong. With an IntelliGrow subscription user gets remote access, data logging, and alerts over mobile. All the units come with a 2 year warranty and unlimited technical support.

Plate 3.4 Front View of Autogrow IntelliClimate Controller

(Source: https://autogrow.com/our-products-solutions/all-products)

1. **Technical Specifications:** It has 9 outputs (24 VDC). The resolution and accuracy of RH is ± 2 %. While resolution and accuracy for temperature is 0.5 °C/ 32.9 °F. Its operating temperature range is 0-50 °C/ 32-125 °F (not in direct sunlight). It has CO_2 resolution and accuracy of 50 ppm
2. **Parameters are to be controlled:** Temperature, CO_2, Relative Humidity, Soil Moisture, Light, PAR (Photoactive radiation) and Barometric pressure
3. **Sensor used:** Folium F2 (is an integrated sensor used to collects data of six parameters temperature, CO_2, relative humidity, PAR, RAD and barometric pressure), Soil moisture sensor, etc.
4. **Access:** Wire/ Wireless based access available
5. **Data transfer:** Autogrow IntelliClimate Controller system alerts operator via email, text message and mobile push notifications
6. **Suitability:** To control temperature, CO_2, relative humidity, soil moisture, light, PAR and barometric pressure under the protective cover.
7. **Special feature:** Daily CO_2 and Light Integration statistics along with data logging
8. **Cost:** $2199.95

3.4.5 iGrow 800 Greenhouse Controller

The iGrow 800 Greenhouse Controller, as shown in Plate 3.5, can give real-time energy use and track run-time on greenhouse heating and cooling equipment. The iGrow 800 series offers eight different outputs for fans, heaters, vents, irrigation, shade curtains (blackout curtains) and more with Cloud access from any Internet-connected computer or smartphone. The user can track energy usage across 8 intelligently controlled outputs (expandable to 32) and adjust it for creating congenial environment for optimum plant growth to increase yield and profit. Tools such as the iPonic Cloud software expand the capabilities of this versatile line of controllers to further save energy and increase profit. No more programming and reprogramming is required for every crop cycle or season change. The iGrow 800 series USB data logging feature can easily save settings to any USB flash drive. When the time comes to switch settings, user simply can insert USB flash drive into iGrow data.

Plate 3.5 Front View of iGrow 800 Greenhouse Controller

(Source: https://link4controls.com/outdoor-greenhouse/)

1. **Technical Specifications:** It has 8 intelligently controlled outputs (expandable up to 32 outputs), 8 analog inputs, 2 digital inputs, 1 dehumidify stage and 1 humidify stage.
2. **Parameters are to be controlled:** Temperature, Humidity and Light
3. **Sensor used :** Temperature sensor, Humidity sensor and light sensor
4. **Access:** Wireless based access from any internet connected devices like mobile with android system/ PC via cloud
5. **Data transfer:** iGrow 800 Greenhuse Controller alerts operator via email or text message
6. **Suitability:** To control temperature, relative humidity and light under protective cover.
7. **Special feature:** Emergency shut-off guards against power surge and overheating.
8. **Cost:** $1449.00

3.4.6 Procedure for Calculations of Exhaust Fan for a Greenhouse of 560 m^2

The procedure for determination of size of cooling pad was adopted from the Book entitled, "Greenhouse Technology & Application" by Vilas M. Salokhe and Ajay K. Sharma.

The cooling requirements of a greenhouse can be calculated by using the tabular values presented in Appendix II, as given by NGMA (1993).

a) Determine the rate of air removal required for a greenhouse under standard conditions using following equations

Considering the removal as 2.5 $m^3/min/m^2$ of greenhouse floor area (L x W).

Standard cmm = L x W x 2.5 (3.1)

where, cmm = cubic meter per min

L = Length of greenhouse in m and

W = Width of greenhouse in m

b) Correct the standard rate of air removal by multiplying it by the larger of the following two factors F_{house} or F_{vel} given in equation no. 3.2

Where, F_{house} = House factor and F_{vel} = Velocity factor,

Total m^3/min = standard cmm x F_{house} or F_{vel} (3.2)

Where $F_{house} = F_{ele} \times F_{light} \times F_{temp}$ (3.3)

Where F_{ele} = elevation factor i.e. height of site from MSL (m)

F_{light} = factor for maximum light intensity in the greenhouse

F_{temp} = Fan to Pad temperature rise factor

(Note: F_{ele}, F_{light}, F_{temp} and F_{vel} values are reported in Table No. 7.2.1, 7.2.2, 7.2.3 and 7.2.4 respectively in Appendix II)

Thus, the final capacity of the exhaust fan is:

Total m^3/min = standard cmm x (F_{house} or F_{vel})

c) Selection of size and number of exhaust fans

- The fans, collectively, should be at least equal to the rate of air removal required and should be rated to do so at the static water pressure of 0.1 inch (30 Pa). This static pressure takes care of the resistance that the fans meet in drawing air through pads. Appendix II, Table 7.2.4 gives air velocity ratings for various sizes of fans.
- Fans should not be more than 7.6 m apart. For example if the end of greenhouse is 25 m wide, a minimum of four fans are necessary.

- Capacity of each fan is equal to total air removal divided by number of fans.
- Select the fan from Table 7.2.5 and 7.2.6 and should be evenly spaced along the end of the greenhouse, at plant height if possible to guarantee a uniform flow of air through plants.

d) Dripping of water on cooling pads

- Water must be delivered at the top of 100 mm thick pad at the rate of 6.21 lit/min/m width of pad and 18.3 m is the longest recommended pipe length having 3 mm holes at every 75 mm length.
- For 150 mm pad flow rate of 9.3 lit/min/m of pad is required. The longest pipe of 15.2 m length having 3 mm holes at every 75 mm is recommended.
- For excelsior pads, water should be delivered at the top at the rate of 4.1 lit/min for each meter of pad.
- A gutter at the base of the pad collects the water and permits it to flow to a sump where it is pumped back at the top of pad.

3.4.7 Closure of survey and study of environmental control systems available in the market:

The selection of environmental control system is based on the crops to be taken, cost of the system, environmental parameters to be controlled and area under protective cover to be controlled. Limitations of the existing environmental control system are: i) high initial cost, ii) requirement of skilled manpower, iii) continuous energy supply, iv) high maintenance, v) recalibration after energy failure, vi) unavailability of spares, vii) sometimes installation of the system becomes complicated and farmers finds difficulties to install it in their greenhouses, viii) time based or volume based systems for irrigation have limitations like it does not take into account precipitation, inadequate to supply right amount of water during energy failure, etc.

Therefore, considering the above limitations there is scope for design and development of cost effective environmental control system for protective cultivation with GSM which will be i) cost effective, ii) easy to operate, iii) No need to calibrate even after energy failure, iv) Minimum or nil maintenance, v) receiving operational details of the system to mobile through SMS.

3.5 Design Considerations

After carrying out the exhausting survey for collecting the detailed technical information, working principles, merits and demerits of the available environmental control systems in the market and further critically studying them it is revealed that, there is vast scope for design and development of cost effective environmental control system for protective cultivation with GSM.

3.5.1 Design consideration

For design and development of the cost effective environmental control system following considerations were made;

i. The system should be low cost so that marginal farmers can afford the cost of that automatic environmental control system.
ii. User friendly management of temperature, humidity and real time soil moisture based irrigation system.
iii. No need to recalibrate system.
iv. Minimum or nil maintenance.
v. The accessories required for development of system should be available in the local market so that cost will be minimum.
vi. It should be easy to install and operated by farmer.
vii. No requirement of skilled manpower.
viii. Real time soil moisture based irrigation should be applicable to any type of soil.
ix. The spares should be easily available for its easy maintenance.
x. The neatly designed and developed environmental control system should have wide range of application and adoption with affordable price.

3.6 Materials used to develop the cost effective environmental control system for protective cultivation with GSM

3.6.1 Controller

The controller is an integral part of an environmental control system. It receives temperature, humidity and available soil moisture status from temperature, humidity and soil moisture sensor respectively. Then it analyzes the data and store it. According to temperature, humidity and soil moisture status data, it takes decision to ON/ OFF the exhaust fan, fogger and real time soil moisture based irrigation system. It is assembled by using microcontroller, temperature and humidity sensors, soil moisture sensors, GSM module, Bluetooth module, relay module, etc. The digital temperature and humidity sensor are internally connected to the controller. However, exhaust fan and fogger are externally connected to the controller. The components of controller are described as follows:

3.6.1.1 Microcontroller and its components

Microcontroller is the heart of the system, which works as a mini computer and receives as well as sends information or command to the peripheral devices connected to it.

An **Arduino Mega 2560**, is used as a microcontroller in this system as shown in Plate 3.6. This microcontroller is programed in Arduino IDE to run the environmental control system automatically based on readings of temperature, humidity and soil moisture sensor.

The various accessories and components with specific specifications of microcontroller are as follows (Louis, 2016):

- **a) USB plug:** This plug is a very important port in this board. It is used to upload (burn) a program to the microcontroller using a USB cable. It also has a regulated power of 5V which also powers the Arduino board in case when the external power supply is absent.
- **b) Internal Programmer:** The developed software code can be uploaded to the microcontroller via USB port, without an external programmer.
- **c) Reset button:** This button is present on the board and is to be used to reset the Arduino microcontroller.
- **d) Analog Pins:** There are 16 analog pins ranging from A0 – A15. These pins are used for the analog input / output.
- **e) Digital I/O Pins**: There are 54 digital pins ranging from D0 - D53 (of which 15 can be used as PWM outputs). These pins are used for the digital input / output.
- **f) Power and GND Pins**: There are pins on the development board that provide 3.3V, 5V and ground through them.

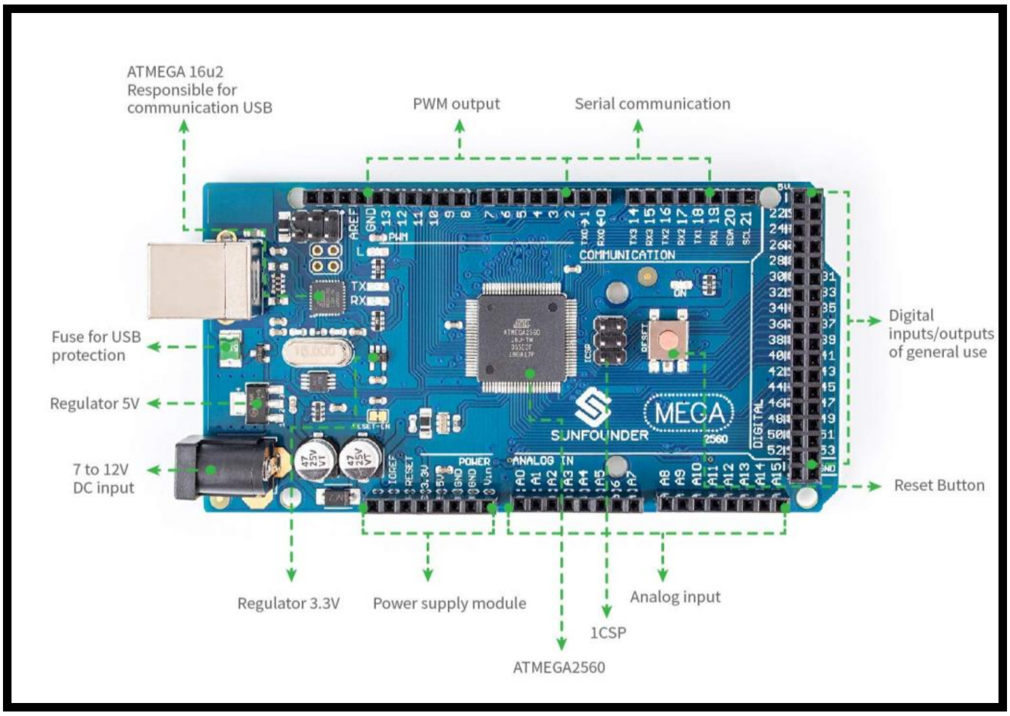


Plate 3.6 Pictorial View of Aurdino Mega (Microcontroller)

3.6.2 DHT 22 Sensor (AM2302)

- As shown in the Plate 3.7, it is a capacitive humidity sensing digital temperature and humidity module that contains the compound that has been calibrated digitally to signal output of the temperature and humidity sensors.
- The sensor includes a capacitive sensor, wet components and a high-precision temperature measurement devices, and connected with a high-performance 8-bit microcontroller.
- The product has excellent quality, fast response and strong anti-jamming capability.
- Operating range: Humidity 0 to 100 % RH; Temperature -40 ^{0}C to 80 ^{0}C.

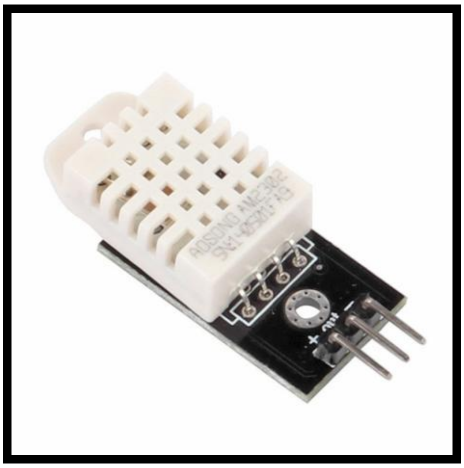


Plate 3.7 DHT 22 sensor

3.6.3 Analog soil moisture sensor

- As shown in the Plate 3.8, it is a device which gives the analog readings of the soil moisture in terms of voltage.
- Dual probe, antioxidant and anticorrosive soil moisture sensors are used to measure the moisture content of the soil in terms of voltage.
- Conductance based soil moisture sensors are used to record the soil moisture.

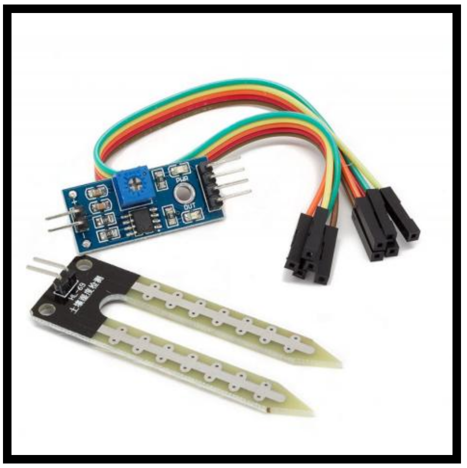


Plate 3.8 Analog soil moisture sensor

3.6.4 GSM (Global Service for Mobile Communication) Module

- As shown in Plate 3.9 GSM module is a chip or circuit. It is used to establish communication between mobile device and computing machine in a very reasonable cost.
- It uses serial communication to interface with the user and need Hayes compatible AT (Attention) commands for communication with the computer (any microprocessor or microcontroller system).
- It requires SIM (Subscriber Identity Module) card to operate all the activities.

Plate 3.9 GSM module

3.6.5 Bluetooth module

- The Bluetooth module is shown in Plate 3.10, it is used to set serial wireless connection which makes an easy way to interface with controller or PC.
- The range of Bluetooth module is about 10 m.
- It uses low power, free to use and compact in nature.

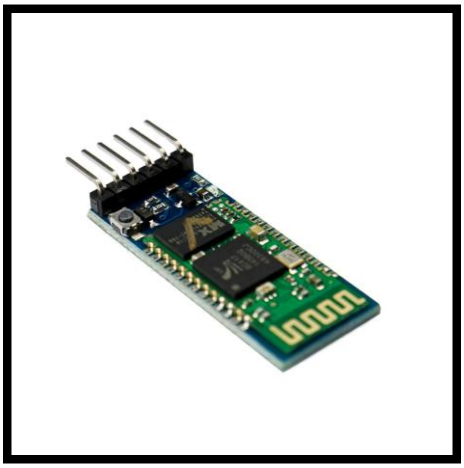


Plate 3.10 Bluetooth module

3.6.6 Relay module

- The relay module is presented as shown in Plate 3.11.
- A relay is an electronic switching device that switches ON or OFF when a small external voltage is applied across its control terminals.
- The coupling mechanism is responsible to enable the control signal to activate this switch.
- It is designed to switch either AC or DC load.
- It does not have any moving part.

Plate 3.11 Relay module

3.6.7 Solenoid valve

- A solenoid valve is an electromagnetically operated valve as shown in Plate 3.12.
- The electric current control the operation of solenoid valve through a solenoid.
- Multiple solenoid valves can be placed together on a manifold.

Plate 3.12 Solenoid valve

3.6.8 Pump

- The pump is used to transfer energy from a power source to a fluid, and as a result to create greater flow or lifts pressure on the fluid.
- It is used to deliver water through the distribution system.
- It is controlled by the relay so as to irrigate the field when there is depletion in the moisture content of soil.
- The pump is shown in Plate 3.13.

Plate 3.13 Pump

3.6.9 Fogging and Irrigation system

3.6.9.1 Fogging

Fogging is the visible cloud and very micro droplets of water present in the air when reaches to the canopy of crop and or ground surface gets evaporated. It is the amount of water present in the air expressed in % on volume basis called relative humidity. Artificially relative humidity can be increased with fogging system to increase the water percentage in the air suits to the crop to be cultivated under the protective cover. Most of the high valued crops are to be grown under the protective cover needs humidity ranging from 55 to 65 %, which can be maintained by the fogging system. Automation is required in fogging system to maintain the appropriate humidity suits to the crops under protective cover and without manual intervention for quality and quantity yield.

3.6.9.2 Irrigation and Irrigation System

Irrigation is the artificial application of irrigation water to the crop to fulfill its water requirement during its growth period. Always its advisable and mandatory to use advance irrigation/ pressurized irrigation system to irrigate the crops are to be grown under protective cover. Under micro-irrigation drip irrigation is found to be most suited irrigation system to irrigate the crops under protective cover. Automation plays an important role in such type of drip irrigation system to maintain the field always to the field capacity to keep crop more active for longer period for higher quality yield. The time and or volume based irrigation system have their own limitations as described in the section 3.4.7 and found difficulties to maintain the soil to the field capacity always. Therefore the real time soil moisture based automatic irrigation system is very important.

The fogging and irrigation system combined consists of a water storage tank (water source), a pump, solenoid valve, relay, sensors, lateral, fogger, dripper, controller, etc. The schematic pictorial view of prototype greenhouse of the automatic environmental control system is as shown in Plate 3.14.

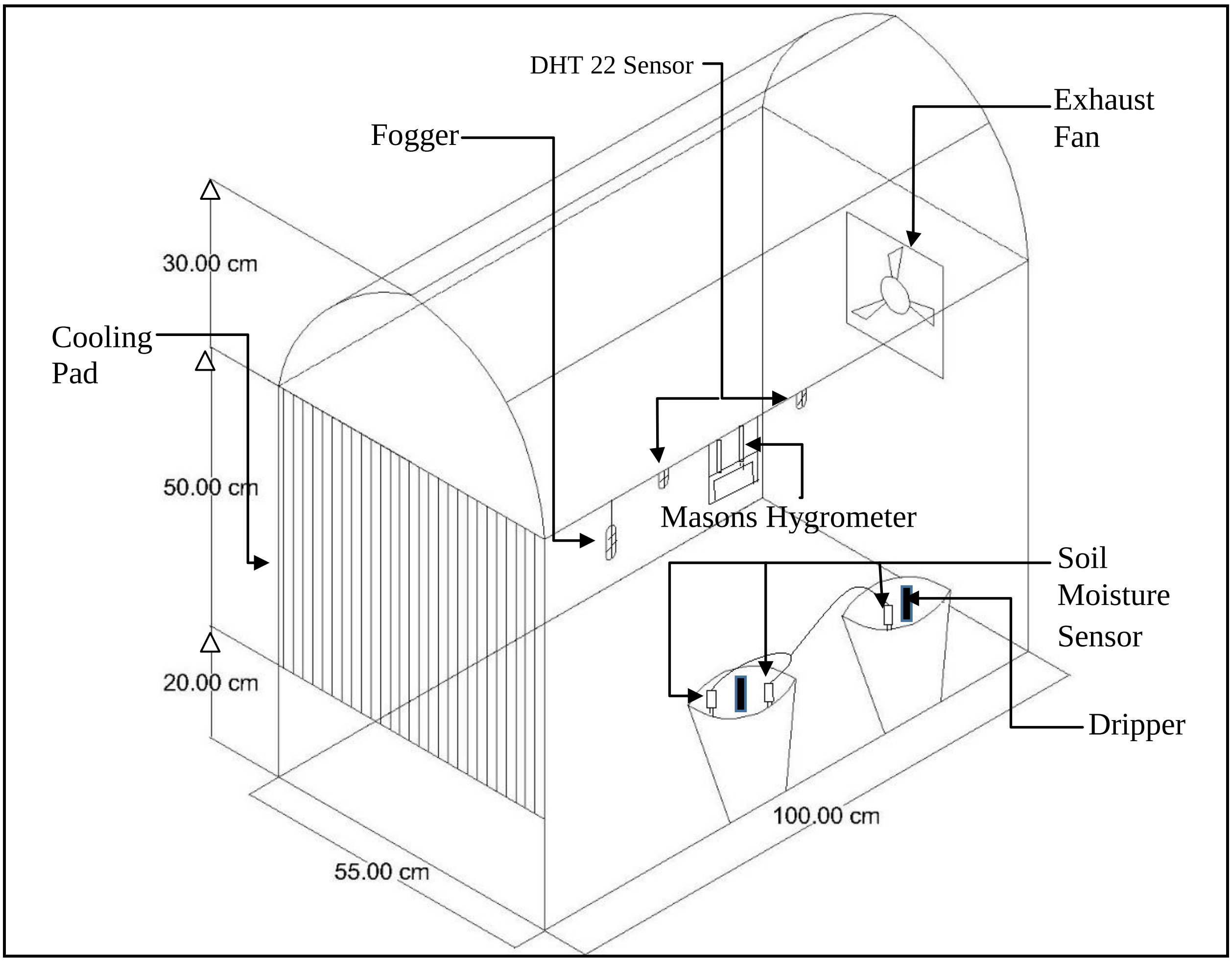


Plate 3.14 Pictorial view of prototype greenhouse of Automatic environmental control system

3.7 Methodology

The methodology adopted for design and development of cost effective environmental control system for protective cultivation with GSM is described neatly in following section.

3.7.1 Automation of the environmental control system

3.7.1.1 Hardware

The automatic environmental control system consist of different hardware such as microcontroller, temperature and humidity sensors, soil moisture sensors, relays, solenoid valves, GSM module, Bluetooth module etc. and assembled together as a unit of automatic environmental control system as shown in Plate 3.18, Plate 3.19 and fig. 4.2.

3.7.1.2 Power Supply

- Temperature and Humidity sensors, Soil moisture sensors, solenoid valve, relay and GSM module works on 5 V DC supply. The 9-12 V DC supply @ 5 A is used to power the Arduino Mega.
- Temperature and Humidity sensors, Soil moisture sensors, solenoid valve, relay, Bluetooth module, SD card module and GSM module are powered through Aurdino pin, 5 V output pin.

3.7.2 Calibration of sensors

The description of the sensors for temperature, relative humidity and moisture content is given in section 3.5.2 and 3.5.3.

3.7.2.1 Calibration of temperature sensor

The calibration of DHT 22 sensor for temperature was done to minimize the error and to get reliable and most accurate readout for further processing. Which intimately used for consideration for fixing the HSP and LSP. The temperature reading of DHT 22 sensor were compared with the Thermometer. The temperature sensor readings are recorded after five minutes required for stabilizing the DHT 22 sensor. After obtaining temperature readouts from DHT 22 sensor and the thermometer, comparison was made of the readings obtained from both measuring instruments viz., thermometer as ideal one and the sensor.

The following procedure was adopted for the calibration of the temperature sensors:

Calibration of temperature sensors was done by the standard procedure as suggested by Koestoer *et al.* (2019);

I. Step 1- Properly place Thermometer and DHT 22 sensor and keep them for five minutes period to get stabilize.
II. Step 2- Record the corresponding temperature reading in degree celsius of DHT 22 sensor 1 and DHT 22 sensor 2 after stabilizing.
III. Step 3- Follow step 2 and 3 after every 15 minutes intervals continuously so that we can get sufficient data to check the error.
IV. Step 4- After getting readouts find the average error in measurement of temperature of DHT 22 Sensor 1 and DHT 22 Sensor 2.
V. Step 5- Use this average error obtained during setting of LSP and HSP.

3.7.2.2 Calibration of relative humidity sensor

The calibration of DHT 22 sensor for relative humidity was done to minimize the error and to get reliable and most accurate readout for further processing. Which intimately used for consideration for fixing the HSP and LSP. The relative humidity reading of DHT 22 sensor were compared with the Masons Hygrometer's wet bulb and dry bulb temperature (which on interpolation from psychrometric chart, as shown in Appendix- V gives relative humidity reading). The relative humidity sensor readings are recorded after five minutes required for stabilizing the DHT 22 sensor. After obtaining relative humidity readouts from DHT 22 sensor and wet bulb and dry bulb reading data from Masons Hygrometer, comparison was made of the readings obtained from both measuring instruments viz., Masons Hygrometer as ideal one and the sensor.

The following procedure was adopted for the calibration of the relative humidity sensors:

Calibration of relative humidity sensor was done by the standard procedure as suggested by Koestoer *et al.* (2019);

I. Step 1- Properly place Masons Hygrometer and DHT 22 sensor and keep them for five minutes period to get stabilize.
II. Step 2- Record the wet bulb and dry bulb reading from Masons Hygrometer.
III. Step 3- Find the relative humidity in % from psychometric table using wet bulb and dry bulb readings.
IV. Step 4- Record the corresponding reading of relative humidity in % from DHT 22 sensor after stabilizing.
V. Step 5- Follow step 2, 3 and 4 after every 15 minutes intervals continuously so that we can get sufficient data to check the error.
VI. Step 6- After getting readouts find the average error in measurement of temperature of DHT 22 Sensor 1 and DHT 22 Sensor 2.
VII. Step 7- Use this average error obtained during setting of LSP and HSP.

3.7.2.3 Calibration of soil moisture sensor

The gravimetric method which is most accurate method, for determination of the soil moisture content on volumetric basis was used to know the accurate soil moisture content. Then in the same soil the soil moisture sensors were inserted and kept for a period of five minutes to get stabilized voltage reading, which then converted and calibrated as soil moisture content on volumetric basis. Cobos and Chambers (2010) gave in detail the method of calibration of sensor, in which, the voltage is recorded for the known per cent of moisture. Using regression equation, other values of voltage for the respective moisture content were estimated. The regression equation is inserted in the program of the system, so this will directly give the amount of moisture content in the soil when the sensor is truly inserted in the soil.

The following procedure was used for the calibration of the sensors:

1. **Preparation of soil sample**: The soil sample was collected from the field by passing it through the 4.75 mm screen. Then the soil sample was dried in the oven at 105 ºC for a period of 24 hours.
2. **Calibration was done by the standard procedure as suggested by Cobos and Chambers (2010);**
   I. Step 1- 1 kg oven dry soil has been taken as shown in Plate 3.15. 5 % water was added in it and mixed properly as shown in Plate 3.16.
   II. Step 2- The sensors were properly inserted in the soil and recorded the reading in voltage as shown in Plate 3.17.
   III. Step 3- Added 5% more water and mixed it thoroughly. The respected soil moisture sensor readings was recorded in voltage.
   IV. Step 4- follow the Step-3 for 15%, 20% 25% and 30% water content. Record the respective moisture content in mV, scale or unit.
3. **Finding the calibration function:** The calibration function was calculated quite easily after performing above procedure. Simply made a scatter plot with the sensor output on the X-axis and the soil moisture content on Y-axis. Then by using the trend line or curve fitting function a mathematical model of the relationship is constructed. Further this calibration equation was inserted in the program to get more precise readings.

Plate 3.15 Nine sets of one kilogram oven dried soil samples for calibration of Soil Moisture Sensor

Plate 3.16 Addition of known amount of water to the oven dried soil sample and mixing it uniformly

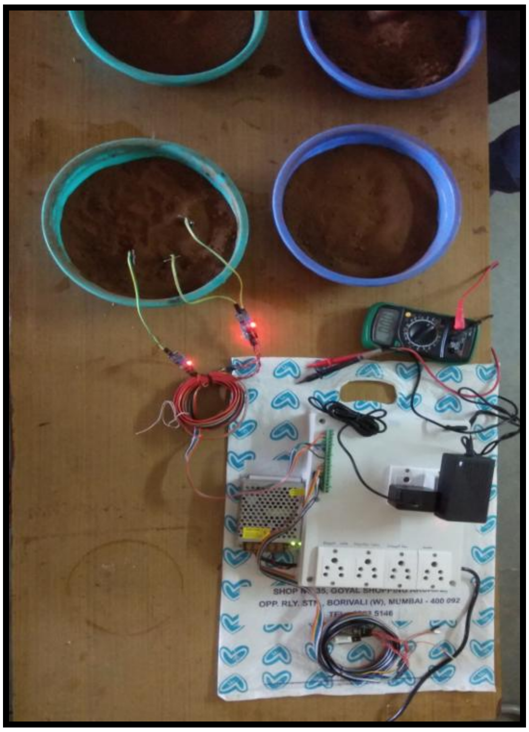


Plate 3.17 Inserting soil moisture sensors in the sample to get Voltage readouts

3.7.3 Steps for automation of the environmental control system

The temperature and humidity sensors were installed in the greenhouse prototype. Also, soil moisture sensors were buried in the effective root zone depth of a potted crop. The smartphone / computer was connected to the system for setting the lower and higher set point. The temperature and humidity sensors and soil moisture sensors are continuously sensing the temperature, humidity and moisture content in soil respectively and sending the data to the microcontroller. The microcontroller sends the signal to the relay to ON/OFF depending upon the determined set point of temperature, humidity and soil moisture which controls the solenoid valve and the pump. Also, the text message is sent to the user to intimate about the status of the exhaust fan, fogger and irrigation motor operation. The required programing is done in the Arduino IDE.

The steps for automation of the environmental control system is given in the flow chart as shown in Fig. 3.1. The pictorial outer view of the controller is shown in the Plate 3.18; the main hardware connections of automatic environmental control system are shown in the Plate 3.19.

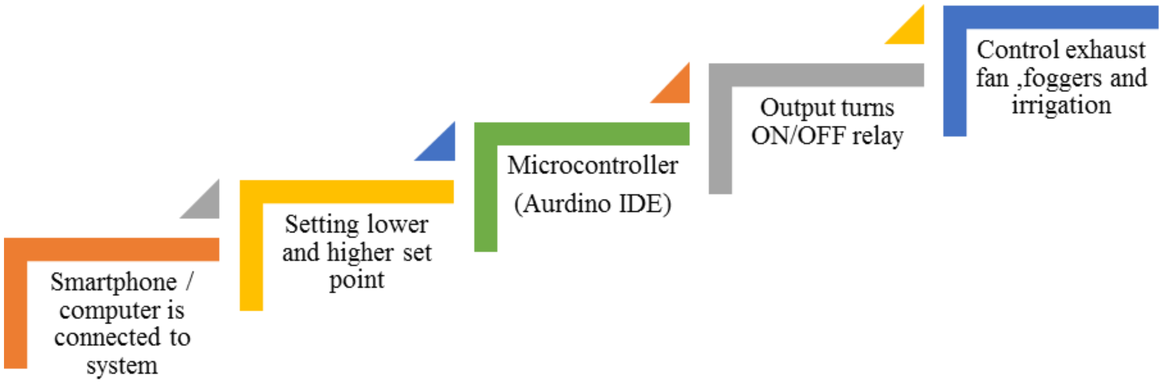


Fig. 3.1 Flow chart of the steps for automation of environmental control system

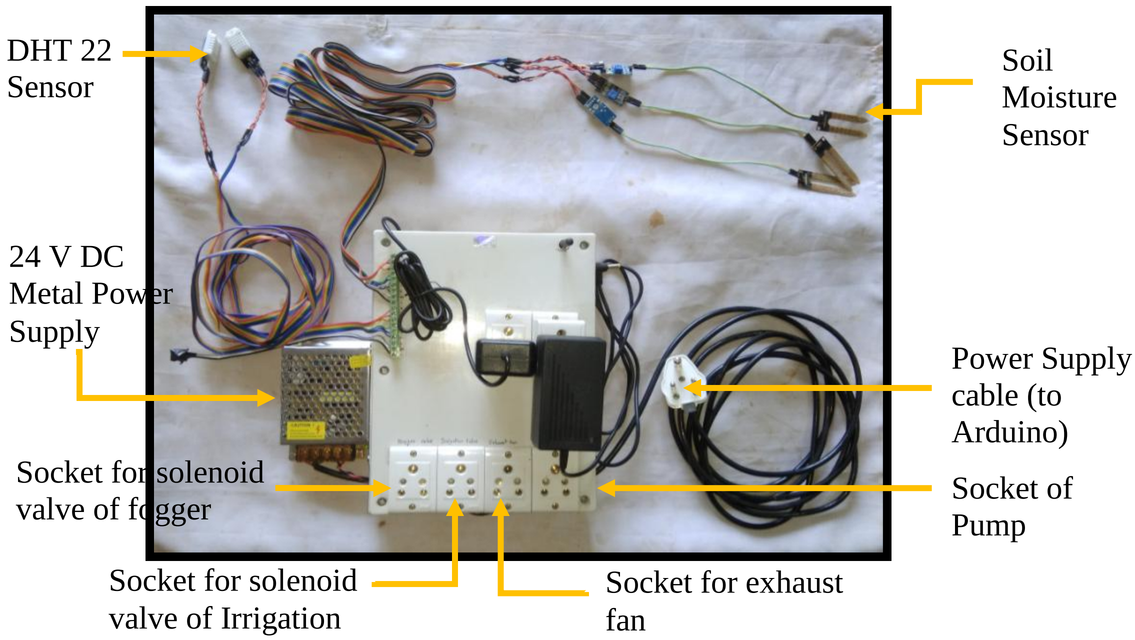


Plate 3.18 Outer view cabinet of controller

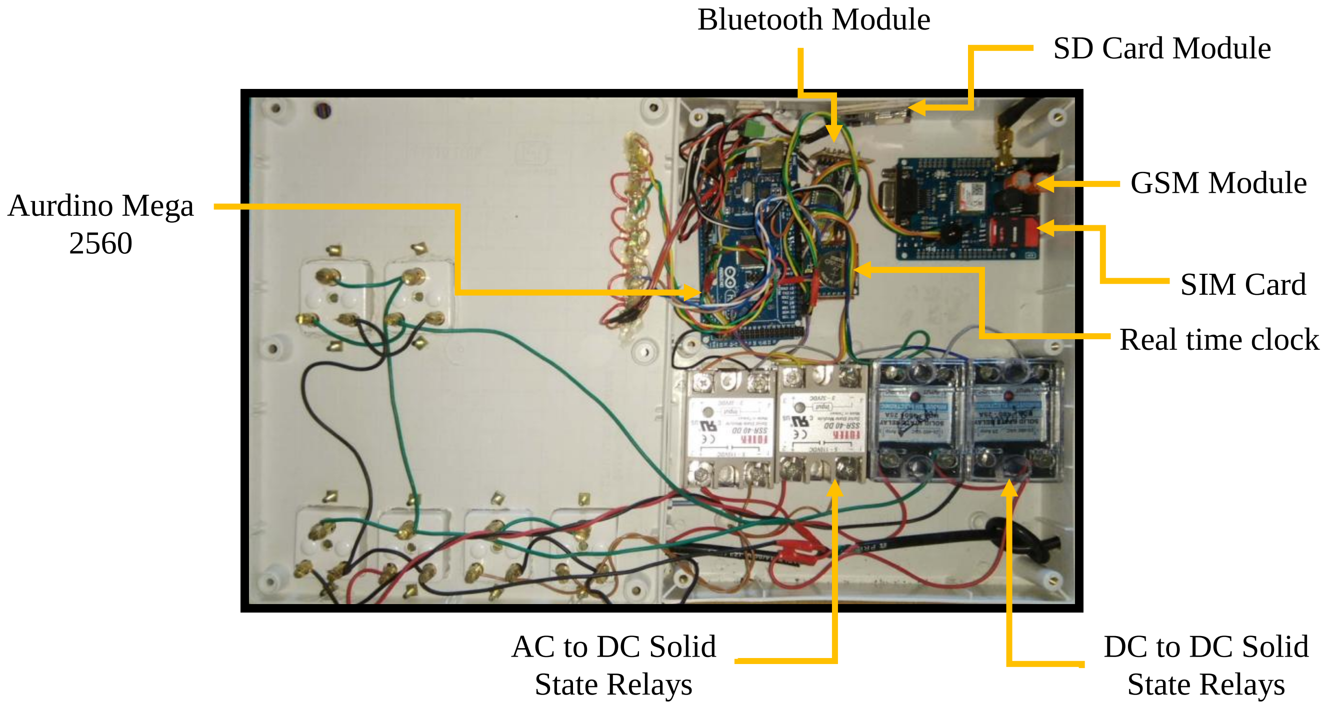


Plate 3.19 Inner view cabinet of Controller

3.7.4 Operation and system setting

The controller will start after plugging it in to power supply plug. The mobile application **Serial Bluetooth** is a freeware used for setting the lower and higher set point. It is easy to operate and required three clicks on mobile to set lower and higher set point. The information for deciding the lower and higher set points is described as follows:

3.7.4.1 Lower Set Point (LSP) of Temperature

- To set a lower limit of temperature it is required to know the type of crop and favourable temperature required for its growth.
- Generally favourable temperature range for most of the crops is 28 ^{0}C to 32 ^{0}C (https://www.commercial-hydroponic-farming.com/ideal-temperature-humidity-greenhouse-crops/)
- Therefore lower limit of 28 ^{0}C is set, when the temperature goes below this point the system will stop exhaust fan and fogger.

3.7.4.2 Higher Set Point (HSP) of Temperature

- To set higher limit of temperature it is required to know the type of crop and favorable temperature required for its growth.

- Generally favorable temperature range for most of the crops is 28 ^{0}C to 32 ^{0}C. (https://www.commercial-hydroponic-farming.com/ideal-temperature-humidity-greenhouse-crops/)
- According to it, higher limit of 32 ^{0}C for temperature is set to start the exhaust fan and foggers by the system when temperature is beyond this point.
- Accordingly when the system will start at 32 ^{0}C it will continue upto achieving the temperature of 28 ^{0}C and stop automatically.

3.7.4.3 Lower Set Point (LSP) of Relative Humidity

- To set a lower limit of relative humidity it is required to know the type of crop and favourable humidity required for its growth.
- Generally favourable relative humidity range for most of the crops is 55 % to 65 % respectively. (https://www.commercial-hydroponic-farming.com/ideal-temperature-humidity-greenhouse-crops/)
- Therefore lower limit of 55 % is set, when humidity goes below this point the system will start foggers.

3.7.4.4 Higher Set Point (HSP) of Relative Humidity

- To set higher limit of relative humidity it is required to know the type of crop and favourable relative humidity required for its growth.
- Generally favourable relative humidity range for most of the crops is 55 % to 65 % respectively.
- According to it, higher limit of 65 % for relative humidity is set to stop foggers by the system when humidity is beyond this point.
- Accordingly when the system will start at 55 % it will continue upto achieving the relative humidity of 65 % and stop automatically.

3.7.4.5 Lower Set Point (LSP) of Soil Moisture

- To set a lower limit of irrigation to start the system it is required to know the field capacity and wilting point of the soil.
- The available soil moisture is determined by considering the field capacity and wilting point as given by equation 3.4.

Available soil moisture content = Field capacity – Wilting point ……..… (3.4)

- Generally most of the crops withstand with depletion of 50 % of available soil moisture content. However for the water loving or some sensitive crops available soil moisture content may be considered as 20 %, 30 % or 40 %.
- As described in Appendix-I, the field capacity is 26.8 % and wilting point is 12 %. Therefore available soil moisture content is 14.8 % and 50% depletion of available soil moisture content is 7.4 %.
- Therefore lower set point for moisture content is selected as 20 % and when the available moisture content of the soil goes below this point the system will start to irrigate the field.

3.7.4.6 Higher Set Point (HSP) of Soil Moisture

- To set higher limit for irrigation to stop the system it is required to know the field capacity.
- Non Congenial root environment is created at field capacity that leads to increase uptake of water and nutrient which increase growth ultimately the yield.
- In this situation water is readily available to crop, there is no need to spend energy in search of water. So this saved energy is used for the growth of crop.
- Therefore, when the available moisture content of soil is reached up to this point then the system will stop automatically.

3.7.4.7 Steps to set the Lower Set Point and Higher Set Point

For setting LSP and HSP of temperature and humidity it is required to know type of crop, optimum temperature and humidity requirement of crop, etc. And for setting LSP and HSP of irrigation it is required to know the field capacity, wilting point and available soil moisture content. These soil properties changes according to soil type. However for water loving or some sensitive crops available soil moisture content may be considered up to 20 %, 30 % and 40 %. The smartphone and serial Bluetooth mobile application has facility to set LSP and HSP easily. Once the lower and higher set point are decided by using the steps as mentioned above. The LSP and HSP can be set as shown in Fig. 3.2.

i. Open the Serial Bluetooth  application in smartphone.
ii. Click on  symbol for connecting with the system.
iii. Then connected status will be displayed on the screen.

iv. Then enter the values of LSP and HSP in format ‘s<HSP of Soil moisture, LSP of Soil moisture, HSP of Temperature, LSP of Temperature, HSP of Humidity, LSP of Humidity>’.
v. Do not use space between LSP and HSP during entering values for all parameters.
vi. After pressing the ENTER key the window displays “Values updated”.
vii. Hence setting of LSP and HSP is completed.

3.7.4.8 Steps to know the current status of Temperature, Humidity and Soil Moisture inside the greenhouse/ prototype

The smartphone with serial Bluetooth application has the facility to view the current status of Temperature, Humidity and Soil Moisture inside the greenhouse/ prototype and ON/OFF details of exhaust fan, fogger and irrigation. It requires two clicks. The detailed about clicks is described below and shown in Fig. 3.3.

i. Open the Serial Bluetooth application in smartphone.
ii. Click on for connecting with the system.
iii. Enter the ‘**c**’ alphabet and press **ENTER**.
iv. In next window you will see the present status of available soil moisture content, temperature and humidity inside the greenhouse/ prototype. It will also enable to know whether the exhaust fan, fogger and irrigation is ON or OFF along with date and time.

3.7.4.9 Steps to view the set points of the system

The smartphone with serial Bluetooth application has the facility to view the set points of the system. It shows all the HSP and LSP for the Temperature, Humidity and irrigation. It requires two clicks. The detailed about clicks is described below and shown in Fig. 3.4.

i. Open the Serial Bluetooth application in smartphone.
ii. Click on for connecting with the system.
iii. Enter the ‘**v**’ word and press **ENTER**.
iv. In next window one will see all the six set points of the Temperature, Humidity and Irrigation.

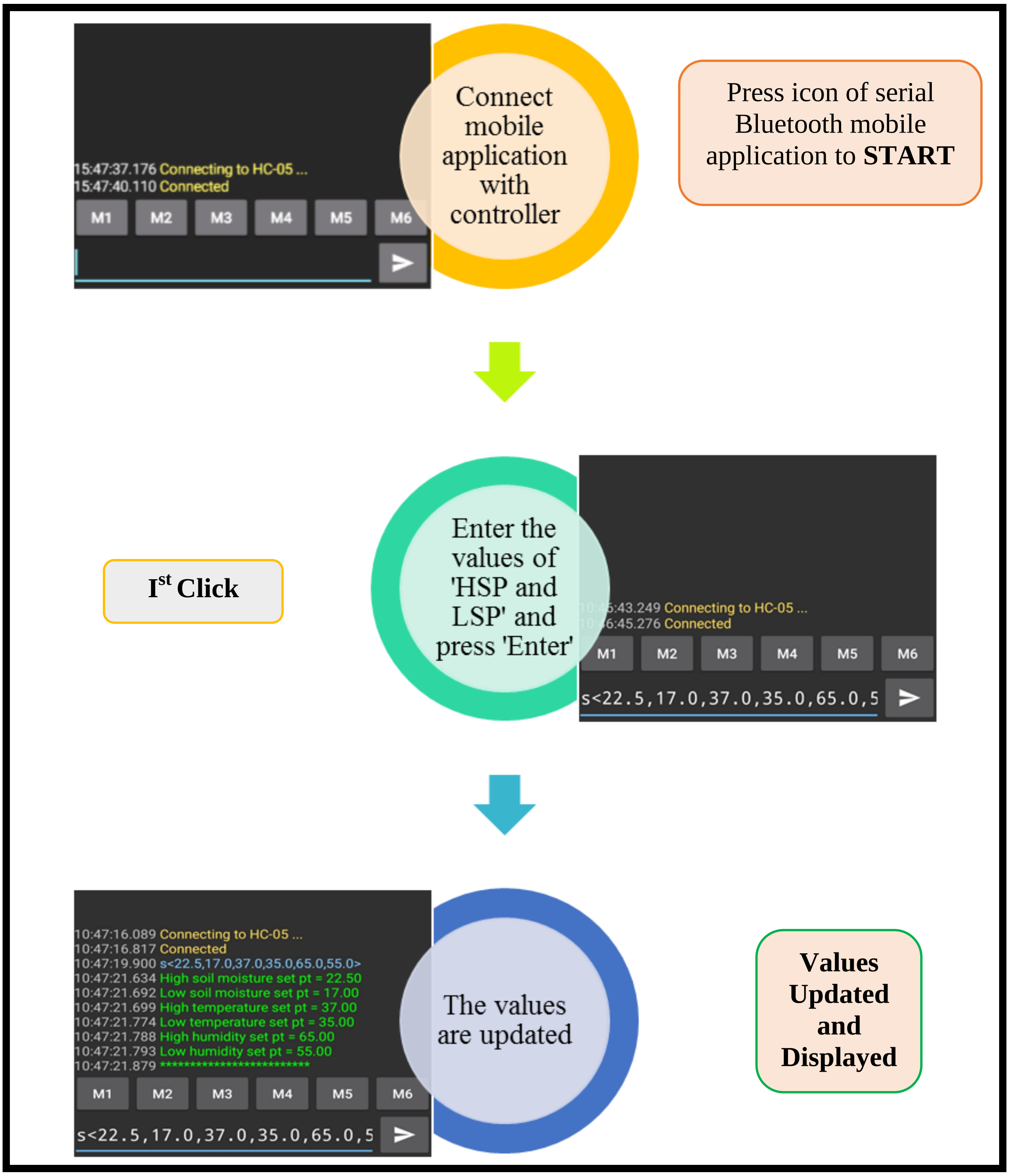


Fig. 3.2 Steps to set the LSP and HSP of temperature, humidity and soil moisture

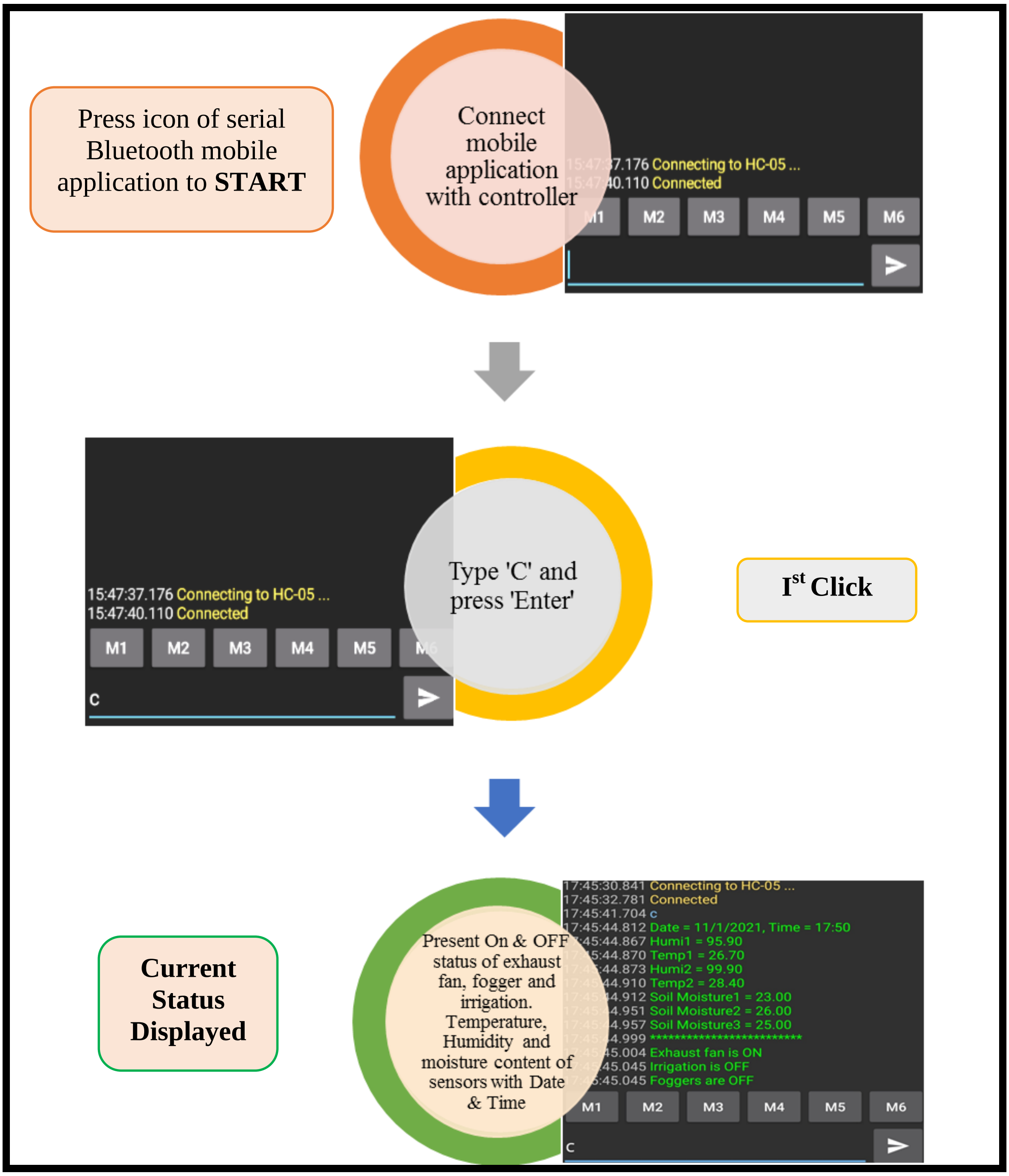


Fig. 3.3 Steps to view present status of temperature, humidity and soil moisture of the system

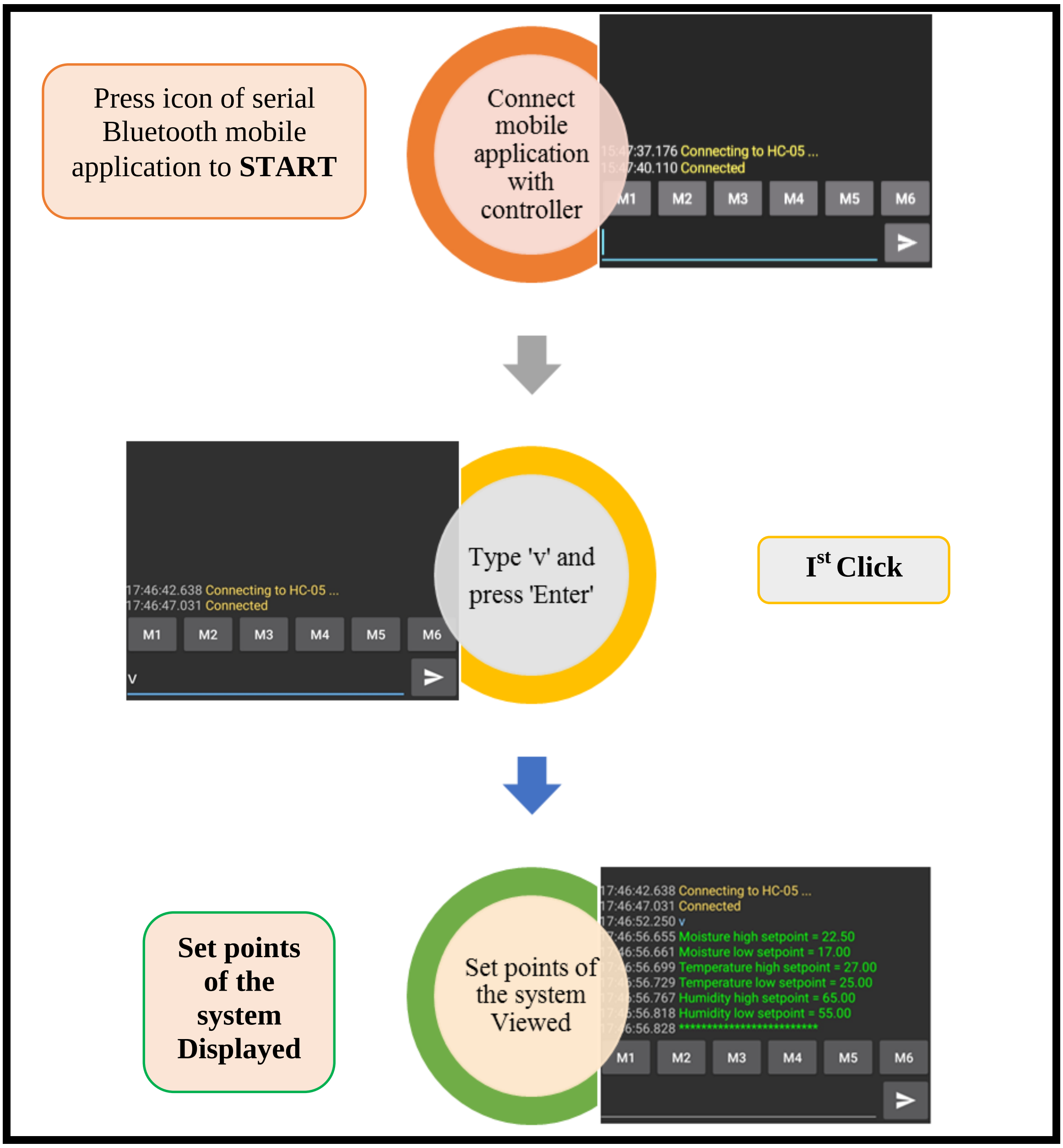


Fig. 3.4 Steps to view set points temperature, humidity and soil moisture of the system

3.8 Working of the automatic environmental control system

1. The automatic environmental control system maintains optimum temperature and humidity favorable for the crop inside the greenhouse/ a prototype according to the type of crop along with maintaining moisture content according to field capacity.
2. For achieving this condition temperature and humidity sensors could be installed inside the greenhouse/ a prototype and soil moisture sensor to be installed in the effective root zone i.e. at 7.5 cm deep from surface of media/ soil of the specific

crop in an undisturbed soil. After installing the sensors, set the lower set point (LSP) and the higher set point (HSP) as described in section 3.7.4.1 to 3.7.4.6.

3.8.1 Controlling Temperature

1. When the temperature is above the HSP, the sensor sends signal to controller to start exhaust fan, pump and solenoid valve of fogging system at the same time it sends the text message to user's mobile about ON status of the Exhaust fan and fogger.
2. The exhaust fan and fogger is operated to lower down temperature inside greenhouse/ a prototype.
3. The exhaust fan removes out hot air from the surrounding inside the greenhouse and entry of fresh air through cooling pad (having cooling arrangement) which is placed at the other end (opposite to exhaust fan) of the greenhouse/ a prototype.
4. When hot air is passed through cooling pad air gets cooled. But while this cooled air passes from cooling pad to exhaust it becomes hotter due to temperature inside greenhouse and later it is exhausted out.
5. The temperature inside greenhouse is reduced to LSP, due to operation of fogger and exhaust fan.
6. Once the temperature inside greenhouse reaches LSP, controller stops exhaust fan, pump and the solenoid valve of fogger and sends the text message to user's mobile about OFF status of the exhaust fan and fogger.

3.8.2 Controlling Relative Humidity:

1. When the relative humidity is below the LSP, the sensor sense and sends signal to controller to start pump and ON the solenoid valve of fogging system. At the same time, it sends the text message to user's mobile about ON status of the fogger.
2. The fogging action helps to gain humidity inside the greenhouse/ a prototype.
3. The system operates till relative humidity reaches upto HSP and once the relative humidity inside greenhouse reaches HSP, controller stops pump and close the solenoid valve and sends the text message to user's mobile about OFF status of the fogger.
4. The controller saves the temperature and relative humidity data at every 15 minute interval in the memory card over entire crop period. So one can easily get information about greenhouse condition of the entire crop period.

3.8.3 Controlling Automatic Irrigation:

1. The main hypothesis of the automatic irrigation section of the system is to apply the right amount of water at right time to fulfill the water requirement of the crop and to maintain the soil always at field capacity with allowable 50 % available soil moisture depletion.
2. For achieving this condition sensors could be installed at the effective root zone of the specific crop in an undisturbed soil. After installing the sensors, set the lower set point (LSP) and the higher set point (HSP) as described in section 3.7.4.5 and 3.7.4.6. The depth of soil moisture sensor placement is taken 7.5 cm for current study (Mane, 2019).
3. When the available soil moisture content is below the LSP, the sensor sends signals to controller to start the irrigation system to deliver water up to the field capacity (HSP). The controller starts pump and opens the solenoid valve and at the same time it sends the text message to user's mobile about ON status of the irrigation system.
4. Once the soil has reached at HSP, the sensors send a signal to the micro controller. The micro controller stops pump and close the solenoid valve and at the same time it sends the text message to the user's mobile regarding OFF status of the irrigation system.
5. The controller saves the temperature, relative humidity and soil moisture content data after every 15 minutes interval in the memory card over entire testing period.

3.9 Placement of Sensors

3.9.1 Placement of temperature and humidity sensors

To get the average available temperature and humidity condition at LSP and HSP, it is necessary to place and install sensor in a selected areas in the greenhouse, to control environment of the entire greenhouse uniformly. The selection of places in the greenhouse to install the sensors is described as given below.

a) **Placement of sensor:** Select the location for each sensor such that it represents the temperature and humidity of entire greenhouse prototype. Typically, single sensor at the center of the greenhouse is placed as per experience of the designer or grower. Sensors located at both sides of the greenhouse, which are more affected by heat gain from the heat pumps and heat loss from the greenhouse cladding, are selected for optimal detection of the areas with significant air temperature variations (Lee *et al.*, 2019).

b) **Height of sensor placement:** The climatic parameters surrounding crop canopy needs to be maintained. Hence temperature and relative humidity sensors should be installed near but above to crop canopy. The height of placement of sensor at representative site play a key role to achieve higher environmental control efficiency. For that representative sensor reading were a key factor to provide more precise information about the temperature and humidity condition inside the greenhouse. Hence it was necessary to fix temperature and humidity sensor at particular height to sense available temperature and humidity inside the greenhouse. Typically, temperature and humidity should be placed 30 cm above the maximum plant height.

Therefore, total two combined temperature and humidity sensors were placed inside the greenhouse prototype unit at 30 cm above of the maximum plant height to be grown inside the greenhouse and comparative study was undertaken.

3.9.2 Placement of soil moisture sensors

To get the average available soil moisture condition at LSP and HSP, it was necessary to install more than two soil moisture sensors in the selected areas in the field, to irrigate entire field uniformly and to fulfill the exact amount of water requirement of the crop in that field. The selection of places in the field to install the sensors is described as given below.

a) **Field location:** Select the location for each sensors that is accessible, yet at least 5 feet away from the edge of the field (Dukes *et al.*, 2015). Find the areas or spots having lowest water holding capacity or will dry earlier than the other field area and the area with the most sun exposure. Therefore, it is best to manage the irrigation of the whole field so that the area doesn't experiencing water stress and rest of the field should be fine. This often means irrigating more frequently but in smaller amounts.

b) **Depth:** The depth of placement of sensor at representative site play a key role to achieve higher irrigation efficiency. For that representative sensor reading were a key factor to provide more precise information about the average soil water condition at the root zone. Hence it was necessary to fix soil moisture sensor at particular depth to sense available soil moisture content. (Mane *et* *al.*, 2019) selected 7.5 cm, 10 cm and 12.5 cm depth of placement of sensor and obtained best results at 7.5 cm depth of sensor placement. Thus, considering the depth of soil, effective root zone depth of the crop under study the 7.5 cm depth was selected for present study. The close agreement in terms of depth of placement of sensor was found by several researchers during their studies as shown in the following Table 3.1.

Table 3.1: Depth of sensor used by researchers in their studies

Sr. No.	Researcher	Year	Depth of placement of sensor
1.	Kennedy *et al.*	2003	Sensors at 5 cm and 15 cm respond quickly
2.	Nallani and Hency	2015	8 cm
3.	Bowlekar A. P.	2017	Two sensor used at 5 cm and 10 cm
4.	Mane *et. al.*	2019	Three sensors at depth of 7.5 cm, 10 cm and 12.5 cm

Therefore, 7.5 cm depth of placement of soil moisture sensor was selected and total 3 sensors were installed (to get average readings of the entire field) in the field vertically at the depth of 7.5 cm and comparative study was undertaken.

3.10 Calculations for size of Exhaust Fan for a Fan and Pad type Greenhouse (Greenhouse Type-II) of 20 × 28 m^2

The procedure for determination of size of cooling pad was adopted from the Book: Greenhouse Technology & Application by Vilas M. Salokhe and Ajay K. Sharma

The cooling requirements of a greenhouse can be calculated by using the tabular values presented in Appendix II, as given by NGMA (1993).

a) Determine the rate of air removal required for a greenhouse under standard conditions using following equations

Considering the removal as 2.5 m^3/min/m^2 of greenhouse floor area (L x W).

Standard cmm = L x W x 2.5 (3.1)

where, cmm = cubic meter per min

L = Length of greenhouse in m and

W = Width of greenhouse in m

b) Correct the standard rate of air removal by multiplying it by the larger of the following two factors F_{house} or F_{vel} given in equation no. 3.2

Where, F_{house} = House factor and F_{vel} = Velocity factor, Total m^3/min = standard cmm x F_{house} or F_{vel} (3.2)

Where $F_{house} = F_{ele} \times F_{light} \times F_{temp}$ (3.3)

Where F_{ele} = elevation factor i.e. height of site from MSL (m)

F_{light} = factor for maximum light intensity in the greenhouse

F_{temp} = Fan to Pad temperature rise factor

(Note: F_{ele}, F_{light}, F_{temp} and F_{vel} values are reported in Table No. 7.2.1, 7.2.2, 7.2.3 and 7.2.4 respectively in Appendix II)

Thus, the final capacity of the exhaust fan is:

Total m^3/min = standard cmm x (F_{house} or F_{vel})

c) Selection of size and number of exhaust fans

- The fans, collectively, should be at least equal to the rate of air removal required and should be rated to do so at the static water pressure of 0.1 inch (30 Pa). This static pressure takes care of the resistance that the fans meet in drawing air through pads. Appendix II, Table 7.2.4 gives air velocity ratings for various sizes of fans.
- Fans should not be more than 7.6 m apart. For example if the end of greenhouse is 25 m wide, a minimum of four fans are necessary.
- Capacity of each fan is equal to total air removal divided by number of fans.
- Select the fan from Table 7.2.5 and should be evenly spaced along the end of the greenhouse, at plant height if possible to guarantee a uniform flow of air through plants.

3.11 Performance evaluation of designed controller

The field performance evaluation and operation of the designed controller was carried out at Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. The experimental setup used for performance evaluation includes greenhouse prototype construction, irrigation and fogging system installation, sensor installation, exhaust fan and cooling pad installation is performed.

The detailed experimental setup is shown in Plate 3.20.

3.11.1 Greenhouse Prototype

The Greenhouse prototype of 1 m x 0.55 m x 1 m was constructed at Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. The Greenhouse prototype was covered with poly-film covering of 250 micron. Greenhouse was also provided with arrangement of exhaust fan and cooling pad along with fogging and irrigation system. Inside the greenhouse two DHT 22 sensors for collecting data of temperature and humidity were installed. Also three soil moisture sensors were installed in the pots placed inside the greenhouse at the depth of 7.5 cm. The developed cost effective environmental control system for protective cultivation with GSM was used by monitoring and controlling the temperature, humidity and soil moisture continuously for 1 month.

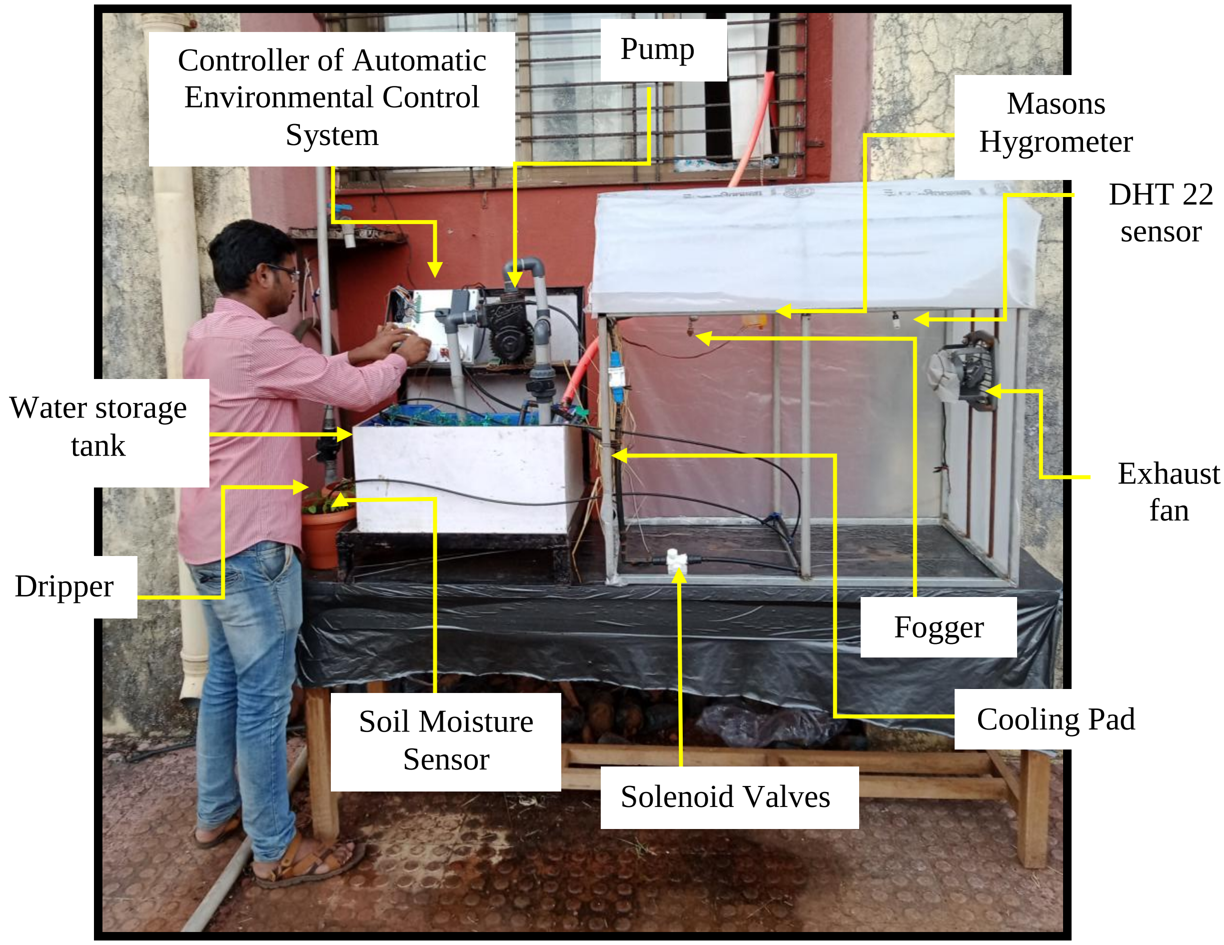


Plate 3.20 Experimental Setup of Automatic environmental control system

3.11.1.1 Installation of exhaust fan

After preparing the greenhouse prototype, the exhaust fan was installed at its one end as described in chapter III section 3.4.6 and as shown in Plate 3.21. This exhaust fan was installed for maintaining temperature inside greenhouse by removing out hot air present inside the greenhouse prototype whenever required as per requirement of the crop.

3.11.1.2 Preparation and Installation of Cooling Pad

Cooling Pad as shown in Plate 3.23, was prepared of 50 cm × 55 cm × 5 cm (Height × width × thickness) using the rice straw as shown in Plate 3.22, as it was readily available and thus reduced costing. It was installed exactly opposite to the exhaust fan with cooling arrangement at top so that hot air sucked by exhaust can be cooled down while passing through it. Further this cooled air was getting warmer as it passed from cooling pad to exhaust and later it was thrown out by exhaust.

3.11.1.3 Installation of fogger system

Fogging system includes one 4-way, 20 LPH anti-leak fogger, lateral, solenoid valve and accessories installed inside the greenhouse prototype to maintain temperature and humidity. The fogger was operated to lower down temperature, when the temperature inside the greenhouse was high. Also when humidity inside the greenhouse was low then the fogger was operated to gain the humidity.

3.11.1.4 Installation of Irrigation System

Irrigation system includes three drippers of 2 lph along with 12 mm lateral, solenoid valve for irrigation, etc. The irrigation system was operated when moisture content falls below 50 % of field capacity.

3.11.1.5 Plantation of seedlings

Two types of seedlings viz., Math and Spinach were potted in two different pots on 27/12/2020 and 28/12/2020 respectively and kept inside the greenhouse. It was provided irrigation on the basis of real time soil moisture content.

3.11.2 Performance Evaluation of Temperature Sensor

Evaluation of temperature sensor was done by taking air temperature readings inside the greenhouse prototype on daily basis during entire testing period (for 1 month), after fixed time intervals of four hours starting from 8.30 am followed by 12.00 pm and 4.30 pm with the help of sensors and the controller and were compared with Thermometer readings to get the per cent variation in the readouts obtained by the developed system.

3.11.3 Performance Evaluation of Relative Humidity Sensor

Evaluation of relative humidity sensor was done by taking relative humidity readings inside the greenhouse prototype on daily basis during entire testing period (for 1 month), after fixed time intervals of four hours starting from 8.30 am followed by 12.00 pm and 4.30 pm with the help of sensors and the controller and were compared with Masons Hygrometer readings to get the per cent variation in the readouts obtained by the developed system.

3.11.4 Performance Evaluation of Soil Moisture Sensor

Evaluation of soil moisture sensor was done by taking soil moisture readings of soil in the pot on weekly basis during entire testing period (for 1 month), at fixed time intervals of four hours starting from 8.30 am followed by 12.00 pm and 4.30 pm with the help of sensors and the controller and were compared with gravimetric reading to get the per cent variation in the readouts obtained by the developed system.

Plate 3.21 Installation of exhaust fan

Plate 3.22 Preparation of Cooling Pad

Plate 3.23 Schematic picture and view of developed Greenhouse Prototype

3.12 Cost analysis of the controller

The cost analysis of developed controller was worked out by calculating the total cost of all the materials required for the development of the controller for prototype unit as well as cost of the controller was estimated for 560 m^2 greenhouse area. The materials included Arduino mega, GSM module, temperature and humidity sensor, soil moisture sensors, Bluetooth module, memory card module, transformer, solenoid valve, relays, plugs, sockets, wires, etc. The cost comparison of the developed system was done with the system which are available in the market.

IV. RESULTS AND DISCUSSION

The experiment entitled "Design and Development of Cost Effective Environmental Control System for Protective Cultivation", was carried out at the Instructional farm and in the laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, DBSKKV, Dapoli. The material required and the necessary procedure adopted for developing the system is described neatly in Chapter 3 (Material and Methodology). This chapter deals with the survey and study of available environmental control systems in the market to decide the design consideration for design and development of the system for the present study. It also describes automation of environmental control system along with its different components under the consideration, circuit diagram, calibration of sensor, steps for automatic environmental control, field testing, working of automatic irrigation system and performance evaluation of the designed and developed system. The necessary data is collected, analyzed and interpreted in the suitable scientific manner and presented in this chapter to fulfil the objectives of the present study. This chapter also deals with the cost estimation of the system.

4.1 Study area

The experiment was conducted at the Instructional Farm and in the Laboratory of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Agriculture University, Dapoli. (MS), India during the year 2019-20 and 2020-21.

4.2 Survey and study of available environmental control systems in market

To fulfil the first objective of the study, the survey and study of the different environmental control systems was conducted by adopting the procedure as described in section 3.4. The observations of the study are tabulated in Table 4.1.

Table 4.1 Merits and Demerits of the environmental control systems available in the market

S. N.	Name of device	Merits	Demerits
1.	Priva Compass	1. Integrated control of all parameters 2. Clear insights are available of greenhouse at a glance 3. Easy operation	1. High cost (Rs. 5 lakh) 2. Not suitable for small and marginal farmers 3. Requires skilled manpower for operation

		4. Good quality and high production 5. Receives alarm when failure occurs	4. The farmers has to depend on company representative for repairs and maintenance which involves the cost. 5. Spares not easily available in the local market
2.	Growtronix Automation System	1. Ability to add up to 512 additional add-on hardware items 2. Advanced Control Options to control every aspect of rooms from a single controller 3. Time Lapse Movie Maker 4. Advanced Charting System 5. Remote Access from any PC, Smartphone or Tablet 6. Text message and email alerts	1. High initial cost ($599 for basic package) 2. Requires skilled manpower for operation 3. Servicing not possible at local level 4. The farmers has to depend on company representative for repairs and maintenance which involves the cost. 5. Spares not easily available in the local market
3.	Growlink System	1. Easy to operate 2. Increases yield 3. Controls all climate inside greenhouse required for crop	1. High initial cost ($899 for basic) 2. Not suitable for small and marginal farmers 3. Requires skilled manpower for operation 4. The farmers has to depend on company representative for repairs and maintenance which involves the cost. 5. Spares not easily available in the local market
4.	Autogrow IntelliClimate Controller	1. Ease of use 2. Complete control 3. Built in fail-safes to ensure the room will continue to function if there is an equipment failure 4. Alarms on all the settings, as well as an intruder alarm 5. Pre-installed growth stage schedules, if desired 6. Daily CO_2 and Light Integration stats	1. High cost ($2199.95) 2. Not suitable for small and marginal farmers 3. Requires skilled manpower for operation 4. The farmers has to depend on company representative for repairs and maintenance which involves the cost. 5. Spares not easily available in the local market
5.	iGrow 800 Greenhouse Controller	1. Fully-programmable; expansion to 32 outputs 2. Use your cell phone to monitor and change settings	1. High cost ($1449) 2. Not suitable for small and marginal farmers 3. Requires skilled manpower for operation

		3. Have peace of mind with alerts for temperature, humidity, CO_2 and more 4. UL Listed for safety and easy permits	4. The farmers has to depend on company representative for repairs and maintenance which involves the cost. 5. Spares not easily available in the local market

From Table 4.1, it is revealed that the different commercial environmental control systems available in the market are having certain merits and demerits, some of them may be working well but costing is high and require skill manpower. Some systems required frequent maintenance. The system is difficult to understand results in problem in its operations, not serviceable locally and spares are not available easily. Therefore, considering the flaws and according to aim of the study the deign consideration are finalized and described in the following section 4.3.

4.3 Design and development of cost effective environmental control system for protective cultivation with GSM

For design and development of the cost effective environmental control system for protective cultivation with GSM, the materials used are described in section 3.6 of chapter III. The adopted methodology is as described in section 3.7. The design considerations are finalized for the design and development of the environmental control system under consideration viz. cost effective, user friendliness, free from recalibration, requires minimum or nil repairs and maintenance, spares should be available in the local market, no requirement of skilled manpower, coupled with real time soil moisture based automatic irrigation system, etc.

After considering and studying the design considerations an attempt was made to design and develop cost effective environmental control system for protective cultivation using GSM enhancing the crop production under protective cover and described in the section 4.4.

4.4 Methodology

4.4.1 Automation of the environmental control system

The controller of automatic environmental control system was developed by assembling the different components of the system as described in Chapter III section 3.6. The hardware connection and connectivity is given in Fig. 4.1 and the circuit diagram is as shown in Fig. 4.2.

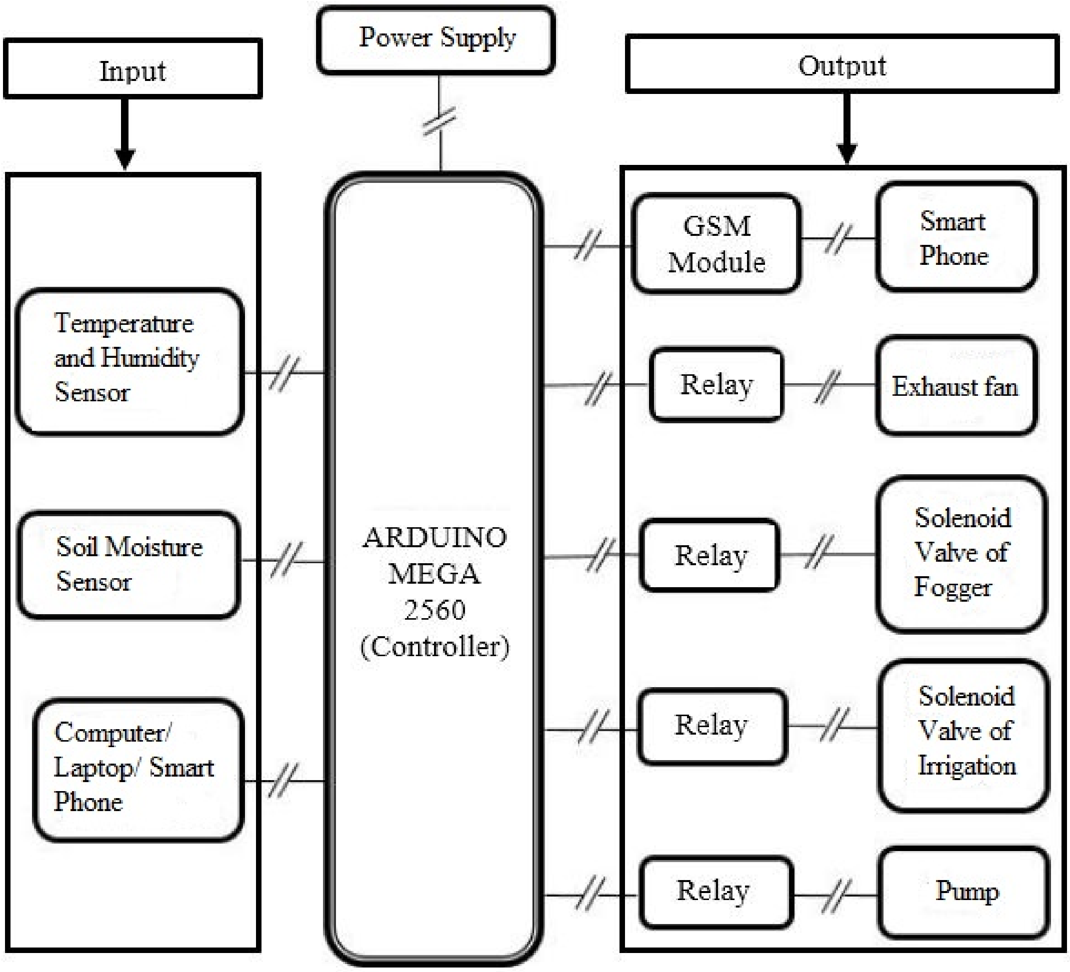


Fig. 4.1 Hardware connections and connectivity

From Fig. 4.1 and Fig. 4.2, it is to state that to the input section different components/ sensors and laptop/ smartphone, etc. are connected to pass the field data to Arduino mega controller for processing and when and while requirement for creating favourable environment inside the protective cover. At the output section the controller process the data as per pre-determined conditions suits to the crop and issuing orders to different relays to ON and OFF the systems automatically which is at once known through SMS to android phone and store data in memory card.

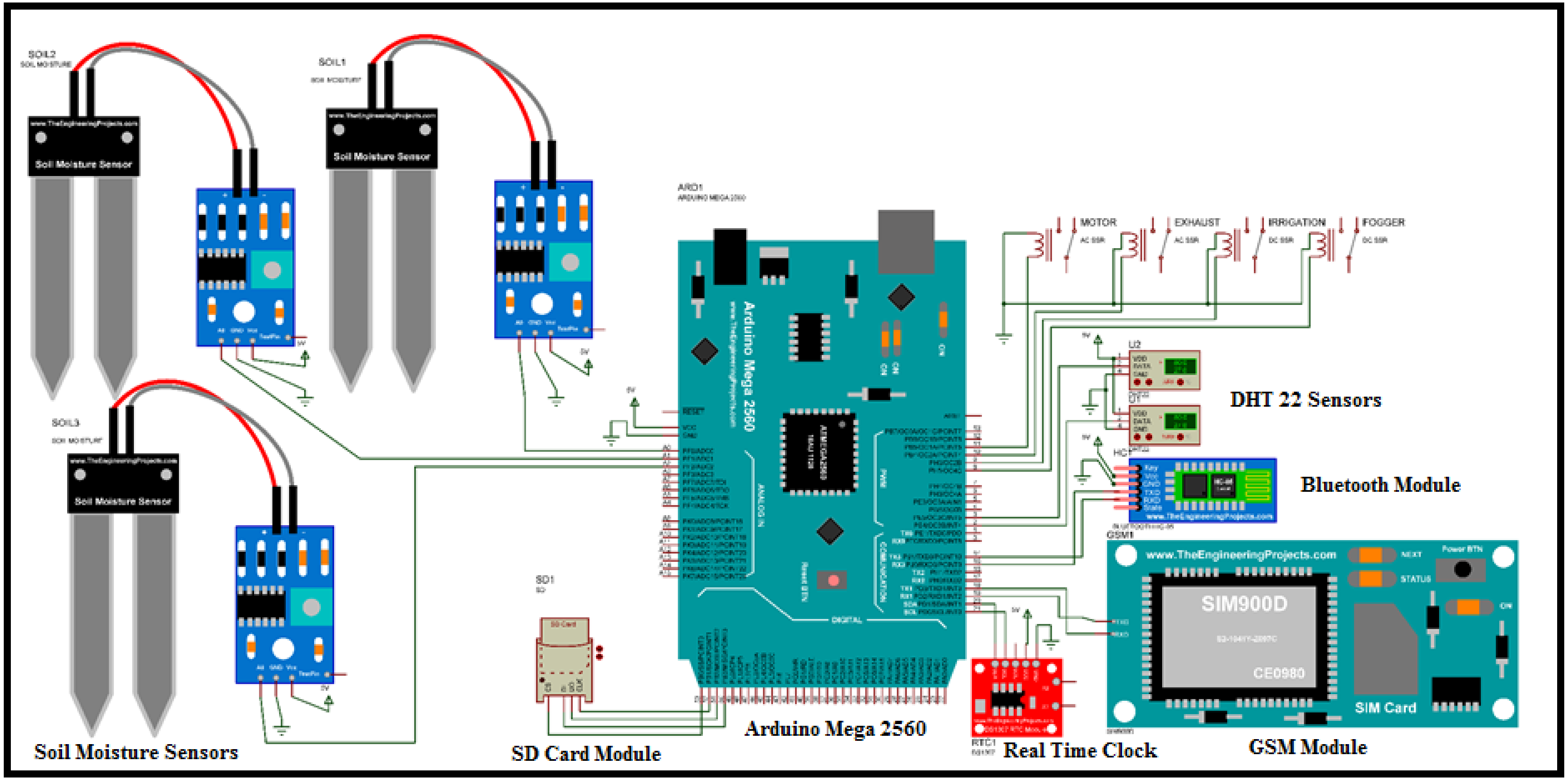


Fig. 4.2 Circuit diagram

4.4.2 Calibration of Sensors

4.4.2.1 Calibration of Temperature Sensor and Humidity sensor

The calibration of DHT 22 (temperature and humidity sensor) was done by adopting the detailed procedure as described in Chapter III section 3.7.2. The temperature and humidity readouts taken by DHT 22 sensors in ^oC (degree celsius) and % (percentage) respectively at different time periods were compared with the respective temperature and humidity determined by Thermometer and Masons Hygrometer respectively for sensor calibration. The respective data of temperature and humidity was collected and presented in Table 4.2 and Table 4.3.

4.4.2.1.1 Calibration of Temperature Sensor

The temperature sensors were calibrated for readout in terms of degree celsius (ºC). This readout was being sent to the controller further it displays on the computer or mobile screen. The readout data was obtained and arranged as shown in Table 4.2 to know the variation between the two measuring instruments viz., thermometer as ideal one and the sensor. It is also depicted in the graph as shown in Fig. 4.3, Fig 4.4 and Fig. 4.5. From Fig. 4.5 the regression equation was sought for taking judgements. However, the sensors were directly giving the readouts in degree celsius (^oC).

Table 4.2: Comparison and calibration of Air temperature readouts of DHT 22 sensor 1 and DHT 22 sensor 2 with Thermometer

Sr. No.	DHT 22 Sensor 1 Temp. Reading (^oC)	DHT 22 Sensor 2 Temp. Reading (^oC)	Avg. readout of sensor (^oC)	Thermo-meter Temp. Reading (^oC)	Error of DHT 22 Sensor 1 (^oC)	Error of DHT 22 Sensor 2 (^oC)	Avg. Error of sensor 1 & 2 (^oC)
1	25.90	26.20	26.05	26.00	0.10	-0.20	-0.05
2	27.50	27.20	27.35	27.00	-0.50	-0.20	-0.35
3	29.00	29.30	29.15	29.00	0.00	-0.30	-0.15
4	31.10	31.30	31.20	31.50	0.40	0.20	0.30
5	33.20	33.50	33.35	33.50	0.30	0.00	0.15
6	30.40	30.70	30.55	30.50	0.10	-0.20	-0.05
7	28.10	28.50	28.30	28.00	-0.10	-0.50	-0.30
8	26.10	26.40	26.25	26.00	-0.10	-0.40	-0.25
		Mean			0.02	-0.2	-0.08

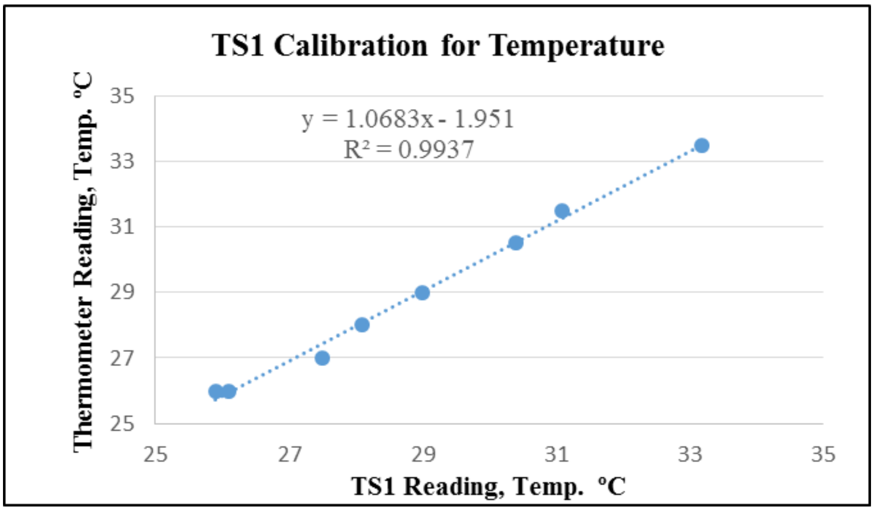


Fig. 4.3 Temp. (°C) of Thermometer Vs Temp. (°C) readout of Sensor 1

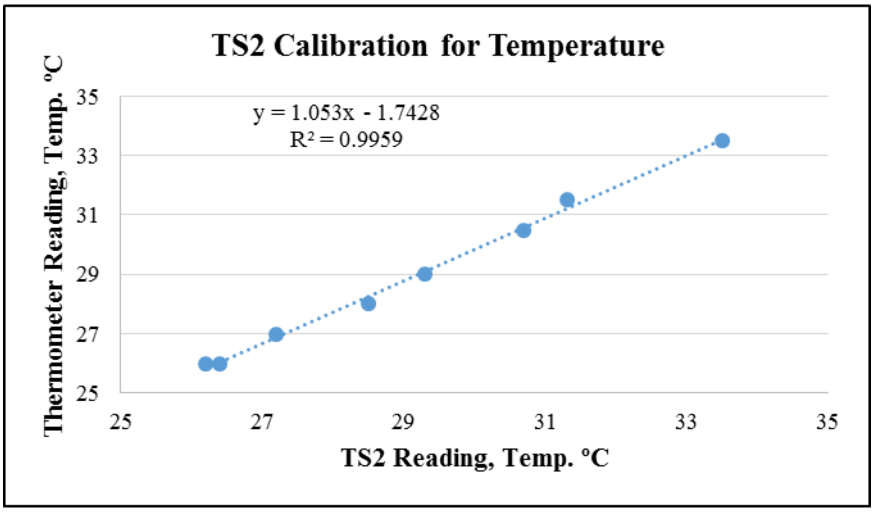


Fig. 4.4 Temp. (°C) of Thermometer Vs Temp. (°C) readout of Sensor 2

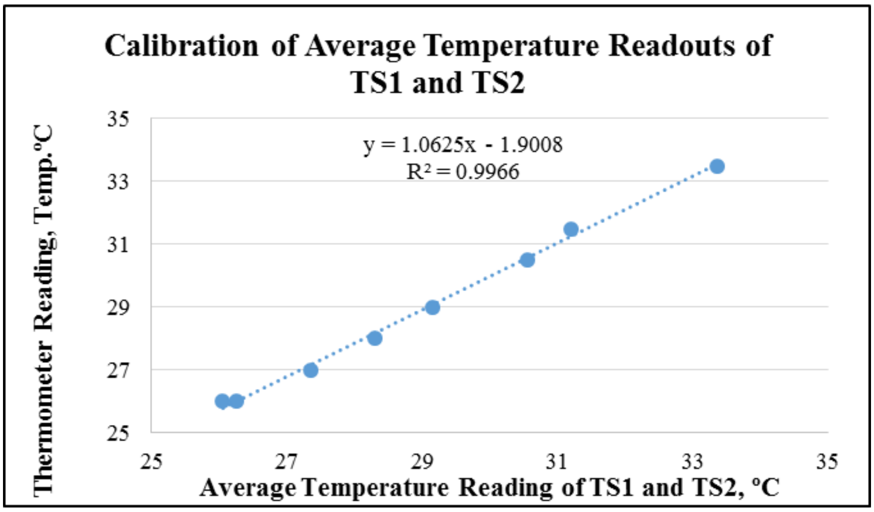


Fig. 4.5 Temp. (°C) of Thermometer Vs Average Temp. (°C) readouts of Temp. Sensor 1 and Temp. Sensor 2

As described in section 3.7.2.1 the procedure was adopted to take the readouts of available ºC temperature at the instant by the two sensors of same make and specifications to check the accuracy in manufacturing error of these sensors DHT 22 as sensor 1 and DHT 22 as sensor 2. It is very pertinent to note that even after having two number of sensors of same and specifications of sensor DHT 22 they are not giving the same readouts and showing significant difference between two numbers of the same sensors. Therefore it is very interesting to note that as it was assumed that there may be variation in the readouts obtained by more than one number of sensor of the same make and specifications holds good. Therefore, to minimize the error in manufacturing of the sensors of the same make and specifications it was felt necessary to use two number of sensors and to check individually whether they are in acceptable limit or otherwise and then to use and compare the average error obtained by these sensors with thermometer and check whether it is in acceptable limit or otherwise. Which ultimately used for consideration for fixing the HSP and LSP of temperature. The readouts by sensors were taken after every 15 minutes to minimize the error and for neat comparison with the thermometer to know difference between two devices. Likewise, 8 nos. of readouts were taken by DHT 22 Sensor 1 and DHT 22 Sensor 2 and compared with the thermometer which is tabulated in Table 4.2 and depicted in Fig. 4.3 and Fig. 4.4. The average error is depicted in Fig. 4.5. From Table 4.2 and Fig. 4.3, Fig. 4.4 and Fig. 4.5, it is observed that the observed error for DHT 22 Sensor 1 is ranging from -0.5 to 0.4 and for DHT 22 Sensor 2 is ranging from -0.5 to 0.2. Therefore it is very important to note that as it was presumed that there may be manufacturing error with the sensors under consideration is holds true and observed error is crossing the acceptable limit i.e. ± 0.5 ºC. Therefore, to match the desired degree celsius temperature to crops grown under protective cover the average error of these two sensors of same was considered and found to be -0.08 ºC which is in acceptable limit i.e. ± 0.5 ºC. Further -0.08 ºC was considered for setting limits of ºC temperature i.e. HSP and LSP.

4.4.2.1.2 Calibration of Relative Humidity Sensor

The relative humidity sensors were calibrated for readout in terms of percent (%). This readout was being sent to the controller further it displays on the computer or mobile screen. The readout data was obtained and arranged as shown in Table 4.3 to know the variation between the two measuring instruments viz., Masons Hygrometer as ideal one and the sensors. It is also depicted in the graph as shown in

Fig. 4.6, Fig. 4.7 and Fig. 4.8. From Fig. 4.8 the regression equation was sought for taking judgements. However, the sensors were directly giving the readouts in percent (%).

Table 4.3: Comparison and calibration of Relative Humidity readouts of DHT 22 sensor 1 and DHT 22 sensor 2 with Masons Hygrometer

Sr. No.	DHT 22 Sensor 1 RH Reading (%)	DHT 22 Sensor 2 RH Reading (%)	Avg. readout of sensor (%)	Masons Hygrometer RH Reading (%)	Error of DHT 22 Sensor 1 (%)	Error of DHT 22 Sensor 2 (%)	Avg. Error of sensor 1 & 2 (%)
1	80.90	75.20	78.05	76.00	-4.90	0.80	-2.05
2	78.20	74.20	76.2	73.00	-5.20	-1.20	-3.20
3	71.30	67.60	69.45	68.00	-3.30	0.40	-1.45
4	68.80	64.50	66.65	60.50	-8.30	-4.00	-6.15
5	62.00	59.00	60.5	53.50	-8.50	-5.50	-7.00
6	64.50	61.00	62.75	65.50	1.00	4.50	2.75
7	76.10	72.80	74.45	70.00	-6.10	-2.80	-4.45
8	78.40	76.30	77.35	76.00	-2.40	-0.30	-1.35
Mean					-4.71	-1.01	-2.86

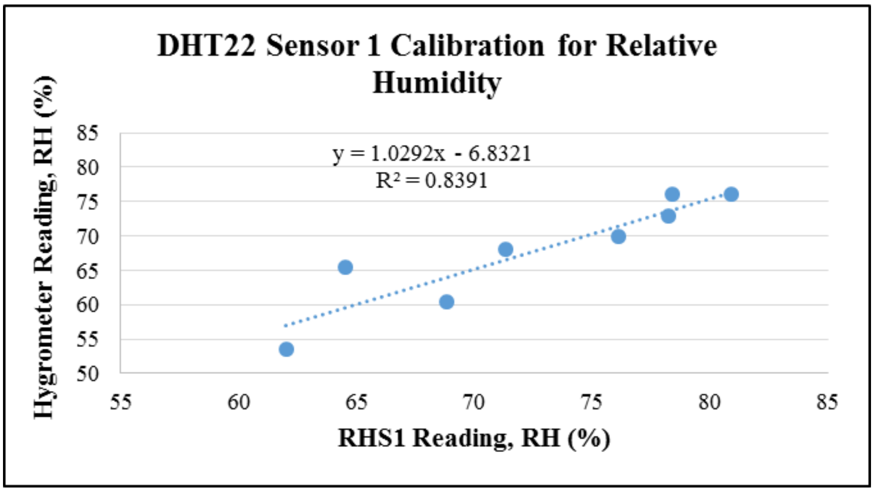


Fig. 4.6 RH (%) of Masons Hygrometer Vs RH (%) readout of Sensor 1

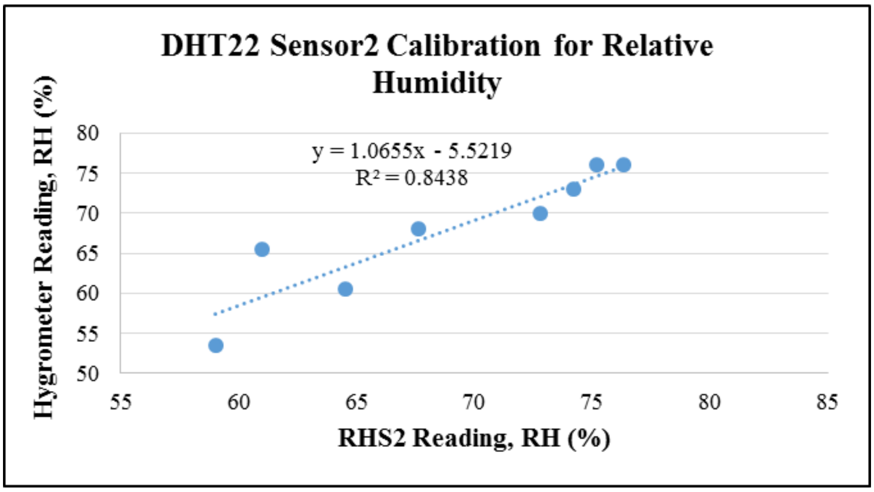


Fig. 4.7 RH (%) of Masons Hygrometer Vs RH (%) readout of Sensor 2

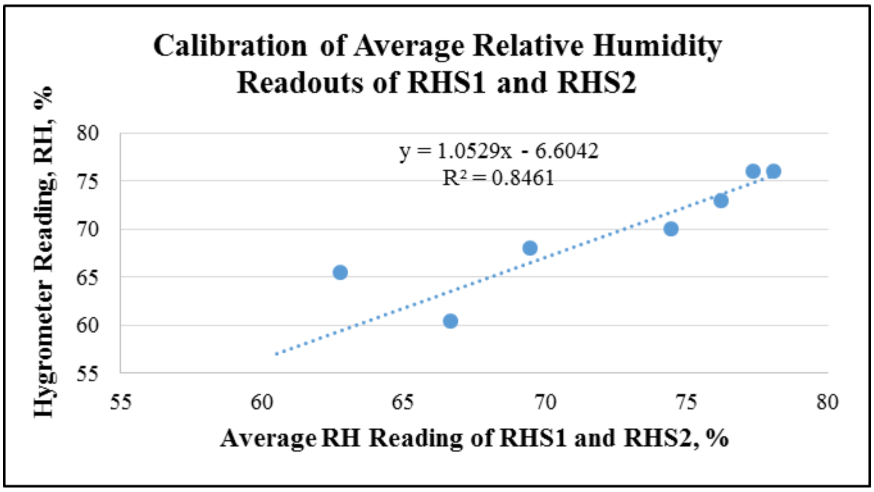


Fig. 4.8 RH (%) of Masons Hygrometer Vs Average RH (%) readout of Relative Humidity Sensor 1 and Relative Humidity Sensor 2

As described in section 3.7.2.2 the procedure was adopted to take the readouts of available % relative humidity at the instant by the two sensors of same make and specifications to check the accuracy in manufacturing error of these sensors DHT 22 as sensor 1 and DHT 22 as sensor 2. It is very pertinent to note that even after having two number of sensors of same and specifications of sensor DHT 22 they are not giving the same readouts and showing significant difference between two numbers of the same sensors. Therefore it is very interesting to note that as it was assumed that there may be variation in the readouts obtained by the more than one number of sensor of the same make and specifications holds good. Therefore, to minimize the error in manufacturing of the sensors of the same make and specifications it was felt necessary to use two number of sensors and to check individually whether they are in acceptable limit or otherwise and then to use and compare the average error obtained by these sensors with hygrometer and check whether it is in acceptable limit or otherwise. Which ultimately used for consideration for fixing the HSP and LSP of relative humidity. The readouts by sensors were taken after every 15 minutes to minimize the error and for neat comparison with the masons hygrometer to know difference between two devices. Likewise, 8 nos. of readouts were taken by DHT 22 Sensor 1 and DHT 22 Sensor 2 and compared with the masons hygrometer which is tabulated in Table 4.3 and depicted in Fig. 4.6 and Fig. 4.7. The average error is depicted in Fig. 4.8. From Table 4.3 and Fig. 4.6, Fig. 4.7 and Fig. 4.8, it is observed that the observed error for DHT 22 Sensor 1 is ranging from -8.5 to 1.0 and for DHT 22 Sensor 2 is ranging from -5.5 to 4.5. Therefore it is very important to note that as it was presumed that there may be manufacturing error with the sensors under consideration is holds true and observed error is crossing the acceptable limit i.e. ± 5.00 %. Therefore, to match the desired % relative humidity to crops grown under protective cover the average error of these two sensors of same was considered and found to be -2.86 % which is in acceptable limit i.e. ± 5.00 %. Further -2.86 % was considered for setting limits of % relative humidity i.e. HSP and LSP.

4.4.2.2 Calibration of the soil moisture sensors

The calibration of soil moisture sensors was done by adopting the detailed procedure as described in Chapter III section 3.7.2.3. The readout taken by soil moisture sensors in mV at different moisture content were compared with the respective moisture content determined by gravimetric method for sensor calibration. The respective data was collected and presented in Table 4.4.

Table 4.4: Soil moisture readouts at gravimetric moisture content and sensor readout

Sr. No.	Volume of water (ml) added to 1000 g oven dried soil sample	Moisture content (%) by gravimetric method	Sensor Readout (mV)
1.	0	0	1023
2.	50	5	1014
3.	100	10	992
4.	150	15	930
5.	200	20	845
6.	250	25	661
7.	300	30	564

8.	350	35	389
9.	400	40	235
10.	450	45	205

From the Table 4.4, it is revealed that when we add 0 ml/, nil amount of water in 1000 gm of oven dried soil then the sensor readout was observed to be 1023 mV, the soil moisture content by the gravimetric method was obtained as 0 %. When the amount of water is increased i.e., from 50 to 450 ml with an increment of 50 ml, the sensors readout were observed to be decreased i.e., from 1014 mV to 205 ml while the soil moisture content trend was observed to be increased and i. e., from 5 to 45 %. Further as described in appendix 7.1 regarding field capacity which is 26.81 %, therefore from Table 4.4 it is observed that the soil may be at a field capacity when amount of water between 250 ml to 300 ml added/ present in 1000 gm of oven dried soil sample when the sensor readout are to be obtained 661 mV and 564 mV, respectively.

Further, from Table 4.4, it is observed that the moisture content in the oven dried soil was increased from 0 to 45 per cent by adding 50, 100, 150, 200, 250, 300, 350, 400 and 450 g of water. The corresponding readouts were displayed on the computer screen in terms of millivolts (mV). The readout shown by the controller were 1023, 1014, 992, 930, 845, 661, 564, 389, 235 and 205 for 0, 5, 10, 15, 20, 25, 30, 35, 40 and 45 per cent soil moisture content in the soil, respectively. The readout approaches nearly close to field capacity between 25 to 30 per cent moisture content, which is in close agreement as stated by Nallani and Hency, 2015 and Bowlekar, 2017.

The controller was calibrated for readout in terms of per cent moisture content. The controller shows per cent moisture content on the computer or mobile screen. The controller was calibrated to moisture content ranging from 0-5 % for 1023-1014 mV readout, 6-10 % for 1014-992 mV readout, 11-15 % for 992-930 mV readout, 16-20 % for 930-845 mV readout, 21-25 % for 845-661 mV readout, 26-30 % for 661-564 mV readout, 31-35 % for 564-389 mV readout and further for next readings it remained almost constant.

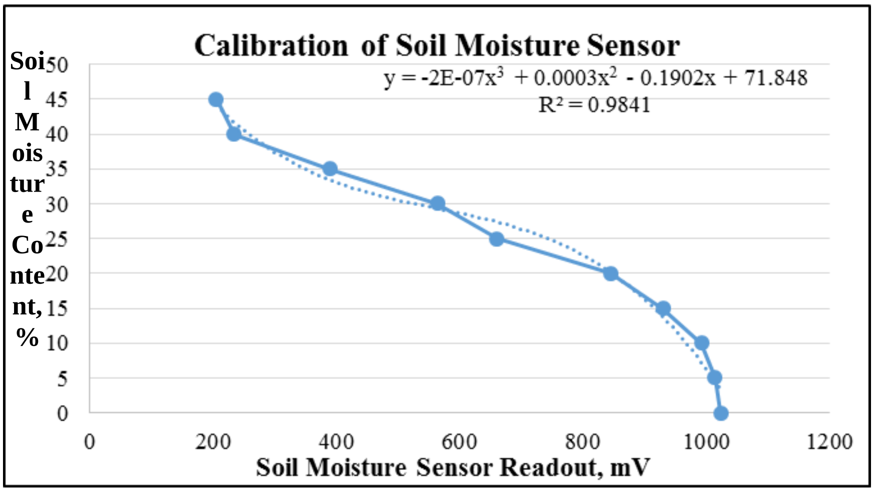


Fig. 4.9 Graph of Moisture content (%) Vs soil moisture sensor readout

The non-linear polynomial equation of degree 3 in terms of ‘x’ and ‘y’ was developed and the other values of corresponding moisture content were determined using interpolation. The graphical trend of moisture content and readout in nonlinear interpolation is shown in Fig. 4.9. The soil is heterogeneous in nature. Which means the readout obtained from soil varies from place to place. This calibration method is enough flexible to cope up with this condition and by using this method one can calibrate for any type of soil.

4.4.3 Operational steps for automation of environmental control system

Immediately after completion of calibration, the required steps were taken as described in Chapter III section 3.7.3 and as shown in Fig. 3.1 for the automation of environmental control system.

4.4.4 Operation and system setting

The controller was ON after plugging to the power supply. The lower and upper set point was set by adopting procedure as suggested and described in chapter III section 3.7.4. It was operated with three clicks only as shown in Fig. 3.2 to 3.4.

4.4.4.1 Setting of lower set point (LSP) for Temperature

The lower set point of temperature was set by adopting the procedure as described in chapter III section 3.7.4.1. But from Table 4.2, it is observed that average combined error of the two sensors i.e. DHT 22 sensor 1 DHT 22 sensor 2 for temperature measurement is -0.08 ºC. Hence, the lower set point (LSP) for temperature was set as 28.08 ^{0}C for getting 28 ºC to stop exhaust fan and fogger.

4.4.4.2 Setting of higher set point (HSP) for Temperature

The higher set point of temperature was set by adopting the procedure as described in chapter III section 3.7.4.2. But from Table 4.2, it is observed that average combined error of the two sensors i.e. DHT 22 sensor 1 DHT 22 sensor 2 for temperature measurement is -0.08 ºC. Hence, the higher set point (HSP) for temperature was set as 32.08 ^{0}C for getting 32 ºC to start exhaust fan and fogger.

4.4.4.3 Setting of lower set point (LSP) for Relative Humidity

The lower set point of relative humidity was set by adopting the procedure as described in chapter III section 3.7.4.3. But from Table 4.3, it is observed that average combined error of the two sensors i.e. DHT 22 sensor 1 DHT 22 sensor 2 for relative humidity measurement is -2.86 %. Hence, the lower set point (LSP) for relative humidity was set as 57.86 % for getting 55 % to start fogger.

4.4.4.4 Setting of higher set point (HSP) for Relative Humidity

The higher set point of relative humidity was set by adopting the procedure as described in chapter III section 3.7.4.4. But from Table 4.3, it is observed that average combined error of the two sensors i.e. DHT 22 sensor 1 DHT 22 sensor 2 for relative humidity measurement is -2.86 %. Hence, the higher set point (HSP) for relative humidity was set as 67.86 % for getting 65 % to stop fogger.

4.4.4.5 Setting of lower set point (LSP) of Soil Moisture

The lower set point of soil moisture was set by adopting the procedure as described in chapter III section 3.7.4.5. The lower set point (LSP) for irrigation was set by considering the field capacity as 26.8 %, wilting point 12 % and available moisture content 14.8 %. Further, the 50 % depletion of available moisture content about 20 % was considered to start the system.

4.4.4.6 Setting of higher set point (HSP) of Soil Moisture

The higher set point of soil moisture was set by adopting the procedure as described in chapter III section 3.7.4.6. The higher set point (HSP) for irrigation HSP was set by considering the field capacity as 27 % to stop the system.

4.4.4.7 Setting of LSP and HSP by mobile phone / laptop / desktop

Immediately after deciding the LSP and HSP, the standard procedure was adopted as described in chapter III section 3.7.4.7. The steps were followed as shown in Fig. 3.2 to set LSP and HSP by using mobile application or laptop.

4.4.4.8 Steps to know the current status of temperature, relative humidity and available soil moisture content

The present status of temperature, relative humidity and available soil moisture content in soil was obtained using mobile application Serial Bluetooth along with date and time by two clicks as described in chapter III section 3.7.4.8 and Fig. 3.3. This was used during the calibration and performance evaluation to know the present temperature, humidity and soil moisture content of soil sample and date were presented in Table 4.2 to Table 4.8.

4.4.4.9 Steps to view the set points of the system

The set points of temperature, relative humidity and available soil moisture content in soil was viewed using mobile application Serial Bluetooth along with date and time by two clicks as described in chapter III section 3.7.4.9 and Fig. 3.4.

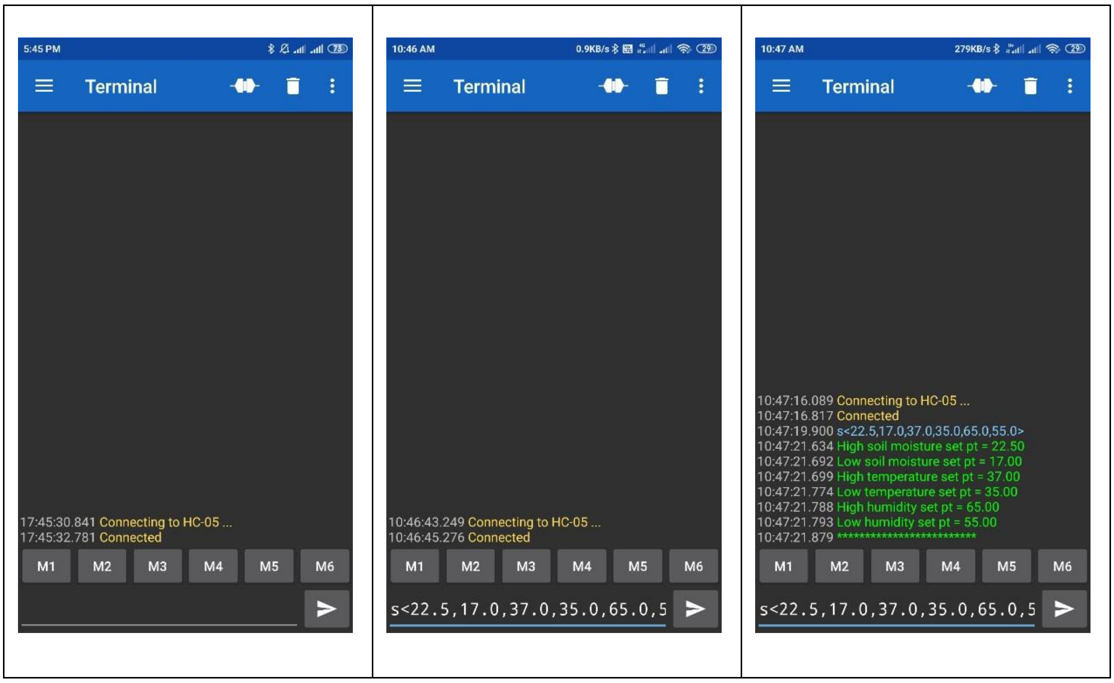
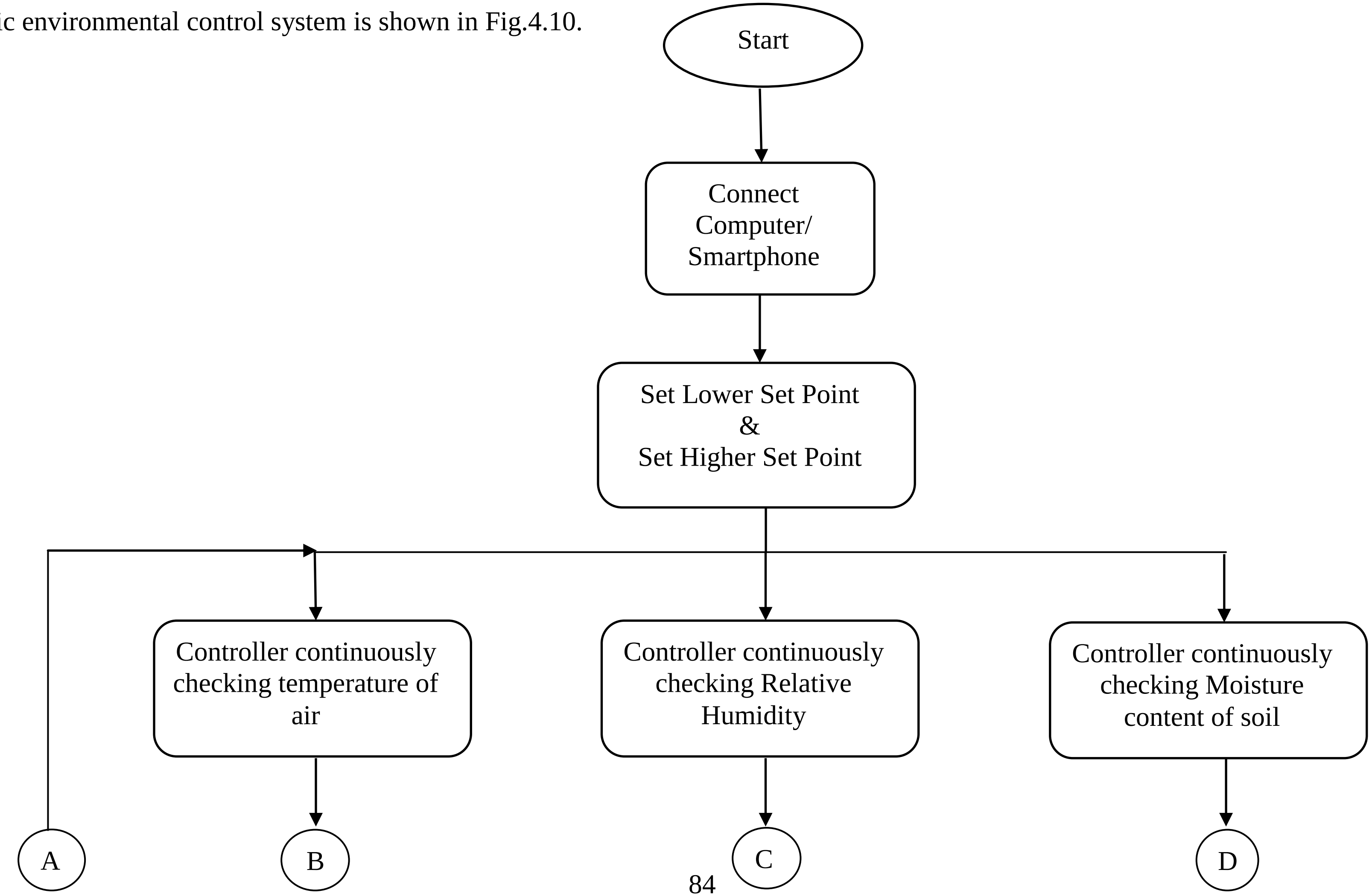


Plate 4.1 Screenshot of setting LSP and HSP for the Mobile Application

4.5 Working of automatic environmental control system

The working of the automatic environmental control system was neatly described in chapter 3 section 3.8. The flow chart of working of automatic environmental control system is shown in Fig.4.10.



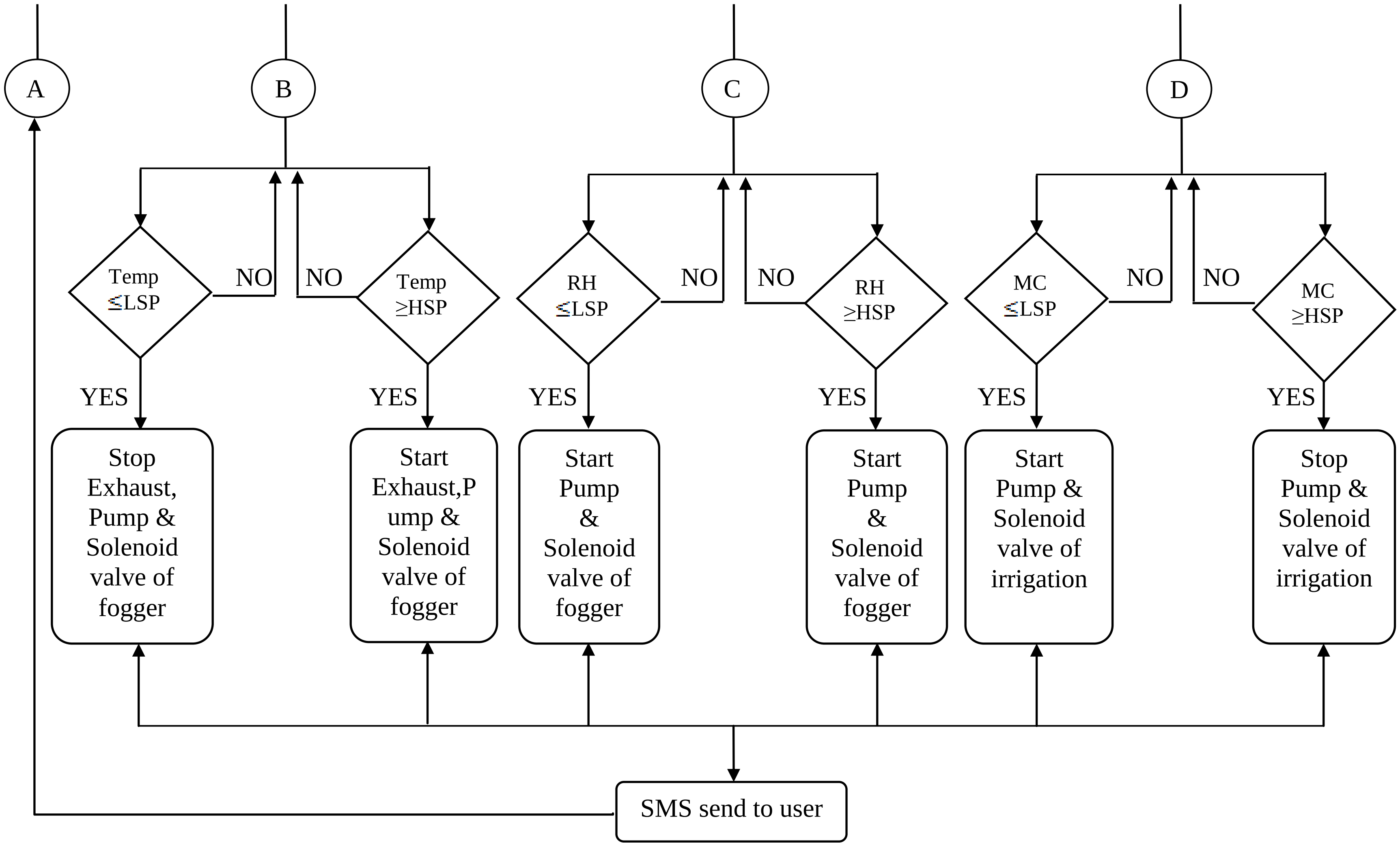


Fig. 4.10 Flow chart of working of an automatic environmental control system

4.6 Placement of Sensors

It was necessary to fix the ideal position and place of different sensors under consideration to get the normalize readout to have the uniform along the length and width of structure. The detailed procedure is described in the following section i.e. 4.6.1 and 4.6.2.

4.6.1 Placement of Temperature and Humidity Sensors

The temperature and humidity sensors are a key factor to provide more precise information about environmental conditions inside the greenhouse and further it facilitates the ON and OFF the exhaust and fogging system automatically as per predetermined LSP and HSP. The appropriate method was used to select appropriate position for placement of sensor as mentioned in chapter III section 3.9.1. Considering the facts, the sensors were closely placed 30 cm above the canopy of crop to get actual climatic condition surrounding the crop. Two sensors for temperature and relative humidity were used placed at 30 cm above maximum height of the crop grown inside the greenhouse.

(Source: https://aranet.com/wp-content/uploads/2019/07/Greenhouse_Guidelines.pdf)

4.6.2 Placement of soil moisture sensors

The representative sensor readings are a key factor to provide more precise information about the available soil moisture content at the root zone and further, it facilitates to ON and OFF the irrigation system automatically as per predetermined LSP and HSP. The proper method was adopted for the selection of representative site as mentioned in chapter III section 3.9.2. Considering the depth of soil, effective root zone depth of the crop under study the sensors were installed at 7.5 cm (Mane *et. al*., 2019), as shown in Plate 4.2.

Plate 4.2 Soil Moisture Sensors installed in the pot

4.7 Design of Exhaust Fan

Exhaust fan was designed as per standard procedure mentioned in chapter III section 3.10. Exhaust fan was being used to remove the volume of hot air present in the protective cover with the safe velocity of flowing air within the stipulated time period to control the temperature inside the protective cover within predefined limits as per the requirement of the crop.

4.7.1 Design of exhaust fan for 20 x 28 m^2 area greenhouse (Fan and Pad Type i.e. Greenhouse type-II))

Exhaust fan was designed by adopting the standard procedure described in chapter III section 3.10.

Dimensions of 560 m^2 Fan and Pad type (Greenhouse Type-II) Polyhouse are

Length of Greenhouse (L) = 28 m

Width of Greenhouse (W) = 20 m

Height of Greenhouse (H) = 6 m

a) The rate of air removal required for a greenhouse/ polyhouse under standard conditions is given by using following equation no. 4.1, considering the air removal rate as 2.5 $m^3/min/m^2$ of the greenhouse floor area (L x W).

$$\text{Standard cmm} = L \times W \times 2.5 \qquad (4.1)$$
$$= 28 \times 20 \times 2.5$$
$$= 1400 \text{ cmm}$$

(Where cmm = cubic meter per min air removal rate)

b) To correct the standard rate of air removal by multiplying it by the larger of the following two factors F_{house} or F_{vel}, where F_{house} = House factor and F_{vel} = Velocity factor, given in equation no. 4.2

$$\text{Total } m^3/min = \text{standard cmm x } F_{house} \text{ or } F_{vel} \qquad (4.2)$$

$$\text{Where } F_{house} = F_{ele} \times F_{light} \times F_{temp} \qquad (4.3)$$

Where F_{ele} = elevation factor i.e. height of site from MSL (m)

F_{light} = factor for maximum light intensity in the greenhouse

F_{temp} = Fan to Pad temperature rise factor

(Note: F_{ele}, F_{light}, F_{temp} and F_{vel} values are reported in Table No. 7.2.1, 7.2.2, 7.2.3 and 7.2.4 respectively in Appendix II and the corresponding matching values were taken for calculations)

i) Calculation of F_{house}

Elevation of Dapoli above sea level = 244 m

F_{ele} = 1.0 (∵ from Table 7.2.1)

For Dapoli Region during hot summer (May) light intensity may be upto 43.1 Klux

F_{light} = 0.8 (∵ from Table 7.2.2)

Temperature rise from pad to fan will be 4.4 ºC approximately

F_{temp} = 0.88 (∵ from Table 7.2.3)

$\therefore F_{house} = F_{ele} \times F_{light} \times F_{temp}$

$= 1.0 \times 0.8 \times 0.88$

$= 0.704$

ii) Now from Table 7.2.4, the F_{vel} is given as 1.05

$\therefore F_{vel} = 1.05$

As, F_{house} (0.704) < F_{vel} (1.05)

Therefore as stated in section 4.7.1 (b) to correct the standard rate of air removal by multiplying it by larger among the factor i.e. F_{vel} or F_{house}. Here, F_{vel} is larger

∴ The final capacity of the exhaust fan is:

Total m^3/min = standard cmm x F_{vel} (∵ F_{vel} is larger than F_{house}) (4.4)

$= 1400 \times 1.05$

= 1470 cmm

= 88200 cmh

= 51912.56 cfm

As described in section 3.4.6 of Chapter III, it is necessary to remove the hot air uniformly from the structure with the safe velocity to avoid any further damage of the standing crop may be due to high speed (velocity of air) and or concentrated hot air passing through the specific path way. Therefore, to remove the total volume of air i.e. 51912.56 cfm by the single exhaust fan which require high hp with higher rpm involves the above problems. Always it is better to remove the hot air with sufficient number of exhaust fan with safe velocity. Therefore, in this case four number of exhaust fans are considered to remove the hot air uniformly and that to with safe velocity.

∴ Total volume of air to be removed = 51912.56 cfm

As 4 number of exhaust fans are considered to remove the air volume of 51912.56 cfm

∴ The volume of air to be removed by single fan = 51912.56/4

= 12978.14 cfm

Table No. 7.2.5 in Appendix-II, contains Blade diameter, CFM rating, RPM and wattage of the exhaust fans of different sizes. From the Table No. 7.2.5, for removal of air at 12978.14 cfm Blade diameter, RPM and wattage are given as below:

i) Blade diameter = 1100 mm (36")
ii) RPM = 600
iii) Wattage = 750 i.e. hp = 1 hp (approximately)

4.7.2 Design of exhaust fan for Greenhouse Prototype (Fan and Pad Type i.e. Greenhouse type-II))

Exhaust fan was designed by adopting the standard procedure described in chapter III section 3.10.

Dimensions of Fan and Pad type (Greenhouse Type-II) Prototype Polyhouse are

Length of Greenhouse (L) = 1 m

Width of Greenhouse (W) = 0.55 m

Height of Greenhouse (H) = 1 m

a) The rate of air removal required for a greenhouse/ polyhouse under standard conditions is given by using following equation no. 4.1, considering the air removal rate as 2.5 $m^3/min/m^2$ of the greenhouse floor area (L x W).

Standard cmm = L × W × 2.5 (4.1)
= 1 × 0.55 × 2.5
= 1.375 cmm
(Where cmm = cubic meter per min air removal rate)

b) To correct the standard rate of air removal by multiplying it by the larger of the following two factors F_{house} or F_{vel}, where F_{house} = House factor and F_{vel} = Velocity factor, given in equation no. 4.2

Total m^3/min = standard cmm x F_{house} or F_{vel} (4.2)

Where $F_{house} = F_{ele} \times F_{light} \times F_{temp}$ (4.3)

Where F_{ele} = elevation factor i.e. height of site from MSL (m)

F_{light} = factor for maximum light intensity in the greenhouse

F_{temp} = Fan to Pad temperature rise factor

(Note: F_{ele}, F_{light}, F_{temp} and F_{vel} values are reported in Table No. 7.2.1, 7.2.2, 7.2.3 and 7.2.4 respectively in Appendix II and the corresponding matching values were taken for calculations)

i) Calculation of F_{house}

Elevation of Dapoli above sea level = 244 m

F_{ele} = 1.0 ($\because$ from Table 7.2.1)

For Dapoli Region during hot summer (May) light intensity may be upto 43.1 Klux

F_{light} = 0.8 ($\because$ from Table 7.2.2)

Temperature rise from pad to fan will be 1.1 ºC approximately

F_{temp} = 3.5 ($\because$ from Table 7.2.3)

$$\therefore F_{house} = F_{ele} \times F_{light} \times F_{temp}$$
$$= 1.0 \times 0.8 \times 3.5$$
$$= 2.8$$

ii) Now from Table 7.2.4, the F_{vel} is given as 5.78

$\therefore F_{vel} = 5.78$

As, F_{house} (2.8) < F_{vel} (5.78)

Therefore as stated in section 4.7.2 (b) to correct the standard rate of air removal by multiplying it by larger among the factor i.e. F_{vel} or F_{house}. Here, F_{vel} is larger

$\therefore$ The final capacity of the exhaust fan is:

Total m^3/min = standard cmm x F_{vel} ($\because F_{vel}$ is larger than F_{house}) (4.4)

$$= 1.375 \times 5.78$$
$$= 7.95 \text{ cmm}$$
$$= 477 \text{ cmh}$$
$$= 280.75 \text{ cfm}$$

As described in section 3.4.6 of Chapter III, it is necessary to remove the hot air uniformly from the structure with the safe velocity to avoid any further damage of the standing crop may be due to high speed (velocity of air) and or concentrated hot air passing through the specific path way. Always it is better to remove the hot air with sufficient number of exhaust fan with safe velocity. However, to remove the total volume of air i.e. 280.75 cfm by the single exhaust fan which does not involves the above problems is acceptable. Therefore, in this case single exhaust fan is considered to remove the hot air uniformly and that to with safe velocity.

$\therefore$ Total volume of air to be removed by single fan = 280.75 cfm

Table No. 7.2.6 in Appendix-II, contains Fan size, CFM rating, RPM and motor hp of the exhaust fans of different sizes. From the Table No. 7.2.6, for removal of air at 280.75cfm Fan size, RPM and motor hp are given as below:

i) Fan Size = 7" (177.8 mm)
ii) RPM = 1725
iii) Motor hp = 1/20 hp

However, in order to fulfill the air removal rate requirement, there is need to select the exhaust fan available in the market with capacity matching to the required capacity. So, the exhaust fan available in the market matching with our requirements was found to be 150 mm size, 600 cmh air removal rate, 2200 rpm and 0.067 hp.
(https://shop.bajajelectricals.com/home/home-essentials/fans/exhaust-fan/070031_P)

Hence, exhaust fan of 150 mm size and 600 cmh capacity with 2200 rpm and 0.067 hp was used for the experiment, as it is with close agreement with the required fan capacity obtained as given equation no. 4.4.

4.8 Field testing of the designed and developed automatic environmental control system

The designed and developed environmental control system installed in polyhouse prototype was tested by following the procedure as described in section 3.11.1 and shown in Plate 3.14, Plate 3.20 and Plate 4.5.

As described in section 4.6, the placement and position was fixed and made to get the temperature and relative humidity readouts. Two sensors each of them sensing temperature and humidity combinely were placed inside the greenhouse prototype such that each sensor represent the temperature and humidity of the entire greenhouse prototype. Each of these sensor gave certain temperature and humidity readouts of the current environment inside the greenhouse. As described in section 3.7.4 and 4.4.4, the HSP and LSP were set and as temperature exceeds HSP, the sensors sense the data and sent it to the controller to process it and then controller issued the order to the relay to automatically start exhaust fan and at the same time to start solenoid valve and then pump inorder to start foggers to lower down the temperature. Further when temperature is within permissible limit i.e. LSP, again sensors sensed the data and sent it to the controller then controller process the data and issued the order to the relay to stop exhaust fan, pump and close solenoid valve automatically. Similarly, when humidity inside greenhouse falls down i.e. below the LSP, then sensors sensed the data and send it to the controller to process it and then controller issued the order to the relay to start pump and fogging system with the help of solenoid valve to gain humidity and after humidity reaches predetermined limit of HSP, then again sensors sensed the data and sent it to the controller then controller process the data and issued order to the relay to stop the pump and fogging system with the help of solenoid valve automatically.

For recording the real time soil moisture the sensors were placed by adopting the procedure as described in section 4.6.2 and Plate 4.2. Considering the depth of soil, effective root zone depth of the crop under study the three soil moisture sensors were placed at 7.5 cm depth. Each of these sensors gave certain readouts matching to the available soil moisture content in each pot. At 50 per cent depletion of available soil moisture as the field capacity, the relay automatically opened the solenoid valve for irrigation and the pump started automatically. Further, during irrigation when the sensor readouts again matched with moisture content close to field capacity, the pump automatically turned OFF with the help of relay and then the solenoid valve was closed. All the average readings of the temperature, humidity and soil moisture were recorded and stored in the memory card. The ON or OFF status of the exhaust fan, fogger and Irrigation was obtained in the form of SMS on users mobile as shown in Plate 4.3.

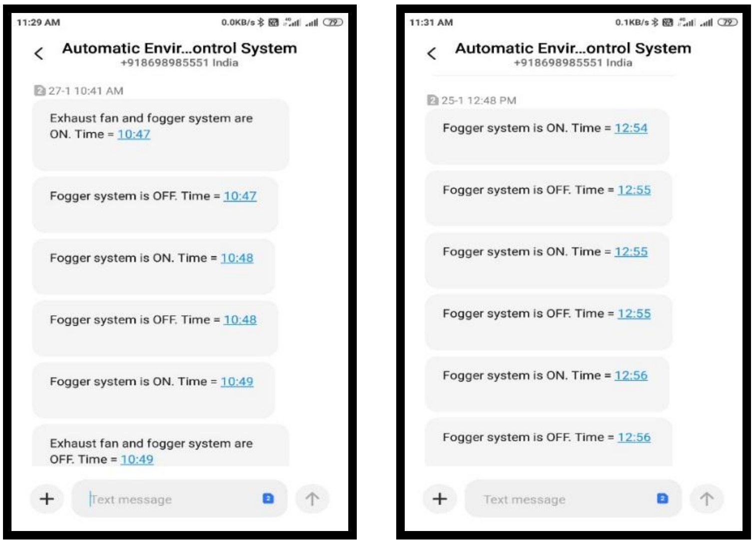


Plate 4.3 Screenshots of ON and OFF SMS obtained on mobile

4.9 Performance evaluation

The performance of the developed automatic environmental control unit was evaluated by adopting the procedure as described in Chapter III section 3.11. It includes filler trials, weekly field testing of the temperature, humidity and soil moisture sensor inside the greenhouse prototype. This is described in the following section.

4.9.1 Filler trial for field performance of the sensors

It was felt necessary after adopting the procedure as described in section 4.3 and 4.4 for design and development of the automatic environmental controller to take the filler trial whether the designed and developed automatic environmental controller along with real time based automatic irrigation system performing well and as per predetermined objectives or not. Therefore, a test run was taken in the greenhouse prototype on 28/12/2020 for the period of 12 hours and 15 minutes from 8.30 am to 8.45 pm. The controller was provided with provision to collect the data and record it for the said operating period with an 15 minutes time interval for temperature, relative humidity and soil moisture sensors respectively. The data collected for temperature, relative humidity and soil moisture is presented in Table 4.5 to 4.7 and Fig 4.11 to 4.13

4.9.1.1 Filler test for trend of temperature readouts of developed controller

To study the performance of the developed controller to control temperature automatically, the filler test for trend of temperature readouts by the developed controller was studied from 8.30 am to 8. 45 pm on 28/12/2020 and presented in Table 4.5 and Fig 4.11

Table 4.5: Trend of temperature readouts of developed controller

Time	Temperature Sensor Readings	Status of		
		Exhaust	Fogger	Pump
8:30:00	25.75	OFF	OFF	OFF
8:45:00	26.80	OFF	OFF	OFF
9:00:00	27.05	**ON**	**ON**	**ON**
9:15:00	26.95	OFF	OFF	ON
9:30:00	26.90	OFF	OFF	OFF
9:45:00	27.25	**ON**	**ON**	**ON**
10:00:00	26.70	OFF	OFF	OFF
10:15:00	27.05	**ON**	**ON**	**ON**
10:30:00	27.35	**ON**	**ON**	**ON**
10:45:00	27.10	**ON**	**ON**	**ON**
11:00:00	27.40	**ON**	**ON**	**ON**
11:15:00	27.85	**ON**	**ON**	**ON**
11:30:00	27.50	**ON**	**ON**	**ON**
11:45:00	26.70	OFF	OFF	OFF

12:00:00	27.40	ON	ON	ON
12:15:00	26.95	OFF	OFF	OFF
12:30:00	27.55	ON	ON	ON
12:45:00	26.65	OFF	OFF	OFF
13:00:00	26.55	OFF	OFF	OFF
13:15:00	26.90	OFF	OFF	OFF
13:30:00	26.95	OFF	OFF	OFF
13:45:00	27.15	ON	ON	ON
14:00:00	26.85	OFF	OFF	OFF
14:15:00	26.55	OFF	OFF	OFF
14:30:00	26.50	OFF	OFF	OFF
14:45:00	26.70	OFF	OFF	OFF
15:00:00	26.45	OFF	OFF	OFF
15:15:00	26.55	OFF	OFF	OFF
15:30:00	26.60	OFF	OFF	OFF
15:45:00	26.65	OFF	OFF	OFF
16:00:00	26.70	OFF	OFF	OFF
16:15:00	26.85	OFF	OFF	OFF
16:30:00	26.95	OFF	OFF	OFF
16:45:00	25.70	OFF	OFF	OFF
17:00:00	25.15	OFF	OFF	OFF
17:15:00	24.80	OFF	OFF	OFF
17:30:00	24.40	OFF	OFF	OFF
17:45:00	23.80	OFF	OFF	OFF
18:00:00	23.20	OFF	OFF	OFF
18:15:00	22.60	OFF	OFF	OFF
18:30:00	22.15	OFF	OFF	OFF
18:45:00	21.65	OFF	OFF	OFF
19:00:00	21.35	OFF	OFF	OFF
19:15:00	20.75	OFF	OFF	OFF
19:30:00	20.25	OFF	OFF	OFF
19:45:00	19.95	OFF	OFF	OFF
20:00:00	19.70	OFF	OFF	OFF
20:15:00	19.35	OFF	OFF	OFF
20:30:00	19.15	OFF	OFF	OFF
20:45:00	18.95	OFF	OFF	OFF

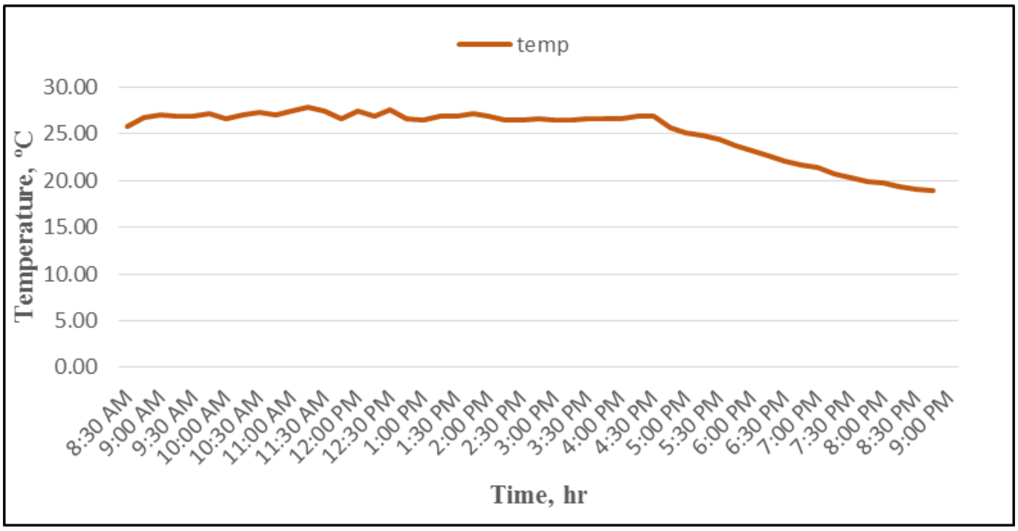


Fig. 4.11 Trend of temperature readouts of developed controller

The continuous trend for the temperature readout of developed controller was studied from 8:30 am to 8:45 pm on 28/12/2020 and is presented in Table 4.5 and Fig. 4.11 at an interval of 15 mins. The average value of the readouts obtained from TS-I and TS-II is presented in the Table 4.9 and Fig 4.11. The controller was set for temperature HSP at 27 ºC and LSP at 25 ºC. The sensors were placed in greenhouse prototype to sense the temperature and then the study was carried out. It is interesting to note that within this set limits the maximum temperature of about 27.85 ºC was not exceeded inside the greenhouse prototype. From data presented in Table 4.5 and Fig 4.11, it is very pertinent to note that the developed environment controller is working within predetermined set limits of HSP and LSP. From Table 4.5, it is clearly observed that as earlier described that for trial purpose the HSP was set at 27 ºC. Therefore, as the system was plugged in from 8.30 am and at the same time the temperature sensor recorded the temperature as 25.75 ºC likewise for 8.45 am as 26.80 ºC and when at 9.00 am it was recorded as 27.05 ºC the system automatically get started to bring the increased temperature i.e. from 27.05 ºC to predetermined lower limit and then turned off. The similar cycles were observed for rest of the time taken for testing i.e. up to 8.45 pm. However, it is very important to note that during this test period and as data presented in Table 4.5 and Fig. 4.11, if temperature readouts falls below the LSP the controller gets turned OFF automatically.

From the Table 4.5, it is also clearly revealed that whenever the temperature inside the greenhouse prototype was exceeding pre-determined HSP of 27 ºC then the controller automatically started exhaust fan and foggers to lower down temperature and when the temperature was reached within the permissible limits then exhaust fan and fogger were switched OFF with the help of relay and solenoid valve respectively. Also text messages were simultaneously sent to the user whenever the system was started and stopped.

Thus, it can be concluded that the temperature inside the greenhouse was always successfully maintained in the pre-determined limits by using this automatic environmental control system. In this way the filler test completed for managing the temperature inside the greenhouse prototype by developed automatic environmental controller.

4.9.1.2 Filler test for trend of relative humidity readouts of developed controller

To study the performance of the developed controller to control the relative humidity automatically, the filler test for trend of relative humidity readouts by the developed controller was studied from 8.30 am to 8. 45 pm on 28/12/2020 and presented in Table 4.6 and Fig 4.12

Table 4.6: Trend of relative humidity variation readouts of developed controller

Time	Humidity Sensor Readings	Status of		
		Exhaust	Fogger	Pump
8:30:00	84.75	OFF	OFF	OFF
8:45:00	83.95	OFF	OFF	OFF
9:00:00	88.50	ON	ON	ON
9:15:00	88.70	OFF	OFF	ON
9:30:00	90.70	OFF	OFF	OFF
9:45:00	90.10	ON	ON	ON
10:00:00	86.65	ON	ON	ON
10:15:00	86.80	ON	ON	ON
10:30:00	88.70	ON	ON	ON
10:45:00	90.50	ON	ON	ON
11:00:00	87.55	ON	ON	ON
11:15:00	87.25	ON	ON	ON
11:30:00	89.15	ON	ON	ON
11:45:00	91.80	ON	ON	ON
12:00:00	88.65	ON	ON	ON
12:15:00	90.75	OFF	OFF	OFF
12:30:00	88.65	ON	ON	ON
12:45:00	88.50	OFF	OFF	OFF
13:00:00	91.25	OFF	OFF	OFF
13:15:00	76.90	OFF	OFF	OFF
13:30:00	83.60	ON	ON	ON
13:45:00	87.65	OFF	OFF	OFF
14:00:00	84.05	ON	ON	ON
14:15:00	79.50	OFF	OFF	OFF
14:30:00	82.85	OFF	OFF	OFF
14:45:00	80.75	OFF	OFF	OFF
15:00:00	75.25	OFF	OFF	OFF
15:15:00	77.35	OFF	OFF	OFF
15:30:00	73.35	OFF	OFF	OFF
15:45:00	71.85	OFF	OFF	OFF
16:00:00	66.35	OFF	OFF	OFF
16:15:00	69.70	OFF	OFF	OFF
16:30:00	80.50	OFF	OFF	OFF
16:45:00	75.15	OFF	OFF	OFF
17:00:00	80.60	OFF	OFF	OFF
17:15:00	81.45	OFF	OFF	OFF
17:30:00	83.70	OFF	OFF	OFF
17:45:00	87.60	OFF	OFF	OFF
18:00:00	88.55	OFF	OFF	OFF
18:15:00	89.10	OFF	OFF	OFF
18:30:00	90.40	OFF	OFF	OFF
18:45:00	90.50	OFF	OFF	OFF

19:00:00	89.75	OFF	OFF	OFF
19:15:00	90.75	OFF	OFF	OFF
19:30:00	90.75	OFF	OFF	OFF
19:45:00	90.85	OFF	OFF	OFF
20:00:00	91.20	OFF	OFF	OFF
20:15:00	93.45	OFF	OFF	OFF
20:30:00	92.65	OFF	OFF	OFF
20:45:00	92.55	OFF	OFF	OFF

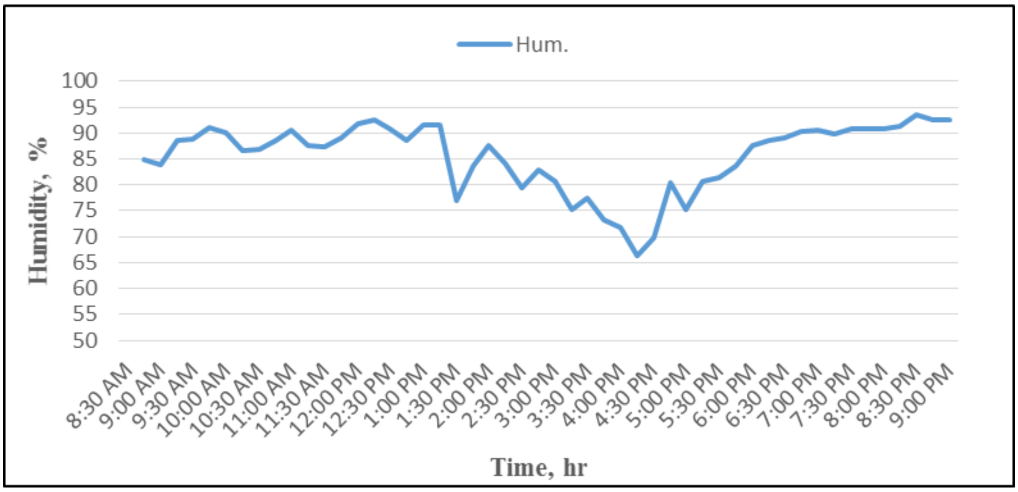


Fig. 4.12 Trend of humidity readout of developed controller

The continuous trend for the Humidity readout of developed controller was studied from 8:30 am to 8:45 pm on 28/12/2020 and is presented in Table 4.6 and Fig. 4.12 at an interval of 15 mins. The average value of the readouts obtained from Humidity Sensor-I and Humidity Sensor-II is presented in the Table 4.6 and Fig 4.12. The controller was set for relative humidity LSP at 55 % and HSP at 65 % by following the procedure described in 4.4.4.3 and 4.4.4.4 respectively. The sensors were placed in greenhouse prototype to sense the relative humidity and then the study was carried out. From the data presented in Table 4.6 and Fig 4.12, it is very pertinent to note that the developed environment controller is working within predetermined set limits of HSP and LSP. From Table 4.6, it is clearly observed that as earlier described that for trial purpose the LSP was set at 55 %. Therefore, as the system was plugged in from 8.30 am and at the same time the relative humidity sensor recorded the relative humidity as 84.75 % likewise for 8.45 am as 83.95 %. From Table 4.6 and Fig 4.12, it is observed that at 9.00 am relative humidity raised to 88.50 %, it was due to the operation of the exhaust fan and fogger to bring the increased temperature within pre-determined limits, which also led to increase in relative humidity. The similar cycles were observed for rest of the time taken for testing i.e. up to 8.45 pm. However, it is very important to note that during this test period and as data presented in Table 4.6 and Fig. 4.12, the average relative humidity inside the greenhouse prototype unit never fall below the predetermined limits as exhaust fan and foggers were frequently operated to control temperature. This automatically led to maintain relative humidity inside the greenhouse prototype. Likewise, from Table 4.6, it is revealed that during the night/ cool hours relative humidity inside the greenhouse prototype was always high. Hence, no operation of fogger was observed during night time also.

The controller was set for algorithm that whenever the relative humidity inside the greenhouse prototype was less than pre-determined LSP of 55 % then the controller automatically started Pump and foggers to gain humidity and when the relative humidity was reached within the permissible limits i.e. HSP then pump and fogger were switched OFF with the help of relay and solenoid valve respectively. Also text message was simultaneously sent to the user whenever the system was started and stopped.

Thus, it is to be concluded that the relative humidity inside the greenhouse was always successfully maintained in the pre-determined limits by using this automatic environmental control system. In this way the filler test was completed for managing the relative humidity inside the greenhouse prototype by developed automatic environmental controller.

4.9.1.3 Filler test for trend of Soil Moisture variation under the control of developed controller

To study the performance of the developed controller to control soil moisture automatically, the filler test for trend of soil moisture readouts by the developed controller was studied from 8.30 am to 8.45 pm on 28/12/2020 and presented in Table 4.7 and Fig 4.12

Table 4.7: Trend of available soil moisture variation readouts under the control of developed controller

Time	Soil Moisture Readings	Status of	
		Irrigation	Pump
8:30:00	21.00	OFF	OFF
8:45:00	20.67	OFF	OFF
9:00:00	20.67	OFF	ON
9:15:00	20.33	OFF	OFF
9:30:00	20.00	**ON**	**ON**
9:45:00	26.67	**ON**	**ON**
10:00:00	28.00	OFF	ON

10:15:00	28.00	OFF	ON
10:30:00	28.00	OFF	ON
10:45:00	28.00	OFF	ON
11:00:00	28.00	OFF	ON
11:15:00	27.67	OFF	ON
11:30:00	27.67	OFF	ON
11:45:00	27.67	OFF	ON
12:00:00	27.67	OFF	ON
12:15:00	27.67	OFF	OFF
12:30:00	27.33	OFF	ON
12:45:00	27.33	OFF	OFF
13:00:00	27.33	OFF	OFF
13:15:00	27.00	OFF	OFF
13:30:00	27.00	OFF	ON
13:45:00	27.00	OFF	OFF
14:00:00	27.00	OFF	ON
14:15:00	26.67	OFF	OFF
14:30:00	26.67	OFF	OFF
14:45:00	26.67	OFF	OFF
15:00:00	26.67	OFF	OFF
15:15:00	26.33	OFF	OFF
15:30:00	26.33	OFF	OFF
15:45:00	26.33	OFF	OFF
16:00:00	26.33	OFF	OFF
16:15:00	26.00	OFF	OFF
16:30:00	26.00	OFF	OFF
16:45:00	26.00	OFF	OFF
17:00:00	25.67	OFF	OFF
17:15:00	25.67	OFF	OFF
17:30:00	25.67	OFF	OFF
17:45:00	25.67	OFF	OFF
18:00:00	25.67	OFF	OFF
18:15:00	25.67	OFF	OFF
18:30:00	25.33	OFF	OFF
18:45:00	25.67	OFF	OFF
19:00:00	25.33	OFF	OFF
19:15:00	25.33	OFF	OFF
19:30:00	25.33	OFF	OFF
19:45:00	25.33	OFF	OFF
20:00:00	25.33	OFF	OFF
20:15:00	25.33	OFF	OFF
20:30:00	25.33	OFF	OFF
20:45:00	25.33	OFF	OFF

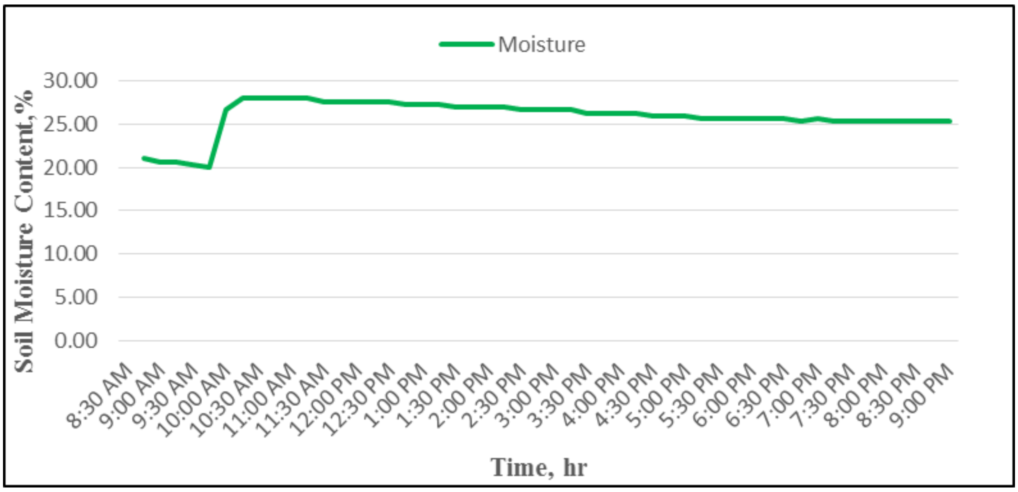


Fig. 4.13 Trend of soil moisture readouts of developed controller

The continuous trend for the Soil Moisture readouts of developed controller was studied from 8:30 am to 8:45 pm on 28/12/2020 and is presented in Table 4.7 and Fig. 4.13 at an interval of 15 mins. The average value of the readouts obtained from SMS-I, SMS-II and SMS-III is presented in the Table 4.7 and Fig 4.13. The controller was set for soil moisture content HSP at 27 % and LSP at 20 %. The sensors were placed in pots kept inside the greenhouse prototype to sense the soil moisture content. It is interesting to note that within this set limits the maximum soil moisture content of about 28 % was not exceeded within the pots and was not allowed to drop below 20 %. From data presented in Table 4.7 and Fig. 4.13, it is very pertinent to note that the developed environment controller is working within predetermined set limits of HSP and LSP. From Table 4.7, it is clearly observed that as earlier described that for trial purpose the HSP was set at 27 %. Therefore, as the system was plugged in from 8.30 am and at the same time the soil moisture sensor recorded the available soil moisture content as 21.00 % likewise for 8.45 am, 9.00 am and 9.15 am as 20.67 %, 20.67 % and 20.33 % respectively. And when at 9.00 am it was recorded as 20 % the system automatically get started to bring the decreased available soil moisture i.e. from 20 % to 27 % and when it reached to 28 % i.e. close to field capacity it turned off. The similar cycles were not observed for rest of the time taken for testing i.e. up to 8.45 pm as available soil moisture never fell below LSP further. However, it is very important to note that during this test period and as data presented in Table 4.7 and Fig. 4.13, if available soil moisture readouts reaches HSP i.e. the field capacity, the controller gets turned OFF automatically.

Also, from the Table 4.7, it is clearly revealed that at 9:00 am when the moisture content inside the pot was equal to or below pre-defined LSP of 20 % then the controller automatically started Pump and solenoid valve to start irrigation to gain moisture content and when the soil moisture reached upto HSP then the pump and solenoid valve were switched OFF with the help of relay. Also text messages were simultaneously sent to the user whenever the system was started and stopped.

Thus, it can be concluded that the available soil moisture inside the pot was always successfully maintained in the pre-determined limits by using developed automatic environmental control system. In this way the filler test was completed for managing the available soil moisture inside the pots by developed automatic environmental controller.

4.9.2 Performance evaluation of the developed system

After completing the filler trials the actual performance evaluation of the designed and developed automatic environmental controller for its parameter (temperature, relative humidity and available soil moisture) measurement and controlling was carried out as described in chapter III section 3.11.2 to 3.11.4. Therefore, performance evaluation of the developed system was carried out in the greenhouse prototype from 28/12/2020 to 27/01/2021 i.e. for a period of one month. The observations of temperature and relative humidity were recorded daily at three different time period at an interval of four hours starting from 8.30 am followed by 12.30 pm and 4.30 pm respectively. And the observations of available soil moisture content were recorded weekly at three different time period at an interval of four hours starting from 8.30 am followed by 12.30 pm and 4.30 pm respectively. The error in the measurement obtained of the each parameters via. Temperature, relative humidity and available soil moisture during the performance evaluation is given in detail in Appendix IV and were rearranged weekly in this section and presented in Table 4.8 to 4.18 and fig 4.14 to Fig. 4.24.

4.9.2.1 Performance evaluation of the Temperature Sensor

To study the performance evaluation of temperature sensor of the developed automatic environmental controller, the controller was set with the temperature LSP of 28.08 ºC and HSP of 32.08 ºC as described in section 4.4.4.1 and 4.4.4.2 respectively, to get more precise readouts. The performance evaluation of temperature sensor was carried out by adopting procedure as described in Chapter III section

3.11.2. The data collected was presented in Table 4.8 to Table 4.12 and by Fig 4.14 to Fig 4.18 for the period from 28 Dec. 2020 to 27 Jan. 2021.

Table 4.8: Performance evaluation and testing of temperature sensors of developed controller and comparison of sensor readouts (Air Temperature) with by Thermometer readings for Week 1

Week 1 Temperature Readings						
Date	**Time**	**TS - I**	**TS- II**	**Average**	**Thermometer Reading**	**Average % variation of TS-I & TS-II**
28-12-2020	8:30 am	25.70	25.80	25.75	25.50	0.98
	12:30 pm	27.50	27.60	27.55	27.00	2.04
	04:30 pm	26.80	27.10	26.95	27.00	0.19
29-12-2020	8:30 am	24.10	24.50	24.30	24.00	1.25
	12:30 pm	31.50	30.60	31.05	31.00	0.16
	04:30 pm	28.40	27.90	28.15	28.50	1.23
30-12-2020	8:30 am	23.80	24.00	23.90	24.00	0.42
	12:30 pm	31.30	30.20	30.75	31.00	0.81
	04:30 pm	28.40	28.00	28.20	28.00	0.71
31-12-2020	8:30 am	25.30	25.10	25.20	25.00	0.80
	12:30 pm	32.70	31.70	32.20	32.50	0.92
	04:30 pm	29.20	28.60	28.90	29.00	0.34
01-01-2021	8:30 am	23.20	23.60	23.40	23.50	0.43
	12:30 pm	32.20	31.60	31.90	33.00	3.33
	04:30 pm	28.50	27.70	28.10	29.00	3.10
02-01-2021	8:30 am	23.45	23.45	23.45	23.00	1.96
	12:30 pm	32.45	32.15	32.30	32.50	0.62
	04:30 pm	30.30	29.30	29.80	29.50	1.02
03-01-2021	8:30 am	24.10	24.70	24.40	24.50	0.41
	12:30 pm	32.65	31.85	32.25	32.00	0.78
	04:30 pm	30.50	29.70	30.10	30.00	0.33

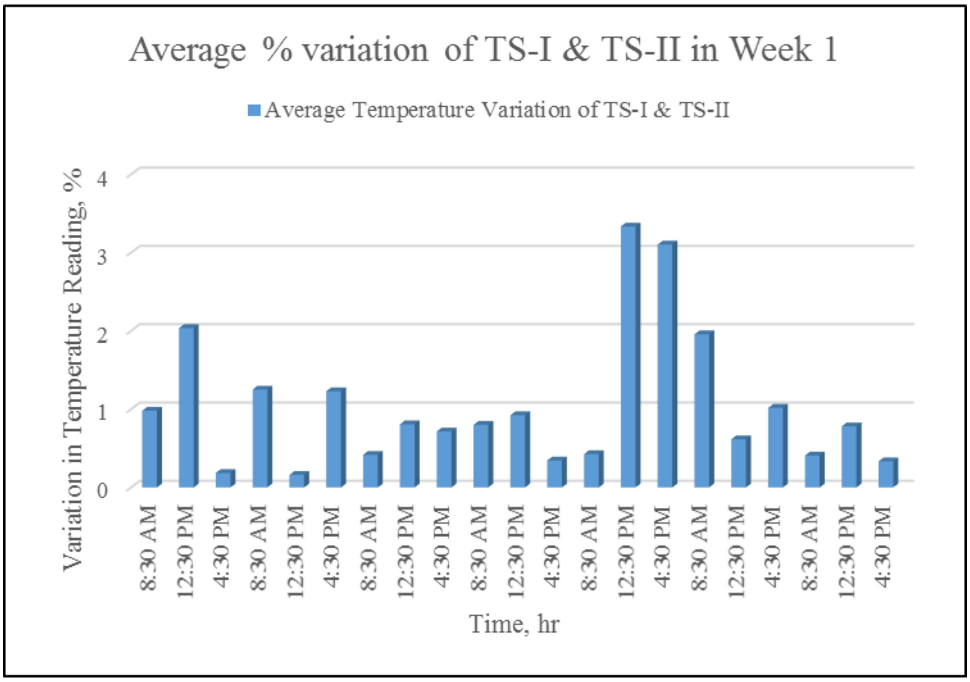


Fig. 4.14 Average % variation in temperature of TS-I & TS-II in Week 1

Table 4.8 and Fig. 4.14 shows the readouts for the period from 28/12/2020 to 03/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average temperature readouts of the sensors were compared with Thermometer reading and variation was determined. It is observed from the data, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. However from the data presented in Table 4.8 and Fig. 4.14, it is revealed that for the different time periods the minimum average temperature variation of the sensors was 0.16 % obtained on 29/12/2020 at 12:30 pm and the maximum average temperature variation of the sensor was 3.33 % obtained on 01/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average temperature readouts of TS-I & TS-II and checked by Thermometer are more or less similar i.e. from 0.16 to 3.33 % in Week 1. The representative temperature samples for determining the temperature inside the greenhouse prototype was recorded at two different locations (which represents temperature of the entire greenhouse prototype) as described in section 3.8 and were further compared with Thermometer.

Thus, it is revealed from the study that the temperature was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 1.

Table 4.9: Performance evaluation and testing of temperature sensors of developed controller and comparison of sensor readouts (Air Temperature) with Thermometer readings for Week 2

Week 2 Temperature Readings						
Date	**Time**	**TS - I**	**TS- II**	**Average**	**Thermometer Reading**	**Average % variation of TS-I & TS-II**
04-01-2021	8:30 am	24.70	24.20	24.45	24.50	0.20
	12:30 pm	31.90	30.50	31.20	32.00	2.50
	04:30 pm	29.00	27.90	28.45	29.00	1.90
05-01-2021	8:30 am	25.40	24.70	25.05	25.00	0.20
	12:30 pm	32.30	30.90	31.60	32.00	1.25
	04:30 pm	29.90	29.50	29.70	30.00	1.00
06-01-2021	8:30 am	24.40	24.80	24.60	24.50	0.41
	12:30 pm	31.70	30.40	31.05	31.50	1.43
	04:30 pm	29.80	27.90	28.85	29.00	0.52
07-01-2021	8:30 am	23.80	23.40	23.60	23.50	0.43
	12:30 pm	32.45	31.85	32.15	32.50	1.08
	04:30 pm	29.50	28.20	28.85	29.00	0.52
08-01-2021	8:30 am	24.00	23.70	23.85	24.00	0.62
	12:30 pm	31.50	30.50	31.00	31.50	1.59
	04:30 pm	30.20	28.90	29.55	30.00	1.50
09-01-2021	8:30 am	24.50	24.20	24.35	24.50	0.61
	12:30 pm	31.30	29.80	30.55	31.00	1.45
	04:30 pm	29.40	28.30	28.85	29.00	0.52
10-01-2021	8:30 am	24.80	24.40	24.60	24.50	0.41
	12:30 pm	31.85	30.65	31.25	32.00	2.34
	04:30 pm	29.70	29.10	29.40	29.50	0.34

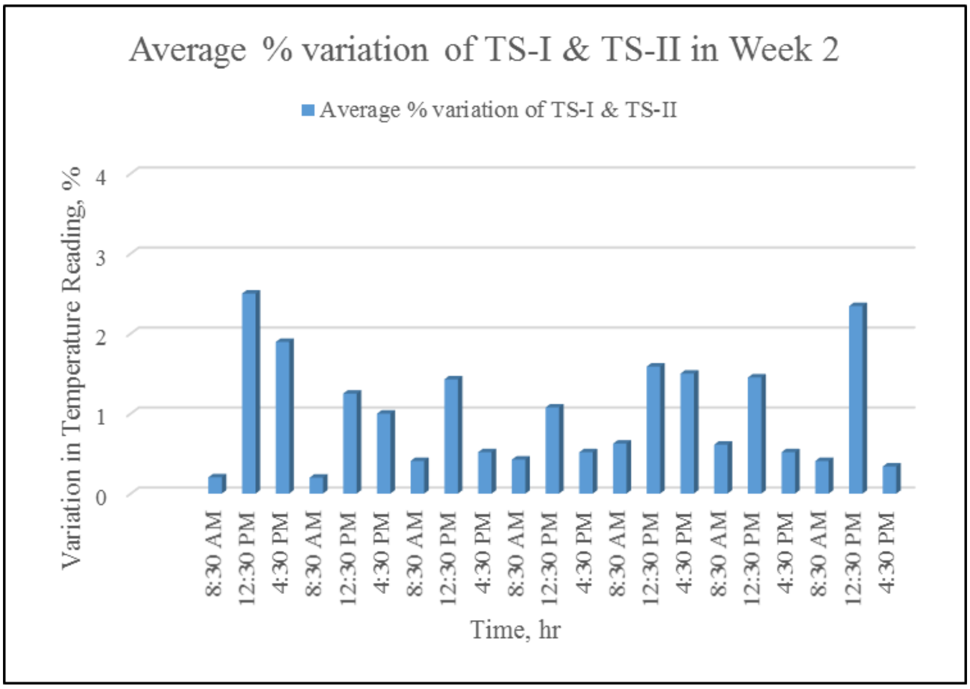


Fig. 4.15 Average % variation in temperature of TS-I & TS-II in Week 2

Table 4.9 and Fig. 4.15 shows the readouts for the period from 04/01/2021 to 10/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average temperature readouts of the sensors were compared with Thermometer reading and variation was determined. It is observed from the data, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. However from the data presented in Table 4.9 and Fig. 4.15, it is revealed that for the different time periods the minimum average temperature variation of the sensors was 0.20 % obtained on 04/01/2021 and 05/01/2021 at 08:30 am and the maximum average temperature variation of the sensor was 2.50 % obtained on 04/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average temperature readouts of TS-I & TS-II and checked by a Thermometer are more or less similar i.e. from 0.20 to 2.50 % in Week 2. The representative temperature samples for determining the temperature inside the greenhouse prototype was recorded at two different locations (which represents temperature of the entire greenhouse prototype) as described in section 3.8 and were further compared with Thermometer.

Thus, it is revealed from the study that the temperature was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 2.

Table 4.10: Performance evaluation and testing of temperature sensors of developed controller and comparison of sensor readouts (Air Temperature) with Thermometer readings for Week 3

Week 3 Temperature Readings						
Date	**Time**	**TS - I**	**TS- II**	**Average**	**Thermometer Reading**	**Average % variation of TS-I & TS-II**
11-01-2021	8:30 am	24.50	23.90	24.20	24.00	0.83
	12:30 pm	31.70	31.10	31.40	31.50	0.32
	04:30 pm	29.60	27.80	28.70	29.50	2.71
12-01-2021	8:30 am	24.20	24.50	24.35	24.00	1.46
	12:30 pm	32.50	32.10	32.30	32.00	0.94
	04:30 pm	29.50	28.90	29.20	29.50	1.02
13-01-2021	8:30 am	24.50	24.10	24.30	24.00	1.25
	12:30 pm	31.80	31.50	31.65	31.50	0.48
	04:30 pm	29.80	29.20	29.50	29.50	0.00
14-01-2021	8:30 am	23.60	23.30	23.45	23.50	0.21
	12:30 pm	32.40	32.20	32.30	32.00	0.94
	04:30 pm	30.30	29.50	29.90	30.00	0.33
15-01-2021	8:30 am	24.60	24.30	24.45	24.50	0.20
	12:30 pm	32.50	32.30	32.40	32.00	1.25
	04:30 pm	29.70	28.90	29.30	29.50	0.68
16-01-2021	8:30 am	24.80	24.10	24.45	24.50	0.20
	12:30 pm	32.10	31.10	31.60	32.00	1.25
	04:30 pm	29.60	28.70	29.15	29.50	1.19
17-01-2021	8:30 am	24.30	24.00	24.15	24.00	0.62
	12:30 pm	32.10	31.60	31.85	31.50	1.11
	04:30 pm	29.50	28.90	29.20	29.50	1.02

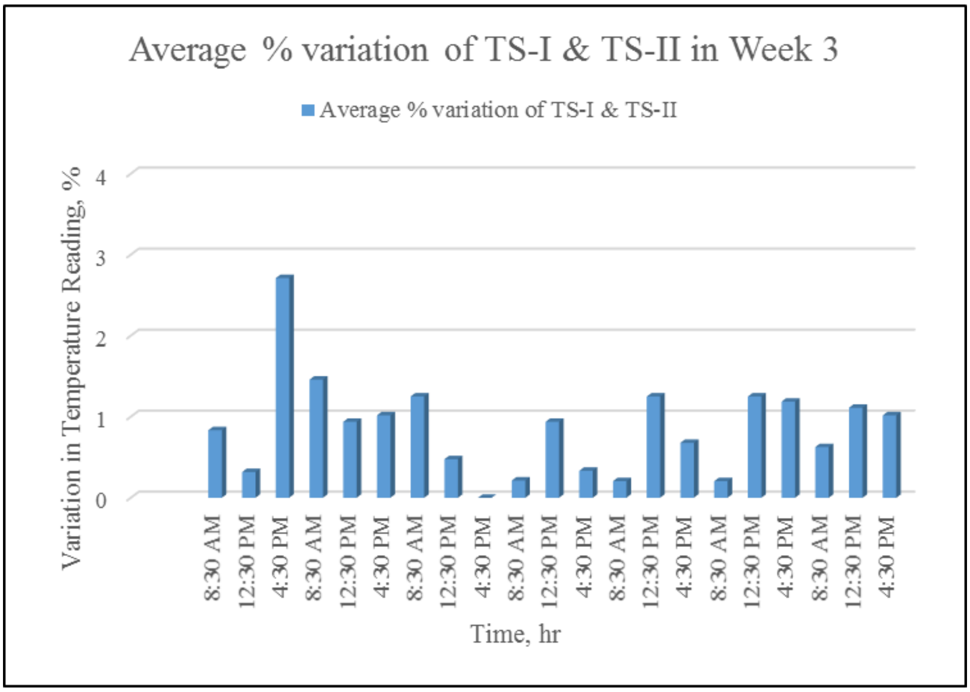


Fig. 4.16 Average % variation in temperature of TS-I & TS-II in Week 3

Table 4.10 and Fig. 4.16 shows the readouts for the period from 11/01/2021 to 17/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average temperature readouts of the sensors were compared with Thermometer reading and variation was determined. It is observed from the data, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. However from the data presented in Table 4.10 and Fig. 4.16, it is revealed that for the different time periods the minimum average temperature variation of the sensors was 0.00 % obtained on 13/01/2021 at 04:30 pm and the maximum average temperature variation of the sensor was 2.71 % obtained on 11/01/2021 at 04:30 pm. It is very important to note that the percentage variation recorded by the average temperature readouts of TS-I & TS-II and checked by a Thermometer are more or less similar i.e. from 0.00 to 2.71 % in Week 3. The representative temperature samples for determining the temperature inside the greenhouse prototype was recorded at two different locations (which represents temperature of the entire greenhouse prototype) as described in section 3.8 and were further compared with Thermometer.

Thus, it is revealed from the study that the temperature was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 3.

Table 4.11: Performance evaluation and testing of temperature sensors of developed controller and comparison of sensor readouts (Air Temperature) with Thermometer readings for Week 4

Week 4 Temperature Readings						
Date	**Time**	**TS - I**	**TS- II**	**Average**	**Thermometer Reading**	**Average % variation of TS-I & TS-II**
18-01-2021	8:30 am	24.70	24.60	24.65	24.50	0.61
	12:30 pm	31.90	31.50	31.70	31.50	0.63
	04:30 pm	30.10	29.50	29.80	30.00	0.67
19-01-2021	8:30 am	24.30	23.90	24.10	24.00	0.42
	12:30 pm	32.40	32.10	32.25	32.00	0.78
	04:30 pm	30.20	29.70	29.95	30.00	0.17
20-01-2021	8:30 am	23.80	23.40	23.60	23.50	0.43
	12:30 pm	32.10	30.80	31.45	32.00	1.72
	04:30 pm	29.70	28.90	29.30	29.50	0.68
21-01-2021	8:30 am	24.40	23.70	24.05	24.00	0.21
	12:30 pm	32.50	31.70	32.10	32.50	1.23
	04:30 pm	30.30	29.50	29.90	30.00	0.33
22-01-2021	8:30 am	24.80	24.30	24.55	24.50	0.20
	12:30 pm	31.80	31.50	31.65	32.00	1.09
	04:30 pm	29.70	29.20	29.45	29.50	0.17
23-01-2021	8:30 am	24.60	24.50	24.55	24.50	0.20
	12:30 pm	32.40	31.90	32.15	31.50	2.06
	04:30 pm	29.30	28.70	29.00	29.00	0.00
24-01-2021	8:30 am	24.80	24.30	24.55	24.50	0.20
	12:30 pm	32.20	31.90	32.05	32.00	0.16
	04:30 pm	29.90	28.60	29.25	29.50	0.85

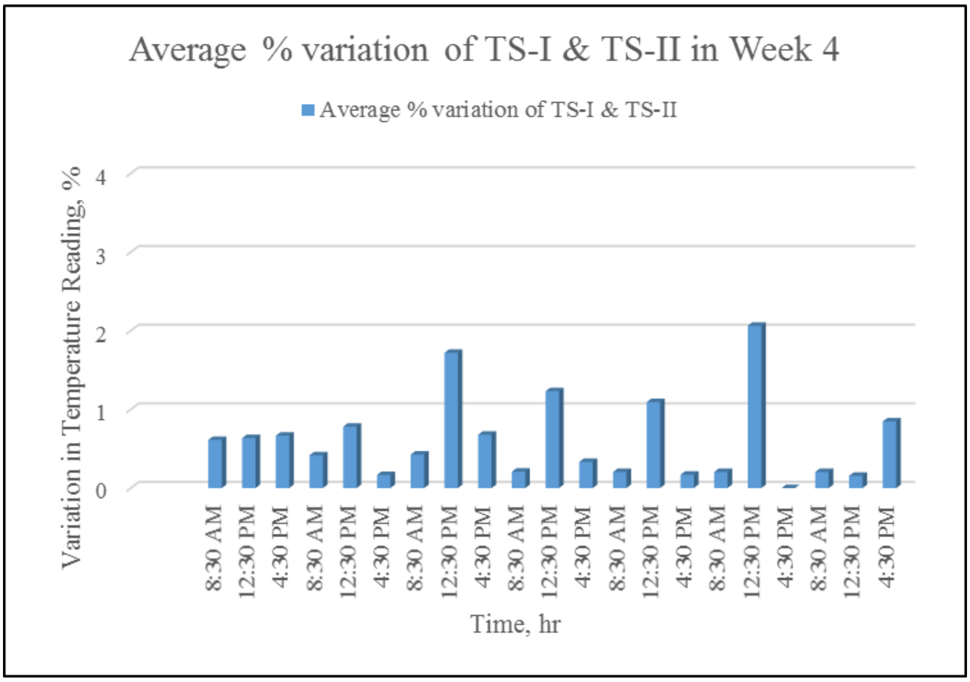


Fig. 4.17 Average % variation in temperature of TS-I & TS-II in Week 4

Table 4.11 and Fig. 4.17 shows the readouts for the period from 18/01/2021 to 24/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average temperature readouts of the sensors were compared with Thermometer reading and variation was determined. It is observed from the data, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. However from the data presented in Table 4.11 and Fig. 4.17, it is revealed that for the different time periods the minimum average temperature variation of the sensors was 0.00 % obtained on 23/01/2021 at 04:30 pm and the maximum average temperature variation of the sensor was 2.06 % obtained on 23/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average temperature readouts of TS-I & TS-II and checked by a Thermometer are more or less similar i.e. from 0.00 to 2.06 % in Week 4. The representative temperature samples for determining the temperature inside the greenhouse prototype was recorded at two different locations (which represents temperature of the entire greenhouse prototype) as described in section 3.8 and were further compared with Thermometer.

Thus, it is revealed from the study that the temperature was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 4.

Table 4.12: Performance evaluation and testing of temperature sensors of developed controller and comparison of sensor readouts (Air Temperature) with Thermometer readings for Week 5

Week 5 Temperature Readings						
Date	**Time**	**TS - I**	**TS- II**	**Average**	**Thermometer Reading**	**Average % variation of TS-I & TS-II**
25-01-2021	8:30 am	24.90	24.20	24.55	24.50	0.20
	12:30 pm	31.80	30.80	31.30	31.50	0.63
	04:30 pm	29.60	28.40	29.00	29.00	0.17
26-01-2021	8:30 am	24.70	24.40	24.55	24.50	0.20
	12:30 pm	32.50	32.20	32.35	32.00	1.09
	04:30 pm	30.10	29.40	29.75	30.00	0.83
27-01-2021	8:30 am	24.20	23.70	23.95	23.50	1.91
	12:30 pm	31.80	30.70	31.25	31.50	0.79
	04:30 pm	29.70	29.20	29.45	29.50	0.17

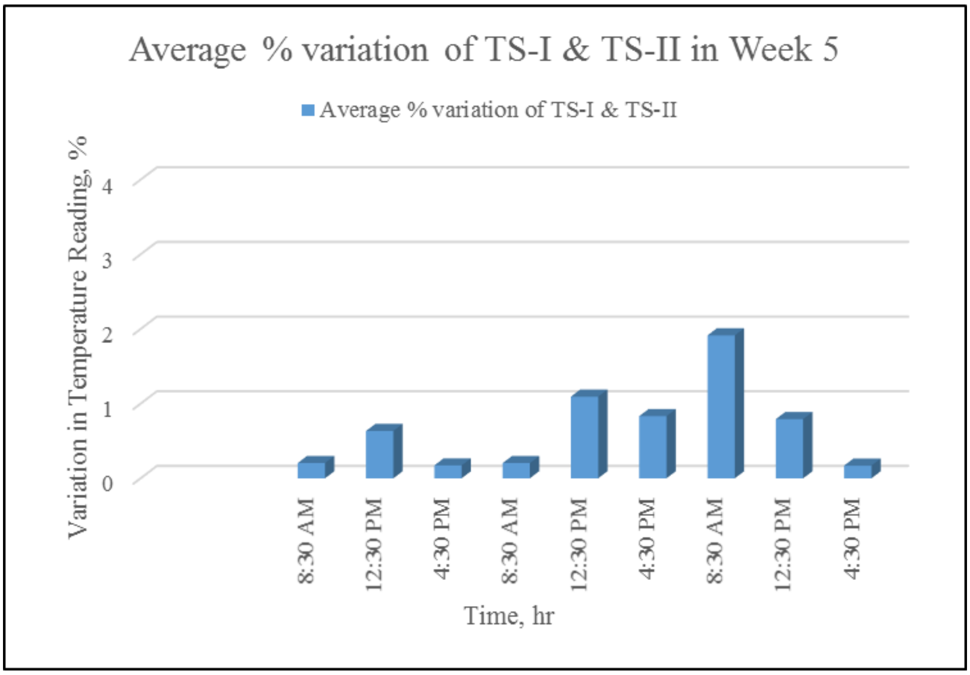


Fig. 4.18 Average % variation in temperature of TS-I & TS-II in Week 5

Table 4.12 and Fig. 4.18 shows the readouts for the period from 25/01/2021 to 27/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average temperature readouts of the sensors were compared with Thermometer reading and variation was determined. It is observed from the data, the average readout shown by TS-I and TS-II nearly matches with the actual temperature of the air shown by Thermometer. However from the data presented in Table 4.12 and Fig. 4.18, it is revealed that for the different time periods the minimum average temperature variation of the sensors was 0.17 % obtained on 25/01/2021 and 27/01/2021 at 04:30 pm and the maximum average temperature variation of the sensor was 1.91 % obtained on 27/01/2021 at 08:30 am. It is very important to note that the percentage variation recorded by the average temperature readouts of TS-I & TS-II and checked by a Thermometer are more or less similar i.e. from 0.17 to 1.91 % in Week 5. The representative temperature samples for determining the temperature inside the greenhouse prototype was recorded at two different locations (which represents temperature of the entire greenhouse prototype) as described in section 3.8 and were further compared with Thermometer.

Thus, it is revealed from the study that the temperature was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 5.

4.9.2.2 Performance evaluation of the Relative Humidity Sensor

To study the performance evaluation of relative humidity sensor of the developed automatic environmental controller, the controller was set with the relative humidity LSP of 57.86 % and HSP of 67.86 % as described in section 4.4.4.3 and 4.4.4.4 respectively, to get more precise readouts. The performance evaluation of relative humidity sensor was carried out by adopting procedure as described in Chapter III section 3.11.3. The data collected was presented in Table 4.13 to Table 4.17 and by Fig 4.19 to Fig 4.23 for the period from 28 Dec. 2020 to 27 Jan. 2021.

Table 4.13: Performance evaluation and testing of Humidity sensors of developed controller and comparison of sensor readout (Relative Humidity) with Masons Hygrometer readings for Week 1

Week 1 Humidity Readings						
Date	**Time**	**RHS - I**	**RHS- II**	**Average**	**Masons Hygrometer Reading**	**Average % variation of RHS-I & RHS-II**
28-12-2020	8:30 am	85.20	84.30	84.75	84.00	0.89
	12:30 pm	88.90	88.40	88.65	84.00	5.54
	04:30 pm	78.2	82.8	80.50	77.00	4.55
29-12-2020	8:30 am	84.40	87.80	86.10	87.00	1.03
	12:30 pm	69.50	73.70	71.60	69.00	3.77
	04:30 pm	78.10	82.10	80.10	77.50	3.35
30-12-2020	8:30 am	90.70	90.60	90.65	87.00	4.20
	12:30 pm	68.20	70.00	69.10	72.50	4.69
	04:30 pm	78.50	81.70	80.10	77.00	4.03
31-12-2020	8:30 am	84.75	87.15	85.95	84.00	2.32
	12:30 pm	56.90	54.80	55.85	55.00	1.55
	04:30 pm	76.20	78.00	77.10	74.00	4.19
01-01-2021	8:30 am	89.10	89.40	89.25	87.00	2.59
	12:30 pm	56.70	60.20	58.45	53.00	10.28
	04:30 pm	78.90	82.10	80.50	74.00	8.78
02-01-2021	8:30 am	87.70	88.60	88.15	87.00	1.32
	12:30 pm	53.10	58.80	55.95	58.50	4.36
	04:30 pm	68.00	74.40	71.20	68.00	4.71
03-01-2021	8:30 am	83.50	87.00	85.25	87.50	2.57
	12:30 pm	53.00	58.60	55.80	55.00	1.45
	04:30 pm	74.50	78.70	76.60	72.00	6.39

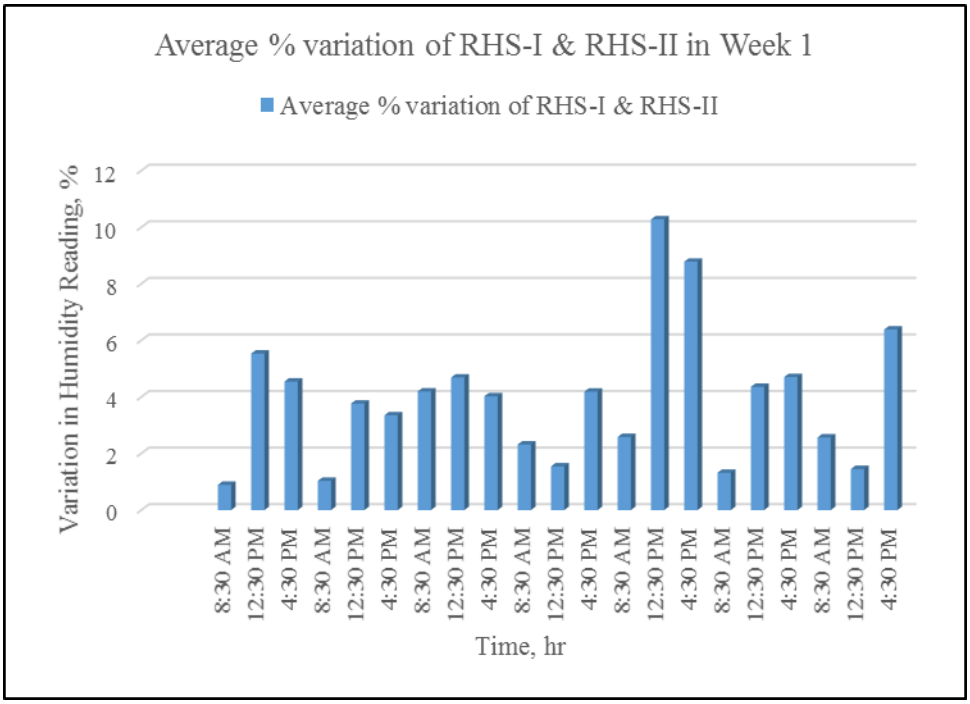


Fig. 4.19 Average % variation of RHS-I & RHS-II in Week 1

Table 4.13 and Fig. 4.19 shows the readouts for the period from 28/12/2020 to 03/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average relative humidity readouts of the sensors were compared with Masons Hygrometer reading and variation was determined. It is observed from the data, the average readout shown by RHS-I and RHS-II nearly matches with the actual relative humidity shown by Masons Hygrometer. However from the data presented in Table 4.13 and Fig. 4.19, it is revealed that for the different time periods the minimum average relative humidity variation of the sensors was 0.89 % obtained on 28/12/2020 at 08:30 am and the maximum average relative humidity variation of the sensor was 10.28 % obtained on 01/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average relative humidity readouts of RHS-I & RHS-II and checked by a Masons Hygrometer are more or less similar i.e. from 0.89 to 10.28 % in Week 1. The representative relative humidity samples for determining the relative humidity inside the greenhouse prototype was recorded at two different locations (which represents relative humidity of the entire greenhouse prototype) as described in section 3.8 and were further compared with Masons Hygrometer.

Thus, it is revealed from the study that the relative humidity was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 1.

Table 4.14: Performance evaluation and testing of Humidity sensors of developed controller and comparison of sensor readout (Relative Humidity) with Masons Hygrometer readings for Week 2

Week 2 Humidity Readings						
Date	**Time**	**RHS - I**	**RHS- II**	**Average**	**Masons Hygrometer Reading**	**Average % variation of RHS-I & RHS-II**
04-01-2021	8:30 am	85.50	86.90	86.20	87.50	1.49
	12:30 pm	62.60	64.40	63.50	61.50	3.25
	04:30 pm	77.80	82.20	80.00	78.00	2.56
05-01-2021	8:30 am	81.20	85.60	83.40	84.00	0.71
	12:30 pm	65.10	68.50	66.80	64.00	4.38
	04:30 pm	74.70	79.10	76.90	75.00	2.53
06-01-2021	8:30 am	84.85	86.15	85.50	83.00	3.01
	12:30 pm	68.70	72.90	70.80	69.50	1.87
	04:30 pm	73.40	78.10	75.75	74.00	2.36
07-01-2021	8:30 am	87.20	88.40	87.80	87.00	0.92
	12:30 pm	53.40	58.20	55.80	55.00	1.45
	04:30 pm	76.80	80.10	78.45	78.00	0.58
08-01-2021	8:30 am	85.90	88.40	87.15	87.00	0.17
	12:30 pm	69.70	70.50	70.10	66.50	5.41
	04:30 pm	71.40	77.80	74.60	72.00	3.61
09-01-2021	8:30 am	84.70	85.60	85.15	83.50	1.98
	12:30 pm	68.85	71.20	70.03	66.00	6.10
	04:30 pm	74.10	79.50	76.80	74.00	3.78
10-01-2021	8:30 am	84.10	85.80	84.95	83.50	1.74
	12:30 pm	59.65	63.90	61.78	58.00	6.51
	04:30 pm	70.50	79.20	74.85	74.50	0.47

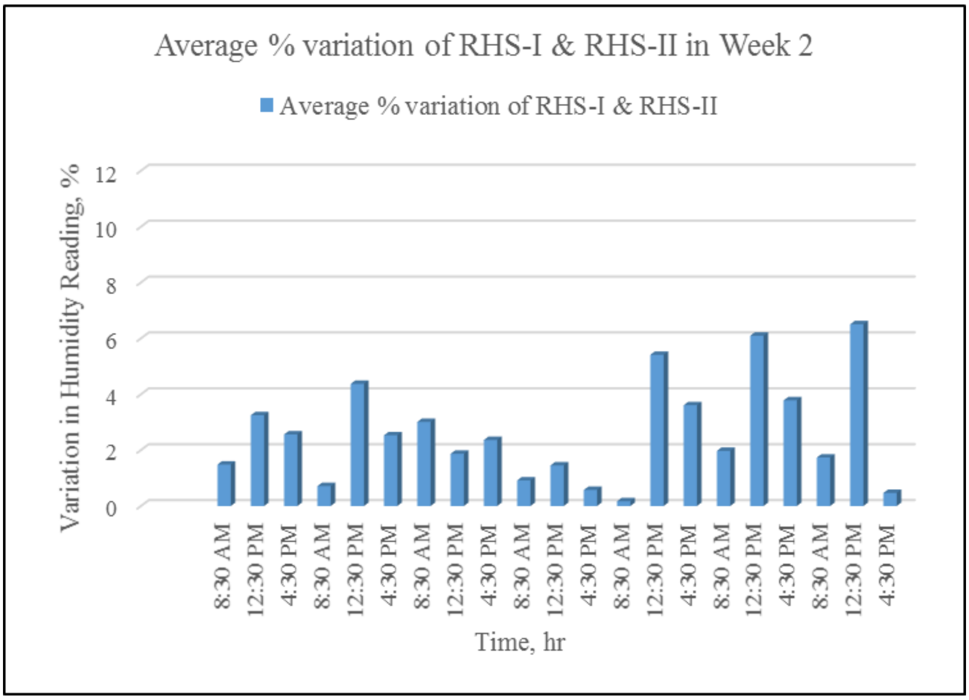


Fig. 4.20 Average % variation of RHS-I & RHS-II in Week 2

Table 4.14 and Fig. 4.20 shows the readouts for the period from 04/01/2021 to 10/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average relative humidity readouts of the sensors were compared with Masons Hygrometer reading and variation was determined. It is observed from the data, the average readout shown by RHS-I and RHS-II nearly matches with the actual relative humidity shown by Masons Hygrometer. However from the data presented in Table 4.14 and Fig. 4.20, it is revealed that for the different time periods the minimum average relative humidity variation of the sensors was 0.17 % obtained on 08/01/2021 at 08:30 am and the maximum average relative humidity variation of the sensor was 6.51 % obtained on 10/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average relative humidity readouts of RHS-I & RHS-II and checked by a Masons Hygrometer are more or less similar i.e. from 0.17 to 6.51 % in Week 2. The representative relative humidity samples for determining the relative humidity inside the greenhouse prototype was recorded at two different locations (which represents relative humidity of the entire greenhouse prototype) as described in section 3.8 and were further compared with Masons Hygrometer.

Thus, it is revealed from the study that the relative humidity was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 2.

Table 4.15: Performance evaluation and testing of Humidity sensors of developed controller and comparison of sensor readout (Relative Humidity) with Masons Hygrometer readings for Week 3

Week 3 Humidity Readings						
Date	**Time**	**RHS - I**	**RHS- II**	**Average**	**Masons Hygrometer Reading**	**Average % variation of RHS-I & RHS-II**
11-01-2021	8:30 am	84.90	86.20	85.55	83.00	3.07
	12:30 pm	59.80	64.10	61.95	63.50	2.44
	04:30 pm	67.80	71.20	69.50	68.00	2.21
12-01-2021	8:30 am	87.10	86.20	86.65	87.00	0.40
	12:30 pm	62.10	65.30	63.70	61.00	4.43
	04:30 pm	74.20	79.80	77.00	74.50	3.36
13-01-2021	8:30 am	85.20	87.90	86.55	87.00	0.52
	12:30 pm	67.50	70.20	68.85	66.50	3.53
	04:30 pm	71.10	75.40	73.25	71.50	2.45
14-01-2021	8:30 am	87.20	89.10	88.15	87.00	1.32
	12:30 pm	59.80	63.20	61.50	58.00	6.03
	04:30 pm	69.80	73.70	71.75	72.00	0.35
15-01-2021	8:30 am	86.50	88.10	87.30	87.50	0.23
	12:30 pm	57.50	58.90	58.20	55.00	5.82
	04:30 pm	73.50	81.40	77.45	74.50	3.96
16-01-2021	8:30 am	85.50	87.10	86.30	87.50	1.37
	12:30 pm	61.70	67.80	64.75	61.00	6.15
	04:30 pm	72.60	80.20	76.40	74.50	2.55
17-01-2021	8:30 am	86.20	87.90	87.05	87.00	0.06
	12:30 pm	64.20	68.10	66.15	63.50	4.17
	04:30 pm	70.80	76.70	73.75	74.50	1.01

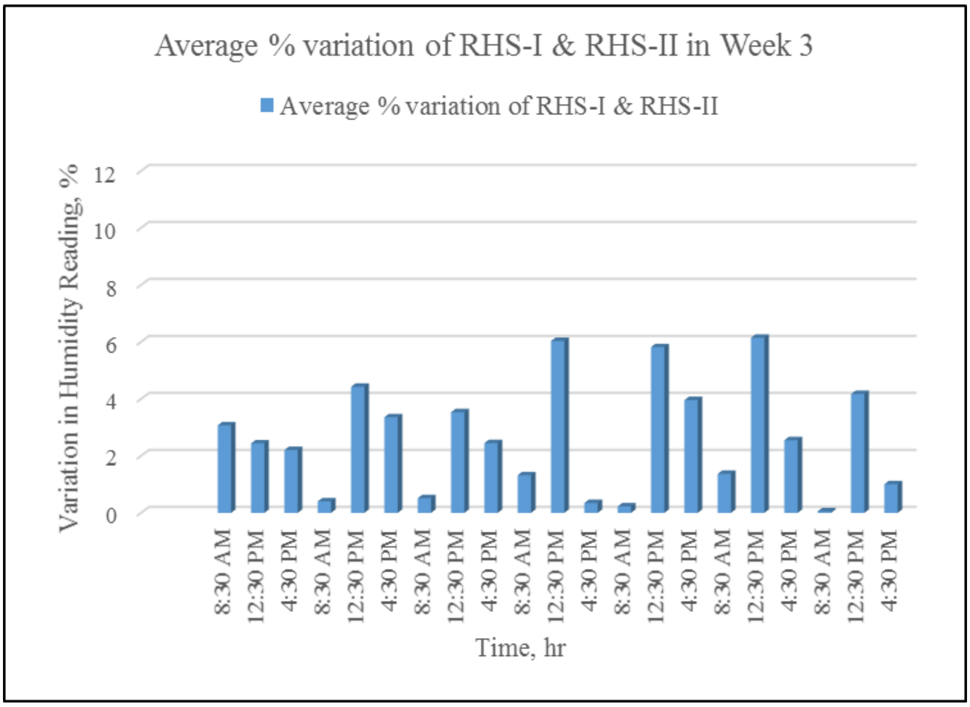


Fig. 4.21 Average % variation of RHS-I & RHS-II in Week 3

Table 4.15 and Fig. 4.21 shows the readouts for the period from 11/01/2021 to 17/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average relative humidity readouts of the sensors were compared with Masons Hygrometer reading and variation was determined. It is observed from the data, the average readout shown by RHS-I and RHS-II nearly matches with the actual relative humidity shown by Masons Hygrometer. However from the data presented in Table 4.15 and Fig. 4.21, it is revealed that for the different time periods the minimum average relative humidity variation of the sensors was 0.06 % obtained on 17/01/2021 at 08:30 am and the maximum average relative humidity variation of the sensor was 6.15 % obtained on 16/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average relative humidity readouts of RHS-I & RHS-II and checked by a Masons Hygrometer are more or less similar i.e. from 0.06 to 6.15 % in Week 3. The representative relative humidity samples for determining the relative humidity inside the greenhouse prototype was recorded at two different locations (which represents relative humidity of the entire greenhouse prototype) as described in section 3.8 and were further compared with Masons Hygrometer.

Thus, it is revealed from the study that the relative humidity was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 3.

Table 4.16: Performance evaluation and testing of Humidity sensors of developed controller and comparison of sensor readout (Relative Humidity) with Masons Hygrometer readings for Week 4

Week 4 Humidity Readings						
Date	**Time**	**RHS - I**	**RHS- II**	**Average**	**Masons Hygrometer Reading**	**Average % variation of RHS-I & RHS-II**
18-01-2021	8:30 am	85.20	86.50	85.85	87.00	1.32
	12:30 pm	64.70	71.10	67.90	66.50	2.11
	04:30 pm	69.10	77.20	73.15	72.00	1.60
19-01-2021	8:30 am	87.40	88.50	87.95	87.00	1.09
	12:30 pm	60.80	62.10	61.45	58.00	5.95
	04:30 pm	67.30	70.20	68.75	68.00	1.10
20-01-2021	8:30 am	88.60	88.40	88.50	87.00	1.72
	12:30 pm	63.30	70.50	66.90	64.00	4.53
	04:30 pm	72.10	76.70	74.40	71.50	4.06
21-01-2021	8:30 am	85.90	87.50	86.70	87.00	0.34
	12:30 pm	57.80	59.50	58.65	55.00	6.64
	04:30 pm	67.20	70.10	68.65	68.00	0.96
22-01-2021	8:30 am	86.50	86.20	86.35	87.50	1.31
	12:30 pm	65.40	68.30	66.85	64.00	4.45
	04:30 pm	72.50	75.80	74.15	71.50	3.71
23-01-2021	8:30 am	86.50	86.20	86.35	87.00	0.75
	12:30 pm	58.70	65.80	62.25	60.50	2.89
	04:30 pm	74.80	81.50	78.15	78.00	0.19
24-01-2021	8:30 am	85.70	86.50	86.10	87.00	1.03
	12:30 pm	59.20	62.90	61.05	58.00	5.26
	04:30 pm	70.90	75.10	73.00	71.50	2.10

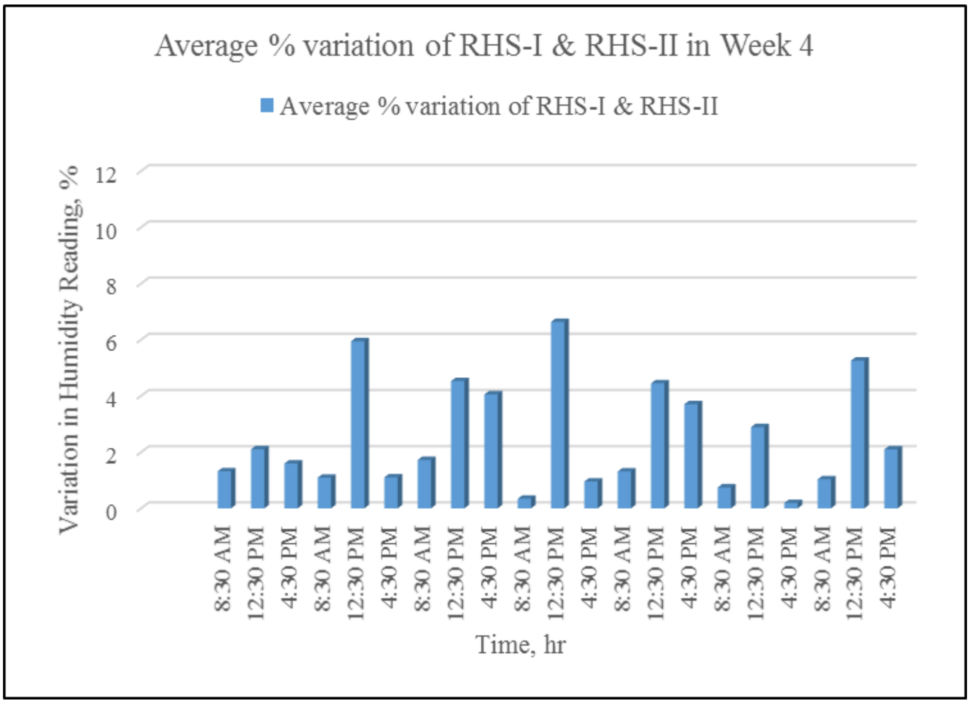


Fig. 4.22 Average % variation of RHS-I & RHS-II in Week 4

Table 4.16 and Fig. 4.22 shows the readouts for the period from 18/01/2021 to 24/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average relative humidity readouts of the sensors were compared with Masons Hygrometer reading and variation was determined. It is observed from the data, the average readout shown by RHS-I and RHS-II nearly matches with the actual relative humidity shown by Masons Hygrometer. However from the data presented in Table 4.16 and Fig. 4.22, it is revealed that for the different time periods the minimum average relative humidity variation of the sensors was 0.19 % obtained on 23/01/2021 at 04:30 pm and the maximum average relative humidity variation of the sensor was 6.64 % obtained on 21/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average relative humidity readouts of RHS-I & RHS-II and checked by a Masons Hygrometer are more or less similar i.e. from 0.19 to 4.06 % in Week 4. The representative relative humidity samples for determining the relative humidity inside the greenhouse prototype was recorded at two different locations (which represents relative humidity of the entire greenhouse prototype) as described in section 3.8 and were further compared with Masons Hygrometer.

Thus, it is revealed from the study that the relative humidity was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 4.

Table 4.17: Performance evaluation and testing of Humidity sensors of developed controller and comparison of sensor readout (Relative Humidity) with Masons Hygrometer readings for Week 5

Week 5 Humidity Readings						
Date	**Time**	**RHS - I**	**RHS- II**	**Average**	**Masons Hygrometer Reading**	**Average % variation of RHS-I & RHS-II**
25-01-2021	8:30 am	85.20	86.10	85.65	83.50	2.57
	12:30 pm	68.10	70.70	69.40	66.50	4.36
	04:30 pm	72.30	75.00	73.65	71.00	3.73
26-01-2021	8:30 am	85.80	86.40	86.10	83.50	3.11
	12:30 pm	54.90	58.70	56.80	55.00	3.27
	04:30 pm	69.70	73.90	71.80	70.00	2.57
27-01-2021	8:30 am	86.30	87.70	87.00	87.00	0.00
	12:30 pm	60.90	69.80	65.35	64.50	1.32
	04:30 pm	70.30	77.10	73.70	71.50	3.08

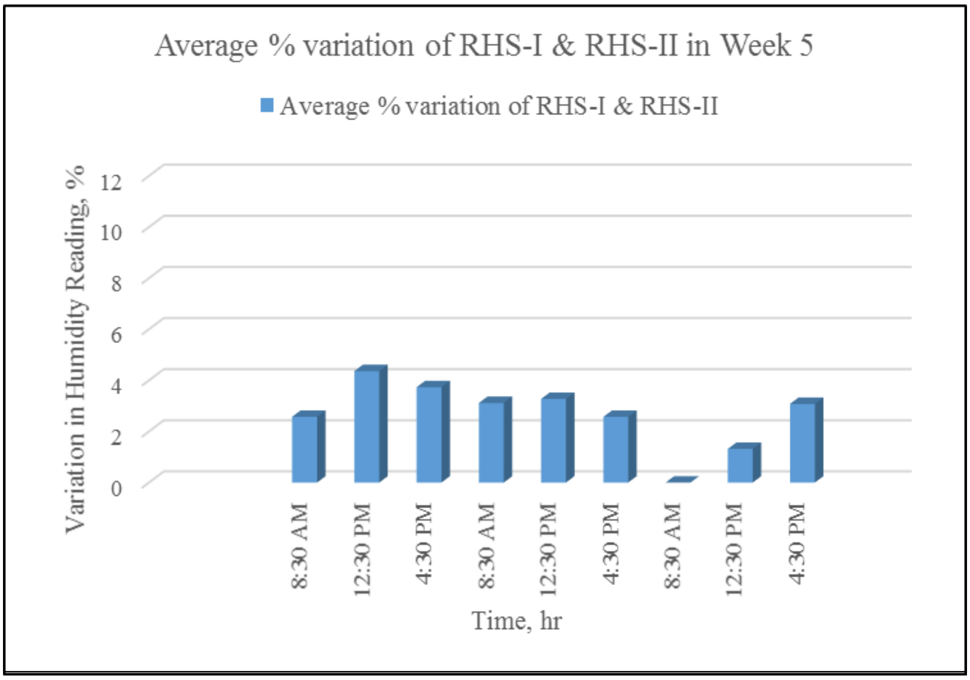


Fig. 4.23 Average % variation of RHS-I & RHS-II in Week 5

Table 4.17 and Fig. 4.23 shows the readouts for the period from 25/01/2021 to 27/01/2021 at 08:30 am, 12:30 pm and 04:30 pm. Average relative humidity readouts of the sensors were compared with Masons Hygrometer reading and variation was determined. It is observed from the data, the average readout shown by RHS-I and RHS-II nearly matches with the actual relative humidity shown by Masons Hygrometer. However from the data presented in Table 4.17 and Fig. 4.23, it is revealed that for the different time periods the minimum average relative humidity variation of the sensors was 0.00 % obtained on 27/01/2021 at 08:30 am and the maximum average relative humidity variation of the sensor was 4.36 % obtained on 25/01/2021 at 12:30 pm. It is very important to note that the percentage variation recorded by the average relative humidity readouts of RHS-I & RHS-II and checked by a Masons Hygrometer are more or less similar i.e. from 0.00 to 3.71 % in Week 5. The representative relative humidity samples for determining the relative humidity inside the greenhouse prototype was recorded at two different locations (which represents relative humidity of the entire greenhouse prototype) as described in section 3.8 and were further compared with Masons Hygrometer.

Thus, it is revealed from the study that the relative humidity was always maintained within the pre-determined limits by using this automatic environmental control system for the Week 5.

4.9.2.3 Performance evaluation of the Soil Moisture Sensor

To study the performance evaluation of soil moisture sensor of the developed automatic environmental controller, the controller was set with the soil moisture LSP of 20 % and HSP of 27 % as described in section 4.4.4.5 and 4.4.4.6 respectively, to get more precise readouts. The performance evaluation of soil moisture sensor was carried out by adopting procedure as described in Chapter III section 3.11.4. The data collected was presented in Table 4.18 and by Fig 4.24 for the period from 28 Dec. 2020 to 25 Jan. 2021.

Table 4.18: Performance evaluation and testing of Soil Moisture sensors of developed controller and comparison of average readouts (available soil moisture content) with Gravimetric Method

Weekly Soil Moisture Readings							
Date	**Time**	**SMS - I**	**SMS- II**	**SMS- III**	**Average**	**Gravimetric Reading**	**Average % variation of Soil Moisture Sensors**
28-12-2020 (Week 1)	8:30 am	21.00	21.00	21.00	21.00	22.13	5.10
	12:30 pm	27.00	28.00	27.00	27.33	27.97	2.29
	04:30 pm	25.00	27.00	26.00	26.00	26.89	3.31
04-01-2021 (Week 2)	8:30 am	21.00	22.00	21.00	21.33	21.85	2.38
	12:30 pm	27.00	28.00	27.00	27.33	27.94	2.18
	04:30 pm	26.00	26.00	26.00	26.00	27.15	4.24
11-01-2021 (Week 3)	8:30 am	23.00	23.00	23.00	23.00	23.54	2.29
	12:30 pm	27.00	28.00	28.00	27.67	28.29	2.19
	04:30 pm	26.00	27.00	27.00	26.67	27.72	3.79
18-01-2021 (Week 4)	8:30 am	25.00	26.00	26.00	25.67	26.57	3.39
	12:30 pm	24.00	25.00	24.00	24.33	25.23	3.57
	04:30 pm	22.00	22.00	22.00	22.00	23.10	4.76
25-01-2021 (Week 5)	8:30 am	23.00	24.00	24.00	23.67	23.17	2.16
	12:30 pm	28.00	28.00	28.00	28.00	27.33	2.45
	04:30 pm	26.00	27.00	26.00	26.33	25.27	4.19

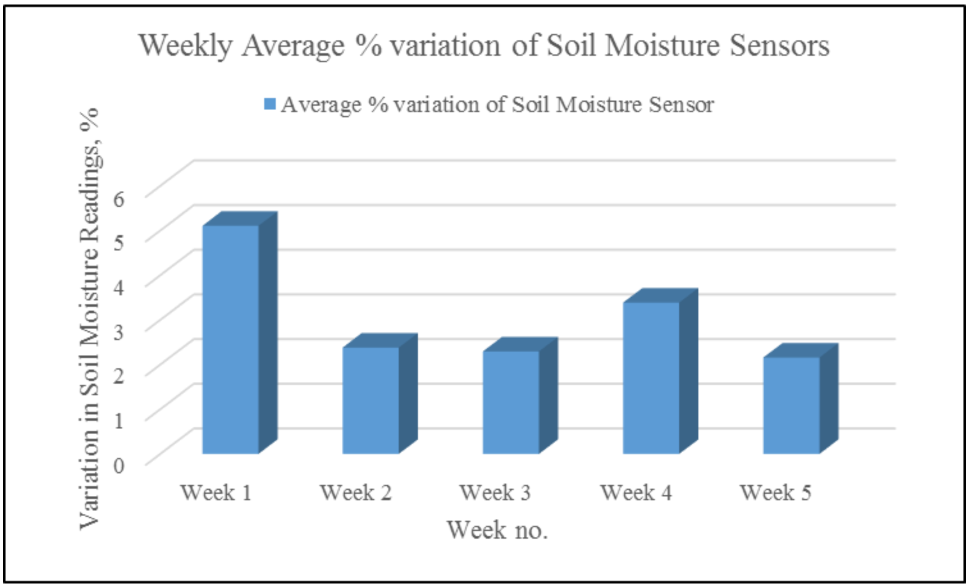


Fig. 4.24 Weekly Average % variation of Soil Moisture Sensors

Table 4.18 and Fig. 4.24 shows the Weekly readouts for the period from 28/12/2020 to 25/01/2021 at 8.30 am to 4.30 pm with four hour time interval. Average available soil moisture content readouts of the soil moisture sensors were compared with Gravimetric reading and variation was determined. It is observed from the data, the average readout shown by SMS-I, SMS-II and SMS-III nearly matches with the actual available soil moisture content shown by Gravimetric method. However from the data presented in Table 4.18 and Fig. 4.24, it is revealed that for the entire time period of the performance evaluation the minimum average available soil moisture content variation of the soil moisture sensors was 2.16 % obtained at 8.30 am in Week 5 and the maximum average available soil moisture content variation of the soil moisture sensors was 5.10 % obtained at 8.30 am in Week 1. It is very important to note that the percentage variation recorded by the average available soil moisture content readouts of SMS-I, SMS-II & SMS-III and checked by a Gravimetric Method are more or less similar i.e. from 2.16 to 5.10 %. The representative available soil moisture content samples for determining the available soil moisture content of the soil was collected from depth of 7.5 cm as described in section 3.9 and were further compared with Gravimetric Method.

Thus, it is revealed from the study that the available soil moisture content was always maintained to the field capacity by using this automatic environmental control system for the entire testing period of one month.

4.10 Cost analysis of the automatic environmental control system

The cost analysis of the developed controller was carried out as discussed in section 3.12. This section includes cost analysis of the developed controller for prototype greenhouse as well as for greenhouse of size 20 × 28 m^2 respectively.

4.10.1 Cost analysis of the automatic environmental control system for the Prototype Greenhouse

The cost estimation of the cost effective environmental control system for protective cultivation with GSM for the prototype of size 0.55 m^2 has been estimated by the current rates of the materials available in the market as described in Chapter 3 section 3.12. Table 4.19 gives the cost of the developed automatic climate controller with sensors for prototype greenhouse.

Table 4.19: Cost of the developed automatic climate controller with sensors for prototype greenhouse

Sr. No.	Description	Quantity	Unit	Rate (Rs.)	Cost (Rs.)
1.	Arduino Mega	1	No.	885	885
2.	Adopter 9V/ 1 amp for MEGA	1	No.	250	250
3.	USB cable A to B for MEGA	1	No.	59	59
4.	Bluetooth Module	1	No.	360	360
5.	GSM module	1	No.	944	944
6.	Adaptor for GSM Module	1	No.	350	350
7.	VI SIM card	1	No.	250	250
8.	Real time clock	1	No.	270	270
9.	16 GB micro SD card	1	No.	400	400
10.	Memory card module	1	No.	190	190
11.	Solid State Relay	4	No.	450	1800
12.	Wire connections (2 pairs each)	50	No.	5	250
13.	10' Electric Box	1	No.	150	150
14.	3 pin electricity Plug	5	No.	65	325
15.	3 pin electricity socket	5	No.	42	210
16.	Rainbow strip wire	6.5	M	50	325
17.	3 Core wire 3 Amp current	5	M	45	225

18.	12-0-12 V 1A Transformer	1	No.	150	150
19.	Soil moisture sensor	3	No.	500	1500
20.	DHT 22 Sensor	2	No.	350	700
21.	Solenoid valve	2	No.	450	900
22.	Other accessories	-	-	1000	1000
Total (Rs.)					11,493

The cost of the Arduino mega is Rs. 885 which was used as a microcontroller for the automatic environmental control system. Besides this, solid state relays were used to control the exhaust fan, solenoid valves and pump having the cost of Rs. 450. The GSM module was used to intimate irrigation operation having cost Rs. 944. The 16 GB micro SD card was used as storage media having the cost of Rs. 400, which was inserted in memory card module having cost of Rs. 190. Remaining components such as wires, plugs, switches, cabinet, 3 pin tops, etc. were used as per the requirement. The DHT 22 sensors and soil moistures sensors were used to collect the air temperature, relative humidity and soil moisture from the soil. The total cost incurred for the design and development of cost effective environmental control system for protective cultivation with GSM along with accessories for the prototype greenhouse is Rs. 11,493/-.

4.10.2 Cost analysis of the automatic environmental control system for the Greenhouse of size 20 × 28 m^2

The cost estimation of the cost effective environmental control system for protective cultivation with GSM for the greenhouse of size 20 × 28 m^2 has been estimated by the current rates of the materials available in the market as described in Chapter 3 section 3.12. Table 4.20 gives the cost of the developed automatic climate controller with sensors for greenhouse of size 560 m^2.

During cost analysis, when we consider the greenhouse of size 20 × 28 m^2 then in addition to the above mentioned accessories in Table 4.19, the number of sensors and position/ placement of sensors plays very important role in controlling of the parameters as well as in terms of costing as wiring costing depends totally on the location of sensor from the controller. Hence, for greenhouse of size 20 × 28 m^2 total 9 DHT 22 sensors (which combinely measures temperature and relative humidity) need to be placed that represent the overall temperature and relative humidity of the entire greenhouse. The layout for the temperature and relative humidity sensors placement is given in the Plate 4.4. But, in case of soil moisture sensor as the soil inside the greenhouse is nearly homogenous three sensors are sufficient to maintain soil moisture to the field capacity.

Also, as per the design of exhaust fan as mentioned in section 4.7.1, there is requirement of 4 exhaust fans to remove hot air from the greenhouse of 560 m^2. Thus, additional three relays will be required to operate these fans.

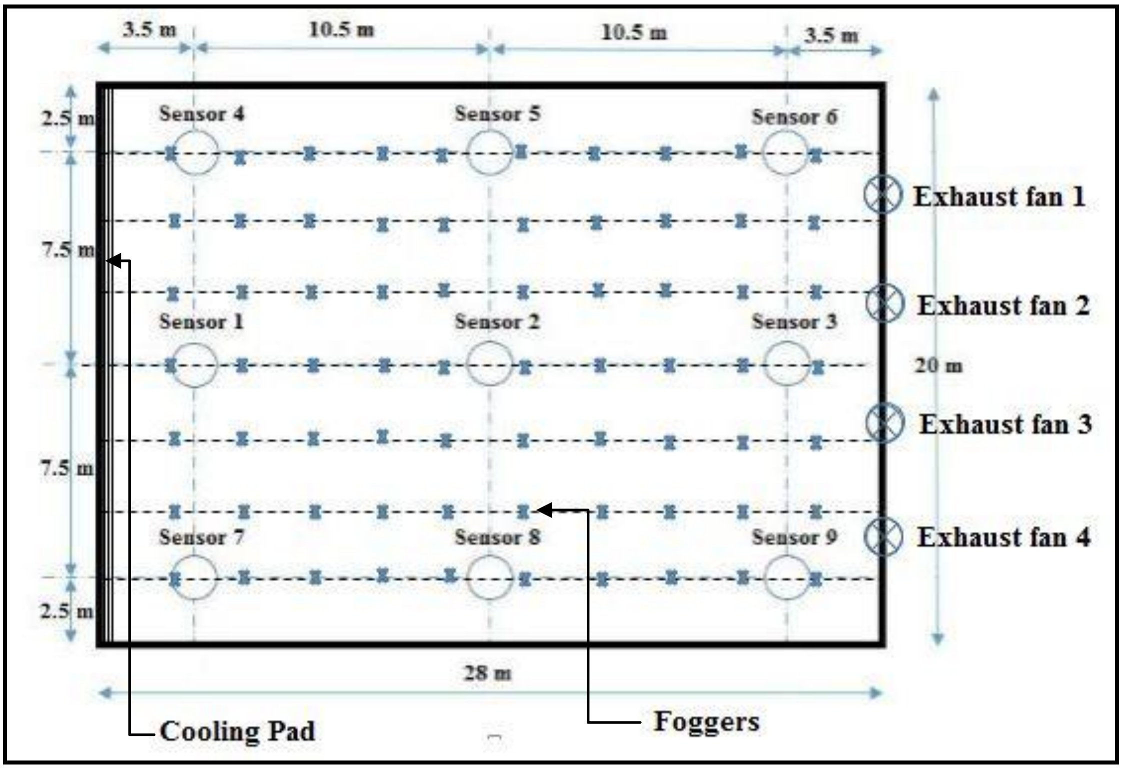


Plate 4.4 Top View of Position of Sensor Placement in the greenhouse of size 20 × 28 m^2

Table 4.20: Cost of the developed automatic climate controller with sensors for greenhouse of size 560 m^2

Sr. No.	Description	Quantity	Unit	Rate (Rs.)	Cost (Rs.)
1.	Arduino Mega	1	No.	885	885
2.	Adopter 9V/ 1 amp for MEGA	1	No.	250	250
3.	USB cable A to B for MEGA	1	No.	59	59
4.	Bluetooth Module	1	No.	360	360
5.	GSM module	1	No.	944	944
6.	Adaptor for GSM Module	1	No.	350	350

7.	VI SIM card	1	No.	250	250
8.	Real time clock	1	No.	270	270
9.	16 GB micro SD card	1	No.	400	400
10.	Memory card module	1	No.	190	190
11.	Solid State Relay	8	No.	450	3600
12.	Wire connections (2 pairs each)	50	No.	5	250
13.	10' x 10' box	1	No.	900	900
14.	3 pin electricity Plug	9	No.	65	585
15.	3 pin electricity socket	9	No.	42	378
16.	Rainbow strip wire	100	M	50	5000
17.	3 Core wire 3 Amp current	15	M	45	675
18.	12-0-12 V 1A Transformer	1	No.	150	150
19.	Soil moisture sensor	3	No.	500	1500
20.	DHT 22 Sensor	9	No.	350	3150
21.	Solenoid valve	3	No.	950	2850
22.	Other accessories	-	-	2000	2000
Total (Rs.)					24,996

The cost of the Arduino mega is Rs. 885 which was used as a microcontroller for the automatic environmental control system. Besides this, solid state relays were used to control the exhaust fan, solenoid valves and pump having the cost of Rs. 450. The GSM module was used to intimate irrigation operation having cost Rs. 944. The 16 GB micro SD card was used as storage media having the cost of Rs. 400, which was inserted in memory card module having cost of Rs. 190. Remaining components such as wires, plugs, switches, cabinet, 3 pin tops, etc. were used as per the requirement. The DHT 22 sensors and soil moistures sensors were used to collect the air temperature, relative humidity and soil moisture from the soil. The total cost incurred for the design and development of cost effective environmental control system for protective cultivation with GSM along with accessories for the greenhouse of size 20×28 m^2 is Rs. 24,996/-.

The cost of the available automatic climate control systems in India quoted by the firms is ranging from Rs. 100000/- to Rs. 500000/-. Thus, the developed system is a low cost system.

Plate 4.5 Setup for Actual Performance Evaluation of the Developed System

Plate 4.6 Recording the Readings of Masons Hygrometer

Plate 4.7 Showing Demonstration of performance of the developed system to Dr. B. P. Patil Sir and their colleagues

Plate 4.8 Showing Demonstration of performance of the developed system to Group of farmers from Maldoli Village, Chiplun

Plate 4.9 Showing Demonstration of performance of the developed system to Dr. G. D. Joshi Sir and Dr. Deepak Sawant Sir by Prof. Dr. U. S. Kadam Sir

V. SUMMARY AND CONCLUSIONS

The experiment entitled "Design and Development of Cost Effective Environmental Control System for protective cultivation with GSM" was carried out at the Laboratory and the Instructional Farm of Department of Irrigation and Drainage Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. The research work aimed with specific objectives: survey of available systems in the market, design and development, field testing and cost analysis of cost effective environmental control system for protective cultivation with GSM. The findings of the study are summarized and concluded under the following sections of this Chapter.

5.1 Summary

The present investigation carried out in the laboratory and at Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli concluded that environment could be efficiently controlled in the protective cover by using developed low cost controller, which is easy to install, user friendly, requires less technical knowledge and ready to use system. The developed system does not need any recalibration and has provision to set limits according to the type of the crop in the protective cover via mobile phone which is the additional benefit over some of the existing system.

5.1.1 Design and Development of Automatic Environmental Control System

The unit of the automatic environmental control system was designed and developed by assembling the different components such as DHT 22 sensor, soil moisture sensor, Arduino mega, GSM module, relay, Bluetooth module, solenoid valve, pump, etc.

5.1.2 Calibration of DHT 22 Sensors

The temperature and relative humidity readouts taken by DHT 22 sensors in ^{o}C and %, respectively at different time periods were compared with the respective temperature and relative humidity readouts determined by Thermometer and Masons Hygrometer respectively for sensor calibration. After getting readouts, the average error in measurement of temperature and relative humidity of DHT 22 Sensor 1 and DHT 22 Sensor 2 was obtained and used later for setting of LSP and HSP to minimize the error and to get reliable and most accurate readout for further processing.

5.1.3 Calibration of Soil Moisture sensor

The unit of the automatic environmental control system was calibrated for soil moisture readout in terms of per cent moisture content. The nonlinear polynomial equation of degree 3 in terms of 'x' and 'y' i.e. soil moisture readout and moisture content was developed and other values of moisture content were determined by using interpolation. The beauty of this calibration method is that by using this method one can calibrate any type of soil.

5.1.4 Steps for Automation of Environmental Control System

After calibration, the LSP (28 ºC for temperature, 55 % for relative humidity and 50% depletion of available soil water for moisture content) and HSP (32 ºC for temperature, 65 % for relative humidity and field capacity for moisture content) was set by using Serial Bluetooth mobile application or laptop. The Serial Bluetooth mobile application had the facility to view present air temperature, relative humidity and available soil moisture content and the set points by simply three clicks in the mobile application.

5.1.5 Working of automatic environmental control system

The aim of automatic environmental control system is to maintain optimum/ desired temperature and relative humidity inside the greenhouse. When the temperature was above the HSP, the exhaust fan, pump and solenoid valve of fogging system were operated until temperature reaches LSP at the same time text message was sent to user's mobile about ON and OFF status of the Exhaust fan and fogger. Similarly, when the humidity was below the LSP, pump and the solenoid valve of fogging system were operated upto HSP and at the same time text message was sent to user's mobile about ON and OFF status of fogger.

Also, main hypothesis of the automatic irrigation part of the system is to apply the right amount of water at right time to fulfill water requirement of the crop and to maintain soil moisture always to the field capacity with allowable 50 % available soil moisture depletion. When the available soil moisture content was at the LSP, then the system had delivered water up to field capacity of soil i.e. HSP and at the same time, it sent the text message to user's mobile about ON and OFF of irrigation system.

5.1.6 Placement of temperature and relative humidity sensors

The location for each sensor was selected such that, it represents the temperature and humidity of entire greenhouse prototype. Adopting proper method two combined temperature and humidity sensors were placed inside the greenhouse prototype unit at 30 cm above the maximum plant height to be grown inside the greenhouse and comparative study was undertaken.

5.1.7 Installation of soil moisture sensors

The sensors were installed in representative sites of pots. Adopting standard method three sensors were placed at 7.5 cm depth from the ground surface.

5.1.8 Field testing

The developed unit of the automatic environmental control system was tested in the greenhouse prototype of size 1 m x 0.55 m x 1 m, developed at Instructional Farm of Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli. Greenhouse was provided with arrangement of exhaust fan and cooling pad along with fogging and irrigation system. Inside the greenhouse two DHT 22 sensors for collecting data of temperature and humidity were installed. Also three soil moisture sensors were installed in the pots outside greenhouse (to get more events due to evaporation) at the depth of 7.5 cm. The developed cost effective environmental control system for protective cultivation with GSM was tested by monitoring and controlling the temperature, relative humidity and soil moisture for 1 month.

5.1.9 Performance evaluation

The field performance and testing of sensors includes the temperature, relative humidity and soil moisture sensor readout which was compared with the thermometer, Masons Hygrometer and moisture content by gravimetric method respectively for one month. The unit of automatic environmental control system has the facility to save the readout data after 15 minutes interval daily. The saved data of air temperature, relative humidity and soil moisture content was further compared with the thermometer, Masons Hygrometer and gravimetric method at the same time. Hence, from the data obtained it is revealed that maximum variation for temperature and relative humidity was 3.33 %, 10.28 % and 5.10 % respectively.

5.1.10 Cost analysis

The total cost incurred for the design and development of the controller along with accessories for prototype greenhouse is Rs. 11,781/- and estimated cost for the greenhouse of size 20 × 28 m^2 is Rs. 24,996/-. The cost of the available automatic environmental control systems in India quoted by the firms is ranging from Rs. 100000/- to Rs. 500000/-. Thus, the developed system is a low cost system.

5.2 Conclusions

From the present study, the following conclusions were drawn:

- The developed automatic environmental control system successfully maintains the temperature, relative humidity and soil moisture within predefined limits and hence, automatically controls the environment inside the greenhouse.
- The developed unit of automatic environmental control system works in any type of soil for irrigation.
- The developed unit of automatic environmental control system has maximum variation in temperature readings of about 3.33 % in comparison with thermometer.
- The developed unit of automatic environmental control system has maximum variation in relative humidity readings of about 10.28 % in comparison with Masons Hygrometer.
- The developed unit of automatic environmental control system has maximum variation in available moisture content readings of about 5.10 % in comparison with gravimetric method.
- The designed and developed unit of automatic environmental control system avoids or minimizes the recalibration compared to other automatic irrigation systems available in the market.
- It is possible to fix the upper and lower limit of temperature, relative humidity and soil moisture content to facilitate ON and OFF the exhaust, fogging and irrigation system respectively by laptop or mobile phone using Serial Bluetooth mobile application.
- The automatic environmental control system having the facility to view the present temperature, relative humidity and available soil moisture content with just three clicks.
- The developed automatic environmental control system minimizes and removes manual interventions in ON and OFF the system and recording the observations of temperature, relative humidity and available soil moisture content in the field.

- It automatically starts even after the energy failure during the earlier event and it maintains optimum temperature and relative humidity for the crop in real time without any input or recalibrating the system.
- It also automatically starts even after the energy failure during the earlier event and it delivers the remaining water requirement of the crop hence no need to input or recalibrate the system.
- It has the facility to receive details of ON and OFF through SMS to mobile phone.
- It has the facility to store temperature, relative humidity and soil moisture data and it can be downloaded any time.
- This system takes care of and protects the crop to be grown in the field from moisture stress. Simultaneously it also takes care not to exceed the soil moisture condition beyond field capacity.
- The system was designed and developed with the low cost i.e. Rs. 24,996/- for 560 m^2.

5.3 Future Scope

The following are the future scope for this project which can be anticipated:

- There is future scope to use wireless sensors as the wiring creates the obstructions for field operations.
- Fertigation should be added along with irrigation.
- Needs more research to develop cost effective long lasting temperature, humidity and soil moisture based controller.

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VII. APPENDICES

APPENDIX – I

7.1 Physical characteristics of the soil

7.1.1 Textural classification of soil by using Hydrometer method

Observations:

- Weight of oven dry soil = W = 40 g
- Hydrometer reading at 4 min (R_4) = 9.5
- Temperature at 4 min = 28°C = 82.4 °F
- Hydrometer reading at 120 min (R_{120}) = 3.0
- Temperature at 4 min = 28°C = 82.4 °F
- Calibration correction = R_L =0

Calculations:

Temperature correction = [Working temperature - 67 °F] x 0.2

= [82.4-67] x 0.2

= 3.08

$$P_4 = \frac{R_4 - RL}{W} x\,100 \pm r$$

$$= \frac{95 - 0}{40} x\,100 + 3.08$$

$$= 26.83$$

$$P_{120} = \frac{R_{120} - RL}{W} x\,100 \pm r$$

$$= \frac{3.0 - 0}{40} x\,100 + 3.08$$

$$= 10.58$$

- % sand = 100-P_4

  = 100 – 26.83

  = 73.17%

- % clay = P_{120}

  = 15.2 %

- % silt = P_4-120

  = 26.83 – 15.2

  =11.63%

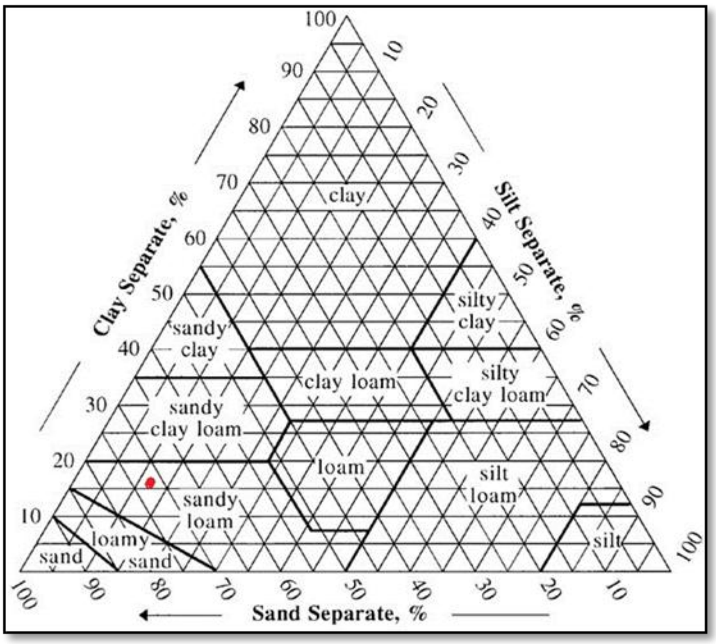

Fig. 7.1: Textural classification of the soil

- Per cent sand, silt and clay are 73.17%, 15.2% and 11.63% respectively.
- The textural class of the soil was sandy loam.

7.1.2 Bulk density of the soil

Observations:

- Height of the core cutter = 13 cm
- Diameter of the core cutter = 10 cm
- Radius of the core cutter = 5 cm

$$\text{Volume of the core} = \pi r^2 \text{h}$$
$$= 3.14 * 5^2 * 13$$
$$= 1020.5 \text{cm}^3$$

Determination of the bulk density of the soil

Replication	**Weight of core cutter (g)**	**Weight of core cutter + wet soil (g)**	**Weight of core cutter + oven dry soil (g)**	**Weight of soil core (g)** ***(3) - (1)***	**Bulk density = $\frac{\text{Mass of soil core}}{\text{Volume of soil core}}$ (g/cm^3)**
1	952	2649	2324	1372	1.334
2	952	2740	2449	1497	1.460
3	952	2738	2400	1446	1.410
Average					1.40

- The average bulk density of the soil was 1.40 g/cm^3.

7.1.3 Porosity of the soil

Replication	Bulk Density (g/cm^3)	Particle density	Porosity = $\left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) * 100$ (%)
1	1.34	2.65	49.43
2	1.46	2.65	44.90
3	1.41	2.65	46.79
Average			47.04

- Porosity of the soil = 47.04%

7.1.4 Field capacity

Replication	I				II				III			
Time	16:00	20:00	24:00	26:00	18:00	08:00	12:00	16:00	18:00	08:00	12:00	16:00
Weight of empty box (g)	36	37	37	37	36	36	37	36	37	36	37	36
Weight of box + moist soil (g)	48	55	64	55	50	50	56	51	52	55	62	46
Weight of box + dry soil (g)	45	51	58	51	46	47	52	48	48	51	57	44
Moisture Content (%)	33.33	28.57	28.57	28.57	40.00	27.27	26.67	25.00	36.36	26.67	25.00	25.00
Field capacity (%)	28.57				26.31				25.55			
Average Field capacity (%)	26.81											

Field capacity of the soil = 26.81 %

7.1.5 Basic infiltration rate of the soil

Replication 1					Replication 2					Replication 3				
Elapsed time (min)	Distance of water surfaces from ref. point		Infiltration during period		Elapsed time (min)	Distance of water surfaces from ref. point		Infiltration during period		Elapsed time (min)	Distance of water surfaces from ref. point		Infiltration during period	
	Before filling (cm)	After filling (cm)	Depth (cm)	Average infiltration ($cm.hr^{-1}$)		Before filling (cm)	After filling (cm)	Depth (cm)	Average infiltration ($cm.hr^{-1}$)		Before filling (cm)	After filling (cm)	Depth (cm)	Average infiltration ($cm.hr^{-1}$)
-	-	10	-	-	-	-	10	-	-	-	-	10	-	-
5	8.5	10	1.5	18	5	8.6	10	1.4	16.8	5	8.5	10	1.5	18
10	9.0	10	1.0	12	10	8.8	10	1.2	14.4	10	9.0	10	1.0	12
15	9.1	10	0.9	10.8	15	9.0	10	1.0	12	15	9.0	10	1.0	12
30	8.2	10	1.5	7.2	30	8.2	10	1.5	7.2	30	8.6	10	1.4	5.6
45	8.2	10	1.5	7.2	45	8.3	10	1.5	6.8	45	8.6	10	1.4	5.6
60	8.4	10	1.6	6.4	60	8.3	10	1.5	6.8	60	8.5	10	1.5	6
75	8.4	10	1.6	6.4	75	8.4	10	1.6	6.4	75	8.5	10	1.5	6
90	8.4	10	1.6	6.4	90	8.4	10	1.6	6.4	90	8.5	10	1.5	6
105	8.4	10	1.6	6.4	105	8.4	10	1.6	6.4	105	8.5	10	1.5	6
120	8.4	10	1.6	6.4	120	8.4	10	1.6	6.4	120	8.5	10	1.5	6
Basic infiltration rate ($cm.hr^{-1}$)														
6.4					6.4					6.0				
Average infiltration rate ($cm.hr^{-1}$)														
6.27														

Basic infiltration rate of the soil = 6.27 cm/hr.

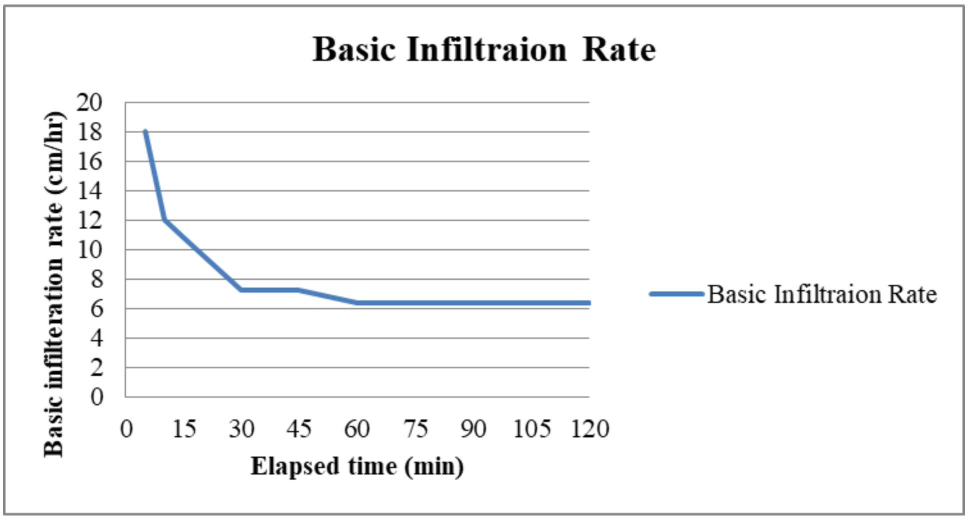

Fig. 7.2: Graph of basic infiltration rate (cm/hr) vr elapsed time (min) for replication I

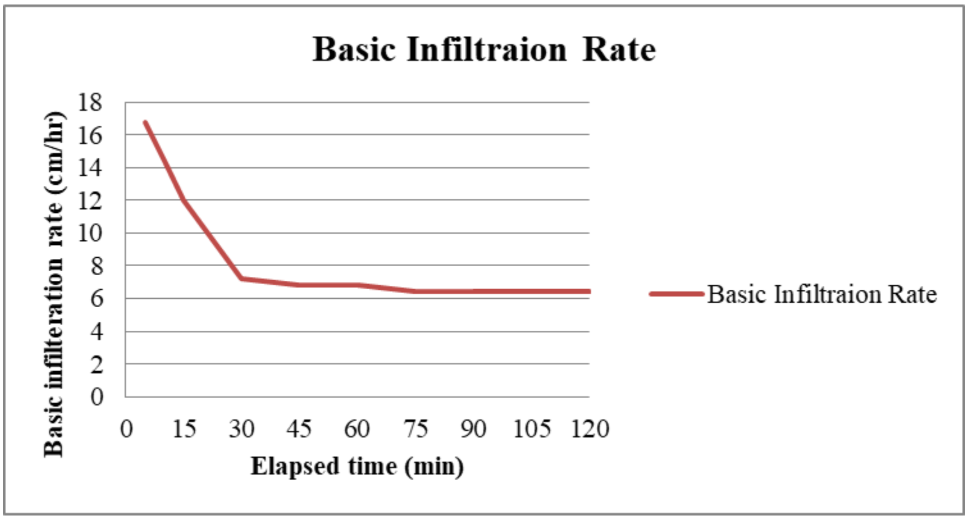

Fig. 7.3: Graph of basic infiltration rate(cm/hr) vs elapsed time (min) for replication II

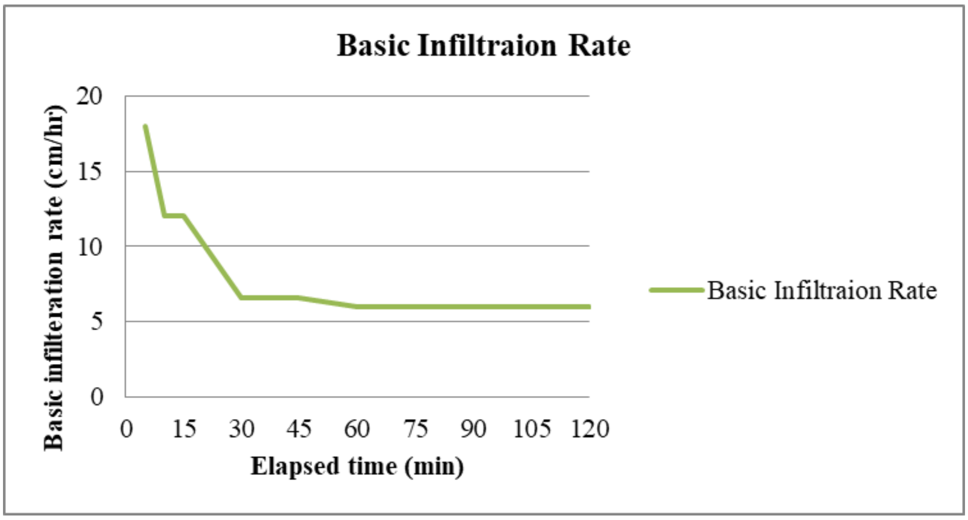

Fig. 7.4: Graph of basic infiltration rate(cm/hr) vs elapsed time(min) for replication III

7.1.6 Hydraulic conductivity of the soil

Replication 1				Replication 2				Replication 3			
d = 6cm r = 3 cm				d = 6cm r = 3 cm				d = 6cm r = 3 cm			
D’ = 38 cm				D’ = 44 cm				D’ = 48 cm			
t (sec)	**H_t (cm)**	**H_t=D’-H_t (cm)**	**$h+\frac{1}{2}r$ (cm)**	**t (sec)**	**H_t (cm)**	**H_t=D’-H_t (cm)**	**$h+\frac{1}{2}r$ (cm)**	**t (sec)**	**H_t (cm)**	**H_t=D’-H_t (cm)**	**$h+\frac{1}{2}r$ (cm)**
0	35.5	2.5	4.0	0	42.0	2.0	3.5	0	45.5	2.5	4.0
50	35.0	3.0	4.5	30	41.5	2.5	4.0	35	45.0	3.0	4.5
115	34.5	3.5	5.0	80	41.0	3.0	4.5	90	44.5	3.5	5.0
200	34.0	4.0	5.5	135	40.5	3.5	5.0	145	44.0	4.0	5.5
290	33.5	4.5	6.0	200	40.0	4.0	5.5	200	43.5	4.5	6.0
400	33.0	5.0	6.5	275	39.5	4.5	6.0	290	43.0	5.0	6.5
525	32.5	5.5	7.0	370	39.0	5.0	6.5	385	42.5	5.5	7.0
670	32.0	6.0	7.5	465	38.5	5.5	7.0	480	42.0	6.0	7.5
740	31.5	6.5	8.0	565	38.0	6.0	7.5	565	41.5	6.5	8.0
975	31.0	7.0	8.5	730	37.5	6.5	8.0	690	41.0	7.0	8.5
-	-	-	-	820	37.0	7.0	8.5	795	40.5	7.5	9.0
-	-	-	-	-	-	-	-	910	40.0	8.0	9.5

Hydraulic conductivity (cm/hr)		
$K = 1.15 * r * \left[\frac{\log\left(h_0 + \frac{1}{2}r\right) - \log\left(h_t + \frac{1}{2}r\right)}{t - t_0} \right]$ $K = 1.15 * 3 * \left[\frac{\log(4.5) - \log(8)}{740 - 50} \right]$ $K = 1.249 * 10^{-3}$ cm/hr $K = 4.5$ cm/hr	$K = 1.15 * r * \left[\frac{\log\left(h_0 + \frac{1}{2}r\right) - \log\left(h_t + \frac{1}{2}r\right)}{t - t_0} \right]$ $K = 1.15 * 3 * \left[\frac{\log(4) - \log(8)}{730 - 30} \right]$ $K = 1.478 * 10^{-3}$ cm/hr $K = 5.32$ cm/hr	$K = 1.15 * r * \left[\frac{\log\left(h_0 + \frac{1}{2}r\right) - \log\left(h_t + \frac{1}{2}r\right)}{t - t_0} \right]$ $K = 1.15 * 3 * \left[\frac{\log(4.5) - \log(9)}{795 - 35} \right]$ $K = 1.36 * 10^{-3}$ cm/hr $K = 4.90$ cm/hr
Average hydraulic conductivity ($cm.hr^{-1}$) = 4.90		

Basic infiltration rate of the soil = 4.90 cm/hr

APPENDIX – II

7.2.1 Factors used to correct the rate of air removal for elevation above sea level

Table 7.2.1: Factors used to correct the rate of air removal for elevation above sea level

	Under							
Meters	300	300	600	900	1200	1500	1800	2100	2400
F_{elev}	1	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

7.2.2 Factors used to correct the rate of air removal for the maximum light intensity in the greenhouse

Table 7.2.2: Factors used to correct the rate of air removal for the maximum light intensity in the greenhouse

F_c	4000	4500	5000	5500	6000	6500	7000	7500	8000
Klux	43.1	48.4	53.8	59.2	64.6	70.0	75.3	80.1	86.1
F_{light}	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60

7.2.3 Factors used to correct the rate of air removal for given pad-to-fan temperature rises

Table 7.2.3: Factors used to correct the rate of air removal for given pad-to-fan temperature rises

ºC	5.6	5.0	4.4	3.9	3.3	2.8	2.2
F_{temp}	0.70	0.78	0.88	1.00	1.17	1.40	1.75

7.2.4 Factors used to correct the rate of air removal for various pad- to-fan distances

Table 7.2.4: Factors used to correct the rate of air removal for various pad- to-fan distances

Meters	6.1	7.6	9.1	10.7	12.2	13.7	15.2	16.8	18.3
F_{vel}	2.24	2.00	1.83	1.69	1.58	1.48	1.41	1.35	1.29

Meters	19.8	21.3	22.9	24.4	25.9	27.4	29.0	30.5 and over
F_{vel}	1.24	1.20	1.16	1.12	1.08	1.05	1.02	1.00

7.2.5 Air delivery ratings and required fan size, rpm and wattage by Greentech India

Table 7.2.5: Air delivery ratings and required fan size, rpm and wattage by Greentech India

(Source: https://www.greentechindia.net/catalogue.pdf)

Blade diameter	CFM @ 0 SP	RPM	Body Size	Watt
609 mm (24")	6900	960	710	370
1100 mm (36")	13600	600	1270	750
1270 mm (50")	25890	440	1380	1100
1470 mm (55")	32842	325	1530	1500

7.6: Air delivery ratings and required fan size, rpm and wattage by American Coolair Corporation

Table 7.2.6: Air delivery ratings and required fan size, rpm and wattage by American Coolair Corporation

(Source: https://www.coolair.com/clientuploads/directory/product_catalog/910-11.pdf)

Fan Model	Fan size	Motor hp	Fan RPM	CFM at Static Pressure		Shutter Model
				0"	10"	
CDP/WS7B17	7	1/20	1725	333	263	SU7-8
CDP/WS8B17	8	1/20	1675	530	458	SU7-8
CDP/WS10B15	10	1/20	1560	793	706	SU10-12
CDP/WS14B15	14	1/20	1450	1144	1028	SU14-16
CDP/WS16G11	16	1/4	1140	2388	2243	SU14-16
CDP/WS18G10	18	1/4	1060	3281	2932	SU18-20

APPENDIX - III

7.3 Program for controlling the exhaust fan, fogger and irrigation

```
#include <SPI.h>
#include <EEPROM.h>
#include <Wire.h>
RTC_DS1307 rtc;
int hh, mm, ss, dd, mmm, yy;
int interval_t = 15; //data recording interval in min.
#include <SD.h>
int sd_cs = 53;
String myLogName;
File myLog;
//#########################################################
// For using the DHT22 sensor
#include <DHT.h>
#define DHTTYPE DHT22   // DHT 22  (AM2302)
DHT dht1(DHT1PIN, DHTTYPE);
DHT dht2(DHT2PIN, DHTTYPE);
DHT dht3(DHT3PIN, DHTTYPE);
int val = 0;
boolean timeout;
float mois = 0;
float temp = 0;
float humi = 0;
float moist3 = 0.0;
int counter = 1;
char keystroke;
int address = 0;
char receivedChars[numChars];
char tempChars[numChars];
//############ Set Parameters ######################
float upMois = 89.0;
float lowMois = 80.0;
```

```
float upTemp = 89.0;
float lowTemp = 80.0;
float upHumi = 89.0;
float lowHumi = 80.0;
//##########################################################
static boolean recvInProgress = false;
char startMarker = '<';
char endMarker = '>';
char rc;
char * strtokIndx;
//##########################################################
void setup()   /****** SETUP: RUNS ONCE ******/
{
  Serial.begin(9600);   //for PC serial port
  Serial3.begin(9600); // for bluetooth serial port
  Serial1.begin(9600); //for GSM serial port
  dht1.begin(); //start DHT22 module
  dht2.begin();
  //make assigned pin as output port
  pinMode(exhaust, OUTPUT);
  pinMode(irrigation, OUTPUT);
  pinMode(fogger, OUTPUT);
    // pinMode(SS, OUTPUT);
  delay(1000);
  if (SD.begin(sd_cs))
  {
    Serial.println("SD card is initialized and it is ready to use");
    RTC();
    myLogName = String(dd) + String(mmm) +  String(yy)  + ".csv";
    myLog = SD.open(myLogName, FILE_WRITE);
    // myLog.print(String(dd) + "/" + String(mmm) + "/" + String(yy));
    // myLog.print(',');
    myLog.print("Time");
    myLog.print(',');
```

```
    myLog.print("Humidity");
    myLog.print(',');
    myLog.print("Temperature");
    myLog.print(',');
    myLog.println("Moisture");
    myLog.flush();  // Saves the file
    myLog.close();
    SDFlag = true;
  } else
  {
    Serial.println("SD card is not initialized");
    SDFlag = false;
    return;
  }
}
//##########################################################
void loop()
{
  if (Serial3.available())
  {
    keystroke = Serial3.read();
    if (keystroke == 's')
    {
      recvWithStartEndMarkers();
      if (newData == true) {
        showParsedData();
        newData = false;
        delay(1000);
      }
      Serial3.print("Moisture high setpoint = ");
      Serial3.println(upMois);
      Serial3.print("Moisture low setpoint = ");
      Serial3.println(lowMois);
      Serial3.println(upHumi);
```

```
  Serial3.print("Humidity low setpoint = ");
  Serial3.println(lowHumi);
  Serial3.println("************************");
}
if (keystroke == 'c')
{
  RTC();
  Serial3.println("Time = " + String(hh) + ":" + String(mm));
  Serial3.print("Humi1 = ");
  Serial3.println(Humi1);
  Serial3.print("Temp1 = ");
  Serial3.print("Temp2 = ");
  Serial3.println("************************");
  if (Iflag == true)
  {
    Serial3.println("Irrigation is ON");
  }
  if (Eflag == true)
  {
    Serial3.println("Exhaust fan is ON");
  }
  if (Fflag == true)
}
if (keystroke == 'r')
{
  if (SDFlag == true)
  {
    Serial3.println("SD card is initialized and it is ready to use");
  }
  if (SDFlag == false)
  {
    Serial3.println("SD card is not initialized");
  }
}
```

```
  }
  mainloop();
}//--(end main loop )---
//######################################################
void mainloop()
{
  EEPROM.get(0, upMois);
  EEPROM.get(4, lowMois);
  EEPROM.get(8, upTemp);
  EEPROM.get(12, lowTemp);
  EEPROM.get(16, upHumi);
  EEPROM.get(20, lowHumi);
  //Get humidity and temperature and moisture
  Humi1 = dht1.readHumidity();
  Temp1 = dht1.readTemperature();
  Humi2 = dht2.readHumidity();
  Temp2 = dht2.readTemperature();
  //float Humi3 = dht2.readHumidity();
  //float Temp3 = dht2.readTemperature();
  //get soil moiture sensor readings from analog ports
  moist1 = analogRead(A0);
  moist1 = map(moist1, 0, 1023, 35, 1);
  moist2 = analogRead(A1);
  moist2 = map(moist2, 0, 1023, 35, 1);
  moist3 = analogRead(A2);
  moist3 = map(moist3, 0, 1023, 35, 1);
  Serial.print("Humi1 = ");
  Serial.println(Humi1);
  Serial.println(humi);
  Serial.print("Avg. Temperature = ");
  Serial.println(temp);
  Serial.print("Avg. Moisture = ");
  Serial.println(mois);
  Serial.println("************************");
```

```
  SDData();
  Control();
  delay(5000);
}
//#######################################################
void Control()
{
  if ((mois < lowMois) && Iflag == false)
  {
    RTC();
    digitalWrite(irrigation, HIGH); // ON signal
    digitalWrite(motor, HIGH);
    Serial.println("*************************");
    Serial3.println("*************************");
    gsm();
    Serial1.println("Irrigation motor is ON. Time = " + String(hh) + ":" + String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    Iflag = true;
  }
  if ((mois > upMois) && Iflag == true)
  {
    gsm();
    Serial1.println("Irrigation motor is OFF. Time = " + String(hh) + ":" +
String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    digitalWrite(exhaust, HIGH);
    digitalWrite(fogger, HIGH);
    digitalWrite(motor, HIGH);
    Serial.println("Exhaust fan and fogger system are ON. Time = " + String(hh) + ":"
+ String(mm));
```

```
    Serial3.println("Exhaust fan and fogger system are ON. Time = " + String(hh) + ":"
+ String(mm));
    Serial.println("*************************");
    Serial3.println("*************************");
    gsm();
    Serial1.println("Exhaust fan and fogger system are ON. Time = " + String(hh) + ":"
+ String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    Eflag = true;
  }
  if ((temp < upTemp) && Eflag == true)
  {
    RTC();
    digitalWrite(exhaust, LOW);
    digitalWrite(fogger, LOW);
    digitalWrite(motor, LOW);
    Serial.println("Exhaust fan and fogger system are OFF. Time = " + String(hh) + ":"
+ String(mm));
    Serial3.println("Exhaust fan and fogger system are OFF. Time = " + String(hh) +
":" + String(mm));
    Serial.println("*************************");
    Serial3.println("*************************");
    gsm();
    Serial1.println("Exhaust fan and fogger system are OFF. Time = " + String(hh) +
":" + String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    Eflag = false;
  }
  if ((humi < lowHumi) && Fflag == false)
  {
```

```
    RTC();
    digitalWrite(fogger, HIGH);
    digitalWrite(motor, HIGH);
    Serial.println("Fogger system is ON. Time = " + String(hh) + ":" + String(mm));
    Serial3.println("Fogger system is ON. Time = " + String(hh) + ":" + String(mm));
    Serial.println("*************************");
    Serial3.println("*************************");
    gsm();
    Serial1.println("Fogger system is ON. Time = " + String(hh) + ":" + String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    Fflag = true;
  }
  if ((humi > lowHumi) && Fflag == true)
  {
    RTC();
    digitalWrite(fogger, LOW);
    digitalWrite(motor, LOW);
    Serial.println("Fogger system is OFF. Time = " + String(hh) + ":" + String(mm));
    Serial3.println("Fogger system is OFF. Time = " + String(hh) + ":" + String(mm));
    Serial.println("*************************");
    Serial3.println("*************************");
    gsm();
    Serial1.println("Fogger system is OFF. Time = " + String(hh) + ":" + String(mm));
    delay(100);
    Serial1.println((char)26);
    delay(1000);
    Fflag = false;
  }
  delay(1000);
  mois = temp = humi = 0;
}
//#########################################################
```

```
void recvWithStartEndMarkers() {
  delay(5);
  while ( newData == false && Serial3.available() > 0)
  {
    rc = Serial3.read();
    if (recvInProgress == true)
    {
      if (rc != endMarker)
      else
      {
        receivedChars[ndx] = '\0';
        recvInProgress = false;
        ndx = 0;
        newData = true;
      }
    }
    else if (rc == startMarker)
    {
      recvInProgress = true;
    }
  }
}
//######################################################################
void parseData() {
  strtokIndx = strtok(tempChars, ",");
  upMois  = atof(strtokIndx);
  writeEEPROM(lowMois);
  strtokIndx = strtok(NULL, ",");
  upTemp = atof(strtokIndx);
  writeEEPROM(upTemp);
  strtokIndx = strtok(NULL, ",");
  lowHumi = atof(strtokIndx);
  writeEEPROM(lowHumi);
  address = 0;
```

```
}
void showParsedData() {
  // show data on PC serial port
  Serial.print(F("High soil moisture set pt = "));
  Serial.println(upMois);
  Serial.print(F("Low soil moisture set pt = "));
  Serial.println(lowMois);
  Serial.println("*************************");
  //show data on mobile device
  Serial3.print(F("High soil moisture set pt = "));
  Serial3.println(upMois);
  Serial3.print(F("Low soil moisture set pt = "));
  Serial3.println(lowMois);
  Serial3.print(F("High temperature set pt = "));
  Serial3.println(upTemp);
  Serial3.print(F("Low temperature set pt = "));
  Serial3.println("*************************");
}
//##########################################################
void writeEEPROM(float coeff)
{
  EEPROM.put(address, coeff);
  address += sizeof(float);
  if (address == EEPROM.length())
  {
    address = 0;
  }
}
//##########################################################
void SDData()
{
  RTC();
 if ((mm % interval_t) == 0)
  {
```

```
    //myLog.println(String(dd) + "/" + String(mmm) + "/" + String(yy));
    //myLog.print(',');
    myLog.print(String(hh) + ":" + String(mm) + ":" + String(ss));
    myLog.print(',');
    myLog.print(humi);
    myLog.print(',');
    myLog.print(temp);
    myLog.print(',');
    myLog.println(mois);
    myLog.flush();  // Saves the file
    myLog.close();
  }
}
//##########################################################
void RTC() {
  DateTime now = rtc.now();
  hh = now.hour();
  dd = now.day();
  mmm = now.month();
  yy = now.year();
}
//##########################################################
void gsm()
  delay(500);
  Serial1.print("AT+CMGF=1");                    // Switch to text mode
  delay(1000);
  Serial1.print("AT+CSMP=17,167,0,0\r\n");
  delay(500);
  Serial1.print("AT+CMGS=");
  Serial1.print("\"+919730727550\"");
  Serial1.println();// Send SMS to a cell number
  delay(1000);  // wait for a 500ms delay
}
//*********( THE END )***********
```

APPENDIX – IV

7.4.1 Variation of Temperature and Humidity Readings

Table 7.4.1: Variation of Temperature and Humidity Readings

Time	Temperature Readings					Humidity Readings					Status of		
	TS - I	TS-II	Hygro. Reading	% variation of TS- I	% variation of TS- II	HS - I	HS–II	Hygro. Reading	% variation of HS- I	% variation of HS- II	Exhaust fan	Fogger	Pump
28-12-2020													
8:30 am	25.70	25.80	25.5	0.78	1.18	85.2	84.3	84	1.43	0.36	OFF	OFF	OFF
12:30 pm	27.50	27.60	27	1.85	2.22	88.9	88.4	84	5.83	5.24	ON	ON	ON
04:30 pm	26.80	27.10	27	0.74	0.37	78.2	82.8	81	3.46	2.22	OFF	OFF	OFF
29-12-2020													
8:30 am	24.10	24.50	24	0.42	2.08	84.4	87.8	87	2.99	0.92	OFF	OFF	OFF
12:30 pm	31.50	30.60	31	1.61	1.29	69.5	73.7	69	0.72	6.81	OFF	OFF	OFF
04:30 pm	28.40	27.90	28.5	0.35	2.11	78.1	82.1	77.5	0.77	5.94	OFF	OFF	OFF
30-12-2020													
8:30 am	23.80	24.00	24	0.83	0.00	90.7	90.6	87	4.25	4.14	OFF	OFF	OFF
12:30 pm	31.30	30.20	31	0.97	2.58	68.2	70	72.5	5.93	3.45	OFF	OFF	OFF
04:30 pm	28.40	28.00	28	1.43	0.00	82.5	87.7	81	1.85	8.27	OFF	OFF	OFF
31-12-2020													
8:30 am	25.30	25.10	25	1.20	0.40	84.75	87.15	84	0.89	3.75	OFF	OFF	OFF
12:30 pm	32.70	31.70	32.5	0.62	2.46	56.9	54.8	55	3.45	0.36	ON	ON	ON
04:30 pm	29.20	28.60	29	0.69	1.38	86.2	88	83	3.86	6.02	OFF	OFF	OFF
01-01-2021													
8:30 am	23.2	23.6	23.5	1.28	0.43	89.1	89.4	87	2.41	2.76	OFF	OFF	OFF
12:30 pm	32.2	31.6	33	2.42	4.24	56.7	60.2	53	6.98	13.58	ON	ON	ON

04:30 pm	28.5	27.7	29	1.72	4.48	78.9	82.1	74	6.62	10.95	OFF	OFF	OFF
02-01-2021													
8:30 am	23.45	23.45	23	1.96	1.96	87.7	88.6	87	0.80	1.84	OFF	OFF	OFF
12:30 pm	32.45	32.15	32.5	0.15	1.08	53.1	58.8	58.5	9.23	0.51	ON	ON	ON
04:30 pm	30.3	29.3	29.5	2.71	0.68	68	74.4	67.5	0.74	10.22	OFF	OFF	OFF
03-01-2021													
8:30 am	24.1	24.7	24.5	1.63	0.82	83.5	87	87.5	4.57	0.57	OFF	OFF	OFF
12:30 pm	32.65	31.85	32	2.03	0.47	53	58.6	55	3.64	6.55	ON	ON	ON
04:30 pm	30.5	29.7	30	1.67	1.00	74.5	78.7	72	3.47	9.31	OFF	OFF	OFF
04-01-2021													
8:30 am	24.7	24.2	24.5	0.82	1.22	85.5	86.9	87.5	2.29	0.69	OFF	OFF	OFF
12:30 pm	31.9	30.5	32	0.31	4.69	58.6	64.4	61.5	4.72	4.72	OFF	OFF	OFF
04:30 pm	29	27.9	29	0.00	3.79	77.8	82.2	78	0.26	5.38	OFF	OFF	OFF
05-01-2021													
8:30 am	25.4	24.7	25	1.60	1.20	81.2	85.6	84	3.33	1.90	OFF	OFF	OFF
12:30 pm	32.3	30.9	32	0.94	3.44	63.1	68.5	64	1.41	7.03	OFF	OFF	OFF
04:30 pm	29.9	29.5	30	0.33	1.67	74.7	79.1	75	0.40	5.47	OFF	OFF	OFF
06-01-2021													
8:30 am	24.4	24.8	24	1.67	3.33	84.85	86.15	83	2.23	3.80	OFF	OFF	OFF
12:30 pm	31.7	30.4	31.5	0.63	3.49	68.7	72.9	69.5	1.15	4.89	OFF	OFF	OFF
04:30 pm	29.8	27.9	29	2.76	3.79	73.4	78.1	75	2.13	4.13	OFF	OFF	OFF
07-01-2021													
8:30 am	23.8	23.4	23.5	1.28	0.43	87.2	88.4	87	0.23	1.61	OFF	OFF	OFF
12:30 pm	32.45	31.85	32.5	0.15	2.00	53.4	58.2	55	2.91	5.82	ON	ON	ON
04:30 pm	29.5	28.2	29	1.72	2.76	76.8	80.1	78	1.54	2.69	OFF	OFF	OFF
08-01-2021													
8:30 am	24	23.7	24	0.00	1.25	85.9	88.4	87	1.26	1.61	OFF	OFF	OFF
12:30 pm	31.5	30.5	31.5	0.00	3.17	60.7	66.5	63.5	4.41	4.72	OFF	OFF	OFF
04:30 pm	30.2	28.9	30	0.67	3.67	71.4	77.8	72	0.83	8.06	OFF	OFF	OFF

<table>
<tr><td colspan="14">09-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.5</td><td>24.2</td><td>24.5</td><td>0.00</td><td>1.22</td><td>84.7</td><td>85.6</td><td>83.5</td><td>1.44</td><td>2.51</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>31.3</td><td>29.8</td><td>32</td><td>2.19</td><td>6.88</td><td>55.85</td><td>61.2</td><td>58</td><td>3.71</td><td>5.52</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>04:30 pm</td><td>29.4</td><td>28.3</td><td>29</td><td>1.38</td><td>2.41</td><td>74.1</td><td>79.5</td><td>74</td><td>0.14</td><td>7.43</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">10-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.8</td><td>24.4</td><td>24.5</td><td>1.22</td><td>0.41</td><td>84.1</td><td>85.8</td><td>83.5</td><td>0.72</td><td>2.75</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>31.85</td><td>30.65</td><td>32</td><td>0.47</td><td>4.22</td><td>59.65</td><td>63.9</td><td>61</td><td>2.21</td><td>4.75</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>04:30 pm</td><td>29.7</td><td>29.1</td><td>29.5</td><td>0.68</td><td>1.36</td><td>70.5</td><td>79.2</td><td>74.5</td><td>5.37</td><td>6.31</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">11-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.5</td><td>23.9</td><td>24</td><td>2.08</td><td>0.42</td><td>84.9</td><td>86.2</td><td>83</td><td>2.29</td><td>3.86</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>31.7</td><td>31.1</td><td>31.5</td><td>0.63</td><td>1.27</td><td>59.8</td><td>64.1</td><td>63.5</td><td>5.83</td><td>0.94</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>04:30 pm</td><td>29.6</td><td>27.8</td><td>29.5</td><td>0.34</td><td>5.76</td><td>67.8</td><td>71.2</td><td>68</td><td>0.29</td><td>4.71</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">12-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.2</td><td>24.5</td><td>24</td><td>0.83</td><td>2.08</td><td>87.1</td><td>86.2</td><td>87</td><td>0.11</td><td>0.92</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>32.5</td><td>32.1</td><td>32</td><td>1.56</td><td>0.31</td><td>57.1</td><td>61.3</td><td>58</td><td>1.55</td><td>5.69</td><td>ON</td><td>ON</td><td>ON</td></tr>
<tr><td>04:30 pm</td><td>29.5</td><td>28.9</td><td>29.5</td><td>0.00</td><td>2.03</td><td>74.2</td><td>79.8</td><td>74.5</td><td>0.40</td><td>7.11</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">13-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.5</td><td>24.1</td><td>24</td><td>2.08</td><td>0.42</td><td>85.2</td><td>87.9</td><td>87</td><td>2.07</td><td>1.03</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>31.8</td><td>31.5</td><td>31.5</td><td>0.95</td><td>0.00</td><td>67.5</td><td>70.2</td><td>66.5</td><td>1.50</td><td>5.56</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>04:30 pm</td><td>29.8</td><td>29.2</td><td>29.5</td><td>1.02</td><td>1.02</td><td>71.1</td><td>75.4</td><td>71.5</td><td>0.56</td><td>5.45</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">14-01-2021</td></tr>
<tr><td>8:30 am</td><td>23.6</td><td>23.3</td><td>23.5</td><td>0.43</td><td>0.85</td><td>87.2</td><td>89.1</td><td>87</td><td>0.23</td><td>2.41</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>32.4</td><td>32.2</td><td>32</td><td>1.25</td><td>0.63</td><td>56.8</td><td>61.2</td><td>58</td><td>2.07</td><td>5.52</td><td>ON</td><td>ON</td><td>ON</td></tr>
<tr><td>04:30 pm</td><td>30.3</td><td>29.5</td><td>30</td><td>1.00</td><td>1.67</td><td>69.8</td><td>73.7</td><td>72</td><td>3.06</td><td>2.36</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">15-01-2021</td></tr>
<tr><td>8:30 am</td><td>24.6</td><td>24.3</td><td>24.5</td><td>0.41</td><td>0.82</td><td>86.5</td><td>88.1</td><td>87.5</td><td>1.14</td><td>0.69</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td>12:30 pm</td><td>32.5</td><td>32.3</td><td>32</td><td>1.56</td><td>0.94</td><td>52.5</td><td>58.9</td><td>55</td><td>4.55</td><td>7.09</td><td>ON</td><td>ON</td><td>ON</td></tr>
<tr><td>04:30 pm</td><td>29.7</td><td>28.9</td><td>29.5</td><td>0.68</td><td>2.03</td><td>73.5</td><td>81.4</td><td>74.5</td><td>1.34</td><td>9.26</td><td>OFF</td><td>OFF</td><td>OFF</td></tr>
<tr><td colspan="14">16-01-2021</td></tr>
</table>

8:30 am	24.8	24.1	24.5	1.22	1.63	85.5	87.1	87.5	2.29	0.46	OFF	OFF	OFF
12:30 pm	32.1	31.1	32	0.31	2.81	55.7	62.8	58	3.97	8.28	OFF	OFF	OFF
04:30 pm	29.6	28.7	29.5	0.34	2.71	72.6	80.2	74.5	2.55	7.65	OFF	OFF	OFF
17-01-2021													
8:30 am	24.3	24	24	1.25	0.00	86.2	87.9	87	0.92	1.03	OFF	OFF	OFF
12:30 pm	32.1	31.6	31.5	1.90	0.32	57.2	64.1	60.5	5.45	5.95	OFF	OFF	OFF
04:30 pm	29.5	28.9	29.5	0.00	2.03	70.8	76.7	74.5	4.97	2.95	OFF	OFF	OFF
18-01-2021													
8:30 am	24.70	24.60	24.50	0.82	0.41	85.2	86.5	87	2.07	0.57	OFF	OFF	OFF
12:30 pm	31.90	31.50	31.50	1.27	0.00	64.7	71.1	66.5	2.71	6.92	OFF	OFF	OFF
04:30 pm	30.10	29.50	30.00	0.33	1.67	69.1	77.2	72	4.03	7.22	OFF	OFF	OFF
19-01-2021													
8:30 am	24.30	23.90	24.00	1.25	0.42	87.4	88.5	87	0.46	1.72	OFF	OFF	OFF
12:30 pm	32.40	32.10	32.00	1.25	0.31	54.8	59.1	58	5.52	1.90	ON	ON	ON
04:30 pm	30.20	29.70	30.00	0.67	1.00	67.3	70.2	68	1.03	3.24	OFF	OFF	OFF
20-01-2021													
8:30 am	23.80	23.40	23.50	1.28	0.43	88.6	88.4	87	1.84	1.61	OFF	OFF	OFF
12:30 pm	32.10	30.80	32.00	0.31	3.75	62.3	72.5	66.5	6.32	9.02	OFF	OFF	OFF
04:30 pm	29.70	28.90	29.50	0.68	2.03	72.1	76.7	71.5	0.84	7.27	OFF	OFF	OFF
21-01-2021													
8:30 am	24.40	23.70	24.00	1.67	1.25	85.9	87.5	87	1.26	0.57	OFF	OFF	OFF
12:30 pm	32.50	31.70	32.50	0.00	2.46	52.8	54.5	55	4.00	0.91	ON	ON	ON
04:30 pm	30.30	29.50	30.00	1.00	1.67	67.2	70.1	68	1.18	3.09	OFF	OFF	OFF
22-01-2021													
8:30 am	24.80	24.30	24.50	1.22	0.82	86.5	86.2	87.5	1.14	1.49	OFF	OFF	OFF
12:30 pm	31.80	31.50	32.00	0.62	1.56	62.4	67.3	63.5	1.73	5.98	OFF	OFF	OFF
04:30 pm	29.70	29.20	29.50	0.68	1.02	72.5	75.8	71.5	1.40	6.01	OFF	OFF	OFF
23-01-2021													
8:30 am	24.60	24.50	24.50	0.41	0.00	86.5	86.2	87	0.57	0.92	OFF	OFF	OFF

12:30 pm	32.40	31.90	31.50	2.86	1.27	58.7	63.8	61	3.77	4.59	OFF	OFF	OFF
04:30 pm	29.30	28.70	29.00	1.03	1.03	74.8	81.5	78	4.10	4.49	OFF	OFF	OFF
24-01-2021													
8:30 am	24.80	24.30	24.50	1.22	0.82	85.7	86.5	87	1.49	0.57	OFF	OFF	OFF
12:30 pm	32.20	31.90	32.00	0.63	0.31	55.2	59.9	58	4.83	3.28	ON	ON	ON
04:30 pm	29.90	28.60	29.50	1.36	3.05	69.9	75.1	72	2.92	4.31	OFF	OFF	OFF
25-01-2021													
8:30 am	24.9	24.2	24.5	1.63	1.22	85.2	86.1	83.5	2.04	3.11	OFF	OFF	OFF
12:30 pm	31.8	30.8	31.5	0.95	2.22	64.1	71.7	66.5	3.61	7.82	OFF	OFF	OFF
04:30 pm	29.6	28.4	29	2.07	2.07	72.3	76	71.5	1.12	6.29	OFF	OFF	OFF
26-01-2021													
8:30 am	24.7	24.4	24.5	0.82	0.41	85.8	86.4	83.5	2.75	3.47	OFF	OFF	OFF
12:30 pm	32.5	32.2	32	1.56	0.63	54.9	58.7	55	0.18	6.73	ON	ON	ON
04:30 pm	30.1	29.4	30	0.33	2.00	69.7	73.9	70	0.43	5.57	OFF	OFF	OFF
27-01-2021													
8:30 am	24.2	23.7	23.5	2.98	0.85	86.3	87.7	87	0.80	0.80	OFF	OFF	OFF
12:30 pm	31.8	30.7	31.5	0.95	2.54	60.9	69.8	64.5	5.58	8.22	OFF	OFF	OFF
04:30 pm	29.7	29.2	29.5	0.68	1.02	70.3	77.1	71.5	1.68	7.83	OFF	OFF	OFF

7.4.2 Weekly Variation of Soil Moisture Readings

Table 7.4.2 Weekly Variation of Soil Moisture Readings

Weekly Variation of Soil Moisture Readings								
Date	**Time**	**SMS - I**	**SMS- II**	**SMS- III**	**Gravimetric Reading**	**% variation of SMS-I**	**% variation of SMS-II**	**% variation of SMS-II**
28-12-2020 (Week 1)	8:30 am	21.00	21.00	21.00	22.13	5.11	5.11	5.11
	12:30 pm	27.00	28.00	27.00	27.97	3.47	0.11	3.47

	04:30 pm	25.00	27.00	26.00	26.89	7.03	0.41	3.31
04-01-2021 (Week 2)	8:30 am	21.00	22.00	21.00	21.85	3.89	0.69	3.89
	12:30 pm	27.00	28.00	27.00	27.94	3.36	0.21	3.36
	04:30 pm	26.00	26.00	26.00	27.15	4.24	4.24	4.24
11-01-2021 (Week 3)	8:30 am	23.00	23.00	23.00	23.54	2.29	2.29	2.29
	12:30 pm	27.00	28.00	28.00	28.29	4.56	1.03	1.03
	04:30 pm	26.00	27.00	27.00	27.72	6.20	2.60	2.60
18-01-2021 (Week 4)	8:30 am	25.00	26.00	26.00	26.57	5.91	2.15	2.15
	12:30 pm	24.00	25.00	24.00	25.23	4.88	0.91	4.88
	04:30 pm	22.00	22.00	22.00	23.1	4.76	4.76	4.76
25-01-2021 (Week 5)	8:30 am	23.00	24.00	24.00	23.17	0.73	3.58	3.58
	12:30 pm	28.00	28.00	28.00	27.33	2.45	2.45	2.45
	04:30 pm	26.00	27.00	26.00	25.27	2.89	6.85	2.89

APPENDIX – V

7.5 Table of Wet and Dry Bulb Thermometer Readings with corresponding Percentages of Humidity

TABLE OF WET & DRY BULB THERMOMETER READINGS WITH CORRESPONDING PERCENTAGES OF HUMIDITY

CELSIUS SCALE

Dry Bulb °C	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
	DEPRESSION OF WET BULB °C													
—1	90	79	69	59	49	39	30	20	10	1				
0	90	81	71	61	52	44	34	25	16	7				
+1	90	81	73	64	55	47	38	29	20	13	4			
2	91	82	73	64	57	49	41	33	24	17	9	1		
3	91	83	74	65	57	49	43	36	28	21	14	7		
4	92	83	75	67	59	51	43	35	32	25	18	11	4	
5	92	84	76	68	61	53	46	38	31	24	21	15	8	2
6	92	85	77	70	62	55	48	41	34	27	20	14	12	6
7	93	85	78	71	64	57	50	44	37	30	24	17	11	5
8	93	86	79	72	65	59	52	46	39	33	27	21	15	9
9	93	86	80	73	67	60	54	48	42	36	30	24	18	12
10	93	87	81	74	68	62	56	50	44	38	33	27	21	16
11	94	87	81	75	69	63	58	52	46	41	35	30	24	19
12	94	88	82	76	70	65	59	54	48	43	37	32	27	22
13	94	88	83	77	71	66	60	55	50	45	40	35	30	25
14	94	89	83	78	72	67	62	57	52	47	42	37	32	27
15	94	89	84	78	73	68	63	58	53	48	42	39	34	30
16	95	89	84	79	74	69	64	59	55	50	43	41	37	32
17	95	90	85	80	75	70	65	61	56	52	47	43	39	34
18	95	90	85	80	76	71	66	62	57	53	49	45	40	36
19	95	90	86	81	76	72	67	63	59	54	50	46	42	38
20	95	91	86	81	77	73	68	64	60	56	52	48	44	40
21	95	91	86	82	78	73	69	65	61	57	53	49	45	42
22	95	91	87	82	78	74	70	66	62	58	54	50	47	43
23	96	91	87	83	79	75	71	67	63	59	55	52	48	45
24	96	91	87	83	79	75	71	68	64	60	57	53	49	46
25	96	92	88	84	80	76	72	68	65	61	58	54	51	47
26	96	92	88	84	80	76	73	69	66	62	59	55	52	49
27	96	92	88	84	81	77	73	70	66	63	59	56	53	50
28	96	92	88	85	81	77	74	70	67	64	60	57	54	51
29	96	92	89	85	81	78	74	71	68	64	61	58	55	52
30	96	93	89	85	82	78	75	72	68	65	62	59	56	53
32	96	93	89	86	82	79	76	73	70	67	64	61	58	55
34	96	93	89	86	83	80	77	74	71	68	65	62	59	56
36	96	93	90	87	84	81	78	75	72	69	66	63	61	58
38	96	94	90	87	84	81	78	75	73	70	67	64	62	59
40	96	94	91	88	85	82	79	76	74	71	69	66	63	61
42	97	94	91	88	85	82	80	77	75	72	70	67	65	62
44	97	94	91	88	86	83	81	78	75	72	70	67	65	63
46	97	94	91	89	86	83	81	78	76	73	71	68	66	64
48	97	95	92	89	86	83	81	78	76	74	72	69	67	65
50	97	95	92	89	87	84	82	79	77	74	72	70	68	65
52	97	95	92	89	87	84	82	79	77	75	73	70	68	66
54	97	95	93	90	87	85	83	80	78	75	73	71	69	67
56	97	95	93	90	87	85	83	80	78	76	74	71	69	67
58	97	95	93	90	87	85	83	81	79	76	74	72	70	68
60	98	96	93	90	87	85	83	81	79	77	75	72	70	68

CELSIUS SCALE

Dry Bulb °C	7.5	8.0	8.5	9.0	9.5	10	11	12	13	14	15	16	Dry Bulb °C
	DEPRESSION OF WET BULB °C												
—1													—1
0													0
+1													+1
2													2
3													3
4													4
5													5
6													6
7													7
8	3												8
9	7	1											9
10	10	5											10
11	14	9	4										11
12	17	12	7	2									12
13	20	15	11	6	1								13
14	23	18	14	9	6	1							14
15	25	21	17	-12	8	4							15
16	28	24	19	15	11	7							16
17	30	26	22	18	14	10	3						17
18	32	28	24	21	17	13	6						18
19	34	30	27	23	19	16	9	2					19
20	36	32	29	25	22	18	11	5					20
21	38	34	31	27	24	20	14	7	1				21
22	40	36	33	29	26	23	16	10	4				22
23	41	38	34	31	28	25	18	12	6	1			23
24	43	39	36	33	30	27	20	15	9	3			24
25	44	41	38	35	31	28	22	17	11	6	1		25
26	45	42	39	36	33	30	24	19	13	8	3		26
27	47	44	41	38	35	32	26	21	15	10	5	1	27
28	48	45	42	39	36	33	28	23	17	12	8	3	28
29	49	46	43	40	37	35	29	24	19	14	10	5	29
30	50	47	44	42	39	36	31	26	21	16	12	7	30
32	52	49	46	44	41	39	34	29	24	20	15	11	32
34	54	51	48	46	43	41	36	32	27	23	19	15	34
36	55	53	50	48	45	43	38	34	30	26	22	18	36
38	57	54	52	50	47	45	40	36	32	28	24	20	38
40	58	56	53	51	49	47	42	38	34	30	27	23	40
42	60	57	55	53	50	48	44	40	36	32	29	25	42
44	61	58	56	54	52	50	46	42	38	34	31	27	44
46	62	59	57	55	53	51	47	43	39	36	33	29	46
48	63	60	58	56	54	52	48	44	41	37	34	31	48
50	63	61	59	57	55	53	49	45	42	38	36	32	50
52	64	62	60	58	56	54	50	47	43	40	37	34	52
54	65	63	61	59	57	55	51	48	44	41	38	35	54
56	66	64	62	60	58	56	52	49	45	42	39	37	56
58	66	64	63	61	59	57	53	50	47	43	40	38	58
60	67	65	64	62	60	57	54	51	48	45	42	39	60

CELSIUS SCALE

17	18	19	20	21	22	23	24	25	26	27	28	29	30	Dry Bulb °C
DEPRESSION OF WET BULB °C														
														—1
														0
														+1
														2
														3
														4
														5
														6
														7
														8
														9
														10
														11
														12
														13
														14
														15
														16
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														21
														22
														23
														24
														25
														26
														27
														28
1														29
3														30
7	3													32
11	7	3												34
14	10	7	3											36
17	13	10	7	4	1									38
20	16	13	10	7	4	1								40
22	19	16	13	10	7	4	2							42
24	21	18	15	12	10	7	4	1						44
26	23	20	18	15	12	10	8	5	3	1				46
28	25	22	20	17	14	12	10	7	5	3	1			48
29	27	24	21	19	16	14	12	9	7	6	3	1		50
31	28	26	23	21	18	16	14	11	9	8	5	3	1	52
32	30	27	25	22	20	18	15	13	11	10	7	5	3	54
34	32	29	27	24	21	19	17	15	13	11	9	7	5	56
35	33	30	28	25	23	21	19	17	15	13	11	9	7	58
36	34	32	29	27	25	23	20	18	16	15	13	11	9	60