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Research Article

Development and Cost-Effectiveness Analysis of a Fogging Pump Control System Commercial Prototype for Oyster Mushroom Cultivation based on Open-System Greenhouse

Non Pinngern[1], Bhannawat Wanganusorn[2,*]

[1] Department of Digital Business Innovation, Faculty of Business Administration, Maejo University, Chiang Mai 50290, Thailand
[2] Department of Finance, Faculty of Business Administration, Maejo University, Chiang Mai 50290, Thailand
* Corresponding author: Bhannawat Wanganusorn, payothust56@gmail.com

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Abstract: This study proposes a commercial development model for a fogging pump control system (FPCS) for oyster mushroom cultivation in open-system greenhouses, which are the most common type of greenhouses used for mushroom cultivation in Thailand. A prototype system was developed using a commercially available controller that was modified to make it easier to produce in large quantities. The system was designed with two separate components: The first component controlled the operation of the fog pump by alternating between spraying and pausing to maintain the desired humidity. It also acted as an access point to release a Wi-Fi signal that allowed users to access the system settings via a website. The second component was installed in the mushroom greenhouse and sent weather data from sensors to the first component via Wi-Fi. The whole system does not require internet usage. The prototype system was tested in an oyster mushroom greenhouse for 60 days. The results showed that the system was easy to install and operate in commercial mushroom farms. It was also effective in controlling humidity for oyster mushroom cultivation. An economic analysis of the system showed that it could help farmers to reduce unit costs by up to 72.30%. The system also had a positive net present value (NPV) of +332,600, an internal rate of return (IRR) of 281%, and a payback period of one production cycle (2 months). These results suggest

that the proposed FPCS is suitable for commercial production for controlling humidity in oyster mushroom cultivation in open-system greenhouses.

1. Introduction

Oyster mushrooms are an economically important mushroom species in Thailand, with two popular varieties among farmers: Hungarian oyster mushrooms and Bhutan oyster mushrooms. These mushrooms are typically cultivated by allowing the mycelium to consume nutrients from sterilized substrate materials inside plastic bags. Once the mycelium has fully colonized the bags, the bags have been opened to allow the mushrooms to grow in a suitable environment. Oyster mushrooms thrive in relatively cool temperatures, ideally between 20 to 30 degrees Celsius, and require humidity levels ranging from 55 to 70 percent (Laead-on, 2021). They can grow well in Thailand throughout most seasons, except during the summer (Isaranontakul & Rukphong, 2019). Creating a suitable environment for mushroom growth is crucial, considering factors such as temperature, humidity, carbon dioxide levels, and air circulation (Vengsungnle *et al*., 2019).

Currently, there are two types of mushroom cultivation houses: open-system greenhouses and close-system greenhouses. The advantage of the open-system is that it requires lower investment compared to the close-system. On the other hand, the close-system greenhouses allow farmers to have better control over the internal conditions of the greenhouses, such as temperature, humidity, light exposure, and carbon dioxide levels (Jongpluempiti *et al*., 2020). Although the close-system offers better controllability, many Thai farmers still prefer the open-system greenhouses due to their lower cost. The open- system greenhouses can be constructed using locally available and low-cost materials such as bamboo, eucalyptus wood, vetiver grass, plastic, and sun shade net. Proper design of the open-system greenhouses could also help reduce external heat, effectively retain moisture, and facilitate air circulation (Arreerard, T., Arreerard, W, & Ruangsan, 2021).

Once the mushroom bags are placed in a suitable cultivation house, a crucial subsequent process is providing moisture to the mushrooms. Traditionally, farmers use a hose to water the entire floor of the house, avoiding direct contact with the mushroom bags and preventing waterlogging at the surface of the bag. This practice aims to prevent direct exposure of water to the mushroom caps, as well as to avoid excessive moisture, which can lead to unwanted characteristics in the mushrooms that are undesirable in the market. The frequency of watering depends on the humidity level inside the cultivation house. If the humidity is high, watering may occur just twice a day, in the morning and afternoon. However, in low humidity conditions, farmers may need to water more frequently, possibly 3-5 times a day. Farmers typically observe the drying edges of the mushroom caps as an indicator to start watering (Lorprasert, 2010).

Due to the traditional method of providing moisture relying heavily on their experience, time, and labor of farmers, there had been a development to modernize moisture provision in mushroom greenhouses. It was found that using very fine water mist in greenhouses shaded from direct sunlight with good air circulation not only increased relative humidity but also effectively reduced greenhouse temperature (Saowarat, 2017). Consequently, fogging systems had been combined with automated control systems for moisture provision in mushroom greenhouses. Jongpluempiti *et al*. (2020) recommended using humidity and temperature as conditions for controlling fogging and ventilation fan equipment in the greenhouse, as it promoted optimal mushroom growth. Precise environmental control led to significantly higher mushroom yields, up to 30% more than conventional cultivation, with minimal contamination rates (Arreerard, T., Arreerard, W, & Ruangsan, 2021; Marzuki & Ying, 2017; Ten *et al*., 2021). Hendrawan *et al*. (2019) applied fuzzy logic to control equipment sets, achieving quick entry into steady-state operation, and thereby enhancing system efficiency. In addition to automated control, users could monitor and adjust settings remotely via various mobile devices, using Internet of Things (IoT) technology. This diverse functionality allowed for remote operation of equipment in mushroom greenhouses, such as remoted pump fogging on/off control and automated scheduling (Isaranontakul & Rukphong, 2019). Processing and controlling were carried out by microcontrollers equipped with ESP8266 chips, connected to sensors for environmental data collection within the greenhouse (Fongngen *et al*., 2018). These microcontrollers were cost-effective and feature wireless data transmission compliant with IEEE 802.11 b/g/n standards or Wi-Fi (Patnaikuni, 2017). Furthermore, there is currently development of robots for detecting fungal diseases and sending alerts via Internet signals. These robots can operate with precision by utilizing deep learning (Jareanpon *et al*., 2023; Patcharee & Suchart, 2022), leading to efficient reduction of production losses.

However, the researchers believe that the systems mentioned above still have three limitations for practical use for farmers. These are:

1) Sensor cable length and range limitations: In most farmers' farms, there is a considerable distance between the greenhouse and the water pumps. Therefore, using digital data transmission cables from sensors to controllers regulating the pumps can be challenging because long cables are required. These cables are often hard to find and come at a high cost. Generally, the data transmission cables used with sensors that are readily available have a length of no more than 1 meter (Adafruit Industries, n.d.; ET TEAM, n.d.). This limitation makes it inconvenient to install in actual mushroom farms, especially in greenhouses with long distances between the sensors and the water pump installation points.

2) Uncertainty in investment: Most farmers lack high-speed internet access in their farms. Using IoT technology would require additional expenses for internet installation and services, increasing the overall production costs. Moreover, in preceding research on the cost-effectiveness of mushroom cultivation, the predominant focus has been on the comprehensive expenses linked to mushroom farming (Duangta, 2016; Ruamtum & Tulasombat, 2019; Thaneerananon & Vilalai, 2019; Hongyon, 2019). These studies traditionally delve into the costs associated with constructing mushroom houses, production expenses, total expenditures, and unit costs to evaluate profitability. However, they may lack of undertaking a comparative analysis of costs and benefits when transitioning to a new process, where automatic system is employed as opposed to the traditional method. This lack of comparison between the cost and benefits of the two methods introduces uncertainty regarding the return on investment. This uncertainty raises apprehensions among farmers, as they are uncertain whether the investment in the new method would prove cost-effective in comparison to traditional mushroom cultivation practices.

3) Complexity in device assembly: Developing a control system involves purchasing and assembling multiple electronic components. This complexity makes it challenging to create a ready-made device, resulting in higher costs and difficulty in large-scale production.

Further research has found that the basic features of Wi-Fi connectivity for ESP8266 microcontrollers can be developed to allow data transfer between microcontrollers in a Wireless Local Area Network (WLAN). This can be achieved by using the first microcontroller as an access point (AP) and the second microcontroller as a wireless station (STA) (Zhou, 2017). The standard Wi-Fi range of 40 meters can be achieved with efficient data transfer. Installing additional antennas can extend the data transfer range up to 140 meters in open areas (Yoppy *et al*., 2018). Moreover, the Access Point microcontroller can function as a web server, enabling users to access and adjust system settings through various devices using a web browser interface. This capability enhances the flexibility and accessibility of the control system, allowing users to manage settings remotely via web browsers on different devices.

Currently, there is a development of control devices in the form of ready-made kits for convenient use. One such device is called Sonoff, which includes a microcontroller with the ESP8266 chip, a relay, and a 220-volt power converter. This product is manufactured by Itead Intelligent Systems Co. LTD, Shenzhen, China, and is compatible with the eWeLink application. However, developers have the flexibility to modify and customize the firmware themselves based on ESP8266 programming (Froiz-Míguez *et al*., 2018). Gutiérrez-Peña *et al*. (2020) proposed the use of Sonoff to connect with electrical devices for the development of an energy management system in smart homes. Sonoff is preferred due to its convenience and cost-effectiveness, and it can be easily interfaced with sensors, allowing for firmware customization. Subsequently, García-Vázquez *et al*. (2021) modified the Sonoff kit to control electrical devices within their software platform, named e-Switch.

2. Research Objective

The purpose of this research was to develop the commercial prototype for an automated fogging pump control system (FPCS) and cost-effectiveness analysis of using this equipment for humidity control in commercial mushroom open-system greenhouses. The main focus was on addressing three key issues:

1) Convenience of installation in mushroom farms.

2) Operation without an internet connection.

3) Low cost and easy production for commercial use.

3. Materials and Methods

This research is an experimental research aimed at developing a prototype and analyzing the cost-effectiveness of a fogging pump control system installed separately for providing moisture to oyster mushroom cultivation in open-system greenhouses. The population and sample group used in the research consist of commercial mushroom farmers who cultivate oyster mushrooms in plastic bags. The research employed a specifically targeted sampling method to select farmers who were ready to adopt the technology and had similar open-system greenhouse structures, using two identical greenhouses for comparing different moisture provisions. Specifically, greenhouse 1 provided moisture to the mushrooms using the traditional method of manually watering with a hose in an open-system greenhouse. On the other hand, greenhouse 2 provided moisture to the mushrooms using an FPCS prototype developed to regulate moisture automatically. The oyster mushroom usually grow well throughout most seasons, except during the summer in Thailand due to the high temperatures, which are challenging for oyster mushroom cultivation (Isaranontakul & Rukphong, 2019). In this experiment, testing was conducted during the summer in Thailand because it is considered the most challenging period for controlling the environment in open-system greenhouses. The research process involved six stages: 1) designing the architecture of the system, 2) designing the system’s workflow, 3) selecting suitable materials and equipment, 4) software development, 5) installation in mushroom farms for testing, and 6) data collection and analysis. The details are as follows:

3.1 Designing the Architecture of the System

In each mushroom farm, there are varying sizes of open-system greenhouses and different water system arrangements.

Therefore, the equipment set should possess the flexibility to be adequately adaptable for installation in each farm. The researchers aimed to design a system that could be conveniently installed without reliance on the internet network for operation. They divided the equipment into 2 sets:

Set 1 comprises devices to be installed with the fogging pump, consisting of a microcontroller that serves 3 main functions:

1) Acting as an access point to release Wi-Fi signals and support wireless network connections.

2) Serving as a web server to allow users to access the system's operational settings. Users can access this website via web browser programs through various mobile devices like personal computers, laptops, smartphones, or tablets connected to the access point.

3) Control the electrical current to enable the fogging pump to operate according to conditions.

Set 2 comprises devices to be installed within the mushroom greenhouse, including a microcontroller acting as a wireless station to transmit data read from sensors to Set 1 via Wi-Fi signals, as depicted in the system architecture shown in Figure 1.

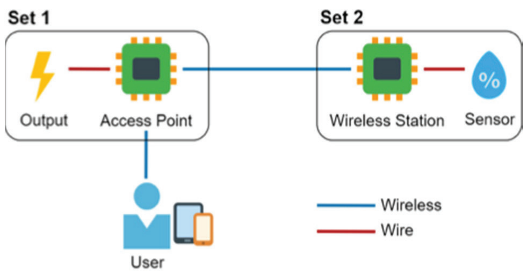


Figure 1. System Architecture

3.2 Designing workflow of the system

Due to the requirement of mushrooms for suitable moisture without an excess amount of water trapped around the mycelium, which could lead to waterlogged mushrooms and deteriorated mycelium, the researchers devised a fogging control method alternating between spraying and intervals. This approach aimed to prevent an excess of water within the greenhouse that could damage the produce.

The workflow of Set 1 initiates by activating the access point to distribute Wi-Fi signals and await connections. It then reads operational data used for controlling the fogging pump stored in the memory unit, including the minimum relative humidity to initiate pump operation, pump on-time (seconds), and pump off-time (seconds). Subsequently, it enters a repetitive cycle, awaiting sensor data transmitted from Set 2. Upon receiving data, it checks the operating conditions, primarily utilizing air relative humidity as the sole factor for control conditions due to this research's focus on misting solely to provide humidity in open-style mushroom greenhouses. When the sensed humidity falls below the set threshold, the control unit commands the pump to alternate between on and off states based on the predetermined operation

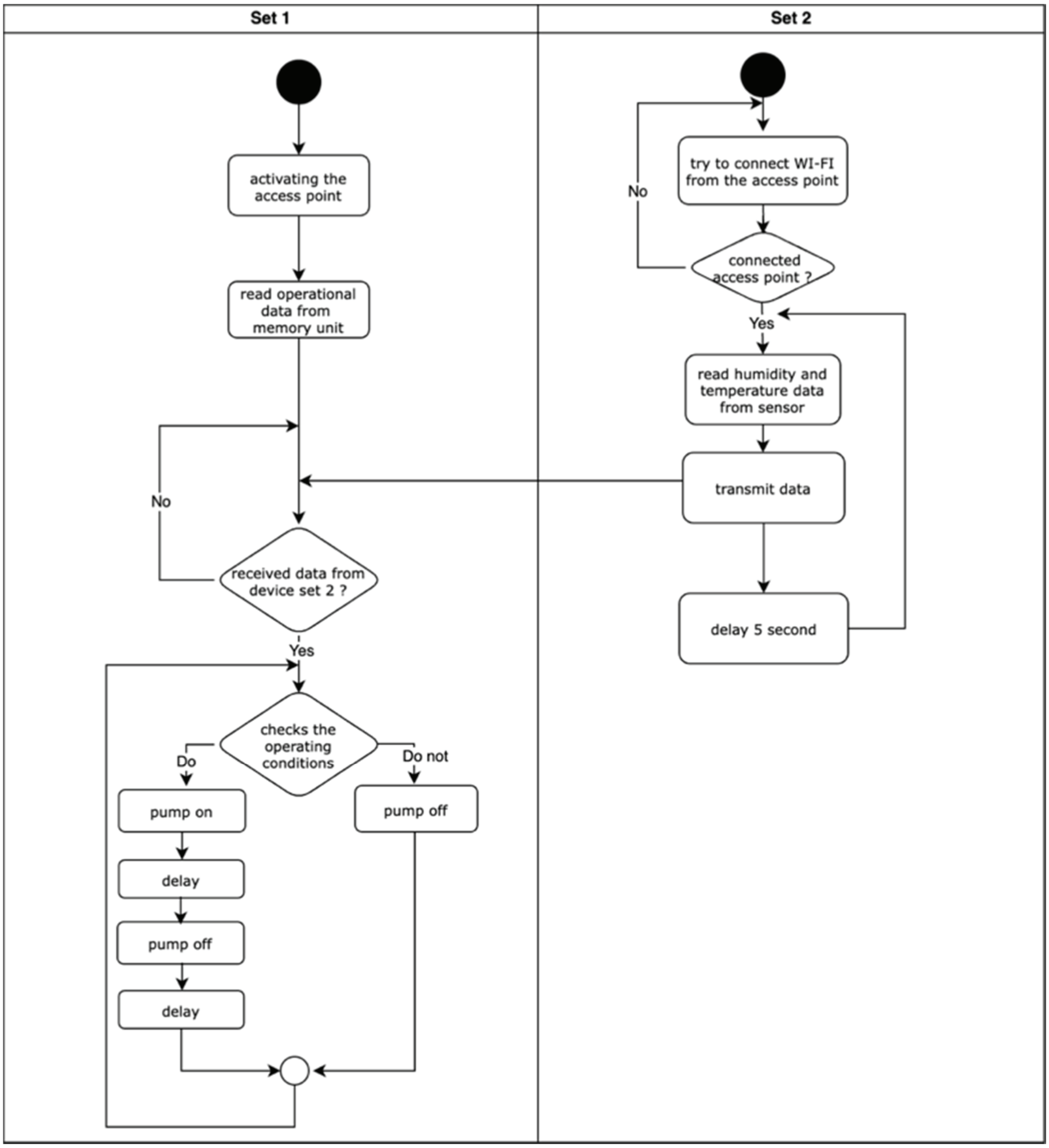


Figure 2. Workflow of the system

parameters. Conversely, if the sensed humidity equals or exceeds the set value, indicating sufficient moisture in the greenhouse, the system directs the pump to stop.

The sequence of operations for Set 2 starts with connecting to the Wi-Fi signal emitted by the access point of Set 1. It then enters a loop, reading humidity and temperature data from sensors to transmit this data to Set 1. After a 5-second interval, it proceeds to read the next set of data, as illustrated in the workflow of the system in Figure 2.

3.3 Selecting suitable materials and equipment

From the aforementioned design, the pivotal component in each equipment set was the micro-controller. Its functioned encompass data processing, communication via Wi-Fi signals, sensor data retrieval, and electrical device control. To meet these requirements, the preferred microcontroller for cost-effective control applications was the ESP8266 chip-based microcontroller. However, this control unit required to be supplemented with various other devices to operate comprehensively.

Following an examination of commercially available equipment that met the desired specifications, the researchers opted for the pre-assembled electrical control equipment, Sonoff. This set included fundamental components essential for complete control systems. These components consist of the ESP8266 chip-based micro-controller, a 3.3-volt power supply for board operation, a 220-volt relay, a push button, and status indicator lights. Specifically, the researchers chose the Sonoff Basic R2 model for Equipment Set 1 and the TH10 model for Equipment Set 2 due to the presence of a 3.5-millimeter jack (ITEAD Studio, n.d.).

These selections were made to collaborate with the SHT15 sensor, capable of measuring temperature and humidity within a single unit. This sensor can operate within a temperature range of -40 to 123.8 degrees Celsius, providing data accuracy to two decimal places with a precision of 0.3 degrees Celsius (Liu, Zhang, & Zhu, 2011).

3.4 Software Development

This study has developed the program based on the designed architecture. The processing part of the program was written in the C++ language, while the user interface was developed using HTML and JavaScript to display and function on web browsers. Afterward, the source code was installed on the microcontroller, and the equipment set

(a) (b)

Figure 3. (a) Sonoff Basic R2 model, (b) Sonoff TH10 model (ITEAD Studio, n.d.)

Figure 4. Completed prototype kit

Figure 5. Connecting to Wi-Fi from the set 1 of devices using a smartphone and the user interface displayed on the web browser

was assembled to completion, and ready for use, as shown in Figure 4.

The researchers conducted preliminary system functionality tests in a laboratory setting. They utilized a smartphone connected to the Wi-Fi emitted by the access point of Equipment Set 1. Accessing the web browser program and entering the designated IP address, 192.168.4.1, displayed the user interface web page. The initial page exhibited air temperature and humidity obtained from the SHT15 sensor installed within Equipment Set 2. Users could adjust control conditions for the fogging pump, with settings available for: 1) minimum air relative humidity to initiate pump operation, 2) pump operational duration, and 3) pump resting duration, as shown in Figure 5.

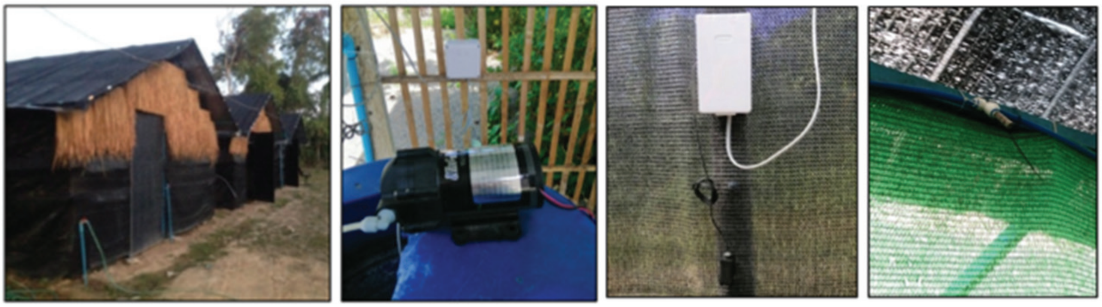
The researchers set initial parameters for testing purposes and observed the sequential operational process for a total of 5 days, each day running for 12 hours. The findings indicated that the equipment functioned as anticipated, as shown in the preliminary system functionality test results in Table 1.

3.5 Installation in the Mushroom Greenhouse for Testing

After conducting preliminary system operation tests in the laboratory, the researchers developed a prototype system for installation and testing in the mushroom cultivation farm of a targeted group of farmers. The testing took place with farmers cultivating Bhutan oyster mushrooms in the Sansai district of Chiang Mai province, using an open-system greenhouse measuring 8x10 meters. The greenhouse was constructed with a plastic roof, and plastic and mesh walls, as shown in Figure 6.

Table 1. Preliminary system operation test results

Test Number	Test Item	Test Result
1	Equipment set connection	Functioning correctly
2	Operation based on humidity conditions	Functioning correctly
3	Pump operating time according to set value	Functioning correctly
4	Pump resting time according to set value	Functioning correctly



(a) (b) (c) (d)

Figure 6. (a) The greenhouse, (b) Installation of the set 1 of equipment to control the fogging pump, (c) the set 2 of sensors, (d) the mist spray head

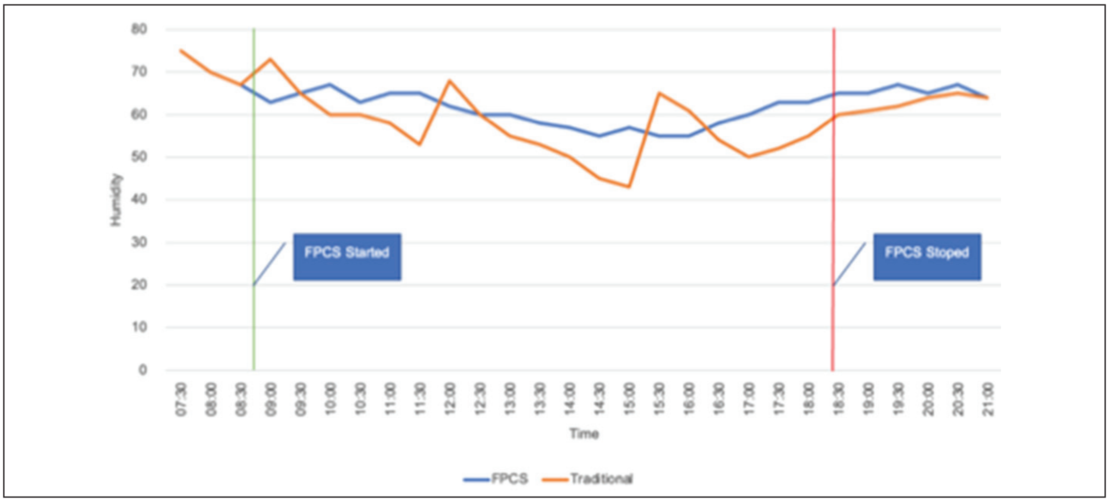


Figure 7. Comparison of the 2 moisture-providing methods

In the actual installation on the farm, the researchers installed the humidity control equipment developed along with a fogging pump with a pressure of 15 bars, low-pressure hoses, and misting nozzles with a size of 0.2 millimeters. They also set up a 200-liter plastic water tank, a floating ball valve for automatic water filling, and pressure reduction devices to suit the number of misting nozzles installed in each greenhouse. The misting nozzles were installed at a distance of 1 meter apart, and the equipment sets were spaced 25 meters apart from each other in each greenhouse.

Afterwards the researchers recorded the humidity data of both of the 2 test houses and observed the traditional watering method of farmers by using hoses, which relied on observation and experience. The researcher found that farmers would start watering for the first time in the late morning when the humidity in the air decreased to a level that began to cause the mushroom flowers to dry out. From the recorded data, it was found that the average humidity at that time was 65%. Subsequently, the researcher adjusted the equipment's working conditions to match those of the farmers, working when the humidity was less than 65% and spraying mist for 20 seconds alternated with a 40-second pause. When left to work continuously automatically throughout the day, it was found that providing moisture was as effective as watering by farmers. The system would stop automatically in the evening when natural humidity began to increase. This demonstrates a performance comparison of the 2 moisture-providing methods as shown in Figure 7.

3.6 Data Collection and Analysis

This research involves data collection for analysis in two aspects: collecting information on system testing and data accumulation for cost-effectiveness analysis. The data was collected from March to April which is the summer of Thailand. The details are as follows:

3.6.1 Data Collection for System Testing

The researchers designed the system operation tests to cover 3 areas: 1) Usability Testing, 2) Performance Testing, and 3) Reliability Testing (Murad *et al*., 2018). The recording procedures for device operations were designed in accordance with the test objectives. After installing the equipment, farmers were requested to observe the equipment's performance while working in the greenhouse and to record data daily. The recorded observations centered around four aspects: 1) equipment connectivity, visible through the device's indicator lights; 2) operation concerning predefined humidity conditions; 3) operational duration aligned with preset values; and 4) pump stoppage time according to set criteria.

3.6.2 Data Collection for Cost-Effectiveness Analysis

This research gathered production cost and yield data by conducting interviews with target farmers using open-ended questions. The cost-benefit analysis included: 1) Analyzing manufacturing costs per unit, 2) Assessing production efficiency using T-test statistics for comparison (Tiparat *et al*., 2018), and 3) Evaluating investment returns, considering Payback Period (PB), Net Present Value (NPV), and Internal Rate of Return (IRR).

4. Results and Discussion

The study was divided into 2 parts: Part 1 focused on system testing results, while Part 2 delved into the cost-effectiveness analysis findings.

4.1 System Testing Results

The results of the system testing include the analysis of usability testing, system efficiency testing, and system reliability testing. The details are as follows:

4.1.1 Usability Testing

The prototype and developed system were user-friendly, allowing farmers to install it in mushroom farms easily. The wireless data transmission between devices worked efficiently in the actual farm environment. Farmers quickly grasped the user interface, demonstrating the accuracy and suitability of the developed system.

4.1.2 System Efficiency Testing

Over a period of 60 days, the yield of mushroom in the greenhouse equipped with the developed system was significantly higher compared to the yield from the greenhouse using the traditional humidity provision system. This indicates that the developed system could effectively substitute the traditional watering system used by farmers. It autonomously controlled the fogging pump operation based on the air's humidity, which would be highly beneficial for farmers in coping with the current weather variability. Previously being reliant on manual labor and experience, this developed system can significantly reduce labor costs for humidity provision and enhance mushroom production.

4.1.3 System Reliability Testing

Throughout the actual operation over a period of 60 days, the equipment might have encountered unsuitable conditions for operation, such as high humidity and temperature within the greenhouse. Continuous usage may lead to malfunctions. However, the developed prototype set could still perform accurately and precisely as anticipated. This demonstrates that the selected equipment set was durable and suitable for practical use in mushroom farming. In the case of the test farm, over a period of 60 days, there were a few instances of power outages, and each outage was of short duration.

Additionally, the greenhouse utilized effective moisture-retaining materials, resulting in minimal impact on humidity levels inside the mushroom house and no significant damage to mushroom production.

The test results indicated that the equipment could effectively regulate the operation of the low-pressure fogging pump to provide moisture to the mushrooms in the greenhouse. It performed comparably to the original system that relied on manual labor, operating accurately and reliably.

4.2 Results of Cost-Benefit Analysis

The results of the cost-benefit analysis included the analysis of manufacturing costs, production efficiency, and return on investment. The details are as follows:

4.2.1 Manufacturing Costs

Based on the cost calculations for the manufacturing components of the product at a production level of 1,000 mushroom bags, categorized by the production system, the traditional system incurred direct material costs of 7,000 Baht, labor costs of 20,250 Baht, and overhead expenses of 307.82 Baht, totaling 27,557.82 Baht. This resulted in a cost per mushroom bag of 27.55 Baht.

In contrast, the automated mushroom cultivation system incurred equipment investment costs of 7,260 Baht, as shown in Table 2. The depreciation expenses for production, amounted to 403.33 Baht. This brings the total cost to 7,636.24 Baht and a cost per mushroom bag of 7.63 Baht.

A comparison of the two systems revealed that the use of the automated system enhances production efficiency, leading to a reduction in manufacturing costs per unit of up to 72.30% [(7.63 – 27.55)/27.55*100].

Table 3 presents details of manufacturing cost calculation.

Table 2. Investment in the control system for the fogging pump kit prototype

Item	Price (Baht)	Quantity	Unit	Total (Baht)
Sonoff TH16 Model 1 Set	115	1	Set	115
Sonoff Basic R2 Model 1 Set	200	1	Set	200
SHT15 Sensor 1 Set	750	1	Set	750
Electrical Wires	10	2	Meter	20
Water Pump 15 Bar	1,700	1	Set	1,700
Low-Pressure Water Hose	15	40	Meter	600
0.2mm Nozzle	78	20	Set	1,600
200-Liter Plastic Tank	500	1	Tank	500
Automatic Float	100	1	Set	100
Assembly Labor Cost	-	-	-	1,675
Total Equipment Investment				**7,260**

Note: Retrieved September 19, 2023 from https://www.shopee.co.th

Table 3. Details of manufacturing cost calculation

Item	Cost Calculation Method and Cost Value (in Baht)
Raw Materials: Mushroom Spawn	= Quantity of spawn at production level x Cost per spawn (in case of purchasing each spawn at 7 Baht) At the production level of 1,000 spawns: 1,000 x 7 = 7,000 Baht. At the production level of 5,000 spawns: 5,000 x 7 = 35,000 Baht
Direct Labor Cost: Irrigation	= Daily labor cost of 300 Baht, calculated per hour of work (8 hours), multiplied by the number of hours worked in one production cycle = HW x NW x NDP = 37.50 x 9 x 60 = 20,250 Baht HW; Hourly wage, NW; Number of working hours per day, NDP; Number of days in one production cycle. Not applicable as an FPCS is used.

Table 3. Details of manufacturing cost calculation (cont.)

Item	Cost Calculation Method and Cost Value (in Baht)
Overhead Expenses	**1) Depreciation Cost of FPCS** – Traditional watering is not applicable as no FPCS is installed. For the FPCS, calculated linear depreciation, with a service life of 3 years and no salvage value. Depreciation cost = FPCS 's cost / Number of years of use = 7,260 / 3 = 2,420 per year which 1 year contain 6 crops so the depreciation cost per crop = 2,420 /6 = 403.33 Baht **2) Water Cost Water cost** = [Water flow rate (liters/minute) x Irrigation time (minutes) x Number of irrigation cycles x Water rate (Baht)] For 1,000 spawns: [34.23 x 3 x 3 / 1,000] x 60 x Regional water service rate = 307.82 For 5,000 spawns: [34.23 x 10 x 3 /1,000] x 60 x Regional water service rate = 1,259.24 Baht **3) Electricity Cost** - No electricity cost for watering. Calculated electricity cost for the FPCS using a water pump and Sonoff devices. Pump electricity cost = Electrical power (watts) / 1000 x Number of hours used per production cycle (60 days) x Electricity rate = [220 / 1,000] x [(20 / 60] x (18.30-9.30) x 60 = 2,376 x Electricity rate = 136.98 Sonoff electricity cost = [1 / 1,000] x (18.30-9.30) x 60 = 0.54 x Electricity rate = 136.98 Baht
Total Manufacturing Cost	At the production level of 1,000 spawns: 7,000 + 20,250 + 307.82 = 27,557.82 Baht At the production level of 5,000 spawns: 35,000 + 20,250 + 1,259.24 = 56,509.24 Baht
Manufacturing Cost per Unit	At the production level of 1,000 spawns: 27.55 Baht At the production level of 5,000 spawns: 11.30 Baht At the production level of 1,000 spawns with FPCS: 7.63 Baht At the production level of 5,000 spawns with FPCS: 7.15 Baht

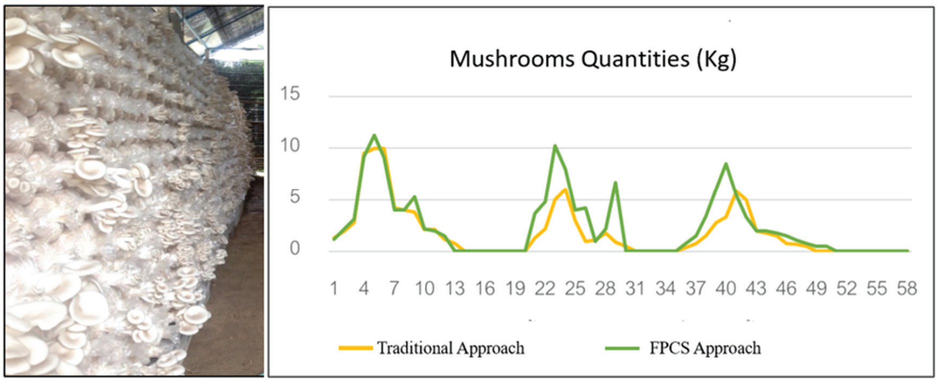


Figure 8. Daily mushroom production volume of Hungarian oyster mushrooms

4.2.2 Production Efficiency

Based on the collected data, the daily mushroom yield for each day of a production cycle (60 days) is shown in Figure 8. An analysis was conducted by comparing the average yields of mushrooms between the traditional system and the FPCS.

The traditional system showed an average yield of 2.55 kg with a standard deviation of 2.93 kg., while the FPCS showed an average yield of 3.41 kg with a standard deviation of 3.37 kg. When comparing them using an independent sample t-test, it was found that, on average, the yield from the traditional system did not significantly differ from the yield of the FPCS (P-value > 0.05), as shown in Table 4.

The traditional and FPCS, along with the t-value and significance level (Sig.) from the independent t-test. The results indicate that there is no significant difference in the average mushroom yield between the traditional and FPCS, as the p-value (Sig.) is greater than 0.05.

4.3.3 Return on Investment

This study involved the comparison of two distinct production systems, specifically the modification of the temperature and humidity control process between the conventional watering system and the FPCS. The FPCS entailed the utilization of human labor for watering. However, it is crucial to note that the implementation of the FPCS necessitates an additional investment, estimated at 7,260 Baht. Users are required to make this investment. The Return on Investment (ROI), derived from key financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PB), indicated a positive NPV of +332,600 Baht, an IRR of 281% (exceeding the 5% Weighted Average Cost of Capital), and a payback period within a one production cycle, as shown in Table 5. These findings suggested that transitioning from the traditional watering system to the FPCS was deemed viable and suitable for implementation.

Table 4. The results of the production efficiency analysis, specifically the weight of mushrooms harvested in one production cycle, measured in kilograms (kg)

Mushroom Variety	Traditional System (N=30)		Automatic Control System (N=30)		t	Sig.
	$\bar{X}$	S.D.	$\bar{X}$	S.D.		
	2.55	2.93	3.41	3.37	-1.058	0.295

Table 5. The results of the present value analysis by comparing the efficiency of replacing human labor

Item	Accounting profit (Baht)	Cash flow (Baht)
Cost Savings or Additional Income		
- Reduced Labor Costs	20,250	20,250
- Reduced Water Costs	211	211
Marginal Costs		
- Increased Depreciation (7,260-0/18)	-403	
- Maintenance Costs	- 50	- 50
Net Profit (Cash Flow)	20,008	20,411
Net Cash Flow for 1 Production Cycle		20,411
NPV & IRR Computing		
- Initial Outlay = 7,260 Baht		
- Cash flow from operation (per 1 production cycle) 6 times per year for 3 years total of 18 times with 20,411 Baht per time		
- The discount rate is 5% PA In this research Assume that farmers use 100% of the loan from BAAC. Therefore, WACC = 5% based on the interest rate on farmers' loans. of the Bank of Agriculture and Agricultural Cooperatives (BAAC), information as of 20 September 2018		
$\mathbf{NPV} = \sum_{t=1}^{n} \frac{\mathbf{CF_t}}{(\mathbf{1+r})^{\mathbf{t}}} - \mathbf{IO}$	= (20,411*16.65083) -7,260 = **+332,600**	
$\mathbf{NPV} = \sum_{t=1}^{n} \frac{\mathbf{CF_t}}{(\mathbf{1+IRR})^{\mathbf{t}}} - \mathbf{IO} = \mathbf{0}$	= **281%**	

5. Conclusions

The objective of this research was to propose a suitable model for developing a separate installation control system for fogging pumps to provide humidity for oyster mushroom cultivation, which was suitable for Thai farmers who primarily use open-system greenhouses and lack internet signal readiness on their farms. The researcher had presented a development approach using Sonoff devices, which were commercially available and cost-effective. The system was divided into 2 sets, utilizing Wi-Fi signals for communication within the wireless network. Set 1 served as an access point to emit Wi-Fi signals and support connections, functioning as a web server for user access to system settings. It controlled the release of electricity to manage fogging pump operations. Set 2 was connected to the sensor inside the mushroom house, sending readable data to Set 1. Farmers can access the system settings using smartphones via Wi-Fi signals, eliminating the need for internet connectivity for operation.

The developed system could be easily assembled and practically installed in mushroom farms. It efficiently controlled the humidity for oyster mushrooms in the summer of Thailand, which has been considered unsuitable for the growth of oyster mushrooms, replacing the manual labor required for watering. The system was suitable for large-scale production and was cost-effective.

The cost-benefit analysis revealed that the FPCS could reduce costs per unit by up to 72.30%. In terms of production efficiency, there was no significant difference between using the FPCS and the traditional one. Regarding investment returns, adopting the FPCS system has resulted in a Net Present Value (NPV) of +332,600 Baht, an Internal Rate of Return (IRR) of 281%, and a Payback Period (PB) within one production cycle, approximately 2 months. This demonstrated the economic viability of the FPCS for commercial mushroom cultivation in open-system greenhouses.

In conclusion, the research suggested that the FPCS should be suitable for the commercial production of oyster mushrooms. The findings indicated cost-effectiveness, operational efficiency, and ease of installation, making it viable for controlling humidity in the oyster mushroom cultivation in the open-system greenhouses.

6. Recommendations

In practical application, farmers can use a single control unit to manage large quantities of mushroom in a greenhouse by adjusting pressure or the number of pumps to cover the entire facility. Additionally, various equipment is easily available for purchase. In case of any component damage, farmers can procure and perform repairs by themselves. Moreover, humidifying mushroom cultivation houses through misting can significantly reduce water usage, making it suitable for current agricultural scenarios facing water scarcity. The experimental farm in this research is located in an area without power outage issues. However, for areas prone to frequent power outages, the researchers recommend using an uninterruptible power supply to prevent any damage to mushroom production.

Currently, Thai farmers have relatively limited use of technological equipment, despite facing severe labor shortages. The primary reasons are the high cost of equipment and uncertainty about making investments. This research demonstrates that in developing farm control equipment, developers should focus only on essential features necessary for practical use. Utilizing pre-existing equipment for improvement could significantly reduce the overall equipment cost. This approach could lead to a quick return on investment in agricultural operations. The recommended approach in this research could be implemented by entrepreneurs for commercial production to cater to the needs of Thai farmers.

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