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Automated Agricultural Greenhouse with PV Energy Using IoT-Based Monitoring System

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Abstract- This research focuses on developing an automated agricultural greenhouse that employs photovoltaic (PV) electricity and a monitoring system based on the technology of the Internet of Things (IoT). The Anto IoT platform was applied to enable real-time monitoring and control of the agricultural greenhouse environment in this system. In addition, the system used a grid-connected PV system to provide sustainable energy. The LoRa module and 3G module were used for wireless communication between the system components and the Anto IoT platform. For real-time monitoring and controlling of the environmental parameters, the IoT sensors were applied such as temperature, humidity, electrical conductivity, and pH of fertilizer. The use of renewable energy sources such as the 900 Wp of grid-connected PV system provides a reliable and cost-effective source of energy to power the system by reducing grid energy consumption by 23.6%. The results show that the proposed approach can be used to implement sustainable agricultural practices while also increasing the productivity of crops. Moreover, this accuracy technology can assist in reducing labor costs and managing expenses while enhancing productivity in terms of both quantity and quality since it can give users real-time information, which it can be used timely agricultural decisions.

Keywords Anto IoT platform, Agricultural greenhouse, Grid-connected PV system, 3G module, Environment control.

1. Introduction

The conventional greenhouse in Thailand has been established and is extensively used for vegetable and flowering production. Lately, a modern greenhouse construction has been designed, and IOT solution is being employed for long-term operation. Sensors capture temperature, relative humidity, and light intensity, [1] which are then adjusted by a fan, evaporation system, and shade curtain via IOT operation [2]. The greenhouse is now set up for hydroponic vegetable culture as well as organic strawberry, melon, and flowering plant production

Since 2010, Thailand has used electronic sensors and data communication devices with digital technology to apply automatic control systems. To increase efficiency and reduce greenhouse management costs. This is the beginning of the development of a smart greenhouse [3]. Initially, author [4] first built and tested a sensor network in the greenhouse to measure temperature (Temp) and relative humidity (RH). Later, the author [5] developed polyethylene for the greenhouse for curcuma off-season production. There were lamp-based artificial lights and automatic timing control fogging systems. It could reduce Temp by 30% and increase RH by around 40%. Subsequently, hydroponic greenhouses were developed that controlled the greenhouse environment with a PLC and LabVIEW. They had an evaporative cooling and fogging system. They could control the average Temp in the greenhouse, which was 30.45 °C, and the average RH, which was 80.54% [6].

In addition, the author [7] presents an environmental control system. Control supplemental lighting and a monitor for 9 m^2 of plastic greenhouse for the lettuce 'Red Rapids'

(Lactuca sativa). Solar energy is used as the greenhouse's main power supply. The proposed system controls the temperature and humidity of the planting material according to the goal increase crop yield by 36%.

Since 2017, IoT technology has played an increasing role in the agricultural industry, especially in precision agriculture, as well as in the development of smart greenhouses. A review of the papers shows that there are applications of IoT-based control of Temp-RH and moisture content in hydroponic greenhouses controlled by node MCUs with several sensors and Blynk applications [8]. The data was transferred to a cloud database in ThingSpeakTM [9]. Later, [10] presented a deep learning method combined with IoT to create a closed-type hydroponic greenhouse of 8.64 m^2 with fan, evaporation, and fogging control. It was found that such a system reduces the Temp in greenhouse to 5.4 ℃ and 2.8 °C lower outside and RH is 25% and 21% higher than outside. In addition, IoT is integrated with Blynk, a smartphone application, works with an ESP8266 Node MCU, a DHT21 temperature sensor, and a capacitive soil moisture sensor, and utilizes solar energy as the power supply. The proposed system can control house temperature at 36–40 °C and soil moisture content at 62–70 % [11].

The author [12] reports on the development of an automated control system application for growing melons in greenhouses using fuzzy controllers and Node-Red technology in conjunction with IoT [13]. Next, the cannabis greenhouse of [14] used IoT based control Temp, RH, irrigation, and Red-Blue LED supplement lighting. They reported that cannabis grew efficiently under pink LEDs at a light intensity of 40 watts/m^2. The growth of cannabis increased by 32% compared to the conventional method. The system can control the Temp and RH inside the greenhouse which are 29.8 ℃ and 72% respectively. The author [15] reports the development of an IoT monitoring system to measure soil moisture. Measure temperature and humidity inside a greenhouse. Electricity is combined using solar cells with the power from the electricity, but we cannot monitor the power consumption. The author [16] presents an automatic control system for an organic greenhouse using IoT and WiFi technology and monitoring by a web server and the Blynk application.

The author [17] reports on the development of an environmental control system in a roofed greenhouse. Curve a 3 m^2 area with IoT and analyze electricity and water consumption. Using an autonomous fogger system with an Arduino as a controller to control the sensor and water pump, [18] they found that the temperature control system had a maximum power and water consumption of 40%. Soil fertilization 34% of total electric power. They can reduce the temperature inside the house to a maximum of 5 °C below the temperature outside the house.

The State Enterprise Development Plan (2023–2027) of Thailand outlines the direction of national development in nine areas, including energy (new energy sources and renewable energy), communication (promoting and developing the digital economy), agriculture (enhancing production and marketing capacity), and so on. It can be seen that the issue of agricultural, energy, and digital communication is a hot one that requires continuous research and development. It is also in line with the Thailand 4.0 policy to bring the economy and society towards a "value-based economy". The policy focuses on 5 groups of technology and targeted industries, which comprise: (1) Food, Agriculture, and Bio. -Tech; (2) Health, Wellness, and Biomedical; (3) Smart Devices and Robotics - Mechatronics; (4) Digital, Internet of Things (IoT), Artificial Intelligence (AI), and Embedded Technology; and (5) Creativity, Culture, and High-Value Services [19].

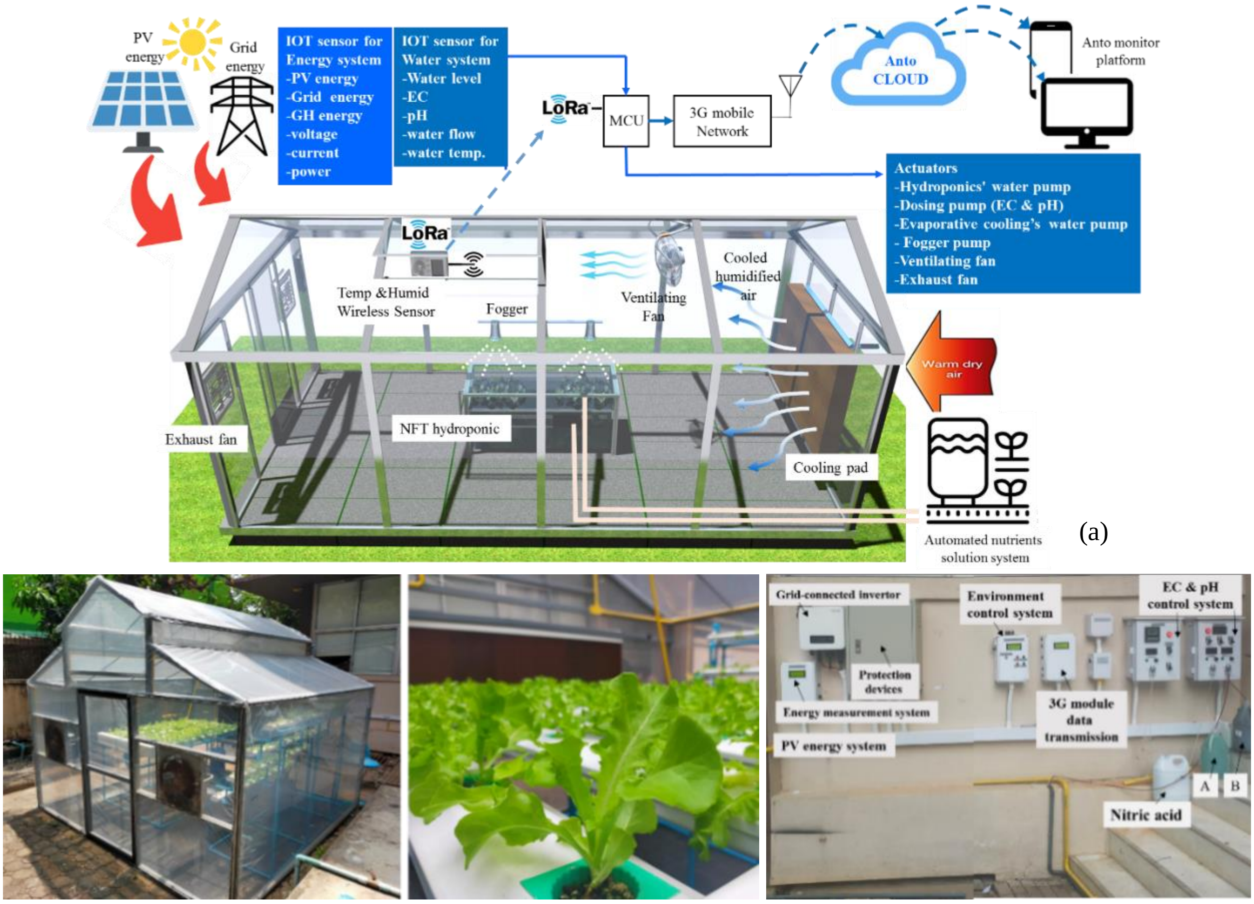
From the aforementioned background, it was found that Thailand still has insufficient research on automated smart hydroponic greenhouses, both in terms of sustainability and reducing the use of fossil resources, which are becoming increasingly expensive and linked with intelligent automation control. And data management with IoT, cloud-based systems [20]-[21], and the big data that Thai people own. To lead to sustainable ownership of innovation related to smart hydroponic greenhouses in the next phase.

The development of an autonomous hydroponic greenhouse model that optimizes hybrid power from solar panels and a low-voltage grid is presented in this paper. Create a greenhouse environment control system using a cooling system (evaporative cooling pad in conjunction with a fogging system and ventilating fan), as well as a control system for water nutrient solution in a hydroponics system using IoT-based sensors on the LoRa network and 3G communication. Finally, using the Anto IoT platform, create real-time monitoring and historical data with cloud-based data collection.

2. Material and Method

2.1. *Automated Hydroponic Greenhouse Concept Model (AHGCM)*

The conceptual model of an automated hydroponic greenhouse consists of six major systems. There are energy systems, water systems, environmental systems, hydroponics growing systems, micro-controller units (MCUs) [22] with 3G mobile networks, and IoT cloud-based measurement and monitoring [23]. This concept is a small greenhouse with dimensions of 3.5 m × 4 m × 3 m, covered with a low-density polyethylene film of 150 microns. Fig.1 shows the system diagram of AHGCM and photos.



(b) (c) (d)

Figure 1. The system diagram and photos of AHGCM (a) A system diagram (b) AHGCM prototype (c) hydroponic bed and lettuce on the 14th day of growing. (d) The hardware of the main system controller

2.2 Design the Photovoltaic (PV) Energy System

The author uses an on-grid PV system with the goal of reducing greenhouse electricity consumption by 30%. When analyzing the load of AHGCM, the total load is 650 W (exhaust fan 180 W × 2=360 W + water pump for cooling pad 60 W + hydroponics pump 60 W × 2= 120 W + fogger pump 35 W + dosing pump 5 W × 3=15 W + ventilating fan 50 W). These loads operate for 14 hours (h) per day (estimation), so total load energy/d=650 W × 14 h=9.1 kWh/d, 30% of total energy = PV energy output = 30% of 9.1 kWh/d = 2.73 kWh/d; from the solar map of Thailand, the sun hour per day is 4.1 h [24], and the derating factor of the PV system is 0.731 [25]. According to equations (1) and (2), the PV installed capacity is about 902 W.

$$PV\ power\ require = \frac{PV\ energy\ output}{sun\ hour\ per\ day} \tag{1}$$

$$PV\ install\ capacity = \frac{PV\ power\ require}{derating\ factor} \tag{2}$$

2.3. The Energy Measurement System

The author designs and uses an energy measurement module (PZEM-004T.V.3) [26] to measure AC voltage and AC current and process active power and active energy with an accuracy of 0.5% (energy). Compatible with Arduino Mega micro-controller. The author installs two energy measurement modules to measure energy from a PV system (EPV) and energy consumed by our AHGCM (EGH) as shown in Fig.2(a). Energy from the grid (EG) is obtained from EGH-EPV. Program flowchart of the energy measurement system, as shown in Fig.2(b).

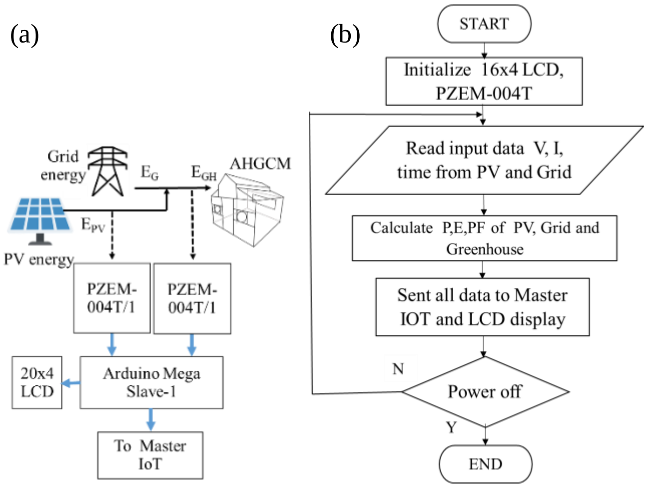


Figure 2. Energy measurement system. (a) Block diagram (b) Flowchart of the program

2.4. The Environment Sensor System

The sensor node consists of a sensor module and a LoRa module. The LoRa module is LoRa32U4, which consists of an ATmega 32U4 and a LoRa Ra-02 to process and transmit data free of charge at 433 MHz. Temp and RH sensor DHT22 are used with operating range of RH 0-100%; Temp -40℃ - 80℃. One set of sensor nodes is installed in the center of the greenhouse (Fig.3 (a)). LoRa technology is selected because of its long transmission distance and lower power consumption compared to other technologies [27]. The goal of controlling the greenhouse environment is to keep the temperature below or equal to the T_{set} and the RH between 70% and 85%. Sensor DHT-22 will measure those parameters, process them with an Arduino Mega 2560 (slave 2), and send them. Control commands for evaporative cooling, ventilation fans, and fogging system to operate according to the program designed by the author. The program flowchart of the environment control and measurement system is shown in Fig.3 (b).

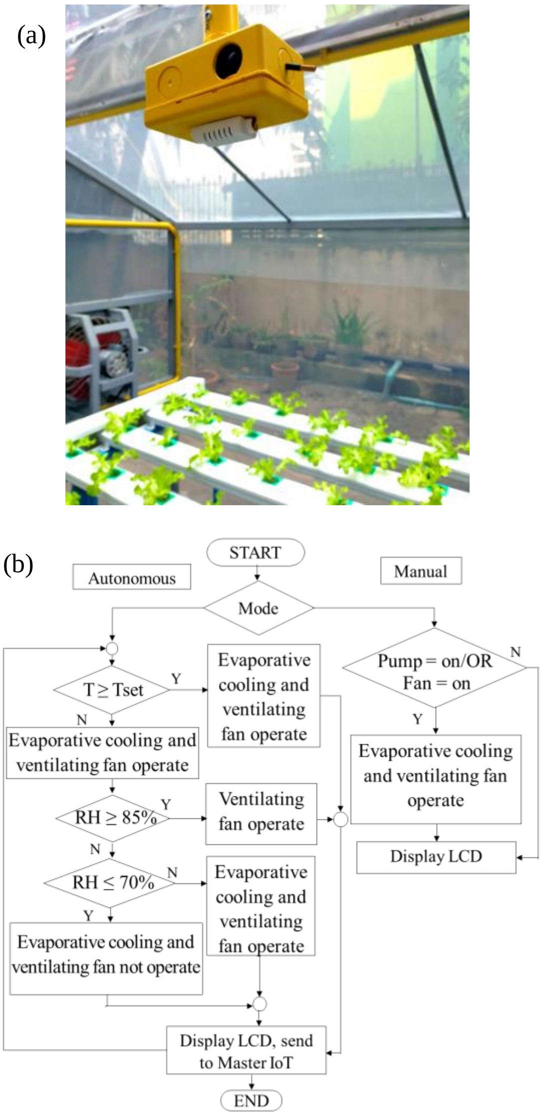


Figure 3. The environment sensor system (a) Sensor node for temperature and humidity control. (b) Flowchart of the control program

2.5. The Water System, Nutrient Solution, and Hydroponic Bed

The author designs for controlling the parameters of the water system and nutrient solution in a hydroponic cultivation bed. Two water tanks are designed, the first tank for 200 liters of water and the second tank for a nutrient solution as shown in Fig.4(a). The EC and pH control by automatic dosing machine (model 594HD Ponpe Instruments, Thailand) uses an ON-OFF control principle with hysteresis to mix the nutrient solution at EC and pH to the desired value [28]-[29].

The control program of the EC sends the measurement data to the master IoT, as shown in Fig.4 (b). The control flowchart of the pH control is consistent with the EC, so the author does not show it in this article. The nutrient solution is mixed in a 200-liters tank. Once the solution is mixed, it is supplied to the hydroponics bed next to the greenhouse (Fig.4 (a)) by a submersible pump. The water system also measures the flow rate of water by using a flow sensor (model YF-B1), a thermocouple type K to measure the temperature, and an ultrasonic sensor (ultrasonic module HC-SR04) to measure the water level (%) of the nutrient solution in the tank [28]. These data, such as EC, pH, water flow rate, water temperature, and water level, were displayed by the authors in real-time on the Anto monitor platform as mentioned in section 2.7. The nutrient film technique (NFT) was used in this greenhouse, and our hydroponic bed can grow a total of 120 vegetables at a time (Fig.1).

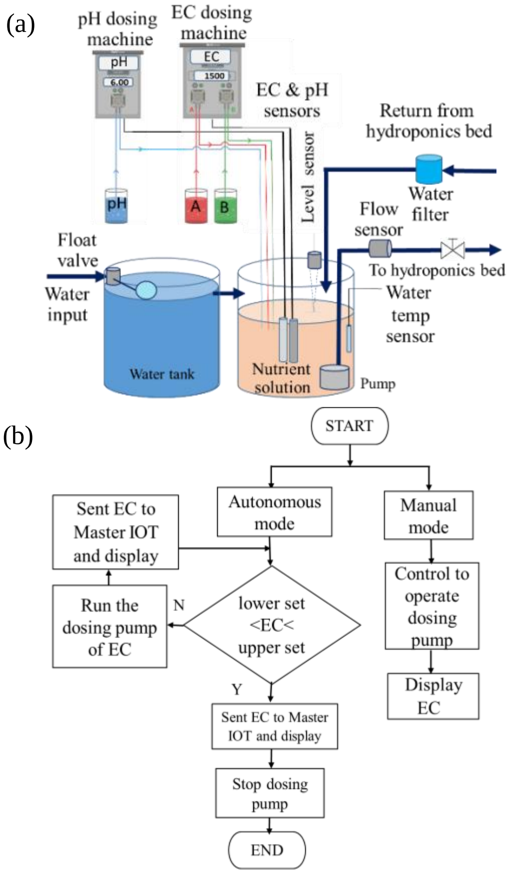


Figure 4. The water system diagram of AHGCM (a) EC and pH control /connection and flow diagram (b) Program flowchart

2.6. Micro-Controller Unit (MCU) with 3G Mobile Network.

Our MCU consists of four Arduino Mega 2560 used as Master IoT 1, the rest is set as Slave IoT 1-2 and 3. That requires multiple microcontrollers because the author designed the hardware of the main control system. For example, the energy measurement system, EC and pH control device, and environment sensor system have separate processing units (Fig.5). Arduino Mega slave-1 is responsible for processing and transmitting data. Power consumption of the AHGCM (section 2.3). The Arduino Mega slave-2 performs the processing. Controls electrical devices and sends data from an environment sensor system (section 2.4), and Arduino Mega slave-3 processes and sends EC and pH data from EC and pH controller devices and from a water flow rating sensor to the Master IoT (section 2.5) with the serial protocol (Fig.5). Data from water temperature and water level sensors is fed to Master IoT's digital I/O. Data managed by Master IoT consists of three groups: (1) Energy systems such as voltage, current, power, and energy from the utility grid, PV, and greenhouse (2) Water system as follows: water temperature, water level, water flow rate, EC, and pH. (3) Environment system; air temperature and humidity inside and outside the greenhouse. Once the Master IoT receives the data, it will be displayed on a 20 × 4 I2C LCD installed in front of the closed set of the Master IoT (Fig.5). Then, the data will be sorted and sent to the 3G module UC15 -T and then send those data in real-time through the 900 MHz telephone wave to be stored in the cloud database of ANTO.IO further.

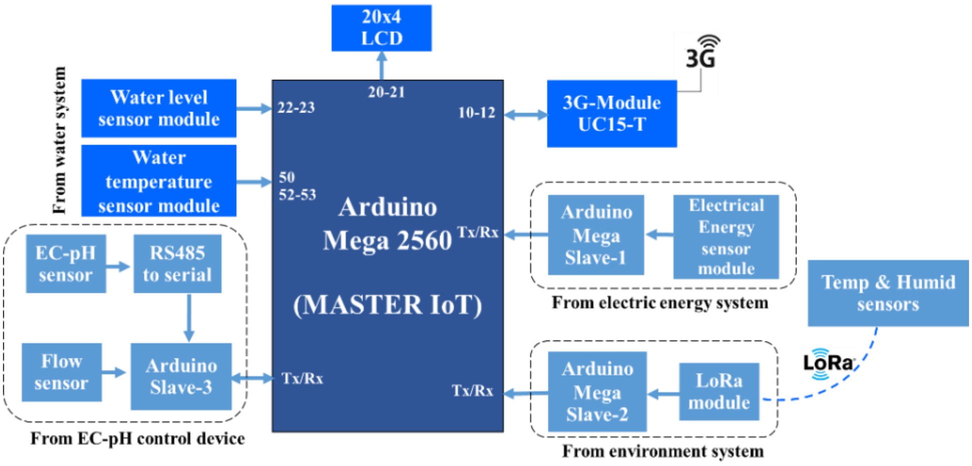


Figure 5. Connection of the Arduino Mega 2560 (Master IoT) and all things of our AHGCM

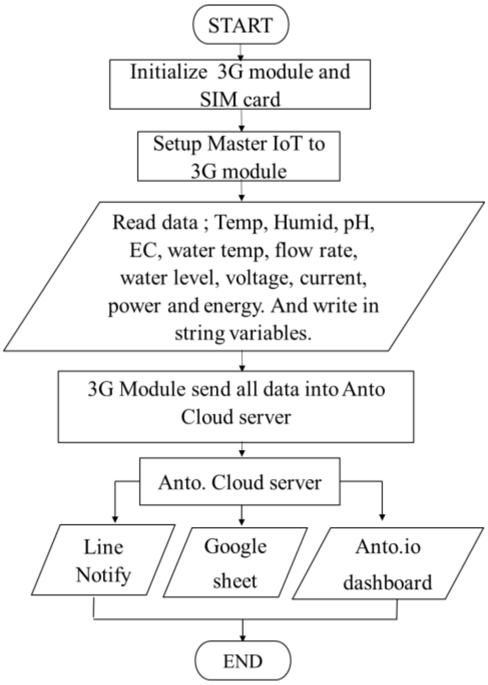


Figure 6. Flowchart of the operating of IOT cloud-based monitor system

2.7. IoT Cloud-Based Monitoring System

The author uses the Anto platform (Anto.io) because it was developed by Thai people. It's easy to learn, takes little time to develop, and doesn't cost money to store data. In addition, Anto's dashboard is flexible and beautiful. Anto is a cloud platform for connecting things on the internet together. Anto supports HTTP, HTTPS, MQTT, and MQTTS. A program to send and receive data is written on the Arduino Mega 2560 to send data to the 3G Module UC15-T and then send it through the 900 MHz phone signal. All data will be sent to be stored on the Anto cloud server. Through the Internet on the Anto.io website by creating a dashboard in a specific way according to the user's needs. When Master IoT starts up, it initializes the 3G module and verifies the connection to the internet using the cellular SIM card. Once the initialization is complete, it will start getting the parameters measured by those sensors, such as Temp, RH, pH, EC, water temperature, flow rate, water level, electric voltage, current, power, and energy. To be stored in a variable that has been defined before, then send to the Anto cloud. After that, those variable values will be displayed on the website to be used as decision-making information for greenhouse control settings that are suitable for the situation. All data in Anto cloud will be automatically written every 5 minutes to a Google Sheets for backup and effectively used for generating reports. In addition, the author developed a notification system for power outages via Line Notify (Fig.6).

3. Results and Discussion

3.1. Energy and Power Analysis

The measurement of electrical energy in the greenhouse was conducted between March 1 and March 28, 2023, with an electrical energy measurement system developed by the authors. The results show that the total daily average electrical energy consumed by our greenhouse is 12.44 ± 0.44 kWh, or 0.88 kWh/m^2/d. When analyzed, it is found that the cooling load is around 80% of the total power consumed by the greenhouse. This is consistent with the findings of the [17], [30] studies. According to Fig.7, there is a tendency to show that electricity consumption in a greenhouse increases with increasing ambient temperatures outside the greenhouse. Increasingly, the environmental control system will work harder to maintain the internal temperature at desired values.

From Fig.8 (a), it is found that the average power from PV and the grid is 2.94 ±0.44 kWh/d and 9.51±0.42 kWh/d, respectively. The total energy consumption of AHGCM is about 12.44±0.44 kWh/d. The electricity produced by the PV system corresponds to the theoretical value (2.73 kWh/d). The goal of the PV system set by the authors is to produce 30% of total load energy, but studies show that PV energy produces electricity equal to 23.6%, which is less than the target. The total energy consumption of AHGCM is about 12.44±0.44 kWh/d (0.88 kWh/m^2/d), which is 26.8% higher than the estimated value. This is because the cooling load in the AHGCM system is more than 14 h/d (section 2.2). The main reason is the location of greenhouses in tropical countries. For example, in Thailand, the temperature will reach 41 °C in the summer (March to May), causing the cooling system in the greenhouse to work harder than usual. This is consistent with the report in [31] that there is also a higher electrical energy requirement for the long-term operation of loads like water pumps and air circulation fans. In addition to load types and operating times, electrical energy demand is significantly influenced by appliance efficiency and the climate where a greenhouse is located. Despite the fact that photovoltaic technology can help greenhouses consume less fuel and grid electricity [32].

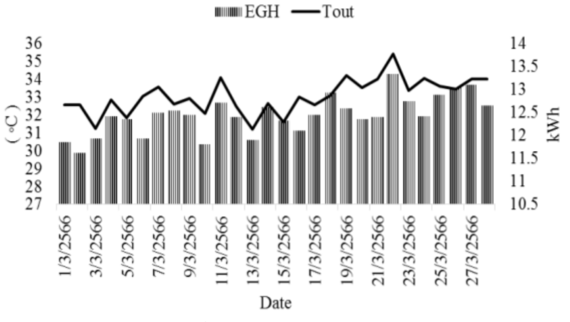


Fig.7. Total daily energy consumption of the AHGCM compared with the ambient temperature.

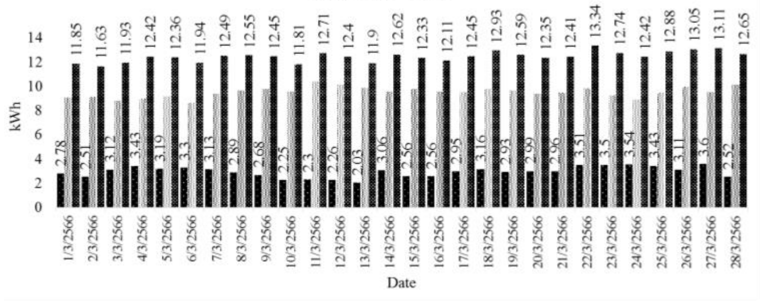


Figure 8. Daily energy production from PV system energy from the grid, and energy consumption.

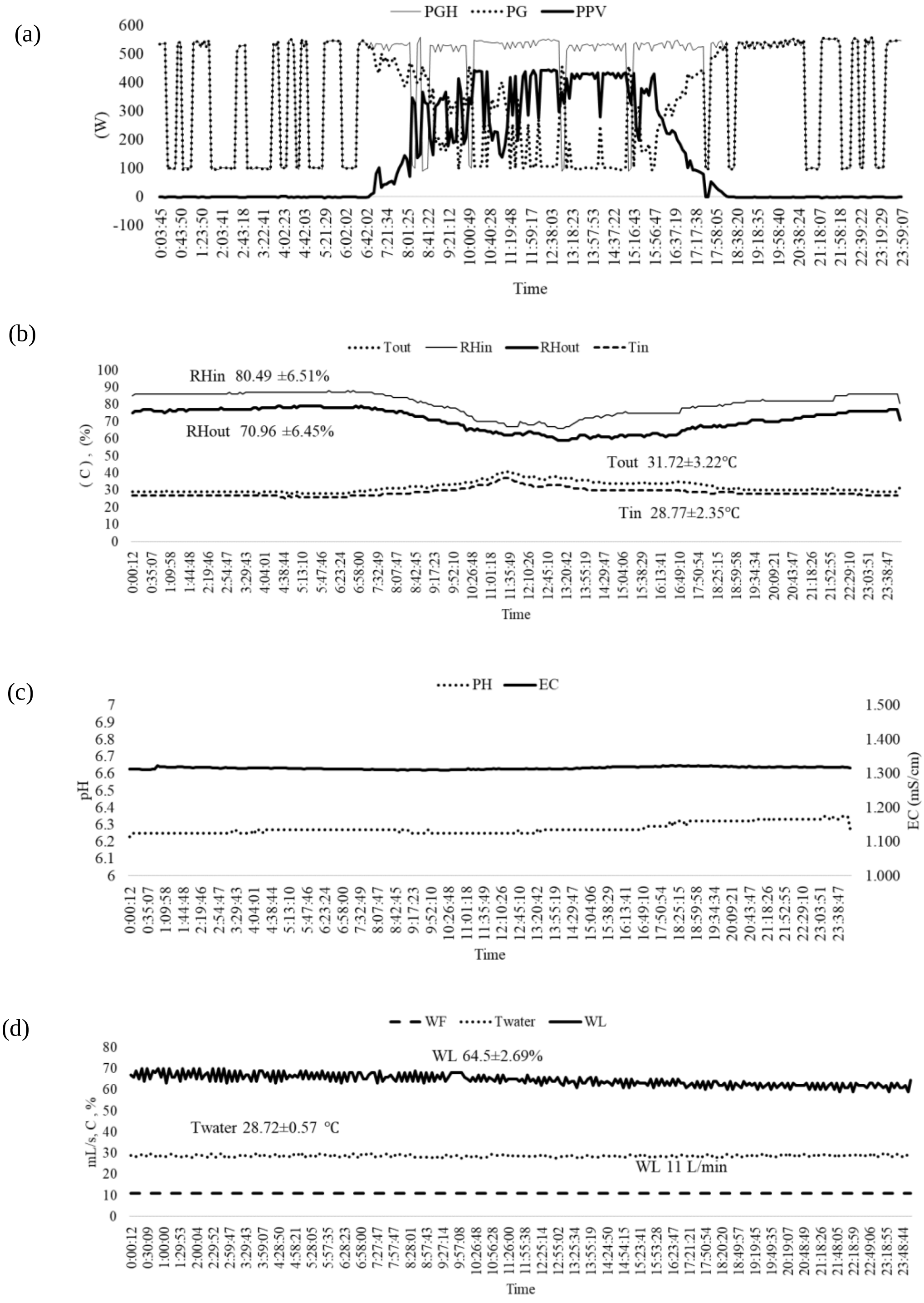


Figure 9. Measurement data of the energy system, environmental system, and water system (a) Power analysis from the PV system, the grid, and the greenhouse (b) Temperature and humidity (c) EC and pH (d) Water flow rate (W_F), water temperature (T_{water}), and water level (W_L) (measurement on March 16, 2023)

Fig.9 (a): Comparison of power from the grid (P_G), power of a greenhouse (P_{GH}), and power of a PV system (P_{PV}) measured by PZEM-004T. Measurement results during the summer of Thailand on March 16, 2023. The maximum PV power output is 444.46 W at 12:40 a.m., while the maximum power load is 550.59 W at 12.42 a.m. The PV energy system will operate between approximately 6 a.m. and 6 p.m. The maximum power produced depends on the solar irradiance intensity. Therefore, during this time, AHGCM will draw less power from the grid (black dot line, P_G), because there is additional power from PV energy (black thick line, P_{PV}). The P_{GH} curve shows that power is supplied to the AHGCM loads continuously during the daytime from 8 a.m. to 6 p.m. At night, from 9 p.m. to 5 a.m., those loads are intermittent for a short time. This makes sense because the daytime temperature outside the greenhouse on an experimental day was as high as

41 °C, while the nighttime temperature was lower, as shown in Fig.9(b). However, the authors found that the proposed system had two fertilizer pumps, one of which worked all the time. This results in a power consumption of approximately 98 W per 24 h, or 2.35 kWh/d (Fig.9(a)). The system should therefore be retrofitted using a single fertilizer pump. This will help reduce electric energy by 9.35% of total energy consumption (50% × 2.35 kWh/d/12.52 kWh × 100% = 9.35%).

3.2. Environmental and Water System Analysis

In this study, the setting Temp (T_{set}) at 28 °C and RH was set at 70%–85%. Considering Fig.9(b), it is found that the inside temperature (T_{in}) and humidity (RH_{in}) of a greenhouse are equal to 28.77 ± 2.53 °C and 80.49 ± 6.51% respectively. It shows that the measurements with the sensor module and the transmission between the sensor node and the LoRa module are accurate. How micro-controllers work that send commands to control the exhaust fan, ventilating fan, fogger pump, and cooling pad pump to work as instructed No errors were found on the day of the experiment. The system proposed by the author reduces Temp and increases RH in the greenhouse by a maximum of 3 °C and 10%, respectively. Compared to [17], [14], our system can control Temp in the greenhouse no differently. But it reduces temperature more than the cooling system offered by [11] because they use a fogger with circulating fan cooling only, without a cooling pad like the work of [17]. The pad and fogger will reduce Temp and increase RH in the greenhouse better than using a cooling device alone.

In this study, the authors set an EC of 1.2 to 1.4 mS/cm and a pH of 6.0 to 6.5 because it was suitable for the plants (green oak lettuce) used in the experiment. According to Fig.9 (c), EC measurement results are shown and pH obtained from the control system presented in section 2.5. The mean values of EC and pH were 1.32 ± 0.004 mS/cm and 6.28 ± 0.03 respectively, satisfying the specified conditions. On-off with hysteresis EC and pH controllers can control the EC and pH in fertilizers to target values similar to fuzzy logic control systems. However, fuzzy logic control systems may reduce the amount of nutrient solution more than on-off control [33]. Meanwhile, the measurement result for W_F is 11 L/min, T_{water} is 28.72 ± 0.57 °C, and W_L is about 64.5 ± 2.67% (Fig.9 (d)) in the water system, such as overflowing the water tank, an empty tank, a low rate of water flow, etc.

3.3. IoT-Based Monitoring System

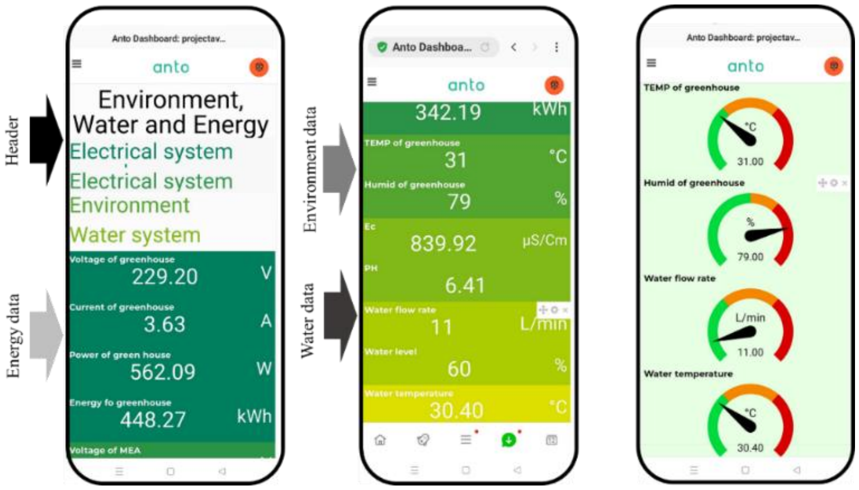
All measured data from AHGCM is divided into three groups: energy, environment, and water. For example, P_G, P_{GH}, P_{PV}, T_{in}, T_{out}, RH_{in}, RH_{out}, EC, pH, W_F, T_{water}, W_L, and so on. These are stored in the Anto cloud. These variables are then displayed in the Anto dashboard developed by the author (described in Section 2.7). When users login to the Anto.io website and access the dashboard, they will see a display page divided into 4 sections: (1) The header and (2) The energy data including the ac voltage, current, power, and energy as shown in Fig.10 (a), (3) Environment data included T_{in} and RH_{in}, and (4) Water data are shown in Fig.10 (b). Fig.10 (c) indicated that the needle pointed for a quick view of environment and water data such as W_F, T_{water}, and W_L. All data in Anto cloud will be automatically written every 5 minutes to a Google Sheets for backup and used for generating reports. When users login to the same Google account as Anto.io and click to open a Google Sheets, all data will be stored in the sheet and updated every 5 minutes (Fig.11). In addition, the author developed a notification system when there is a power outage via Line Application (Fig.6). The results of five tests on March 16, 2023, showed that the notification system works perfectly. Every time the electrical supply to the AHGCM is cut off (details not shown in the article), this alarm system reduces the damage to the plant production and reduces the labor cost.

Compared to IoT-based monitoring [2] for greenhouses that have been studied in Thailand, it was found that most authors [9], [10], [14], [16]-[17] bring the Blynk application with the Node MCU by communicating via Wi-Fi. Authors [9]-[10] use IoT for measurement and monitoring Temp and RH only. Author [14], [16] not only measures Temp and RH but also uses them to control irrigation for soil, fogging system, and the LED artificial light. The IoT system presented by the author serves to monitor 17 measured variables covering environment, water, and energy variables. Using 3G signal frequency communication, data communication is stable and has more confidence. Able to transmit signals over long distances in all weather conditions. There is no problem with transmission distance. The system that the author presents is practical in all areas where there is a telephone signal. Covering 99% of Thailand. Also, the Anto platform is easier to use than the Blynk platform in terms of aesthetics and dashboard creation.

The IoT – enabled greenhouse platform based on cloud services presented by the authors has a system structure that is consistent with the results of the study of [34]-[36] especially measuring and displaying Temp and RH with mobile devices. The goal is to bring smart devices to install in greenhouses to measure and monitor environmental parameters for optimal growth of plants or vegetables. Some of the previous authors also measured and monitored other parameters, such as light and CO_2 [34], soil moisture [34], vapor pressure [35], etc.

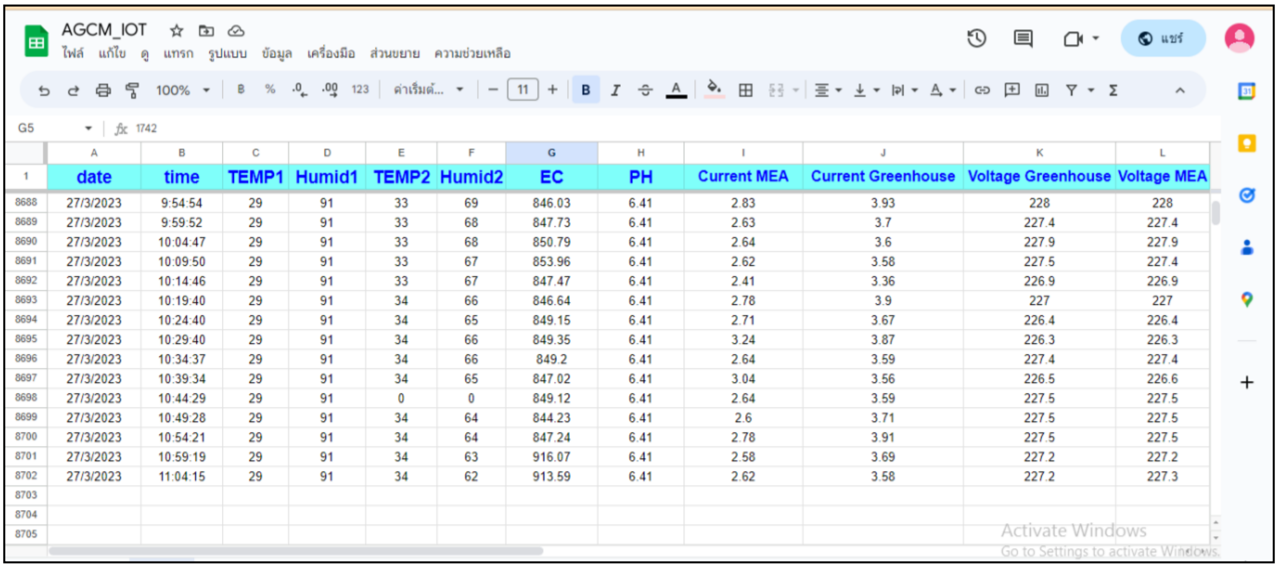
The most accepted communication protocol is 3G, 4G, or WiFi [35]-[36] which corresponds to the system proposed by the author. Because WiFi is appropriate for the home environment, such as greenhouse farming, many authors opt to employ it. Small, medium, and large greenhouse farms can easily create a network connection and obtain the necessary data. Radio waves, an antenna, and a router are used to operate this network. Furthermore, the 3G/4G wireless communication standard, based on Global System for Mobile Communication (GSM) technologies, transfers data at high speeds between mobile devices [37]. Its advantage is the highest rate of data transfer (around 100 MHz), higher performance, and lower latency rates experienced during data transfer.

In order to be considered efficient for continuous monitoring of greenhouses throughout all growing seasons, this approach should demonstrate precision accuracy, connection reliability within the sensing covers, and low power consumption. An IoT- monitoring framework can be affected by the physical internal and external conditions [22] of the greenhouse environment, in addition to the specifications and characteristics of the sensors and communication algorithms that influence these functional properties .



(a) (b) (c)

Fig.10. Screen capture of the real-time monitoring data from the Anto dashboard accessed by mobile phone (March 26, 2023) (a) Header and energy, power, voltage, and current (b) Temperature, humidity inside the greenhouse, the EC, pH, and water level (and temperature), and (c) display needle pointing for a quick view of some data



	date	time	TEMP1	Humid1	TEMP2	Humid2	EC	PH	Current MEA	Current Greenhouse	Voltage Greenhouse	Voltage MEA
8688	27/3/2023	9:54:54	29	91	33	69	846.03	6.41	2.83	3.93	228	228
8689	27/3/2023	9:59:52	29	91	33	68	847.73	6.41	2.63	3.7	227.4	227.4
8690	27/3/2023	10:04:47	29	91	33	68	850.79	6.41	2.64	3.6	227.9	227.9
8691	27/3/2023	10:09:50	29	91	33	67	853.96	6.41	2.62	3.58	227.5	227.4
8692	27/3/2023	10:14:46	29	91	33	67	847.47	6.41	2.41	3.36	226.9	226.9
8693	27/3/2023	10:19:40	29	91	34	66	846.64	6.41	2.78	3.9	227	227
8694	27/3/2023	10:24:40	29	91	34	65	849.15	6.41	2.71	3.67	226.4	226.4
8695	27/3/2023	10:29:40	29	91	34	66	849.35	6.41	3.24	3.87	226.3	226.3
8696	27/3/2023	10:34:37	29	91	34	66	849.2	6.41	2.64	3.59	227.4	227.4
8697	27/3/2023	10:39:34	29	91	34	65	847.02	6.41	3.04	3.56	226.5	226.6
8698	27/3/2023	10:44:29	29	91	0	0	849.12	6.41	2.64	3.59	227.5	227.5
8699	27/3/2023	10:49:28	29	91	34	64	844.23	6.41	2.6	3.71	227.5	227.5
8700	27/3/2023	10:54:21	29	91	34	64	847.24	6.41	2.78	3.91	227.5	227.5
8701	27/3/2023	10:59:19	29	91	34	63	916.07	6.41	2.58	3.69	227.2	227.2
8702	27/3/2023	11:04:15	29	91	34	62	913.59	6.41	2.62	3.58	227.2	227.3
8703												
8704												
8705												

Figure 11. Laptop’s screen capture of monitored data in a Google Sheets from Anto.io (Accessed on March 27, 2023, 11:07 am)

4. Conclusion

Thailand continues to complete absent research on automated smart hydroponic greenhouses, both in terms of energy sustainability and data management using IoT. An automated hydroponic greenhouse concept model (AHGCM), as proposed by the authors, can answer this need. The energy consumed by the AHGCM is 12.44 ± 0.44 kWh (0.88 kWh/m^2/d), and it is found that the cooling load consumes around 80% of the total energy of the greenhouse. The 900 Wp of the PV grid-connected system will reduce grid energy consumption by 23.6%. In hot climates, using solar PV in greenhouses significantly reduces the need for extra energy for cooling. The embedded technology control for the environment, fertilizer solution, and water storage works well to control those parameters according to the target. Cloud services support the IoT-enabled greenhouse platform as demonstrated in this article. The data transmission over the 3G network is stable, fast, and accurate. It works without regard to space constraints when applied to automated greenhouses. The system can provide real-time information for users to make timely crop production decisions, reducing labor and management costs and increasing productivity both quantitatively and qualitatively. It is additionally suitable for use in both soil and soilless agricultural greenhouses. IoT combined with microcontrollers, as well as the use of renewable energy in greenhouses in Thailand, can make vegetable growth a profitable investment.

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