Greenhouse Environmental Control Using Optimized, Modeled and Simulated Fuzzy Logic Controller Technique in MATLAB SIMULINK

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Abstract: The main objective of this study is the control of the agricultural greenhouse in view of the economic interest generated by such an activity. A simulation model is developed, gathering all the external and internal climatic conditions that influence the microclimate of the greenhouse to predict the temporal evolution of the state variables characterizing this microclimate. The fuzzy control is an alternative to the approaches proposed by the automatic for the control of complex systems. The performance objectives of the looped systems and the corresponding actions are summarized in the form of rules of expertise, which are spelled out in plain language. This technique thus makes it possible to dispense with the use of mathematical models which are sometimes difficult to obtain. Our objective is the multivariable strategy synthesis and the fuzzy application to a multivariate system (MIMO ° such as the agricultural greenhouse.) First, the principles of fuzzy logic and fuzzy control are recalled. The origins of non-Linearitys of the command are explained. One of the practical problems of this technique is the combinatorial explosion of the rule base when the number of variables involved becomes large. A solution to simplify the complexity of the system is presented together with an optimization algorithm to automatically adjust the parameters of the fuzzy controller. The last part is devoted to the synthesis of an optimal control of the greenhouse in order to compare it to the fuzzy control implemented.

Key words: Greenhouse, microclimate, modeling, fuzzy controller, optimization, solar energy, climate model, temperature.

1. Introduction

Agricultural greenhouse originally designed as a simple enclosure limited by a transparent wall, as is the case for conventional tunnel greenhouses and largely answered chapel in several countries including those of the Mediterranean basin. They amplify certain characteristics of the surrounding environment, thus involving variations of internal energy and fairly significant heat loss due to the low inertia [1] of the clamp system.

To maintain a microclimate suited to the demands of the protected culture, energy intake and the introduction of new technologies and air conditioning

operation becomes necessary and essential, to do so faces the challenge of supply and demand of agricultural products fresh throughout the year for a strictly increasing population.

We are interested in this product conditioning of agricultural greenhouse while characterizing the dynamic operation of the complex system that is the greenhouse with its various compartments [2], develop models to reproduce the essential properties, mechanisms and interactions in different compartments and to approach the analysis of thermo-fluid behavior of agricultural greenhouse.

New climate techniques have emerged, including the use of regulation devices ranging from classical to the use of artificial intelligence [3], such as neural

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networks and/or fuzzy logic, etc.

Many facilities have been designed to regulate and monitor climate variables in an agricultural greenhouse [4, 5], such as: Temperature, Humidity, CO_2 concentration, Irrigation, the ventilation [6], etc. The possibilities offered by greenhouse climate computers have solved the problems relating to the regulation and respect of climate instructions required by protected cultivation.

The climate computer greenhouse will have to be integrated as a tool for dynamic management of production, able to choose the most appropriate climate route, meet objectives and production orders, while minimizing inputs.

The complexity of managing and optimizing [7] this environment cannot be addressed only through a comprehensive approach to operating greenhouses-systems.

Greenhouse management and the urgent and varied consumer demand make the problem multivariable, nonlinear and highly complex [8, 9].

2. Modeling the Greenhouse

This article deals with the modeling and simulation of our greenhouse model which is based on the method of GUESS [10].

GUESS is a model set in parameter block, meaning that spatial heterogeneity is ignored and it is assumed that the inner content and the flow through the system boundary are evenly distributed. .

The conservation equations are used to model the rate of system status change.

• For a warm greenhouse these state variables would be the indoor temperature, relative humidity, air pressure and CO_2 concentration.

• For the plant state variables are the water content, the body temperature, dry weight or biomass, and internally sheet CO_2.

A complete equation for the transport of some scalar quantity through a control volume is as following:

$$CV \ \frac{\partial \Phi}{\partial x} = A(F_{int} - F_{out}) + V(Q_{source} - Q_{sink}) \ (1)$$

C: The heat capacity (J/m^3.k);

V: System Volume (m^3);

$\partial \Phi$: A quantity describing the state of the system (W/m^2);

∂x: Material thickness (m);

A: The flow boundary surface (control surface) (m^2);

F_{int}, F_{out}: Internal and external flux (W/m^2).

2.1 Modeling the Climate of the Greenhouse Systems

2.2.1 Cooling Pad Model

In a greenhouse, evaporative cooling devices are used to reduce the temperature when the fan cannot reach appropriate levels for optimal plant growth. In equipped greenhouses, cooling evaporation is the second part of the unrealized gain. Most evaporative cooling methods can be modeled as adiabatic cooling process; the minimum temperature and the achievable maximum vapor pressure is equal to the wet bulb.

The effectiveness of the typical tablet is about 85%. The heat loss rate depends on the fan speed.

$$H_{pad} = H_{out + \eta_{pad}}(H_{wb} - H_{out}) \qquad (2)$$
$$T_{pad} = T_{out - \eta_{pad}}(T_{wb} - T_{out}) \qquad (3)$$
$$Q_{pad =} \rho \ \dot{V} Fan \ C_P \ \eta_{pad} \ (T_{out} - T_{wb}) \qquad (4)$$

η_{pad}: Pad efficiency;

T_{out}, T_{wb}: The difference between the outside temperature and wet bulb (K);

C_P: Specific heat (J/kg.k);

ρ: Density (kg/m^3);

$\dot{V}$: Fan speed (m/s).

2.2.2 Model of Fogging System

The flow of steam and heat are determined through Ohm's Law and are as following:

$$\dot{e} = KA_{net} (VP_{sat} (T_{wb} [T_{air}, rh_{air}]) - VP_{air}) \ (5)$$
$$q = \lambda \dot{e} \qquad (6)$$

q: The heat transfer between the nebulizer and the air of agricultural greenhouse (W/m^2);

K: Global coefficient of heat transmission (W/m^2.k);

P_{sat} : Saturation pressure (Pascale);

P_{air}: Pression de l'air ambiant (pascale) ;

λ: Thermal conductivity (W/m^2.k).

2.2.3 Evaluation Model of the Wall Temperature T_p

The T_p wall temperature evaluation model, closest to reality is determined based on the average temperatures T_{p_i} and T_{p_e}

$$T_p = \frac{T_{p_i} + T_{p_e}}{2} \qquad (7)$$

The indoor and outdoor temperatures T_{p_i} and T_{p_e} are:

$$T_{p_i} = T_{air,i} - \frac{K(T_{air,i} - T_{air,e})}{h_{p_i}} \qquad (8)$$

$$T_{p_e} = T_{air,e} + \frac{K(T_{air,i} - T_{air,e})}{h_{p_e}}$$

The temperature evaluation model of T_p wall will be expressed:

$$T_p = \frac{T_{air,i} + T_{air,e}}{2} + \frac{k(h_{p_i} - h_{p_e})}{h_{p_i}.h_{p_e}} \cdot \frac{T_{air,i} - T_{air,e}}{2}$$

$$T_p = \frac{T_{air,i} + T_{air,e}}{2} + C_B \frac{T_{air,i} - T_{air,e}}{2}$$

where: $C_B = \frac{\lambda(h_{p_i} - h_{p_e})}{\lambda(h_{p_i} + h_{p_e}) + eh_{p_i}.h_{p_e}}$

$T_{air,i}, T_{air,e}$: Dry Air temperature Inside/Outside (K);

h_{p_i}, h_{p_e}: Coefficient of superficial exchanges at the inter wall, of the outer wall (W/m^2.k);

C_B: Quotient de BIBI(.).

This report dimensionless C_B is used in evaluating the T_p wall temperature, it is now called the quotient of BIBI, which is the ratio of the difference of surface thermal exchange by conduction, convection and radiation occurring at the level of the greenhouse coverage.

2.2.4 Heating System

The heat produced per unit of fuel is modeled as:

$$h_{combution \atop sensible} = LHV + ...$$

$$\lambda\phi * \left[\frac{36}{16} \phi^{-1} - e_{sat} (T_{exhaust}) \right] ...$$

$$- (1 - r)C_{P,air} T_{exhaust} \qquad (9)$$

$h_{combution \atop sensible}$: Sensible heat load of a condensing water heater (J);

LHV: Lower heating value (KJ/kg);

Φ: The fuel air;

36/16: The weight ratio of the produced steam to supply the burner;

$T_{exhaust}$: The temperature of the exhaust gas (k);

r: The return ratio.

2.3 Energy Balance of the Greenhouse

The analytical energy balance equation of the greenhouse:

Stored energy change = Gain from internal sources+ Gain from the sun - Losses due to conduction through the cover - Losses due to long wave radiation - Unrealized losses (evaporation) - Losses due to the exchange of air .

$$\overbrace{\rho_{air} V_{GH} C_{P,GH} \frac{dT_{in}}{dt}}^{STORAGE} = \overbrace{\underbrace{\alpha_{SW} \tau_{glass}}_{Shortwave \atop Solar} I + Q_{heaters}}^{GAIN} + ...$$

$$+ \overbrace{\underbrace{\frac{r_{conv,out} + r_{cond,cover}}{r_{conv,in} + r_{cond,cover} + r_{conv,out}} \lambda K_{cond} A_{cover} [VP_{in} - VP_{sat}(T_{cover})]}_{Condensation}}^{GAIN} ... -$$

$$\overbrace{\underbrace{h_{r,sky} (1 - \varepsilon_{cover})(T_{in} - T_{sky}) - 08\varepsilon_{cover} h_{r,cver} (T_{in} - T_{cover})}_{longwave}}^{LOSSES} ...$$

$$- \overbrace{A_{floor}\,\eta_{utilization}\,\frac{\Delta R_{net}}{\Delta+\gamma}}^{\text{LOSSES}} \;...\; - \tag{10}$$
$$\underbrace{\phantom{A_{floor}\,\eta_{utilization}\,\frac{\Delta R_{net}}{\Delta+\gamma}}}_{\text{Evapotranspiration}}$$

$$\overbrace{\left[\frac{1}{r_{conv,in}+r_{cond,cover}+r_{conv,out}}A_{cover}+P_{floor}\,(U\ell)_{perimeter}\right](T_{in}-T_{out})}^{\text{LOSSES CONT}} \;..$$
$$\underbrace{\phantom{\left[\frac{1}{r_{conv,in}+r_{cond,cover}+r_{conv,out}}A_{cover}+P_{floor}\,(U\ell)_{perimeter}\right](T_{in}-T_{out})}}_{\text{conduction}}$$

$$.... \; - \overbrace{\lambda K A_{net}\,\left(VP_{sat}\,(T_{wb}\,[T_{air},rh_{air}])-VP_{air}\right)}^{\text{LOSSES CON}} \;...\; -$$
$$\underbrace{\phantom{\lambda K A_{net}\,\left(VP_{sat}\,(T_{wb}\,[T_{air},rh_{air}])-VP_{air}\right)}}_{\text{Foggers}}$$

$$\overbrace{\rho C_{(P,air)}\,\dot{V}_{inf}\,(T_{in}-T_{out})-\rho C_{(P,air)}\,\dot{V}_{net}\,(T_{in}-T_{pad})}^{\text{LOSSES CON}}$$
$$\underbrace{\phantom{\rho C_{(P,air)}\,\dot{V}_{inf}\,(T_{in}-T_{out})-\rho C_{(P,air)}\,\dot{V}_{net}\,(T_{in}-T_{pad})}}_{\text{advection}}$$

e_{sat} : Indicates the report saturated with the relative humidity in the sub-model of combustion (Kg steam/kg air);

$Q_{heaters}$: The heat provided by the heating system (W);

$r_{conv,in}$, $r_{conv,out}$: Heat transfer coefficient inside and outside by convection (W/m^2.k).

2.4 The Mass Transfer in the Greenhouse

The mass balance for moisture in the greenhouse can be written as following Eq. (11):

$$\rho_{air}\,V_{greenhouse}\,\frac{de_{in}}{dt}$$

$$= -\dot{V}_{inf}*\rho_{air}\,(H_{in}-H_{out})-\dot{V}_{vent}*\rho_{air}\left(H_{in}-H_{pad}\right)+\frac{1}{\lambda}A_{floor}\,\eta_{uilization}\underbrace{\frac{\Delta R_{net}}{\Delta+\gamma}}_{\text{Evapotranspiration}}$$

$$-\underbrace{K_{cond}A_{cover}[VP_{in}-VP_{sat}(T_{cover})]}_{\text{condensation}}+\underbrace{KA_{net}\left(VP_{sat}\left(T_{wb}[T_{air},rh_{air}]\right)-VP_{air}\right)}_{\text{foggers}}$$

$$+\underbrace{r\phi e_{sat}(T_{exhaust})\frac{Q_{heat}}{h_{combustion}}}_{\text{combustion}}$$

$\dot{V}_{inf}$: The speed of air infiltration (m/s);

$V_{greenhouse}$: The total volume of agricultural greenhouse (m^3);

H_{in}, H_{out}: The indoor and outdoor humidity (KJ/kg);

$\dot{V}_{vent}$: Ventilation rate (m^3 air/s);

And for the humidity balance:

Rates of change in absolute humidity = Infiltration + Ventilation * (humidity difference with the outside) + Misting + Cooling + AND - Condensation.

The status of humidity function is Eq. (12):

$$\frac{dH_{in}}{dt}=\underbrace{-nV_p(H_{in}-H_{sat})}_{\text{Ventilation infiltration}}+K_{foggers}\left(VP_{in}-VP_{sat,wetbulb}\right)-K_{condensation}(VP-VP_{sat})+\underbrace{E}_{\text{Evapotranspiration}}$$

$\underbrace{E}_{\text{Evapotranspiration}}$: The amount of heat provided by evapotranspiration (W).

Mass balance for CO_2 is Eq. (13):

$$\rho_{air} V_{greenhouse} \frac{100}{29} \frac{dC_{co_2\,in}}{dt}$$

$$= -\rho_{air} \frac{100}{29}\left(\dot{V}_{inf} + \dot{V}_{vent}\right)\left(C_{co_2\,in} - C_{co_2\,out}\right)$$

$$+ -\dot{F}_{photosynthesis} + \underbrace{r\zeta \frac{100}{MW_{fuel}} \frac{Q_{heat}}{h_{combution}}}_{combustion}$$

CO_2 Mass Balance in molar units (ppm or μmol CO_2 per mol air).

ζ: The number of moles of carbon per mole of fuel;

$\dot{V}_{inf}$: Ventilation rate (m^3 air/s);

$\dot{F}_{photosynthesis}$: The amount of heat supplied by photosynthesis (W).

2.5 Photosynthesis

Photosynthesis is a complex process. CO_2 fixation and subsequent conversion into carbohydrates are not a single reaction, but a series of steps, the Calvin cycle (see Fig. 1) [11].

According to Farquhar model, the CO_2 compensation model is:

$$P = \left(1 - \frac{\Gamma}{c_i}\right) * min\{W_c, W_j\} \tag{14}$$

Farquhar model with Γ, CO_2 compensation point.

C_i: Internal CO2 concentration (ppm).
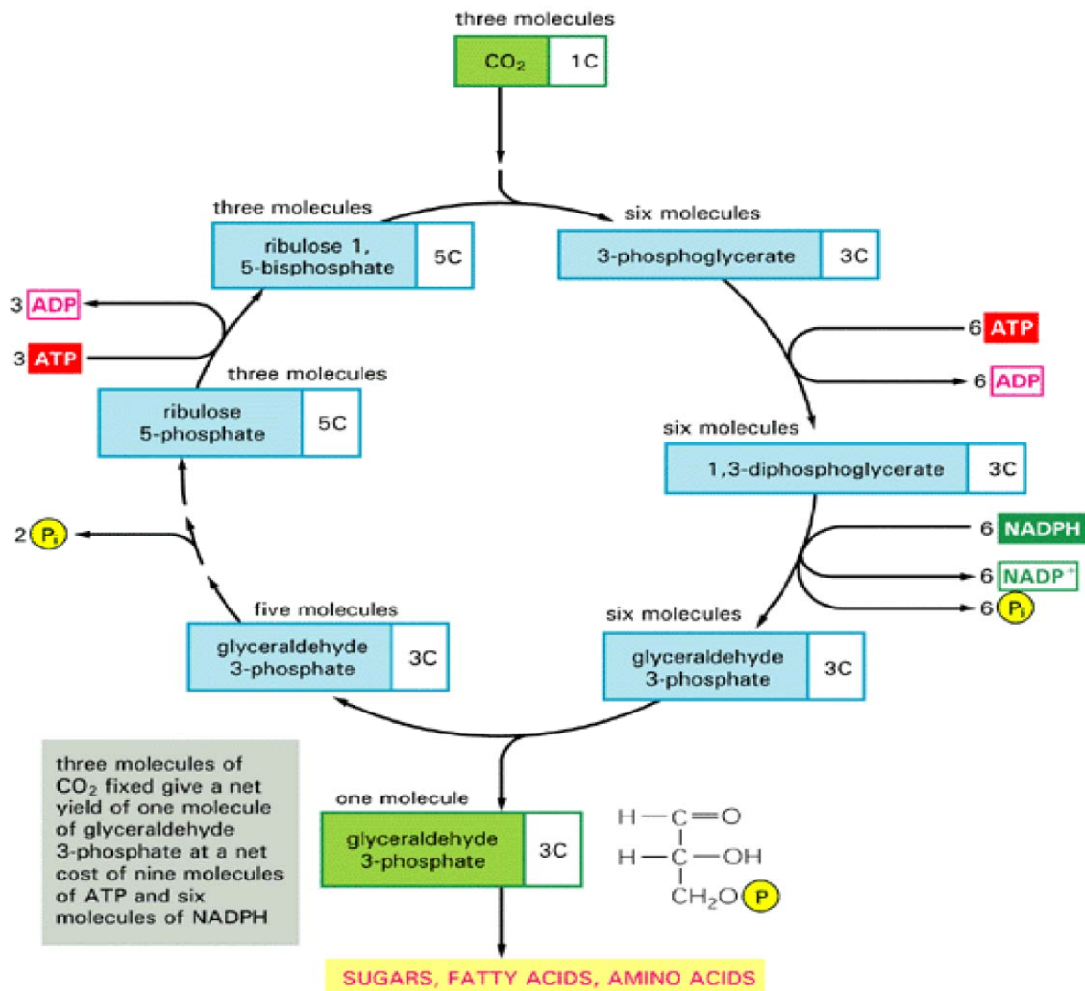
Fig. 1   Schematic Calvin cycle. The reaction at the apex (CO_2 fixation and RuBP) is catalyzed by the enzyme Rubisco. This reaction ordered carbon assimilation rates, and that is modeled by Farquhar. al. equations. Source: Cellupedia, Calvin cycle.

2.6 Plant State of Water Balance

$$C_{PLANT} \frac{d\psi_{plant}}{dt} = \frac{(\psi_{soil} - \psi_{plant})}{R_{root} A_{root}} - E \qquad (15)$$

In the model of GUESS, we assume that the soil is well watered, so that the physiological effects of the state of water should be minimal, except in stomata.

ψ : The potential of water;

C_{PLANT}: The capacity of the plant (mole*m^2);

E: Evapotranspiration;

A_{root}: The root surface (m^2);

R_{root}: The growth rate.

2.7 Stomatal Conductance and Balance CO_2

The rate of photosynthesis in the Farquhar model depends on the internal concentration of CO_2.

To determine the concentration of CO_2, a mass balance is performed on the sheet.

$$C_{leaf} \frac{d[co_2]_i}{dt} = \frac{([CO_2]_e - [CO_2]_i) - P_{net}}{\frac{1}{g_{stomatal}} + \frac{1}{g_{aerodynamic}}} \qquad (16)$$

According to GUESS the plant stomatal equation of is:

$$g_{stomatal} = min \left\{ g_{closed} + m \left(\frac{rh_{leaf} P_{net}}{[CO_2]_{leaf}} \right) \right.$$

$$\left. * \left(\frac{\theta_{soil} - \theta_{WP}}{\theta_{FC} - \theta_{WP}} \right), g_{open} \right\}$$

Ball-Berry modified model used in GUESS Eq. (17).

$g_{stomatal}$: *Stomatal conductance in units of (mole.s^{-1}.m^{-2}).*

3. Fuzzy Sets

The input variables in a fuzzy control system are generally mapped by sets of membership functions similar to it, called "fuzzy set". The process of converting a crisp input value to a fuzzy value is called "fuzzy logic". A control system may also have different types of switch, or "ON-OFF", inputs and analog inputs and during switching inputs will always be a truth value of 1 or 0, but the system can handle as simplified fuzzy functions happen to be one value or another. Given "mappings" of input variables membership functions and truth values, the microcontroller then makes decisions for action on the basis of a set of "rules".

3.1 Membership Functions

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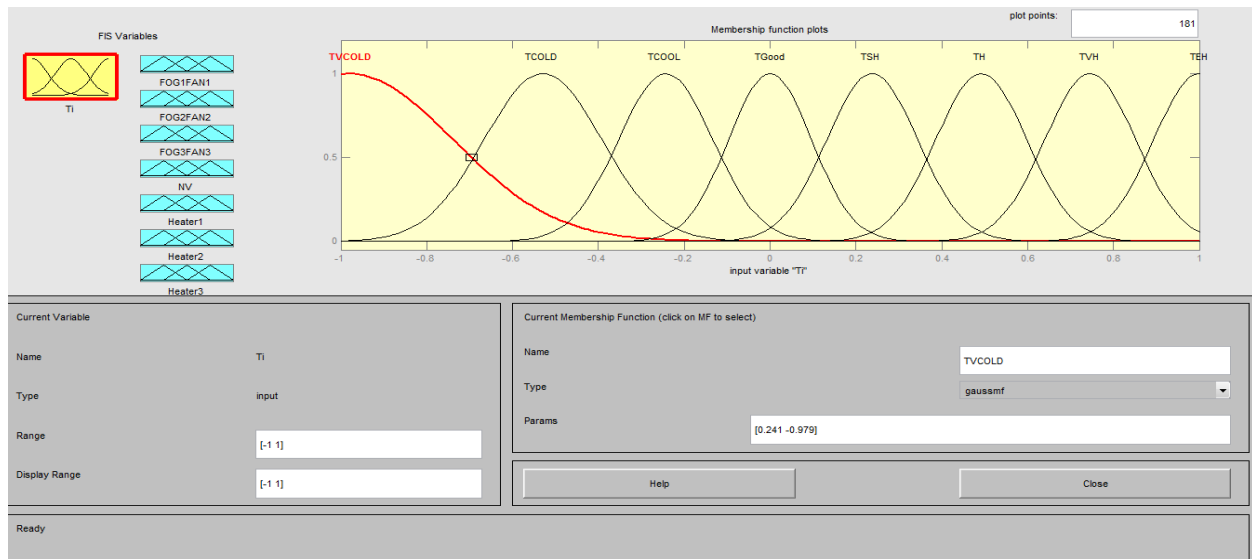
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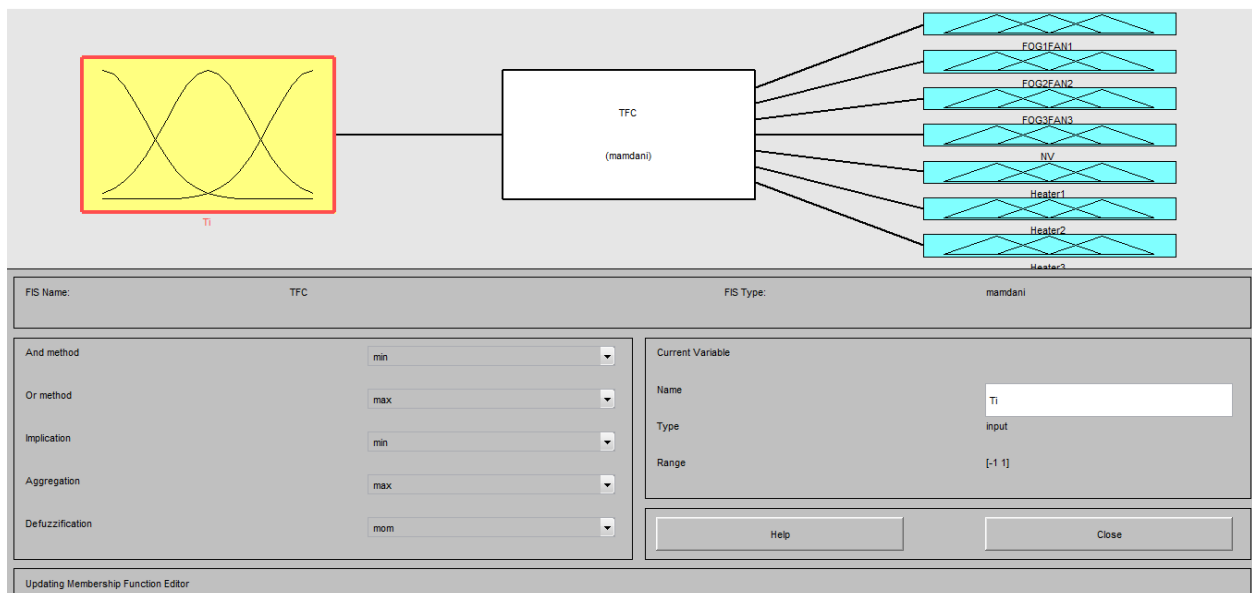
Fig. 2   Representation rules of membership.

3.2 Rules of Decisions

• If (Ti is TVCOLD) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is ON)(Heater3 is ON) (1)

• If (Ti is TCOLD) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is ON)(Heater3 is OFF) (1)

• If (Ti is TCOOL) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is OFF)(Heater3 is OFF) (1)

• If (Ti is TSH) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is ON)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)

• If (Ti is TH) then (FOG1FAN1 is ON)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)

• If (Ti is TVH) then (FOG1FAN1 is ON)(FOG2FAN2 is ON)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)

• If (Ti is TEH) then (FOG1FAN1 is ON)(FOG2FAN2 is ON)(FOG3FAN3 is ON)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)

4. Simulation and Model Validation

Our model is based on the greenhouse GUESS model that is set for a multi greenhouse chapel which each module is 8.5 m wide, 34 m deep and ridge height of 4.5 m. Infiltration rate is 1.1 air changes per hour, and a U value of 5.76 W/m^2.K was used. The model of the plant was set for Douglas seedling plants which were started at 0.57 g dry weight, and harvested 1.67 g dry weight; a new growing season was recorded at harvest.

A set of hourly data for 2015 (1 January to 31 December) weather station of Biskra Algeria, was used to validate our model as a CSV file that consists of four columns (global solar radiation, temperature, humidity and wind speed).

The model of the greenhouse was coded using the full version of Windows MATLAB R2012b (8.0.0.783), 64bit (win64) with Simulink. The simulation was performed on a Toshiba laptop. The laptop is equipped with a hard drive 700 GB and 5 GB of RAM. Simulink model of the parties was made in "Accelerator" mode that has first generated a compact representation of Code C of the diagram, then compiled and executed.
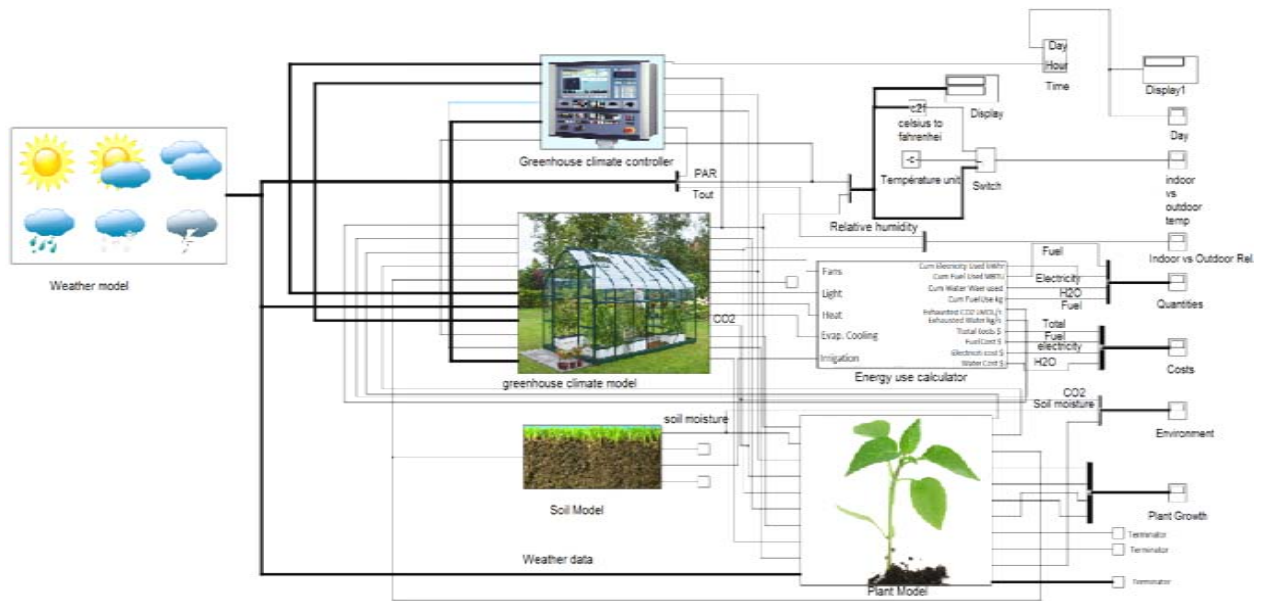
4.1 Greenhouse Global Model

Fig. 3   Simulink representation of the global greenhouse model.

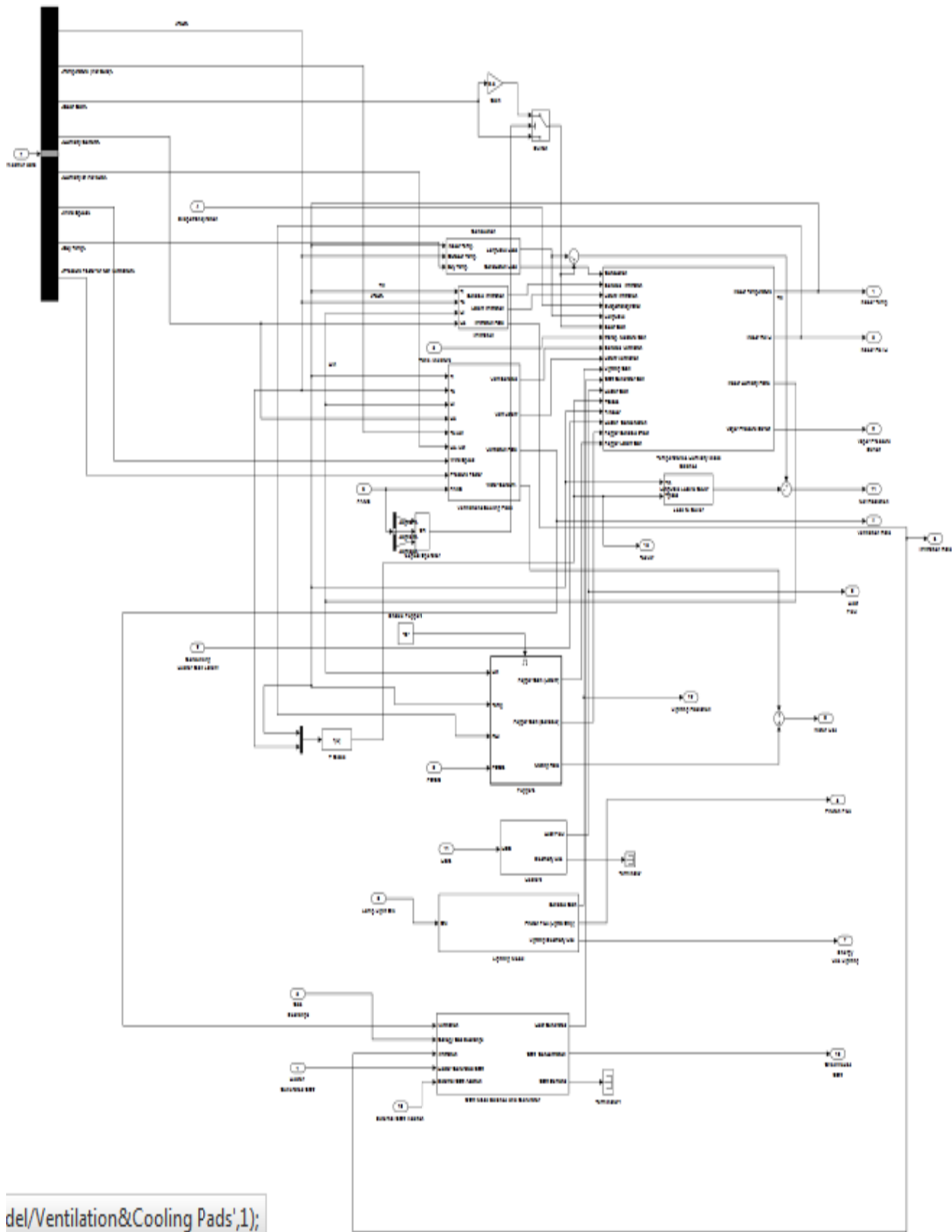*4.2 Greenhouse Climate Model*

Fig. 4   Simulink representation of the greenhouse climate model.

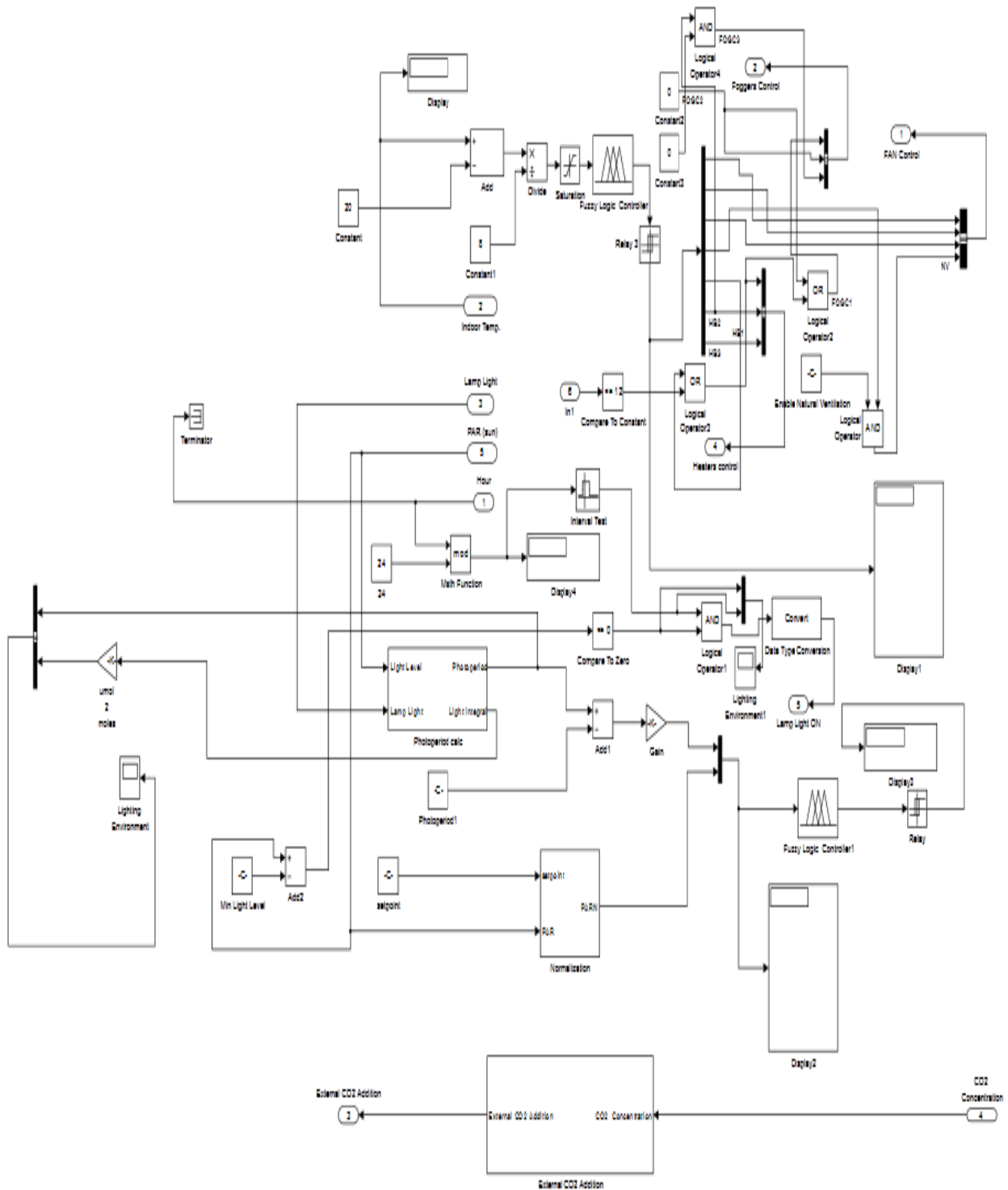*4.3 Fuzzy Logic Controller Simulation Model of the Greenhouse*

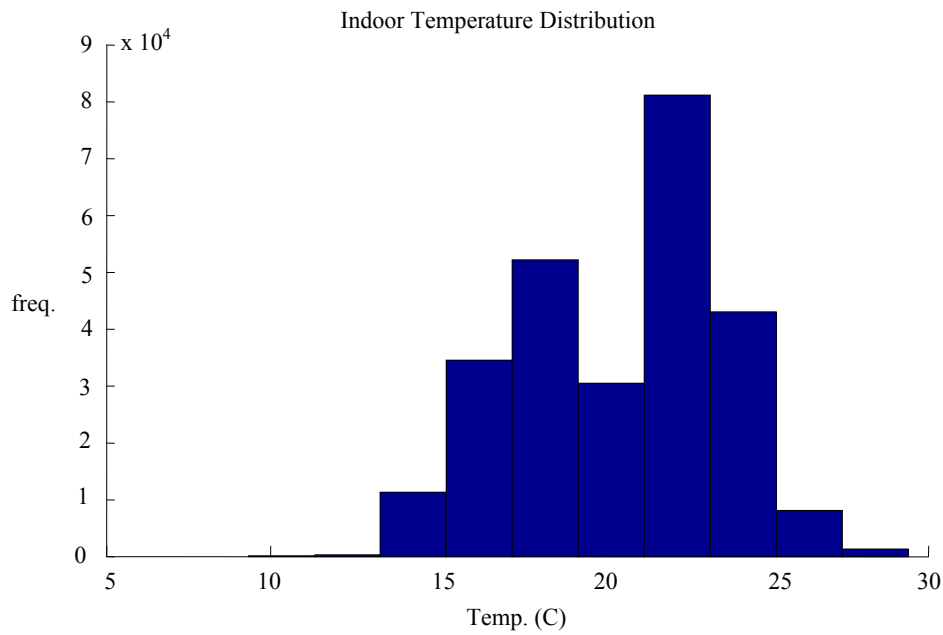**Fig. 5　Simulink representation of the fuzzy logic controller model.**

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Fig. 6 **Histogram shows the distribution of indoor temperature.**
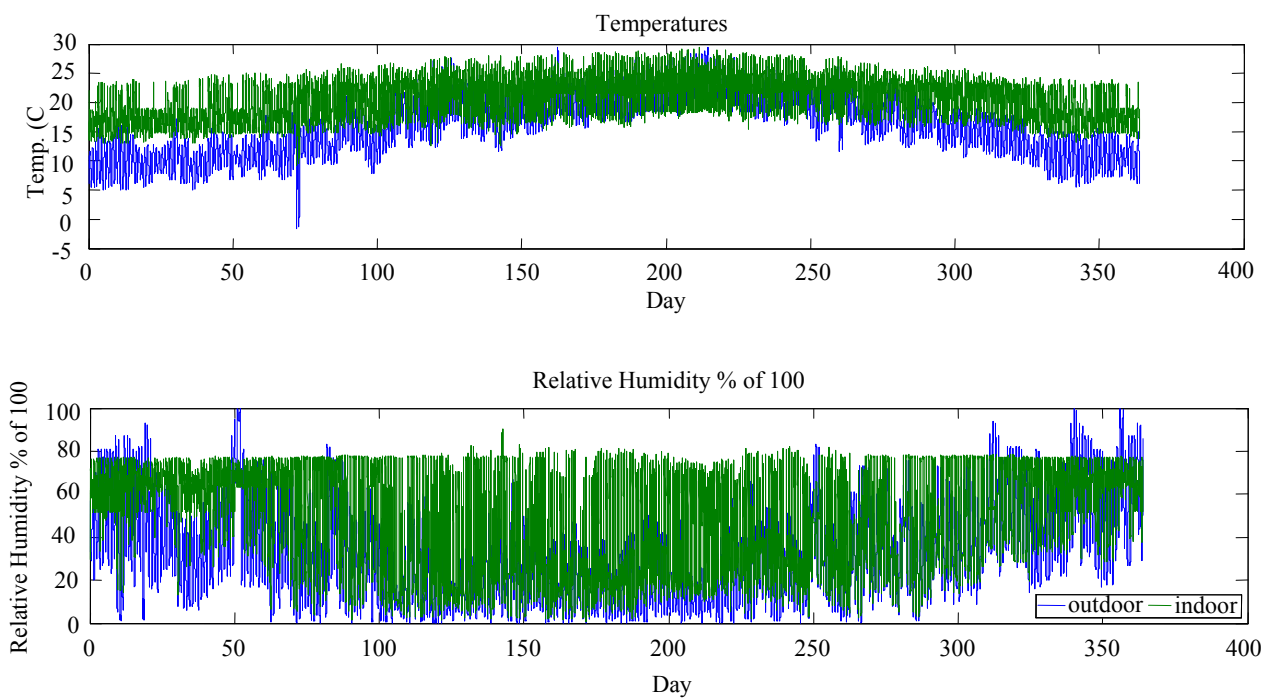
Fig. 7 **The evolution of humidity and temperature (interior/exterior).**

5. Results

The simulation results clearly visualize the actual thermo-energy behavior of agricultural greenhouse, applying the model of artificial intelligence, namely the application of fuzzy logic in arid region [12].

It is found that most of the internal temperature values are in the range of 15 °C to 25 °C for the autumn winter period, and in the range 20 °C to 28 °C for the spring summer period in a large variation the temperature during the winter autumn period is due to heat loss during the night, clearing heating is

insufficient and expensive for this improved thermal insulation of the covering wall is necessary.

The improved thermal insulation of the cover may be carried out in practice by the addition of a plastic air bubble layer mounted to the inside wall face.

During the period of spring-summer the temperature is almost within the desired range except for half of the summer where the temperature is a little increase. The use of cooling systems and spray is necessary to lower the temperature in the interval longed for.

But this solution is insufficient and really expensive, for this purpose we should improve the characteristics of the coverage of the agricultural greenhouse for example thermal insulation or blanket double wall which demonstrates improved efficiency of heating, cooling, etc.

The relative humidity generally stays close to the optimum for all the year except in summer when the humidity drops below threshold due to significant vaporization used for temperature compensation, to resolve this problem adding a screen on the roof of the greenhouse and improving irrigation can compensate the lack of relative humidity in the arid region.

6. Conclusions

However, our objective is achieved to the extent that it has been shown through modeling and control by the use of fuzzy logic, this area is very difficult because it is a multi control variable which the greenhouse is a biophysical system where parameters are highly correlated as shown by the results. This technique of fuzzy logic has been adapted to the greenhouse to a promising future for the climate control and management of the greenhouse. For greenhouse growers, it is a preferred approach for structuring and knowledge aggregation and as a means of identification of gaps in the understanding of mechanisms and interactions that occur in the system-greenhouse.

Fuzzy logic is a branch of artificial intelligence,

which must point out its advantages and disadvantages. Its use has led to quite satisfactory results of the control and regulation perspective.

We remain optimistic in the near future, as to the operation of artificial intelligence, including the use of fuzzy logic which indicates:

• For the control and regulation of the greenhouse microclimate;

• By the conservation of energy;

• For the efficiency of energy use in the greenhouses operation;

• For improved productivity of crops under greenhouses;

• In a significant reduction of human intervention.

Acknowledgement

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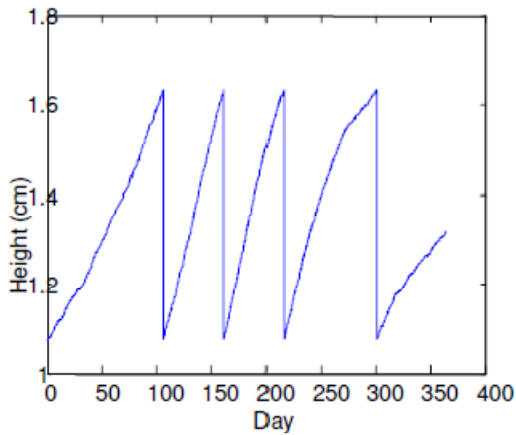
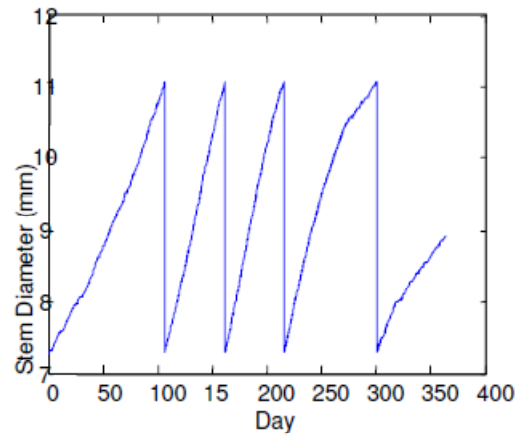**Appendix: Plant growth caracteristics**
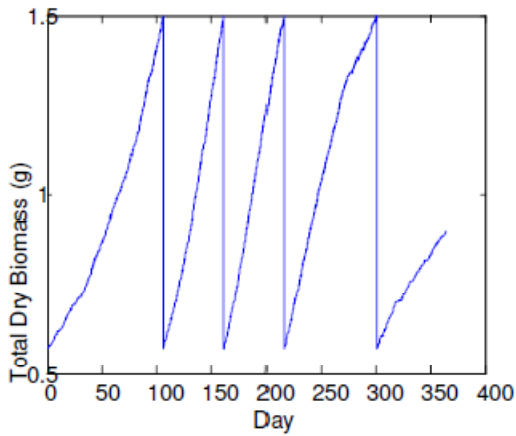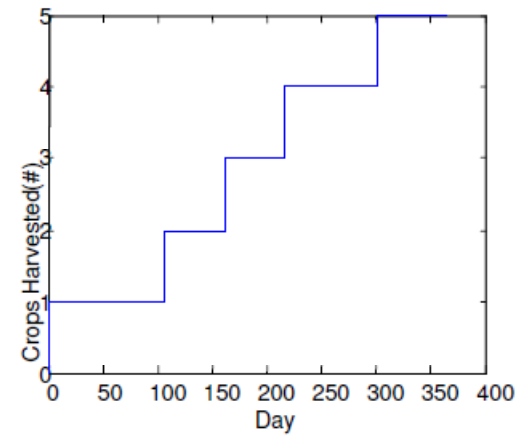

figure 1

figure 2

Figure 3

figure 4

Figure 1 is the height in cm, Figure 4 is the cumulative number of growing season, Figure 3 is the total biomass (dry weight), and Figure 2 is the rod diameter in mm

The speed of growth of the mass of the plant is normal for most of the year except in the end of autumn and beginning of winter because of the temperature drops at night and we discussed this problem and its correction previously.