*J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol 11 (8): 395- 401, 2020*

**Journal of Soil Sciences and Agricultural Engineering**

**Journal homepage: www.jssae.mans.edu.eg**
**Available online at: www.jssae.journals.ekb.eg**

# Passive Solar Greenhouse Heating Modeling with Watering Polyethylene Tubes

**Taha, A. T. H.***

Agric. Eng. Dept., Fac. of Agric., Menoufia Univ., Egypt

## ABSTRACT

A simplified mathematical model based on heat, math transfer and energy balance has been developed which integrate each of solar collector (polyethylene tubes “PE” filled with water), energy storage, and the greenhouse parameters (cover material/ plants/ soil/ air). This model may be useful for understanding the extreme complexity of the heat and mass transfer that influenced by above designing parameters. The model are included temperatures for each of; air inside the greenhouse, soil surface, plant, greenhouse cover, water in PE and relative humidity. Consequently, it can be used to estimate the energy stored in the water and energy fluxes between greenhouse components. The simulation results were compared with those of the experiment depending on the bias error of main and the coefficient of determination. A good agreement was found between measured and expected values. In a greenhouse with height of cucumber plants (*Cucumis Sativus l.*) 2.2 m and under passive solar collector (water tubes), the minimum average of inside temperature was found in between 3–7°C higher than the outside air temperature and with about 4°C higher than control greenhouse. At January, the collection factor of solar energy for greenhouse with solar tubes increased up to 1.1 times relative to traditional. It can be decided that the current model can be used for an estimate temperatures, energy stored and energy fluxes in the greenhouse use PE filled with water. The developed thermo dynamic model can be further used for optimizing the thermal storage sizes.

***Keywords:*** Polyethylene tube, solar energy, energy stored, heat transfer, mathematical modeling.

## INTRODUCTION

Egypt is one of the countries where solar energy is abundant. On Egyptian land, the solar energy recorded about 12-30 MJ/m$^2$ per day with sunshine duration in between 3500 and 4500 h per year. Solar energy can answer a part of energy request problem. Nevertheless, using a solar energy in Egypt could production a useful part in satisfying energy necessities of most urban zones in appropriate conditions (Tadros, 2000; Chedid and Chaaban, 2003; El-Metwally, 2005).

The thermal behavior in the greenhouse is depending on the control system of environments that can affect the greenhouse microclimate and production. A numerous theoretical and mathematical studies were conformed depending on heat and mass equilibrium inside the greenhouse to expect the greenhouse thermal environment (Parker, 1991; Mavrogianopoulos and Kyritsis, 1993 and Abdel-Ghany and Kozai, 2006). Thermo-dynamic microclimate models of greenhouse were developed to expect the microclimate inside a greenhouse with naturally ventilated constructed of numerous different states comparison with a heating system in greenhouse (Thomas, 1994; Tadros, 2000 and Shen *et al*., 2008).

Increasing the unit's production of greenhouse requires supplying it with essential heating, synthetic lighting and with exaggerated systems of production and this all increases energy consumption, which is then reflected on the total costs.

Heating of a greenhouse is a great problem in the subtropical country like Egypt, where there is abundance of sunlight and temperature in daytime during winter period. Temperature inside the greenhouse drops below desirable level at the night day owing to heat losses to the surrounding. In El-Menoufia governorate, the mean daily maximum air temperature ranges from 18°C to 36°C ( in January and July respectively) and mean daily minimum from 9°C to 22°C (in January and July; Taha, 2003). The harmful effects of low temperatures inside the greenhouse cause injury of stem, decreasing flower size and delay in flowering consequentially, reducing fruits and seeds production.

In Mediterranean region, generally, the greenhouses with plastics cover have large daytime variations of air temperatures at cold seasonal that mainly take a place through climate environments of clear sky. In such conditions at night, minimum air temperatures regularly drop well below adequate levels and extreme air temperatures growth above wanted levels (Zabeltitz, 2011). So, heating greenhouses during the cold days and the night has a great influence on the class and products cultivation time (Jolliet *et al*., 1999). In order to obtain ideal ambient temperature in the greenhouse, this requires supplying a large amount of thermal energy and the source of this energy is usually from electricity, natural gas, or fossil fuels.

Several experiments were expected to use water-filled transparent tubes (WFT) as an inactive heating construction in greenhouses (Parker, 1991; Mavrogianopoulos and Kyritsis, 1993; Thomas, 1994; Jolliet *et al*., 1999; and Metin *et al*., 2013). Through the day, the tubes absorb total radiation and when the

---

* **Corresponding author.**
**E-mail address: atht2020@gmail.com**
**DOI: 10.21608/jssae.2020.114861**

temperature and radiation are reduced, the thermal energy is relieved by the radiation and convection. The results of these experiments conformed that; there was a temperature difference between heated and unheated greenhouses that was caused by the heat storage effect of the plastic film tube. On the other hand, the crop that was heated about two weeks earlier than the unheated showed better and faster green growth at first, but later in the season, there wasn't much difference. At Mediterranean, the passive solar systems for greenhouses are the only solar systems adapted for its. Water has been used for perceptible storage because of two reasons; the first it's high specific heat of water and second is, in most cases, the total mass will be contributed due to the fact that natural convection overcomes any temperature distribution within the water (Taha, 2003).

Mavrogianopoulos and Kyritsis (1993) established a heat transfer model to compute the heat energy in a solar polyethylene tubes filed with water which located between crops. According to theoretical calculations, the saving of energy using the above system for heating greenhouse with tomato crop recorded 8% of the energy consumed. Taha (2010) defined the specification of the passive solar polyethylene tube, in which the heat medium was water, and examined the solar energy balance of system. Moreover, the system heat specification was examined during adding a second tube that was positive circulating using air pump. Nevertheless, all of the above references conformed a heat storage using a water-filled polyethylene tube "WFT" in greenhouses without/or with plants (Ntinas *et al*., 2011).

This investigation has been done to identify mathematically the heat behavior of solar energy redeemable system "SESS" for a greenhouse in winter season. Also, to develop a mathematical model to predict temperature of water inside polyethylene tubes "WFT" and the thermal performance efficiency of the SESS. To recognize this objective, a tray is done to recognize this objective, a tray is done to estimates the energy equilibrium of the SESS and to match the expected with experimental results. Likewise, to examine the thermal reciprocities through the greenhouse components and the temperature behavior of water inside polyethylene tubes "WFT". Additionally, this system was used for cucumber planting

## Mathematical Model

The model bases on the fondamental mechanism that gave the active exchange or heat loading and water vapor among the several layers that are supposed to be similar and immeasurable in the projection plane. These typical features of model inputs for the greenhouse that included five layers "plastic cover, inner air, soil surface, crop, and water-filled polyethylene tubes" that can be divided in two main groups as shown in figure (1) :

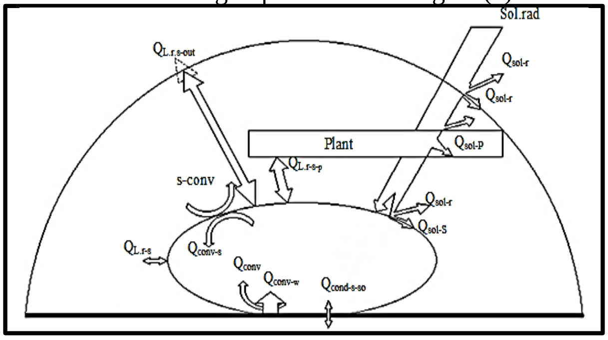

**Fig. 1. Energy fluxes of WFT system**

- **The first set:** includes factors provided by user such as :- 1- Duration time ; 2- Depth of soil measured in the model and it's layer thickness; 3- plants covering ratio with surface of soil ; 4- Filling ratio of the tubes with water and 5- Angle of latitude and the number of the days that using to calculate the solar radiation.

**-The second set:** contains factors taken from the literature such as:- 1- Inside and outside of heat transfer coefficient for greenhouse, 2- Wind speed average values, 3- Absorptivity of the soil/tubes and plant-surfaces, 4- Physical properties for each of soil, water and material of tube, such as, capacity of heat, heat conductivity and density 5- Surrounding temperature or temperature of sky.

**Conditions of boundary and initial:** Heat transfer flows are identified as outlines conditions in all outside surfaces. The unstable heat flow for plant surface, soil and WFT include solar radiation absorbed, convection and long-wave radioactive exchange between surfaces and sky. The heat flow by evaporation, transpiration and condensation are identifie and taken into account in present study.

**Solar radiation:** The total radiation established on the plane surface ($Q_G$) consider as the sum of the direct ($Q_b$) and diffuse radiation ($Q_d$) (Taha, 2010).

$$Q_G = Q_b + Q_d \ \textbf{[Wm}^{-2}\textbf{]} \qquad \textbf{(1)}$$

Inside greenhouse, heat is moved directly to each segment as long wave radiation, and some heat is radiantly swapped with the air. It is likely to compute the radiant energy ($Q_{LR}$) influences of the solar storage system. The surface of any portion at a specified temperature (T) produces electromagnetic radiation is subjected to the Stefan-Boltzmann law as:

$$Q_{rad} = \varepsilon.\sigma.AT^4 \ \textbf{[W]} \qquad \textbf{(2)}$$

**Where:** **ε: emissivity of surface is < 1 [-]**
**σ: constant of STEFAN-BOLTZMANN = 5.67×10$^{-8}$ [Wm$^{-2}$K$^{-4}$]**
**A : area of surface [m$^2$]**

**Solar convection: For** any greenhouse, heat exchange by convection happens at five different settings: on the inner and outer sides of the cover, on surface of soil, on plant surface and on heating system (polyethylene tubes). The convective heat flow between pair of inward sides, called ($Q_{conv}$), is proportional to the temperature difference (ΔT), between the inward side and the air. In the current study, it has been assumed that, the various heat transfer coefficients ($h_{conv}$) involved have different values. Consequently, the ($Q_{conv}$) is given by the following equation:

$$Q_{conv} = h_{conv}.A\Delta T \ \textbf{[W]} \qquad \textbf{(3)}$$

**Solar conduction: T**he flow of conductive heat ($Q_{cond}$) through any section measured in (W) depends upon the cross/sectional area of the element, the temperature gradient and element thermal conductivity. This can be expressed as follows:

$$Q_{cond} = \frac{k.A\Delta T}{X} \qquad \textbf{[W]} \qquad \textbf{(4)}$$

**Where:** ***k*** **: Material thermal conductivity of [Wm$^{-1}$K$^{-1}$]**
**X : Material thickness [m]**

**Ventilation equation:** The thermal energy exchange through inside /outside air of greenhouse was taken into account and this is due to the greenhouse was sometimes opened by the workers. The ($Q_{\text{ven}}$) is given by the following equation:

$$Q_{ven} = Z V_g \rho C_p (T_a - T_{ou}) \quad [\text{W}] \tag{5}$$

**Where:** $Z$ **: air exchange number [$h^{-1}$]**
$V_g$ **: green house volume [$m^3$]**
$\rho$ **: air density [$kgm^{-3}$]**
$C_p$ **: the air specific heat [$Whkg^{-1}K^{-1}$]**
$T_a$ **: inner temperature [K]**
$T_{ou}$ **: outer temperature [K]**

**Differential equation:** To compute temperature "T " for greenhouse layers (cover, internal air, soil, plants, and water-filled polyethylene tubes), the following differential equation by Taha, (2003) used:

$$T = \frac{1}{\rho . C_p . X} \int_{\tau=0}^{\tau=n} (Q_{\text{sup}} - Q_{los}) d\tau \quad [°\text{K}] \tag{6}$$

**Where:** $\tau$ **: time [sec]**
$Q_{sup}$ **: Amount of heat gained per unit area [$Wm^{-2}$]**
$Q_{los}$ **: Amount of heat loss per unit area [$Wm^{-2}$]**

**Energy balance of greenhouse:** The equation of energy balance for various greenhouse elements combined with solar energy storage system (water-filled polyethylene tubes) can be constructed on the basis of the following assumption:

- Inside air temperature of greenhouse is assumed to be constant,
- Energy balance is based on steady state conditions,
- Heat flow in one-dimensional,
- All long wave irradiative heat transfer are calculated
- Influence of humidity and water latent heat of vapor are not neglected.

Energy balance equations for greenhouse cover (Eq. 7); soil surface (Eq. 8); plant (Eq. 9); inside air and water-filled polyethylene tubes (WFT) (Eq. 10 and Eq. 11) are as follows:

$$Q_{conv\text{-}out} + Q_{conv\text{-}in} + Q_{LR\text{-}C\text{-}So} + Q_{LR\text{-}C\text{-}P} + Q_{LR\text{-}C\text{-}sk} + Q_{LR\text{-}C\text{-}WFT} + Q_{cond} = 0 \tag{7}$$

$$Q_{G\text{-}SO} + Q_{conv\text{-}So} + Q_{LR\text{-}C} + Q_{LR\text{-}p} + Q_{cond\text{-}so2} + Q_{cond\text{-}WFT} + Q_{evap} = 0 \tag{8}$$

$$Q_{G\text{-}P} + Q_{conv\text{-}P} + Q_{LR\text{-}C\text{-}P} + Q_{LR\text{-}so\text{-}P} + Q_{LR\text{-}P\text{-}WFT} + Q_{trans} = 0 \tag{9}$$

$$Q_{conv\text{-}C} + Q_{conv\text{-}So} + Q_{conv\text{-}p} + Q_{conv\text{-}WFT} + Q_{Ven} = 0 \tag{10}$$

$$Q_{G\text{-}WFT} + Q_{conv\text{-}WFT} + Q_{LR\text{-}C} + Q_{LR\text{-}p} + Q_{cond\text{-}so} + Q_{cond\text{-}WFT} = 0 \tag{11}$$

**Where:**

$Q_{conv\text{-}out}$ **: Heat transfer by convection at cover outside**
$Q_{LR\text{-}P\text{-}WFT}$ **: Thermal radiation exchange between plant and WFT**
$Q_{conv\text{-}in}$ **: Heat transfer by convection at cover inside**
$Q_{LR\text{-}C\text{-}WFT}$ **: Thermal radiation exchange between cover and WFT**
$Q_{conv\text{-}So}$ **: Convection heat transfer at soil surface**
$Q_{LR\text{-}so\text{-}P}$ **: Thermal radiation exchange between soil and plant**
$Q_{conv\text{-}P}$ **: Heat transfer by convection at plant surface**
$Q_{cond\text{-}in}$ **: Heat transfer by conduction in side greenhouse**
$Q_{conv\text{-}C}$ **: Cover heat transfer by convection**
$Q_{cond\text{-}So}$ **: Soil heat transfer by conduction**
$Q_{conv\text{-}so}$ **: Heat transfer by convection at soil**
$Q_{cond\text{-}WFT}$ **: Heat transfer by conduction for WFT**
$Q_{conv\text{-}WFT}$ **: Heat transfer by convection at water filled-polyethylene tube**
$Q_{evap}$ **: Heat transfer by evaporation**
$Q_{LR\text{-}C}$ **: Thermal transfer radiation for cover**
$Q_{trans}$ **: Latent heat loss from plant due to transpiration**
$Q_{LR\text{-}P}$ **: Heat transfer by thermal radiation for plant**
$Q_{Ven}$ **: Ventilation heat transfer**
$Q_{LR\text{-}C\text{-}P}$ **: Heat radiation reciprocity cover and plant**
$Q_{G\text{-}SO}$ **: Total solar radiation of soil**
$Q_{LR\text{-}C\text{-}so}$ **: Heat radiation reciprocity cover and soil**
$Q_{G\text{-}P}$ **: Total solar radiation of plant**
$Q_{LR\text{-}C\text{-}sk}$ **: Heat radiation reciprocity between cover and sky**
$Q_{G\text{-}WFT}$ **: Total solar radiation at the water filled tube surface**

All above equations are conformed to calculate the energy balance under operations conditions using a program that runs in combination with MATLAB and also using a Simulink tool for demonstrating, simulating and evaluating active systems. It supports linear and nonlinear methods for modeled each of continuous time methods or sampling time or a combination of the two.

## MATERIALS AND METHODS

The experiments were piloted throughout the winter season of 2018 on two identical semi-circle greenhouses. One is experimental and other is control (Fig. 2 a and b). Each greenhouses had a total surface area of $A_g = 50$ m$^2$. There were covered with a single polyethylene sheet (PE) of 130 µm with conformed a total surface area of 67.54 m$^2$. Plastic tubes filled with 70% water were placed between the plants rows inside experimental greenhouse.

Cucumbers seeds (Cucumis sativus l.) were planted in a clay soil. Crop treatments were the same in both greenhouses. The cucumber needed high temperatures and soil moisture for satisfactory yields and an optimum moisture level was very suitable, that is easy to achieve for growers. Ample sunshine is also needed, so planting during the summer is beneficial, with an estimated 2,700-2800 hours of sunshine. Optimum temperature required for the plants ranged from 21 to 24 °C in day time and between 18 and 20 °C at the night (Jiménez-Ballesta *et al.*, 2018).

Apply Radio Meter was used to amount the solar radiation on the flat surface. The wet and dry temperatures inside greenhouse were identified by thermocouple wires located in required measuring points. The data collection and recording frequency was 10 seconds, 10 minutes average of each measurements was recorded using Lab Jack (U3). It has a full-speed USB connection; this connection provides communication and power from PC to Lab Jack and from Lab Jack to PC. The data collector used to gather data of air/soil/and water temperatures, relative humidity and solar irradiation where were identified during conformed the experiments.

The system has two input parameters as ambient temperature and solar irradiation. The parameter solar irradiation has been simulated based on the information about modeling found in the relevant literature (Taha, 2010). The simulation models of the greenhouse with water-filled polyethylene tubes and without were designed using Simulink (El-Sheikh, 2001; Taha, 2003 and Taha, *et al.*, 2009) which is a program that runs in combination with MATLAB. Simulink is an interacting device for designing, simulating, and analyzing dynamic systems. It supports linear and nonlinear methods for modeled each of continuous time methods or sampling time or a combination of the two. Also, it uses to construct a graphical block drawing, computing system performance and sanitizing the designs. MATLAB is both a computer programming language and a software environment for using that language effectively (Shen, *et al.*, 2008).

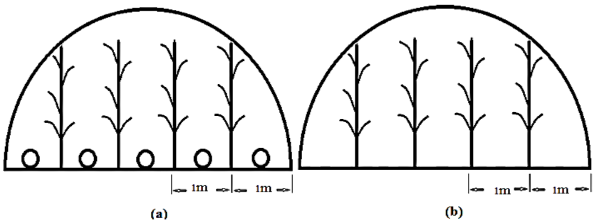

**Fig. 2.** Semi-circle greenhouses (a) by WFT and (b) without WFT

## RESULTS AND DISCUSSIONS

### Ambient conditions (temperature and solar radiation)

In the days of experiments, the differences of the solar radiation and temperature of ambient air are shown in Fig. 3. During the experiment, the mean values of temperature for ambient air and solar radiation per day were recorded "minimum/maximum 4/24°C" and 100/600W/m$^2$ respectively. The ambient air temperature and solar radiation were reached the highest values between 12:00 and 15:00 clock. The temperature has always been relatively low at the beginning and end of the day while it reaches its maximum in the afternoon and then begins to drop again.

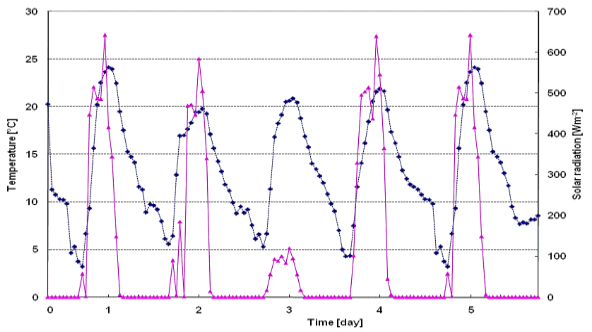

**Fig. 3.** Diurnal cycles of temperature and solar radiation

### Validation of the simulation model

### Solar radiation on horizontal surface

Fig. 4-a illustrated the results of total solar radiation results on horizontal surface measured and predicted during daylight hours where solar radiation changes in the range of 103–594 Wm$^{-2}$ and the values used in the typical configurations and operating conditions. It can be seen that a good convention was found between simulation and experimental result. Fig. 4-b demonstrations coefficient of determination between the total solar radiations for the horizontal surface with measured and predicted data that resulting of model that gave an R$^2$ of (0.989).

### Greenhouse temperatures

The simplest mathematical demonstration of the fluctuating thermodynamic system in a greenhouse is the assumption that temperature varies as a harmonic (sinusoidal) function of time. The peak temperature is shifted progressively over time. Greenhouse air temperature was fluctuated with time which could be fitted with a sinusoidal function for the five temperature parts; cover (Tc), soil (Tso), water (Tw) and ambient (To). As observed from this plotting, the highest peak was found (Tp) with 30°C followed by (Tw) with 25°C, (Ta) 22°C, (Tso) with 19°C, (Tc) with 14°C and (To) with 10°C. As observed in Fig. 5, the peaks of the plotted temperature curves of the different greenhouse elements are deviating from each other in relation to time, due to several reasons, including the heat capacity of the element and the ratio of exposure to direct solar irradiation and the absorptivity of the element.

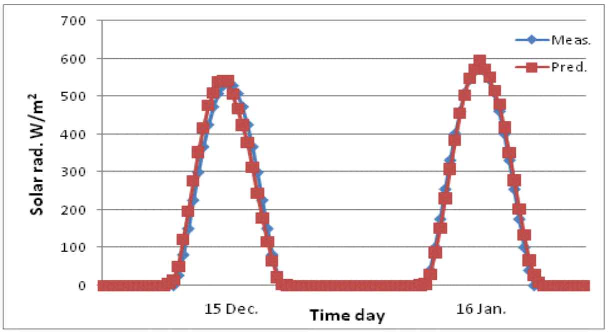

**Fig. 4-a.** Solar radiation at December and January

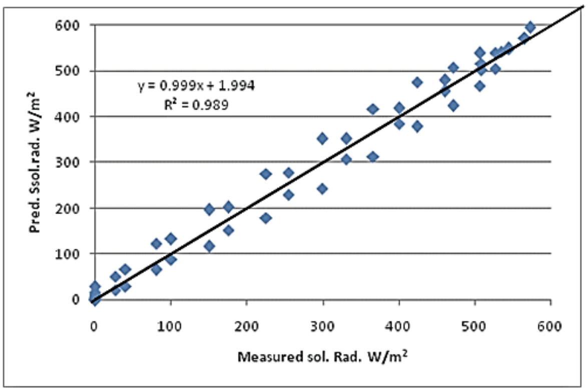

**Fig. 4-b.** Comparison between measured and predicted of solar radiation

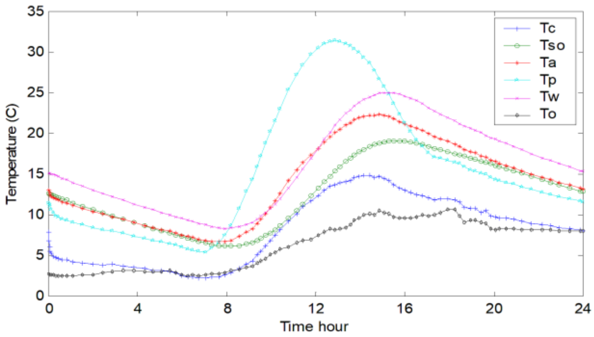

**Fig. 5.** Diurnal cycles of temperature inside the greenhouse with WFT

### Air temperature

The temperature variation per hour for ambient and greenhouse air (or inside air temperature) with WFT for archetypal winter day (a) and without heating system (b) have been illustrated in Fig. 6. From the figure, it is seen that the minimum as well as maximum temperatures for ambient air, greenhouse air with WFT and without WFT varied between 3-10°C, 5-20°C and 1-25°C respectively indicating the increase of minimum temperature inside the greenhouse with WFT as compared to ambient air and greenhouse air without WFT. This is due to the entry of thermal heat to the greenhouse by WFT arrangement.

From above figure, temperature per night of the greenhouse with WFT is always higher than the ambient temperature, while the night the greenhouse temperature without WFT is sometimes lower than the ambient, and this is due to the thermal loss through the convection to the surround and also by radiation to the sky.

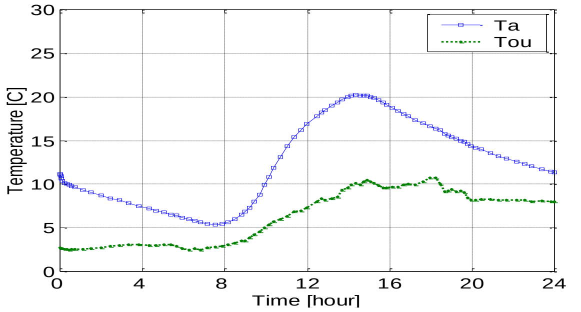

**Fig. 6-a. Measured temperature for daytime cycles inside the greenhouse per WFT**

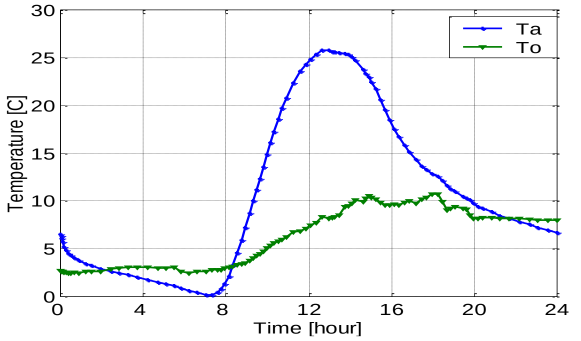

**Fig. 6-b. Measured temperature for daytime cycles inside the greenhouse without WFT**

Fig. 7 shows the comparison between predicted (Ta-p) and measured (Ta-m) values of greenhouse air temperature (Ta) with WFT, during one day of changeable climatic conditions. It can be seen that a good agreement was found between simulation and experimental result. Fig. 7-b shows the coefficient of determination between computed and measured values of the heated greenhouse air temperature that resulting from model have an R2 of (0.959).

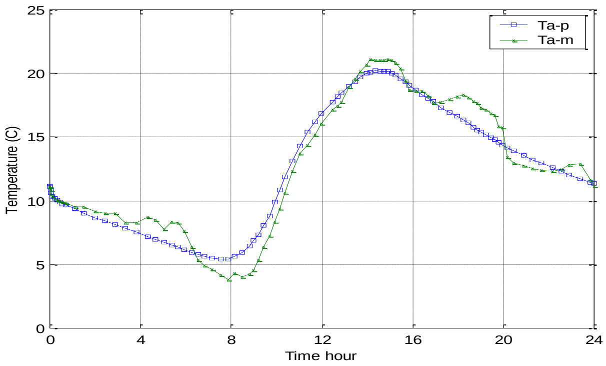

**Fig. 7-a. The comparison between "Ta-p" and "Ta-m" values of (Ta) with WFT**

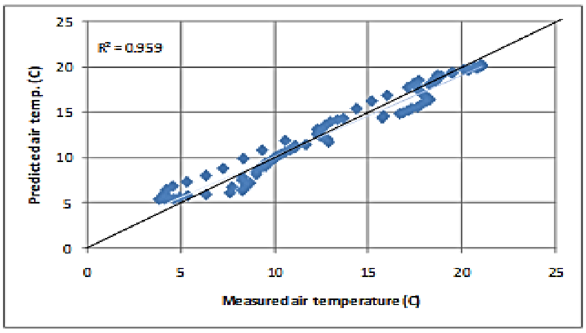

**Fig. 7-b. Coefficient of determination $R^2$ between predicted and measured air temperature**

## Soil surface temperature (Ts)

Figure 8 shows that the time evolution of simulated and measured soil surface temperatures per sunny days. It was spotted that temperature of soil surface oscillate and increased per time with a maximum value of 15 °C compared to the inside greenhouse air temperature Fig.7, it is reduced by five degrees, and this can be due to three reasons, the first is the percentage of shading from plants, the second is covering ratio from the tubes and the last is that the soil surface has been affected by the greenhouse environment. A perfect uniformity can be observed between simulation of soil surface temperature and available field measurements.

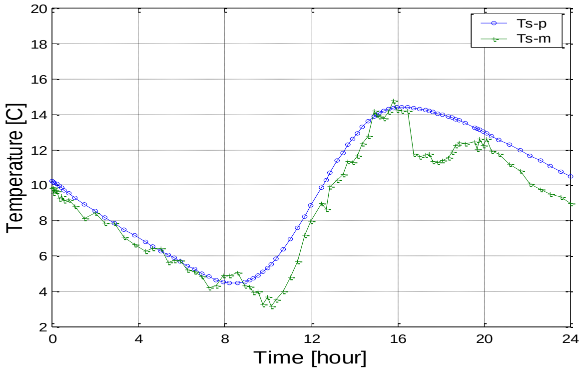

**Fig. 8-a. Comparison between predicted and measured soil surface temperature**

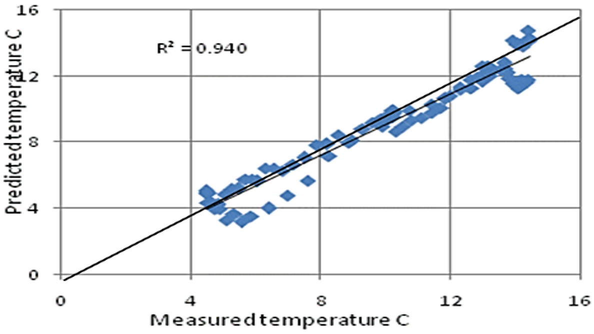

**Fig. 8-b. Coefficient of determination "$R^2$" between predicted and measured soil surface**

## Water temperature

On sunny days, the water temperature (Tw) reaches its peak later in the day than the indoor air temperature (Ta). Figure (9-a) shows a comparison between the measured water temperature and the simulated temperature (Tw-p) for the simulation period studied. The figure shows that the simulated water temperature take the same directions as measured (Tw-m), but with some differences especially at peak temperature values. The simulated water temperature was sometimes higher and sometimes lower or roughly equal to the measured variable. The temperature of the solar radiation water and the greenhouse environment reached to maximum value of 23 °C at midday.

From the figure (9-a), it can be observed the difference between Tw-m and Tw-p values of water temperature for the simulation period studied. It can be seen that the bigs difference can found in the middle of the day and decreases in the late afternoon and early morning. The maximum difference between the measured and expected temperature was 3 °C. This situation can be caused by various causes, such as changes in solar irradiance, measurement error and error in determining heat capacitances of the polyethylene tube material and water specification. However, the errors get are identical to general passive solar wall modeling. The coefficient of determination ($R^2$) of the water temperature between simulation and measurements throughout simulation period was 0.983 (Fig. 9-b).

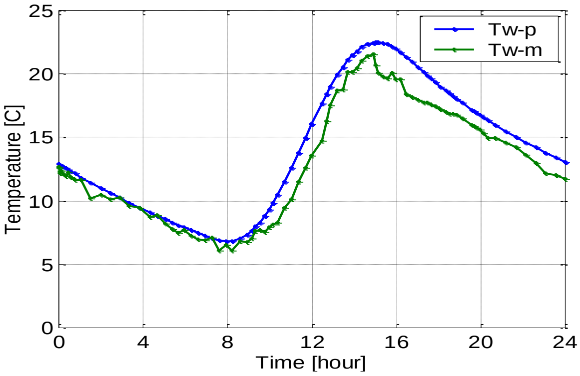

**Fig. 9-a. Comparison between predicted and measured water temperature**

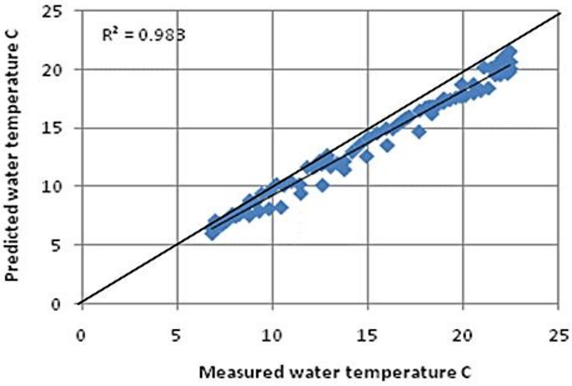

**Fig. 9-b. Coefficient of determination $R^2$ between predicted and measured water temperature**

The diurnal variations of total heating potential obtained from WFT for a typical day in winter have been computed and presented in Fig.10. The figure illustrates daily energy fluxes and heat loss from the water filled-tube through the convection to the greenhouse inside air, in addition to the thermal loss of the greenhouse cover by the convection to the ambient air and by long-wave radiation to the sky. From the figure, the highest value of the thermal energy that can be added from WFT to greenhouse air is 20 W/m$^2$, and the lowest value is 10W/m$^2$, after sunset and at night time. The value of thermal losses from the greenhouse cover to the sky ranges between 50 to 60 W/m$^2$. This is due to, that the temperature of the sky is always less than the ambient temperature from 15 to 20°C and the greenhouse is considered as one entity. Moreover, the system contributes to raising the internal greenhouse air temperature to a higher degree than the surrounding degree, but not to the desired degree.

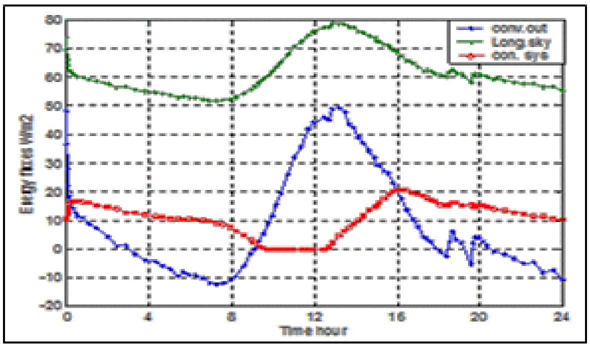

**Fig. 10. Daily energy fluxes and heat loss from the WFT and thermal loss from the greenhouse cover**

This simulation model will be useful in understanding the extreme complexity of the heat and mass transfer which influenced by many design parameters. Good agreement was found between the experimental and simulated values. These results are consistent with findings data from Hussain *et al.* (2007).Similar results have been reported in the literature for various heated greenhouses such as Metin *et al.* (2013), Katsoulas *et al.* (2011), Ntinas *et al.* ( 2011) and Taha (2010).

## CONCLUSIONS

The object of the investigation may be not only to obtain the optimum gain, but also to eliminate or reduce the loss or damage. There occurs 3-7 $^0$C increasing of greenhouse air temperature during the nighttime at winter season due to the incorporation of WFT as related to without WFT. Proposed mathematical model is useful for evaluating the climatic conditions of greenhouse with water filled-tubes for different days.

## REFERENCES

Abdel-Ghany, A.M. and T. Kozai (2006). Dynamic modeling of the environment in a naturally ventilated, fog-cooled greenhouse Renew. Energy, 31 (10), pp. 1521–1539.

Chedid, R. and F. Chaaban, (2003). Renewable-energy developments in Arab countries: a regional perspective. *Applied Energy*, 74 : 211–220.

El-Metwally, M. (2005). Sunshine and global solar radiation estimation at different sites in Egypt. Journal of Atmospheric and Solar-Terrestrial Physics, 57: 1331–1342

El-Sheikh, I. H. (2001).Soil heating and climate simulation model for greenhouses. Ph.D.Thesis, University of Hannover, Germany.

Hossain, M.A. and B.K. Bala (2007). Drying of hot chilli using solar tunnel drier. Solar Energy 81, 85–92.

Jiménez-Ballesta, R.; F. J. García-Navarro; R. García-Giménez; J. M. Trujillo-González; V. Iñigo and C. Asensio (2018). Agroecological Analysis of Cucumber (Cucumis sativus L.) Crops in Orchards in a Mediterranean Environment Journal of Agriculture and Crops Vol. 4, Issue. 3, pp: 16-28.

Jolliet O.; L. Danloy; J. Gay; G. Munday and A. ReistHorticern (1999). An improved static model for predicting the energy consumption of a greenhouse. Agric. Forest Meteor. 55, pp. 265–294.

Katsoulas, N.; C. Kittas; C. Fidaros; T. Bartzanas and K. Baxevanou (2011). Study of a passive solar heating greenhouse crop grow gutter. Acta Hort., 893, pp. 381–388.

Mavrogianopoulos, G. and S. Kyritsis (1993). Analysis and performance of a greenhouse with water filled passive solar sleeves Agric. Forest Meteor., 65, pp. 47–61.

Metin, K.; B. lEkin; M. Mehmet and A. Ayhan (2013). Modeling and simulation of a hybrid solar heating system for greenhouse applications using Matlab/Simulink Energy conversion and management. 72, pp. 147–155.

Ntinas, G. K.; P. G. Kougias and Ch. Nikita-Martzopoulou (2011). Experimental performance of a hybrid solar energy saving system in greenhouses. Int. Agrophysics, 25 (3), pp. 257–264.

Parker, B. F. (1991). Energy in world agriculture, Solar energy in agriculture. Elsevier Science Publishers, New York, pp: 1- 55.

Sethi, V. P.; K. Sumathy; Chiwon Lee and D. S. Pal (2013). Thermal modeling aspects of solar greenhouse microclimate control: A review on heating technologies Sol. Energy, 96, pp. 56–82.

Shen, C.; Y. He; Kashaninejad Y. Liu and W. Tao (2008). Modeling and simulation of solar radiation data processing with simulink. *Simulation Modeling Practice and Theory*, 15: 721–735.

Tadros, M. T. Y. (2000). Uses of sunshine duration to estimate the global solar radiation over eight meteorological stations in Egypt. *Renewable Energy*, 21: 231–245.

Taha, A. T. (2003). Simulation Model of Energy Fluxes in Passive Solar Greenhouses with a concrete North-Wall. PhD Thesis Institute of Horticultural and Agricultural Engineering, Faculty of Horticultural, Hannover University, Germany.

Taha, A. T. (2010). Estimation of Hourly Global Solar Radiation in Egypt Using Mathematical Model. In the 17th Conference of Misr society of agricultural engineering collaboration with the Department of Agricultural Engineering, Faculty of Agriculture, Tanta University, Egypt, pp55

Taha, A. T.; A. H. A. Eissa ; G. R. Gamea and H. M. Hidarh (2009). Simulation model of flat plate solar collecter performance. In the 1st Scientific Conference for Marketing the Applied University Research, Minoufia University, Egypt, pp. 421- 438

Thomas, J. (1994). Investigation for optimization and suitability of water filled plastic tubes as collector and storage elements in greenhouses. PhD Thesis. Hannover: Hannover University; 1994.

Zabeltitz, Von C. (2011). Integrated Greenhouse Systems for Mild Climates. Climate Conditions, Design, Construction, Maintenance, Climate Control. Ch 3, Springer-Verlag, Berlin Heidelberg. Pp 29-43.

# نمذجة التدفئة السلبية للأنابيب البلاستيك المملوءة بالماء فى الصوب الزراعية

**أحمد توفيق طه**
**قسم الهندسة الزراعية – كلية الزراعة – جامعة المنوفية**

يهدف هذا البحث الى تصميم موديل رياضي لدراسة تأثير استخدام انابيب بلاستيكية مملوءة بالماء لتدفئة الصوب الزراعية. ولتصميم هذا النموذج أخذ في الاعتبار انتقال الحرارة والكتلة، لذلك تم اجراء الاتزان الحراري على جميع عناصر الصوبة (غطاء الصوبة والهواء الداخلي وسطح التربة والنبات والأنابيب البلاستيكية المملؤة بالماء). من هذا النموذج يمكن حساب كمية الأشعة الشمسية الساقطة على سطح افقي داخل وخارج الصوبة وحساب كميات الحرارة المنتقلة بين عناصر الصوبة، كما يمكن من توقع درجات الحرارة للعناصر المختلفة والرطوبة النسبية داخل الصوبة. وقد تم اجراء تجربة على صوبتين بمنطقة المنوفية وكانت أبعاد الصوبة 10* 5 * 2.8م طول وعرض وإرتفاع على الترتيب. وتمت تغطية الصوب بطبقة من البوليثيلين بسمك 130 ميكرون كما تم وضع انابيب بلاستيكية ملئت بنسبة 70% بالماء بين صفوف نباتات الخيار في صوبة واستخدمت الأخرى بدون أنابيب (الكنترول). وقد أوضحت النتائج أن: ـدرجة حرارة الهواء الداخلي للصوبة المدفأة أعلى بحوالى 3 – 7°م من درجة حرارة الوسط المحيط بالمقارنة بالصوبة الكنترول. ـ معامل التحديد لنتائج النموذج الرياضي فى مقابل النتائج المقاسة كان 0.959 ، 0.940، 0.98 لكل من درجة حرارة الهواء الداخلي وسطح التربة ودرجة حرارة الماء على الترتيب. مما يوضح التوافق الجيد بين النتائج المتحصل عليها من النموذج الرياضي والمقاسة في ارض التجربة. وعلى هذا فإن النموذج الرياضي المقترح يصلح لحساب الأشعاع الشمسي الساقط على سطح افقي داخل وخارج الصوبة. كما يمكن من خلاله حساب الطاقات الحرارية المختلفة المنتقلة بين عناصر الصوبة. وأيضا يمكن حساب وتوقع درجات الحرارة لغطاء الصوبة وسطح التربة والنبات والهواء الداخلي ودرجة حرارة الماء في الأنابيب. وكذلك توقع وحساب الرطوبة النسبية داخل الصوبة الزراعية.