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SIMULATION OF AGRICULTURE GREENHOUSE INTEGRATED WITH ON-ROOF PHOTO-VOLTAIC PANELS: CASE STUDY FOR A WINTER DAY

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ABSTRACT

This paper investigates analytical study for an agricultural greenhouse (GH) integrated with Photo Voltaic/Thermal (PV/T) units in its roof and south wall in addition to Humidification-Dehumidification system (HDH). This system uses the extra solar radiation to generate electricity which is used in HDH system to condensate water recovered from plant transpiration and use it in irrigation. This system provides plants with a proper climate conditions and its requirements of solar radiation and water. MATLAB is used to develop a mathematical model based on energy equations to simulate the GH performance. The results predict that the system can be self-sufficient of energy and can provide proper conditions for the plant growth for the climate conditions of winter in Zagazig.

Keywords

Greenhouse, Desalination, HDH, Solar Energy

1. INTRODUCTION

Nowadays, the water resources of Egypt are very limited compared to 40 or 50 years ago. Egypt is suffering from a severe shortage of water resources or what we can call “Egypt-water-crisis.” The water scarcity problem in Egypt increases with time due to several vital factors including the rapid population growth, lack of awareness of the wise use of freshwater, deterioration of the water quality, climate change impact and the impact of the huge upstream structures on the reduction of water resources of Egypt. To close the food gap in Egypt, 114 Billion m3/year is needed, which implies great challenges facing Egypt and the Egyptian as well. Desalination is of the solution to produce more fresh water for the Egyptian communities.

In this paper, the authors present a case study from a funded project where a greenhouse is proposed to use the desalinated water or the precisely the brackish groundwater to produce more food without any environmental impact. The brine is particularly used to produce helophytes as fodder for the animal and the salt for industries or domestic use. To increase the productivity of the greenhouse, its environmental conditions should fits perfectly with the plants environmental needs. The simulation results are presented in the paper a typical winter day.

2. State of the Art

Hassan et. al [1] developed a novel stand-alone agriculture greenhouse integrated with on-roof transparent solar still to produce its need of irrigating water. They developed a mathematical model to predict the GH performance in Borg El-Arab city, Alexandria. Their system is predicted to produces 8.6 L/m2.day which are enough for plant growth. Salah et. al [2,3] studied analytically the performance of hassan et. al [1] for different operational scenarios to minimize power consumption and maximize water production of the system. They found that the system can produce up to 6 L/m2.day of water in summer conditions with power consumption of 1.4 kW.hr/m2.day and produces only up to 2.44 L/m2.day of water in winter conditions with power consumption of 0.77 kW.hr/m2.day for Borg El-Arab city. Yohannes and Fath [4] developed mathematical model predicts the performance of a GH integrated with on-roof transparent photo-voltaic in Abu Dhabi, UAE. Hassan et. al [5] developed and applied Yohannes and Fath [4] model on Borg El-Arab climate conditions and made a parametric study to present the change in water production and power consumption for the developed system. They found that system is suitable for Egypt climate around the year. Salah et. al [6] developed a new stand alone, solar driven agriculture GH integrated with on-roof photo-voltaic/ thermal. They used Matlab to simulate the GH for a typical day in summer in Zagazig city, Sharqia, Egypt. The system gave positive results for plant growth and water production.

3. Configuration of the Simulated System

The case study presents a new agriculture greenhouse (GH) which is integrated with photo-voltaic (PV) panels and desalination system, fig 1. This system will be suitable for coastal areas where harsh climate and saline water are found. This system uses the surplus solar radiation to generate electricity via photo-voltaic panels which are placed in the GH roof and recovers most of plant transpiration via humidification-dehumidification process (H-DH).

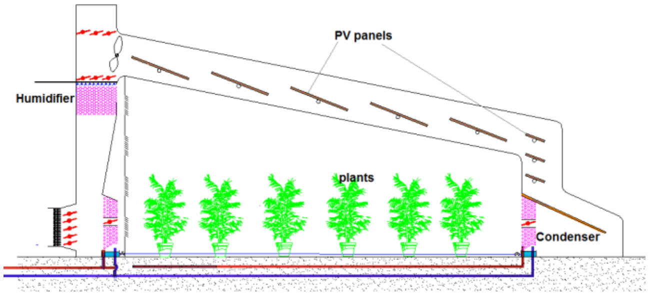


Figure1. Graphical representation for GH integrated with on-roof PVs

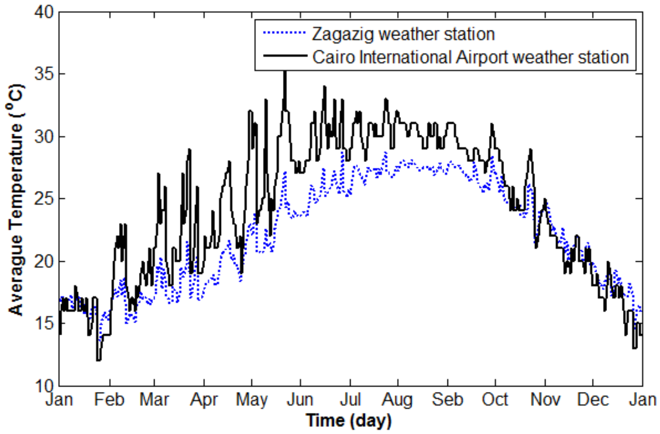
4. Methodology

Mathematical model -based on mass and heat balance equations- is developed using MATLAB to predict the GH performance. Air temperature and relative humidity inside GH are predicted. Additionally, water production and electricity generation via (H-DH) system and (PV) panels respectively are quantified instantaneously. This study is applied for a typical day in winter for climate conditions of Zagazig city, Sharqia, Egypt.

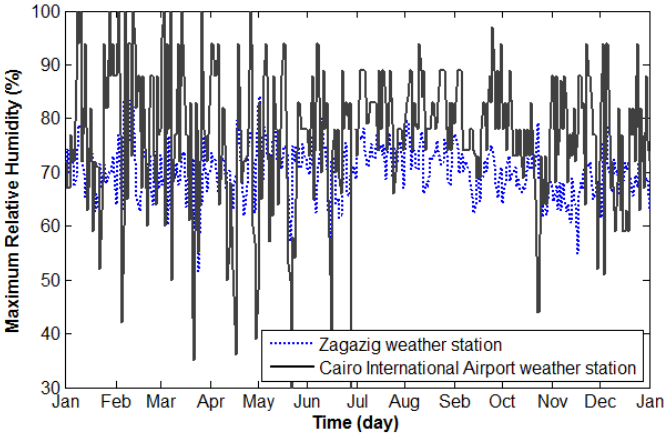
Firstly, ambient climatic conditions for Zagazig city, Egypt are obtained from a website which collects data from weather stations [7]. The nearest weather station of Zagazig was Cairo International Airport weather station. Ambient climate conditions for Cairo International Airport weather station is compared to climate conditions measured in Zagazig. The measured daily climate conditions and conditions collected from the website are very close, fig.2. So, the hourly climate conditions are obtained from the website to be used in the greenhouse modelling. After validating, a typical day in the winter is selected to be studied as a case study. Data for three years have been obtained and the average values are considered in the modelling, fig,3. **Secondly**, geometrical, thermal, optical and physical properties for the GH components are defined and listed in tables.1 & 2, [6]. **Thirdly**, solar radiation absorbed/transmitted by/via each GH wall is calculated based on **Clear Sky Day model**, eqs.1-6, [6]. **Finally**, all data resulted from the previous steps are introduced to thermal model to predict GH performance and quantify water production in addition to electricity generation and consumption in the system, eqs. 7-12, [6].

5. Results and Discussions

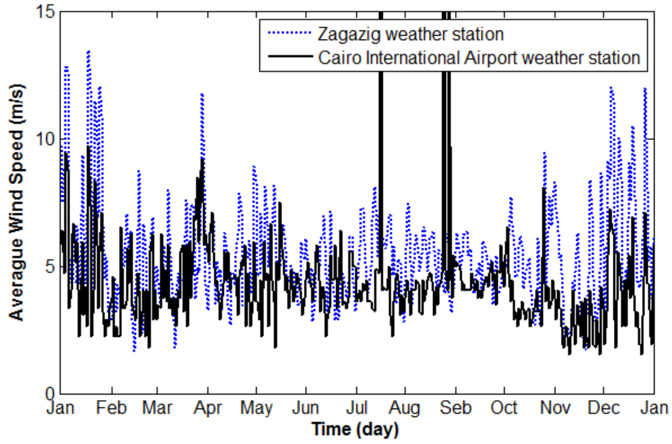
Figure.2. shows the validation between data collected from the website and that measured in Zagazig. As seen, there is a good agreement between them. Figure.3. presents ambient conditions for a typical day of winter in Zagazig city, Egypt.



(a) Temperature

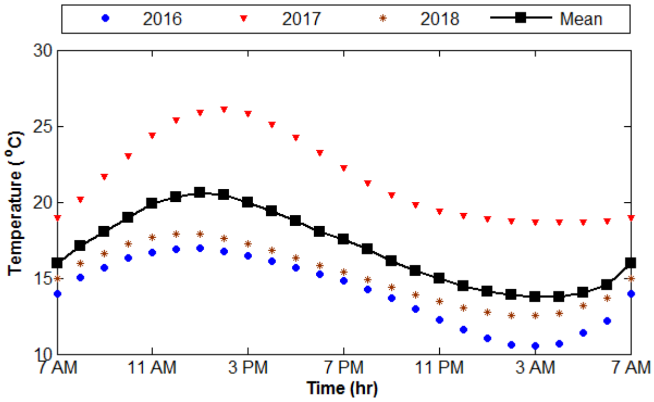


(b) Relative humidity

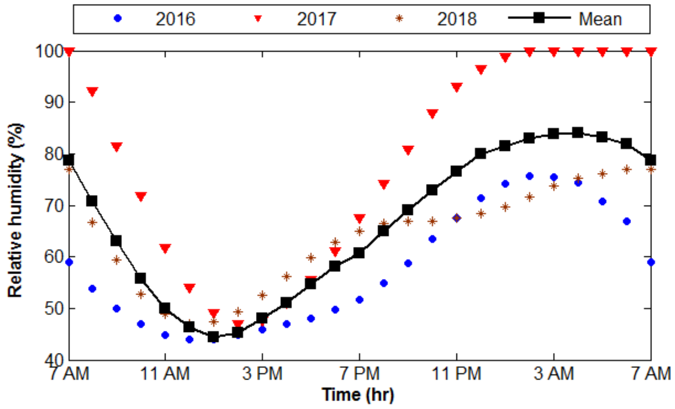


(c) Wind speed

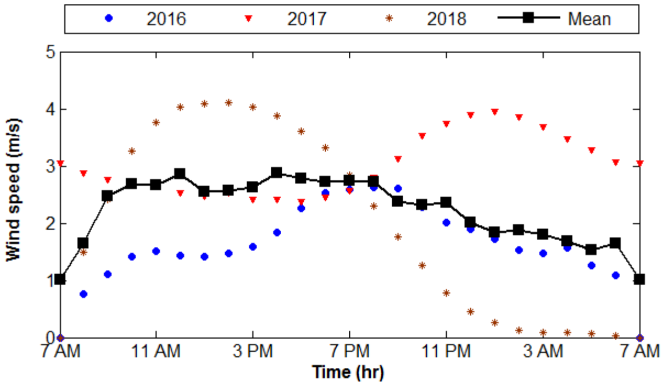
Fig.2. Daily Averague Ambient Climate Conditions for year of 2018 in Zagazig and Cairo International Airport



(a) Temperature



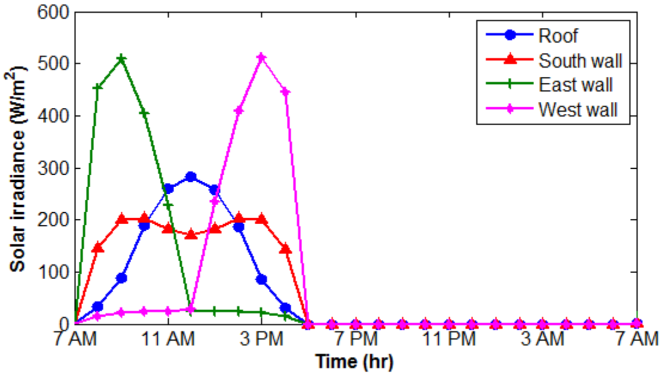
(b) Relative humidity



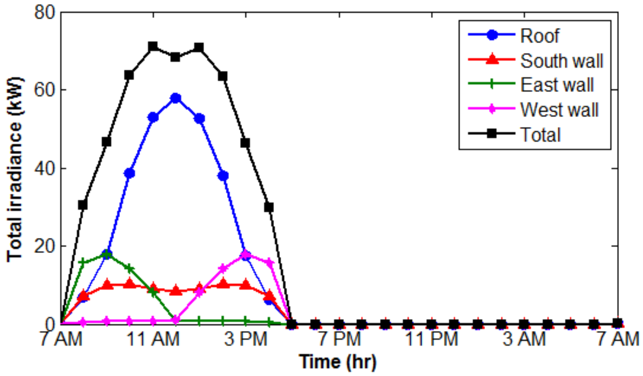
(c) Wind Speed

Fig.3. Climate conditions for a typical day in winter for Zagazig, Egypt

Figure 4 illustrates the solar radiation availability on each GH cover and total solar radiation transmitted into GH cavity. It is seen that most of solar radiation enters GH from East and West walls due to low altitude angle of solar radiation in winter. The maximum total solar radiation enters the GH is about 70 kW which make the total solar radiation per day about 2.5 kW.hr/m^2. This amount of solar radiation is close to threshold of plant requirements of solar radiation in FAO (3.14 kW.hr/ m^2.day), [8].



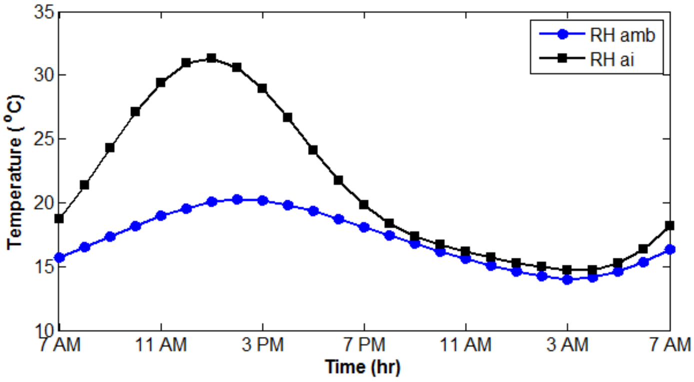
(a) Solar irradiance



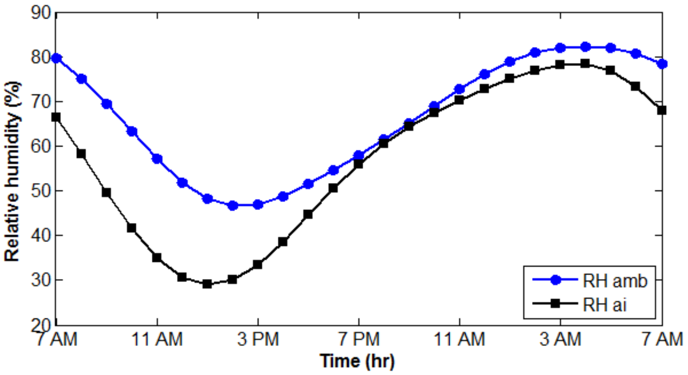
(b) Total solar radiation

Fig.4. Transmitted solar radiation into GH cavity with PVs spacing of 0.25 m, for a typical day of winter in Zagazig, Egypt

As a reference case, inlet condenser and humidifier are fully bypassed. The bypass ratio for outlet condenser is 90% and fresh air ratio is 20%. Figs.5. shows the climate conditions inside and outside the GH cavity. It seen that the mean temperature increased from 17 °C outside GH to 21 °C inside GH cavity and the mean relative humidity decreased from 67% to 57% to be within range of comfort zone of plant growth. Figs.6 and 7 illustrate water productivity, power consumption in the condenser and power generation from PV/Ts in the ground, vertical riser and inclined riser. It is seen that this system can produce about 0.25 L/m^2.day of water. This amount of water is not enough for plant growth which needs 2-8 L/m^2.day according to its type and life stage, [8]. But this water can be mixed with other brackish water to get proper salinity or can use extra water from RO unit. Power consumption in condenser is about 0.45 kW.hr/m^2.day while power generation in PV/Ts is about 0.65 kW.hr/m^2.day. That indicates that the system can be self-sufficient of electricity.



(a) Temperature



(b) Relative humidity

Fig.5. GH cavity conditions for a typical day of winter of Zagazig, Egypt

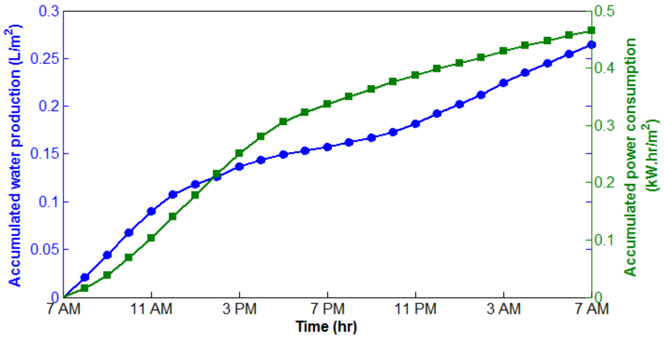


Figure 6. Water production and power consumption for a typical day of winter in Zagazig, Egypt

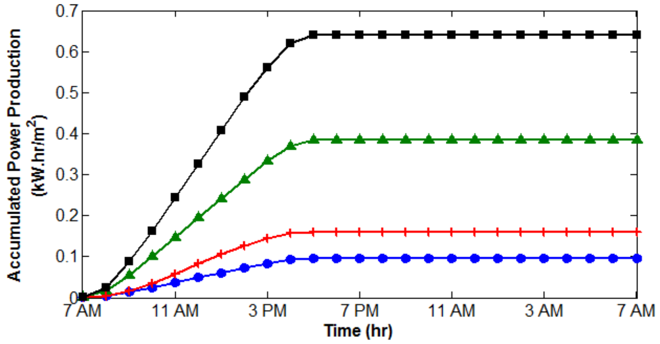


Figure 7. Power production for a typical day of winter in Zagazig, Egypt

6. CONCLUSIONS

- The results show that the system provides proper conditions for plant growth (temperature, relative humidity and solar radiation).
- The system can produce part of water required in irrigation purposes.
- The system will be self-sufficient of electricity.

7. ACKNOWLEDGMENTS

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9. APPENDICES

Appendix-A (Nomenclatures)

Parameter	**Nomenclature**
A_p	Plant área
A_i	Area of ith surface for the GH
B_c	Risers breadth
$C_{p,ai}$	Specific heat of air in GH cavity, $J/kg\ k$
COP	Coefficient of performance
h_{in}	Enthalpy at the inlet
H_N	Inner north wall height
h_{out}	Enthalpy at the outlet
hr	Hour angle
H_s	Inner south wall height
I_C	Incident global solar radiation on an inclined Surface
I_{BC}	Direct beam radiation
I_{DC}	Diffused radiation
I_i	Incident solar radiation of ith surface for the GH
I_{RC}	Reflected radiation from the ground in front of the surface.
LAI	Leaf Area Index
L	GH length
$L_{pv,h}$	Length of PV in inclined riser
$L_{pv,r}$	Length of PV in vertical riser
$L_{pv,land}$	Length of PV on the ground
M	Mass
m_a	Air mass flow rate
M_{EP}	Mass of water evaporated from plants
m_w	Mass of water condensate in condenser
m_{air}	Mass of total air passes through GH
Parameter	**Nomenclature**
w_{in}	Absolute humidity of air at inlet
w_{out}	Absolute humidity of air at outlet
m_{cond}	Mass of air passes through the condenser
P_{ai}	Pressure of air in GH cavity
$P_s(T_p)$	Saturated pressure of air at plant temperature
Q_{in}	Heat go to the component
Q_{out}	Heat exits from the component
ra	Plant aerodynamic resistance, s/m
rs	Plant stomatal resistance, s/m
S_t	Total solar radiation available on surface
T	Temperature
t	Time
T_p	Plant temperature
W	GH width
α_g	Glass absorptivity
β	Tilt angle
γ_s	Azimuth angle
γ	Psychrometric constant, 66.7 Pa/K
δ	Declination angle
τ_g	Transmissivity of glass
θ_z	Zenith angle on an inclined surface
ρ_{ai}	Density of air in GH cavity
ϕ	Latitude angle
η_{pv}	PV efficiency

Appendix-B (Inputs parameters)

Table 1 Geometrical inputs, location data and optical properties for GH components

Parameter	value	Parameter	value
W	20 (m)	L	10 (m)
H_s	2.5 (m)	H_N	4.5 (m)
$L_{pv,h}$, & $L_{pv,r}$	0.5 (m)	$L_{pv,Land}$	2 (m)
B_c	1 (m)	τ_g	0.9
ϕ	31°	α_g	0.06 [9]

Table 2 Thermal and operational inputs

Parameter	Value	Parameter	Value
LAI	3 [10]	M_p	10 (kg/m^2)
r_a	50(day) - 5000(night) (S/m) [11]	α_{gr}	0.4 [12]
r_s	250 (S/m) [11]	α_p	0.4 [13]
m_{air}	0.5 (kg/s)	COP	3.5

Appendix-C (Solar radiation model)

$$I_C = I_{BC} + I_{DC} + I_{RC} \tag{1}$$

$$I_{BC} = Ae^{-k*sec\theta_z} * cos\theta_z \tag{2}$$

$$I_{DC} = C * Ae^{-k*sec(\theta_z)} * 0.5(1 - cos\beta) \tag{3}$$

$$\begin{aligned} \boldsymbol{\theta_z = cos^{-1}}[\boldsymbol{sin\delta sin\ \phi\ cos\beta} \\ \boldsymbol{- sin\ \delta cos\ \phi sin\ \beta cos\ \gamma_s} \\ \boldsymbol{+ cos\ \delta cos\ \phi cos\ \beta cos\ hr} \\ \boldsymbol{+\ cos\ \delta sin\ \phi sin\ \beta cos\ \gamma_s\ cos\ hr} \\ \boldsymbol{+ cos\ \delta sin\ \beta sin\ \gamma_s\ sin\ hr}] \end{aligned} \tag{4}$$

$$\delta = 23.45\ sin\left(360\frac{284 + n}{365}\right) \tag{5}$$

$$S_t = \sum A_i I_i \tag{6}$$

Appendix-D (Thermal model)

$$\frac{dT}{dt} = \frac{1}{M.C_p}\left(\sum Q_{in} - \sum Q_{out}\right) \tag{7}$$

$$\dot{m}_a(h_o - h_{in}) = \left(\sum Q_{in} - \sum Q_{out}\right) \tag{8}$$

$$M_{Ep} = A_p \left(\frac{\rho_{ai} C_{p,ai}\, LAI}{\gamma}\, \frac{(P_s(T_p) - p_{ai})}{r_a + r_s}\right) / h_{fg,p} \tag{9}$$

$$\dot{m}_w = \dot{m}_{air}(w_{in} - w_{out}) \tag{10}$$

$$Cooling\ Power = \frac{\dot{m}_{cond}(h_{in} - h_{out})}{COP} \tag{11}$$

$$PV_{power} = A_i\, I_i\ \ \eta_{pv} \tag{12}$$