International Journal of Research and Review
Volume 11; Issue: 9; September 2024
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Internet of Things (IoT) Based Micro Climate Control Optimization System for Tropical Greenhouses in Responding to Climate Change

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DOI: https://doi.org/10.52403/ijrr.20240916

ABSTRACT

This research aims to develop an Internet of Things (IoT) based cooling system that is integrated with Blynk, using a fan cooling system to monitor and regulate temperature, humidity and light intensity in the room. This system was evaluated for eight days by comparing sensor data with conventional measuring instruments. The results show a low coefficient of determination (R^2), indicating high accuracy in data prediction. The study found that these IoT systems effectively provide real-time data, enabling rapid response to environmental changes with an overall average error rate of less than 5%. The main advantages of this system are its ability to perform continuous cooling and data integration that facilitates monitoring and allows timely intervention. However, these systems have limitations, including fluctuations in temperature and humidity measurements. Nevertheless, this system has proven effective in monitoring and managing environmental conditions. In conclusion, IoT-based monitoring with fan cooling systems offers a powerful solution for real-time environmental data collection and provides a foundation for future research that may include the integration of additional environmental variables as well as the use of machine learning algorithms for deeper data analysis and predictive capabilities . Recommendations for future research include improving sensor accuracy and exploring advanced data analysis to improve system performance.

Keywords: *IoT, fan cooling system, temperature, humidity, Blynk.*

INTRODUCTION

Indonesia, a tropical country in Southeast Asia rich in biodiversity and natural resources, is located on the equator, which provides consistent sunlight throughout the year. Indonesia's tropical climate is characterized by warm temperatures, high rainfall, and two main seasons: rainy and dry. Currently, global climate change has become a significant challenge for Indonesia, affecting various aspects of life, including agriculture. The latest data from the Meteorology, Climatology and Geophysics Agency (BMKG) shows that the average temperature in Indonesia in 2023 will reach 27.2 degrees Celsius, up 0.5 degrees from the average between 1991 and 2020. The previous hottest year was 2016 with a temperature anomaly of 0.6 degrees Celsius. 2023 will be the second hottest year with a temperature difference of 0.5 degrees Celsius (BMKG, 2023).

Global climate change has caused 2023 to be one of the hottest years on record, with new daily temperature records set for more than 200 days. According to a report from the World Meteorological Organization

(WMO), 2024 may be even hotter due to the predicted record sea surface heat. This report indicates that it is likely that temperatures in 2024 will exceed the 1.5°C increase threshold for the first time, as per the 2015 Paris agreement (WMO, 2023). This increase in global temperature has increased the frequency and intensity of extreme weather such as heat waves and heavy rain, which have a negative impact on ecosystems and organisms in Indonesia.

In tropical areas such as Indonesia, stable temperatures range between 25-30°C with small daily variations of around 10°C (IPCC, 2023). Adaptation to high temperatures makes tropical organisms more vulnerable to extreme temperature changes. Heat waves can increase human and animal health risks and disrupt the balance of ecosystems. One way to overcome this increase in temperature is to use a cooling system, such as a fan cooling system. This system can help reduce temperatures in certain environments, maintaining more comfortable and safe conditions for humans and animals, while reducing negative impacts on the ecosystem. Recent references from WMO reports and scientific research related to climate change show that adaptation and mitigation actions are very important to face the challenges posed by increasing global temperatures (WMO, 2023). The use of cooling technology such as fan cooling systems can be an effective solution in reducing the negative impacts of climate change, especially in tropical countries like Indonesia.

Climate change is expected to have a significant impact on Indonesia's climate, especially in tropical areas which are home to 40% of the global population (WMO, 2023). Already visible impacts include the increasing frequency of coral reef bleaching and the fragmentation of natural habitats due to the expansion of agriculture and infrastructure. Indonesia's climate has three rainfall patterns: monsoon, equatorial, and local (BMKG, 2023). Monsoon and equatorial patterns have different rainfall peaks, while local patterns are often opposite to the monsoon type of rainfall (Yim, Wang, Liu, & Wu, 2014).

Climate uncertainty in urban areas greatly affects various activities, including urban agriculture and crop observations by farmers and academics. One of the solutions adopted to overcome this challenge is precision agriculture, which aims to increase productivity and reduce costs and environmental impacts through the use of appropriate technology (FAO, 2023). Precision agriculture combines technologies such as sensors, information systems, and data-based management to optimize production by accounting for variability and uncertainty in agricultural systems. This approach allows adjusting agricultural practices according to specific crop needs, limits the use of chemical products, and increases resource efficiency.

In Indonesia, the implementation of precision agriculture faces challenges such as limited technological knowledge at the farmer level and the perception that this technology is expensive and difficult to reach. However, local knowledge and best practices in conventional farming can be used to adapt this technology, especially in open-field tropical farming. Precision agriculture is expected to produce the best harvest by using the right amount and time of input and preserving the environment.

A greenhouse is a technology designed to manipulate the environmental conditions of plants (R Shamshiri et al., 2018). Greenhouses protect plants from extreme weather, dust, pests and disease. The plants that are often cultivated in greenhouses are vegetables, which require special attention and care to get quality results. Greenhouses are used for the production of plants that cannot grow optimally in the open field due to poor climatic conditions.

The use of a cooling system with a fan (fan cooling system) is very important to support efficiency in the greenhouse. This system helps regulate the temperature in the greenhouse, creating a stable environment for plants to grow optimally. In the midst of increasingly extreme climate change, the use of fan cooling systems is becoming increasingly important to prevent plants from stress due to excessive heat. This technology not only improves the quality and quantity of crop production, but also supports environmental sustainability by reducing the need for resources such as water and energy.

In hot climates, greenhouses often face the problem of high solar heat loads, which can inhibit plant growth. According to Ahmed et al, the optimal temperature for plant growth in a greenhouse is usually between 12ºC and 30ºC (Ahmed, Ali, & Asif, 2020). To reduce the heat load, several techniques such as natural ventilation, fans, shade nets, and roof whitening can be used. However, natural ventilation is often not effective enough to eliminate thermal loads during periods of high radiation, making the use of fans a better solution for removing excess heat. Shade netting and roof whitening can also help, although they reduce light intensity which can negatively impact plant growth.

A fan cooling system is the most effective technique for reducing the heat load in a greenhouse, especially during periods with high solar radiation. This system works by spreading and evaporating water to absorb heat from the environment, thereby lowering the temperature in the greenhouse. With this technology, temperature can be controlled effectively, which is very important for maintaining optimal conditions for plant growth.

The development of an Internet of Things (IoT) based microclimate control system for tropical greenhouses can provide an efficient solution to the challenges of climate change in the agricultural sector and increase food security in tropical regions (Maraveas & Bartzanas, 2021). IoT technology allows farmers to monitor and control environmental conditions in real-time, optimize the microclimate in the greenhouse, and increase the efficiency of water and energy use. Studies show that using IoT in greenhouses increases resource efficiency. According to the report by Mishra & Singh (2017), IoT enables automatic monitoring and control, reducing resource usage. Parida, Saini, & Jakka (2019) also stated that IoT can increase plant productivity by maintaining optimal growth conditions [10].

Microclimate control is critical for tropical greenhouses that face unique challenges. Research by Ahmed et al. (2020) found that IoT can reduce the negative impact of climate change on tropical plants and reduce risks due to weather fluctuations. The development of IoT technology for microclimate control focuses on increasing efficiency, productivity and environmental sustainability. Kaur and Kaur (2019) emphasized the importance of IoT in promoting environmentally friendly agricultural practices, while Ray et al. (2019) show that smart technology can be a solution to the challenges of climate change in food production.

In addition, adjustments are needed to equipment standards based on the application of the Indonesian National Standard (SNI) for greenhouses, which include the use of high quality raw materials, sturdy structures, effective ventilation, optimal irrigation and regular monitoring.

Greenhouse technology allows temperature and humidity control to create an optimal growing environment, although dynamic tropical weather can challenge the effectiveness of the internal microclimate. Regulations in Indonesia, such as Minister of Agriculture Regulation no. 34 and 35 of 2013 and Law no. 18 of 2012, supports the use of sustainable and environmentally friendly greenhouses.

Greenhouses in tropical areas face challenges such as high temperatures which can cause thermal stress in plants. To overcome this problem, innovative solutions such as IoT-based cooling systems have been developed. This system regulates temperature effectively using fan cooling system technology. According to research by Smith et al. (2021), an IoT-based fan cooling system is able to increase energy efficiency and plant productivity by monitoring and adjusting temperature and humidity in real-time, which can also be controlled remotely.

Studies show that IoT in greenhouses can significantly improve resource efficiency. According to the report by Zhang et al. (2022), the use of IoT in greenhouse management enables automatic monitoring and control, reduces resource use, and increases plant productivity by maintaining optimal growth conditions.

By developing IoT technology for microclimate control, it is hoped that it can reduce the negative impact of climate change on tropical plants and reduce the risks due to weather fluctuations. Research by Lee et al. (2023) emphasizes the importance of IoT in promoting environmentally friendly agricultural practices, while research by Martinez et al. (2024) shows that smart technology can be a solution to the challenges of climate change in food production.

MATERIALS & METHODS

This research applies observational methodology and quantitative analysis to evaluate the effectiveness of tools in supporting precision agriculture and greenhouse management in urban areas. Observations were carried out to identify needs and challenges in implementing agricultural technology and environmental management in greenhouses, followed by research planning that considered equipment performance and variables such as temperature, humidity and plant productivity. To make it easier to carry out research, a planning flow was created as shown in the image below.

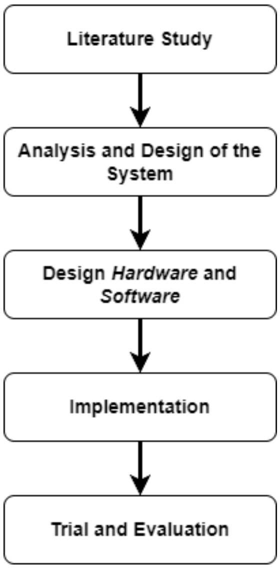

Figure 1. Research Planning Flowchart

This research implements a tool and material planning methodology by selecting equipment and materials that are relevant for this study. The tool design process involves adjusting technical specifications to ensure optimal performance under various environmental conditions. Initial steps include literature study for an in-depth understanding of the research topic and identification of relevant problems. Followed by an analysis of technical specifications which includes the selection of materials and components for the integrated system.

Hardware design includes schematic creation, device design, and integration of components such as the DHT22 temperature sensor, soil moisture sensor, BH17750 light sensor, and push button. The ESP32 microcontroller is used as a data processing center, with relays to control components such as DC evaporative cooling, DC exhaust fan, water pump, planting lights, and 20x4 LCD screen. The system also connects to web and Blynk applications for remote monitoring, with a power supply system that supports various component power needs.

Validation is carried out through comprehensive testing to verify system performance and accuracy. The resulting data is analyzed using graphic and numerical visualization models, and stored in the cloud for data accessibility and security.

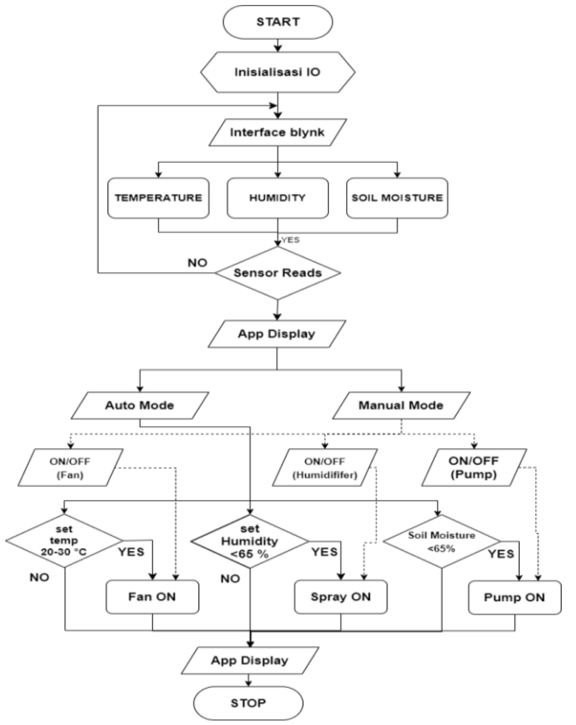

Figure 2. Hardware System Block Diagram

This flowchart helps visualize processes in the system, from collecting sensor data to displaying and controlling actuators. With a clear understanding of this workflow, software development can be carried out in a structured and efficient manner, ensuring all components work in synergy to achieve research goals. Data collected from field observations and equipment testing in the greenhouse were then analyzed quantitatively. Quantitative analysis is used to evaluate the effectiveness of tools in increasing agricultural productivity and sustainability of greenhouse use by comparing prototype data with references from measuring tools such as the HTC-2 thermometer, TA290 hygrometer, and lux meter (Johnson et al., 2023).

This quantitative analysis uses additional metrics such as Coefficient of determination (R^2) measures how close the actual data is to the predicted values. For a more thorough evaluation, the model was analyzed using R^2 (Arulmozhi, 2019). So it can be concluded in the following equation,

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - p_i)^2}{\sum_{i=1}^{n}(y_i - \frac{1}{n}\sum_{i=1}^{n} y_i)^2} \quad \text{(Eq.1)}$$

RESULT

This research aims to develop an IoT-based monitoring system that is effective in monitoring environmental conditions such as temperature, air humidity, soil moisture and light intensity. The initial stage of research involves literature study for identification of relevant issues, followed by analysis of technical specifications for selection of appropriate components. Hardware and software design was carried out to create a system capable of collecting data from various sensors, displaying information via an LCD screen, and storing data in the cloud. Performance validation is carried out with comprehensive testing to ensure the accuracy of the data obtained, in accordance with the latest reference standards.

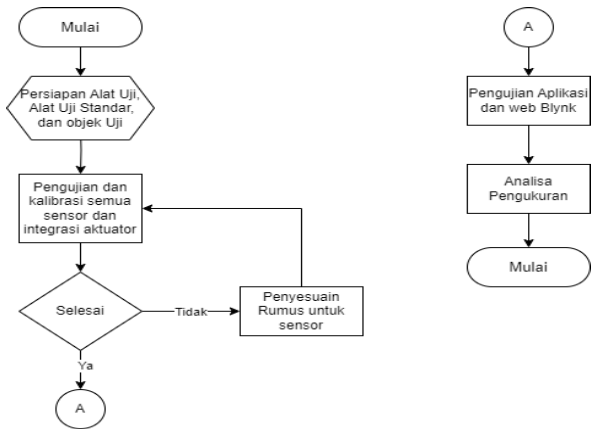

Figure 3. Measurement and Testing Flowchart

The flowchart shown below illustrates the operational process of the tool in continuously collecting measurement data for eight days using the Blynk dashboard as the main interface for monitoring. Data on temperature, air humidity, soil moisture and light intensity are collected daily and analyzed via the Blynk platform.

The flowchart that has been prepared for measurement and testing becomes the main guide in the data collection process, ensuring that each step is carried out systematically and accurately. Daily data such as temperature, air humidity, soil moisture, and light intensity are monitored and analyzed via the Blynk dashboard, which provides graphic visualization to make it easier to identify patterns and changes in environmental conditions during the test period. The use of Blynk dashboards not only increases monitoring efficiency but also provides in-depth insight into environmental conditions, which is very important for making informed decisions based on accurate data.

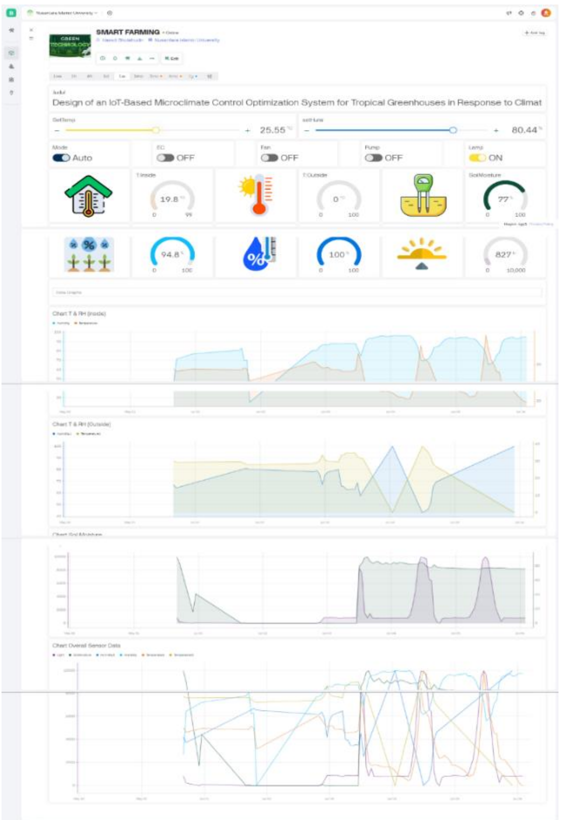

Figure 4. Web Dashboard Display on Mobile Devices

The Blynk dashboard display used as the main interface to increase efficiency in the monitoring process is as follows. Blynk provides an integration platform that facilitates connections between hardware and software through structured data streams, enabling real-time monitoring via web views. This dashboard design is designed to provide intuitive data visualization, using graphs and numerical indicators to display current environmental conditions. Virtual buttons on the dashboard allow users to control the system directly, offering operational flexibility.

The data collected shows that indoor temperatures experience stable daily fluctuations, while outdoor temperatures tend to be lower. Indoor air humidity shows a similar pattern to temperature, whereas outdoor air humidity shows greater variations. Soil moisture was stable throughout the test, providing a consistent indication of soil moisture conditions at the site. Light intensity shows significant variations between day and night, consistent with natural daily patterns.

The data obtained is compared with reference tools such as the Thermo Hygrometer for air temperature and humidity, Hygrometer for soil moisture, and lux meter for light intensity, to ensure the accuracy of the measurement results. The information presented in the form of tables and graphs provides a comprehensive picture of the environmental conditions monitored during the test period as follows.

Table 1. Comparison of indoor temperatures

Day	Temperature (Inside)	Thermo Hygrometer	Error %
1	24,28	23,66	2,62%
2	24,60	23,70	3,80%
3	24,27	23,87	1,68%
4	25,26	24,07	4,94%
5	25,64	24,43	4,95%
6	26,83	25,54	5,05%
7	26,73	25,99	2,85%
8	26,34	25,97	1,42%

Table 2. Comparison of outdoor temperatures

Day	Temperature (Outside)	Thermo Hygrometer	Error %
1	29,70	27,93	6,34%
2	31,30	29,51	6,07%
3	30,25	29,47	2,65%
4	32,68	30,97	5,52%
5	32,93	31,21	5,51%
6	31,67	29,98	5,64%
7	28,28	28,38	3,17%
8	29,61	28,23	4,89%

Table 3. Comparison of Indoor Humidity

Day	Humidity (Inside)	Thermo Hygrometer	Error %
1	81,80	78,98	3,57%
2	80,86	79,12	2,20%
3	78,42	76,87	2,02%
4	78,84	76,50	3,06%
5	82,98	80,88	2,60%
6	79,86	77,70	2,78%
7	73,52	71,48	2,85%
8	71,12	69,63	2,14%

Table 4. Comparison of Outdoor Humidity

Day	Humidity (Outside)	Thermo Hygrometer	Error %
1	65,74	63,26	3,92%
2	55,40	52,80	4,92%
3	74,00	71,50	3,50%
4	56,53	54,44	3,84%
5	63,33	60,88	4,02%
6	72,45	70,41	2,90%
7	80,54	78,21	2,98%
8	65,29	62,76	4,03%

Table 5. Comparison of Soil Moisture

Day	Soil Moisture	Hygrometer	Error %
1	72,92	71,26	2,33%
2	72,74	71,10	2,31%
3	76,17	75,05	1,49%
4	78,77	77,60	1,51%

5	71,71	69,89	2,60%
6	72,44	71,20	1,74%
7	75,94	74,21	2,33%
8	70,70	68,76	2,82%

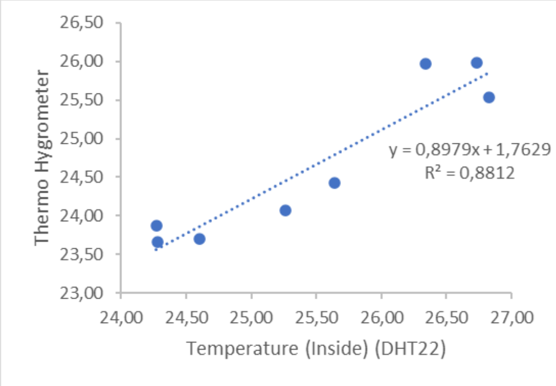

Figure 5. Indoor Temperature Comparison Chart

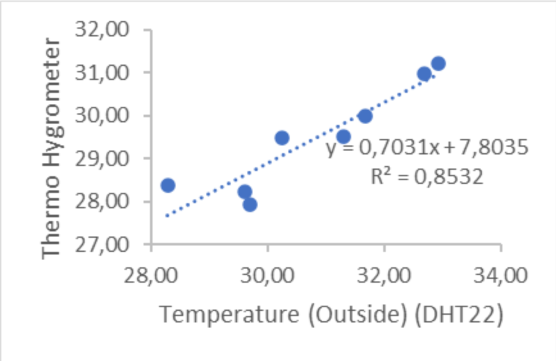

Figure 6. Outdoor Temperature Comparison Chart

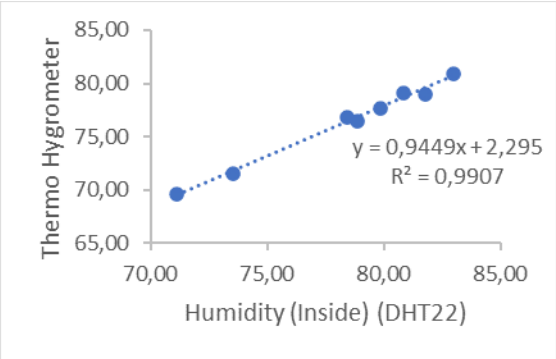

Figure 7. Indoor Humidity Comparison Chart

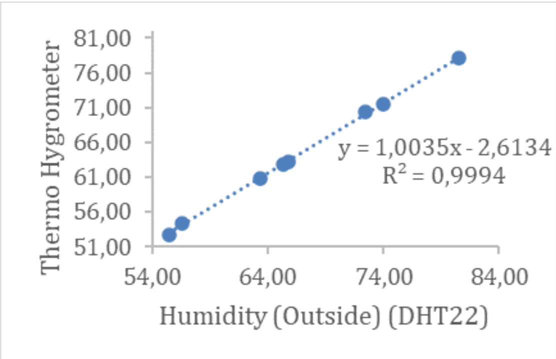

Figure 8. Outdoor Humidity Comparison Chart

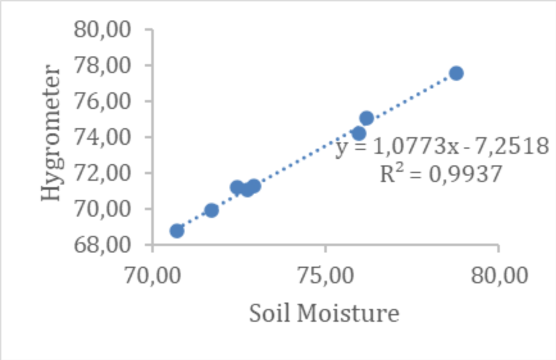

Figure 9. Soil Moisture Comparison Chart

Based on an analysis of the performance of sensors and reference tools for various environmental parameters over an eight-day period, it can be concluded that the sensor system used shows an adequate level of accuracy for environmental monitoring purposes. For indoor temperature, the sensor has a coefficient of determination (R^2) of 0.8812, indicating a strong correlation with the Thermo Hygrometer. Even though there are some fluctuations, the indoor air humidity data has a very high R^2 of 0.9907, indicating the sensor's reliability in measuring this parameter. Meanwhile, outdoor air humidity measurements show an R^2 of 0.9994, indicating very high accuracy in monitoring external conditions. For soil moisture, R^2 reached 0.9937, indicating good consistency in providing accurate data. Overall, the data produced by this sensor system is accurate enough for environmental monitoring with minimal and consistent deviation. However, it should be noted that further adjustment and calibration can improve sensor accuracy, especially for applications that require high precision. This will support more informed decision making in environmental management and precision agriculture.

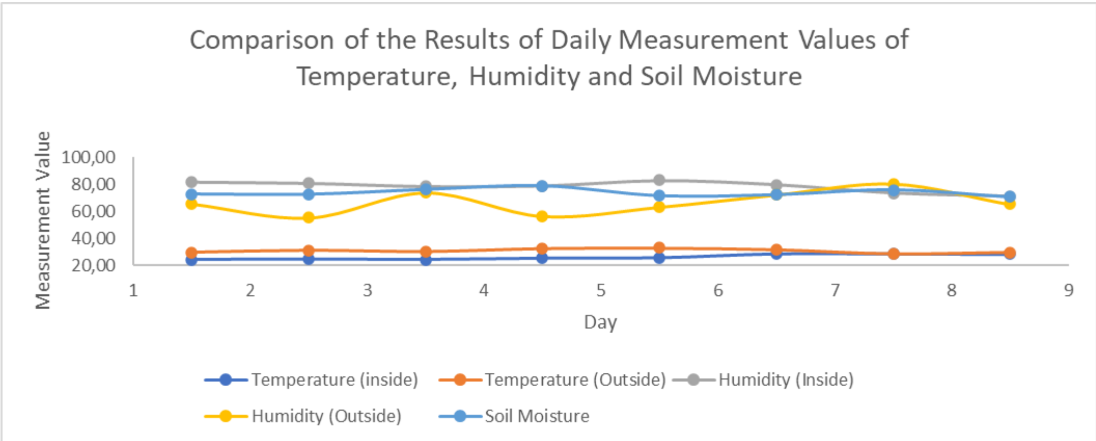

Figure 10. Comparison graph of daily measurement values for temperature, humidity and soil water content

Based on the comparison graph of daily measurement results for indoor and outdoor temperatures, indoor and outdoor humidity, and soil moisture for eight days, it can be seen that indoor temperatures tend to be more stable and controlled compared to outdoor temperatures which are more variable. This shows the effectiveness of indoor environmental control in maintaining temperature stability. Indoor humidity also showed higher values compared to outdoor humidity, indicating that the room may have an internal moisture source that favors more humid conditions. However, soil moisture shows significant fluctuations from day to day, which may be influenced by environmental factors such as rainfall or watering patterns.

Overall, the data show good consistency with acceptable variability, indicating that the sensor system performs well in measuring environmental parameters. The apparent differences between indoor and outdoor conditions reflect the efficiency of indoor environmental control. However, fluctuations in soil moisture indicate the need for more careful management to maintain optimal soil conditions. These results underline that the monitoring system used is reliable in providing accurate data for effective environmental monitoring.

CONCLUSION

The use of an IoT-based monitoring system integrated with temperature, humidity and light intensity sensors via the Blynk platform has proven effective in monitoring environmental conditions in real-time. The data collected shows that this system is capable of providing accurate measurements with a low error rate, as reflected by the coefficient of determination (R^2), which remains within acceptable limits for each variable measured. The main advantage of this technology is its ability to provide continuous data and be integrated with an easily accessible application, allowing users to carry out direct supervision and intervention if necessary. The system also enables early detection of significant environmental changes, which is an added value in fast and accurate decision making.

However, there are several drawbacks that need to be considered, such as significant fluctuations in soil moisture which may be caused by external variables that are not fully controlled. This indicates the need for improvements in soil moisture control or management systems to ensure optimal moisture levels. Additionally, there were small but consistent differences between indoor and outdoor temperature and humidity measurements, indicating that while the system works well, there is still room for improvement in terms of measurement stability in more diverse environments.

This research provides a strong basis for further development in the use of IoT technology for environmental monitoring. In the future, improvements could focus on integrating more environmental variables and increasing sensor accuracy to obtain a more comprehensive picture of environmental conditions. Future research could also explore the use of machine learning algorithms for deeper and more predictive data analysis, which could increase the efficiency and effectiveness of these monitoring systems in a variety of applications.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Ganis Sanhaji, Hamdi Sholahudin, Imam Arief Rahman, Muhammad Jari Nurman S, Sandi Fadilah, Sarah Putri Purnama. Internet of things (IoT) based micro climate control optimization system for tropical greenhouses in responding to climate change. *International Journal of Research and Review*. 2024; 11(9): 141-151.
DOI: *https://doi.org/10.52403/ijrr.20240916*

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