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Optimization of Lingzhi cultivation in a closed smart mushroom cultivation house using control system via online application

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Abstract The result revealed that the proper humidity control system with fogging system for Lingzhi cultivation was in 15 seconds and every 15-minutes pause. The system continuously operated to reach the set value at 90-95%. The temperature must not exceed 30 ℃. The humidifier fan system is operated when the carbon dioxide exceeded to 1,000 ppm. The ability of humidity control section was 16.80% which greater than traditional mushroom farming. The ability of temperature control is 8.84% greater than before. There are 76.51% of carbon dioxide inside the cultivation house that was higher than the traditional methods. There are shown at 100% which less light than traditional methods. In terms of productivity, the yield was 50.19% which better than traditional cultivation. The result on the proper shelving for smart cultivation system showed that A-type of shelving had a flowering rate of 89.75%. Engineering Economics Analysis concluded that the system would payback in a period of 2.3 months.

Keywords: Application, Smart cultivation house, Control system

Introduction

Lingzhi is a large fungus. The scientific name is *Ganoderma lucidum* (Fr.) Karst. It is in the family Polyporaceae (Ganodermataceae). In Thailand, it has been cultivated since 1984 (Jala, 2014). Lingzhi resembles a kidney with a reddish-brown cap. There are many forms of consumption such as dry-powdered capsules, cut into pieces and boil with water, or extracts packed in capsules (Sukapirom *et al.*, 2008). The prices of dried Lingzhies are quite high, about 1,200-1,500 baht per kilograms. In Thailand, it has been used for medicinal purposes as well. The substances contained in the mushroom include B-D-glucan, which is a polysaccharide. It can resist tumors (Jala, 2014), lower blood sugar, reduce LDL and triglyceride in the blood, treat allergy, stimulate the production of blood cells (Ngakham, 2017), treat liver disease, gastritis, and diabetes, and also lowers blood pressure, blood sugar, and cholesterol

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(Sukapirom *et al.*, 2008, Soonthornchareonnon, 2008). Department of Agriculture has been researching and cultivating Lingzhies very successfully. The research results showed that the G2 strain had high yields. The distinguishing feature of this species of mushrooms is that this mushroom has a semicircular shape like an ancient ax. The top part is dark brown (Limsila *et al.*, 2010). Lingzhi houses need to be controlled for important variables including temperature, humidity, carbon dioxide content, light, and airflow. Carbon dioxide content affects mushroom growth (Vengsungnle *et al.*, 2019). The suitable temperature is between 18-30 ℃, and the relative humidity is between 85-95% (Ganoderma Lucidum Biotechnology Garden, 2021). The optimum pH is between 5-6. Lingzhies prefer to grow in a relatively acidic medium (Limsila *et al.*, 2010).

From the survey of Ban PlaiLahan Community Enterprise, Songkhla Province, Thailand, it was found that the group had a problem with Lingzhi cultivation. Temperature and humidity control requires manual labor to use a water hose to humidify the mushrooms, and presume the amount of humidity. Inappropriate humidity affects the mushroom fruiting and the size of the mushrooms. Also, the excess humidity causes the mushroom cubes to become diseased. A review of the relevant literature revealed that a control system for the cultivation of Lingzhies and other mushrooms has been developed by using the technology for the Internet of Things. For example, Ariffin *et al.* (2020), Naimurrokhman *et al.* (2020) has developed a control system for the oyster mushroom cultivation conditions using a NodeMCU connected to a DHT22 temperature and humidity sensor to control a pump to spray fog and ventilation fans, and then data will be sent over the Internet to a webserver to view the temperature and humidity curve. Chieochan *et al.* (2017) and Fongngern *et al.* (2018) developed a prototype system for cultivating Lingzhi and Shiitake mushrooms, respectively, using a dht22 temperature and humidity sensor connected to a NodeMCU, sending data over the Internet every 5 minutes to the NETPIE Cloud, controlling humidity between 90-95% for Lingzhies and 80-85 for oyster mushrooms by using a fog spraying system and sprinkling 3 times a day for 5 minutes each time. The operation can be observed via NET FREEBOARD on mobile and browser. RawideanMohdKassim *et al.* (2019) and Mat *et al.* (2017) developed a Shiitake mushroom cultivation control system using temperature, humidity, and carbon dioxide sensors connected to XBEE, sending data over the Internet to the database server to analyze the data in graphs. The humidity is set between 70-90%. If it is below 70%, then the humidifier will be activated, and if the CO2 is over 1,000, then the exhaust fan will be activated to expel the carbon dioxide gas out of the house. Alim Shakir *et al.* (2019) developed a mushroom cultivation system using microcontroller as separate controllers and sensors by using the DHT22 temperature and humidity sensor, and the MQ-135 carbon dioxide sensor. The MQ-135 sensor uses an LDR as a light sensor, and it can control ventilation fans, fogging pumps, and light bulbs. The sensor data is then sent via the Internet to a web server for viewing and command, and also to display experimental results, graphs of humidity and temperature of the day. SholihulHadi *et al.* (2021) and Najmurrokhman *et al.* (2019) utilized an application of fuzzy logic for temperature and humidity control in an oyster mushroom house using NodeMCU for processing, DHT11 as a humidity sensor, fogging and ventilation systems to control temperature and humidity. Masykur *et al.* (2020), Ariyapim and Addoddorn (2020), Nasution *et al.* (2019), and Sakulrasrisuay *et al.* (2018) developed a temperature-humidity control system in mushroom cultivation by designing the system of the application to control and command the fogging system through a cloud-based system to a microcontroller, and a ventilation fan system via relay.

The results of the review of such relevant research were found that the development of the system did not cover the design of the house that favors conditions suitable for cultivation of Lingzhi as well as the temperature, humidity, and carbon dioxide control systems to autorun when the measure values are below or above the set values. However, if the control system is working continuously, and it still cannot reach the set value, this will affect mushrooms and mushroom cubes to become too moist. They can be damaged or rotten. In addition, if the system operates continuously, it also burdens expenses from the increased electricity bills. In this research, an idea was created to develop an intelligent control system for the Lingzhi cultivation house by designing the house to be suitable for recording the values of the temperature, humidity, carbon dioxide content, and light to fit the environment in Southern Thailand. The control system was designed to save energy, not make the Lingzhi too wet, proper ventilation, and using in both automatic and manual modes. The operations can be observed via the application over the Internet, NB-IoT, and LINE applications.

The objectives of this research were to specify the period of time and the form of fogging that was suitable for the growth of the Lingzhi, to compare the temperature, carbon dioxide, humidity and light between the closed smart mushroom cultivation house with the traditional mushroom cultivation house, to compare the quantity of the obtained products between the closed smart mushroom cultivation house with the traditional mushroom cultivation house, to investigate the shelf layout that was suitable for the growth of the Lingzhi, and and to analyze the payback period according to the principles of engineering economics.

Materials and methods

Study the optimum conditions in the Lingzhi Open House

In this research, the researcher used G2 species of Lingzhi from the Department of Agriculture. The research has shown that the yield is high, and the mushrooms can be cultivated throughout the year using the method of cultivating Lingzhies in a plastic bag using ready-to-open mushroom cubes of the Ban Plai Lahan Community Enterprise Group. The mushroom cubes were traditionally cultivated by a galvanized roof shed around the house and covered with shading nets, and humidified by spraying water with a hose. Researchers have also applied the Smart Mushroom Cultivation Control System to this group. To make mushroom cubes; the following materials were used: 94% rubberwood sawdust, 5% rice bran, and 1% lime. After that, the mushroom cubes in bags were steamed to kill various germs for 6 hours. Rested for 12 hours. Then brought in inoculation, and incubated the bags so that the mycelium can completely spread all over in the bags taking 20-30 days. The bags which were full of mycelium were brought to grow fruits in the mushroom cultivation house of Rattaphum College, Rajamangala University of Technology Srivijaya. The optimum temperature and humidity for Lingzhi growing in the open house in this research were between 18 ℃ - 30 ℃ and the relative humidity was between 90-95%. The mushrooms took about 45 days to be collected. Mushrooms could be harvested for 2 rounds. Then the house would take a break for 1 month to clean and disinfect.

Design and develop the system

System design and development is divided into 5 parts: system overview design, house design, hardware design, application design, and cloud system design

Design an overview of the system

The system is divided into three parts which shown in Figure 1. The application served to command, to view the work, and to view the sensor values from the cloud system over the Internet. The Cloud-based system for data storage can be divided into 3 types: Firebase for real-time data storage, Thingspeak, and NB-IoT for sensor data storage. Both the Firebase and Thingspeak cloud systems received data from the microcontroller through the Internet gateway, while the NB-IoT cloud system received the data through the NB-IoT gateway. The control part consisted of a microcontroller, which controlled the fog spray system, fan system, sprinkler system on the floor, sprinkler system on the roof, and also read the sensor values of the temperature, the humidity, the carbon dioxide content, and the light, by sending sensor values through the Internet gateway and NB-IoT gateway.

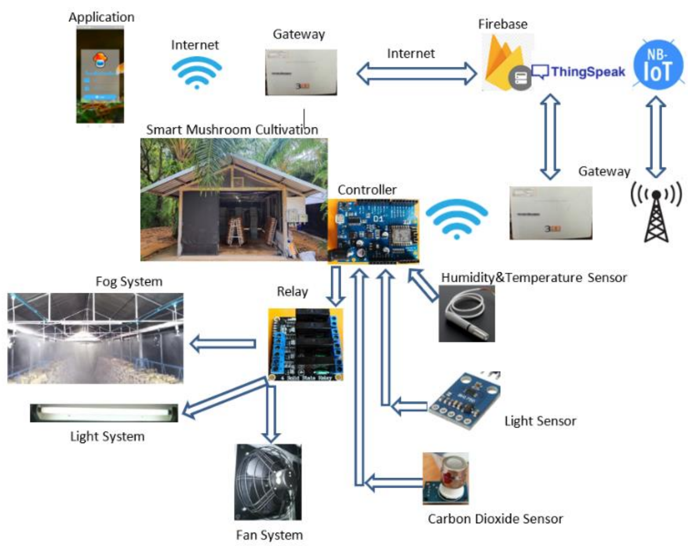


Figure 1. Overview of the System Operation

Hardware design

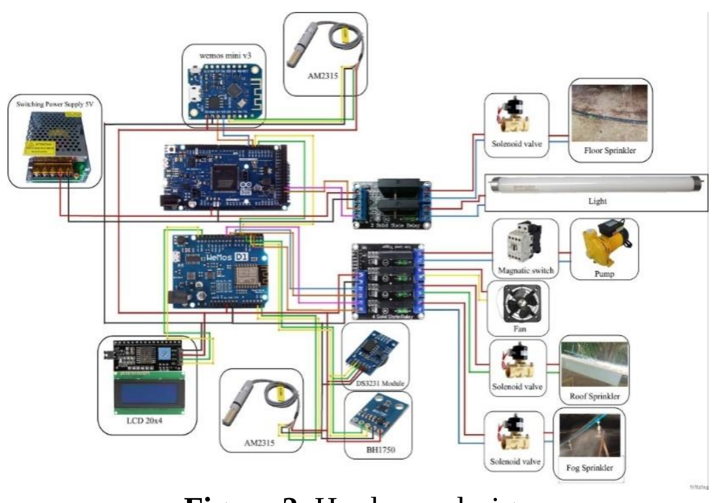


Figure 2. Hardware design

The hardware system is shown in Figure 2 which consisted of three microcontrollers: WEMOS D1 R2, ARDUINO DUE, and WEMOS MINI V3, all of which were connected to transmit data to each other via serial transmission. WEMOS D1 R2 was the main body for controlling and reading sensor values which were controlled via a Solid State Relay to a magnetic switch to control the on/off of the pump for spraying frog through channel 1, to control ventilation fans through channel 2, and to control Solenoid Valve to turn off the roof sprinkler through the channel 3, and to control the Solenoid Valve to turn the fogging system through the channel 4. The WEMOS sensor reads the values from temperature, humidity, and indoor light sensors via the I2C pin, a 20 character 4-line LCD connected via the I2C pin as well, and the carbon dioxide sensor connected via Pin A0.

Closed mart mushroom cultivation house design

As shown in Figure 3, the Smart Mushroom Cultivation House has been designed to have 4 meters wide, and 8 meters long. Inside, there were 3 types of mushroom shelves, namely A-shaped type, Condo type, and hanging type, for studying the shelves that were suitable to mushroom placement for Lingzhi. It contains 2,370 mushroom cubes in total, and each shelf holds 790 mushroom cubes. The house was covered with black plastic. Metal roofs were insulated from heat. Front and back gables were made of clear plastic. The foundation around the house was made of cement walls to allow moisture retention. Ventilation holes were designed to allow air to circulate inward from the bottom up through the ventilation fans above. There were fog spraying systems with 21 fogging nozzles. Six units of ventilation fan system: each of two units for front and rear gables, and two of four units on each sidewall. Eight sprinklers on the roof. Twelve heads of a water sprinkler system on the floor. Lighting system. A solar power system with two 320-watt panels for a total of 640 watts. There were various sensors as follows: temperature and humidity sensor, light sensor, and carbon dioxide sensors, positioned in the middle of the house. It was 4 meters wide, and 5 meters long.

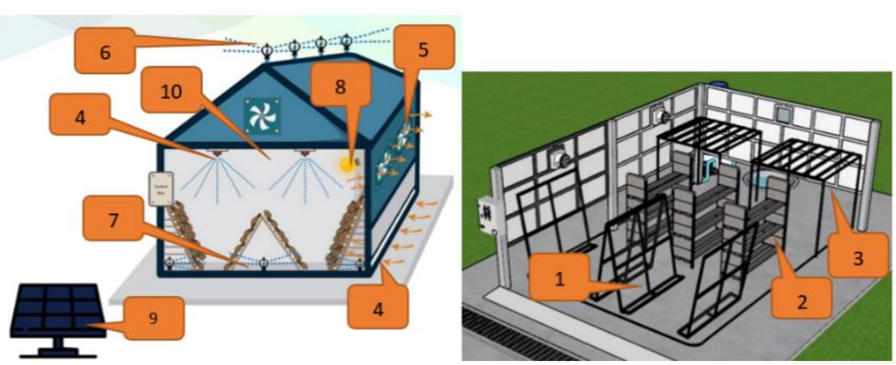


Figure 3. House design

Application section

The application was developed using Google's framework, Flutter, which is a hybrid application that can be used on all the Android, iOS, websites, and desktop operating systems. The application retrieves and sends data via the Internet to the Firebase cloud system.

Cloud system section

It was part of the storage and the medium of communication between the application and the hardware system. There were two types of data stored in the cloud system: sensor data such as temperature, humidity, light, and carbon dioxide content, all of which will be stored in 2 channels: one was transmitted over the Internet to the Thingspeak cloud system, and the other channel via NB-IoT to the Connesthings cloud system of Prince of Songkla University. The data is in real-time, or mushroom house environment settings data, stored in the Firebase Realtime Database cloud system.

System operation process

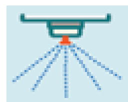
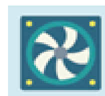
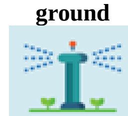
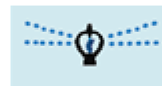
Workflow

The user signed in the system by entering the username and password. The system checks if there was information in the system that will be able to log in. The user will then be able to use 4 parts: control section, which can control modes such as fog, fan, light, and water floor, section to view the operation, which can view temperature and humidity gauges, and graphs of temperature, humidity, light, and carbon dioxide content, settings section, which can be set the suitable temperature and humidity, the optimum humidity, fogging time, stop spraying time, fan turn-on time, fan shutdown time, outside temperature, and times to open the floor sprinkler, and signing out of the application.

Operational conditions of an automatic system

The operating conditions were in automatic mode (Table 1). Condition 1, if the internal humidity was in the range of 90-95%, and the internal temperature was below 30 ℃, the system did not operate. Condition 2, if the internal humidity was less than 90 %, the fog spraying system and the roof sprinkler system operated to increase humidity and reduce the temperature. Condition 3, if the indoor humidity was greater than 95%, and the outdoor humidity is less than 85%, the humidification fan system operated. The reason for the need to set the conditions of the humidity outside to less than 85% was because the fan managed the air from the outside into the house. Then if the outside humidity is also high, the fan system ran all the time and never caused the humidity inside to decrease. Condition 4, if carbon dioxide is released more than 1,000 PPM, the fan system operated to reduce the carbon dioxide content in the house.

Table 1. System operating conditions in automatic mode

Operating Conditions	Fog Spraying System	Fan System	Water sprinkler system on the ground	Water sprinkler system on the roof
				
Humidity within %90 <> %95or temperature <= 30 ℃	✗	✗	✗	✗
Indoor humidity < %90or internal temperature >30 ℃	✓	✗	✓	✓
Indoor humidity > %95and outdoor humidity <%85	✗	✓	✗	✗
Carbon Dioxide > 1000ppm	✗	✓	✗	✗

Testing and evaluating performance

Accuracy of the sensor test

Sensor accuracy test: The AM2315 temperature and humidity sensor was tested for accuracy with the testo 605i thermo-hygrometer. The temperature sensor has a tolerance of -0.1 degrees, and the humidity sensor has a tolerance of -2.0%. These correspond to the characteristics of a temperature sensor with an accuracy of +/-0.1% and a humidity sensor with an accuracy of +/-2 ℃. The BH1750 light sensor was tested for accuracy with the testo 540 light meter. The light sensor has a tolerance of -0.1 degrees. This corresponds to the characteristics of a light sensor with an accuracy of +/-0.1%. The MG-811 carbon dioxide sensor is factory-pretested for accuracy.

The humidity control system performance test

At the right time, the fogging system was turned on, and the system was tested 4 times to determine the temperature and humidity conditions that were most suitable for mushroom cultivation according to the house design, and the following situations as shown in Table 3. Situation 1: Turn on the fogging system only to control the temperature and humidity.Situation 2: Turn on the sprinkler system on the roof only to control the temperature and humidity.Situation 3: Turn on the sprinkler system on the floor only to control the temperature and humidity. Situation 4: Turn on the sprinkler system on the roof and floor to control the humidity. Situation 5: Turn on the fogging system and sprinkler system on the roof to control the humidity. Situation 6: Turn on the fogging system and sprinkler system on the floor to control the humidity. Situation 7: Turn on the fogging system and sprinkler system on the roof and floor to control the humidity.

Table 2. Humidity control system performance test

Situation	Internal humidity	Outside humidity	Internal temperature	Outside temperature	Internal and external humidity difference, %	Internal and external temperature difference, %
1	78.82	72.90	31.55	32.65	8.12	3.48
2	73	70	33	32.50	4.28	1.53
3	76	72	32.50	31.90	5.55	1.88
4	89.45	79.95	30.35	32.41	11.88	6.80
5	77.13	67.41	31.06	33.15	14.41	6.72
6	83.50	77.95	29	29.90	10.63	5.18
7	91.25	77	30.40	33	18.50	8.55

The performance test according to Table 2, it was found that in the 7th situation, the fog spraying system, roof sprinkler, and sprinklers on the floor, were all turned on to control temperature and humidity. This is found to be the best control condition used in this research.

The appropriate fogging time test for Lingzhies

The research team has experimented with fogging when the humidity was lower than 90%, continuously fogging until reaching the optimum humidity range of 95% caused the mushrooms to become too wet and damage the mushrooms and mushroom cubes. If the air outside is very hot and low humidity, causing the fogging system unable to spray until the humidity reached up to 95%, this forced the fogging system to work continuously for a long time, making the mushrooms and mushroom cubes very wet, and damaged. Thus, a new method of spraying is devised that the system that would spray the fog over some time until the optimum humidity is reached. This method did not over-wet the mushrooms and mushroom cubes. As the result, the experiments were conducted on the suitability of the spraying time and stopped the spraying time for the mushrooms to not over-wet the mushrooms as shown in Table 3. It was found that the fog spraying interval of 15 seconds and the fogging break time of 15 minutes were mostly appropriated for optimum use in this research.

Table 3. The optimal fogging time test for Lingzhies

Fogging time (seconds)	**10**	**10**	**10**	**10**	**15**	**15**	**15**	**15**	**20**	**20**	**20**	**20**	**25**	**25**	**25**	**25**
Stop spraying time (minutes)	10	15	20	25	10	15	20	25	10	15	20	25	10	15	20	25
Internal temperature (C)	30.21	30.21	30.64	30.21	30.60	31.40	31.20	30.25	30.76	30.9	32.22	28.93	31	30.34	30.05	31.27
Outside temperature (C)	33.09	31.49	31.70	31.11	32	32.80	32.54	31.45	32.39	32.4	33.70	30.14	33	32	31.07	3270.
Internal humidity %	82..78	91.33	85.06	79.23	86	81.94	80.68	88.49	86.11	90.3	83	93.70	87	89	85	80.94
Outside humidity %	73.66	83.14	78.04	73.20	75.41	71.98	71.67	79.23	73.91	78.5	73.13	83	73.50	76.50	72.32	71.33
Internal and external temperature difference, %	4.61	4.23	3.45	2.97	4.55	4.45	4.29	3.96	5.29	4.85	4.58	4.18	6.45	5.45	4.91	4.54
Internal and external humidity difference, %	12.38	9.85	8.99	8.23	14.03	13.8	12.57	11.68	16.50	15.03	13.49	12.89	18.36	16.33	14.91	13.63
Mushroom status	getting wet	start to dry	dry	dry	getting wet	suitable	start to dry	dry	wet	wet	wet	wet	wet	wet	wet	wet

The performance test of the system

Test of the smart mushroom cultivation house compared to the traditional mushroom house. There were 3 types of Lingzhi shelves, namely A-shape type, condo type, and hanging type. The number of mushroom cubes on each shelf was 790 cubes, with a period of 4 months of one production cycle, with the measurement of the temperature, humidity, light, carbon dioxide content, and the consumption of water and electricity.

Economic analysis

An overall cost estimated on the cost of running a smart mushroom house compared to a regular mushroom house. It included the fixed and variable costs and analyzed the payback period.

Results

Closed smart mushroom cultivation

The control cabinet, it consisted of an electric control cabinet, a mushroom house control cabinet, an electric meter, a 220 V input level, a manual control unit to control 3 systems: the electrical system inside the house, the exhaust fan system, and the fog system, respectively. LCD showed the status of the control cabinet, and status indicators for fog pumps, fans, solenoid valves of roof sprinkler, and solenoid valves arranged from top to bottom as shown in Figure 4.

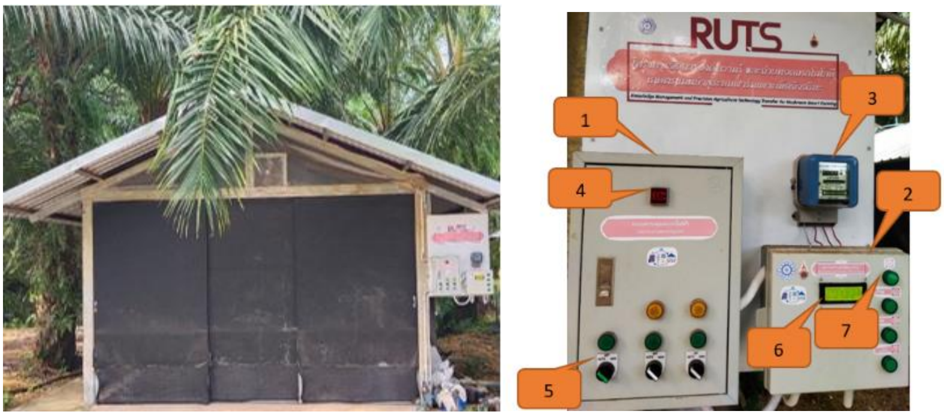


Figure 4. Closed Smart Mushroom Cultivation and Operation Control Cabinet

Application

The components were shown as A is the login page (Figure 5). B is the view parts of the system: the temperature and humidity gauge, graphs of temperature and humidity for both inside and outside the house, light intensity graph, and carbon dioxide curve. C is manual control, which controlled to select the operating mode, turn on and off the frog spraying system, turn off the fan system, and turn off the water system on the floor. D is light on/off environment setting which can set a range of temperature and humidity, suitable temperature, humidity and notify the working status through the LINE application.

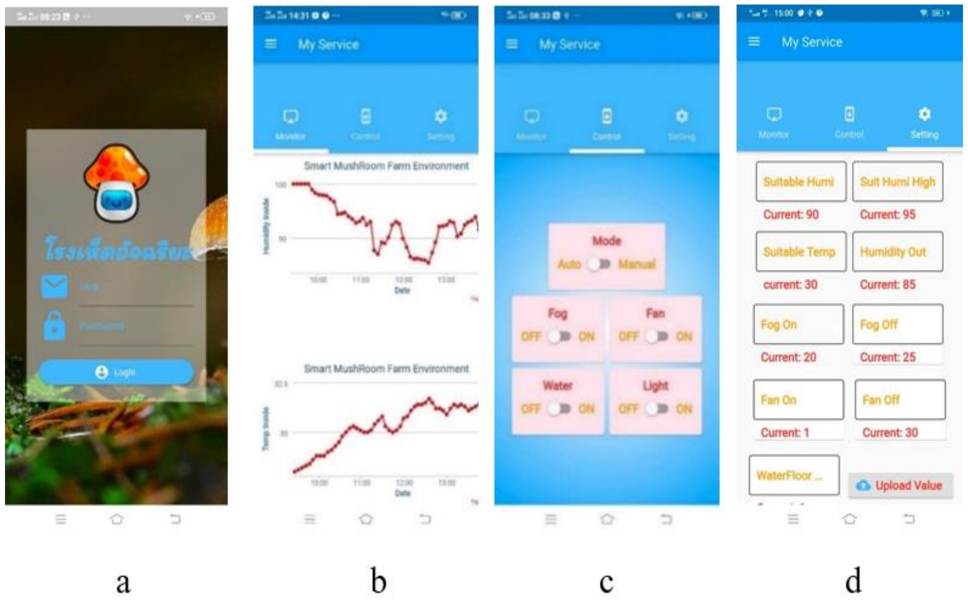


Figure 5. LINE application, a= Login, b = Monitor, c = Control system, and d = Setting

Graph showing the temperature, humidity, light, and carbon dioxide content during the daytime

Resukt showed that the gray graph was the graph of the temperature and humidity outside the house. The orange graph was a graph of temperature, humidity, light, and carbon dioxide content within a traditional house. The blue graph was the graph of temperature, humidity, light, and carbon dioxide content within the smart house.

It showed that the temperature comparison during the daytime in Figure 6. The averaged temperature inside the smart house was 29.22 ℃; the averaged indoor temperature of the traditional house was 31.80 ℃, and the averaged outdoor temperature was 33.02 ℃. The smart house was reduced temperature by 13% compared to the outside temperature, and 8.84% compared to the traditional house. It revealed that the humidity control system could reduce the humidity to a limited extent because the fogging system was turned on longer, and then the mushrooms would be too wet, all of which was a limitation of the system.

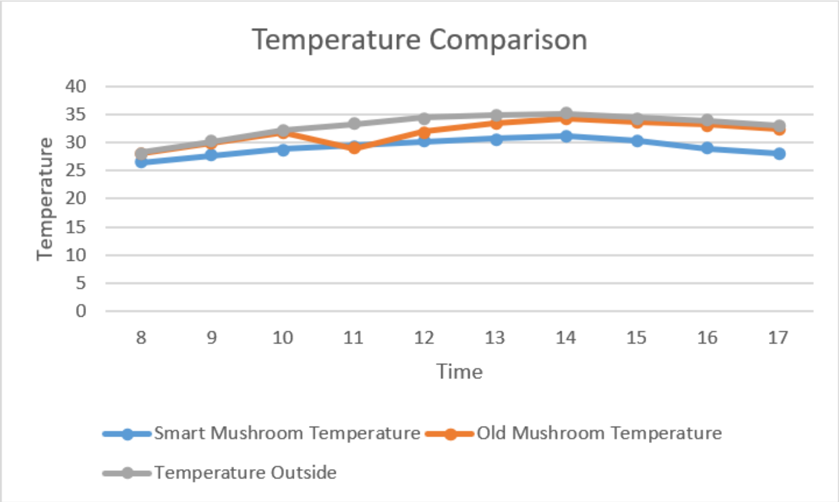


Figure 6. The graph of Temperature Comparison

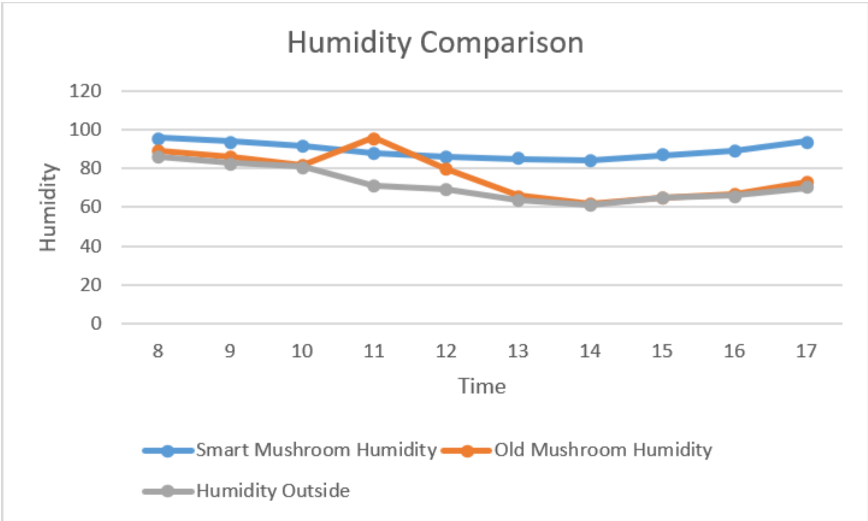


Figure 7. Graph of humidity comparison

Result showed the comparison of humidity during the daytime (Figure 7). The averaged indoor humidity of the smart house was 89.50%; the averaged indoor humidity of the traditional house was 76.60%, and the d outdoor humidity was 71.60 %. The smart house was reduced humidity by 25% compared to the outside temperature, and 16.80% compared to the traditional house. It showed that the humidity control system could reduce the humidity to a limited extent because the fogging system was turned on longer, and then the mushrooms would be too moisted.

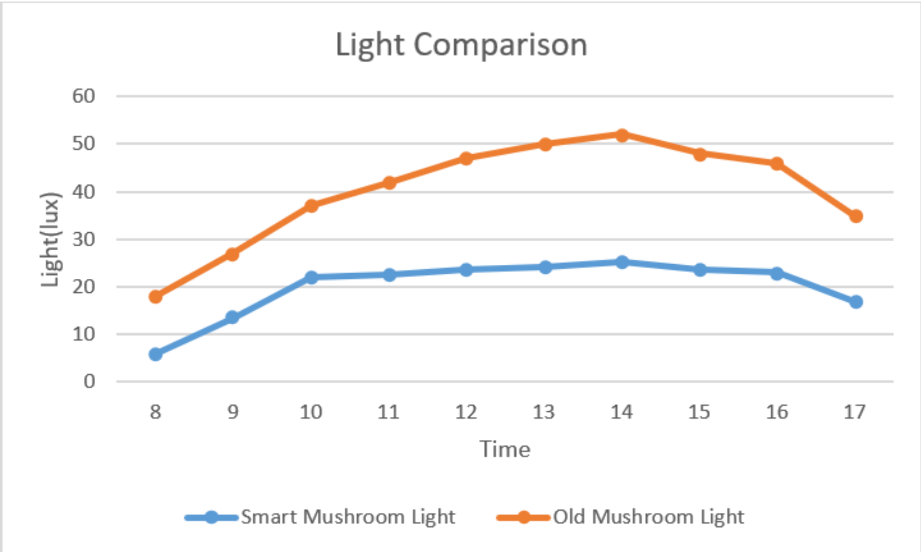


Figure 8. Graph of the light comparison

Resukt showed the light inside the smart house and the traditional house (Figure 8). It was found that the averaged light in the smart house was 20.06 lux, which was 100.39% less light than the traditional house, resulting in better temperature and humidity control. The averaged light in the traditional house was 40.20 lux. It was due to the smart house had the light in the front and rear gables of the house, while the traditional house allowed the light to enter all around the house via shading nets and through the open front and back gables, all of which gave the traditional house with more light than the smart house. It affected the temperature and humidity control in the traditional house more than the smart house.

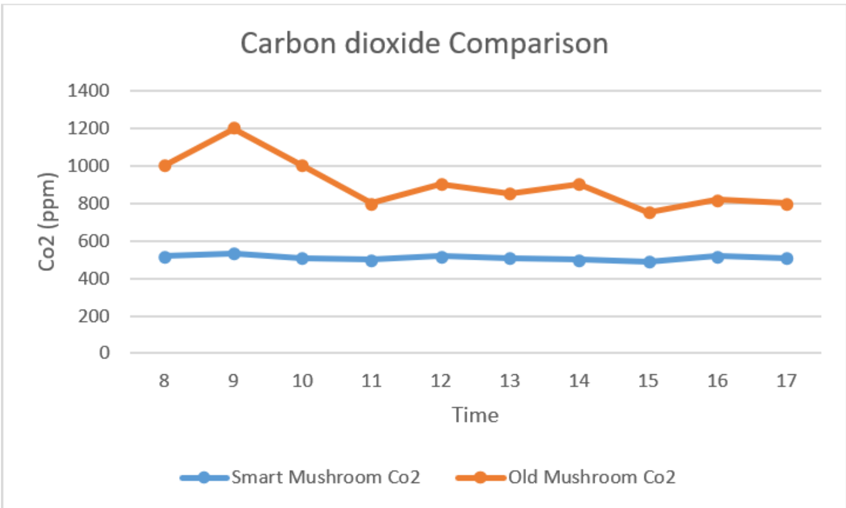


Figure 9. Graph of carbon dioxide comparison

Result showed the carbon dioxide content of the smart house and the traditional house (Figure 9). It was found that the averaged carbon dioxide content of the smart house was 511 ppm, the averaged traditional house was 902 ppm, and the smart house controlled the carbon dioxide within the house 76.51% better than the traditional house, both of which were good for Lingzhi growth. However, the smart house maintained a constant level of carbon dioxide due to the design of the house to circulate air from the bottom up and the fan system to exhaust the carbon dioxide gas.

Economic analysis results

The engineering economic analysis was sown in Table 4. The price of the smart mushroom control equipment was 13,000 baht; the useful life would be in 5 years; the interest rate or opportunity cost was 10%. The fixed cost per year was 3,055 baht per year, the total variable cost was 3,782.40 baht per year, total cost was 6,837.40 baht per year, the net benefit of 66,122.60 baht per year, with a payback period of 2.3 months.

Table 4. The engineering economics calculation of mart mushroom cultivation house

Description	Cost
Fixed Cost	
Price of Smart Mushroom Control Equipment (P)	13,000baht
The value of the Smart Mushroom Cultivation House at the end of Year *5*is *10*percent of the cost price (S)	1,300baht
Depreciation (DP) = (P-S)/L	***2, 300***baht
Interest or opportunity cost (I) = (P+S)/2 x (10/100)	715baht
Total fixed cost per year = depreciation + interest or opportunity cost	3,055baht/year
Variable Cost	
Maintenance cost is averaged *10*baht per day, working *240*days per year	***2***,4 ***00***baht/year
Average electricity cost *0.12*kWh, electricity price *3.5*baht per unit in *1*year, Working *240*days, and *24*hours a day.	806.4 ***0*** baht/year
Average water cost *0.02*units per hour, price of water *5*baht per unit in *1*year, working *240*days, and *24*hours a day	576baht/year
Total variable cost	3,782.40 baht/year
Total Cost	***6, 837.40*** baht/year
Benefits received (scheduled to hire a care worker for *300*baht per day, *1*person, and working *240*days)	72, ***000*** baht/year
Average water value *0.10*units per hour, price of water *5*baht per unit in *1*year, working *240*days, and *8*hours a day	960baht/year
Total benefit received	***72***,960 baht/year
Net Benefit	66,122.60 baht/year
Payback Period	***2.3***months

The yield of Lingzhies from the smart mushroom cultivation house

The front of the smart house is shown in Figure 12, and the right was the inside of the house which had a fogging system and a sprinkler system on the floor. The yield of Lingzhies showed that the total of 77.80 kg in the smart house was 50.19% more than the traditional house as shown in Table 5. The A-shaped shelf had 89.75% of fruiting mushroom cubes, with the highest yield at 35.20 kilograms, followed by a condo-shaped shelf with 65.33% of fruiting mushroom cubes for 30.20 kilograms, and the last was a hanging shelf with fruiting mushroom cubes for 57.06 % amounted to 12.50 kg.

Figure 10. The yield of Lingzhies from the smart mushroom cultivation House

Table 5. Comparison between of the yield production of the Lingzhi traditional cultivation house and the smart mushroom cultivation house

The Smart Mushroom Cultivation House				**The Traditional Mushroom Cultivation House**			
Total of *2, 370*mushroom cubes				Total of ***2, 370***mushroom cubes			
Placement	Fruiting mushrooms, %	Not fruiting mushrooms, %	Yield (kg.)	Placement	Fruiting mushrooms, %	Not fruiting mushrooms, %	Yield (kg.)
A-shape type	***89.75***	***10.25***	***35.2*0**	A-shape type	***59.87***	***40.12***	***21.6*0**
Condo Type	***65.33***	***34.66***	***30.2*0**	Condo Type	***57.84***	***42.15***	***23.4*0**
Hanging type	***57.06***	***42.93***	*124.*0	Hanging type	***42.16***	***57.83***	***6.8*0**
Total			*778.*0	Total			***51.8*0**

Discussion

Smart Lingzhi Cultivation House controlled through the developed online application could be operated in 2 modes: automatic and manual modes. They could control the temperature and humidity through the fogging system, roof sprinkler system, and sprinklers on the floor. The carbon dioxide content was controlled through a house design that circulates air from the bottom of the house to the top through an exhaust fan system. The graphs of temperature, humidity, carbon dioxide content, and light inside the house, could be observed. Temperature and humidity controlled with the fogging system gave the best situation to control the temperature and humidity by turning on the fogging system, roof sprinkler, and sprinklers on the ground at the same time. Intermittent fog spraying kept spraying fog for 15 seconds and stopping spraying for 15 minutes, and kept continuously operating until the humidity set in automatic mode was in the range of 90-95%, and the temperature did not exceed 30 ℃. The ventilation fan system was performed only when the humidity exceeded 95%, or the carbon dioxide exceeded 1000 PPM. Humidity control was 16.80 % more controllable than a traditional house. Temperature control was better than a traditional house for 8.84%. It was consistent with the research by Naimurrokhman *et al.* (2020), on the Development of Temperature and Humidity Control System in Internet-of-Things based Oyster Mushroom Cultivation. It was found that using a fogging system to control humidity temperature in a mushroom cultivation house could increase humidity and reduced the temperature in the house.It was consistent with the research by Ariffin *et al.* (2020) on the Automatic Climate Control for Mushroom Cultivation Using IoT Approach. The system could be observed how does it works automatically, good in controlling the temperature and humidity, low cost, and reduce the use of labor. In terms of carbon dioxide emissions, the smart house was controlled 76.51% better than the traditional house due to the recirculation of air with exhaust fans and the house design. The light inside the smart house was 100.39% less than the traditional house, allowing temperature and humidity more in control. In terms of cost-effectiveness analysis in engineering, it was found that the payback period was 2.3 months. In terms of yield, the yield could be increased by 50.06%, and the quality of the mushrooms was improved by receiving large mushrooms, and weight gain. It was consistent with the research by Arreerard *et al.* (2020) on the IoT System for humidity and temperature monitoring to promote cultivation of mushrooms of Mushrooms in greenhouses to have a complete product. The research had been developed an IoT system for monitoring humidity and temperature to promote flourishing mushrooms in a cultivation house by using a fog spraying system, a heat dissipation system, and an air suction system, to control the temperature and humidity in mushroom cultivation. It was found to increase productivity, and the mushrooms were good in weight. It was consistent with the research by Tantrabundit *et al.* (2020) on the Technology acceptance model: the evidence of nodemcu's mushroom house control system in Thailand. It was found that productivity increased by 15%, saving time, water, energy, and labor. The A-shaped shelf for mushroom cubes had the highest fruiting rate of 89.75% due to proper humidity exposure. The A-shaped shelf was like a ladder, it could absorb the humidity most thoroughly. From research results, humidity control with a fog spraying system had advantages: low system cost compared to the evaporative cooling system (EVAP), easy to install, and easy to maintain. However, there was a limitation in temperature and humidity control. If the fogging system was turned on for too long, the mushrooms would be too moisted. The mushrooms could be rotten and diseased. If the fog is sprayed at an appropriate interval time, it would solve the problem. It was advisable to construct a mushroom house under the shades of trees or partially shaded sunlight to allow the system to retain moisture and resulted in better performance.

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