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Modelling and Analysis of Temperature and Humidity within a Greenhouse System

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Abstract

This research explored the various behaviors of climatic conditioning elements, weakness as well as ways to improve them. Remote monitoring using Arduino Internet of a Thing (IoT) technology was implemented in the automated greenhouse environment used to gain access to some necessary generated data. Implementation unit yield is of vital essence as population of people is on a steady rise, food insecurity is invariably on the rise also. Means need to be developed to enhance agricultural output to meet up with the need of the ever increasing-population of man. One of the main goals of this research is to improve efficiency to enhance agricultural productivity and resource management by enabling real-time data-collection and control of crucial greenhouse parameters such as temperature and humidity. With the integration of sensors like Dht11 and actuators connected to the Esp32 wroom-32 which we employed in this work. This methodology helps to optimize crop growth conditions while overcoming the challenges posed by Nigeria's diverse climatic conditions. The study evaluated the effectiveness of this remote monitoring approach in terms of improved crop yields, and system efficiency thus contributing to sustainable and technology-driven agriculture in Nigeria. This hourly data was taken on Sunday, 31st August 2023 at Ikole – Ekiti at the Faculty of Engineering. From analysis the percentage effectiveness of ambient temperature on this rainy day for the selected crop was 70%. This trend deciphered inefficiency in the microclimatic element but could also end up transforming the dreaded blue-collar agriculture to an attractive niche in the future.

Keywords: micro-climate, Greenhouse, ESP32-wroom-32, real-time data collection, Arduino IoT technology

INTRODUCTION

Agriculture has been one of the primary and inevitable practices of man. The dependence of man on food and its related produce has made agriculture an indispensable art despite the long records of time. Instead, agriculture continued to be revolutionized to meet the ever-changing needs of man Maurizio *et al.* (2010).

This revolution in ways of farming led to the in-house farming popularly known as greenhouse farming. A more effective method of crop production that involves developing an enclosed system with its conditioned climate to suit the requirement of proper farming is called a

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greenhouse. Greenhouse cultivation is the most common way to recreate the microclimate conducive to plant growth throughout the year Maurizio *et al.* (2010). The greenhouse environment is a complex dynamical system characterized roughly by two main subsystems: The microclimate and The crop. López-Cruz *et al.* (2018) review was focused on physics of the greenhouse microclimate and its mathematical modeling.

The current growth trend of the human population, together with the evolution of consumption patterns, increasing demand and food waste are placing unprecedented pressure on agricultural systems and natural resources Foley *et al* (2011). In other words, the global demand for agricultural products continues to rise as the world population increases. Farming methods face numerous challenges such as limited cultivable land, unpredictable weather conditions, crop infection and the need for efficient resource management. According to proven statistics, nearly 50 % of yield is attributed to the influence of climatic factors Shailesh (2021). Climate change is perhaps the most serious environmental threat to the fight against hunger, malnutrition, disease and poverty in Africa. This is mainly through the impact of climate change on agricultural productivity (Anselm & Taofeeq, 2010).

Greenhouse planting is considered a significant measure to ensure food greenhouses play an increasing important role to meet the demand-driven economy Narasimhan *et al.* (2007). It can reduce crop diseases and pests, improve the crop growth environment, and increase yield. Analyzing these climatic conditions within the greenhouse to see flaws and possible areas of improvement is paramount to advance agricultural practices and improve yields. This analysis can lead to better models which would pave way for improved gadgets for automated modern greenhouses and also helps in better, more efficient and effective resource management. The use of models that predict the greenhouse microclimate using external weather data from local meteorological stations have proved to be useful for understanding and improving greenhouse climate control and management Nauta, & Tasnim (2023).

Technology has been able to meet the challenges related to greenhouse farming in both contributing to overcoming its limitations, correcting adverse impacts and ensuring system sustainability Aznar-Sánchez *et al*. (2020). Automated greenhouse models combine advanced technologies such as sensors, actuators, and control systems to create a highly controlled micro-climatic environment for plant growth which was not adequately address in other literatures consulted. By operating at the optimal temperature at each stage of the crop, the greenhouse can easily produce higher amount of yield outside the crop growing season Luis, (1993). These models offer several advantages over traditional open-field farming, including precise control of environmental factors, year-round production, reduced water consumption, and improved crop yield and quality. Enete *et al*. (2010) and Aznar-Sánchez (2020) were limited in precise environmental control which this research work is out to improve on.

METHODOLOGY

The research was carried out at Federal University Oye-Ekiti, Ikole Campus in the research laboratory. The glaze of the model greenhouse used low density polythene sheet of 6 microns, and about 80% light transmittivity. Covering materials modify greenhouse microclimate due to their transmissivity to solar radiation in the visible range and in the long infrared radiation Marucci *et al*. (2012). The glaze was double layered polythene sheet to increase insulation and prevent heat loss from the system. Dht11 sensor was used to measure the temperature within the

system. The temperature was compared with the temperature required by the crop at that particular stage of it's growth cycle as saved in the database of the Esp32 microcontroller used. An exhaust fan was included as well as a heater to automatically turn on and off to adjust the temperature and humidity to that required by the crop in the greenhouse.
Experimental data were collected from the Arduino iot cloud dashboard used.

Model analysis
A physical model greenhouse was developed as a test model for the usual commercial greenhouses. The relationships between various variables such as heat transferred, expected period of power supply to last were modeled mathematically. Mathematicians take simple laws of thermodynamics and motion and manipulate them into explaining how our climate works.

Table 1 Greenhouse Properties

Variables	**Values**
Length(m)	7
Width(m)	5
Area(m^2)	35
Glaze material	Polythene sheet(double inflated poly)
Heater	1(12V 25W)
Exhaust fan	1(0.15A 12V)
Test crop	Tomatoes (non-deterministic variety)

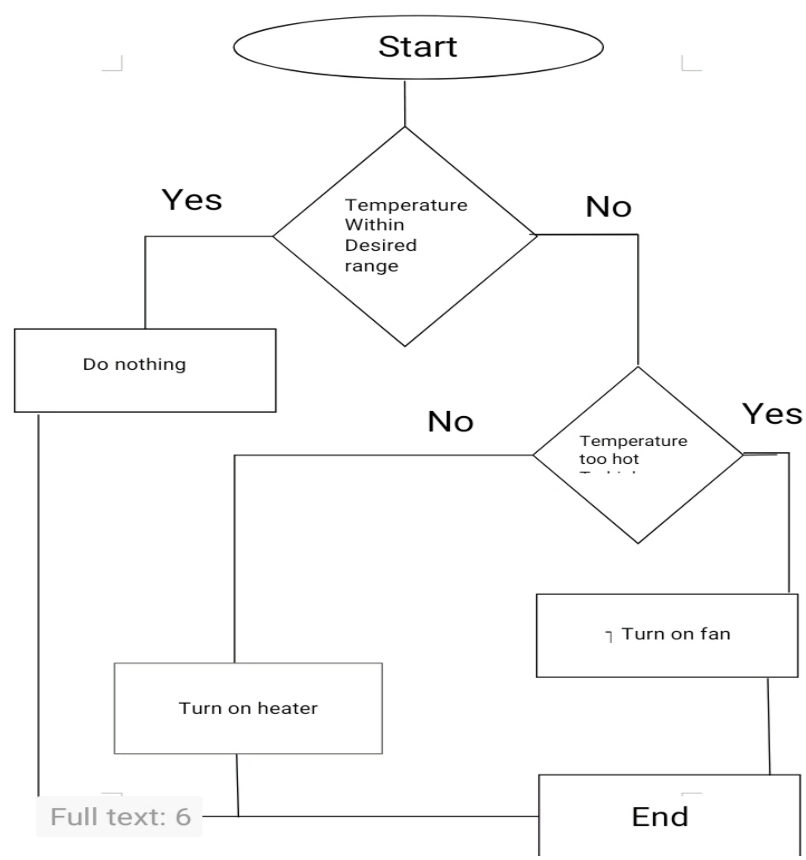

Figure 1: Model flowchart

The modified model for this study is that of a mathematical model called MICroclimate of GREENhouse (MICGREEN) developed by Gurpreet Singh et al. (2006), consisting of set of algebraic equations. This equation was written for four component of greenhouse which include the inside air, cover, canopy surface and bare soil surface. Nevertheless, it was assumed that the greenhouse air is well mixed, thermal properties of materials forming the construction of the setup do not change with time and also solar radiations pass through cover without absorption.

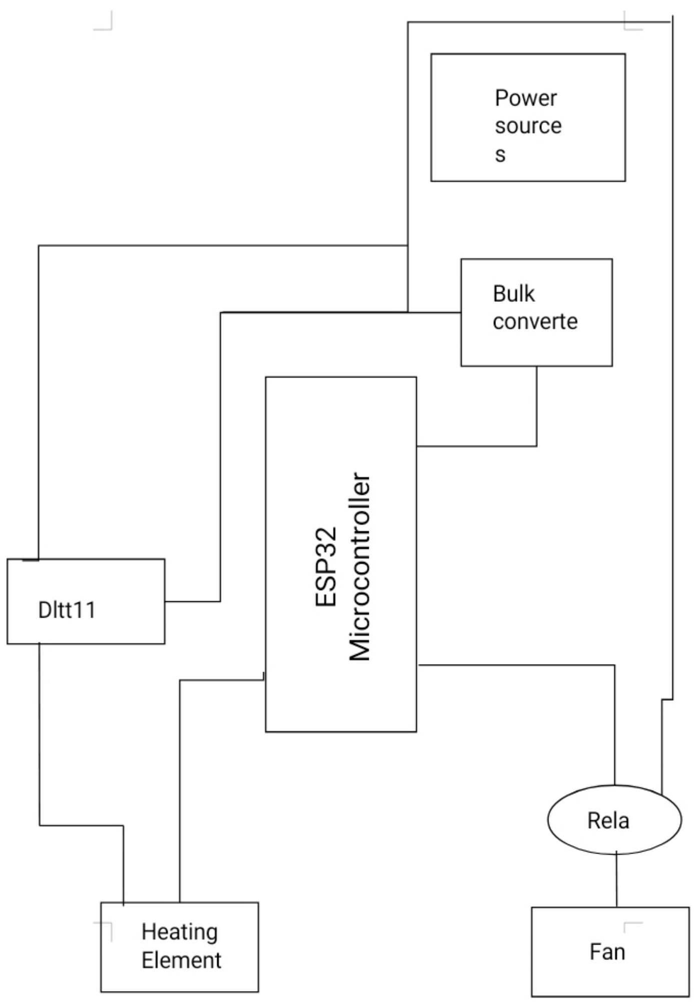

Figure 2: Model System Architecture block chart.

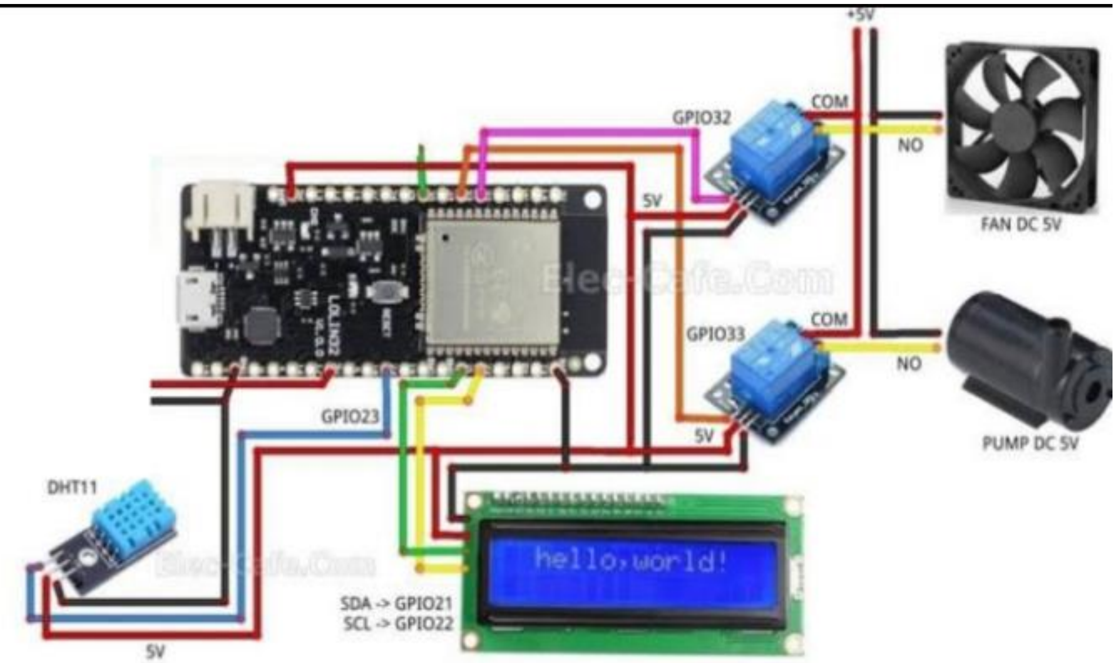

Figure 3: The Electronic circuit diagram of the system

The greenhouse temperature and humidity model were designed and then validated by comparing air temperature (T_a) and relative humidity (RH) measured at the greenhouse with the computed results of the greenhouse model.

The results of computer model (predicted data) were compared with the experimental results. The minimum correlation coefficients between values were 0.960, 0.965, 0.970, 0.976 and 0.80 for germination, vegetable growth, flowering, plant and fruiting respectively. The minimum temperatures were 23, 18.77, 20.57 and 25.8 ^{o}C for germination, vegetable growth, flowering, plant and fruiting. Good agreement between the predicted and measured values was obtained during the entire modelling period. This means that the model can be used to predict a thermal performance of the greenhouse elements in a wide range of humidity and temperatures.

RESULT AND DISCUSSION

Results and discussions section reveals the findings from the experiments and observation to see whether the suggested method is effective.

Table 2 formed the database used as the reference for automatic adjustment of climate in the system. Temperature can be adjusted by detecting these trained features in these plants.

Table 2 -- Growth cycle for specimen (Tomatoes)

Crop/Vegetable	Growth stage	Optimum temperature	Optimum humidity	Number of days	Features
Tomatoes	Germination	20-25	70-80	5-10days	Seedling appearance
	Vegetation growth	18-24	60-70	30-45days	Continuous growth of leaf and stem
	Flowering	20-26	50-60	40-55	Appearance of yellow, star-shaped flowers.
	Fruiting	22-28	60-70	20-30days	Green fruits develop and start to ripen. Gradual color change (e.g., green to red for some varieties).
Lettuce	Germination	20-25	85-90	5-10days	Seedling appearance
	Vegetative growth	15-20	60-70	20-30days	Focus on leaf growth, forming a rosette of leaves. Typically, no stem elongation during this stage.
	Flowering growth	18-22	70-80	15-20	The central stem starts to elongate. The plant produces a tall flowering stalk
	Fruiting				Flowers turn into seed heads. Seeds develop within these heads.
Cucumber	Germination	24-29	70-80	7-14days	Seedling appearance
	Vegetative growth	22-26	60-70	20-30days	leaf and vine growth. Development of a strong root system.
	Flowering	24-28	50-60	20-25days	Appearance of bright yellow, trumpet-shaped flowers. Male and female flowers on the same plant; pollination is essential for fruiting
	Fruiting	26-30	60-70	25-20days	Formation of cucumber fruits. Gradual growth of cucumbers from small to full size

In our system heat emitted from human body and appliances or absorbed by them were not taken into account since it is negligible and which was actually corrected by the automated system. Heat is transferred to the system by means of radiation.

As earlier explained in the methodology an exhaust fan was included as well as a heater to automatically turn on and off to adjust the temperature and humidity which was required by the crop in the greenhouse.

Table 4 showed the required heating curve of the automated heater which indicate small change in temperature against small change in time (curve of $\frac{dT}{dt}$).

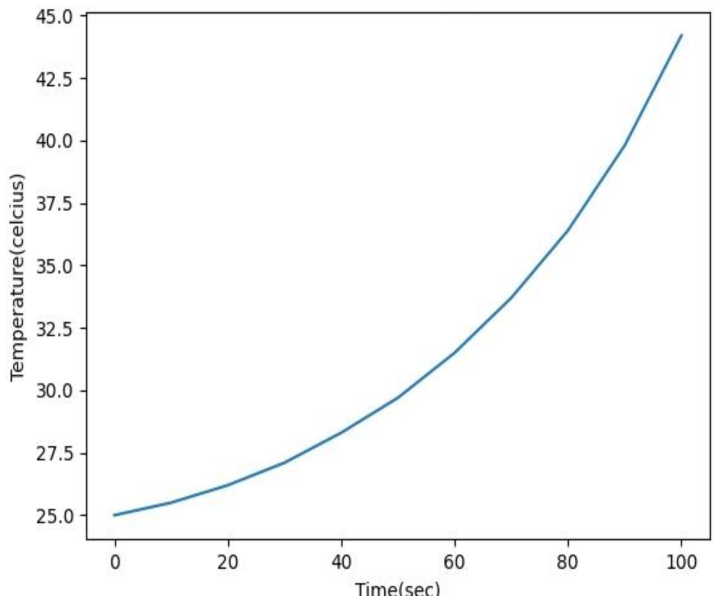

Figure 4: heating curve of automated heater (curve of $\frac{dT}{dt}$)

The exact quantity of energy Q, required over a period of time can be set for usage even before the automated system necessarily triggers. Given an area A, with change in temperature (ΔT) where $\Delta T = T - T_0$. Using a stop watch as timer, a reading for temperature was taken for within a minute.

Applying Stefan-Boltzmann law which describes the total energy radiated per unit surface area per unit time

$$\frac{dQ}{dt} = \varepsilon_r \sigma A(T^4 - T_\circ^4) \qquad (1)$$

Where Q= Radiated heat in watt

σ=Stefan-Boltzmann constant (5.67*10^-8W/m²K⁴)

ε_r=relativity emissivity to a black body

A=Area of surface of the heating element

T=Absolute temperature of Object's surface (in K)

T_A=Absolute temperature of the system (in K)

Quantity of heat supplied,

$$\text{IVt} = Q = \varepsilon_r \sigma A(T^4 - T_\circ^4) \qquad (2)$$

25% of a 20,000mah battery was used to power the heater and was converted from 5v to 12v.

$$Q = \frac{1}{4}\left(\frac{20{,}000 * 3.7}{1000}\right) = 18.5Whour$$

Q in one minute given that it's converted from 5v to 12v=18.5*60=0.308333Wh expended every minute

Temperature reading is shown in figure 4.

$$\varepsilon_r = \frac{Q}{\sigma A(\Delta T^4)} = \frac{0.308333 * (\frac{12}{5})}{(7m * 5m) * 5.6703 * 10^{-8} * (31.5^4 - 25^4)}$$

$\varepsilon_{r=0.699}$ (approximately 0.7 relative to a blackbody)

This represents the output efficiency of the type of power supply (battery) used.

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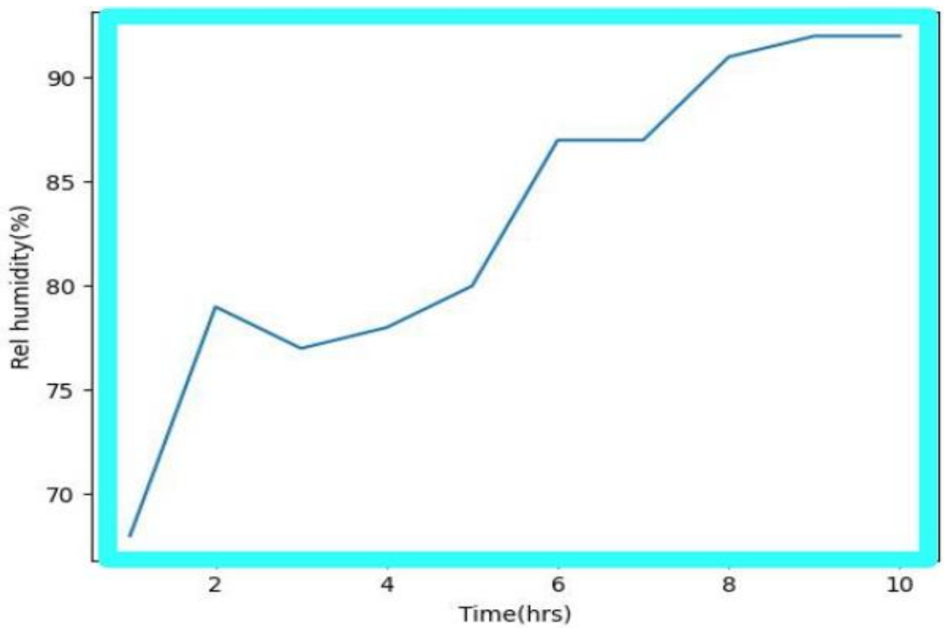

Figure 5: Analysis and modelling of Relative humidity with the system.

In the graph of humidity, the area under the curve seems unsuitable for our chosen test crop. A step taken in the modelling after analysis was to use a glazing sheet that retains least humidity. Further measure was taken to streamline the humidity within accepted range, this was done by use of automated exhaust fan to suck out and dehumidify the microclimate.
The output and modeled humidity is as shown in Figure 6 below.

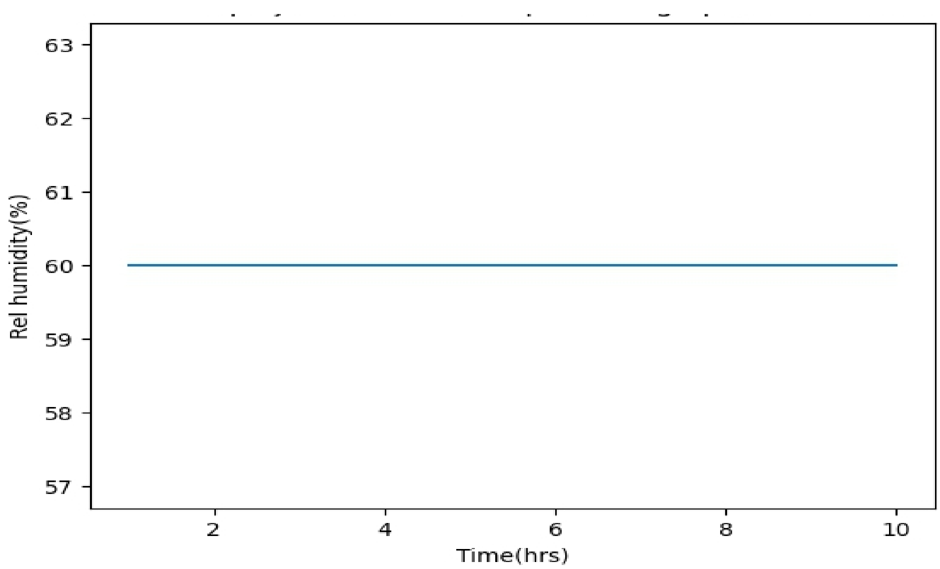

Figure 6: Modified humidity graph for the model greenhouse.

This graph is modeled using the flowering stage; hence the microcontroller compares observed data with the stored data on the database in the flowering stage of tomato (50-60%) relative humidity.

Analysis of temperature.

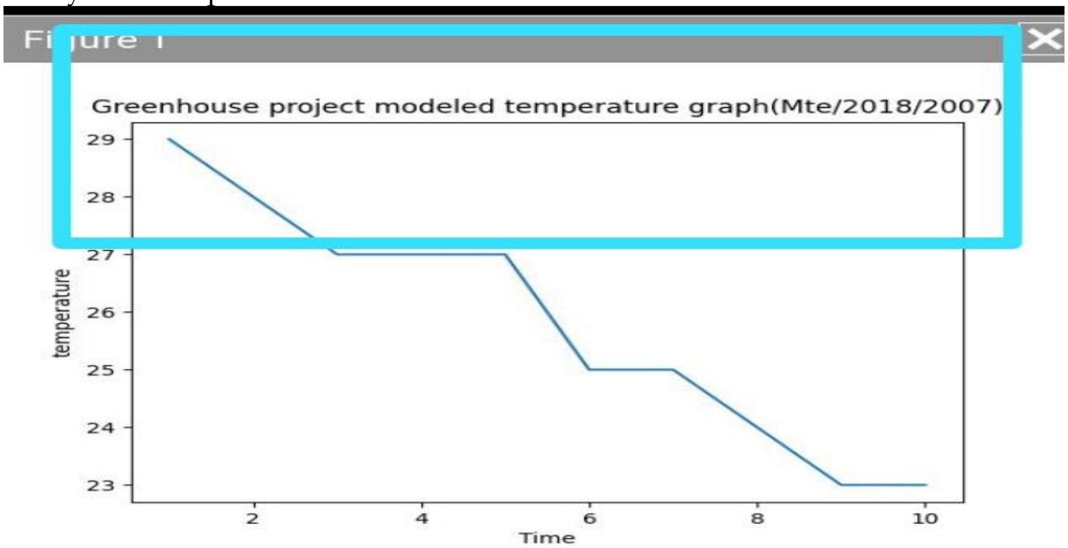

Figure 7: unmodified temperature with section unsuitable for the crop marked

In the analysis for optimum temperature required by the test-plant, by using the fruiting stage as the test phase (within 22-28 degree centigrade). This hourly data was taken on Sunday, 31st August 2023 at Ikole school of Engineering Ekiti. From analysis the percentage effectiveness of ambient temperature on this rainy day for the crop was 70%. The fan and heater were used as cooling element and heating element respectively and programmed to be automatically triggered once the temperature within the system is out of desired range.

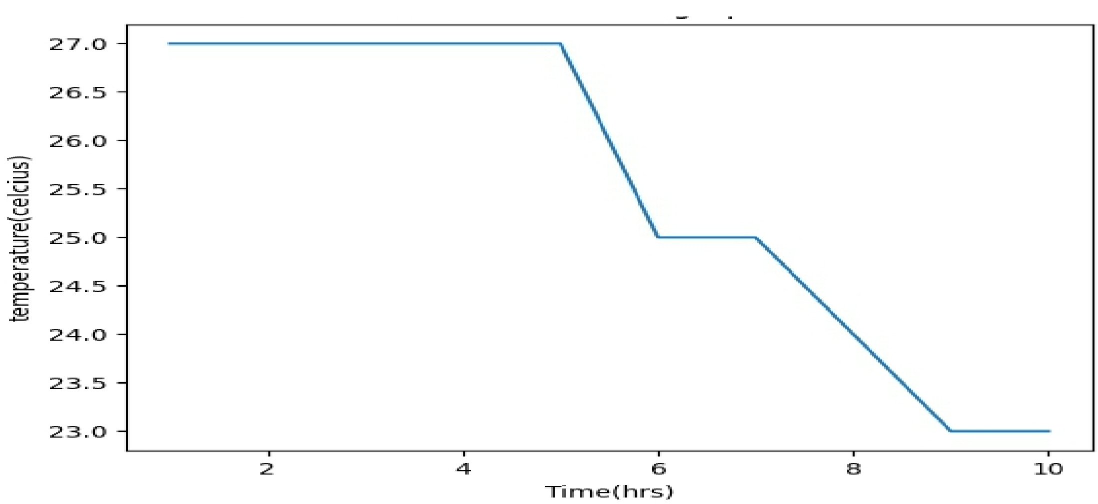

Figure 8: Modified temperature plot suitable for the crop

For the aforementioned temperature modified, the fan, 12V 0.13A was used to cool down the temperature to desired range, the cooling curve of the fan is as plotted below.

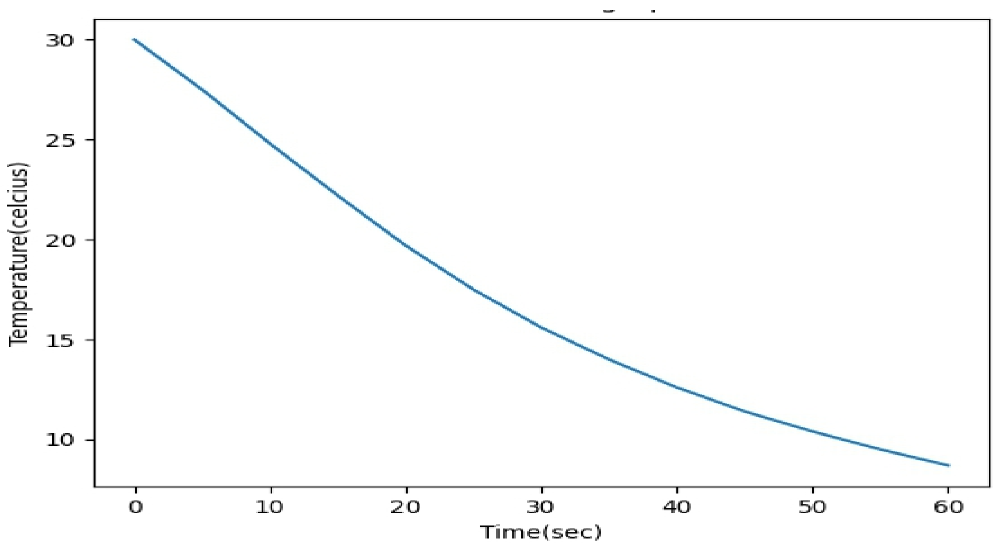

Figure 9: Cooling curve for the automated system

Table 3. Greenhouse Properties

Variables	Actual range (Original value taken from a comparable system)	Modified range (Taken from our system)	Optimum range (suitable range for our test crop)
Rel% Humidity	65,78,78,80,87.5,97	60,60,60,60,60,60	40-60
Temp.	29,27,27,25,24,23.2	27,27,27,25,24,23.2	23-27

CONCLUSION

In conclusion, the modelling and analysis of microclimates within a greenhouse is a critical frontier in agricultural research and sustainable food production. Our work provided an insight into the complex interplay of environmental factors within the artificially controlled temperature of the system, shedding light on the dynamics of temperature, humidity and airflow.
The implications of this research are far-reaching by understanding, and optimizing microclimates, we can significantly enhance crop yields improve resource efficiency and reduce negative environmental impact. This in turn addresses problems of insecurity and even climatic change.

Looking into the future, the integration of cutting-edge sensor technologies, data analytics and machine learning are promising technologies to further advance our understanding of microclimate. This innovation will empower researchers to fine-tune greenhouse conditions with precision for a new era of sustainable agriculture.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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