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PERFORMANCE ASSESSMENT OF THE GREENHOUSE CLIMATE CONTROL PROTOTYPING

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SUMMARY

The greenhouse is a steel-framed building coated with UV-protective plastic sheets, having complete control over the climate factors to ensure optimal growing conditions for the plants within. In Iraq, the main issue is high temperatures in summer days, which directly affect plant growth and lead to considerable crop losses even if using a normal greenhouse. Furthermore, the lack of technological knowledge among the farmers influences the decisions regarding a suitable plant environment. In high temperatures, the life span of greenhouses is unknown, it being unmeasurable. The following study focuses on solving these issues by proposing a practical greenhouse design prototype to identify the optimal climate factors for plant growth inside the greenhouse. The proposed system used an Arduino microcontroller for controlling and monitoring the greenhouse. The collected data helped predict the expected life span of the proposed greenhouse design, which will be the foundation for developing the prototype by managing expenses for different factors, including energy sources, temperature control equipment, building material, and water resources. Compared with related research, this work is the first of its kind that predicts the lifespan of a greenhouse. The farming community with a little technological knowledge can easily utilize the said system, offering different options based on the identified climate.

Keywords: Greenhouse design, controlling system, Arduino system, building material, water resources

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Key findings: The study aimed to evaluate the performance of the proposed greenhouse by predicting its life span using a methodology based on daily data comparisons. The system could be beneficial to the farming community for improving plant growth in the greenhouse**.** The system successfully implemented and achieved its aim to predict the lifespan and control the climate inside the greenhouse**.**

INTRODUCTION

Diverse types of crops, typically grown in greenhouses, usually need some special care about the environmental conditions to be grown. Farmers can protect their crops from harsh weather conditions and extreme temperatures using different types of greenhouses (Al-Asadi *et al.,* 2022, 2023). Greenhouses' main advantage is to provide controlled environmental conditions about the temperature, humidity, radiation, soil quality, and fertilization (Jadallah *et al.,* 2020). Overall, the highest levels of temperature and humidity must not exceed 35 °C and 60%, respectively, in the greenhouse. Inside the greenhouse, exposing crops to high temperatures during the summer would suffer crop stress and burn effects (Ihoume *et al.,* 2023). However, advanced cooling technologies are necessary for the effective utilization of the greenhouse (Al-Helal *et al.,* 2022).

Factors affecting greenhouse costs include site preparation, design, and cooling systems. The use of wood and aluminum frames is common in greenhouses (Choab *et al*., 2019). Advanced technology offers opportunities for developing countries like Iraq, and the automated systems are inexpensive and accessible with decent income (Ahamed *et al.,* 2018b; Al-Asadi *et al*., 2023). The proposed system can better maintain the temperature and humidity levels within the greenhouse to boost plant growth. The system employs two ventilation methods (side cooling unit and fan) and sensors to evaluate its performance and predict its life span. The primary contributions of this work were as follows:

- Present an energy-efficient greenhouse system prototype that could be the first type in Iraq, using sustainable material and sensors to detect the temperature, humidity, light intensity, and soil moisture variations, allowing for corrective actions;
- Investigate the greenhouse temperature fluctuation, comparing performance to traditional control methods, and proposing a methodology for defining an acceptable temperature level in the greenhouse;
- Use two different air ventilation methods (fans and side cooling units) to study the greenhouse environment and check how the sensors' data alters with temperature variations both outside and inside the greenhouse;
- Conduct performance evaluation using daily data comparisons to predict the system lifespan, and
- Display the data of the greenhouse's internal temperature, humidity, light intensity, and soil moisture, and compare it with the previous day and the past average. Similarly, formulate the sensors' data and make decisions that could improve plant growth in a greenhouse. The said system may help the farmers with small holdings and even a balcony to plant and produce crops around the year in Iraq. The said system could further undergo a large-scale replication for commercial use.

During summer of July 2022 in Iraq, the maximum temperature throughout the whole day was 49°C at noon after 12 p.m., while the minimum temperature was 29.5°C at night after 4 a.m. Therefore, we proposed a temperature-controlled greenhouse management using an Arduino microcontroller with environmental sensors and to automate the environmental parameters, optimise the greenhouse conditions, increase the productivity, and minimise the manual intervention.

LITERATURE SURVEY

Ancient agriculturists in Iraq had a long history of examining soil, determining its potential effects, and assessing whether it was suitable for farming. The agriculture sector and farming are the primary food sources in Iraq. The harsh environmental factors, such as temperature, humidity, light intensity, and soil moisture, affect routine farming and develop hindrances for agriculturists. The proposed greenhouse system automates all those factors to optimize greenhouse conditions, increase production, and minimize manual intervention. The following discussion presents several related studies describing various approaches for better climate management in greenhouses.

Past research reported developing an automated irrigation system that irrigates plants through pipes directly and using the drip method to maintain sufficient water supply. Rohimi *et al.* (2019) studied a heating model (green heat) that predicts hourly the heating needs in the greenhouse. The model considers greenhouse indoor environmental parameters, crop properties, and weather data. The study detailed how the model can accurately predict the needed energy for the greenhouse to heat up. In a subsequent study, Ahamed *et al.* (2018b) developed a new model to estimate the energy required of a Chinese-style greenhouse powered by sunlight. Their findings were encouraging, with a respective root-mean-square error (rRMSE) of 11.50% and an average percent error of 8.7%.

Multiple sensors, viz., LM35 temperature sensor, soil moisture sensor, HR 202 humidity sensor, and water level sensor, with an LPC 2148 ARM-7 CPU, succeeded in controlling the water pump's power based on temperature and humidity (Naresh and Munaswamy*,* 2019). The readings from temperature sensors (LM35) bore updating every minute to detect the high temperature, and as the temperature rises, an alarm gets activated. Ahamed *et al.* (2018a) used the TRNSYS software and the Building Energy Simulation (BES) model to investigate the effects of various materials and control methods used in greenhouse cooling and heating systems. They also discovered using multi-layer night thermal screens rather than polyester, Luxous, and Tempa screens could save 20%, 5.40%, and 13.50% of heating energy, respectively.

A study intended to optimize a greenhouse's climate regulation by enhancing the existing cooling and heating systems' efficiency under external temperature and humidity conditions (Haq *et al.,* 2023). The authors presented a system that could control and monitor the temperature and humidity within the greenhouse. The system, as tested for 30 days in September 2021, had temperatures ranging from 26 °C to 31 °C and humidity levels ranging from 65% to 70%. The system successfully maintained the required humidity, carefully raising the humidity throughout the day to offset external heat while substantially reducing night levels by 80%. Although it was difficult to keep the temperature at the desired 26 °C during colder nights, temperature management was often successful in keeping daytime levels at about 32 °C. Energy usage was optimal; the automation resulted in a notable 4%-33% energy savings for cooling and an 8% savings for heating.

The reviewed literature indicates techniques like machine learning (ML) show significant potential in predicting thermal behavior within greenhouses, offering more precise control of environmental factors compared with traditional methods. Some earlier studies used ML techniques as case studies; however, their implementation in the real environment did not proceed**.** Furthermore, the studies found in the literature review received classification as a simulation and in a real environment. Therefore, a study comprising the system's lifespan is essential to enhance the control effectiveness and also lower the system costs (Table 1).

The promising research introduces a solution that can process the temperature, humidity, light intensity, and soil moisture as inputs to provide the valuable outputs. The proposed greenhouse system will be the first for use in Iraq to predict the system's life span using daily measurement of different parameters and their comparison.

Table 1. Comparison with related research.

Similar work	Strengths	Weaknesses	How this work is different
Design and Prototype Development of Automated Greenhouse with Arduino and (IoT) Application	- Reduce temperature disparities by 7 °C.	- The prototype was implemented in the environment with a maximum temperature of 37 °C. -Simple functionality, only two factors are supported.	-The prototype was implemented in the environment with a maximum temperature of 49 °C. -More control factors (temperature, humidity, and sunlight) are supported. -The system reduces temperature disparities by 11 °C.
Development of a thermal model for simulation of supplemental heating requirements in Chinese-style solar greenhouses	-Using differential heat balance equations to estimate the model floor and north wall surface temperatures.	-No real-environment testing has been conducted on the system. -Using a Chinese-style solar to change temperatures only.	-One-control unit that can reduce temperature by 11 °C; - Real-time sensors' data were collected and tested in a real environment.
Modeling heating demands in a Chinese-style solar greenhouse using the transient building energy simulation model TRNSYS	- The mean difference of 1.8 °C for the north wall.	-Using a Chinese-style solar which is complicated and has several components to reduce temperature by 1.8 °C. - No real-time data were collected (a dataset available online was used).	-Reducing the temperature by 11 °C when the maximum temperature in an environment is 49 °C; - All factors were tested in a real-world environment. - Real-time sensors' data were collected and tested in a real environment.
Smart Agriculture System using IoT Technology	-Using IoT, image processing for a color and pattern analysis to detect deficiencies in paddy leaf images; - A precision irrigation system was used to distribute water accurately in agricultural fields.	-Cost, complexity, network infrastructure, and maintenance make it difficult for farmers to use, especially for limited-resource farmers who may lack technical expertise. - The system does not deal with other factors like temperature or sunlight and depends only on the soil moisture analysis and its effects on leaves. - The system has been tested in a laboratory environment only.	The system deals with three factors—temperature, humidity, and sunlight. Simply operated by the user. The system has been implemented using affordable components. Real-time sensors' data were collected and tested in a real harsh environment with a maximum temperature of 49 °C.
Development and optimization of a building energy simulation model to study the effect of greenhouse design parameters	- Creating a simulated model of the greenhouse thermal environment using TRNSYS 17 and evaluating design parameters.	-The system has been implemented using TRNSYS 17 only to evaluate some design parameters and not tested in a real environment.	-The system was implemented using affordable components. -The system was implemented in the environment with a maximum temperature of 49 °C in Iraq. - Three factors (temperature, humidity, and sunlight) were tested in a real-world environment.

MATERIALS AND METHODS

In the presented research, long lifespan, affordability, and shape were the factors for consideration in developing the proposed system's design. All the sensors' data reached direct recording with how much the temperature may drop on a sunny day before and after the power on the cooling elements. Farmers with little technological knowledge can use the proposed system easily, as it offers various options to control the climate inside the greenhouse.

In addition to the Arduino microcontroller, a fan, side cooling unit, air puller, and water pump were part of the system's implementation. In greenhouses, overheating has been the top reason as the main problem during summers in Iraq. A simplified architecture of the proposed system is available in Figure 1. The system used the sensors to keep track of greenhouse temperature, humidity, and sunlight, as handled by the Arduino to control the up and down cooling parameters. Based on weather conditions and requirements, the greenhouse system automatically decides to turn on or off some cooling features, such as the fans and watering units. The system also provides information related to the recommended levels that should progress inside the greenhouse. The following subsections explain in detail the contents used to develop the proposed system:

Arduino Uno

Arduino Uno is an advanced and open-source microcontroller with digital and analog input/output connections, allowing easy interaction and simple processing tasks to control the greenhouse versus the Raspberry Pi and Programmable Logic Controller (PLC) (Ahamed *et al.,* 2018b; Sripradit and Theeradejvanichkul*,* 2022).

Sensors

The sensors, always connected to the Arduino, measure environmental factors, i.e., temperature, humidity, and light intensity. Measurements of humidity detect the amount of water vapor existing in the soil, air, and enclosed areas. The soil sensor detects the volume of moisture in the soil (Ihoume *et al.,* 2023).

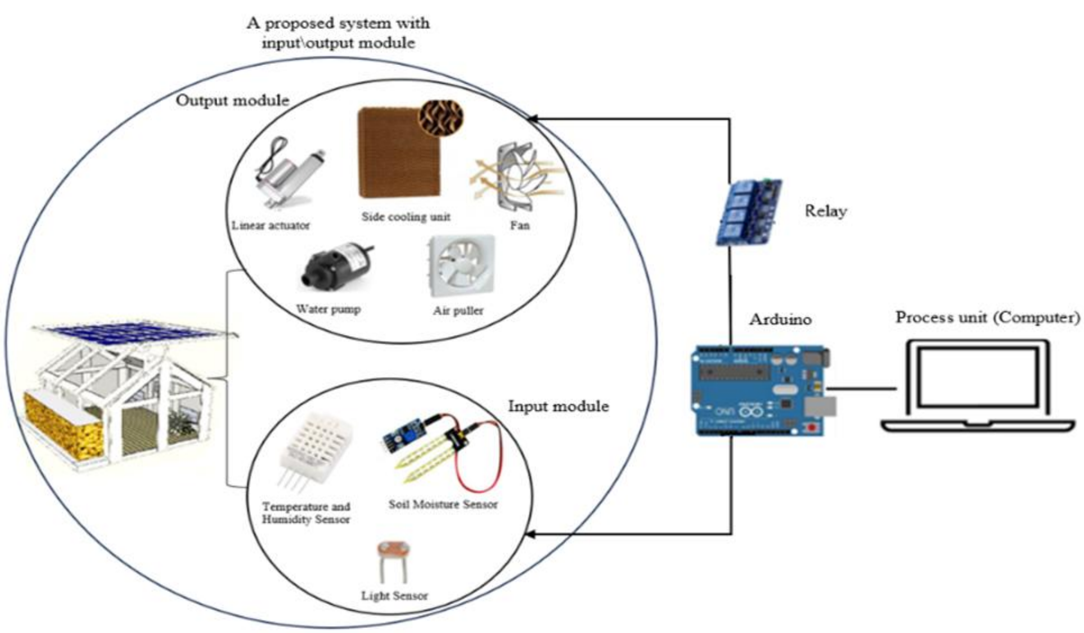

Figure 1. Architecture of the system.

Computer

The computer's task is to receive the sensors' data every four seconds (one-second delay for each relay), process it, and send it back to the Arduino. It also checks and verifies the overall environmental conditions and decides on running different functions inside the greenhouse (Naresh and Munaswamy, 2019; Ahamed *et al.,* 2020).

Other components

The side cooling unit is crucial in reducing high temperatures inside the greenhouse. It is a wood cooling panel, also known as a honeycomb panel. The honeycomb panel's advantages are better thickness, low maintenance requirements, a longer life span, being more efficient, and lesser cost. In the greenhouse system, the fans' design in providing efficient cooling inside the greenhouse is reliant on the environmental conditions. By integrating them with Arduino, the users can program the fans to automatically adjust their airflow based on real-time temperature readings to ensure optimal cooling performance in all types of situations.

The water pump is an essential component to carry out the water flow from one place to another. The pump transfers water to the side cooling unit by dropping from holes along the pipe to moisturize the side cooling unit. It also irrigates the soil when the plants' required moisture level decreases. The puller easily complements with Arduino to effectively reduce the humidity based on environmental conditions inside the proposed greenhouse. A relay can also serve to manage the AC loads, motors, solenoids, lamps, and high current and voltage loads.

System's implementation

The proposed greenhouse system comprises three main parts. The first part is the input and output modules, which include sensors, fans, a side cooling unit, a water pump, and an actuated motor to open a window. The microcontroller (Arduino) is the second part, used to manage the greenhouse operations. The last part is the computer, which records and processes the data.

Hardware implementation

The implementation of the proposed system starts with connecting the computer to the Arduino via USB. Each sensor has three pins- the VCC pin connected to the 5V pin of the Arduino, the data pin connected to the input pin, and the ground of each sensor connected to the Arduino ground (see Figure 2). The hardware components of the system appear in Table 2. Figure 3 shows the front and side views of the implemented system. The automated greenhouse system operates effectively according to the necessary greenhouse conditions (Table 3).

Software implementation

In software implementation, another vital aspect is the continuous monitoring and evaluation of the system's performance. This involves regularly collecting feedback and data from sensors, analyzing it, and making necessary updates for improvement to enhance the system's efficiency (Rasheed *et al.*, 2019; Chen, 2022). The detailed explanation of the procedures used to study the performance and effectiveness of the proposed system is as follows:

Data collection and compilation

The daily sensor data being saved in CSV files is for future analysis and use as reference to improve the predictions of the proposed design's lifespan and understand the patterns of environmental conditions. The saving of said data occurs every four seconds. This data can be beneficial in developing accurate models to predict the impact of different weather patterns on the proposed design's lifespan. The data transmitted from the Arduino to the computer includes the following: the internal/external temperature and humidity variations, changes in soil moisture, the greenhouse water supply, and the connection and disconnection status of the servomotor.

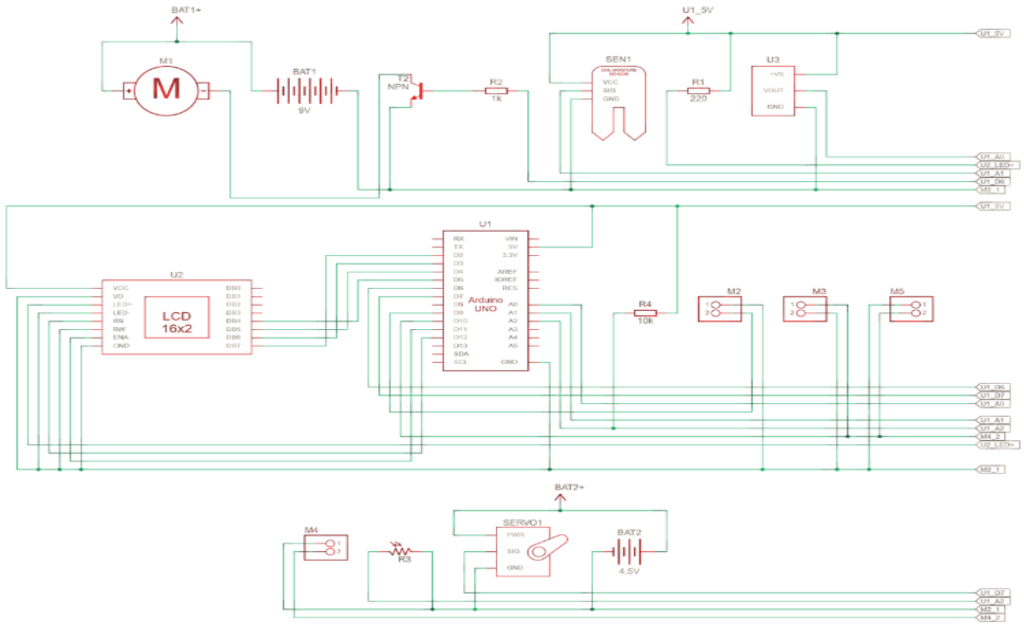

Figure 2. Circuit diagram of the system.

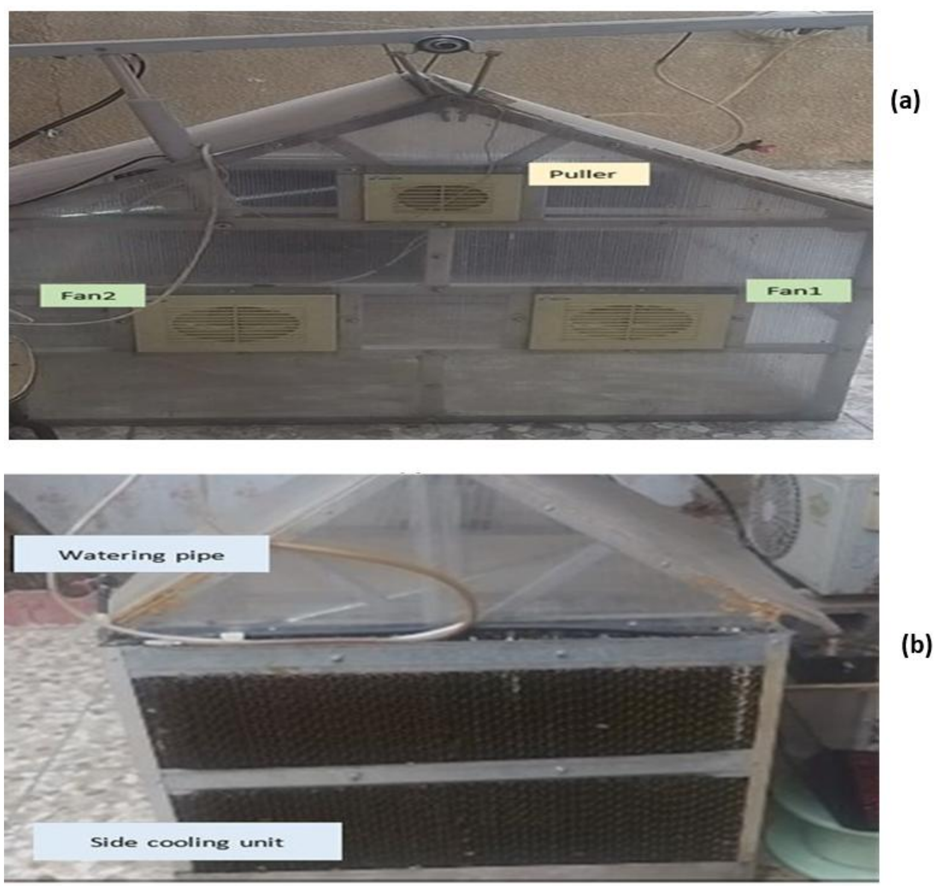

Figure 3. Implementation of the proposed system: (a) Front view; (b) Side view.

Table 2. System's components used in the study.

Component	Quantity
Arduino Uno R3	1
9V Battery	1
Temperature Sensor	1
LCD 16x2	1
NPN Transistor (BJT)	1
220 Ω Resistor	1
Soil Moisture Sensor	1
DC Motor	5
Photoresistor	1
10 kΩ Resistor	1
Positional Micro Servo	1
AA Battery	3

Table 3. Implementing the watering and cooling system under four different ranges of temperature.

Conditions	Control systems	Description
25 °C–31 °C	Actuate relay 1. Run cooling fans.	Decrease heat.
32 °C–38 °C	Actuate relays 1 and 2. Turn on the water pump.	Decrease heat. Spray and reuse water in the side cooling unit.
>39 °C	Stop relay 1. Actuate relays 2 and 3. Run air puller.	Increase humidity.
Low light levels	Actuate relay 4.	Open window.

Model architecture configuration

Based on the proposed greenhouse design, a model for life-span greenhouse prediction underwent development. The number of days (i.e., lifespan) the system will take before losing its efficiency (50%) to functioning gets predicted using a time series forecasting technique called the exponential smoothing formula. The time length for which the system exists is known as the lifespan. Lifespan plays a critical role in determining the warranty status of the proposed system and its spare parts. It represents a dedicated commitment to ensuring the proposed design fulfills the farmer's requirements and serves its purpose flawlessly. Additionally, if the farming community has some concerns, they can make requests about the inspection of the product for the required adjustments, as well as obtain spare parts before finalizing the design.

Forecasting: Exponential smoothing

Climate change and weather patterns impact the overall structure design and maintenance checks, making it hard to preserve the ideal work environment of the greenhouse (Baddadi *et al.*, 2019; Al-Helal *et al.*, 2022). With the insufficient response to these variations, traditional greenhouse management practices have a shorter lifespan, less efficient design, and lower profitability. In this context, forecasting the lifespan of the proposed system is imperative to overcome and reduce the impact of these issues. Thus, it improves farmers' satisfaction and trust, increases their ability to respond to emerging threats, and optimizes their existing resources.

Forecasting is an activity to predict future events by using the data obtained from the past with exponential smoothing and solve time problems of series data. It has also been useful in many applications, such as predicting lithium-ion battery lifespan (Fauzi *et al*., 2024), stock market predictions (Antonopoulos *et al*., 2016), and satellite lifespan predictions (Chen, 2022). In the latest research, the novel idea was the use of exponential smoothing to determine the greenhouse system's lifespan through time series analysis, calculating differences on a day-to-day basis. The method involves developing daily records to count missing values for each column in two CSV files. Then, these are placed into an exponential smoothing function to calculate the approximate number of days until the system starts losing half of its recorded data. This is a bit more detailed in Algorithm 1.

The basic exponential smoothing formula used to calculate the next forecasted value (ES[t]) for each time (t) and the previous forecasted value (ES[t-1]) with smoothing parameter value (ɑ) is as follows:

$$ES[t]= Y[t-1]* \alpha+ (1 - \alpha) * ES[t-1] \qquad (1)$$

Where,
- (ES[t]) is the predicted value;
- (Y[t]) is the first observed value, and
- ɑ = [0, 1].

Monitoring and control devices

The monitoring and controlling system comprises sensors, devices, and an Arduino microcontroller, working together to perform the system's tasks. Arduino Uno is the system's central control unit, which connects sensors to receive real-time data regarding the greenhouse conditions. Arduino also performs the necessary steps based on the received data. For instance, when the internal temperature overrides the set-point temperature, the two fans automatically turn on and the servomotor will open the windows. In contrast, when the temperature drops below the set point, the fan turns off automatically, with the window being closed. A lamp also turns on to keep warm the inside plants. When the ground becomes too dry (as per data based on the soil moisture sensor), the system will turn on the pump and the electro valve for the cooling and watering process. Simultaneously, a third fan turns on to raise the internal air humidity to the required average humidity levels.

The system also activates jumpers to trigger the motor pump when soil moisture levels reach a critical level, triggering the irrigation system. The motor activation begins when a light sensor detects sunshine, and changes may be necessary based on farmer needs. A similarity function helps compare data from two CSV files, simplifying comparisons. Line graphs display cooling system results, such as temperature, humidity, light intensity, and soil moisture, for monitoring and assessment.

RESULTS AND DISCUSSION

The proposed greenhouse system has progressive implementation and testing in Baghdad, Iraq, which has extreme hot weather during the summer. The sensors recorded varied data every four seconds for four weeks daily. The results revealed how the proposed greenhouse differed from other greenhouses presented in the past literature regarding reducing the temperature (Salman *et al*., 2020; Al-Asadi *et al*., 2023). The results' comparison can transpire every two days to analyze the daily change in the greenhouse climate. In this context, temperature and relative humidity were the two important factors (as per the farmer's experience) the greenhouse uses to determine the right values for managing the weather conditions for better plant growth, following the primary needs of the farming community (Hassan *et al.,* 2021).

Given Iraq's hot weather, improving the design continues by adding a side cooling unit. This is essential in enhancing the overall cooling efficiency of the greenhouse system designed in earlier research by Rasheed *et al*. (2019), Jadallah *et al*. (2020), and Ihoume *et al*. (2023). This system has gained testing in a real hot environment at 49 °C, while other systems presented in the literature review have reached trials at lower temperatures than 49 °C. Meanwhile, some systems have not even experienced verifications in a real environment. Moreover, other systems deal with one or two environmental factors, mostly temperature or soil moisture, while this system deals with three environmental factors.

Table 1 presents the comprehensive findings and compares this work with similar ones. The existence of the said cooling unit achieves an impressive temperature reduction of 14 ˚C; however, without its application, it would only reduce 8 ˚C of temperature. Our designed greenhouse has a width and length of 1 m and a height of 1.39 m. On the overall predicted system lifespan, the time series analysis predicted the best possible recorded conditions, which were in March with a temperature of 17.8 °C. The system can also last for approximately 868 days. The worst given forecast was July days, which were out of 74 days in total, with a recorded temperature of 47 °C.

Forecast reliability was also questionable due to temperature variance and summer heat. Despite this, surviving summer without maintenance for a low-cost system is an accomplishment. Graphs illustrated the environmental factors (temperature, humidity, and sunlight). As seen in Table 3, the greenhouse automated system works appropriately under the required greenhouse conditions, even when it rains, and the wired connections also stay stable. Table 4 shows a comparison between the two designs.

The differences in temperature and humidity related to the greenhouse appear in Figure 4. The decrease in temperature following the installation of a side cooling unit was also illustrative. The chart, as labeled with the environmental factors for one day, displayed a time-series plot showing environmental parameters over a specific period, with the time axis marked on the x-axis. Figure 3a showed a notable difference between the temperature inside the greenhouse in the presence of the side cooling unit (the blue line) and the temperature inside the greenhouse with an absence of the side cooling unit (green line). This emphasizes the significance of the side cooling unit's existence in the system (Rasheed *et al.,* 2018).

The importance of an existing fan can be noteworthy by observing the temperature with and without the fan (green and yellow lines). Likewise, a big difference occurs between the temperature inside the greenhouse without using the fan and the side cooling unit (yellow line) and the temperature inside the greenhouse using the fan and the side cooling unit. It also emphasizes the enormous effectiveness of combining these two devices. The difference between inside and outside humidity is available in Figure 3b (Rohimi *et al*., 2019; Jadallah *et al.,* 2020; Al-Helal *et al.,* 2022).

CONCLUSIONS

The greenhouse system's lifespan attained significant effects from temperature after some weeks of use in harsh conditions. Compared with related works, lifespan prediction, as proposed and used for the first time in greenhouse systems, is a novel idea presented in this work. The displayed greenhouse system incurred implementation and testing in a real, harsh, and hot environment (49 °C), becoming an advantage over several most related works being recognized as a better option for countries with hot weather conditions like Iraq. The materials used, the size, and the control system applied in the greenhouse played a

Table 4. Temperature differences between designs.

Designs	Outdoor temperature (°C)	Indoor temperature (°C)	Temperature decrease (%)
Old design	38	34	10.5
New design without cooling	47	46	2.1
New design with ventilation fan		39	17
New design with side cooling unit		37.5	20.2
New design with both ventilation fan and side cooling unit		35	25.5

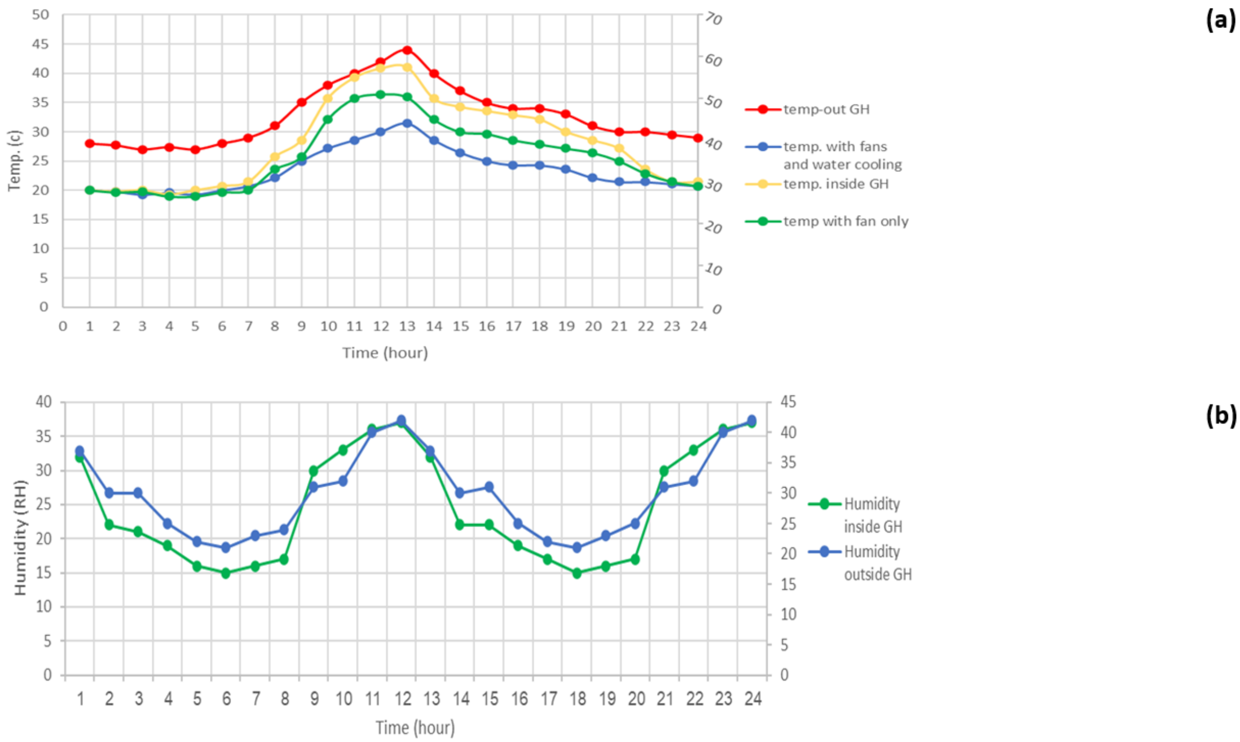

Figure 4. (a) Inside and outside temperature for one day, (b) Inside and outside humidity for one day.

considerable role in reducing the cost, increasing the life span, and ensuring the durability of the proposed design in high temperatures. More enhancements to the system can continue, such as optimizing the prediction accuracy by using machine learning and AI techniques, in the future.

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