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INTEGRATED SOLAR GREEN HOUSE FOR WATER DESALINATION AND PLANTATION IN REMOTE ARID EGYPTIAN COMMUNITIES: MODELING AND ANALYSIS

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ABSTRACT: *Solar desalination is considered as one of the promising renewable energy-powered technology for producing fresh water. The Seawater greenhouse (SWGH) system uses the solar desalination principle and works by saturating the air with moisture vaporizing from saline water inside a greenhouse and later dehumidifying, thus, causing freshwater condensation. The SWGH is a unique concept which combines natural processes, simple construction techniques to provide a low-cost solution to one of the world's greatest needs-fresh water. It is a method of cultivation that provides desalination, cooling and humidification in an integrated system. Self-sufficiency in water production combined with low internal irrigation requirements mean that the SWGH offers significant water saving by reducing agricultural demand on main and groundwater. Its purpose is to provide a sustainable means of agriculture in arid coastal areas where the scarcity of freshwater and expense of desalination threaten the viability of agriculture.*

KEYWORDS: Solar energy, desalination, plantation, modeling, analysis, arid communities

INTRODUCTION

The basic idea in humidification–dehumidification (HDH) process is to mix air with water vapor and then extract water from the humidified air by the condenser. The amount of vapor that air can hold depends on its temperature. Some advantages of HDH units are the following: low-temperature operations, able to combine with renewable energy sources such as solar energy, modest level of technology, and high productivity rates. Using renewable energy sources in water desalination has many advantages and benefits [1]. The most common advantage is that they are renewable and cannot be depleted. They are a clean energy, not polluting the air, and they do not contribute to global warming or greenhouse gas emissions. Because their sources are natural, operational costs are reduced and they also require less maintenance on their plants. Using these resources in water desalination in remote areas also represents the best option due to the very high cost of providing energy from the grid [2]. Solar desalination has emerged as a

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promising renewable energy-powered technology for producing fresh water. Combining the principle of humidification-dehumidification with solar desalination results in an increase in the overall efficiency of the desalination plant, and therefore appears to be the best method of water desalination with solar energy [3]. The Seawater Greenhouse is a new development that produces fresh water from sea water, and cools and humidifies the growing environment, creating optimum conditions for the cultivation of temperate crops [4-5]. The Seawater greenhouse system uses the solar desalination principle and works by saturating the air with moisture vaporizing from saline water inside a greenhouse and later dehumidifying [6], thus, causing freshwater condensation. This system is suitable for coastal arid regions or inland with shortage of freshwater but access to saline/brackish groundwater to create a sustainable environment to settle communities in these arid and remote areas. In the current study, the suggestive integrated solar green house for water desalination and plantation system is included the Water desalination of fresh water from saline one that required a design of the solar water desalination units and design of solar greenhouse for plant propagation that will be integrated with a non-conventional agricultural production of a high valued organic plants, and Plant propagation of high valued plants, acclimatization of selected and high quality plants and plants free from all PCB's, traditional fertilizers or other pollutants. This will cause a protection of the environment by Reuse of treated sewage for agricultural purposes, Compost production for organic fertilizers production, Ground water protection and Decrease the health risk levels and Reduce air emissions and solid waste disposal.

MATHEMATICAL MODEL

The Integrated Solar Green House (ISGH) for Water Desalination and Plantation system shown in Figs. 1 consists of the Seawater greenhouse system (SWGHS) and solar water distillation system (SWDS). The SWGHS describes the air path from the ambient to the solar greenhouse, where an impeded solar air heater is installed at the entrance of the solar greenhouse that rises the air temperature to produce warm and dry air to be passed via across sectional area of the evaporator that made from water absorbent material. Mixing of warm dry air with warm atomized water coming from the condenser, due to the occurrence of heat and mass transfer process, the humid air is passed across the greenhouse plantation area prior condensed on the condenser cold surface.

The condensate water is accumulated on a storage tank. The second part of the SWDS consists of two identical solar distillers. While the high salinity water outlet from the solar stiller can be accumulated in a solar pond which can be used as heating source either for water heating source through heat exchanger or the heating capacity can be used for operating water absorption refrigerating system to enhance the condenser cooling process and consequently increases the productivity of distilled water.

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Design of solar water distillation system: The performance of solar still shown in Fig. 2 is based on productivity, efficiency as well as internal heat and mass transfer coefficient. Hence the performance is directly proportional to the internal heat transfer coefficient and distillate output from solar still. Internal heat and mass transfer coefficients in the solar still are based on three parameters named convection, radiation and evaporation, respectively. Consequently; there are three heat transfer coefficients namely; convective, radiative and evaporative heat transfer coefficients [7-13]:

a- Convective heat transfer (CHT):

Action of buoyancy force due to density difference of humid air and temperature difference accordingly is the major reason behind the CHT coefficient in solar still. The CHT coefficient of water surface to be condensed upon glass cover is given by:

$$q_{cw} = h_{cw}\left(T_w - T_g\right) \tag{1}$$

While, heat transfer coefficient h_{cw} can be calculate by following equation [14]:

$$h_{cw} = 0.884\left[\left(T_w - T_g\right) + \frac{\left(P_w - P_g\right)\left(T_w + 273\right)}{\left(268.9\times10^3 - P_w\right)}\right]^{1/3} \tag{2}$$

Where P_w and P_g are the vapor pressures at water and at glass temperatures respectively, given by:

$$P_w = 0.14862\,T_w - 0.36526\times10^{-2}T_w^2 + 0.11242\times10^{-3}T_w^3 \tag{3}$$

$$P_g = 0.14862\,T_g - 0.36526\times10^{-2}T_g^2 + 0.11242\times10^{-3}T_g^3 \tag{4}$$

b- Radiative heat transfer:

The rate of radiative heat transfer from water surface to condensing cover is given by:

$$q_{rw} = h_{rw}\left(T_w - T_g\right) \tag{5}$$

$$q_{rw}=\varepsilon_{eff}\,\sigma\,[\,(T_w+273)^4 - (T_g+273)^4] \tag{6}$$

Radiative heat transfer coefficient h_{rw} is given by [15]:

$$h_{rw} =\varepsilon_{eff}\,\sigma\,[\,(T_w+T_g+546)]\,[\,(T_w+273)^2+(T_g+273)^2] \tag{7}$$

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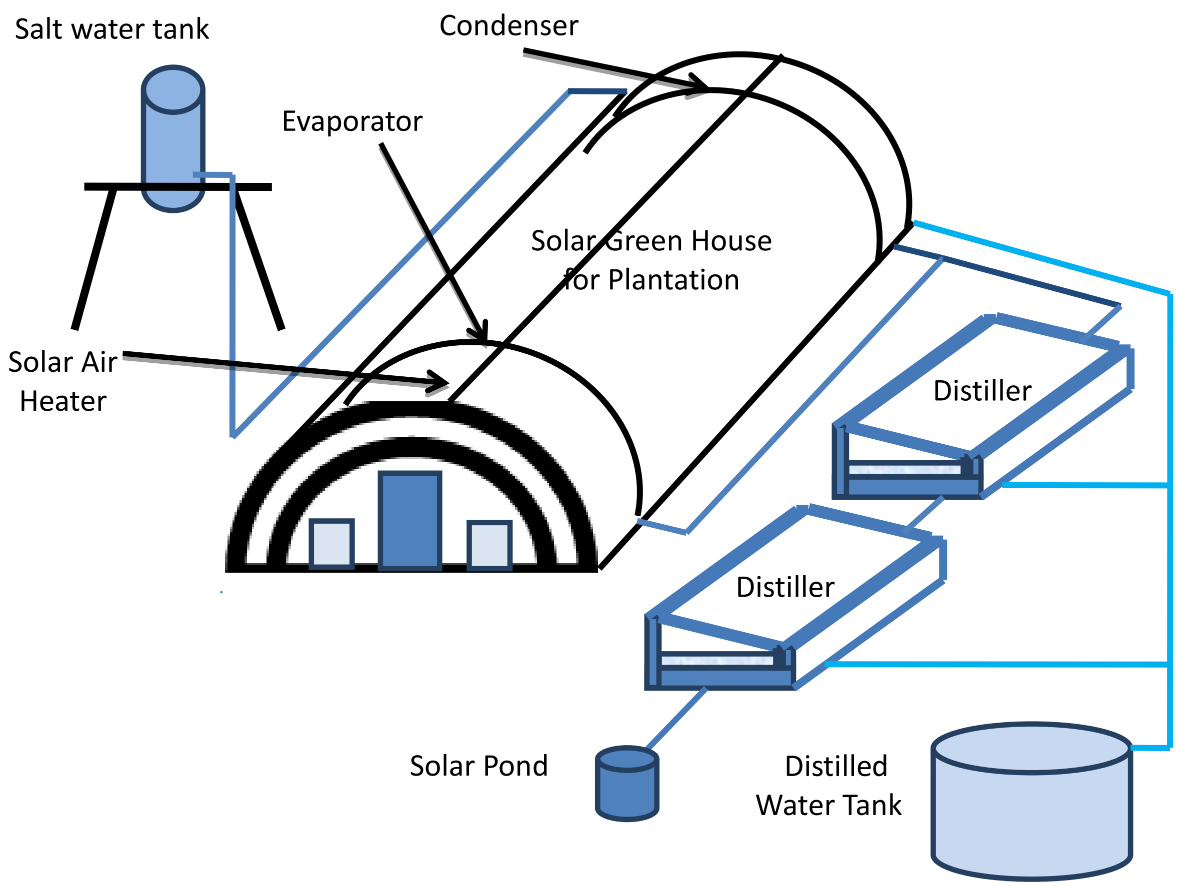

Figure 1. Integrated layout Solar Green House (ISGH) for Water Desalination and Plantation system

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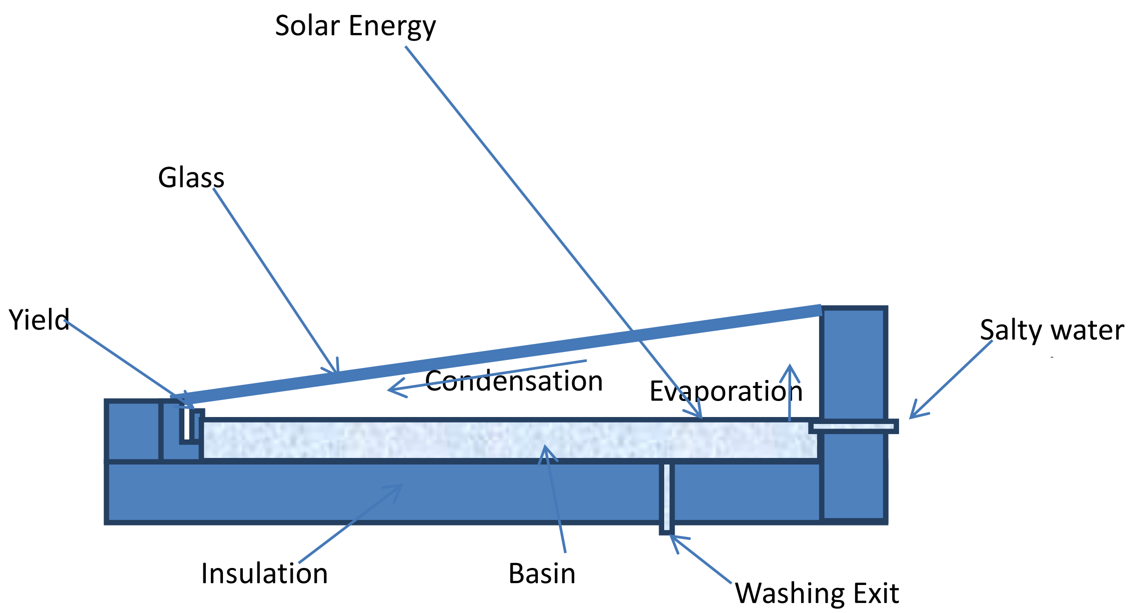

Figure 2. Schematic Layout of the solar distiller

Where

$\sigma = 5.669\times10^{-8} \quad W/m^2 K^4$

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1\right)^{-1}$$

$\varepsilon_g = \varepsilon_w = 0.9$

c- **Evaporative heat transfer:** When solar energy is incident inside the solar still, water evaporates and converted into vapor. Hence, evaporative heat transfer is given by the following equations [16]:

$$q_{ew} = h_{ew}\left(T_w - T_g\right) \quad (8)$$

Evaporative heat transfer coefficient is given by

$$h_{ew} = 16.27\times10^{-3} \times h_{cw} \times \frac{\left(P_w - P_g\right)}{\left(T_w - T_g\right)} \quad (9)$$

The total heat transfer coefficient from water surface to condensing cover is given by following equation

$$h_{tw} = h_{cw} + h_{rw} + h_{ew} \quad (10)$$

Energy balance: When solar energy is incident inside the water basin, heat transfer mechanism starts. Figure 3 shows the energy flow in single slope single basin solar still. Energy balance equations can be written with following assumptions:

1. There is no vapor leakage in solar still units.
2. It is an air tight basin, hence no heat loss.
3. Heat capacity of cover and absorbing material, insulation is negligible.
4. There is no temperature gradient across the water basin and glass cover of solar still.
5. Water level inside the basin maintained at constant level.
6. Only film type condensation is occurred in place of drop type condensation.

Energy balance for glass cover:

$$M_g Cp_g \frac{dT_g}{dt} = \alpha_g I(t) + q_{rw} + q_{cw} + q_{ew} - q_{cga} - q_{rga} \quad (11)$$

Where

$$q_{cga} = h_{cga}\,(T_g - T_a)$$

$$h_{cga} = 5.7 + 3.8V$$

Where V is the wind speed, m/s [17]

$$q_{rga} = \varepsilon\sigma\,(T_g + 273)^4 - (T_{sky} + 273)^4$$

$$T_{sky} = T_a - 6$$

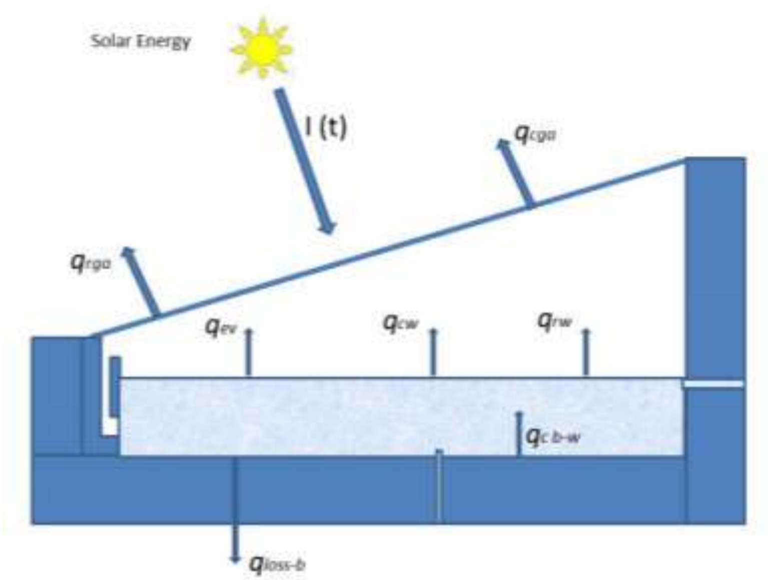

Figure 3. Energy Balance of the solar distiller

Energy balance for water basin:

$$M_w Cp_w \frac{dT_w}{dt} = \alpha_w I(t) + q_{c\,b\_w} - q_{cw} - q_{ew} - q_{rw} \quad (12)$$

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Where

$$q_{cb\_w} = h_{cb\_w}(T_b - T_w) \tag{13}$$

Energy balance for basin:

$$M_b Cp_b \frac{dT_b}{dt} = \alpha_b I(t) - q_{cb\_w} - q_{loss\_b} \tag{14}$$

Where

$$q_{loss\_b} = K_b / L_b (T_b - T_{insulation}) \tag{15}$$

Hourly yield of solar still is given by

$$m_w = \frac{q_{ev}}{L} \times 3600 \tag{16}$$

Where

L Latent heat of vaporization J/kg

Efficiency of solar still is given by

$$\eta = \frac{q_{ev}}{I(t)} \tag{17}$$

RESULTS AND DISCUSSION

Based on the above mathematical model and considering the temperature variations of the ambient temperature, sky temperature, water basin temperature and glass cover temperature are shown in Fig. 4. While the convective, radiative, and evaporative heat transfer coefficients, as well as the total heat transfer coefficient of the solar still are shown in Fig. 5. The calculated water condensate as hourly variation is shown in Fig. 6.

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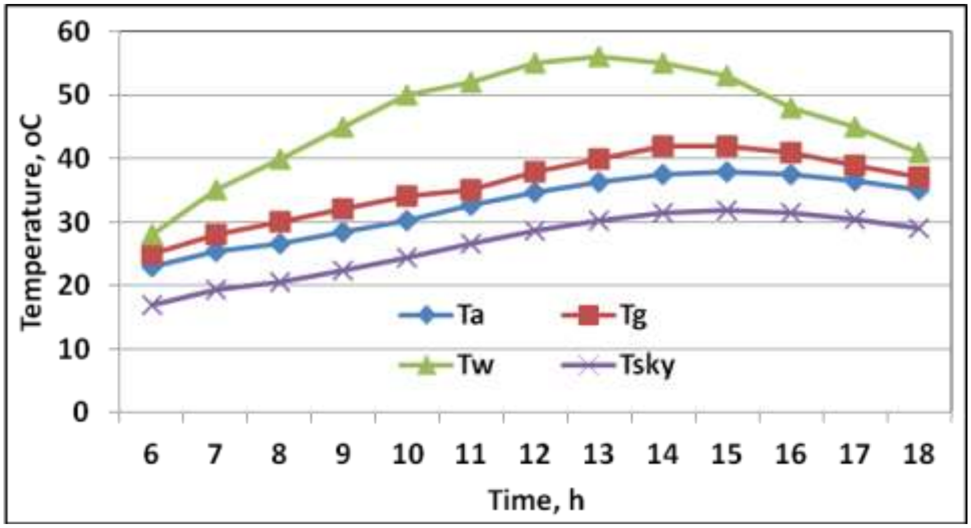

Figure 4. Hourly temperature variations of the solar still parameters

It is found that the integrated amount of water condensate is 6 L/m^2/day. Based on the average solar radiation falling on the horizontal surface in Cairo is 5.5 kWh /m^2 /day and the calculated daily productivity of the distilled water is 6 L/m^2/day. It is estimated that the water load required from the proposed solar distillation system as 18 L/day, then the solar distillation system is designed to make two solar distillers; each has 1.5 m^2 basin areas and can be sized as shown in Fig. 8.

Design of Seawater solar Humidification and Dehumidification greenhouse system

The SWGHS describes the air humidification and dehumidification cycle inside the greenhouse. The ambient air was entered through the air opening at the greenhouse inlet.

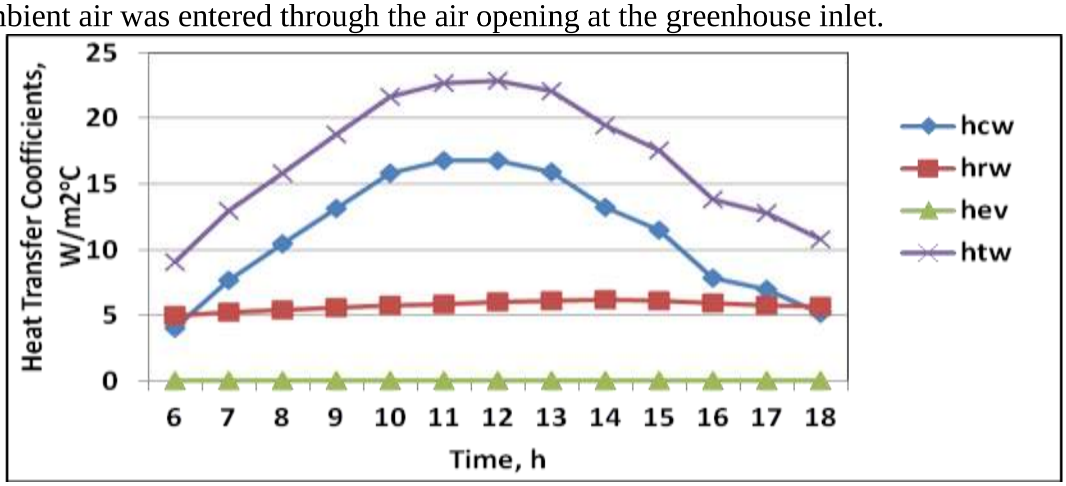

Figure 5. Hourly convective, radiative, and evaporative heat transfer coefficients variations

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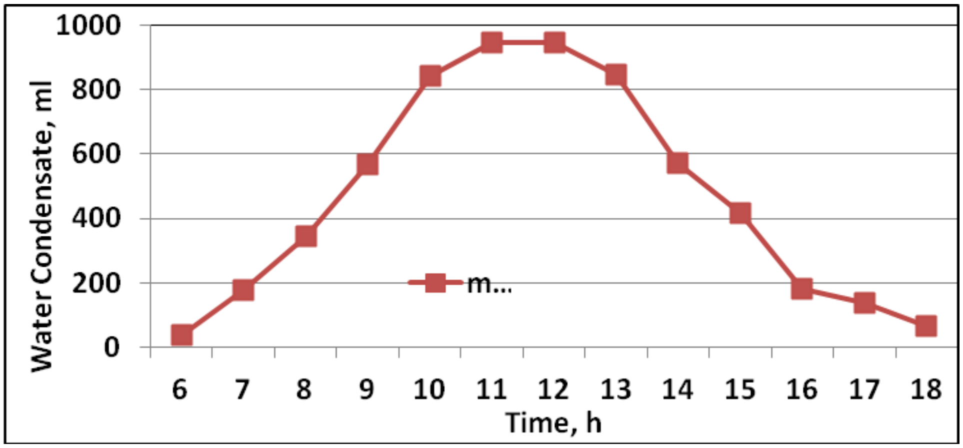

Figure 6. The hourly variation of the calculated water condensate

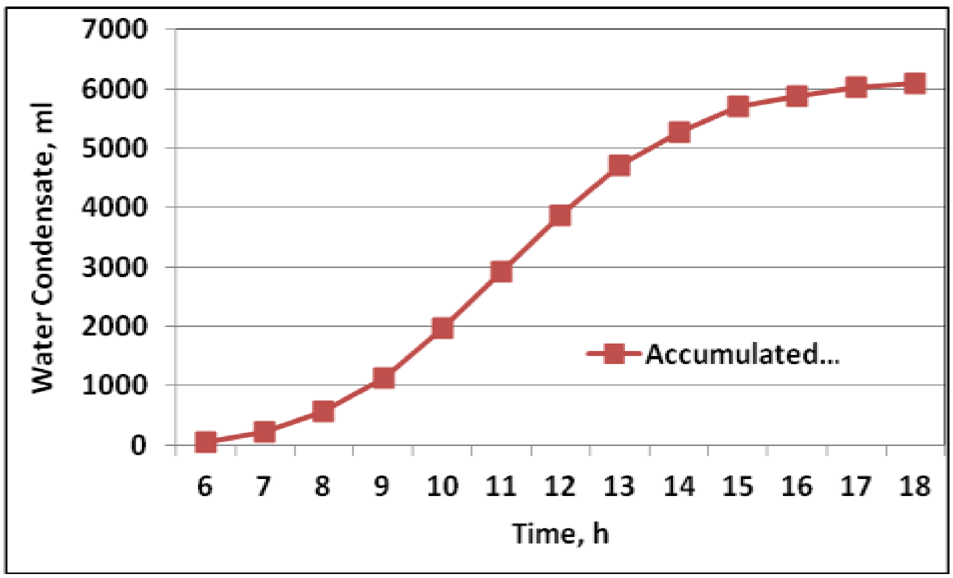

Figure 7. The hourly variation of the calculated accumulated water condensate

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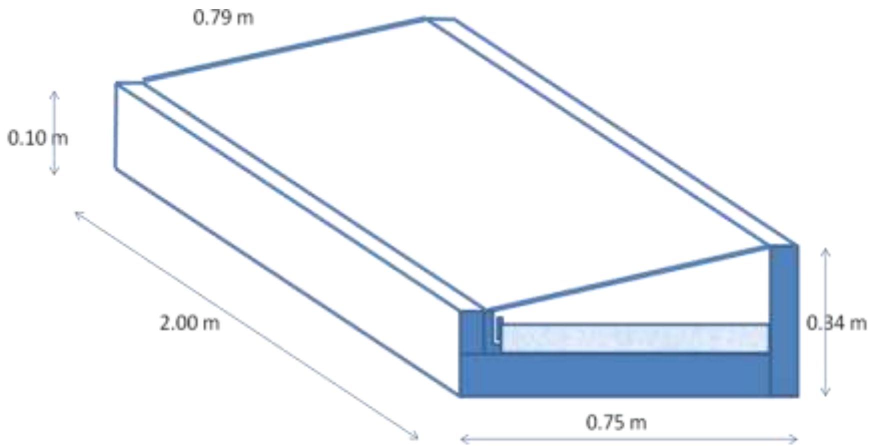

Figure 8. Schematic Layout of the designed solar distiller

Then passing through a built in solar air heater, consequently its temperature increased and humidity decreased. The hot dry air is passed across the evaporator wet surface and outlet as humid air that pass through the greenhouse plantation area prior condensed on the condenser cold surface. Finally, the condensed water is accumulated in the stilled water tank. The air humidification and dehumidification cycle is shown in Fig. 9. The ambient dry and wet bulb temperatures (DBT, WBT) in Cairo in a typical day of August along with its relative humidity (RH) are shown in Fig. 10. While the air heat and mass transfer process can be studied by using the air psychometric chart which describes the air properties inside the solar greenhouse. A sample of the sensible heating process inside the solar air heater and the evaporative cooling process inside the solar greenhouse plantation system is shown in Fig. 11

The amount of air flow rate inside the solar greenhouse is estimated based on the air change per minute, ACM, inside greenhouse equal 1. But in the current study, as the greenhouse is planned to be manufactured from metal frame and covered with transparent plastic sheet, then the ACM is considered to be equal 0.5. Consequently, the air volume flow rate is calculated by multiplying the air change per minute by the volume of the greenhouse as follows:

$$\dot{Q}_a = ACM \times VOLUME = 0.5 \times 37.68 = 18.84 \quad m^3/\min$$

Then the air mass flow rate can be calculated as

$$\dot{m}_a = \rho_a \times \dot{Q}_a = 1.2 \times 18.84 = 22.61 \quad kg_a/\min$$

The condensate water flow rate is estimated by multiplying the air mass flow rate by the difference of the air moisture ratio as follows:

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$$\dot{m}_w = \dot{m}_a \quad (\Delta\omega) \quad kg_w / \min$$

$$\dot{m}_w = 22.61 \times (0.0195 - 0.0139) = 0.127 \quad kg_w / \min = 7.62\, kg_w / h$$

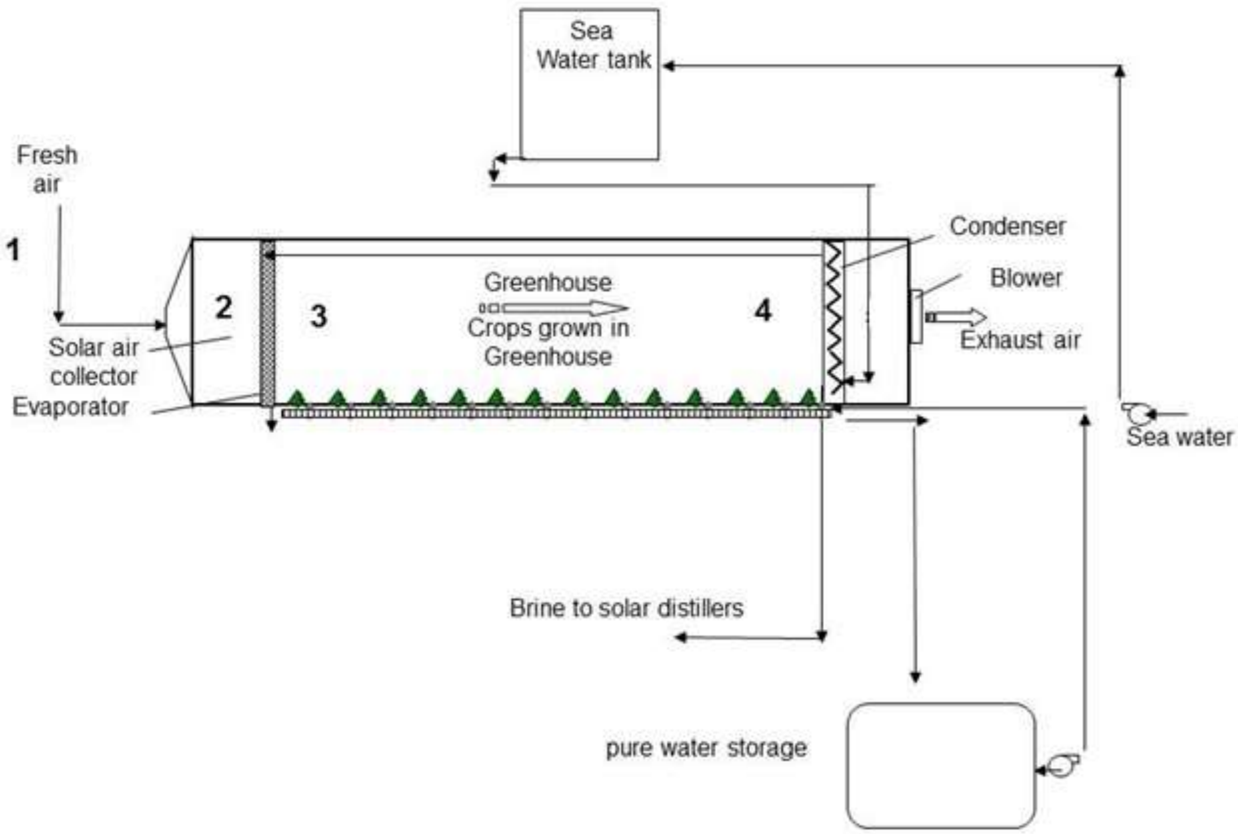

Figure 9. Humidification and Dehumidification Air cycle

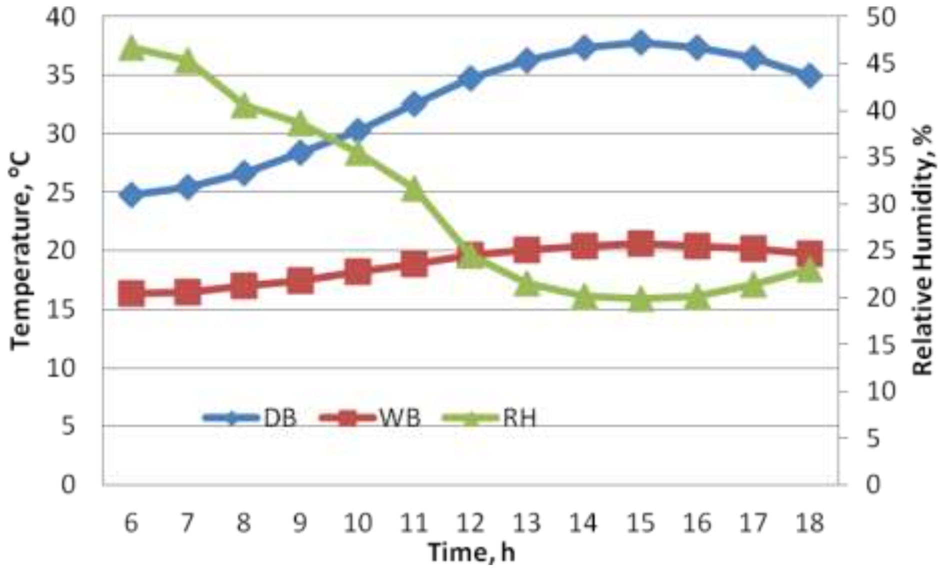

Figure 10. The ambient dry and wet bulb temperatures and relative humidity variation in a typical day of August in Cairo

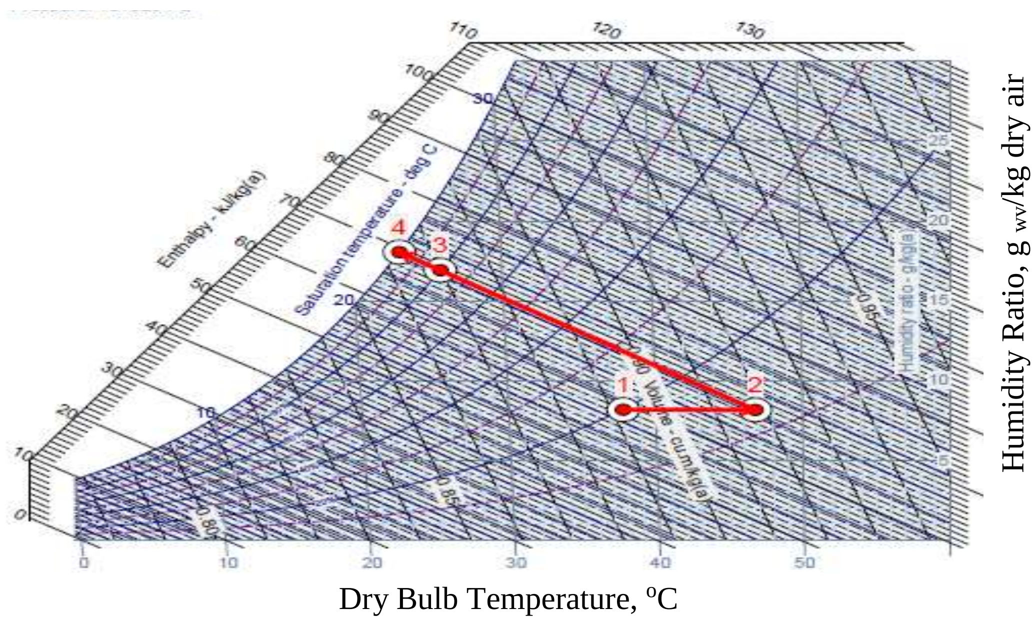

Figure 11. The air heat and mass transfer process on the air psychometric chart

By applying the data of the ambient dry and wet bulb temperatures (DBT, WBT) in Cairo in a typical day of August shown in Fig. 6, on the air psychometric chart and studying the air heat and mass transfer process for each hour from 6 am to 6 pm the amount of distilled water outlet

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from the system is calculated and can be represented in Fig. 8. The accumulated amount of distilled water is found to be 135 l/day.

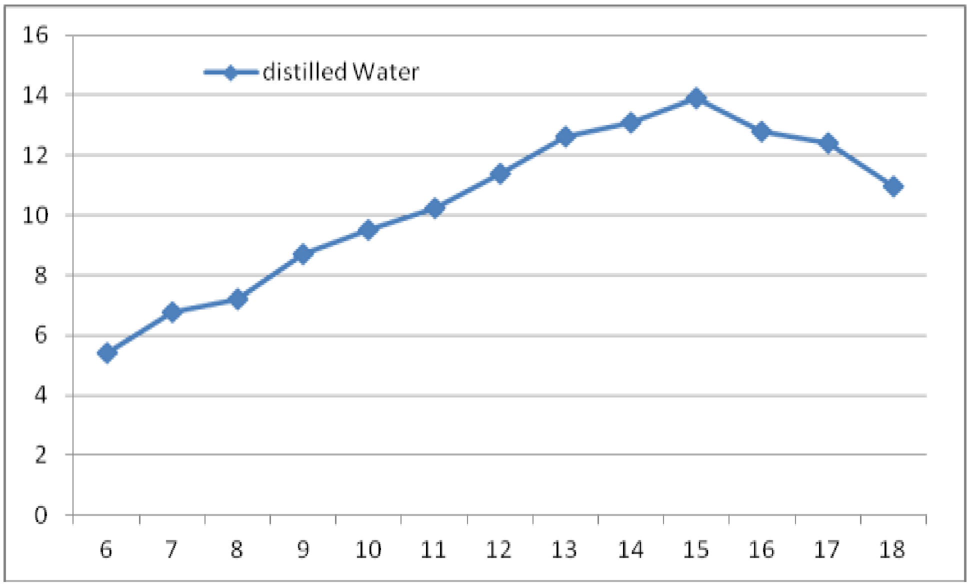

Figure 12. The hourly distilled water variation outlet from the solar greenhouse system

IMPLICATION TO RESEARCH AND PRACTICE

The proposed system can be used developing such communities suffer from the water shortage problem. It contributes also for living in a clean environment and maximizing its benefits as the outlet saline water can be accumulated in a solar pond which can be used as heating source either for water heating source through heat exchanger or the heating capacity can be used for operating water absorption refrigerating system to enhance the condenser cooling process and consequently increases the productivity of distilled water.

CONCLUSION AND RECOMMENDATIONS

The Integrated Solar Green House for Water Desalination and Plantation system is presented to be demonstrated in its actual marketing size to develop Egyptian Communities in Remote Arid areas. Fresh water can be produced by humidification and dehumidification technique inside the solar greenhouse system and also by using solar distillers. It is found that the amount of fresh water produced from the integrated system is 153 l/day; the Seawater solar Humidification and

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Dehumidification greenhouse system produced 135 l/day while the solar distillation system produces 18 l/day.

Nomenclature

A	=	area , m^2
CHT	=	convective heat transfer
Cp_b	=	specific heat of basin, J/K
Cp_g	=	specific heat of glass, J/K
Cp_w	=	specific heat of water, J/K
h_{cbw}	=	convective heat transfer coefficient between basin and water, W/m^2K
h_{cga}	=	convective heat transfer coefficient between glass and air, W/m^2K
h_{cw}	=	convective heat transfer, W/m^2K
HDH	=	humidification–dehumidification
h_{ew}	=	evaporative heat transfer coefficient, W/m^2K
h_{rw}	=	radiative heat transfer coefficient, W/m^2K
$I(t)$	=	Incident solar radiation, W/m^2
$I_{nsulation}$	=	insulation temperature, ^oC
ISGH	=	Integrated Solar Green House
K_b	=	Thermal conductivity of the basin material, W/m K
L	=	Latent heat of vaporization J/kg
L_b	=	Basin thickness, m
M_b	=	Mass of basin, kg
M_g	=	Mass of glass, kg
M_w	=	Mass of water, kg
m_w	=	Hourly yield of solar still, kg
P_g	=	vapor pressures at glass temperature, Pa
P_w	=	vapor pressures at water temperature, Pa
Q	=	heat transfer rate, W
q_{cbw}	=	Convective heat transfer between basin and water, W/m^2K
q_{cga}	=	Convective heat transfer between glass and air, W/m^2K
q_{cw}	=	Convective heat transfer, W
q_{ew}	=	evaporative heat transfer, W
q_{loss_b}	=	Convective heat transfer between basin and ambient, W/m^2K
Q_{rga}	=	Radiative heat transfer between glass and air, W/m^2K
q_{rw}	=	radiative heat transfer, W
SWDS	=	solar water distillation system
SWG	=	Seawater greenhouse
SWGHS	=	Seawater greenhouse system
t	=	time , h
T	=	temperature (K)

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T_a	=	ambient temperature, °C
T_b	=	basin temperature, °C
T_g	=	glass temperature, °C
T_{sky}	=	Sky temperature, °C
T_w	=	Water temperature, °C
V	=	Wind speed, m/s
ε_{eff}	=	effectiveness
σ	=	Stefan-Boltzman constant (W/K^4m^2)
α	=	absorptance, absorptivity
η	=	efficiency

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