Inside Greenhouse Climatic Prediction at North Coastal West Java

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Abstract. This study aims to develop an accurate and reliable model of greenhouse climate conditions. This research focuses on analyzing the complex interactions between temperature, humidity, light intensity, and airflow patterns in a greenhouse environment. Historical data analysis is used to create the model. This methodology involves collecting data from various websites that provide information on parameters such as air temperature, airspeed, and sunlight intensity. Data collection is used to predict temperature and humidity parameters in the greenhouse. Model validation is done by comparing its predictions with real-time sensor data collected. The results show a high degree of accuracy, with the model successfully predicting the temperature and humidity in the greenhouse. These predictions allow farmers to make informed decisions regarding climate control systems, optimize growing conditions, and maximize crop yields. Overall, this research provides a comprehensive framework for greenhouse climate prediction, offering valuable insights into the development of efficient and sustainable growing practices. The results obtained from the model simulation reveal that the temperature inside the greenhouse consistently surpasses the air temperature outside, indicating a more controlled and warmer environment. On the other hand, the simulation also shows that the relative humidity within the greenhouse is notably lower compared to the relative humidity in the external atmosphere. This difference highlights the greenhouse's ability to create a more tailored microclimate that can be adjusted according to the specific needs of the plants being cultivated, thereby optimizing growing conditions.

Keywords: Greenhouse Climate Prediction, Historical Data Analysis, Model Validation, Sustainable Agriculture, Temperature and Humidity Modeling

1 Introduction

A greenhouse is a controlled environment structure designed to protect plants from fluctuating weather conditions, enabling the cultivation of species that may not thrive in local climates. These include ornamental plants, high-value vegetables, and fruits, which are challenging to grow in outdoor conditions. Greenhouses offer numerous advantages, such as precise control over air temperature, humidity regulation, and irrigation schedules, making them ideal for improving agricultural yields.

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Recent advancements in greenhouse modeling and simulation have enabled the prediction of climate responses to various environmental factors, including temperature, humidity, solar radiation, and ventilation dynamics. By transitioning static equations into dynamic models, it is now possible to develop simulations that more accurately reflect the real-time behavior of these variables (Sharma et al., 1999). This shift has facilitated the development of more sophisticated models, which account for heat loss, heat input, ventilation efficiency, condensation, infiltration, and humidity control (Ito & Tabei, 2021; Yau et al., 2020). While effective, the implementation of such models often remains limited to large-scale operations due to high costs, making them less accessible to small-scale farmers.

Despite the significant progress in intelligent control systems for greenhouse environments (Riahi et al., 2020), there remains a gap in practical applications for smaller operations. Studies have explored switching controllers for dynamic models in MATLAB/Simulink (Yau et al., 2020) and have highlighted the interactions between internal variables and the strong influence of external climate conditions (Perdigones et al., 2008; Worley, 2009). Research by Druma (1998) shows that variations in shading and ventilation critically affect internal greenhouse temperatures (Druma, 1998), and other studies have demonstrated the efficiency of multivariable climate control systems in decoupling input and output variables, reducing stabilization time (Salazar-Moreno et al., 2018).

Innovative control techniques, such as fogging control with pulse width modulation, have shown promise in reducing water consumption by up to 15% compared to fixed cycles (Amarin, 2006; Howard et al., 2021). Adaptive neuro-fuzzy inference systems have also been applied to adjust greenhouse temperatures with high accuracy (Bi & Ma, 2011; Paraforos & Griepentrog, 2013), and for more complex systems, Takagi-Sugeno fuzzy models have demonstrated robust performance in simulation environments (Affandi et al., 2013; Amarin, 2006; Stanghellini & De Jong, 1995). However, these approaches, while highly effective, have not been widely implemented in smaller-scale greenhouses due to their complexity and cost.

The current research aims to address this gap by introducing a cost-effective, scalable greenhouse climate control system, leveraging recent advancements in IoT technologies. By integrating real-time monitoring and adaptive control techniques, this study seeks to provide a more accessible solution for small and medium-sized agricultural operations, offering practical innovations in precision agriculture. This research and technology accessibility for small-scale farmers presents the current study as a solution. It also emphasizes the advancements in IoT and control techniques to create a more cost-effective and practical solution for precision agriculture.

2 Methodology

The northern waters of Java are characterized by a range of complex natural phenomena, which are significantly shaped by the monsoon wind system. This system exerts a profound influence on various water characteristics, including wind patterns, ocean currents, and the distribution of temperatures across the region. The fluctuations in sea surface temperature are directly linked to the movement of surface currents, which are driven by the winds sweeping over the sea's surface. Being part of the larger Java Sea, the hydro-oceanographic conditions in the waters of the North Coast of Java are intricately connected to the broader hydro-oceanographic dynamics and atmospheric interactions that occur within the Java Sea. These interactions play a crucial role in determining the overall environmental and climatic patterns in this region (Xu & Chen, 2017). Simulation of climatic conditions on the north coast of Javas in the inside greenhouse, it is necessary to take the following steps:

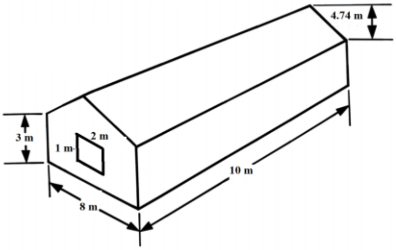

Figure 1. Greenhouse schematic

2.1 Climatic Conditions on The North Coast Of Java

The variables that affect the climatic conditions in the greenhouse are air temperature, humidity, air velocity, and solar radiation. Air temperature, relative humidity, direct normal irradiation, and wind speed on the North Coast of Java are shown in Figures 2-5.

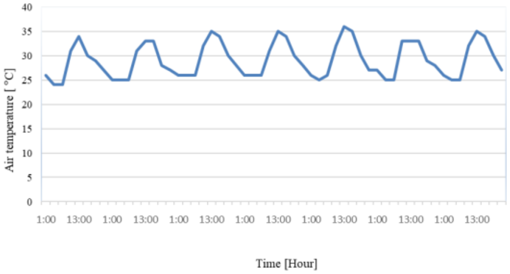

Figure 2. Air temperature on The North Coast of Java

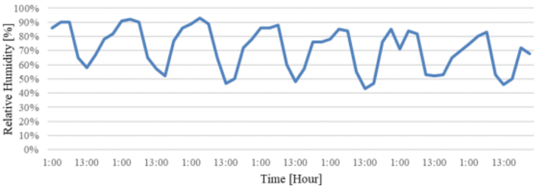

Figure 3. Relative humidity on The North Coast of Java

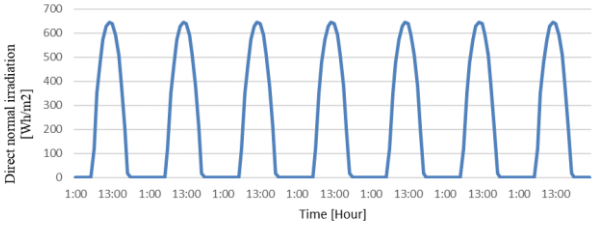

Figure 4. Direct normal irradiation [Wh/m^2]

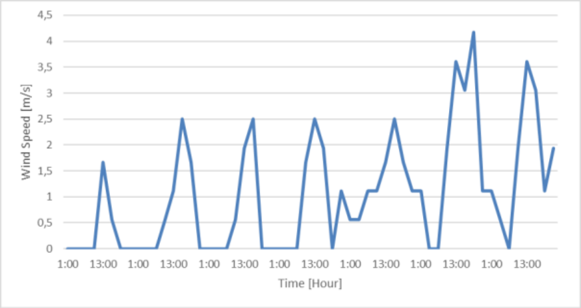

Figure 5. Wind speed [m/s]

2.2 Greenhouse Dynamic Modelling

The dynamic behavior of the climate within a greenhouse can be explained through an equation that combines the principles of energy transfer with those of mass balance equations (Bennis et al., 2008). To thoroughly evaluate the various energy fluxes that play a role in the greenhouse environment, a specialized energy balance model was developed, which is rooted in the fundamental laws of energy conservation. This model is designed to provide a detailed analysis of the energy fluxes that are critical to understanding and predicting the internal climate conditions of the greenhouse. The energy fluxes under consideration, which are essential for maintaining the desired climate within the greenhouse, are detailed as Equation (1) (Su & Xu, 2015).

$$Q_{total} = Q_{gain} - Q_{loss} \tag{1}$$

In this context, Q_{total} represents the overall energy balance (W); Q_{gain} refers to the energy entering the greenhouse (W) and Q_{loss} denotes the energy exiting the greenhouse (W).

Energy Loss Through The Greenhouse. The total amount of energy leaving the greenhouse can be attributed to multiple mechanisms. This includes infiltration through the greenhouse cover, where energy is lost due to the exchange of air with the external environment. Additionally, heat is lost to the ground beneath the greenhouse, and energy is transferred through ventilation processes. Other significant contributors to energy loss include heat transfer through radiation, conduction, and condensation, all of which play a role in reducing the internal energy balance of the greenhouse, as shown in Equation (2) (Bennis et al., 2008; Bibi-Triki et al., 2011; Florides & Kalogirou, 2012; Gupta et al., 2019; Su & Xu, 2015).

$$Q_{loss} = Q_k + Q_s + Q_r + Q_v + Q_{inf} \tag{2}$$

In this equation, Q_k represents the heat loss attributable to conduction (W); Q_s denotes the heat loss to the soil (W); Q_v indicates the heat transfer resulting from ventilation (W); Q_{inf} refers to the heat transfer caused by infiltration (W); Q_r signifies the heat transfer due to long-wave radiation, and Q_{cond} represents the heat loss resulting from condensation (W).

Heat Loss by Conduction. Heat loss by conduction can be formulated with the following Equations (3) and (4) (Su & Xu, 2015):

$$Q_k = A_c h(T_i - T_o) \tag{3}$$

$$h = 2.8 + 1.2w_s \tag{4}$$

In this context T_o denotes the external temperature (K), T_i represents the internal air temperature (K), h is the coefficient for conductive heat transfer (W/m^2), A_c indicates the area of the greenhouse cover (m^2), and W_s refers to the wind speed (m/s).

Heat Loss by Heat Loss to The Soil. Heat losses from the greenhouse environment to the soil can be measured by Su & Xu (2015) as stated in Equation (5).

$$Q_s = 1.86\, U_s\, A_s(T_s - T_{ic})^{4/3} \tag{5}$$

Here Q_s represents the heat loss to the soil (W); U_s is the coefficient for heat transfer through the soil (W/m^2 °C); As denotes the surface area of the soil (m^2); is the internal temperature of the greenhouse (°C) and T_s is the temperature of the soil (°C).

The temperature of the soil is determined by integrating the soil temperature over time from a specified initial condition; this can be computed using the following method (Bennis et al., 2008) as stated in Equations (6) and (7).

:

$$T_s = \int dT_s \tag{6}$$

$$dT_s = \frac{Q_s}{A_s\, D_s\, C_{ps}} \tag{7}$$

In this context, D_s represents the depth of the soil (m); and C_{ps} denotes the specific heat capacity of the soil (3000 J/kg K).

Heat Loss by Radiation. The transfer of thermal long-wave radiation from the inside of the greenhouse to the outside environment, which is governed by the nonlinear Stefan–Boltzmann equation, can be articulated through the following expression. This process reflects the complex relationship between the greenhouse's internal temperature and the external surroundings, illustrating how energy is radiated away from the greenhouse's interior in the form of long-wave radiation following Equation (8) (Choab et al., 2019; Mesmoudi et al., 2010).

$$Q_r = A_c\, \sigma\, \varepsilon\, (T_i{}^4 - T_o{}^4) \tag{8}$$

In this context Q_r represents the radiation loss, ε denotes the combined emissivity of the cover and the sky, σ is the Stefan–Boltzmann constant.

Heat Loss by Ventilation. The heat lost through ventilation is directly related to the rate at which air is exchanged and the temperature difference between the inside and outside of the greenhouse. This loss can be quantified by Choab et al. (2019) and Mesmoudi et al. (2010) following Equations (9) and (10).

$$Q_v = G\, \rho\, C_p(T_i - T_o) \tag{9}$$

$$G = W r_v K_v A_v \tag{10}$$

In this context, ρ represents the air density (kg/m^3), C_p is the specific heat capacity of air (J/kg K), G indicates the air flow resulting from ventilation (m^3/s), W denotes the wind speed (m/s). Additionally, r_v is the percentage of the ventilator opening, K_v is the slope of the curve representing the relationship between ventilation flux and wind speed variation, and A_v is the area of the ventilator (m^2).

Heat Loss by Infiltration. The rate of infiltration is determined by the amount of water vapor that shifts across each unit area of the cover, including the roof and walls. This phenomenon arises from the existence of cracks, which leads to energy loss through the exchange of air following Equation (11) (Bennis et al., 2008).

$$Q_{inf} = 0.5\, V\, N(T_i - T_o) \tag{11}$$

In this context, Q_{inf} represents the heat loss due to infiltration (W); T_i denotes the internal temperature of the greenhouse (K); T_o indicates the external temperature (K); V refers to the volume of the greenhouse (m^3), and N is the number of air changes per hour (h^{-1}).

Energy Gain Through the Greenhouse. The increase in heat within the greenhouse is primarily sourced from the solar radiation that penetrates through its cover. To quantify this internal heat gain, a specific equation is used, which calculates the amount of heat added based on the intensity of solar radiation and its interaction with the greenhouse structure. This is detailed in Equation (12) (Bennis et al., 2008).

$$Q_{sl} = A_g \gamma \tau I \tag{12}$$

In this context, *Qsl* represents the energy from solar radiation entering the greenhouse (W), I is the solar energy incident on a horizontal surface of the greenhouse (W/m^2), A_g refers to the area of the greenhouse floor (m^2), τ is the light transmission coefficient of the greenhouse cover for solar radiation, and γ is a constant that determines the proportion of solar radiation entering the greenhouse, which helps in raising the internal temperature. A typical value of γ in the range of 0.3 to 0.7 has been selected as 0.3 (Bennis et al., 2008).

2.3 Modeling of internal air temperature and relative humidity within the greenhouse

Here the water vapour balance within the greenhouse. The model is a dynamic one, the values of variables describing the system behavior change with time as stated in Equation (13) (Bennis et al., 2008; Su & Xu, 2015).

$$\rho V \, {}^{\partial H_{in}}\!/_{\partial t} = G_v \, X \, \rho \, (H_{out} - H_{in}) \tag{13}$$

3 Result and Discussion

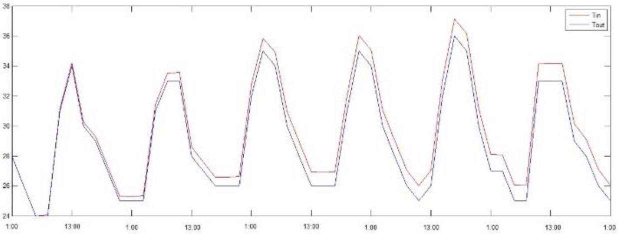

Figure 6. Simulated temperature value in the greenhouse

The temperature simulation was conducted using MATLAB/SIMULINK, incorporating Equations (1-13) into the SIMULINK blocks. As shown in Figure 6, the simulation covers 7 days. During this time, the air temperature inside the greenhouse exhibits a clear diurnal pattern, with the highest temperatures observed around midday (noon). Notably, the temperature inside the greenhouse consistently exceeds the outside air temperature. This is likely due to the greenhouse structure, which traps solar radiation, leading to a warming effect that enhances plant growth. The ability to maintain higher internal temperatures, especially during cooler external conditions, is a key advantage of greenhouse environments, as it creates a more stable and controlled climate for plant cultivation. However, it is essential to monitor this temperature closely, as excessive heat could negatively impact plant health, making temperature control systems critical for maintaining optimal growing conditions.

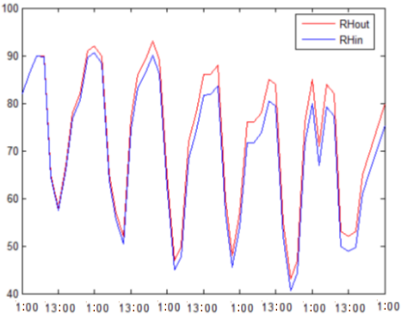

Figure 7. Simulated RH value in the greenhouse

Similarly, the relative humidity (RH) simulation was performed using MATLAB/SIMULINK, with the same equations (1-13) applied in the SIMULINK model. Figure 7 illustrates the RH values over a 7-day simulation period. The results indicate that the relative humidity inside the greenhouse is consistently lower than in the outside environment. This reduction in humidity within the greenhouse is likely due to increased temperature and controlled ventilation, which reduces moisture retention in the air. Lower internal humidity levels are beneficial in preventing fungal growth and other moisture-related plant diseases, but it is crucial to maintain a balance, as overly dry conditions can stress plants and affect their transpiration rates. Thus, effective humidity management, in conjunction with temperature control, is essential for creating an optimal growth environment. The findings underscore the importance of an integrated climate control system that can dynamically adjust both temperature and humidity to sustain ideal conditions for plant development.

The results from both the temperature and relative humidity simulations highlight the dynamic interaction between these two critical environmental factors within the greenhouse. As temperature increases, the relative humidity tends to decrease, illustrating an inverse relationship that is common in controlled environments. This dynamic poses a challenge in maintaining optimal conditions for plant growth, as both factors must be carefully balanced. For instance, elevated temperatures can promote faster plant growth but may lead to excessive water loss through transpiration, especially when coupled with low humidity levels. On the other hand, high humidity levels, while beneficial for reducing water stress in plants, can create conditions favorable for disease and mold development. Therefore, the integration of a precise control system that can simultaneously regulate temperature and humidity, potentially through the use of advanced sensors and real-time feedback mechanisms, is crucial for optimizing plant health and yield. The findings suggest that future work should explore more refined control strategies, such as adaptive control systems or machine learning algorithms, to dynamically adjust both parameters based on real-time conditions and plant needs, ensuring the sustainability and efficiency of greenhouse operations.

4 Conclusion

In conclusion, the study underscores the critical role of greenhouses in modern agriculture, particularly in environments where external climatic conditions are not conducive to cultivating high-value crops like ornamental plants, vegetables, and fruits. By providing a controlled environment, greenhouses allow for the precise regulation of factors such as temperature, humidity, and light exposure, which are essential for optimizing plant growth and yield. The dynamic modeling and simulation conducted using MATLAB/SIMULINK have proven effective in predicting and managing these environmental variables. The results from the simulations highlight that greenhouse conditions can be maintained at optimal levels, even when external weather patterns fluctuate, thus ensuring consistent crop production.

However, the study also reveals some of the challenges associated with greenhouse climate control systems, particularly regarding their practicality and cost-effectiveness for small-scale farmers. While model-based control techniques, including intelligent control systems and adaptive strategies, offer substantial benefits in efficiency and yield improvement, they require significant investment and technical knowledge, which may be beyond the reach of smaller operations. Nonetheless, ongoing research and advancements in greenhouse technologies are paving the way for more accessible and cost-effective solutions, suggesting a future where these systems could become more widely adopted, thereby enhancing agricultural sustainability and food security on a broader scale.

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