Greenhouse Heating Systems Based on Geothermal Energy

F. Fahmy, D. Atia, H. El Madany, and H. Farghally

Abstract— Geothermal energy is one of the most important energy resources for electricity generation and is also used directly in heating, food and agriculture, aquaculture and some industrial processes. This paper presents a design of a greenhouse using a renewable energy resources for the thermal heating and electrical requirements for its operation. Photovoltaic , wind and geothermal energy are used for improve efficiency of crop production. In Egypt, the Suez Gulf is rich of geothermal springs. Ras Sedr is the site under consideration for chilli production, the required temperature is between 25-35 ^{o}C. There are several methods for greenhouse heating systems using geothermal energy which are finned pipe, standard unit heaters, low temperature unit heaters, fan coil units, soil heating, and bare tube. The economical analysis of thermal and electrical is done.

The PV-wind hybrid system is proposed for greenhouse heating system which contains of (0.5 kW) photovoltaic arrays, (6 kW) wind turbines, one battery storage, inverter and charge regulator subsystems with levelized cost of energy of 0.114 $/kWh.

Keywords—Agriculture, geothermal energy, heating system photovoltaic, renewable energy.

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I. Introduction

Geothermal energy has the potential to provide long-term, secure base-load energy and greenhouse gas (GHG) emissions reductions [1, 2]. Accessible geothermal energy from the Earth's interior supplies heat for direct use and to generate electric energy. Direct use provides heating and cooling for buildings including district heating, fish ponds, greenhouses, bathing, wellness and swimming pools, water purification/desalination, and industrial and process heat for agricultural products and mineral extraction and drying [3-5]. Agriculture applications are particularly attractive because they necessitate heating at the lower end of the temperature range where there is a plenty of geothermal resources. Using geothermal energy for greenhouse heating reduces operating costs and permits operation in colder weathers where commercial greenhouses would not normally be economical [6, 7].

The technology of producing crops in greenhouses has been around for decades. Greenhouse agriculture is a growing trend around the world, and crops grown under these conditions are in high demand. Greenhouse has several advantages such as providing cultivators with the ability to accomplish significantly higher yields than open field production, using less land area compared to open field production and using water resources efficiently [8]. Also it declines the using of chemicals to control pests and diseases. Moreover, greenhouses enable a higher quality of products suitable for international markets, it needs less labors than open field production and allows extending period of the crop production [9-11].

This paper presents a design of electrical and thermal subsystems of a greenhouse using solar, wind, and geothermal energy respectively. The analysis of the electrical energy requirements of the greenhouse has been done using HOMER software. The peak heating requirements are calculated to select the appropriate heating system for a greenhouse. Comparison between the geothermal heating systems using analytical and software methods are introduced. Finally, a techno-economic analysis of the sustainable energy supply of the heat and electricity for the greenhouse has been done.

II. Greenhouse Specification

Chilli is selected as the plant under consideration. Chilies are excellent source of vitamin, A, B, C and E with minerals like molybdenum, manganese, folate, potassium, thiamin, and copper. Also chilli is used as a spice, flavour pungent, preserving material. In addition, chilli is used as tonic to ward off many diseases as it activates stomach, eliminates colic and abdominal cramps and pain stopping from the teeth and gums, postate cancer treatment.

For the suggested greenhouse, a combination of fiberglass and plastic film material is used, the greenhouse is arched roof type and the roof is constructed with double poly and the walls are made of fiberglass. The frames of the greenhouse are constructed from aluminum which is relatively light in weight and at the same time very strong. It is malleable, adaptable, water proof and nonpoisonous. It does not rust or erode and conducts heat and electricity [13]. The proposed greenhouse

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specifications and dimensions are indicated in Table 1.

Table 1. Proposed greenhouse specification and dimension.

Length	**45 m**
Width	9 m
Height	4 m
Roof area	418 m^2
Wall area	420 m^2
Volume	1620 m^3
Shape	Arched roof
Side and end wall material	Fiberglass
Frame material	Aluminum
Roof material	Double poly

III. Greenhouse System Design

Greenhouse system is divided into two subsystems which are electrical and heating subsystem. The two subsystems are designed and discussed in details in the following sections.

IV. Electrical Subsystem Design

The Hybrid Optimization Model for Electric Renewable (HOMER) software has been used to perform random selection of sizing and operational strategy of generating system in order to obtain the finest solution of hybrid renewable energy with lowest total net present cost [14-16]. Thus, the information required for this analysis was collected based on the load profile, average monthly wind speed and solar radiation. Ras Sedr is an Egyptian town located on the Gulf of Suez and the Red Sea coast. It is a part of the South Sinai governorate. Ras Sedr is 200 km from Cairo. Ras sedr is located at the latitude and longitude of 29^o 25' N, and 32o 47' E respectively. The daily average radiation and wind speed data are given by Fig. 1 and Fig. 2 respectively [17]. The solar radiation in Ras Sedr (latitude 32^o 47' East and longitude 29^o 25' North) is between 3.58 kWh/(m^2 day) and 8.15 kWh/(m^2 day). The wind speed is between 5.6 m/s and 9.2 m/s. For the greenhouse system, it is required for the designer to stay near the system so a small house is designed for the labors of greenhouse. The electrical load consists of circulating pump, valves, controller, energy saving lamps, fans, refrigerator, washing machine, and television. The monthly load profile is shown in Fig. 3. From the load profile, the peak load is about 1.83 kWh with average energy consumption of 29.1 kWh/day.

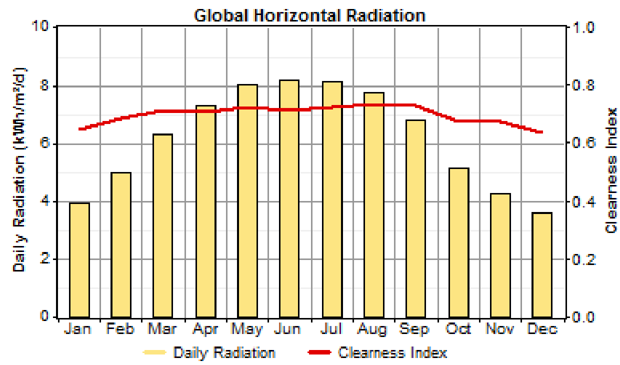

Fig. 1. Monthly average solar irradiance variation over the year.

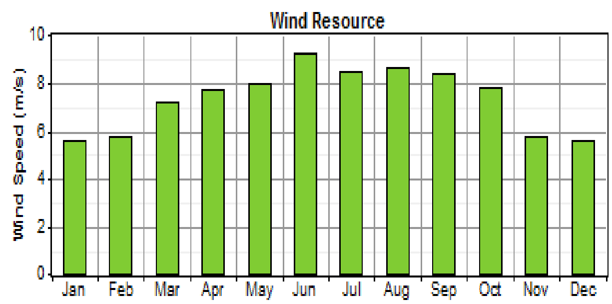

Fig. 2. Monthly average wind speed variation over the year.

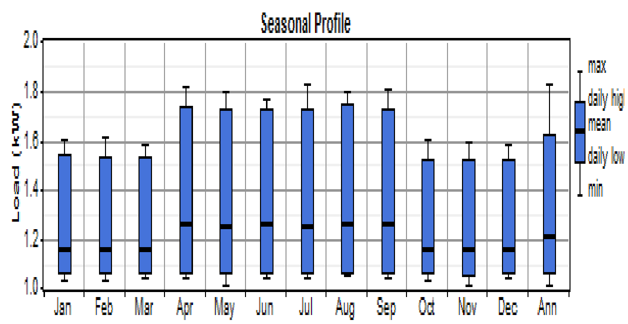

Fig. 3. Monthly average variation of electrical load over the year.

V. Heating Subsystem Design

The proposed greenhouse heating system is shown in Fig. 4. The heat exchanger is required to separate actual heating equipment from the geothermal fluid. The heating system is used to compensate the heat loss in the greenhouse. The greenhouse heat loss is composed of two components which are transmission heat losses (through the walls and roof), and infiltration heat losses caused by outside cold air as shown in Fig. 5. The total transmission heat losses can be estimated as follows [18- 21]:

$$q_t = \left(A_1 \Delta T_d U_1 + A_2 \Delta T_d U_2\right) \quad (1)$$

The air change method is the general method for the calculation of infiltration heat losses. The method is based upon the number of times per hour (ACH) that the air in the greenhouse is replaced by cold air leaking from outside. The infiltration heat losses are calculated as [20, 21]:

$$q_i = 0.018 \times ACH \times V \times_t \Delta T_d \qquad (2)$$

The total heat loss can be calculated by addition of transmission heat loss and infiltration heat loss as follows:

$$q = q_t + q_i \qquad (3)$$

The greenhouse heating load variation during the year is given by Fig. 6. In winter season, the heating load is higher than that of summer due to the difference between inside and outside design temperature.

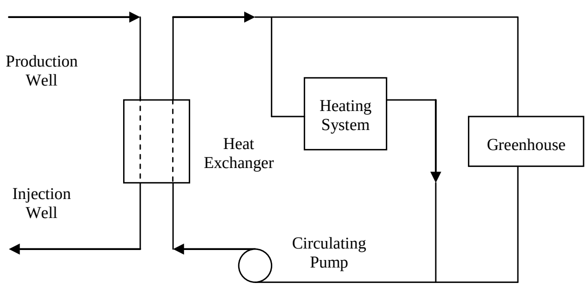

Fig. 4. Proposed greenhouse heating system.

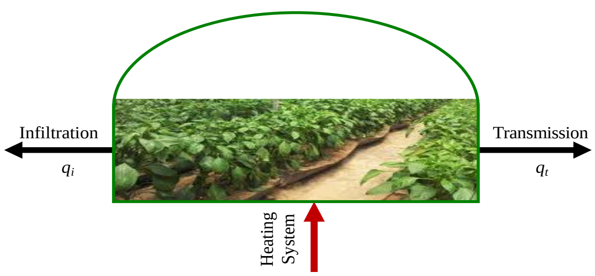

Fig. 5. Energy transfer through the proposed greenhouse.

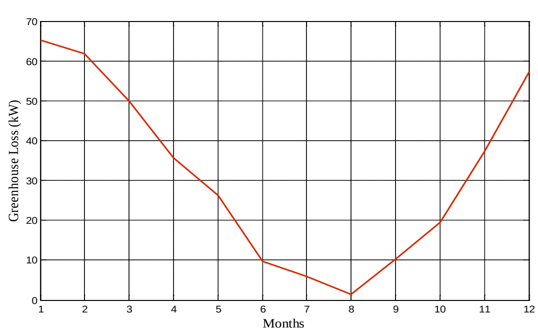

Fig. 6. Monthly average variation of thermal load over the year.

VI. Heating Subsystem Modeling

Conventional greenhouse heating systems can take a wide variety of configurations (unit heater, fan coil unit, bare tube, finned pipe, etc.). There are basically six different heating systems which are applied to greenhouses finned pipe, standard unit heaters, low-temp unit heaters, fan coil units, soil heating, and bare tube systems.

A. Finned pipe

A finned pipe is usually constructed of steel or copper pipe with steel or aluminum fins attached to the outside wall. These fins can either be circular, square or rectangular in shape. In the size range employed in greenhouses, a steel pipe with steel fins is most common. Finned elements are generally installed along the long dimension of the greenhouse adjacent to the outside wall.

The capacity of finned pipe is indexed to average water temperature, not supply water temperature. The temperature drop is calculated according to the following relationship [20, 21]:

$$\Delta T = \frac{q}{\left(c_p \times m\right)} \qquad (4)$$

Where ΔT is the temperature drop (^oC), q is the heating requirement (W), c_p is the specific heat (J/Kg^{o}C), m is the flow rate (kg/s).

The average water temperature (*AWT*) is calculated as a function of supply temperature (T_s) as follows [20, 21]:

$$AWT = T_s - \left(\Delta T / 2\right) \qquad (5)$$

The required element length can be calculated as a function of actual capacity (AC) as follows:

$$L_f = \frac{q}{AC} \qquad (6)$$

B. Standard unit heaters

Unit heaters consist of a finned coil and small propeller fan contained in a pre-designed unit. These units are available in either horizontal or vertical configurations and are generally hung from the greenhouse structure at roof level. Air is discharged either directly into the greenhouse or into a perforated plastic distribution tube [20].

C. Fan Coil

These units are very similar to standard unit heaters discussed previously. It consists of a finned coil and a centrifugal blower in a single cabinet. In the fan coil system, the coil is much thicker and usually has closer fin spacing than the coil in a unit heater. Unit heaters generally have only one or two coil rows. The added surface area allows more effective heat transfer, resulting in the ability to extract more heat from the water [20].

D. Soil Heating

The soil heating system uses the floor of the greenhouse as a large radiator to supply the heat needed by the greenhouse. Warm water is circulated through a buried tubes in the greenhouse floor. Heat from the warm water is transferred through the tube to the soil and eventually, to the air in the greenhouse. The most popular tube material is polybutylene where the corrosion and expansion problems of steel material are avoided. The heat output of the floor is a function of a floor surface temperature, greenhouse air temperature and average temperature of unheated surfaces in the greenhouse. Heat output from the floor occurs by two mechanism, convection and radiation. The required floor surface temperature is calculated as [21]:

$$\frac{q}{A} = 0.472 \times \left[\left(\frac{1.8T_f + 492}{100} \right)^4 - \left(\frac{1.8AUST + 492}{100} \right)^4 \right] + 2.186\left(T_f - T_a\right)^{1.32} \tag{7}$$

$$IST = IDT - \left(0.0756\, \mathrm{U}\Delta T\right) \tag{8}$$

$$AUST = \left(A_1 \times IST_1 + A_2 \times IST_2\right) / \left(A_1 + A_2\right) \tag{9}$$

Where T_f is the floor surface temperature (^{o}C), T_a is the indoor air temperature, IST is the inside surface temperature (^{o}C), IDT is the inside design temperature (^{o}C), ΔT is the design temperature difference (^{o}C), $AUST$ is the average temperature of unheated surfaces in the greenhouse (walls and roof) (°C), A is the surface area of the glazing material (m^2).

The pipe length can be calculated as follows [21]:

$$L_s = \frac{q \times \ln\left[\left(8\left(\frac{H}{d}\right)^2 - 1 \right) + 4\left(\frac{H}{d}\right) \times \sqrt{4 \times \left(\frac{H}{d}\right)^2 - 1} \right]}{4\pi\lambda_j t_m} \tag{10}$$

$$t_m = \frac{\left(T_{wt} - T_{wo}\right)}{\ln\left(\frac{T_{wt} - T_p}{T_{wo} - T_p} \right)} \tag{11}$$

The pipes are arranged parallel to the greenhouse length to obtain homogeneous temperature distribution. The number of pipes (n) is determined by [21]:

$$n = \frac{L_s}{L_{g.h}} \tag{12}$$

Where L_s is the pipe length (m), H is the pipe burial depth (floor surface to pipe) (mm), d is the pipe outside diameter (mm), λ_j is the earth heat conductivity (W/m °C), t_m is the log mean temperature difference (°C), T_{wi} is the water inlet temperature (°C), T_{wo} is the water outlet temperature (°C), T_P is the floor surface temperature (°C), $L_{g.h}$ is the greenhouse length.

E. Bare tube system

The bare tubes can be installed either on the floor or suspended under benches. The tubes are made of a small diameter polybutylene material. The pipe length can be calculated using the following equations as below [21]:

$$T_s = T_g - 10 \tag{13}$$

$$AWT = T_s - \left(\Delta T / 2\right) \tag{14}$$

$$\frac{q}{L_b} = \left(\left(1.016 \times \left(1/D\right)^{0.2}\right) \times \left(1/T_{avg}\right)^{0.181} \times \left(dT^{1.266}\right)\right) + \left(\left(15.7 \times 10^{-10}\right) \times \left(T_1^4 - T_2^4\right)\right) \times ft^2 / lfpipe \tag{15}$$

$$T_{avg} = 460 + \left(AWT + T_a\right)/2 \tag{16}$$

$$dT = AWT - \left(T_a + 3\right) \tag{17}$$

$$T_1 = AWT + 460 \tag{18}$$

$$T_2 = 460 + T_3 \tag{19}$$

$$T_3 = \left(AUST + T_a\right)/2 \tag{20}$$

Where D is the tube outside diameter (ft), A_o is the outside surface area of pipe / unit length (m^2/m), L_b is the pipe length (ft), q is the heating Load (Btu/hr), T_{wi} is the heating water supply temperature (^{o}C), T_a is the greenhouse design air temperature (^{o}C), T_s is the supply temperature (^{o}C), T_g is the geothermal resource temperature (^{o}C).

F. Low temperature unit heater

Low temperature unit heaters are similar to standard unit heaters but their design is optimized for low-water temperature operation. These units incorporate a more effective water coil and a higher capacity fan. Low temperature unit heaters are larger and heavier than standard unit heaters. These units are horizontal in configuration and use a propeller fan type [20].

VII. Geo Heat Centre Software Method

The Geo-Heat Center recently developed a greenhouse information package that provides background information for developers of geothermal greenhouses. The package includes crop market prices, greenhouse operating costs, crop culture information, greenhouse heating system specifications, a greenhouse heating equipment selection spreadsheet, and vendor information [20]. Seven systems are included in the package which are Unit Heaters (UH), Finned Pipe (FP), Bare Tube (BT), Fan Coil units (FC), combination Fan Coil/Bare Tube (FC/BT), low-temperature unit heaters (GLW), and Propane unit heaters (PP).

VIII. Results Discussion

Ras Sedr -2 well is used as a heating source for the suggested greenhouse. Ras Sedr -2 well has a moderate water temperature of 70 ^oC [22]. The analytical method results are given by Table 2. For the finned pipe heating system, the required heating element length is calculated using Eq. 7. To meet the heating load requirements, the UH and FC heating system is chosen from standard unit specification. According to soil heating system, the floor surface temperature is calculated firstly using Eq. 8. The total pipe length required to heat the soil of the greenhouse is determined using Eq. 11. For bar tube heating, the pipe length is determined using Eq. 16. Two types of GLW unit heater are considered which are one fan and two fans. The capacity and number of unit used is determined according to the standard unit specifications.

For the software method, the primary inputs contain the supply water temperature, greenhouse size and construction materials, and economics data [20]. The degree days (DD) can be calculated using the average daily temperature [23]. For Ras Sedr, the DD variation over the year is estimated as given in Table 3. The average DD in winter and summer are 1900 and 582 respectively. The inputs for Geo-Heat Center software and peak heat loss of the proposed greenhouse are estimated using Table 4.

The first proposed heating method considered for greenhouse is the unit heater system. The design parameters for the unit heater are shown in Table 5. Four unit heaters are used with a capacity of 7.85 kW. The second heating system is finned pipe heating system. As shown in Table 6, two finned pipe circuits are suggested with 141 ft/length per circuit with a 0.54 L/s flow per circuits. Finned elements are installed along the length of greenhouse adjacent to the outside wall. Bar tube heating system input and output parameters obtained from the software is indicated in Table 7. The bar tubing system has a total length of 1345.6 m. Table 8 presents the number of fan coil units which used to meet the required load. The last proposed heating method is the low temperature unit heater (GLW unit heater). Two circuits of GLW unit heater are used with a capacity of 15.71 kW per unit as given in Table 9.

Table 2. Analytical method results.

System Type	Size	
BT	T_{avg}	302.44 ^oC
	dT	14.33 ^oC
	T_1	319.3 ^oC
	T_2	283.8 ^oC
	T_3	28.8 ^oC
	Total length	952.16 m
FP	No. of loop passes over greenhouse length	21 pass
	Tube Size and material	2.0" sch 40 aluminum pipe
	Fin Size and material	4.25" by 4.25" by 0.025" [24] aluminum fins at 24 fin/foot
	Actual capacity	1157.5 W/m^2 at 63.77 ^oC AWT
	Length of heating requirement	89.08 m
UH	4 unit of 10.55 kW Horizontal unit heater A poly tube adapter required	
FC	One unit of 120000 btu/hr	
Soil heating	AUST	26.52 ^oC
	T_f	36.86 ^oC
	Ls	517.68 m
	n	12 pipe
GLW	Entering temperature difference	37.22 ^oC
	System flow rate	1.1 L/s
	Single fan	
	Flow rate	0.37 L/s each
	Capacity	31.41 kW
	No. of units required	1 unit
	Two fan	
	Flow rate	0.37 L/s each
	Capacity	53.01 kW
	No. of units required	1 unit

Table 3. Degree days estimation.

Month	T_{av}	DD
January	15.9	437
February	16.6	374
March	19.2	335
April	22.3	231
May	24.3	177
June	27.9	63
July	28.7	39
August	29.7	8
Septemper	27.8	65
October	25.8	130
Novmber	21.9	242
December	17.6	383

Table 4. Geo Heat Centre software input and output data.

Input data	
Supply Water Temp	67.2 ^oC
Delta t	6.85 ^oC
Floor Area	404.7 m^2
Wall area	420 m^2
Wall "U"	3.15 W/ m^2
Roof area	417.9 m^2
Roof "U"	2.208 W/ m^2
Inside Design Temp	30 ^oC
Outside Design Temp.	23.15 ^oC
Average Ceiling Height	3.99 m
Air Change Rate	1.00 changes/hr
Degree Days	1900
Elec Rate	0.11 $/kWh
Interest Rate as decimal	0.08
Loan Term	25 years
Labor Rate	35.00 $/hr
Output data	
Peak Heat Loss	31.43 kW
Wall Loss	16.3 kW
Roof Loss	11.37 kW
Infiltration	3.71 kW
Loss per sq ft	77.66 W/ m^2

Table 5. Unit heaters output data.

Required Capacity Per Unit	7.85 kW
Cost of Selected Unit	755
Hours per Unit	10
KW per unit	0.09
Indoor Design Temp	30 ^oC
Supply Water Temp	67.2 ^oC
Delta T	6.85 ^oC
Temp Correction Factor	0.48
Flow Correction Factor	1.06
Combined Correction	0.50
No of units	4
Total Hours	39.2

Table 6. Finned pipe output data.

Average Water Temp	63.79 ^oC
Inside Design Temp	30 ^oC
Required Length	85.95 m
Temp Correction factor	0.26
Length per Circuit	42.97 m
Flow per Circuit	0.54 L/s
Velocity	0.57 m/s
Peak Flow	1.07 L/s
No of circuits	2
Total Hours	113

Table 7. Bar tubing input /output data.

Input data	
Tube OD	0.019 m
Water flow	0.0372 L/s
Emissivity	0.90
Horiz (1.016) Vert (1.235)	1.016
Tube length	44.98 m
Output data	
Delta T	6.85 ^oC
Air temperature	30 ^oC
Ent. water temp.	67.2 ^oC
Total unit output	76.6 W/m^2
Convective unit output	35 W/m^2
Radiant unit output	41.6 W/m^2
Total output	3586
Outlet temperature	60.38 ^oC
Total length	1345.6 m
Number of loops	30

Table 8. Fan coil unit input and output data.

Input data	
Number of Units	1
Leaving Air Temp	48.88 ^oC
Output data	
Capacity per Unit	31.4 kW
Entering Water Temp	67.2 ^oC
Nominal Tons	7.30
8 FPI	2.23
10 FPI	1.86
12 FPI	1.63
Cost per Unit	2175
Labor hrs	13
Leaving Water Temp	60.38 ^oC
Indoor Design Temp	30 ^oC
Air Flow Per Unit	1115 L/s
LMTD	6.07 30 ^oC
Face Area	0.54 m^2
Air Press. Drop @ 10 FPI	0.31 in wg
Fan KW @ 10 FPI	0.23

Table 9. GLW unit heater input and output data.

Capacity per Unit	15.71 kW
Labor per Unit	13.30 hrs
KW per Unit	0.35
Indoor Design Temp	30 ^oC
Supply Temp	63.79 ^oC
Delta T	6.85 ^oC
No of circuits	2
Total Hours	26.6
Flow per unit	0.55 L/s

A comparison study has been done between the Geo Heat Centre software, and analytical method. Two factors are studied; heating system design and total system cost as indicated in Table 10. Using Geo Heat Centre software, bare tube heating system has the minimum cost followed by FC, single fan GLW unit heater and finally the finned pipe is the most expensive type. For the analytical method, bar tube has the least cost while the unit heater is the highest one. The software package determines the number of units and its capacity for the different heating system using try and error method which satisfy the heating load. Also, the soil heating system isn't included in Geo Heat Centre software package. However the optimal heating system determined by the two methods is the same but the cost of the analytical method lower than the software package. The advantage of the software package comparing the analytical is the speed of calculations and time saving.

The proposed hybrid renewable energy system for the greenhouse consists of primary load, PV array, wind turbine, battery bank and charge regulator. Three different configurations are taken into consideration. Table 2 summarizes the optimal results of the different configurations of power systems. The results show that, PV-Wind hybrid system is the optimal configuration. The hybrid system has the minimum cost with a levelized cost of energy of 0.114 $/kWh. However the wind stand alone gives the highest cost and has a levelized cost of energy of 0.12 $/kWh.

Table 10. Sizing and economic analysis results.

System Type	Analytical Method		Geo Heat Centre Software
UH	Horizontal unit heater	4 unit of 4 unit of 10.55 kW	4 unit of 7.85 W
	Cost ($)	4392	4392
FP	Length of heating system	89	86 m
	Cost ($)	4144.5	6279
BT	Total Tube Length	1346 m, 21 loop	953 m, 30 loop
	Cost ($)	885	1093
SH	Total pipe Length	518 m	–
	Cost ($)	2334	–
FC	Capacity	One unit of 35.1 kW	One unit of 31.4 kW
	Cost ($)	2205	2627
GLW	Capacity	1 unit of 31.4 kW	2 unit of 15.7 kW
	Cost ($)	2580.5	4230

Table 11. Optimal sizing of the proposed heating system.

PV (kW)	0.5	6	0
W.T (kW)	6	0	6
Battery No.	1	3	2
Initial cost ($)	9,704	27,312	8.808
COE ($/kWh)	12,307	33,990	13,114
NPC ($)	0.114	0.314	0.120
Capacity shortage	0.04	0.03	0.03

IX. Conclusion

This paper aimed to present a design of a greenhouse using renewable energy for its optimal operation for chilli plants over the year. In Egypt especially in Suez Gulf, Solar, wind and geothermal energies are available in abundance so they are recommended for operation with the desired system. Finned pipe, standard unit heaters, low temperature unit heaters, fan coil units, soil heating, and bare tube system are several geothermal heating methods which were analyzed. The analysis for different heating methods was studied using the analytical method and the Geo Heat centre software package. The comparative study has taken into account heating system sizing and total system cost. For the desired greenhouse, the most economical method is bare tube heating system followed by fan coil system. Also this paper aimed to generate electricity to the greenhouse system using renewable energy sources. Homer software was used for the analysis of sizing which performed in order to obtain the most feasible configuration of a renewable energy system. The proposed hybrid energy system is a combination of solar, wind and batteries with a levelized cost of energy of 0.114 $/kWh.

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