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Article

Modeling, Simulation and Optimization of agricultural greenhouse microclimate by the application of artificial intelligence and / or fuzzy logic

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Abstract: Agricultural greenhouse is largely answered in the agricultural sphere, despite the shortcomings it has, including overheating during the day and night cooling which sometimes results in the thermal inversion mainly due to its low inertia.

The glasshouse dressed chapel is relatively more efficient than the conventional tunnel greenhouse. Its proliferation on the ground is more or less timid because of its relatively high cost[14-22].

Agricultural greenhouse aims to create a favorable microclimate to the requirements of growth and development of culture, from the surrounding weather conditions, produce according to the cropping calendars fruits, vegetables and flower species out of season and widely available along the year. It is defined by its structural and functional architecture, the quality thermal, mechanical and optical of its wall, with its sealing level and the technical and technological accompanying[12-13].

The greenhouse is a very confined environment, where multiple components are exchanged between key stakeholders and them factors are light, temperature and relative humidity[8].

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This state of thermal evolution is the level sealing of the cover of its physical characteristics to be transparent to solar, absorbent and reflective of infrared radiation emitted by the enclosure where the solar radiation trapping effect otherwise called "greenhouse effect" and its technical and technological means of air that accompany.

The socio-economic analysis of populations in the world leaves appear especially the last two decades of rapid and profound transformations

These changes are accompanied by changes in eating habits, mainly characterized by rising consumption spread along the year[14].

To effectively meet this demand, greenhouse-systems have evolved, particularly towards greater control of production conditions (climate, irrigation, ventilation techniques, CO_2 supply, etc ...). Technological progress has allowed the development of greenhouses so that they become increasingly sophisticated and of an industrial nature (heating, air conditioning, control, computer, regulation, etc ...). New climate driving techniques have emerged, including the use of control devices from the classic to the use of artificial intelligence[10-11] such as neural networks and / or fuzzy logic, etc...

As a result, the greenhouse growers prefer these new technologies while optimizing the investment in the field to effectively meet the supply and demand of these fresh products cheaply and widely available throughout the year.

Keywords: Greenhouse , microclimate , Modelling , fuzzy controller , Optimization , Solar Energy , Energy saving , Climate Model ,Greenhouse effect , Temperature.

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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

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answered chapel in several countries including those of the Mediterranean basin[21]. They amplify certain characteristics of the surrounding environment, thus involving variations of internal energy and fairly significant heat loss due to the low inertia of the clamp system[7-10].

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 face the challenge of supply and demand of agricultural products fresh throughout the year for a strictly increasing population[18].

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[8-21], develop models to reproduce the essential properties, mechanisms and interactions 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, such as neural networks and / or fuzzy logic, etc

Many facilities have been designed to regulate and monitor climate variables in an agricultural greenhouse, such as: Temperature, Humidity, CO2 concentration, Irrigation, the ventilation, 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[19-22].

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.

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The complexity of managing and optimizing this environment can not 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.

2. Modeling the greenhouse

This article deals with the modeling and simulation of our greenhouse model which is based on the method of GUESS. [1]

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 CO2 concentration.
- ✓ For the plant state variables are the water content, the body temperature, dry weight or biomass, and internally sheet CO2.

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

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

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

V: System Volume (m^3)

Φ: is a quantity describing the state of the system (W / m^2)

dx: Material thickness (m)

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

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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 can not 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.

$$H_{pad} = H_{out} + \eta_{pad}(H_{wb} - H_{out}) \tag{2}$$

$$T_{pad} = T_{out} - \eta_{pad}(T_{wb} - T_{out}) \tag{3}$$

$$Q_{pad} = \rho \dot{V} Fan\, C_P\ \eta_{pad} (T_{out} - T_{wb}) \tag{4}$$

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 is as following:

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

$$q = \lambda \dot{e} \tag{6}$$

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q : Is 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 $\mathbf{T_p}$

The T_p wall temperature evaluation model **[8]** ,closest to reality is determined based on the average temperatures T_{p_i} and T_{p_e}

$$T_p = \frac{T_{p_i}+T_{p_e}}{2} \tag{7}$$

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

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

$$T_{p_e} = T_{air,e} + \frac{K(T_{air,i}-T_{air,e})}{h_{pe}} \tag{9}$$

The temperature evaluation model of $\mathbf{T_p}$ wall will be expressed:

$$T_p = \frac{T_{air,i}+T_{air,e}}{2} + \frac{k(h_{p_i}-h_{pe})}{h_{p_i}.h_{pe}} . \frac{T_{air,i}-T_{air,e}}{2} \tag{10}$$

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

Where :
$$C_B = \frac{\lambda(h_{p_i}-h_{pe})}{\lambda(h_{p_i}+h_{pe})+eh_{p_i}.h_{pe}} \tag{11}$$

$T_{air,i}, T_{air,e}$: 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(.)

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This report dimensionless C_B is used in evaluating the $\mathrm{T_p}$ wall temperature, it is now called the quotient of BIBI, it 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 eq (12):

$$\underset{sensible}{h_{combution}} = LHV + \lambda\phi * \left[\frac{36}{16}\,\phi^{-1} - e_{sat}\,(T_{exhaust})\right] - (1-r)C_{P,air}\,T_{exhaust}$$

$\underset{sensible}{h_{combution}}$: Sensible heat load of a condensing water heater (J) , LHV : is lower heating value (KJ/kg) ,

Φ : is the fuel air , 36/16 : is the weight ratio of the produced steam to supply the burner , $T_{exhaust}$: is the temperature of the exhaust gas (k) and r is the return ratio.

2.3 Energy balance of the greenhouse

The analytical energy balance equation of the greenhouse eq (13):

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 .

$$\overbrace{\rho_{air}\,V_{GH}\,C_{P,GH}\,\frac{dT_{in}}{dt}}^{\text{STORAGE}} = \overbrace{\underbrace{\alpha_{SW}\,\tau_{glass}}_{\substack{Shortwave\\ Solar}} I + Q_{heaters} + \underbrace{\frac{r_{conv,out}+r_{cond,cover}}{r_{conv,in}+r_{cond,cover}+r_{conv,out}}\lambda K_{cond}A_{cover}\,[VP_{in} - VP_{sat}(T_{cover})]}_{Condensation}}^{GAIN} -$$

$$\overbrace{\underbrace{h_{r,sky}\,(1-\varepsilon_{cover})(T_{in} - T_{sky}) - 08\varepsilon_{cover}\,h_{r,cver}\,(T_{in} - T_{cover})}_{longwave} - \underbrace{A_{floor}\,\eta_{utilization}\,\frac{\Delta R_{net}}{\Delta+\gamma}}_{Evapotranspiration}}^{LOSSES} -$$

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

$$\overbrace{\underbrace{\lambda K A_{net}\,(VP_{sat}\,(T_{wb}\,[T_{air}, rh_{air}]) - VP_{air})}_{Foggers}}^{LOSSES\ CON} - \overbrace{\underbrace{\rho C_{(P,air)}\,\dot{V}_{inf}\,(T_{in} - T_{out}) - \rho C_{(P,air)}\,\dot{V}_{net}\,(T_{in} - T_{pad})}_{advection}}^{LOSSES\ CON}$$

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e_{sat} : Indicates the report saturated with the relative humidity in the sub-model of combustion

(Kg steam / kg air)

$Q_{heaters}$: Is 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 (14)

$$\rho_{air}\, V_{greenhouse}\, \frac{de_{in}}{dt} = -\dot{V}_{inf} * \rho_{air}\,(H_{in} - H_{out}) - \dot{V}_{vent} * \rho_{air}\big(H_{in} - H_{pad}\big) +$$

$$\underbrace{\frac{1}{\lambda} A_{floor}\, \eta_{uilization} \frac{\Delta R_{net}}{\Delta + \gamma}}_{Evapotranspiration} - \underbrace{K_{cond} A_{cover}[VP_{in} - VP_{sat}(T_{cover})]}_{condensation} +$$

$$\underbrace{KA_{net}\big(VP_{sat}\big(T_{wb}[T_{air}, rh_{air}]\big) - VP_{air}\big)}_{foggers} + \underbrace{r\phi e_{sat}(T_{exhaust}) \frac{Q_{heat}}{h_{combustion}}}_{combustion}$$

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

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

H_{in}, H_{out} : Is 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:

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$$\frac{dH_{in}}{dt} = \underbrace{-nV_p(H_{in} - H_{sat})}_{Ventilation\ infiltration} + K_{foggers}\left(VP_{in} - VP_{sat,wetbulb}\right) - K_{condensation}(VP - VP_{sat}) + \underbrace{E}_{Evapotranspiration} \quad (15)$$

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

Mass balance for CO_2 is :

$$\rho_{air} V_{greenhouse} \frac{100}{29} \frac{dC_{co_2\,in}}{dt} = -\rho_{air} \frac{100}{29} \left(\dot{V}_{inf} + \dot{V}_{vent}\right)\left(C_{co_2\,in} - C_{co_2\,out}\right) + -\dot{F}_{photosynthesis} + \underbrace{r\zeta \frac{100}{MW_{fuel}} \frac{Q_{heat}}{h_{combution}}}_{combustion} \quad (16)$$

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

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

CO_2 Mass Balance in molar units (ppm or µmol CO2 per mol air). ζ is the number of moles of carbon per mole of fuel

2.6 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 diagram below). [2]

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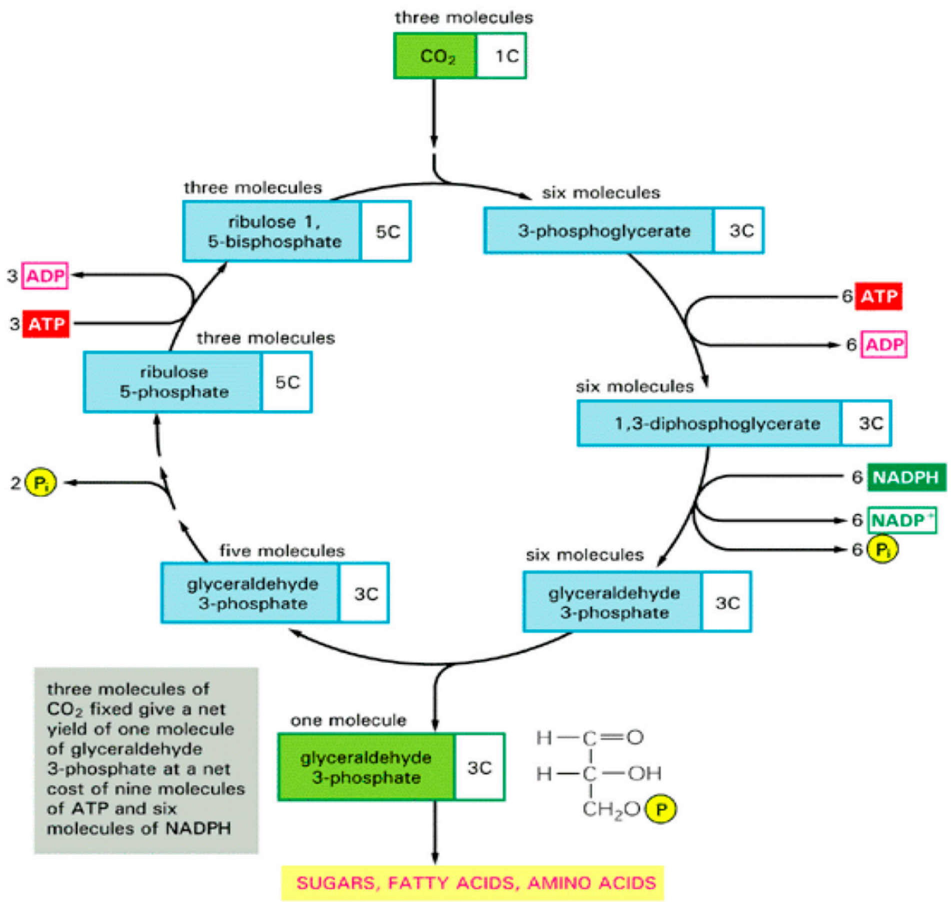

Fig.1 Schematic Calvin cycle. The reaction at the apex (CO2 fixation and RuBP) is catalyzed by the enzyme Rubisco. this reaction ordered carbon assimilation rates, and that is modeled by Farquhar. al. equations. Source: Cellupedia, "Calvin cycle

According to Farquhar model , the CO2 compensation model is:

$$P = \left(1 - \frac{\Gamma}{C_i}\right) * min\{W_c\,, W_j\} \qquad (17)$$

Farquhar model with Γ, CO2 compensation point

C_i : Internal CO2 concentration (ppm)

2.7 Plant state of water balance

$$C_{PLANT} \frac{d\psi_{plant}}{dt} = \frac{(\psi_{soil} - \psi_{plant})}{R_{root} A_{root}} - E \qquad (18)$$

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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} : Is the capacity of the plant (mole*m^2)

E : Is evapotranspiration.

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

R_{root} : The growth rate.

2.8 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.

$$C_{leaf}\frac{d[co_2]_i}{dt} = \frac{([CO_2]_e - [CO_2]_i) - P_{net}}{\frac{1}{g_{stomatal}} + \frac{1}{g_{aerodynamic}}} \quad (19)$$

According to GUESS the plant stomatal equation of is

$$g_{stomatal} = min\left\{g_{closed} + m\left(\frac{rh_{leaf}P_{net}}{[CO_2]_{leaf}}\right) * \left(\frac{\theta_{soil} - \theta_{WP}}{\theta_{FC} - \theta_{WP}}\right), g_{open}\right\} \quad (20)$$

Ball-Berry modified model used in GUESS

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

2.9 Plants Energy Balances

$$T_{leaf} = \frac{(1-\varepsilon_{cover})h_{r,sky}T_{sky} + \varepsilon_{cover}h_{r,cover}T_{cover} + g_{aerodynamic}T_{in} + \tau_{cover}I_{SW} + \lambda E}{(1-\varepsilon_{cover})h_{r,sky} + \varepsilon_{cover}h_{r,cover} + g_{aerodynamic}} \quad (21)$$

Equation for the temperature of a Leaf

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3. Fuzzy controller modeling

Fuzzy logic is widely used in the machine control. The term "fuzzy" refers to the fact that the logic can deal with concepts that can not be expressed as the "true" or "false" but rather as "partially true". [15] While alternative approaches such as genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution can be cast in terms that human operators can understand, so that their experience can be used in the design of the control device. This makes it easier to mechanize the tasks have already been performed successfully by man [3].

3.2 Fuzzy inference method MAMDANI

Fuzzy inference Mamdani type, as defined for Toolbox fuzzy logic, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable to defuzzification. It is possible, and in some cases much more efficient to use a single peak as output membership function, rather than a distributed fuzzy set. This is sometimes known as singleton output membership function, and we can think like a fuzzy set of pre defuzzification. It improves the efficiency of defuzzification because it greatly simplifies the calculation required by the more general method Mamdani which has the center of gravity of a two-dimensional function. [4-5]

To calculate the output of the SIF in view of inputs, six steps should be followed :

- ✓ The determination of a set of fuzzy rules.
- ✓ Fuzzification inputs using the input membership functions.
- ✓ By combining Fuzzificaion entries according to the fuzzy rules to establish a resistance to the rule.

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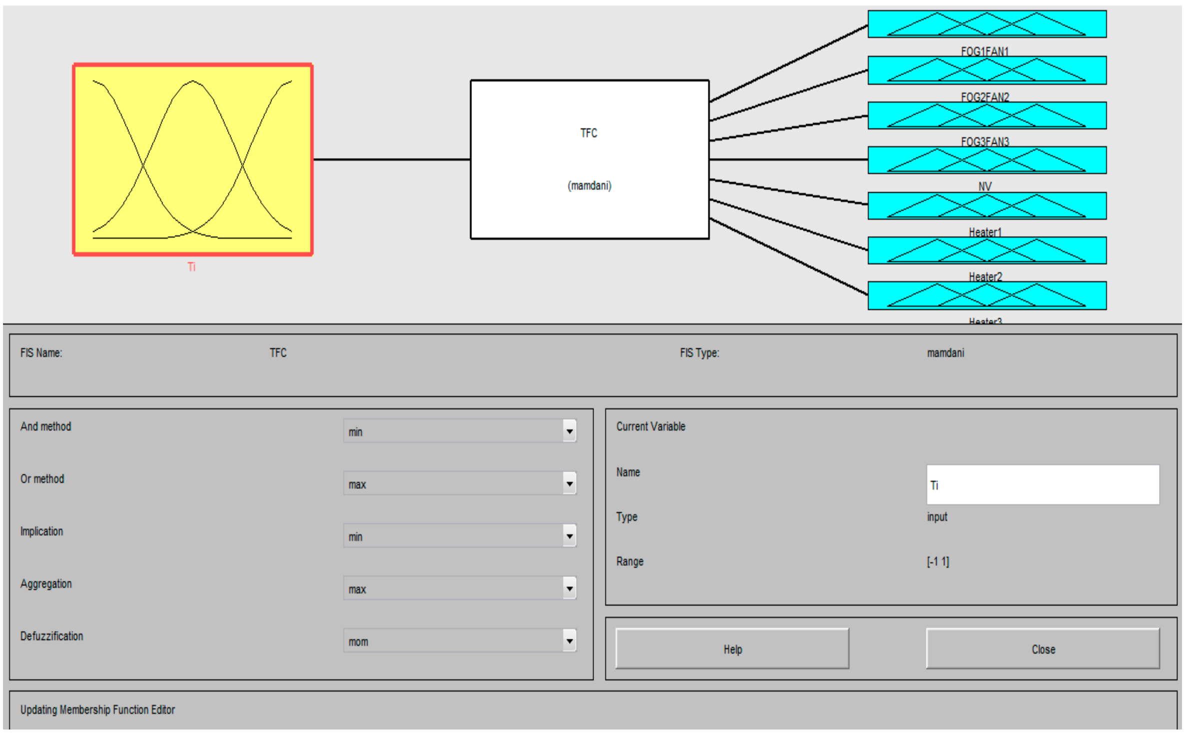
- ✓ Find the consequence of rule by combining the resistance to the rule and the output membership function.
- ✓ By combining the consequences to get a distribution outlet.
- ✓ Defuzzification the output distribution.

3.3 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" .

3.3.1 Membership functions



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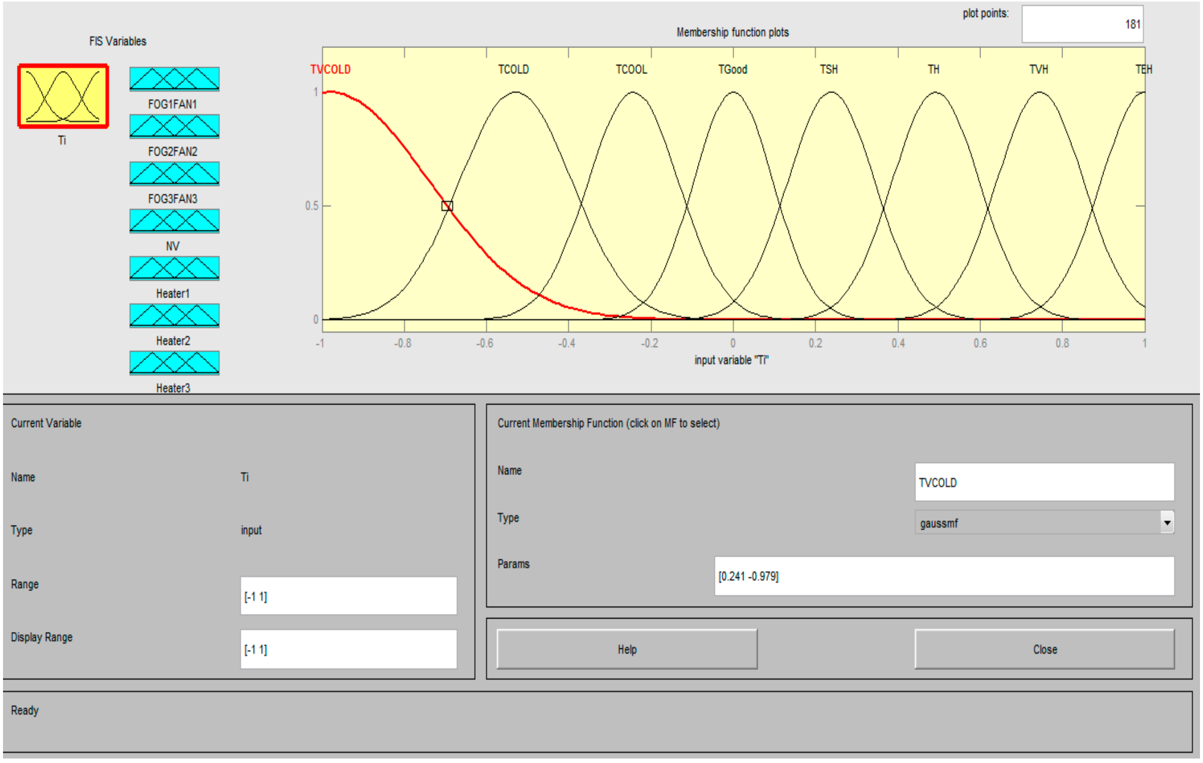

Fig.2 Representation rules of membership

3.3.2 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)

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- ✓ 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 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 [6], 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 were made in "Accelerator" mode that has first generated a compact representation of Code C of the diagram, then compiled and executed.

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4.1 Greenhouse Climate Model

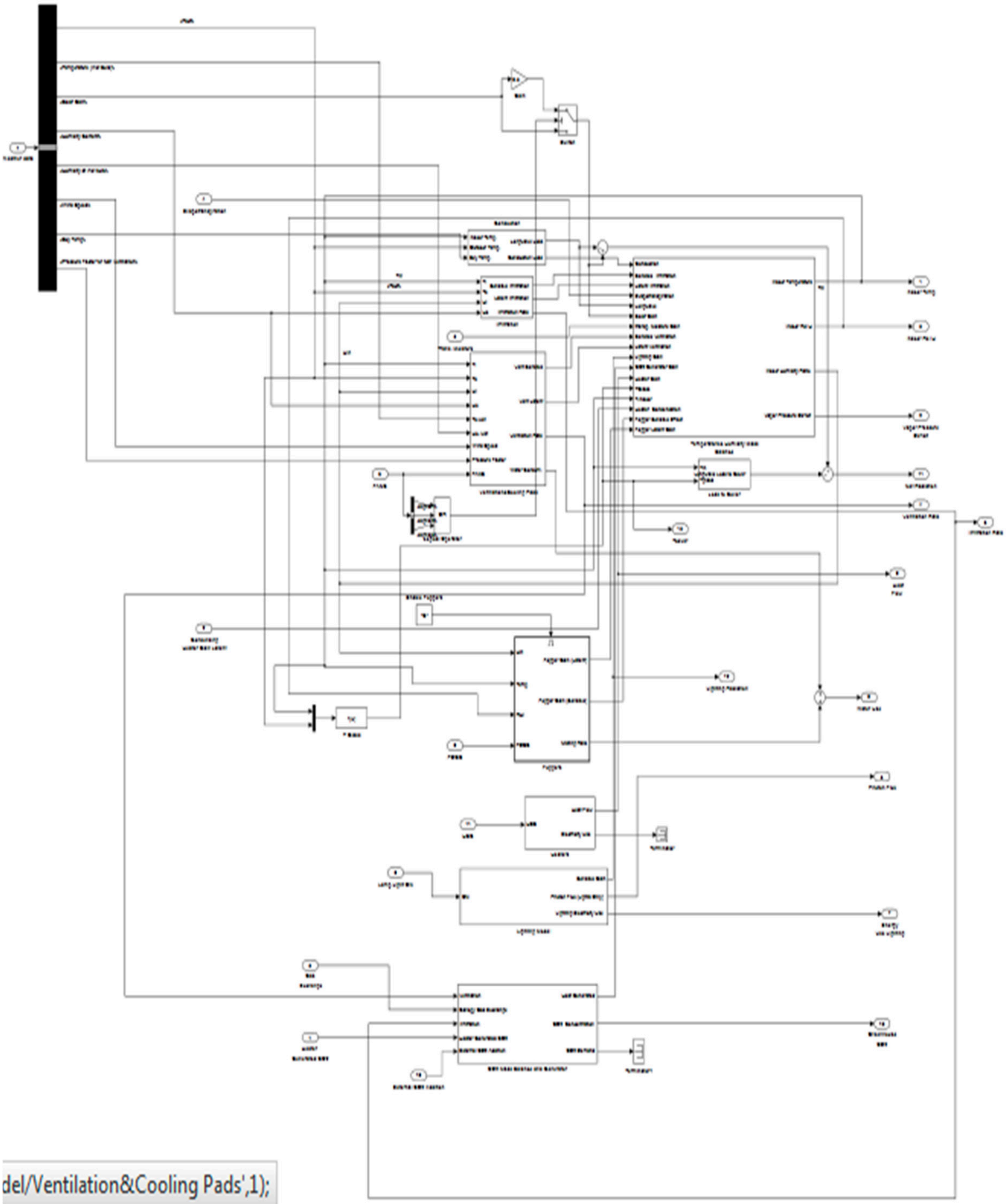

Fig.3 Simulink representation of the greenhouse climate model

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4.2 Fuzzy logic controller simulation model of the greenhouse

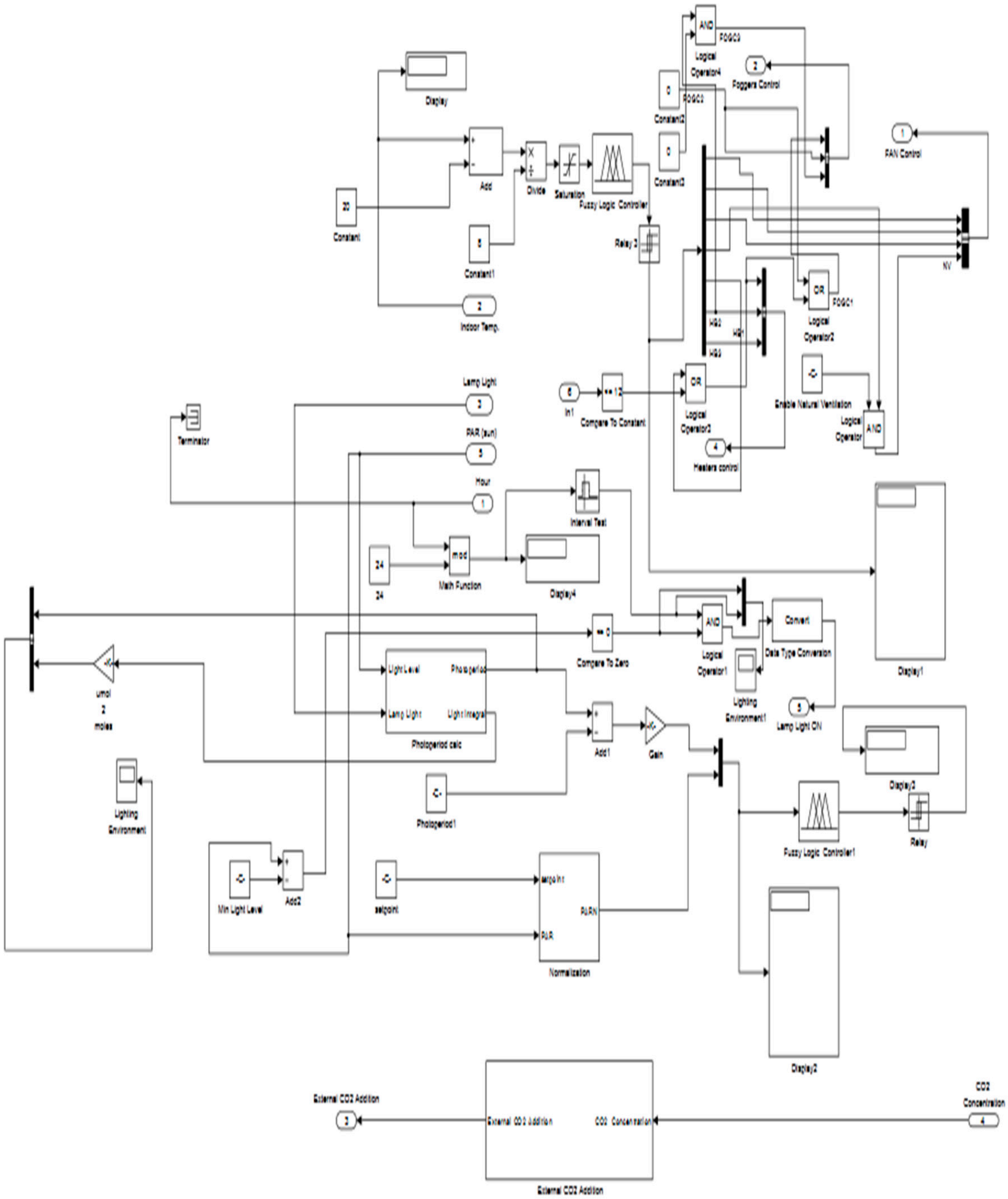

Fig.4 Simulink representation of the fuzzy logic controller model

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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 (Biskra) [6].

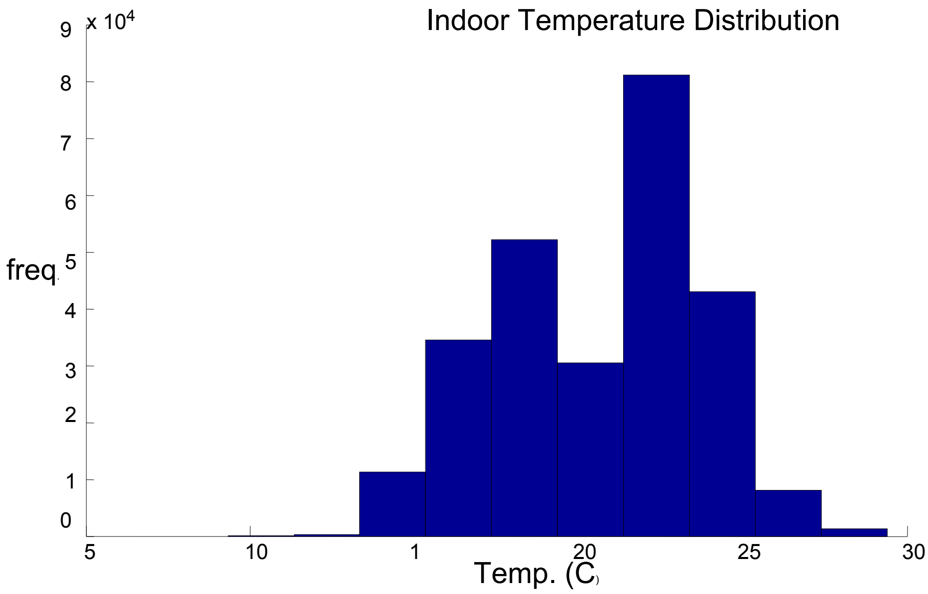

Fig. 5 Histogram shows the distribution of indoor temperature

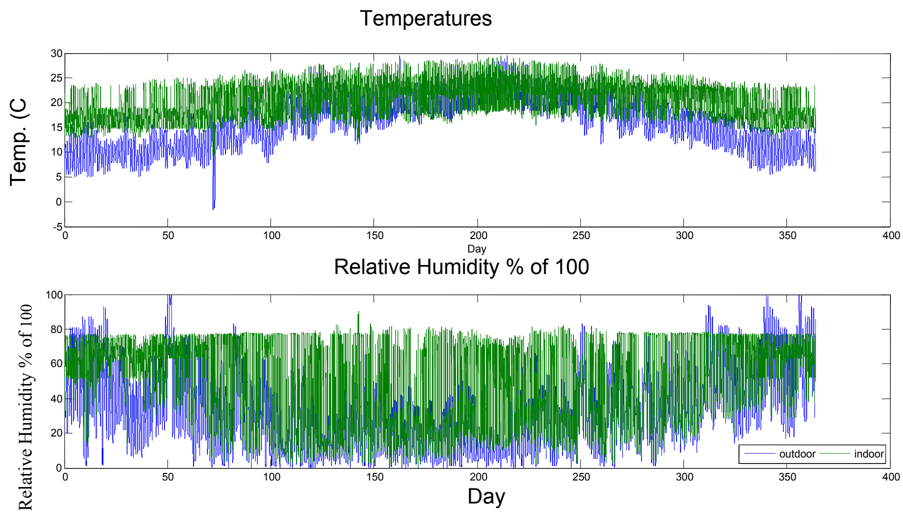

Fig. 6 The evolution of humidity and temperature (interior / exterior)

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It is found that most of the internal temperature values are in the range 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 an plastic air bubble layer mounted to the inside wall face.

During the period 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 and 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.

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Plant growth caracteristics

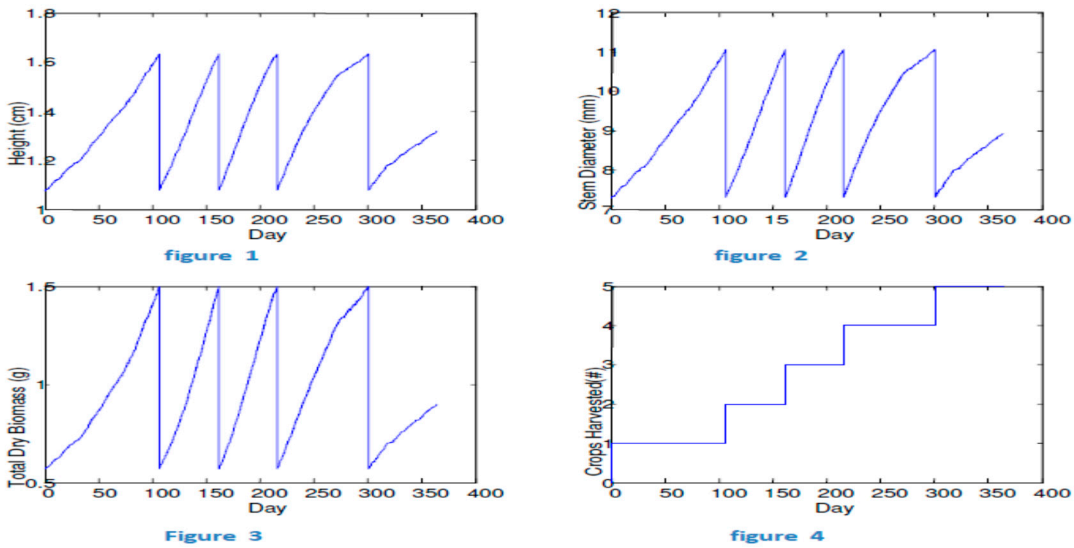

Figure 1 is the height in cm, Figure 4 is the cumulative number of growing season, Figure 3 is the total biomass (dry weight), and Figure 2 is the rod diameter in mm

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.

6. CONCLUSION

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 variables which the greenhouse is a biophysical system where parameters are highly correlated as shown by the results. this technique of fuzzy logic that 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

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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.

✓ 7. References

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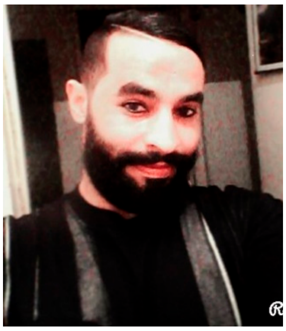
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