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CONSTRUCTION OF A GREENHOUSE PROTOTYPE WITH AUTOMATED CONTROL USING A LOW-COST MICROCONTROLLER AND SENSORS

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ABSTRACT

Family farming is of fundamental importance for food supply in the domestic market. It is not enough to monitor the data for a better understanding of the entire operational chain by the small producer. It is also necessary to automate the system actuators, allowing better use of natural resources such as water intended for irrigation and reduced operating costs through adequate control of the system's energy consumption. This article presents the development design and verification of the functionality of an automated system of a greenhouse prototype using low-cost electronic components and simple implementation. The project made it possible to create a database for future conferences by storing data collected in the cloud using the Google Drive platform and data synchronization via Wi-Fi using the ESP32 microcontroller. The prototype's efficiency and applicability analysis took place over eight days. Data were collected regarding temperature, soil moisture, relative air humidity, water consumption of the irrigation and humidification system, and electricity consumption. The results obtained allowed the verification of the system's functionality and the ability to store the data on the Google Drive platform, enabling remote consultation through the web server.

Palavras-chave:
Agricultura Familiar
Automação
ESP32
Google Firebase
Realtime Database

CONSTRUÇÃO DE UM PROTÓTIPO DE ESTUFA COM CONTROLE AUTOMATIZADO UTILIZANDO MICROCONTROLADOR E SENSORES DE BAIXO CUSTO

RESUMO

A agricultura familiar é de fundamental importância para o abastecimento de alimentos no mercado interno nacional. Para que seja possível uma melhor compreensão de toda a cadeia operacional por parte do pequeno produtor, não basta que somente seja realizado o monitoramento dos dados, é necessário também que seja possível a automação dos atuadores dos sistemas, permitindo uma melhor utilização de recursos naturais como a água destinada a irrigação e redução nos custos operacionais, através do controle adequado do consumo energético do sistema. Este artigo apresenta o projeto do desenvolvimento e a verificação da funcionalidade de um sistema automatizado de um protótipo de estufa, utilizando componentes eletrônicos de baixo custo e simples implementação. O projeto possibilitou a criação de um banco de dados para futuras conferências, através do armazenamento dos dados colhidos em nuvem com a utilização da plataforma Google Drive e a sincronização dos dados via Wi-Fi, utilizando-se do microcontrolador ESP32. A análise da eficiência e aplicabilidade do protótipo se deu durante um período de oito dias, onde coletou-se dados referentes a temperatura, umidade do solo, umidade relativa do ar, consumo hídrico do sistema de irrigação e umidificação, e, consumo de energia elétrica do sistema. Os resultados obtidos permitiram a comprovação da funcionalidade do sistema bem como foi capaz de armazenar os dados na plataforma Google Drive, possibilitando também a consulta remota, através do servidor web.

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INTRODUCTION

According to data pointed out by (UN, 2021), family farming is responsible for producing 80% of food in China, while in Brazil, this production reaches only 10% so that the country would benefit from a greater variety of agricultural productivity. Mainly from products from family farming. “Much of arable land is concentrated in small groups” (UN, 2021), focusing on producing *commodities* for export. These groups have government tax incentives.

Automation applied to solving problems facing family farming is not widespread due to the false idea of complexity and the high cost of the equipment needed for its implementation (CUNHA; ROCHA, 2015).

Autonomous systems present relevant advantages in the processes, such as energy efficiency, efficiency in using natural resources, and precision in analysing the variables. These systems enable positive results for the end user (BOLZANI, 2004).

The use of automated systems in greenhouses, especially those intended for family farming, has been developing slowly, according to technological advances in agricultural production.

These automated systems allow greater control of the production stages of certain crops, thus reducing the possibility of common errors in the daily work of small properties (FERNANDES; PREUS; SILVA, 2017).

The storage of the collected data practically takes place using free tools available on the network so that it is possible to optimise the production processes of different cultures and, at the same time, allow the creation of a place for storing the data using Google Drive.

Through the Google Firebase Realtime Database platform, it is possible to check the readings in real-time by smartphone or other peripheral to improve the end-users’ interaction with the system.

In this work, it was essential to use a microcontroller with easy programming and high reliability, which at the same time was efficient and allowed communication with Wi-Fi. These features are in the ESP32 microcontroller (KOBLAN, 2018).

The ESP32 microcontroller has a low acquisition cost, a high data processing rate, and a module compatible with data transmission through Wi-Fi (KOBLAN, 2018).

The elements used in this project fulfil their objective of having reduced financial costs and having easy access to them in the market. The methodology used in this project is simplified and aimed at replicating small rural producers to improve their food production process.

The objective of this work was to carry out a methodology of easy replication for people with little knowledge in the area through the elaboration of a prototype of an automated greenhouse aimed at family farming, allowing the reading of data referring to temperature, air humidity, soil, energy consumption and water consumption of the system.

According to Brasil (2006), as stated in the Brazilian Constitution and regulated through Law n° 11.326, article 3 addresses family farming and rural family entrepreneurs who practice activities in rural areas,

According to IBGE (2017), Brazil has 80.89 million hectares for family farming. A large part of the products produced in these areas is to supply the national domestic market, thus becoming a fundamental practice for the economy. Brazilian.

To carry out activities on small properties, the family farmer uses little or no automated input, with most of the service performed by manual/mechanical systems and with little or no data control regarding the production of certain crops (CUNHA; ROCHA, 2015).

There is a need to automate family farming processes to allow it to control variables such as humidity, temperature and irrigation to better take advantage of natural resources and improve product quality (ALVARENGA; FERREIRA; FORTES, 2014).

The focus on automated agricultural production processes is to produce significant commodities. Due to high technology, electronic equipment for this area becomes too expensive, making it difficult for small producers to acquire automated equipment (CUNHA; ROCHA, 2015).

Irrigation is essential in agriculture, and its proper use to efficiently use natural water resources can bring both economic benefits to the producer and environmental benefits to society (CAMARGO, 2016).

To implement irrigation systems, a significant investment of capital is necessary, making it difficult and often impossible for the small producer to use an efficient irrigation system (MAROUELI; SILVA, 2000).

This article presents the development design and verification of the functionality of an automated system of a greenhouse prototype using low-cost electronic components and simple implementation.

MATERIAL AND METHODS

Data readings were performed to identify the most relevant data and variables in the control and acquisition of automation data of the greenhouse prototype for family farming. The readings of the variables were carried out through sensors allocated in the structure, activation of different systems through the actuators, and data of relative air humidity, soil humidity, energy and water consumption of the system. Finally, all data collected during the analysis were stored in the cloud.

Assembly and development of the prototype of the automated greenhouse

A simple, low-cost greenhouse was chosen, as shown in Figure 1. Materials of easy access and malleability were primarily used. The structure has a cubic shape and includes an additional part, such as a roof, simulating a house.

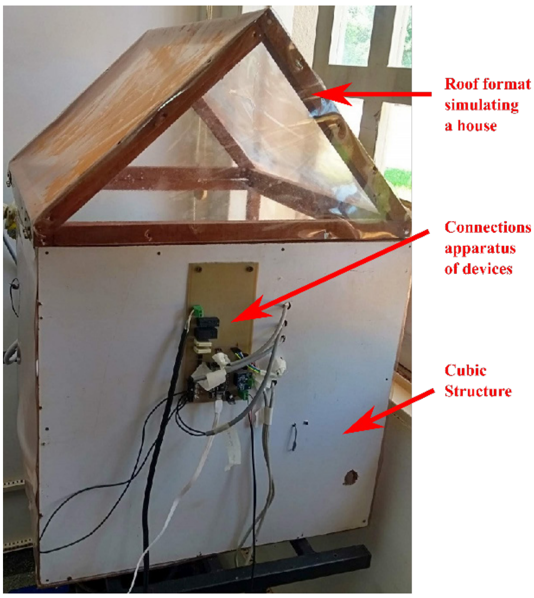

Figure 1. View of the greenhouse structure

Assembly and development of the hydraulic system

The hydraulic system was divided into two systems, one responsible for soil irrigation according to soil moisture parameters, read by the capacitive soil moisture sensor, and the other responsible for the air humidification system.

The air humidification system works with two coolers and a 127Vac solenoid valve, which is different from the 12Vdc solenoid valve for soil irrigation. The solenoid valve supplies water to the homemade expanded clay radiator, and the coolers supply moist air into the prototype according to the relative humidity parameters read by the DHT11 humidity and temperature sensor.

The soil irrigation system has the same working principle; however, it works together with a 12 Vdc solenoid valve and a drip tape.

Finally, the part responsible for the irrigation of the soil, a drip tape of

length 35 cm, previously insulated with silicone glue and thread seal.

Hydraulic soil irrigation system

In assembling the hydraulic system for soil irrigation, a 12.7 mm diameter sleeve connects the system to the outlet of the T derivation that connects the flow sensor with the soil irrigation system.

After the sleeve, a flexible connection with a diameter of 12.7 mm and a length of 30 cm connected the water supply system to a 12 Vdc solenoid valve. At the solenoid valve outlet, a 12.7 mm sleeve and a tap tip of the same dimension were placed.

Finally, the part responsible for soil irrigation, a drip tape 35 cm in length, was previously isolated with silicone glue and a thread seal.

Hydraulic air humidification system

In the assembly of the hydraulic system for the insertion of humid air inside the prototype, called the radiator in this project, low-cost materials are reused from previously discarded products, as shown in Figure 2.

For the assembly of the radiator structure, a plywood type was used, where they were cut into three parts, one of them being the base, having dimensions of 50 cm long and 8 cm wide.

The other two parts were cut 35 cm in length and 8 cm in width to envelop the structure, and two large parts from a used fridge were used to act as a grid to support the expanded clay; these parts are responsible for the water absorption system that comes from the hydraulic system.

Two computer coolers with a supply voltage of 12 Vdc were used for the ventilation system.

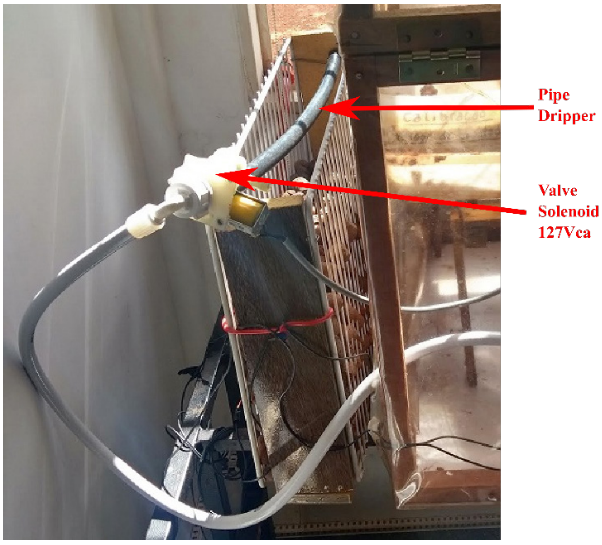

Figure 2. Air humidifier-radiator hydraulic system

The hydraulic humidification system, through a solenoid valve with a nominal voltage of 127Vac, is directly fed with the main voltage. The solenoid valve used in the radiator system is different from the solenoid valve used in the soil irrigation system, the latter having a working voltage of 12 Vdc. There are, therefore, two hydraulic systems, one referring to the system responsible for irrigating the soil and the other system responsible for humidifying the air.

The pipe used is suitable for domestic water use in washing machines and is 1.40 m long. It also has a quick coupling directly connected to the 127Vac solenoid and another in a connection, connected directly to the T-branch, leaving the flow sensor.

The water arrives through the piping to the solenoid valve, which in turn is activated through programming logic. When the parameters are correct, it allows water to pass through the rigid drip hose, which in turn distributes it evenly in the radiator.

The coolers, connected in parallel with a voltage of 12 VAC, are activated, forcing the passage of humid air into the greenhouse.

Capacitive soil moisture sensor calibration

First, a soil sample was collected at the Federal University of Rondonópolis (UFR), as shown in Figure 3. After collection, according to EMBRAPA (1997) recommendations, the soil was sieved in a fine sieve measuring approximately 3 mm and placed in a suitable container for microwave heating for 10 minutes to obtain a homogeneous sample with 0% humidity.

Figure 3. Soil sample collection for capacitive sensor calibration

After drying the sample to reach 0% moisture, a semianalytical balance was used in the soil laboratory at UFR. A cup (2.7 g) is shown in Figure 4(a) to determine the mass to be discounted to obtain a mass of 200 g of soil, as shown in Figure 4(b).

After weighing 200 g from a cup, the same procedure in another cup, to obtain two homogeneous samples of 200 g of soil, must be carried out in two calibration tests.

After the two homogeneous samples of 200 g of dry soil with 0% moisture were separated, a smaller glass of water was tared for later use. Twelve cups containing 10 ml each were used, that is, six cups for each calibration test. A graduated pipette and a pear were used to measure 10 ml of water in the glasses.

Six reading intervals for calibration were divided between the ranges of 0% humidity to 30% humidity. As the density of water is 1 g/cm³, then for a sample of 200 g of soil, 10 ml of water is equivalent to 5%.

(a) (b)

Figure 4. Tare of 2.7 g beaker (a) and 200 g soil sample (b)

The capacitive sensor was put into the first beaker with 0% humidity, and data were collected for ten minutes. The programming and the electrical connection necessary for the sensor reading were the same as those used in the final code of this project (Figure 5).

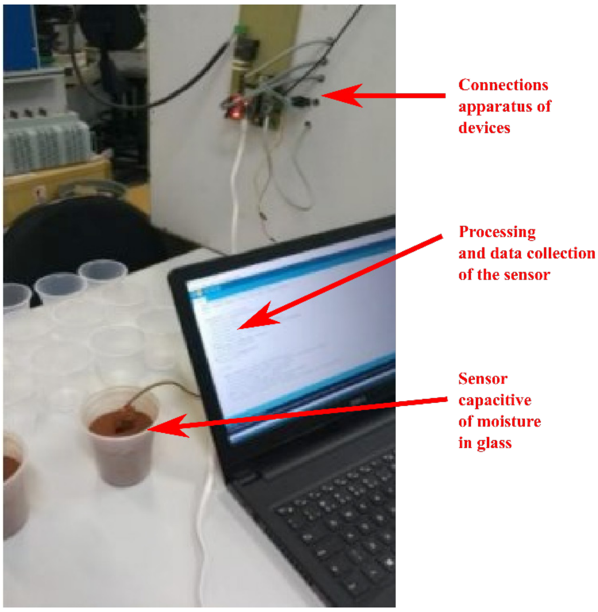

Figure 5. Start of capacitive sensor calibration

An average was collected to delimit the characteristic range in each moisture percentage according to Tables 1 and 2. For example, an analogue reading of 1904 on the capacitive sensor resulted in 10% of the soil unit.

Table 1. Results presented in the first calibration test

Analog reading presented by capacitive sensor	Soil Moisture %
3223	0
2298	5
1904	10
1665	15
1491	20
1419	25
1399	30

In the first ten minutes of data collection, no water was added, and the values presented in the first reading correspond to the value that the sensor considered for the humidity of 0%.

For the other samples, 10 ml of water was added every ten minutes, totalling a 5% increase in soil moisture for each moisture range.

This test was performed for both soil samples to obtain more accurate values. After carrying out the tests, the collected values were arranged in Excel (2016), where distinct linear graphs were generated so that it was possible to compare which sample presented values closer to the real ones, as shown in Figures 6 and 7.

Table 2. Results presented in the second calibration test

Analog reading presented by capacitive sensor	Soil Moisture %
3152	0
2635	5
2139	10
1878	15
1758	20
1651	25
1583	30

To define which equation to use, the one that presented the slightest differences in the readings was defined, and consequently, the reading that presented the slightest variation in the measurements of the points was the one that presented the highest R^2.

The equation used as a parameter was obtained through the second sensor calibration test for humidity values from 0% to 30%.

The equation is defined by:

$$y = -0.0002x + 0.5177 \quad (1)$$

where,

x = Analog reading measured by the capacitive sensor.

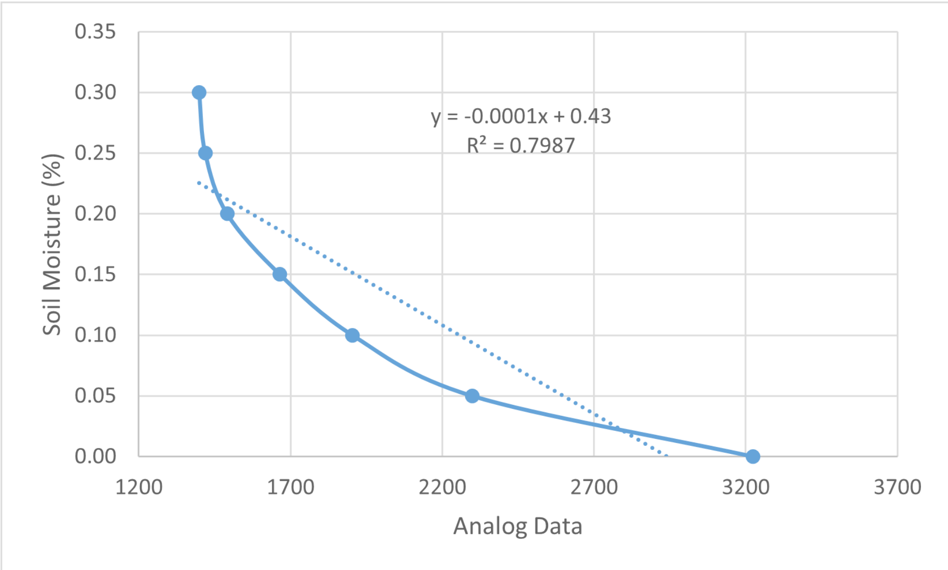

Figure 6. Results of the first calibration test

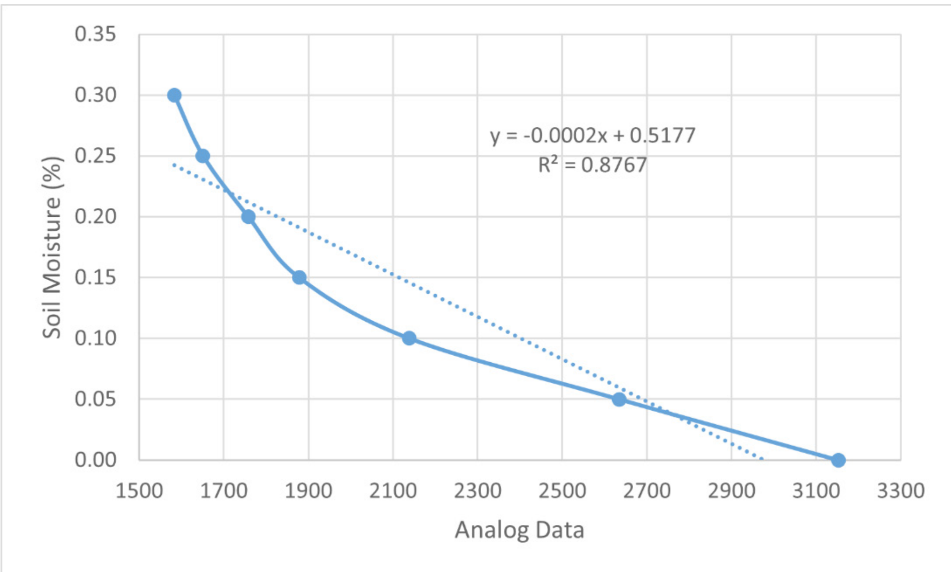

Figure 7. Results of the second calibration test

A similar calibration was also performed on the YF-S201b water flow sensor and the INA 219 current sensor.

Programming code and data reading

To carry out the necessary programming to measure ambient air temperature, relative air humidity, soil humidity, system water consumption and energy consumption, the Arduino IDE was used, in addition to the ESP32 microcontroller drive, which is necessary so that the Arduino interface recognises the ESP32.

Extra PuTTy version 0.29 (EXTRAPUTTY, 2021) was used to collect data. This data monitoring software uses a serial port, which is necessary to display the readings in real time, generating a text file of the readings being carried out by the sensors for later storage, both on the computer and the computer. Additionally, cloud storage is performed through the Google Drive platform (GOOGLE, 2021).

The code can read the temperature, humidity, water consumption and instantaneous power data, as well as trigger the necessary actuators according to parameters preestablished by the user.

Cloud data storage system

For cloud storage, a simple execution method was defined, aimed at applicability by any operator. Google Drive was used on the computer to store the reading data locally. With Extra PuTTy 0.29, the data folder was synced to Google Drive, updating the values as the readings changed.

To declare the data saving location, the location to be saved was defined in Extra PuTTy, generating an automatic and fast task to ensure that, in the event of a power failure, after synchronized data in real-time, it is stored in the cloud.

Data reading

All data collections were performed at the Electrotechnics Laboratory of the Agricultural and Environmental Engineering (EAA) course at UFR. The functionality analyses of the automated greenhouse prototype carried out in eight subsequent days.

The readings were presented every five minutes for eight hours daily, totalling ninety-six data points per day. As presented in the results ahead, the repetitions were performed by averaging all the data obtained by the sensors over the days. The interval period of readings between the data were five minutes, during eight hours. Therefore, each repetition is equivalent to an average of four readings, totalling twenty-four repetitions.

The determination of the ranges of relative humidity of the soil and relative humidity of the air used in this project happened empirically, not having any relation with the actual values of humidity used in greenhouses. Moisture ranges are only helpful as a simple and practical way to determine system functionality over the eight days of data analysis (Table 3). For example, with a soil humidity of 10 to 13%, the parameter of air humidity is 52 to 54%.

Table 3. Parameters of soil moisture and relative air humidity

Day	Soil Moisture Parameter (%)	Parameter Air Humidity (%)
1	0 - 5	48 - 50
2	6 - 9	50 - 52
3	10 - 13	52 - 54
4	14 - 17	54 - 56
5	18 - 21	56 - 58
6	22 - 25	58 - 60
7	26 - 29	60 - 62
8	0 - 30	< = 94

RESULTS AND DISCUSSION

The ranges from 0% (arid soil) to 5% soil moisture and from 48% to 50% of the relative humidity (RH) were adjusted on the first day.

Figure 8 shows the water consumption on the first day of the greenhouse prototype analysis. The parameter for activating the radiator system, which is responsible for the insertion of humidity in the stove (line at 50% RH), was always above the minimum parameter for activation defined in the programming code, which does not present water consumption.

Soil moisture started below the minimum soil moisture parameter (line at 50% RH), so the soil irrigation system was activated (Figure 9), which was responsible for the total water consumption of the system, which was 1.4 litres of water.

Nevertheless, in Figure 9, it is observed that the power used remained constant as the soil irrigation system remained activated, showing low variation. It was noticed that the power used presents a sudden drop as the soil moisture approaches 5%, causing an interruption of the irrigation system. On the second day, further adjustments, unlike the first day analysed, presented a considerably higher water consumption because the relative humidity of the air often remains within the parameters necessary for the activation of the air humidification system.

Figure 10 shows a variation in the power used by the system; this is because the system has frequent radiator activations. In the repetitions where the relative humidity of the air remained equal to or above the black line and the green line, the power remained practically constant.

On the third day, 10-13% of the soil moisture and 52-54% of the RH range were adjusted, as shown in Table 3. There was a sudden drop in the power used by the system when the values of relative air humidity and soil humidity exceeded the humidity parameters for activating the actuators.

On the fourth day, 14-17% soil moisture and 54-56% RH range were adjusted (Table 3). When the relative humidity decreased and the soil moisture did not reach the parameter for the interruption of soil irrigation, the power suffered a slight increase, remaining constant until both the soil moisture and the relative humidity were retained.

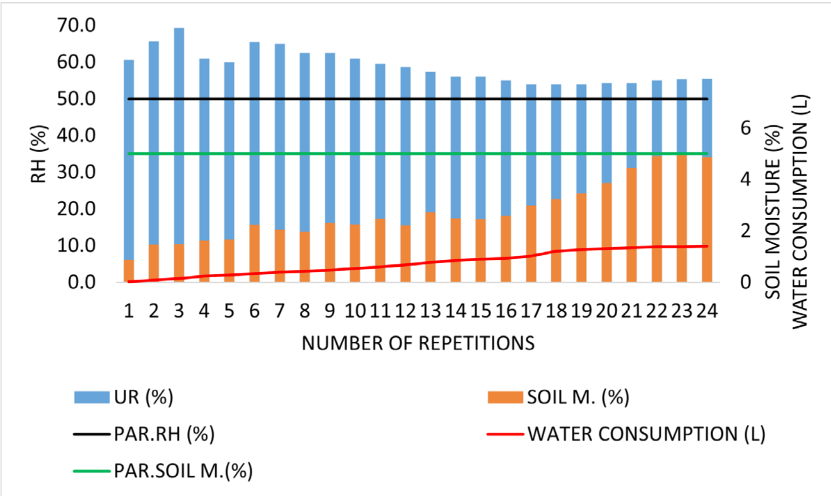

Figure 8. Water consumption on the first day of analysis

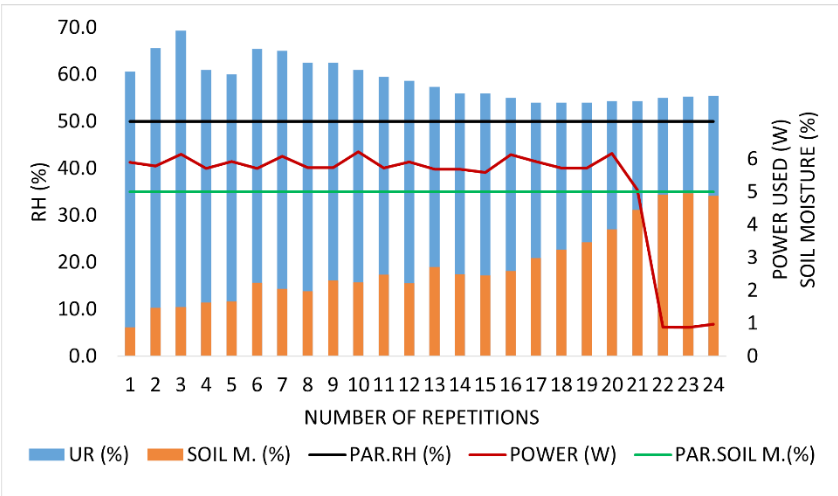

Figure 9. Power used by the system during the first day of analysis

On the other days, the parameters were adjusted to the soil moisture and RH ranges following the progression presented each day in Table 3. Moreover, the values collected showed peculiarities that followed the trend of the others, respecting the adjusted limits.

Analysis of the water and energy consumption of the system

Figure 11 presents the total water consumption values during each analysis day. The days when the average relative humidity, represented by the orange bar, was much above the relative humidity parameter, represented by the black bar, were the days in which the lowest water consumption of the system was obtained.

As the air humidification system is responsible for most of the water consumption of the prototype, it was only represented to prove that on the sixth day, the one that presented very high relative humidity due to rain was the one that presented the lower consumption.

The eighth day, which presented the highest total water consumption, is also justified because the relative humidity of the air presents values practically equal to the parameter defined for the activation of the radiator system, which, therefore, is activated frequently and consequently causes high water consumption.

Figure 12 shows the average daily values of power used by the system. These values were necessary to determine the total energy

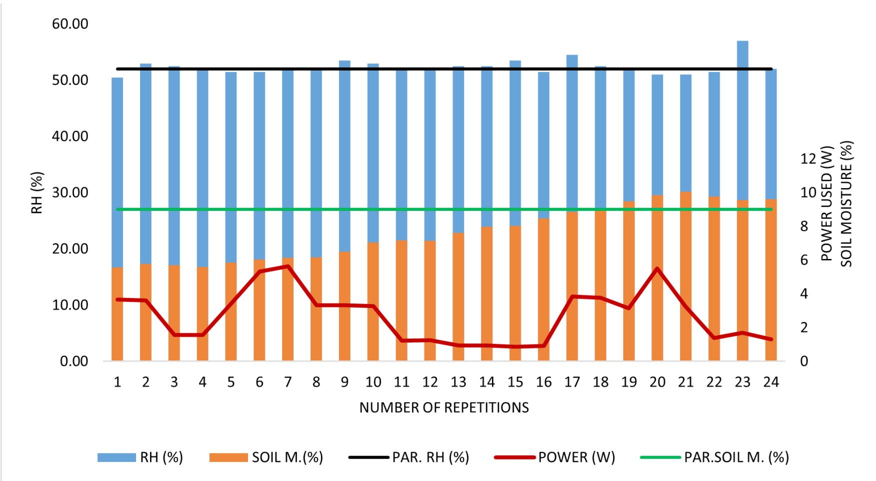

Figure 10. Water consumption on the second day of analysis

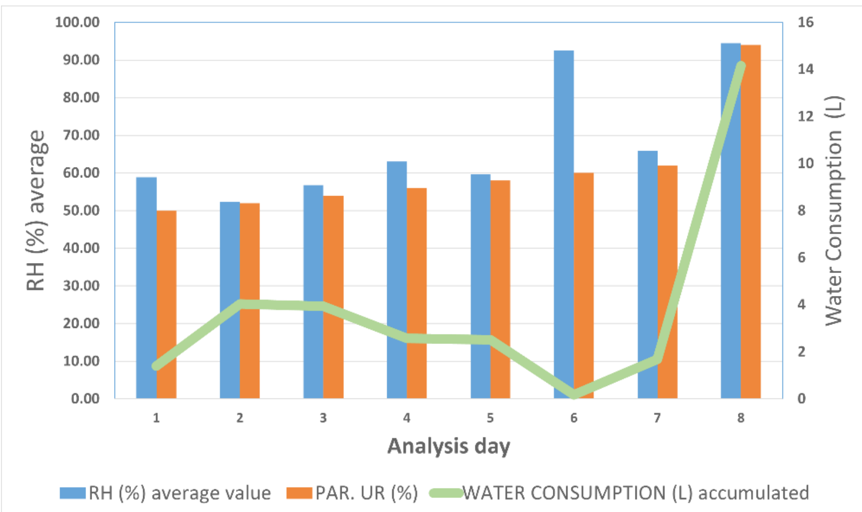

Figure 11. Relation of relative air humidity and water consumption

consumption of the system.

The total energy consumption of the system requires the total average of the power consumed by the system and is given through (2):

$$\text{Consumed Energy } (W\,h) = P.t.d \qquad (2)$$

where,

P = the average power [W];

t = the number of hours per day;

d = the number of days.

Consumption ($W\,h$) = 3.7 $_*$ 8 $_*$ 8 = 236.8 (Wh).

In Figure 13, it is possible to observe both the daily values of energy consumption and the total value consumed by the system within eight days of analysis. The red line represents the total amount consumed by the system, and the daily values are represented by the bars.

Relation of temperature and relative humidity of the air

It is possible to observe a direct relationship between the ambient temperature and the relative humidity of the air, as shown in Figure 14.

The temperature drops by sending moist air into the automated greenhouse prototype; nevertheless, the values of lower relative humidity of the air present an increase in temperature, and at the points where the graph shows higher values of relative humidity of the air, the temperature suffers a reduction.

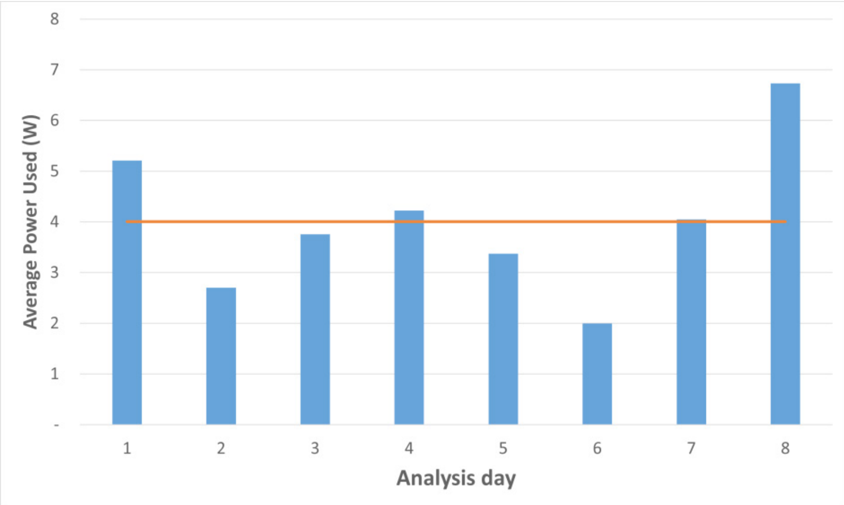

Figure 12. Daily average of the powers used

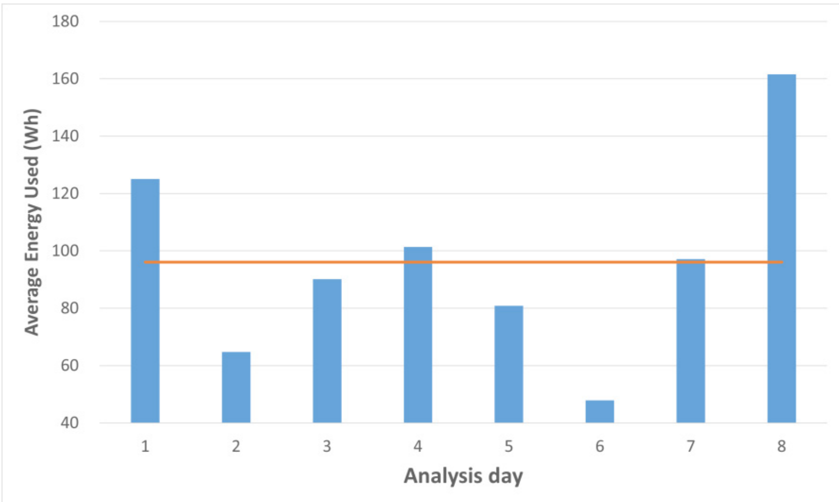

Figure 13. Energy consumption of the prototype in Wh

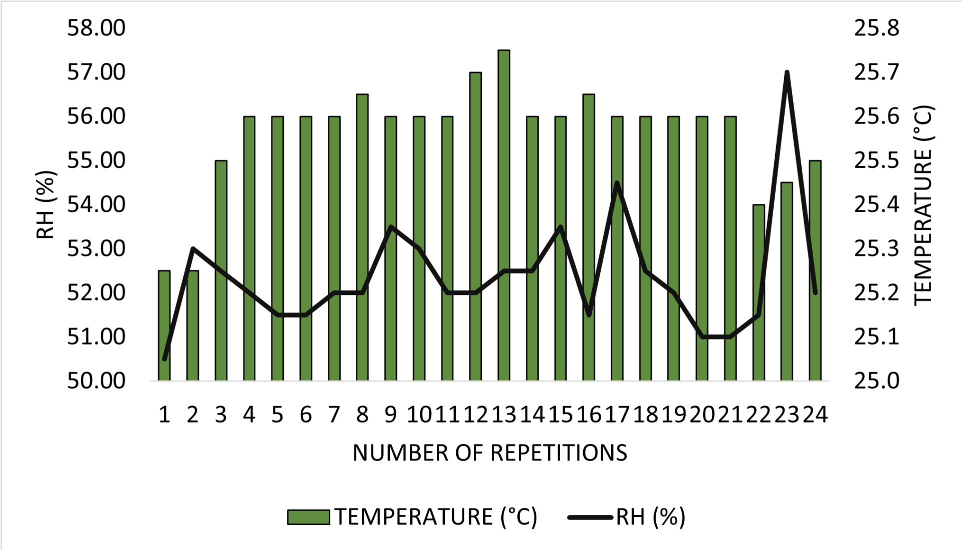

Figure 14. Temperature x relative humidity ratio

CONCLUSIONS

- To create a database that can allow comparing data from different environmental conditions throughout the production periods. The idea can be extended to a future similar database involving different cultures.
- The system can perform concise and coherent readings of the proposed variables to analyse the system's functionality. Variables are defined in temperature, relative air humidity, soil humidity, water consumption and energy consumption of the system.
- The apparatus proved capable of storing the data collected daily on the Google Drive web server, thus being able to generate a database that the user can easily apply. It was also able to present the values obtained by the sensor and synchronised via Wi-Fi for real-time conferencing with Firebase.
- The work achieved its objective of being an automated, low-cost and functional system, with no interruption in the readings and remaining functional throughout data analysis.

AUTHORSHIP CONTRIBUTION STATEMENT

BEUTER, C.H.: Data curation, Validation, Visualization, Writing – original draft, Writing – review & editing; **BORGES, R.C.:** Conceptualization, Data curation, Resources, Supervision, Writing – review & editing; **FOGACA, R.C.:** Conceptualization, Investigation, Methodology, Resources, Software.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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