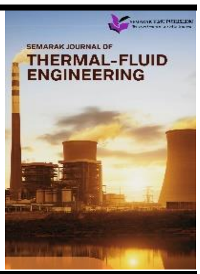
Semarak Journal of Thermal-Fluid Engineering

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sjotfe/index
ISSN: 3030-6639



Optimizing Mushroom Cultivation: PV-Powered Environmental Control Systems

Muhammad Zariq Imran Abdul Manap[1], Hanani Abd Wahab[1,*], Winda Astuti[2]

[1] Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Automotive and Robotics Program, Computer Engineering Department, BINUS ASO School of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

ARTICLE INFO

Article history:
Received 27 November 2024
Received in revised form 30 November 2024
Accepted 2 December 2024
Available online 31 December 2024

Keywords:
Solar PV; mushroom house; Matlab/Simulink; sustainable agriculture

ABSTRACT

Solar Photovoltaic (PV) technology, which converts solar radiation into electrical energy, is increasingly used in agriculture to power farm appliances. However, maintaining optimal environmental conditions for crop cultivation remains challenging. This study addresses this issue by integrating PV technology with an environmental monitoring and control unit to create a self-sustainable greenhouse, enhancing crop breeders' efficiency. The primary problem addressed is the difficulty in maintaining stable temperature and humidity levels in mushroom cultivation environments. The research aims to develop and simulate a PV-powered temperature control system for an oyster mushroom house, chosen due to its high market demand. Using Matlab/Simulink, a working model simulation was created to analyze the system's performance in maintaining optimal temperature and humidity levels. The simulation, based on energy balance equations, connects a mushroom house subsystem to Simscape electrical components and a solar panel. Simulation results indicate that the system can maintain a stable temperature around 25.7℃ throughout the day, regardless of ambient temperature variations. In conclusion, the study successfully developed a solar-powered temperature control system for oyster mushroom cultivation, demonstrating its potential to enhance the efficiency and sustainability of agricultural practices.

1. Introduction

As the global population continues to grow, so does the proportional demand for energy. This surge in energy consumption is largely driven by economic growth, especially in rapidly developing countries, which are projected to account for 90% of the increase in energy demand by 2035 [1]. Meeting this escalating energy requirement through fossil fuels such as oil, natural gas, and coal carries significant environmental and socioeconomic consequences. Environmental concerns include pollution, environmental degradation, global warming, and the resultant climate change. On the socioeconomic front, reliance on these non-renewable resources leads to their depletion and has

* *Corresponding author.*
E-mail address: nani@uthm.edu.my

https://doi.org/10.37934/sjotfe.3.1.112

even triggered conflicts between nations over access to these resources. To address these challenges, it is imperative to shift towards energy sources that are non-polluting, renewable, and sustainable.

Based on the SEDA Malaysia Annual Report 2022, the demand for solar energy is significantly higher compared to biogas and other renewable energy sources like biomass and small hydropower [2]. Solar energy can be harnessed for heating and lighting in greenhouses, creating what are known as solar greenhouses [3,4]. This method aligns with the principles of eco-efficient and sustainable production, which emphasize the efficient use of resources. Greenhouses, commonly used in modern agriculture, are designed to cultivate high-quality plants. Recently, the incorporation of solar energy has led to the development of solar greenhouses. In these structures, solar energy is harnessed to provide both heating and lighting. Utilizing resources efficiently is a key aspect of eco-efficient and sustainable agricultural production.

Malaysia's agro-climatic conditions are highly favorable for industrial mushroom production due to its tropical climate and high humidity, which facilitate successful cultivation with minimal environmental impact compared to other countries. However, challenges persist. Malaysian mushroom entrepreneurs face issues such as poor supply, rising raw material costs, pest attacks, diseases, and subpar mushroom quality [5-8]. A primary concern for mushroom growers in Malaysia is controlling the temperature within the growing halls. Given the labor-intensive nature of mushroom farming are taken from the previous studies [5,6], considerable research and experimentation have been conducted on creating automated mushroom houses to improve productivity.

Climate factor is a critical factor that need to be considered in growing mushroom. This will bring an affect towards the quality of the mushroom. Natural environment such as temperature during the day either on a hot day and the rain is affecting the temperature and moisture in the mushroom house directly. The suitable temperature in growing a high quality of mushroom varies by species but is generally in between 25°C-30°C are taken from [7-9].

Current practices involve manual methods, such as spraying water to cool the environment, which are inefficient and risk contaminating the crops [10]. An automated temperature and humidity control system, powered by solar energy, could address these challenges [11,12]. This system would not only reduce the labor required but also promote the use of renewable energy in agriculture. Despite the potential benefits of solar PV systems for temperature control in mushroom farming, there is limited research specifically addressing their application in mushroom houses. Current conventional methods are labor-intensive and imprecise, highlighting a significant gap in the optimization of productivity and environmental management.

Previous studies have highlighted the importance of temperature regulation in mushroom farming [11-19]. Research by Burton *et al.,* [18] demonstrated that temperature fluctuations can significantly affect mushroom yield and quality. Renewable energy solutions, such as solar PV systems, have been proposed as viable alternatives to conventional energy sources [20-22]. However, there is limited research on the application of solar PV systems specifically for temperature control in mushroom houses as taken from the previous studies [10,11,18].

Addressing this gap is crucial for enhancing mushroom cultivation efficiency, reducing labor costs, and promoting sustainable agricultural practices. By introducing an automated temperature and humidity control system powered by solar energy, this study aims to bridge this gap and provide a sustainable solution for mushroom farmers. This study not only addresses the specific challenges faced by mushroom cultivators in Malaysia but also contributes to the broader field of sustainable agriculture globally. By integrating solar photovoltaic (PV) technology with environmental control systems, the research demonstrates a scalable and eco-friendly solution that can be adapted to various agricultural contexts worldwide. The successful implementation of a PV-powered temperature control system for mushroom cultivation highlights the potential for renewable energy to enhance agricultural productivity, reduce reliance on fossil fuels, and mitigate the environmental impact of farming practices. This approach aligns with global efforts to promote sustainable development and can serve as a model for other regions seeking to improve agricultural efficiency and sustainability through innovative, renewable energy solutions.

Therefore, the objective of this research is to simulate a temperature monitoring and control system, demonstrating the benefits of solar energy in greenhouse applications for oyster mushroom cultivation. This research supports the development of more efficient agricultural practices, reducing the workload on farmers, and aligning with Malaysia's national renewable energy goals.

2. Methodology

2.1 Mushroom House Model

Figure 1 shows the proposed mushroom house with labeled parameters, while Table 1 and Table 2 list the parameters dimension in SI-unit.

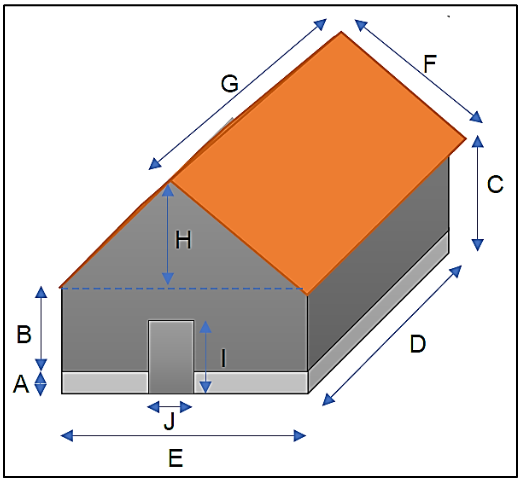


Fig. 1. Proposed mushroom house model

Table 1
The dimension of each house perimeter

Perimeter	Length, m
A	0.500
B	2.548
C	3.048
D	9.144
F	3.500
G	10.144
H	1.720
I	2.000

Table 2
The dimension of each house part

House part	Building materials	Area perimeters	Sides
Upper end wall (front with door)	Polyethylene netting	$BE + IA + \frac{1}{2}HE$	1
Upper end wall (back)	Polyethylene netting	$BE + \frac{1}{2}HE$	1
Lower end wall (front)	Screeded clay brick	$A(E - J)$	1
Lower end wall (back)	Screeded clay brick	AE	1
Upper side walls	Polyethylene netting	BD	2
Lower side walls	Screeded clay brick	AD	2
Floor	Concrete	ED	1
Roof	Lightweight metal deck	FG	2

2.2 Simulation Setup

The simulation work was conducted using MATLAB/Simulink, with a particular focus on the Simulink approach. The foundation of the system included a solar collector, a mushroom house model, and an electrical subsystem. The simulation employed the ON-OFF relay method. The surface layer of the simulation comprised a solar PV block, two data source blocks, and three subsystem blocks: a solar cell temperature subsystem, a mushroom house subsystem, and an electrical system subsystem. The thermal model of the house was adapted from [23].

The thermal model described in [23] focuses on a generic residential heating system, incorporating components such as a heater, thermostat, and the house structure with thermal properties. It simulates the thermal behavior of a house, including heat exchange with the environment through walls, roof, and windows, and calculates heating costs based on energy consumption. In contrast, the thermal model in this study is specifically designed for a mushroom house, integrating solar photovoltaic (PV) technology with environmental control systems to maintain optimal temperature and humidity levels for mushroom cultivation. While both models use thermal dynamics to simulate temperature control, the model in [23] emphasizes residential heating efficiency and cost calculation, whereas this study model targets agricultural applications, utilizing renewable energy to enhance sustainability. This study model includes specialized subsystems for solar cell temperature, mushroom house thermal dynamics, and an electrical system for environmental control, demonstrating a more complex interaction with renewable energy sources compared to the simpler residential focus of the model in [23].

Figure 2 illustrates the main surface level block diagram for the system. The two external data source block is a set of data from the Malaysian Meteorological Department (MMD). The data consists of hourly dry bulb temperature (ambient temperature) and hourly solar radiation. The ambient temperature block supplies data to be calculated in the equations block of the mushroom house and solar cell temperature subsystem. The solar irradiation data block provides data for the solar PV block.

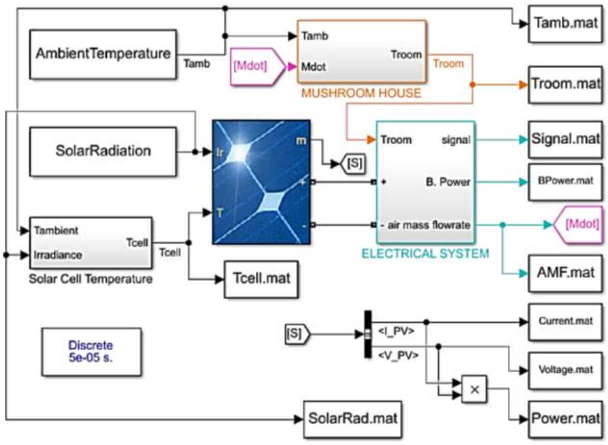


Fig. 2. Model Simulink block diagram for the whole

2.2.1 Solar cell temperature subsystem

Figure 3 shows the Simulink block diagram for the solar cell temperature. For any solar PV panel, the crucial temperature that needs to be known are its solar cell temperatures. This is because a PV panel cells temperature, Tcell has a linear relationship with its voltage production. Based on the characteristic of the solar panel model used in this simulation, the temperature coefficient is recorded to be −0.38%/℃. This means that the voltage output of the panel will decrease by 0.38% for every 1℃ increments of the solar cell temperature from its nominal operating cell temperature (NOCT) which is 25℃ for all PV cells.

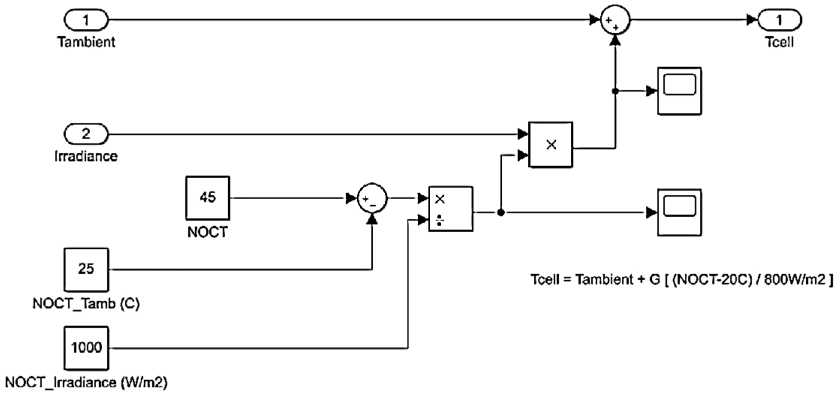


Fig. 3. Simulink block diagram for the solar cell temperature

Thus, it is important to calculate the cell temperature, Tcell to simulate the performance of the panel under real life condition data. This block diagram is build based upon the solar cell temperature, Tcell equation as shown in Eq. (1) below:

$$T_{cell} = T_{amb} + G\left[\frac{(NOCT - 20°C)}{800W/m^2}\right] \quad (1)$$

where G is the amount of solar irradiance received by the panel. Ambient temperature, Tamb and solar irradiance data, G were provided from the external data block.

2.2.2 Mushroom house subsystem

The mushroom house subsystem consisted of four subsystem which represent heat energy equation for cooler unit, ventilation heat, heat loss from floor, and heat conduction from walls and roof. Figure 4 below shows the block diagram for the subsystem. The manipulated variables input that were used in this subsystem is ambient temperature (Tamb), and air mass flowrate ($m\dot{m}$air). While the output of the system is the mushroom house room temperature (Troom). Troom output signals will then be routed back into each subsystem for further calculation. The initial Troom temperature which was set at the integrator block located at the end of the block diagram is 24℃. This temperature is selected under the assumption that the mushroom house is thermally equilibrium with the surrounding temperature. The surrounding temperature at this time is 24℃ at 1.00a.m. based on the meteorological data used.

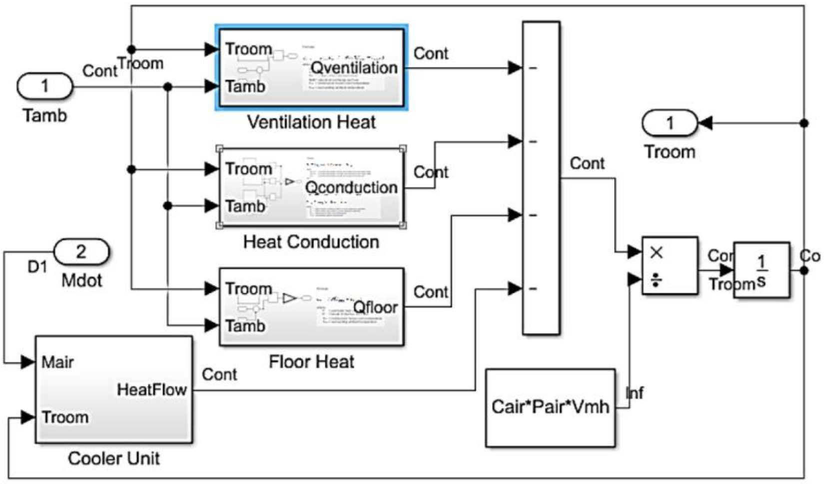


Fig. 4. Simulink block diagram for the mushroom house sub system

2.2.3 Electrical system subsystem

The electrical system subsystem, consists of six components which is buck converter, lead acid battery, booster pump motor, fan motor, signal router, and an RPM to air mass flowrate converter. Figure 5 shows the full component of the subsystem where each part is color coded for easy function recognition.

The working principle of the system is that the PV module connects to the MPPT buck converter which is then connected to a battery to simulate an off-grid system. The battery is then connected to a PMDC motor to simulate the load of a water booster pump, and a BLDC motor to simulate the fan. Both motors together simulate a mist cooling system although only the fan output is directly involved in cooling simulation for this design, as a mean to simplify the block diagram. Both motors are connected with an ON-OFF switch that receive its signal based on the Troom output from the mushroom house subsystem. Once the Troom exceed 30℃, a signal of 1 is given out to the motors to turn them into ON state. After turned ON, the BLDC motor speed is converted into RPM and then goes to the air mass flowrate converter which uses the first fan law to convert motor RPM into the fan RPM.

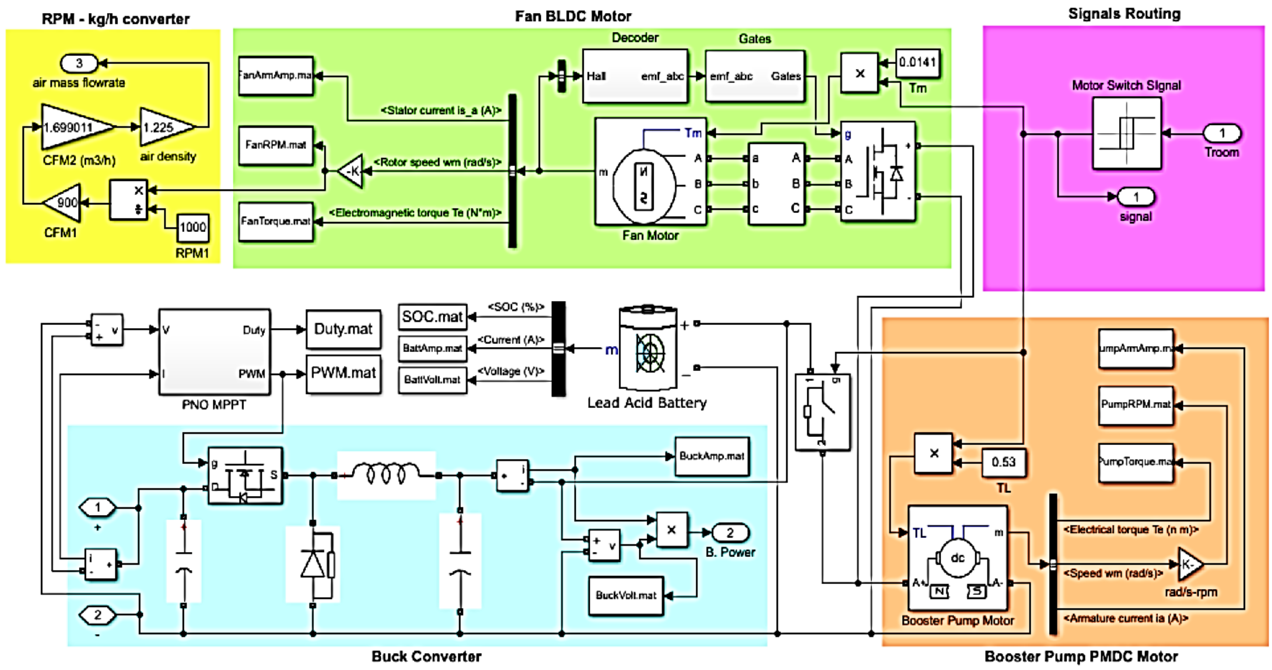


Fig. 5. Simulink block diagram for the electrical system

3. Results

3.1 Simulation Result for Electrical Components

This section discussed the behavioural pattern for the electrical components involved in the simulation. It is part of the investigation and proof of concept for the development of the temperature control system to indicate the electrical components of the simulations is working as theorised. Figure 6 shows the graph of the solar cell temperature (Tcell) and Tamb versus time. The graphical comparison in Figure 6 shows that Tcell has an overall difference of about ±21.09°C as compared to Tamb. The highest Tcell recorded is 55.39°C while Tamb is 34°C. The added heat is the by-product of the process in when the panel absorbs the sunlight to convert it into electrical power.

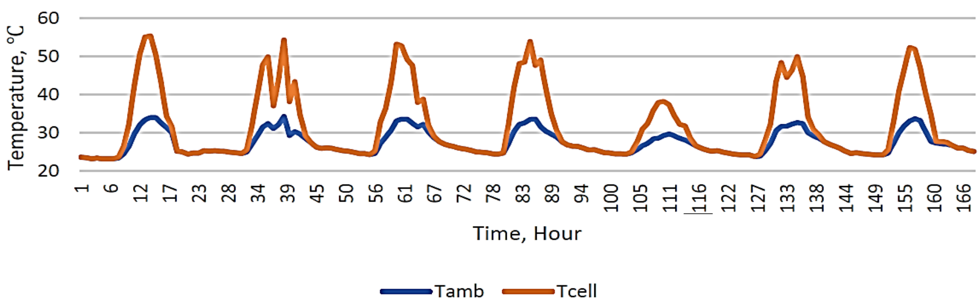


Fig. 6. Tcell and Tamb versus time

Furthermore, the aluminium case of the PV panel will also get hot from the exposure to sunlight which also contribute to the increase in. Solar panels are made from silicon PV cells that when gets too hot, will significantly reduce the solar cell efficiency and which is the output conversion from sunlight to electricity. The point of which this will happen is when the temperature exceeds 65°C. Figure 7 below shows the result of voltage and Tcell versus time.

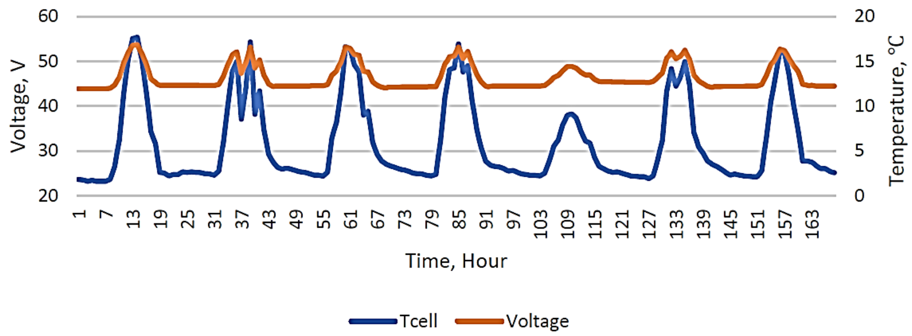


Fig. 7. Voltage and Tcell versus time

The voltage output of a solar panel is directly affected by temperature. As the temperature of a solar panel increases, its voltage output will decrease while current increases. The graph above however, showed a default minimum value of 12V produced by the panel and increases slightly according to temperature. This is achieved with a MPPT buck converter that is connected with the PV model inside the simulation since the PV model used has a voltage rating of 30.97V at maximum power point. The buck converter steps down the voltage to the desired level which in this case is 12V and converts the excess energy into current.

Figure 8 shows the relationship between solar radiation intensity and PV output current. Solar radiation or solar irradiance have the most prominent effects among others on the performance of a PV panel. An increase in solar radiation leads to increase in output current but will also increase Tcell which in turn reduces voltage when it reaches a certain threshold as discussed before. From Figure 8, the relationship between solar radiation and PV current is well established as the production of current output follows the pattern of the solar radiation. The current rating of the panel used in this simulation is 9 Amp but the result showed up to 43 Amp because the simulation uses 4 identical panels in parallel setting along with the equipment of buck converter.

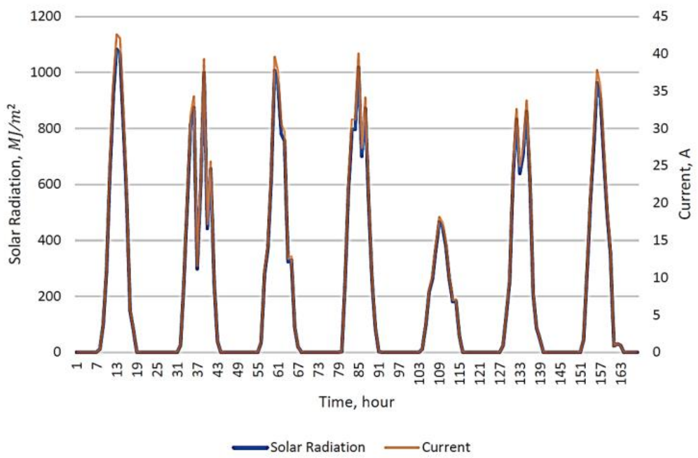


Fig. 8. Solar radiation intensity and PV output current and versus time

Figure 9 shows the graph for Tcell and solar radiation against time. Figure 9 shows that the solar cell temperature, Tcell is directly affected by the solar radiation as both shared identical graph pattern. It can be concluded that as the solar radiation increases, the solar cell temperature also increases accordingly if it received direct exposure from the sun. Solar radiation increases and decreases as the day progress according to the position of the sun.

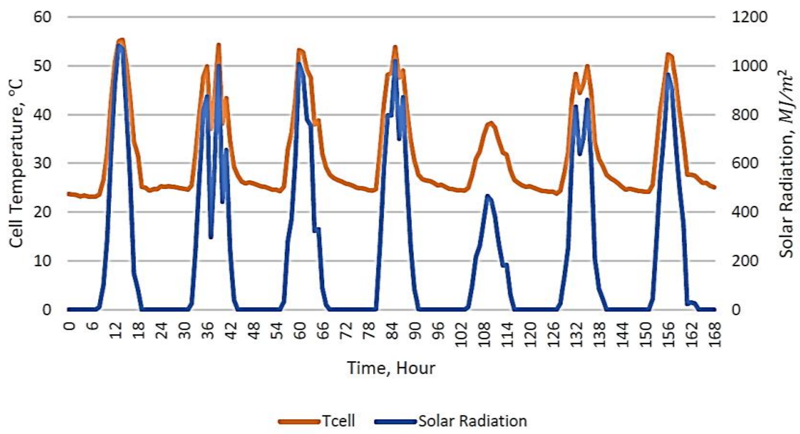


Fig. 9. Tcell and solar radiation intensity versus time

From the graph shown, it can be concluded that the solar radiation will start taking effect from 8 a.m., peak at around 11 a.m. to 2 p.m., and start declining afterwards until 7 p.m. this means that the active time for the solar panel to function is in between 8 a.m. to 7 p.m. every day with the ideal energy generation time is around 11 a.m. to 2 p.m. which is also the timeframe on which the temperature will be the highest as shown in Figure 9. Unfortunately, the relationship between the solar cell temperature and its voltage generation is inversely perpendicular as every 1℃ temperature increases, the voltage generation will decrease by 0.12 V. This leads to future possible improvement for the system in future studies.

3.2 Simulation Results for Temperature Control

The simulation was run using a one-week period data. Three runs were made use the ON-OFF relay switch. The simulation setting for the three relay switch runs are always OFF signal, always ON signal, and ON-OFF signal. These results focus on the temperature controller development of the system. The list of results obtained from the simulations are as follows. Figure 10 shows the simulation results of Tamb, Troom, and control signal vs time for always OFF signal setting under a 7-day simulation.

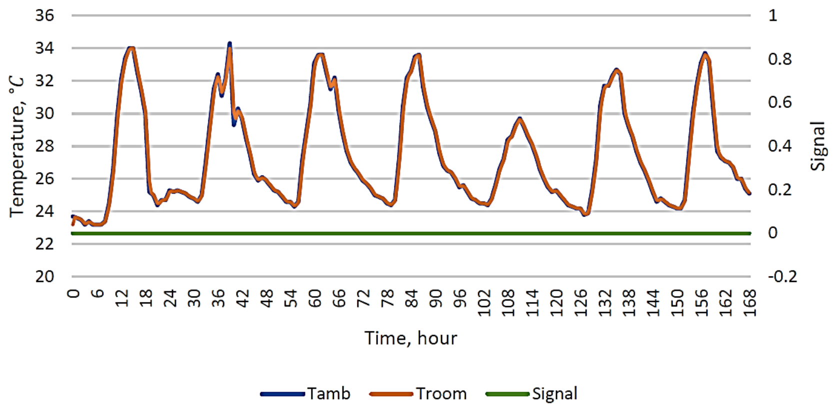


Fig. 10. Tamb, Troom, and signal vs time for always OFF signal setting

The simulation starts at 1 a.m. and represents a whole day whenever the time axis scale reaches its 24 increments. This means that the 24th, 48th, 72th, 96th, 120th, 144th, and 168th mark is representing the end of day 1 until 7 respectively. The simulation results showed that the Troom has a slightly cooler temperature fluctuations but still follows identical temperature pattern from the surrounding Tamb. This setup simulated the condition in which the mushroom house is monitored as is without any temperature control mechanism. Since the setting is set to be always OFF, the electrical signal will always stay at 0. The highest recorded Tamb and Troom are 34.29°C and 34.00°C respectively. The time of day in which the sun is producing the most heat to the environment is between 10 a.m. to 6 p.m. In this setting, the mean Troom during this time for 7 days is 30.76°C.

Figure 11 shows the simulation result for the always ON signal configuration. The always ON signal setting simulates the condition in which the cooling mechanism is always cooling the mushroom house regardless of Tamb. This is showed as the signal is always on 1 which indicated that the cooling system is running. Figure 11 shows a significant temperature difference between the Tamb and Troom. It is shown that the highest Troom level recorded on the 2nd day at 29.54°C while the lowest and mean Troom level from the 7 days run is 29.54°C and 27.89°C respectively.

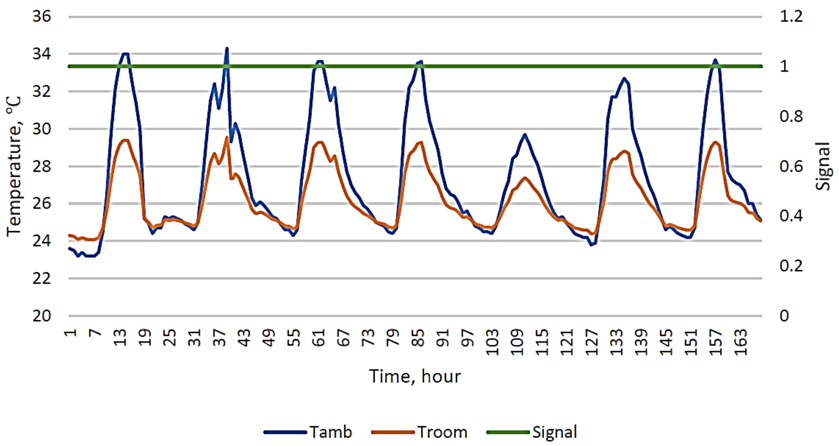


Fig. 11. Tamb, Troom, and signal vs time for always ON signal setting

A classical ON-OFF setting is where the system monitors and control the temperature by turning the system into 'ON' and 'OFF' state based on the Troom level. As per the setting used in this simulation, the system will fully turn ON when Troom exceeds 30°C and turn OFF when it dropped below 26°C. Figure 12 shows the graphical results of Tamb, Troom, and signal vs time for ON-OFF setting.

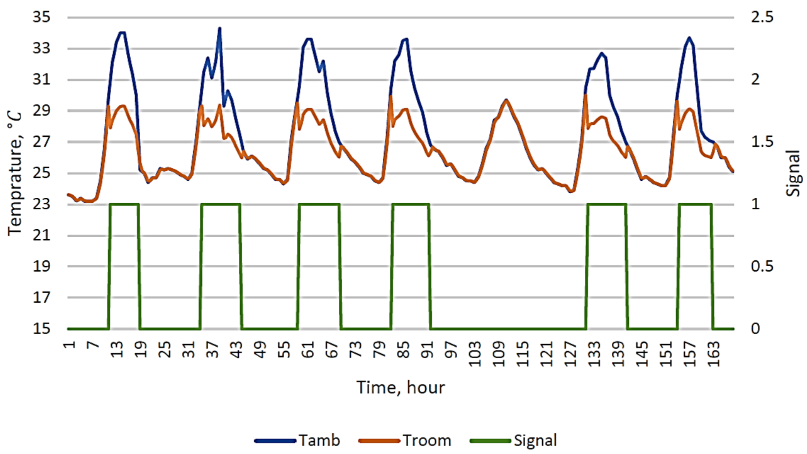


Fig. 12. Tamb, Troom, and signal vs time for ON-OFF signal setting

The temperature pattern showed that the room temperature took a sudden decrease nearing the 12th hour (12.00 p.m.) at the 30°C which indicates that the cooling mechanism is turned ON. This result is aligned with the electrical signal that reached the value of 1 on this time which indicates that the cooler switch is turned ON. The switch is turned ON until the 18.8 hours mark (6.48 p.m.) where the room temperature had decreased to 26°C and the cooling system is turned OFF. The same behaviour is observed on every other day except for the 5th where Tamb is not hot enough to trigger the cooling system.

4. Conclusions

A simulation of a mushroom house was then successfully developed by using MATLAB/Simulink software. The simulation design is based on the thermal energy balance while its parameters were based on various specification commonly used in Malaysia agricultural industry as well as the official Malaysian Standard guideline. At the same time, a temperature control system was also simulated and integrated successfully inside the model. From the simulation run, it is concluded that it was able to simulate the temperature control inside the mushroom house. When the control signal is turned OFF, the result showed that the temperature inside the mushroom house to be similar to that of the ambient temperature. When the signal is set to always ON, the temperature drops below the optimal level. After the setting were set as ON-OFF depending on the temperature, the system manages to maintain a temperature level of between 26℃ and 30℃ throughout the day. Although the mushroom house temperature was able to be controlled as intended, it is observed that the electrical component specifically the pump and fan motors does not achieve the desired performance as per the parameters input on them. This can be traced back to the electrical system subsystem as each component connected to the motors such as the buck converter, MPPT, and battery parameters may contribute to the performance of the motors. Since the mushroom house model was successful developed however it requires revision on the electrical component which can be the subject for future studies.

In conclusion, this study offers a viable solution to several global agricultural challenges by integrating renewable energy with advanced environmental control systems. The successful implementation of a PV-powered temperature control system for mushroom cultivation not only enhances productivity and sustainability but also provides a model that can be replicated and adapted worldwide. By addressing climate change, promoting sustainable energy use, enhancing automation, and improving food security, this study contributes to the global effort to create a more resilient and efficient agricultural sector.

Acknowledgement
This research was not funded by a grant.

References

[1] International Energy Agency (IEA). “World Energy Outlook 2024.” *IEA Publications*, 2024.

[2] Sustainable Energy Development Authority (SEDA). “Laporan tahunan 2022: Annual report 2022.” *Sustainable Energy Development Authority, Malaysia*, 2022.

[3] Espitia, John Javier, Fabián Andrés Velázquez, Jader Rodriguez, Luisa Gomez, Esteban Baeza, Cruz Ernesto Aguilar-Rodríguez, Jorge Flores-Velazquez, and Edwin Villagran. "Solar energy applications in protected agriculture: A Technical and bibliometric review of greenhouse systems and solar technologies." *Agronomy* 14, no. 12 (2024): 2791. https://doi.org/10.3390/agronomy14122791

[4] Chel, Arvind, and Geetanjali Kaushik. "Renewable energy for sustainable agriculture." *Agronomy for Sustainable Development* 31 (2011): 91-118. https://doi.org/10.1051/agro/2010029

[5] Mat Amin, Mohd Zaffrie, Azahar Harun, and Mohd Amirul Mukmin Abdul Wahab. "Status and potential of mushroom industry in Malaysia." *Economic and Technology Management Review* 9b (2014): 103-111.
[6] Rosmiza, M. Z., W. P. Davies, R. C. Aznie, M. Jabil, and M. Mazdi. "Prospects for increasing commercial mushroom production in Malaysia: Challenges and opportunities." *Mediterranean Journal of Social Sciences* 7, no. 1 (2016): 406-415. https://doi.org/10.5901/mjss.2016.v7n1s1p406
[7] Mohd Rosdzimin, Abdul Rahman., Abdul Rahim Mat Sarip, and Haharom, Siti Noor Aliah." Thermal and humidity management of mushroom house using evaporative cooling system." *ASM Science Journal* 13, no. 4 (2020): 113-117.
[8] Abd Wahab, Hanani, Muhamad Zariq Imran Abdul Manap, Ong Pauline, Maznan Ismon, Muhd Hafeez Zainulabidin, Fazimah Mat Noor, and Zaleha Mohamad. "Investigation of temperature and humidity control system for mushroom house." *International Journal of Integrated Engineering* 11, no. 6 (2019): 27-37. https://doi.org/10.30880/ijie.2019.11.06.004
[9] Reed, J. N., S. J. Miles, J. Butler, M. Baldwin, and R. Noble. "AE—Automation and emerging technologies: Automatic mushroom harvester development." *Journal of Agricultural Engineering Research* 78, no. 1 (2001): 15-23. http://dx.doi.org/10.1006/jaer.2000.0629
[10] Hoa, Ha Thi, and Chun-Li Wang. "The effects of temperature and nutritional conditions on mycelium growth of two oyster mushrooms (Pleurotus ostreatus and Pleurotus cystidiosus)." *Mycobiology* 43, no. 1 (2015): 14-23. https://doi.org/10.5941/MYCO.2015.43.1.14
[11] Ten, Seng Teik, Gaisan Krishnen, Khairul Asfamawi Khulidin, Muhd Akhtar Mohamad Tahir, Mohamad Hafiz Hashim, and Syaliyana Khairudin. "Automated controlled environment mushroom house." *Advances in Agricultural and Food Research Journal* 2, no. 2 (2021). https://doi.org/10.36877/aafrj.a0000230
[12] Rukhiran, Meennapa, Chwin Sutanthavibul, Songwut Boonsong, and Paniti Netinant. "IoT-based mushroom cultivation system with solar renewable energy integration: Assessing the sustainable impact of the yield and quality." *Sustainability* 15, no. 18 (2023): 13968. https://doi.org/10.3390/su151813968
[13] Saputra, Erwin Ardias, Yuli Asmi Rahman, Rudi Santoso, and Resky Tegar. "Application of Temperature and Humidity Control Technology in The Oyster Mushroom Cultivation Business." *Journal of Innovation and Community Engagement* 5, no. 3 (2024): 140-153. https://doi.org/10.28932/ice.v5i3.7673
[14] Santos, Alexandre F., Pedro D. Gaspar, and Heraldo J. L. de Souza. "Eco-efficiency in mushroom production: A study on HVAC equipment to reduce energy consumption and CO_2 emissions." *Applied Sciences* 13, no. 10 (2023): 6129. https://doi.org/10.3390/app13106129
[15] Zainuddin, Nur Aishah, Khairul Muslim Nordin, Ahmadkhairi Ishak, Muhammad Syafiq Nuriman, and Tajul Irfan Danial Tajul Azhar. "IoT-based oyster mushroom farming monitoring system." *International Journal For Multidisciplinary Research* 5, no. 3 (2023): 1-7. https://doi.org/10.36948/ijfmr.2023.v05i03.4051
[16] Mahmud, MS Azimi, Salinda Buyamin, Musa Mohd Mokji, and MS Zainal Abidin. "Internet of things based smart environmental monitoring for mushroom cultivation." *Indonesian Journal of Electrical Engineering and Computer Science* 10, no. 3 (2018): 847-852. https://doi.org/10.11591/ijeecs.v10.i3.pp847-852
[17] Kathiria, Abhi, Parva Barot, Manish Paliwal, and Aditya Shastri. "Iot-assisted mushroom cultivation in agile environment." In *International Conference on Data & Information Sciences*, p. 299-308. Singapore: Springer Nature Singapore, 2023. https://doi.org/10.1007/978-981-99-6906-7_26
[18] Burton, K. S., and R. Noble. "The influence of flush number, bruising and storage temperature on mushroom quality." *Postharvest Biology and Technology* 3, no. 1 (1993): 39-47. https://doi.org/10.1016/0925-5214(93)90025-X
[19] Albius, Jilven D., Rica Lorraine B. De La Cruz, John Bert Ivan Gumandoy, William Daryll D. Ofrin, and Engr Paul Enrico F. Puyo. "Solar-powered multi-network greenhouse: Automated mushroom monitoring and management system using microcontrollers and IoT-based applications." *International Journal of Science, Technology, Engineering and Mathematics* 1, no. 2 (2021): 1-18. https://doi.org/10.53378/352853
[20] Maka, Ali OM, and Jamal M. Alabid. "Solar energy technology and its roles in sustainable development." *Clean Energy* 6, no. 3 (2022): 476-483. https://doi.org/10.1093/ce/zkac023
[21] Dada, Modupeola, and Patricia Popoola. "Recent advances in solar photovoltaic materials and systems for energy storage applications: a review." *Beni-Suef University Journal of Basic and Applied Sciences* 12, no. 1 (2023): 1-15. https://doi.org/10.1186/s43088-023-00405-5
[22] Bouich, Amal, Inmaculada Guaita Pradas, Mehwish Aziz Khan, and Yousaf Hameed Khattak. "Opportunities, challenges, and future prospects of the solar cell market." *Sustainability* 15, no. 21 (2023): 15445. https://doi.org/10.3390/su152115445
[23] MathWorks. “Thermal model of a house.” *Open in Simulink Online*, 2024.