Dynamic Modeling of Temperature and Humidity for Greenhouse using Matlab-Simulink Environment

Yau, J.[1, 2], JianWei, J.[1]*, Wang, H.[1], Eniola O.[3], Ibitoye, F. P.[4]

[1]College of Information and Electrical Engineering, Shenyang Agricultural University, Shenyang, Liaoning, China.
[2]Department of Electrical Engineering, Faculty of Engineering, Bayero University Kano, Kano State Nigeria
[3]Department of Electrical and Electronic Engineering, Federal Polytechnic Ile-Oluji, Ondo State Nigeria
[4]Research and Development Department, Prototype Engineering Development Institute, National Agency for Science and Engineering Infrastructure, Ilesa, Nigeria
E-mail: *jianweiji2001@hotmail.com

Abstract In African countries such as Nigeria, there is need to boost the agricultural output, but climate is a major factor that affects crop performance, therefore the design of a greenhouse with properly controlled mciro-climate is necessary to address this issue. This research work designed a dynamic model for the variation of internal humidity and temperature of greenhouse using Matlab/Simulink environment. The dynamic model was designed by using mass and energy balance equations, the weather data was acquired from the appropriate meteorological station, this includes the solar radiation, relative humidity, ambient temperature, wind speed and soil temperature. The results of the simulations shows that internal temperature and humidity vary with the weather conditions, location, number of covers and structure of the greenhouse.

Keywords greenhouse; micro-climate; dynamic model; humidity; temperature; wind speed

1. Introduction

Greenhouses are designed building or structures which its parameters can control the micro-climate which is best for crop production. The control of temperature, air humidity, light intensity, soil moisture, amount of carbon dioxide and wind velocity by experts influence productivity. At present greenhouse facilities are prevalent crop research tools with the advantages of easily achieving optimal plant growth and relatively more uniform environment compared to the field tests [1-2]. The non-uniform distributions of temperature, relative humidity, carbon dioxide concentration and irradiation caused by microclimate have recently received attention by several researchers [3-7].

In this paper the dynamic simulation model will be presented, being the model used for modelling the greenhouse, this method is to reproduce the greenhouse climate response to one or more variables such as temperature, humidity, solar radiation, ventilation, etc. The basis of the dynamic simulation model is the transform of the static equations into non-steady state or "dynamic" equations. The static models are a set of equations relating the various aspects of heat loss, heat input, ventilation, humidity, condensation, infiltration etc., that can be solved for an instant in time when, essentially, the system is in equilibrium. Static models are called "steady-state" models.

Equations are based upon physical laws. Static models do not involve time; in contrast, dynamic models consider changes with time. With the help of the computer it is possible to turn static equations into a dynamic process since a new set of conditions can be calculated each time the computer cycles through its run time.

Simulation is an inexpensive process for studying climate or crop response which reduces the cost of building a greenhouse and testing crop performance within it, but in this research the crop is neglected.

2. Materials and Method

The aim of this research is the development of the greenhouse computer simulator based on the physical conditions. SIMULINK tool was used to develop the dynamic model within the MATLAB environment as described in [8-10]. Included in the data file are all the necessary physical parameters. The ameteostation was then be used to simulate the environmental conditions and look at average values, external temperatures, solar radiation and the speed of wind. A large computer was used for modelling the greenhouse because the system is complex and involves more phenomena.

2.1. Dynamic model of the Nigerian Greenhouse

A simplified dynamic model of the Nigerian greenhouse was developed, the effect of the crop was neglected, and the dynamic behaviour of the green house is the combination of mass and energy balance. Figure 1 shows the layout of a typical Nigerian greenhouse. In Figure 1, all the modelled elements have been schematized. The grey boxes indicate the temperatures calculated (state variables) while the white boxes represent the independent variables linked to the model with an external file (csv format) or directly calculated.

The heat balance can be expressed [11] as

$$Q_{total} = Q_{gain} - Q_{loss} \qquad (1)$$

Where;

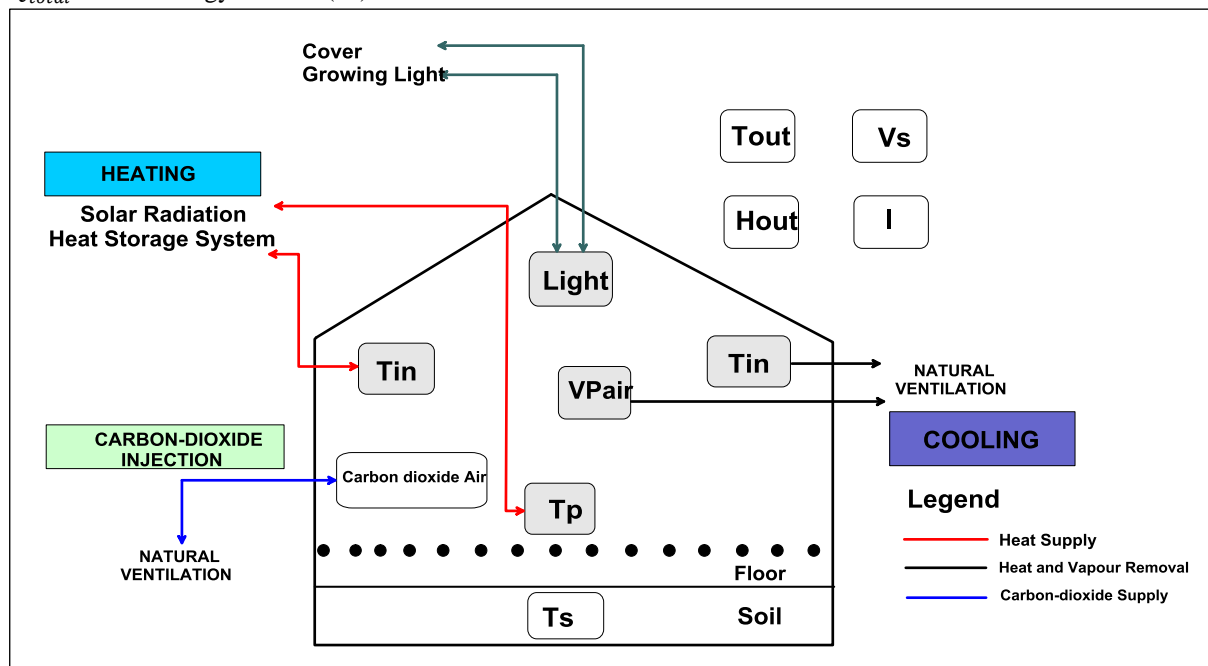Q_{total} = total energy balance (W)

Figure 1: Layout of a Typical Nigerian Greenhouse

Q_{gain} = amount energy entering the greenhouse (W)

Q_{loss} = amount of energy leaving the greenhouse (W)

The amount of energy loss from the greenhouse can be estimated by modifying the equation ([11]) which is:

$$Q_{loss} = Q_{cond} + Q_{soil} + Q_{longw} + Q_{vent} + Q_{infilt} \qquad (2)$$

Where;

Q_{cond} = Heat loss due to conduction (W)

Q_{soil} = Heat loss to soil (W)

Q_{longw} = Heat loss due to longwave radiation (W)

Q_{vent} = Heat loss due to ventilation (W)

Q_{infilt} = Heat transfer due to ventilation (W)

Conductive loss consists of all the heat exchange through the greenhouse cover from the internal to external air. Conductive loss can be calculated using the following equation   ([11])

$$Q_{cond} = A_c h(T_{in} - T_{out})$$ (3)

$$h = 2.8 \times 1.2 V_s$$ (4)

Where;

T_{out} = Outside temperature (°C)

T_{in} = inside/internal temperature (°C)

h = conductive heat transfer coefficient (W/m^2)

A_c = Area of the greenhouse cover (m^2)

V_s = wind speed (m/s)

Heat loss from the greenhouse environment to the soil can be measured by:

$$Q_{soil} = 1.86 U_s A_s (T_s - T_{in})$$ (5)

Where;

A_s = Soil surface area (m^2)

U_s = heat transfer coefficient of the soil (W.m^{-2}K^{-1})

T_{in} = greenhouse internal temperature (°C)

T_s = Soil temperature (°C)

The thermal long wave heat exchange from inside the greenhouse to the exterior, according to non-linear Stefan-Boltzmann relation can be expressed by ([11]).

$$Q_{longw} = A_c \sigma \varepsilon (T_{in}{}^4 - T_{out}{}^4)$$ (6)

Where;

ε = the combining emissivity between cover and sky

σ = Stefan-Boltzmann constant

The heat loss by ventilation is related to the difference between ambient and internal temperature and also proportional to the rate of air exchange.

$$Q_{vent} = G \rho C_p (T_{in} - T_{out})$$ (7)

$$G = V_s r_v K_v A_v$$ (8)

Where;

ρ = air density (kg/m^3)

C_p = specific heat of air (J/Kg °C)

G = air flow due to ventilation (m3/s)

V_s = wind speed

r_v = percent of the ventilator opening

K_v = slope of the curve showing the ventilation flux divided by wind speed variation.

A_v = Area of ventilator

Infiltration is the energy loss due to exchange of air through cracks, it also depends on the age of the greenhouse, heat transfer due to infiltration can be estimated as:

$$Q_{infilt} = 0.5 \times V \times N(T_{in} - T_{out})$$ (9)

Where;

V = greenhouse volume

N = number of air exchange per hour

T_{in} = Internal temperature

T_{out} = Outside temperature

The heat gain for the greenhouse model includes the heat gain due to solar radiation and heating system.

$$Q_{gain} = Q_{solar} + Q_{heatsys}$$ (10)

Where;

Q_{gain} = heat gained by the greenhouse (W)

Q_{solar} = heat gained by solar radiation (W)

$Q_{heatsys}$ = heat gained by heating system (W)

The solar energy entering the greenhouse is calculated according to the following equation:

$$Q_{solar} = A_f \gamma \tau I \qquad (11)$$

Where;

A_f = Area of the greenhouse floor (m²)

γ = constant of proportion of solar radiation entering the greenhouse (is in the range 0.3 - 0.7), a value of 0.3 was chosen

τ = transmittance of the cover

I = total solar energy falling on a horizontal surface (W/m²)

$$Q_{heatsys} = 1.95 A_p \left(T_p - T_{in} \right)^{4/3} \text{ ([12])} \qquad (12)$$

Where;

A_p = the surface area of hot water pipes (m²)

T_p = The temperature of hot water pipes (°C)

T_{in} = The indoor air temperature (°C)

$$Q_{total} = Q_{solar} + Q_{heatsys} - Q_{cond} - Q_{soil} - Q_{longw} - Q_{vent} - Q_{infilt} \qquad (13)$$

$$Q_{total} = A_f \gamma \tau I + 1.95 A_p \left(T_p - T_{in} \right)^{\frac{4}{3}} - A_c h (T_{in} - T_{out}) - 1.86 U_s A_s (T_s - T_{in}) - A_c \sigma \varepsilon \left(T_{in}^{\ 4} - T_{out}^{\ 4} \right) - G \rho C_p (T_{in} - T_{out}) - 0.5 \times V \times N (T_{in} - T_{out}) \qquad (14)$$

$$V \rho C_p \frac{dT_{in}}{dt} = A_f \gamma \tau I + 1.95 A_p \left(T_p - T_{in} \right)^{\frac{4}{3}} - A_c h (T_{in} - T_{out}) - 1.86 U_s A_s (T_s - T_{in}) - A_c \sigma \varepsilon \left(T_{in}^{\ 4} - T_{out}^{\ 4} \right) - G \rho C_p (T_{in} - T_{out}) - 0.5 \times V \times N (T_{in} - T_{out}) \qquad (15)$$

$$T_{in} = \int \frac{Q_{solar} + Q_{heatsys} - Q_{cond} - Q_{soil} - Q_{longw} - Q_{vent} - Q_{infilt}}{V \rho C_p} + T_{i,0} \qquad (16)$$

Where;

V = volume of the greenhouse (m³)

ρ = air density (kg/m³)

C_p = specific heat capacity of air (J/Kg °C)

$T_{i,0}$ = initial value of the greenhouse temperature (°C)

The internal water balance ([13], [14]) can be expressed as

$$\rho_a V \frac{dH_{in}}{dt} = G_v \times \rho_a (H_{out} - H_{in}) \qquad (17)$$

Where;

$$G_v = V_w \times S_c \qquad (18)$$

G_v is the airflow circulating inside the greenhouse

$$\frac{dH_{in}}{dt} = \frac{G_v \times \rho_a (H_{out} - H_{in})}{\rho_a V} \qquad (19)$$

$$H_{in} = \int \frac{G_v \times \rho_a (H_{out} - H_{in})}{\rho_a V} + H_{i,0} \qquad (20)$$

Where;

ρ_a = air density (kg/m³)

H_{out} = External humidity

H_{in} = Internal greenhouse humidity

$H_{i,0}$ = Initial value of greenhouse humidity (%)

3. The Developed Model Using Matlab-Simulink Environment

The simulation was performed using a weather database that was carried out in the Lagos, Southwestern Nigeria during the period of May, 2020 with a sampling time equal to 1 hour, this was divided into 8 days and 9 days intervals to enable faster simulation. This database includes the measurements of solar radiation, outside temperature, relative humidity, precipitation, sunshine duration, shortwave radiation, evapotranspiration, wind speed, wind direction, soil temperature and soil moisture, the signal generator in the simulink was used to import the external database into the simulink. It allows calculating the air temperature inside the typical greenhouse model as seen in the figure 2, the input parameters used in the simulink model are summarised in Table 1.

Table 1: Simulation parameter for Nigerian Greenhouse

Symbol	Numerical value	Units	Description
h	0.028	$Wm^{-2}K^{-1}$	Heat transfer coefficient
A_C	200	m^2	Area of greenhouse cover
V_S	-	Km/h or m/s	Wind speed
A_S	125	m^2	Soil surface area
U_S	220	$Wm^{-2}K^{-1}$	Heat transfer coefficient of soil
T	-	K or °C	Temperature
ε	0.9	-	Emissivity between cover and sky
σ	0.0000000567	-	Stefan-Boltzman constant
ρ	1.2	Kg/m^3	Air density
Cp	1006	J/Kg°C	Specific heat of air
G	-	m^3/s	Air flow due to ventilation
r_V	0.5	-	Percent of the ventilator opening
A_V	2.2	m^2	Area of ventilator
K_V	0.7	-	Slope of the curve showing the ventilation flux divided by wind speed variation.
V	1250	m^3	Greenhouse volume
N	50	-	Number of air exchange per hour
A_f	125	m^2	Area of the greenhouse floor
γ	0.3	-	Constant of proportionality of solar radiation entering the greenhouse
τ	0.85	-	Transmittance of the cover
I	-	Wm^{-2}	Total solar energy falling on horizontal surface
A_P	73.9	m^2	Surface area of hot water pipes
H	-	%	humidity
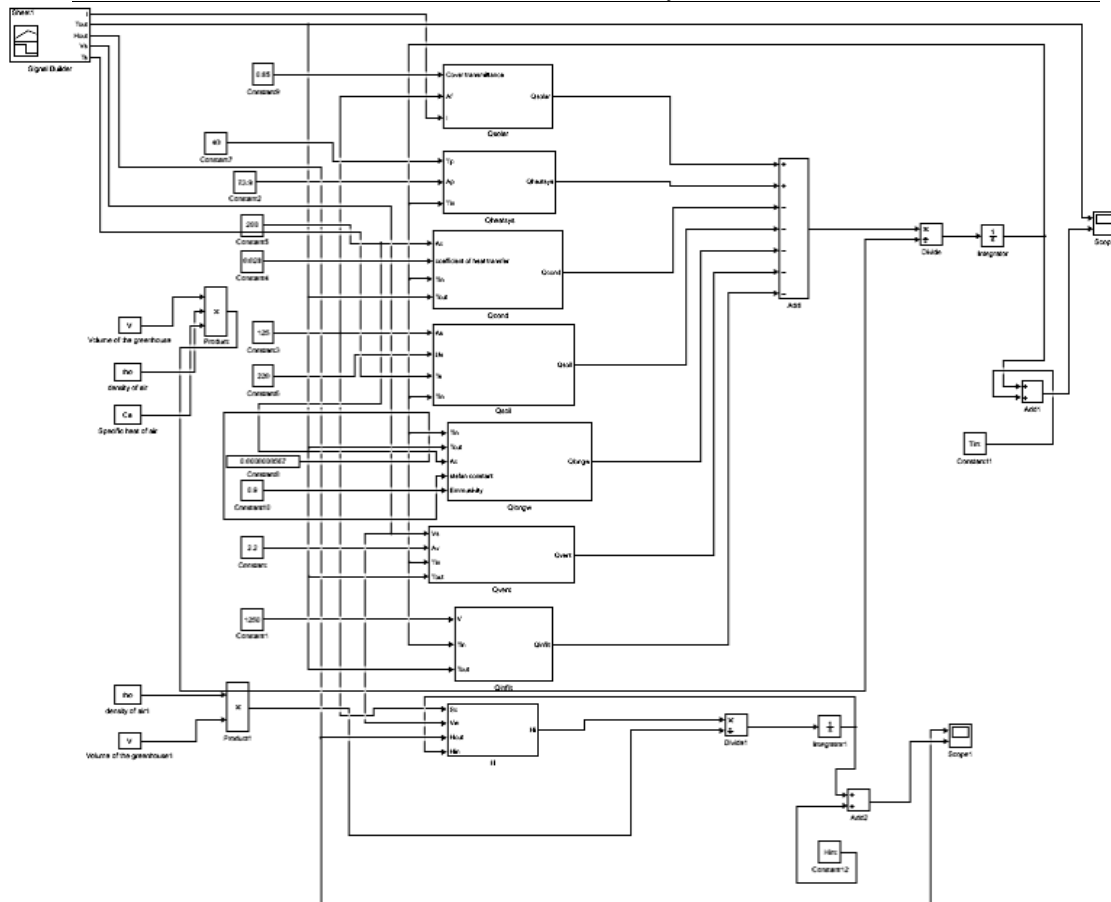
Figure 2: Dynamic Model of the Nigerian Greenhouse using Matlab-Simulink

The subsystems generated using simulink are also shown in Figures 3 - 10, these subsystems depicts how the different blocks in the Simulink environment were connected together.
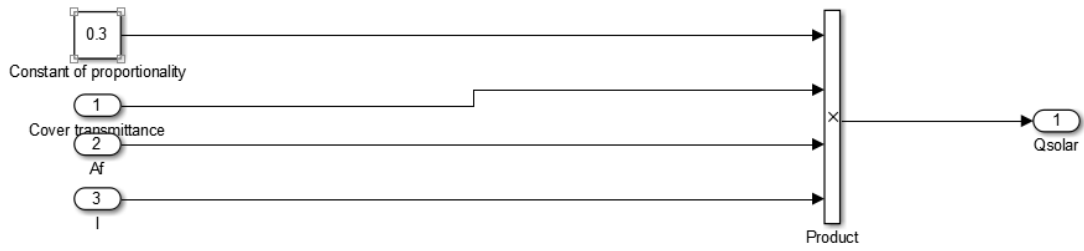

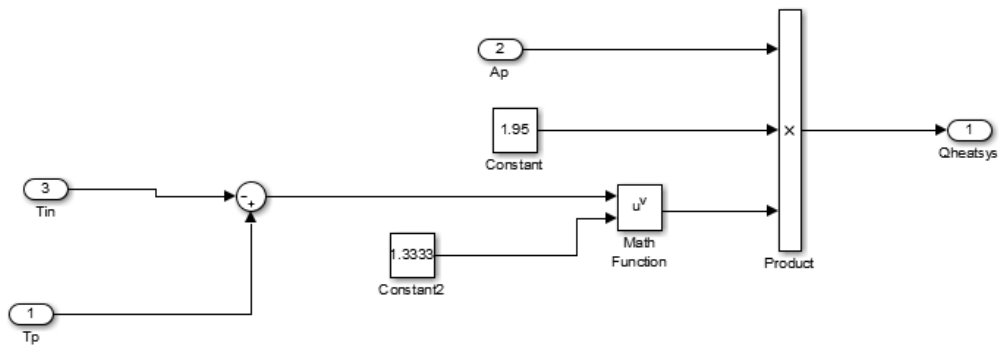*Figure 3: Sub-system for heat gained by solar radiation (Q_{solar})*

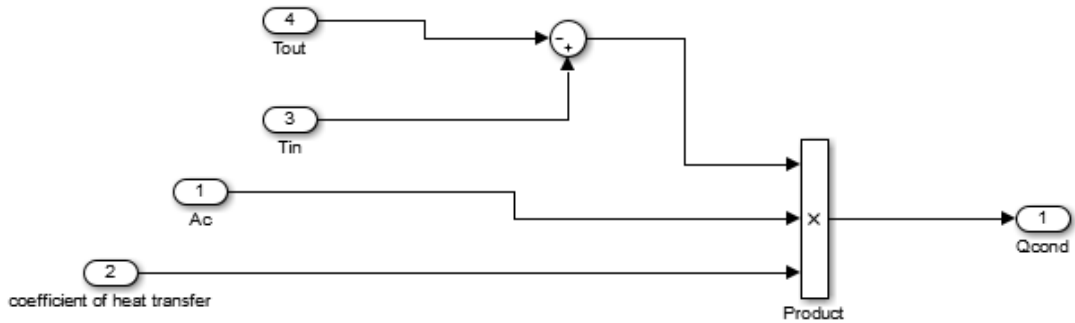*Figure 4: Sub-system for heat gained by heating system ($Q_{heatsys}$)*

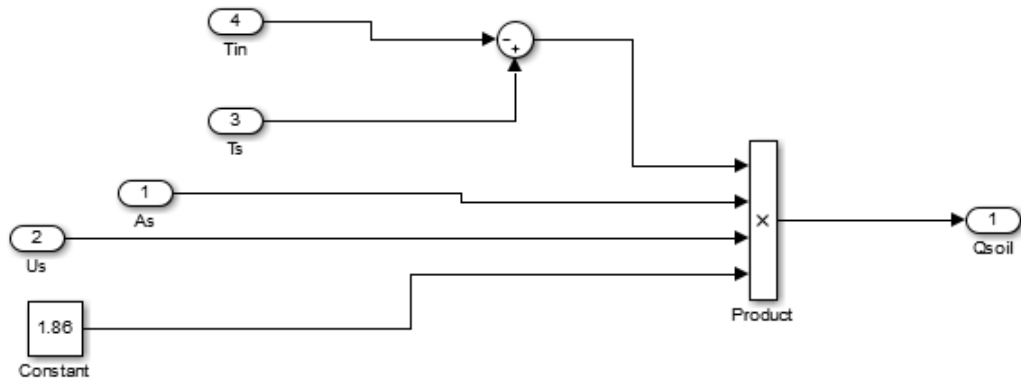*Figure 5: Sub-system for heat loss by conduction (Q_{cond})*

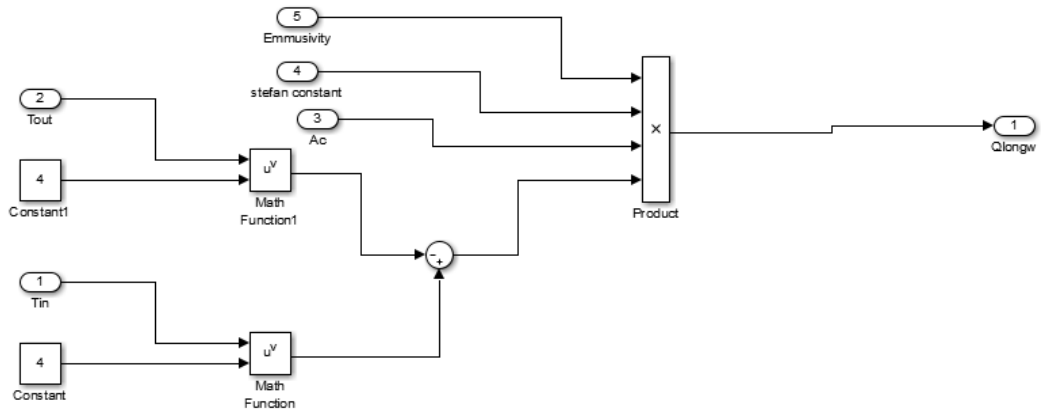*Figure 6: Sub-system for heat loss to soil (Q_{soil})*

Figure 7: Sub-system for Heat loss due to longwave radiation (Q_{longw})
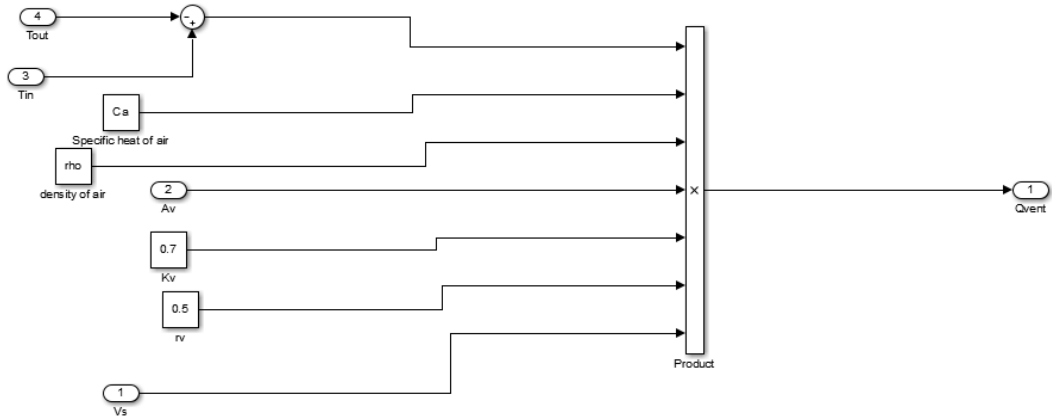
Figure 8: Sub-system for Heat loss due to ventilation (Q_{vent})
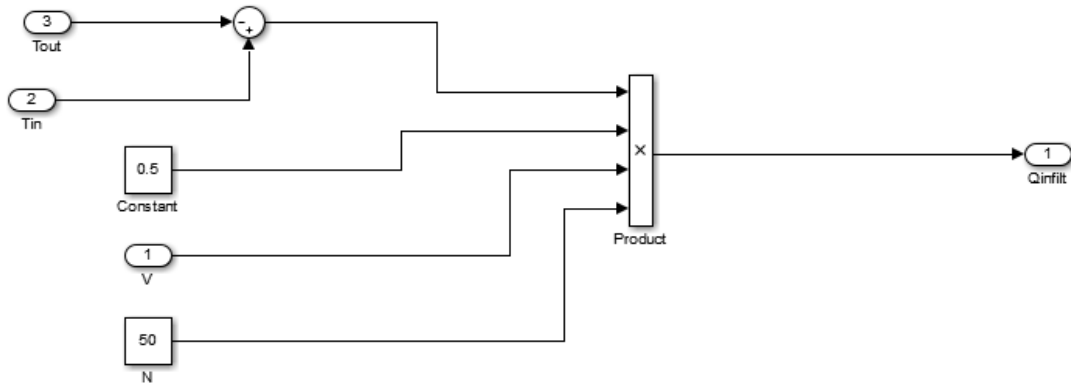
Figure 9: Sub-system for Heat loss due to ventilation (Q_{infilt})
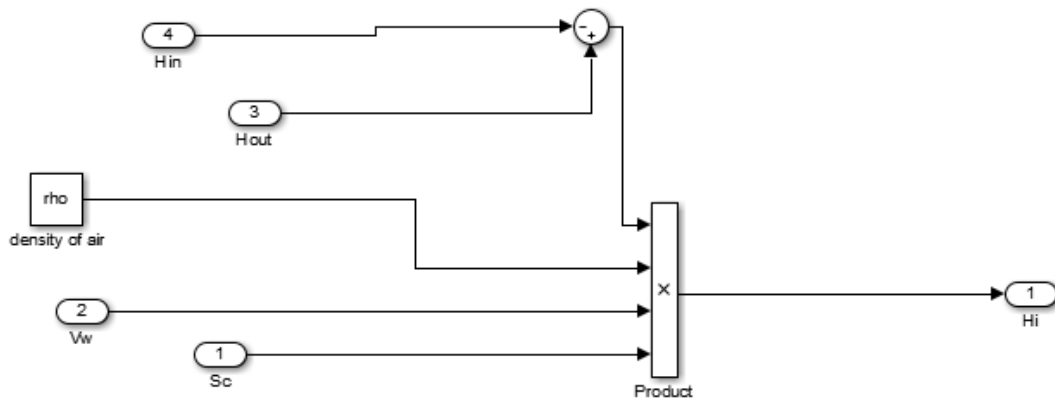

Figure 10: Sub-system for Humidity

The variation of the solar radiation (I), temperature (T_{out}), humidity (h_{out}), wind speed (V_s) and soil temperature (T_s) are displayed using the signal generator block in the simulink environment, these are shown in figure 11, figure 12 and figure 13 respectively, as depicted in these figures, the level of solar radiation reaches maximum of 811 W/m^2 during the day especially at noon. The high (peak) and low values of solar radiation intensities coincides with the high (peak) and low values of external temperature respectively, this is an indication that as the solar radiation increases, there exists low relative humidity. The high (peak) solar radiation values are noticed at noon, but it decreases gradually towards the night, the highest humidity values are noticed in the morning and night and the lowest humidity values are noticed in the noon. In addition, the high and low signatures of solar radiation corresponds to low and high signatures of the relative humidity respectively, this implies that when the solar radiation increases, significant low relative humidity values will be noticed, therefore the solar radiation and temperature are inversely proportional to the relative humidity, there is also an indication that the high (peak) values of the wind speed corresponds with the high (peak) values of solar radiation, temperature and low values of relative humidity.
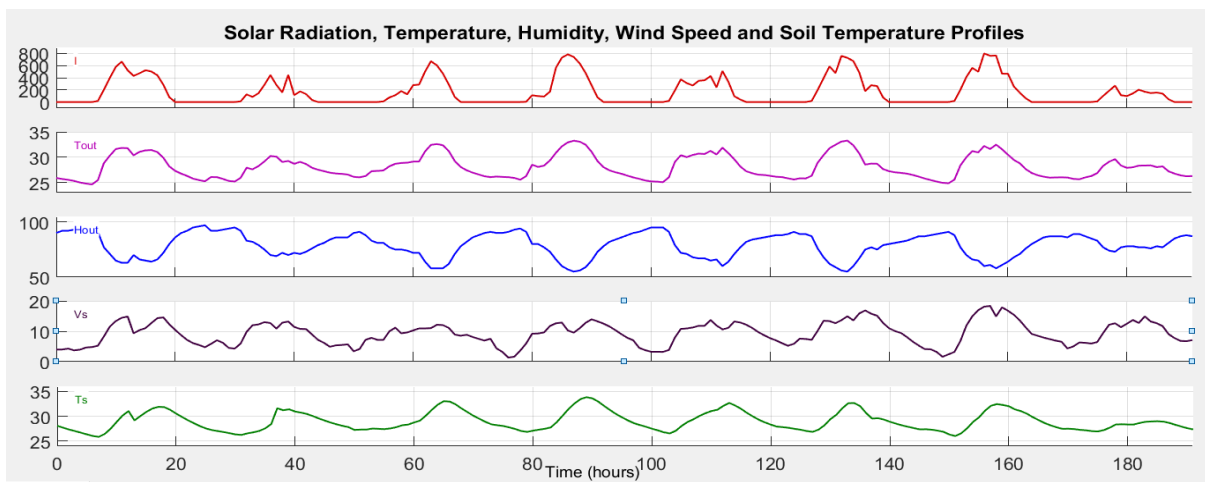

Figure 11: Solar Radiation, Temperature, Humidity, Wind speed and Soil Temperature Profiles during May 14 – 21, 2020
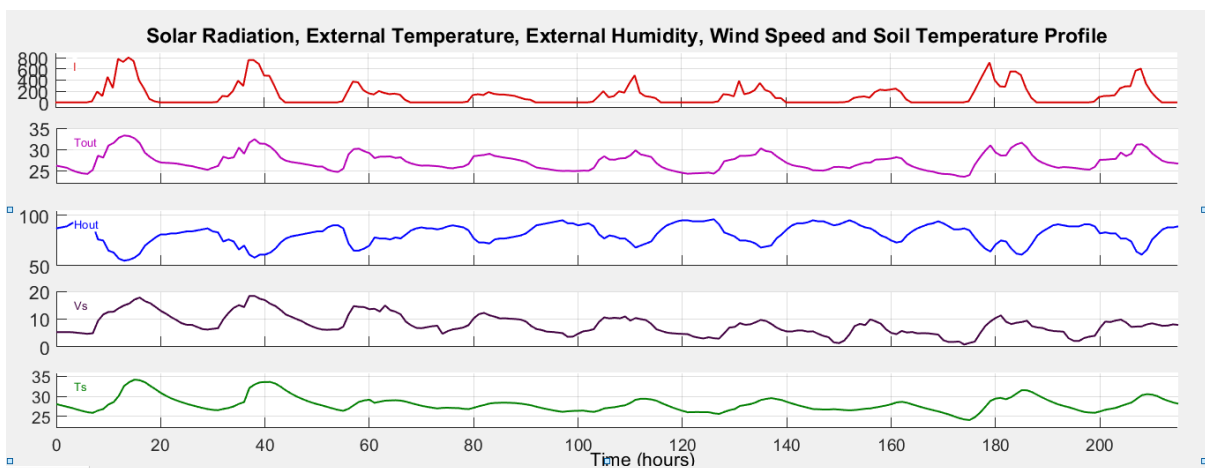

Figure 12: Solar Radiation, Temperature, Humidity, Wind speed and Soil Temperature Profiles during May 19 – 27, 2020
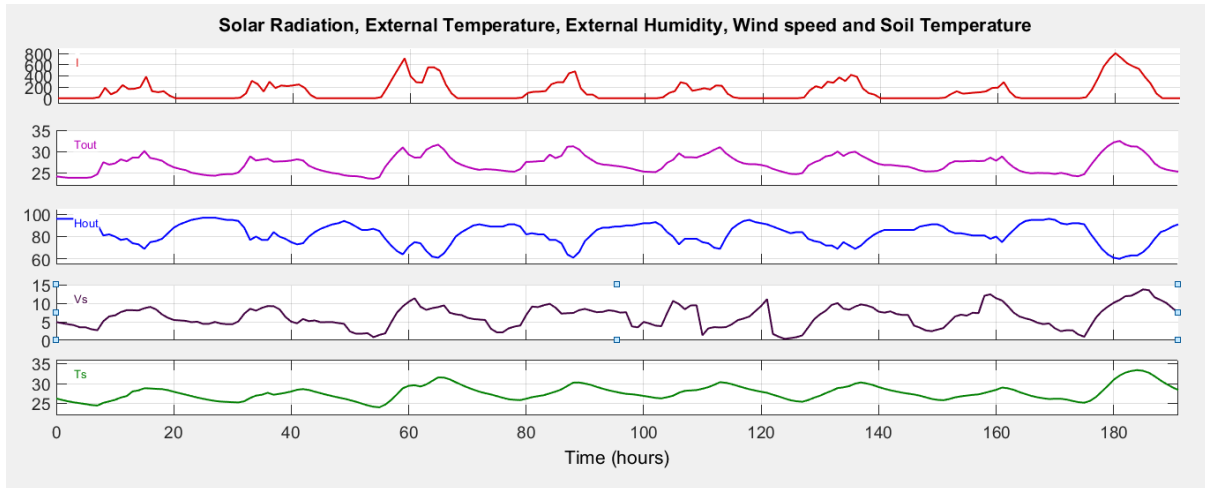
Figure 13: Solar Radiation, Temperature, Humidity, Wind speed and Soil Temperature Profiles during May 24 – 31, 2020

The simulation results of internal temperature, external temperature, internal humidity and external humidity are shown in figures 14 - 19 using simulink, as noted in the figures. 14, 16 and 18, decrease in internal temperatures were noticed, this could be the effect of other external factors such as wind speed. In figures. 15, 17 and 19, the results shows that the internal and external humidity plots have similar curve trend/pattern; this is in conformity with the results obtained by [15] and [9].
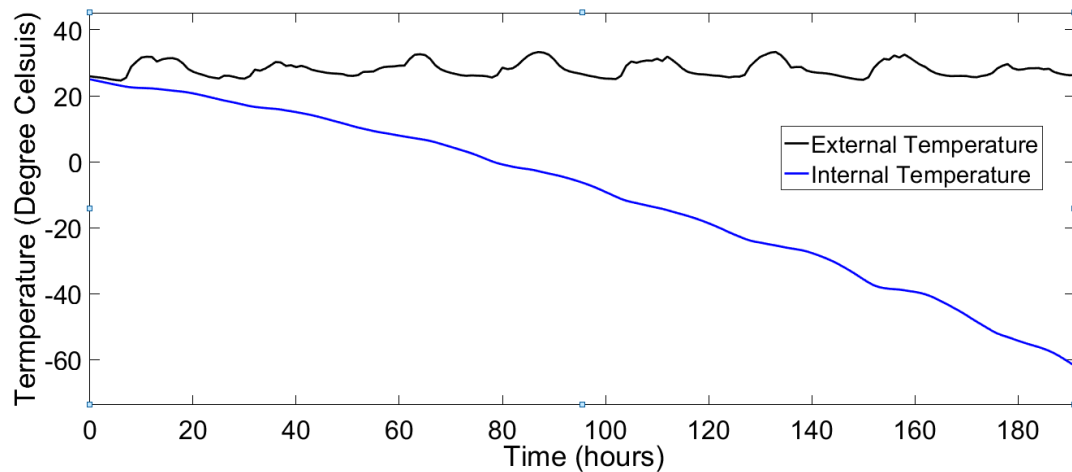

Figure 14: Numerical values of Internal and External Temperature during May 14 – 21, 2020
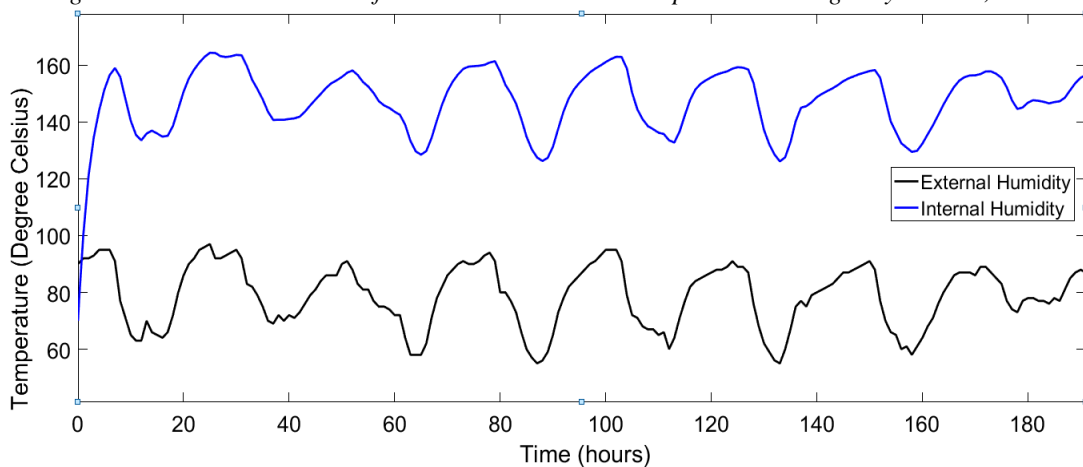

Figure 15: Numerical values of Internal and External Humidity during May 14– 21, 2020
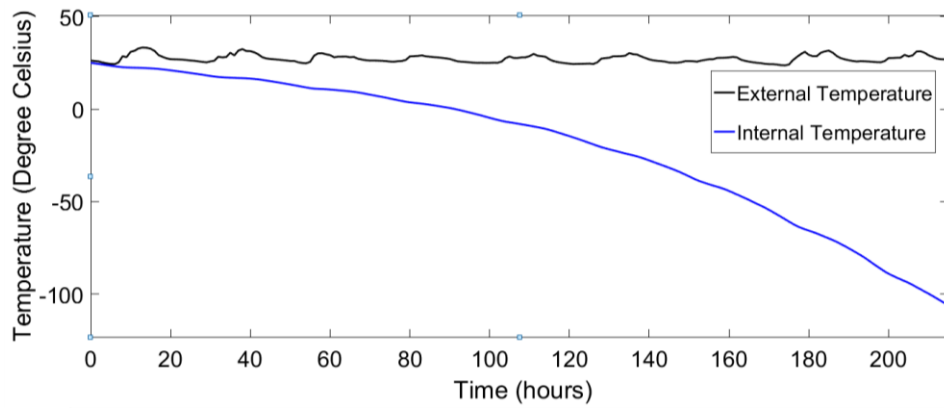
Figure 16: Numerical values of Internal and External Temperature during May 19 – 27, 2020
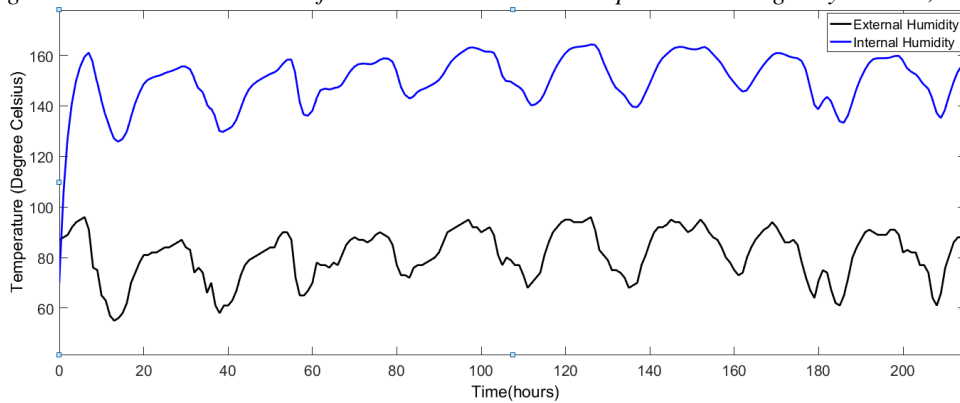

Figure 17: Numerical values of Internal and External Humidity during May 19 – 27, 2020
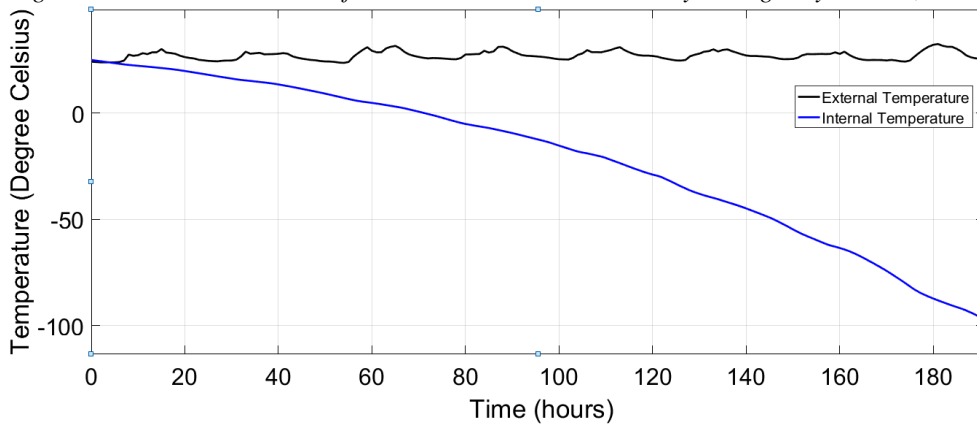

Figure 18: Numerical values of Internal and External Temperature during May 24 – 31, 2020
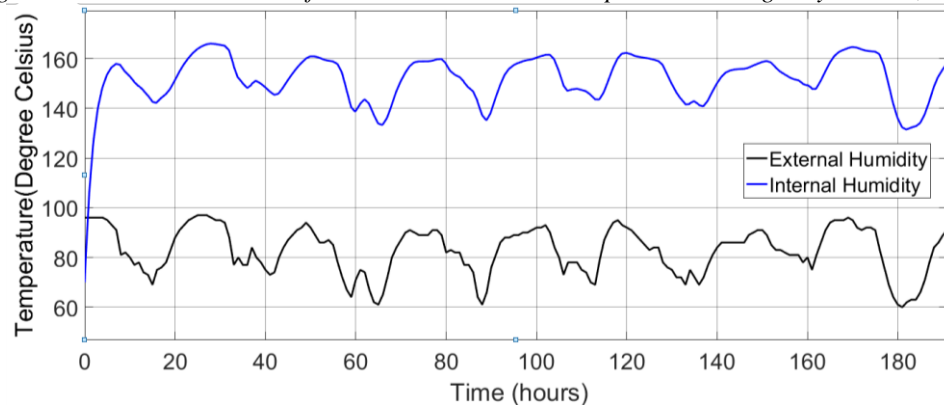

Figure 19: Numerical values of Internal and External Humidity during May 24 – 31, 2020

4. Conclusion

In this paper, a simplified dynamic model of an agricultural greenhouse was developed using Matlab-Simulink environment in order to predict the dynamic pattern of its internal temperature and humidity, the simulation results showed that the internal temperature and humifdity varies with the season (summer, winter, spring or autumn), the external climate parameters (solar radiation, soil temperature, wind speed, outside temperature, outside humidity), the location of the greenhouse, the structure of the greenhouse, the number of covers (double or simple) and the cover type. Therefore, the simulation of internal temperature and humidity can be used in making decisions about the location, structure, number of covers, type of crops which can be grown in the greenhouse and type of construction materials needed for the protective cover.

References

[1]. Vásquez, L., Iriarte, A., Almeida, M., & Villalobos, P. (2015). Evaluation of greenhouse gas emissions and proposals for their reduction at a university campus in Chile. J. Cleaner Prod. 108, 924–930.

[2]. Zhang, L., Maki, H., Ma, D., Sánchez-Gallego, J.A., Mickelbart, M.V., Wang, L., & Jin, J. (2019). Optimized angles of the swing hyperspectral imaging system for single corn plant. Comput. Electron. Agric. 156 (September 2018), 349–359.

[3]. Ahemd, H.A., Al-Faraj, A.A., & Abdel-Ghany, A.M. (2016). Shading greenhouses to improve the microclimate, energy and water saving in hot regions: a review. Sci. Horticult. 201, 36–45.

[4]. Alain, B. (1988). Greenhouse microclimate and its management in mild winter climates. In: Paper Presented at the International Symposium on Protected Cultivation of Ornamentals in Mild Winter Climates 246. pp. 23–36.

[5]. Baille, A., Kittas, C., & Katsoulas, N. (2001). Influence of whitening on greenhouse microclimate and crop energy partitioning. Agric. For. Meteorol. 107 (4), 293–306.

[6]. Castro, V., Isard, S.A., & Irwin, M.E. (1991). The microclimate of maize and bean crops in tropical America: a comparison between monocultures and polycultures planted at high and low density. Agric. For. Meteorol. 57 (1–3), 49–67.

[7]. Körner, O., Aaslyng, J.M., Andreassen, A.U., & Holst, N., (2007). Microclimate prediction for dynamic greenhouse climate control. HortScience 42 (2), 272–279.

[8]. Beccali, T. J., Giaccone, A., & Panno, G. (1992). Modello di calcolo per l'analisi del comportamentotermicodelleserre—Prima parte, Energie Alternative HTE, vol. 4, no. 18, pp. 283–289, July/Aug.

[9]. Ben Ali, R, Aridhi, E., & Mami, A. (2015). Dyanmic model of an agricultural greenhouse using Matlab-Simulink environment, 16th International Conference on Sciences and Techniques of Automatic control & computer engineering, monastir, Tunisia.

[10]. Vanthoor, B.H.E., Stanghellini, C., van Henten, E.J., & de Visser, P.H.B. (2011). A methodology for model-based greenhouse design: Part 1, a greenhouse climate model for a broad range of designs and climates. Biosystems Engineering, Vol. 110, p 363 -377

[11]. Xu, F., Chen, J., Zhang, L., & Zhan, H. (2006). Self-tuning fuzzy logic control of greenhouse temperature using real coded genetic algorithm. In: Proceedings of the 9th International Conference on Control, Automation, Robotics and Vision, IEEE, Singapore, pp. 1−6.

[12]. Jian-kun, G., Shun-sheng, W., Feng, W., Hong-guang, Y., & Jing, H. (2016). Modelling Greenhouse Thermal Environment in North China Based on Simulink. Nature Environment and Pollution Technology, Vol. 15, No 1, pp. 217-220.

[13]. Fitz-Rodrı́guez, E., Kubota, C., Giacomelli, G. A., Tignor, M. E., Wilson, S. B., & McMahon, M. (2010). Dynamic modeling and simulation of greenhouse environments under several scenarios: a web-based application. Computers and Electronics in Agriculture, 70(1), 105-116.

[14]. Souissi, M. (2002). Modélisation et commande du climat d'une serre agricole, Thesis, Faculty of Mathematical, Physical and Natural Sciences ELMANAR University, Tunisia, 2002.

[15]. Li, Q., Zhang, D., Ji, J., Sun, Z., & Wang, Y. (2018). Modelling of natural ventilation using a hierarchical fuzzy control system for a new energy-saving solar greenhouse, Applied Engineering in Agriculture, Vol. 34(6): 953-962.