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Measurement and Control of the Inside Greenhouse Climate Using Neural Network Prediction and Fuzzy Logic Controller

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Abstract: To change the environment in which plants thrive, protected agriculture employs a variety of techniques. In a perfect world, plant growth would happen in climate-optimal locations with no need for protective structures .This is not the case, though, as the majority of nations mandate various types of agriculture in controlled environments to save crops from climatic and environmental extremes. High sun radiation is available in arid areas, but they also have challenging relative humidity and temperature ranges. This study's goal is to evaluate the effectiveness of a cooling system installed in an agricultural greenhouse for a semi-arid environment. The design of two greenhouses—one with and one without a cooling system—is the main topic of the work. The experimental greenhouse (with a cooling system) has cooler temperatures than the control greenhouse. While the humidity is higher than in the control greenhouse, the temperatures are lower in the experimental greenhouse (with cooling system).These results demonstrate the system's dependability in this region, which offers significant solar radiation but also challenging conditions for temperature and relative humidity.

Keywords: *Agricultural greenhouse, cooling system, fuzzy logic, neural network, temperature*

1. Introduction

According to McCartney and Lefsrud [1], arid areas necessitate protected agriculture to sustain crop output due to the limited availability of fresh water, low humidity, high evapotranspiration potential, and high temperatures. Enhancing water use efficiency is crucial in dry climate protected agriculture (Guerrero et al. [2]). Due to population expansion, concerns about food security, and a rising recognition of the decreasing quantity of freshwater, protected agriculture is becoming increasingly popular in desert countries. According to Karthikeyan and Sivakumar [3], over 30% of the earth's surface consists of arid and semi-arid regions, which are home to around 20% of the global population. The dry and semi-arid regions of the world support around 24% of Africa's population, 17% of the people in the Americas and Caribbean, 23% in Asia, 6% in Australia and Oceania, and 11% in Europe. The citation is from Salinger et al. [4] in 2005. An arid environment is characterized by minimal yearly rainfall and significant yearly potential evapotranspiration.

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Arid steppe climate (BS) receives a moderate amount of yearly precipitation, which is less than the annual potential evapotranspiration.

On the other hand, arid desert climate (BW) receives very minimal or no annual precipitation and has high evapotranspiration. The reference is from Jiang et al. [5] in 2014. It is imperative to mitigate heat stress and regulate evapotranspiration in arid and semi-arid regions. According to Al-Ismaili and Jayasuriya [6], in desert conditions characterized by high temperatures and extremely low relative humidity, raising the relative humidity inside the greenhouse can lead to a significant reduction in crop evapotranspiration, ranging from 60% to 80%. In numerous regions of the Middle East and North Africa, the typical daytime temperatures during summer inside greenhouses can rise to 46°C. The average outdoor temperature exceeds 38°C. As noted by Al-Helal & Alhamdan [7], these areas often have limited or no access to freshwater. In a specific case in southeastern Jordan, an unventilated greenhouse reached a maximum temperature of 75°C, while the outdoor ambient temperature was approximately 37°C. During the early morning hours, the inside temperature was lower than the external ambient air temperature because of the exchange of infrared radiation with the greenhouse cover.

The study conducted by Al-Helal et al. [8] in 2007 found that the outdoor temperature ranged from 31.7 °C to 38.7 °C, while the relative humidity varied from 11.2% to 16.7% throughout the day and night. A noteworthy finding from this study is that the mean indoor temperature, when crops were present, decreased to 23.3 °C during night time. Arid and semi-arid climates provide protection for agriculture due to their ability to handle significant fluctuations in seasonal and daily temperatures (Wagner et al. [9]). If agricultural output takes place throughout the year, active ventilation and cooling are essential during hot periods.

According to McCartney and Lefsrud [10], misting systems and fan and pad systems are the most prevalent. By employing a combination of evaporative cooling, active ventilation, and shading techniques, it is feasible to lower the air temperature in greenhouses by as much as 8°C. However, certain studies indicate that cooling of up to 12°C can be achieved in extremely hot and dry areas [11]. López and Delgado [12] found that fan and pad systems effectively cool air, while they also generate temperature and humidity variations from the point of entry to the point of exit. Although the fog-cooled greenhouse may not achieve the same level of cooling as a fan and pad-cooled greenhouse, it offers the advantage of providing more consistent and uniform conditions. Therefore, fog systems are occasionally favored over fan-and-pad systems (Kumar et al. [13]). Furthermore, it is advisable to restrict active ventilation in order to prevent excessive stress on the crop caused by heightened transpiration (Provencio et al. [14]). Evaporative cooling of greenhouses is known to effectively reduce temperatures, however it has been estimated that the water consumed for this purpose can contribute to as much as 67% of the total water needed for greenhouse operations (Ali et al. [15]). As previously recommended, the current trend in passive greenhouse technology is to construct taller greenhouses in order to decrease the maximum air temperatures within the greenhouse. According to Suárez-Romero et al. [16] and Müller et al. [17], this technology is particularly suitable for agriculture in tropical climates where it is not possible to use active ventilation and cooling systems. The efficiency of active ventilation and cooling is diminished as the greenhouse volume increases and the control of air inlets and outputs is limited, hence compromising this design aspect. To operationalize a design that incorporates both passive and active cooling and ventilation systems, it is necessary to include retractable roof systems and closable side and roof vents. Due to the significance of water use efficiency, there is a growing inclination towards constructing buildings that integrate both passive and active ventilation systems in order to minimize energy and water needs (Mahdessian et al. [18]). Evaporative cooling, when combined with forced ventilation, offers effective cooling in ideal operating conditions, but may have limitations in dry climates. Various options exist for greenhouse cultivators in hot, arid regions to manage the greenhouse conditions. Many methods need the implementation of active steps to decrease air temperature and evapotranspiration, resulting in high energy consumption. The objective of the present study is to integrate passive and active methods in order to enhance the efficiency of greenhouse cooling in arid regions.

Studies conducted by Akrami et al. [19] and Revathi et al. [20] indicate that the combination of misting and shading is the most effective method for enhancing the plant environment in semi-arid locations through passive evaporative cooling. Villagrán et al. [21] have documented alternate evaporative cooling methods for arid environment greenhouses that require less forced ventilation compared to conventional fan and pad systems. However, none of them have conducted research on affordable cooling methods utilizing materials that are readily accessible in the local area.

The current paper presents an experimental investigation conducted on two tunnel greenhouses to analyse their thermal performance, both with and without a cooling system. The first greenhouse, lacking cooling systems, serves as a control, while the second greenhouse has been altered to examine the impact of the cooling system. The experimental setup is situated in the Unit of Applied Research in Renewable Energies (URAER) Ghardaia, positioned at latitude of 32.37° north and a longitude of 3.77 west. The study was structured into four components. The first portion provided a detailed description of the experimental site and its characteristics. The second half is dedicated to the implementation, measurements, and experimental findings. The final phase involves comparing the predictions made by the neural network with the fuzzy logic controller. The last section is dedicated to the preserved results and their interpretations.

2. Materials and Method

2.1. Experimental site description

Our experimental work is part of the training course carried out at the level of the Unit of Applied Research on Renewable Energies Ghardaia of Algeria during the period from 15-03-2022 to 15-05-2022. Before describing the region of our work it, to know that about 77% of the Algerian surface presents arid and semi-arid regions. The characteristics of the region of Ghardaia, (Figure 1) are:

- Location 595 Km south of the Mediterranean Sea.
- Latitude and 32°36 N.
- Longitude 3°80 E.
- Altitude of 469 m above sea level.
- Rate of sunny days per year: 77
- Annual average daily global solar irradiation about 7 kWh/m^2.

The temperature in July and August can exceed 45°C, while winters are mild with temperatures rarely exceeding 25°C.

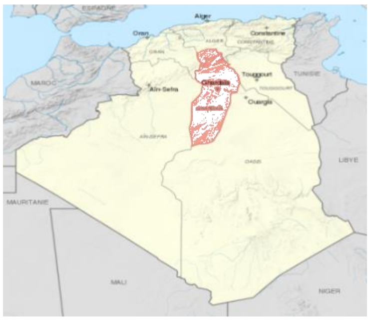

Fig. 1. Ghardaïa position in Algeria maps

2.2 Design of the greenhouse

In order to carry out this study, we used two plastic greenhouses in tunnel form with the same dimensions (Length: 200cm, Width: 100cm, Height: 80cm) and the same design, one considered as experimental greenhouse and the other as control greenhouse (see Figure 2).

Fig. 2. Design of the control greenhouse

We relied on plastic packaging and the structure is made of plastic tubes for easy modification.

2.3 Cooling system used in the experiment greenhouse

In the experimental greenhouse, we used a cooling system that reduces sunlight and winds, with sides that can be opened by folding manually. The fan system and cooling pads are made from locally available materials. The cooling fan is presented in Figure 3, and their characteristics are given in table 1.

Fig. 3. DC cooling fan

Cooling pillows, whose main component is palm fibers palm fibers were placed inside a mesh strainer with a length of 60 cm, height of 50 cm and width of 5 cm slits were placed from the top to ensure the overall moisture of the palm fibers evenly and deeply (see Figure 4). The fans are capable of drawing outside air into the interior through the cooling pad, while ensuring the passage of air through it. The anti-insect filters were used in front of the ventilation holes and doors, and this is to avoid that they leak inside and this is due to the great damage and transmission of diseases to the plants, Figure 5 and 6.

Table 1. DC cooling fan (Zhou et al. [22])

Dimensions	120 x 120 x 25 mm
Voltage	24 V
Speed	2 200 rpm
Cable length	23cm
Type of bearing	plain bearing
Sound level	36 dB
Airflow	79.0 CFM
Current rate:	0.15

Fig. 4. Cooling system made of palm fiber

Fig. 5. Anti-insect filters

Fig. 6. Cooling system in the experimental greenhouse

2.4 Used sensors

In our project we have to use 7 sensors that measure temperature and humidity DHT22,three in the experimental greenhouse , three in the controller greenhouse (without cooling system) and one outside as indicated in Figure 7 and 8.

Fig. 7. Placement of Sensors in the two greenhouses

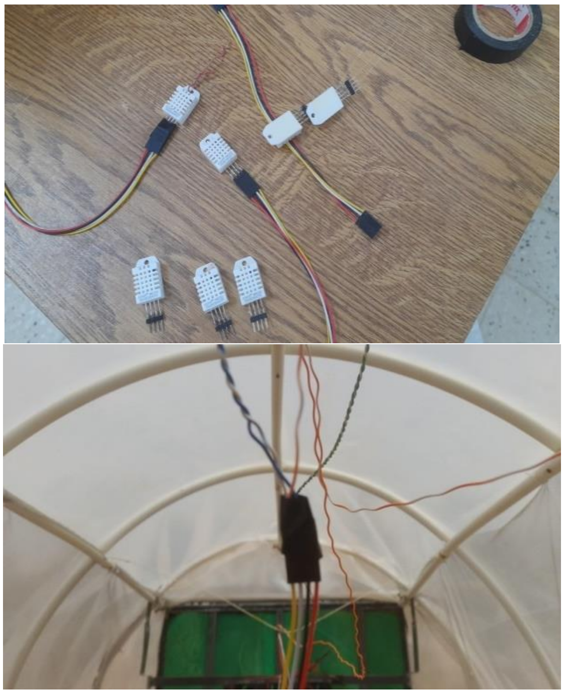

Fig. 8. Sensors used in the experiment

The acquisition system used in our project is an Arduino board type Mega 2560 and relay block. Wiring system, Arduino and memory carte and clock Regulator 24V and Fans powered with two solar panels. Their characteristics are given in table 2.

Table 2. Characterization of the two Solari Monocrystalline panels 100W 12V (Villagrán E. and Rodriguez [23])

Maximum power (Pmax):	100 Wp.
Tolerance between	0 if + 3% the 25°C.
Optimal voltage (Vmp):	18.4V.
Optimal current (Imp):	5.40 A.
Vacuum voltage (Voc):	22,25V.

Short circuit current (Isc):	5.8A.
3 diode bypass	36 cells in series of 125 x 125 mm.
Size:	1000 x 670 x 35 mm.
Weight	9 kg

2.5 Palm leaf enclosure

Wind movement due to high wind speed damages the structure and vegetation, erodes the exposed soil, and carries sand and soil by seepage into the greenhouse. This also affected the temperature inside the greenhouse, so we added natural windbreaks made of palm leaves through hedges and protective belts to reduce the wind speed and thus the effect of the wind (see Figure 9).

Fig. 9. Palm leaf enclosure

3. Experimental Results

In order to study the performances of the cooling system, the obtained results of temperature and humidity are plotted in the Figure 10 and 11 respectively. It can be seen that the temperature inside the experimental greenhouse is very low than the inside controller greenhouse temperature which also more than the outside temperature.

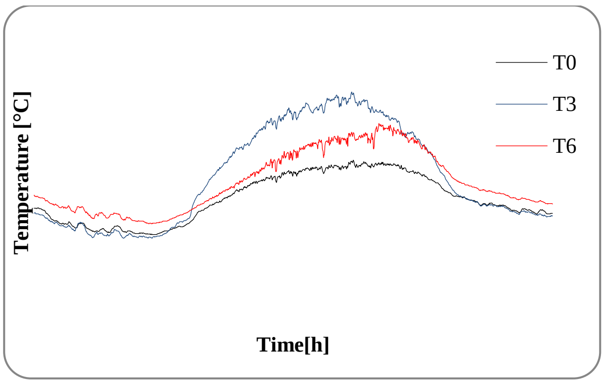

Fig. 10. Inside and outside greenhouse temperature evolution

(26.04.2022 for 13h00 to 17h00)

However the humidity in the experimental greenhouse is more than the controller greenhouse which is also more than the outside. It can be say that the cooling system decrease of the temperature and crease the humidity in the experimental greenhouse.

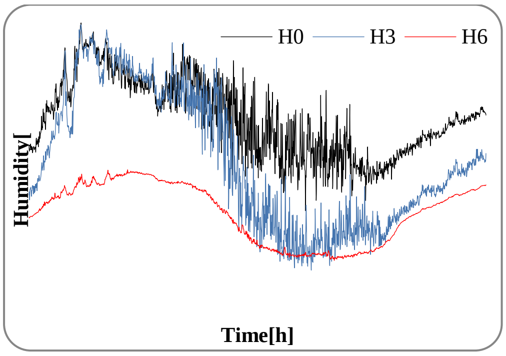

Fig. 11. Inside and outside humidity evolution

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4. Artificial Neural Network

Artificial Neural Networks (ANN) are highly effective tools for modeling systems that exhibit nonlinear interactions. They are extensively employed for solving regression and classification issues. Hence, the utilization of intricate mathematical equations to depict these systems is unnecessary, as pointed out by Ben Amara et al. [24] and Graamans et al. [25]. An artificial neural network (ANN) is a network structure consisting of individual units having the ability to process information, known as neurons. Nevertheless, it is necessary to train the neural network structure in order to establish the correlation between the inputs and outputs. In this regard, it has a striking resemblance to the cognitive processes of the human brain. The data collected were daily data, but were processed using the Microsoft Excel software. The temperature graphs for both greenhouses indicate that the temperature inside is higher than the outside. However, the experimental greenhouse has a lower temperature compared to the control greenhouse. On the other hand, the humidity in the greenhouse cooled by the system is significantly higher compared to both the control greenhouse and the outside. These two comments have enabled us to assert that the cooling system employed has achieved our goal.

The treatment's input data is organized into four columns and processed using MATLAB. The data obtained from the Target is frequently referred to as "target data". The study comprises the subsequent stages:
Step 1: The acquired sample data is split into two sets, one for constructing the model (known as the training dataset) and the other for assessing the accuracy of the model (known as the testing dataset).
Step 2: The identification of the input variables for the model is carried out.

Step 3: Constructing the model: The artificial neural network (ANN) architecture is constructed and refined. Step 4: The efficacy of the proposed model is assessed. Furthermore, the anticipated outputs are contrasted with the measurement outcome, and the discrepancy is computed. The statistical metric RMSE is employed for model validation.

The MATLAB R2020b software, specifically the Neural Network/Data Manager Tool (nntool), was utilized to generate, train, and evaluate models. The study's output layer comprises a single neuron, whereas the input layer consists of seven neurons that are correlated with the number of input variables in the network. The number of neurons in the hidden layer is calculated through an iterative process of gradually increasing the number of neurons in a model until the prediction outcomes and predictive error reach the specified threshold value of 12. The sigmoid hyperbolic tangent mathematical function is employed to convert the data inside the network layers, and the artificial neural network (ANN) is configured and operated within the MATLAB environment. The configuration data are shown in Table 3 below.

Table 3. Configuration of the ANN model (Ramírez et al. [26] and Villagran Munar et al. [27]).

S.No	Particulars	Configuration Details
1	Network Type	Feed Forward Back Propagation
2	Training function	TRAINLM
3	Adaptation Learning Function	LEANGDM
4	Error Function	MSE
5	Numbers of Hidden layers	2
6	Properties of layer-1	Transfer Function: TANSIG, No of Neurons:12
7	Properties of layer-1	Transfer Function: TANSIG
8	Training Info	Input and Output
9	Training Parameters	Epochs:1000,max_fail:10
10	Data Division	Random(divider and)
11	Training function	Levenberg-Marquardt(trainlm)
12	Performance function	Mean Squared Error(MSE)
13	Plot interval	1 Epochs

The performance of the models was evaluated based on the following statistical error indicators; Root Mean Square Error (RMSE) and correlation coefficient (R) recommended by He et al. [28]. The proximity of these two indicators to zero leads to high modeling accuracy. The coefficient of determination (R^2) reflects the quality of the model. The model tends to perform better when R^2 is close to 1.

4.1 Comparison and discussion

The empirical models Artificial Neural Network (ANN) are compared to the experimental results using statistical parameters, specifically Root Mean Square Error (RMSE) and R-squared (R^2). The RMSE value for the ANN model is 1.025, and the coefficient of determination (R^2) is 0.99. Based on the derived statistical parameters, it is observed that the suggested ANN model outperforms the empirical models in terms of the interior temperature of the greenhouse. Four plots displayed the results of training, validation, and test data. These charts illustrate the predictive capability of the model in determining the post-scholarship outcomes based on the relationships between the input and target variables.

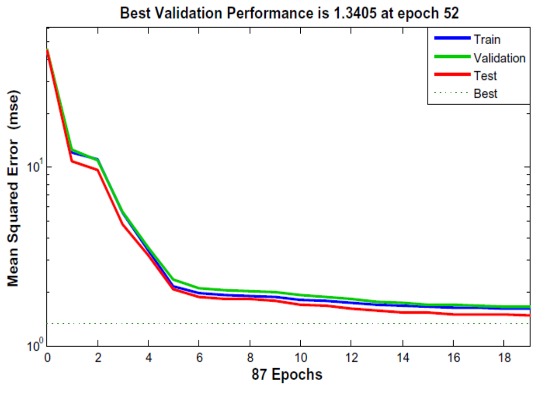

Fig. 12. Performances plot

Figure 12 depicts the performance graph obtained from the training, testing, and validation processes. The graph displays the numerical epochs and the root mean square error. The optimal validation performance was achieved at epoch zero, with a performance value of 0.024. The blue, green, red, and dashed lines indicate the training, validation, testing, and best performance curve, respectively.

Figure 13 displays the relationship between the target and the output. This graphic is generated to represent the data training, testing, and validation purposes. The training R value is 0.9963, the validation R value is 0.99959, the testing R value is also 0.99961, and the overall R value is 0.99961. These values are in close proximity to 1.

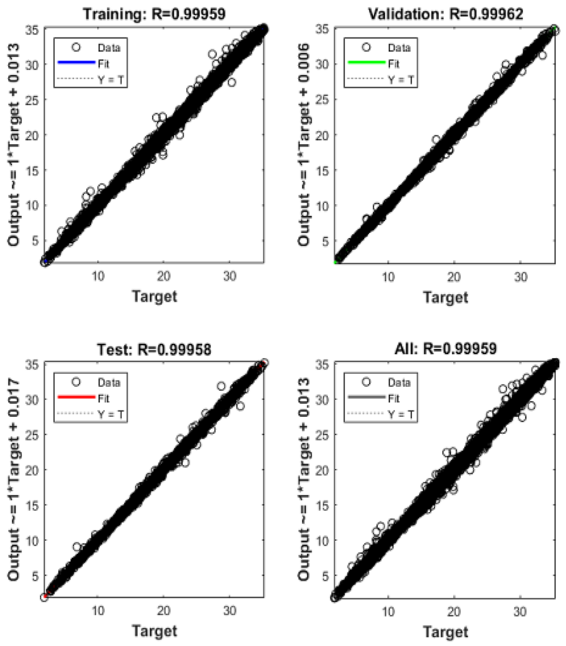

Fig. 13. Regression plot

used for

These numbers suggest that the fit is satisfactory. The regression coefficient (R-value) for the whole response is 99.61%. Figure 14 displays the validation curves depicting the relationship between the predicted temperatures and the actual measured temperatures.

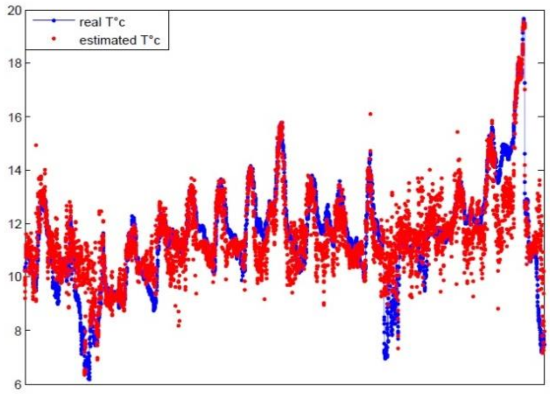

Fig. 14. Estimate temperature with ANN

4.2 Fuzzy logic controller of temperature

A fuzzy logic controller is employed to regulate the internal temperature. The error temperature serves as the input parameter, while the ventilation and heating rates act as the output parameters. The Simulink model constructed using the "Greenhouse" block is depicted in Figure 15.

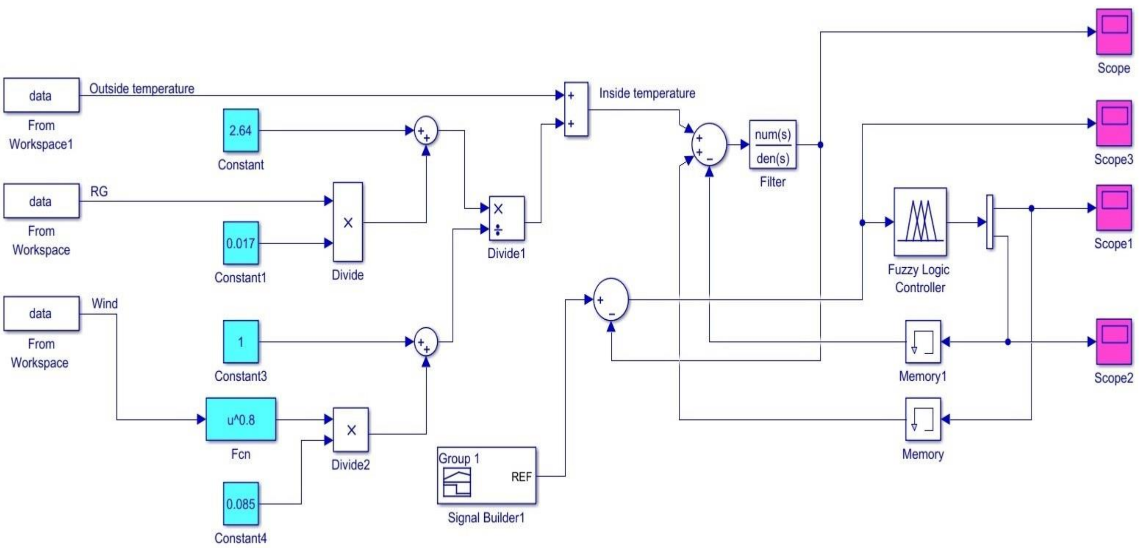

Fig. 15. Sketch of Fuzzy logic temperature controller

The Simulink model of the greenhouse consists of four main components: - The blue block represents the database containing the external and interior climatic conditions. - The MATLAB S-function "Inside-Temperature" is utilized to determine the anticipated inside air temperature.

The red blocks represent the ventilation and heating rates generated by the created 'Fuzzy Logic Controller Temperature'.

The pink color blocks represent the output results of the main Simulink model. Figure 16 displays the membership function of the input variable, which represents the temperature error. Figure 17 and 18 illustrate the membership functions of the output variables, namely the ventilation and heating rates. Figure 19 displays the progression of the interior and external temperature, together with the desired temperature. It is observed that the internal temperature accurately tracks the set point with a rapid increase in time, but with significant overshoots. In order to adhere to the notion of command modeling, the set point was selected to ensure rapid transient response while maintaining differentiability. However, the continuous letter does not enhance the legibility of the graphs.

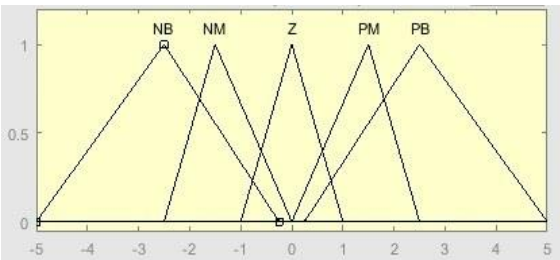

Fig. 16. Membership function of the temperature error

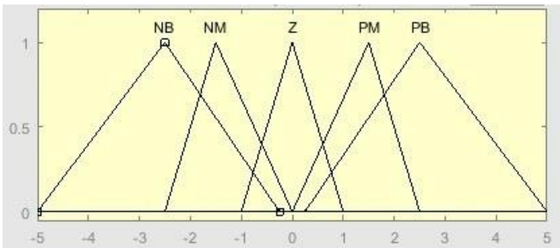

Fig. 17. Membership functions of the heating rate

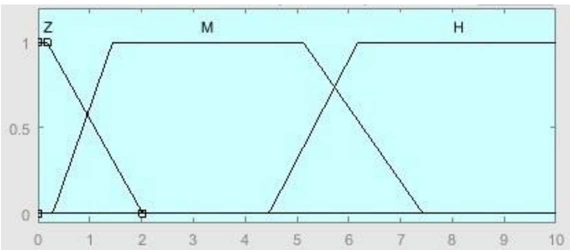

Fig. 18. Member ship functions of the ventilation

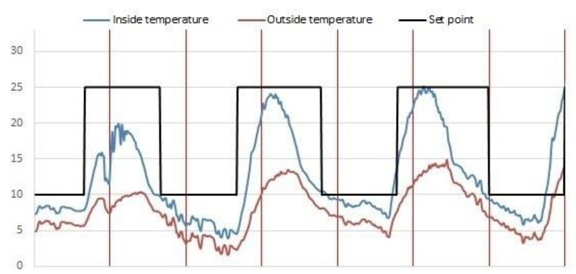

Fig. 19. Inside, outside and set point temperature

5. Conclusion

The objective of our study is to predict and control the temperature in an agricultural greenhouse.In the experimental part, the study is focused on the realization of an agricultural greenhouse occupied by a cooling system compared with another control greenhouse. At the end of this study, we found the success of the system in the experimental greenhouse compared to the second greenhouse (without system).

This is noticed in the difference of average internal temperature, where the control greenhouse recorded 40 and the experimental greenhouse less than this value along the duration of data collection.On the other hand, the system provided in the experimental greenhouse proved to be a great advantage in terms of effect on the reduction of the internal temperature, due to the cooling system of pillows and fans powered by solar panel. The activation of the steam cooling system in the cooling increases the humidity in order to grow crops in an appropriate atmosphere in this area.

The design of the greenhouse ventilated through the side openings, you can be folded. It is worth mentioning that the use of anti-insect screens in the hatches and doors, because insects can affect the quality of products and transmit diseases to plants, or they can destroy it.

The use of shading helps to reduce solar radiation entering the greenhouse, thus involving reducing the temperature by a notable percentage after installing it. The advantages of the wind breaks, which depended on the significant reduction of wind speed and sand encroachment. If on one of the days of study, the wind speed reached 65 km/h, the experimental greenhouse suffered no damage, and the other greenhouse (the control) moved from its place and suffered damage.

All this system made the greenhouse with an atmosphere suitable for plants to some extent in the hot climates of the dry and semi-arid region, which often experiences these difficulties in agriculture, as these solutions can be, for example, in the cultivation of tomatoes, where high temperatures affect their productivity and make them burn.

The use of artificial intelligence tools, a neural network and data that we collected over a period of about a month allowed us to predict the internal temperature in the greenhouse. An Artificial neural network (ANN) was used to predict the inside greenhouse temperature via the environmental factors in Ghardaia region (Algeria) .The efficiency of the model is acceptable with the different calculate statistical like the RMSE, MAPE and R^2.

A Fuzzy logic controller is proposed and modeled under MATLAB/Simulink environment in order to increase the inside temperature in night and decrease it at during the day for the plants .The efficiency of this model indicate the low percentage of the error between the experiment and prediction. For more efficiency of this model it is important to conserving the necessary humidity of vegetation inside the greenhouse. In the end we can conclude that the inside microclimate is depending on:

- The external parameters and conditions, wind speed, outside temperature and solar irradiation.
- The greenhouse location, Mediterranean or Saharan region
- The material structure of greenhouse covers

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