IJEES

International Journal of Electrical Engineering and Sustainability (IJEES)

ISSN (online): 2959-9229

https://ijees.org/index.php/ijees/index

ISI 2023-2024: (0.557) Arab Impact Factor: 1.51 SJIF 2024 = 5.274

Volume 2 | Number 4 | October-December 2024 | Pages 27-37

Research Article

Design Of A Single-Cover Solar Collector To Heat Water For A Typical Building

Yahy M. Othman[1*], Mohammed. A. M. Haweel[2], Kamal Mohamed Saied[3], Abdelgader. A. S. Gheidan[4], Ashraf J. Meelad[5]

[1] Chemical Engineering Department, University of Bright Star-Albrega, Libya
[2] Mechanical Engineering Department, University of Bright Star-Albrega, Libya
[3] Department of Electrical Engineering, University of Bright Star-Albrega, Libya
[4] Mechanical Engineering Department, University of Bright Star-Albrega, Libya
[5] Mechanical Technology Department, Higher Institute of Petroleum Technology-Albrega, Libya

*Corresponding author: **haweelmohamed2@gmail.com**

Received: August 15, 2024 Accepted: November 04, 2024 Published: December 17, 2024

Abstract: The increasing global demand for hot water, coupled with the environmental impact of traditional energy sources, underscores the need for sustainable alternatives. Solar energy, as a clean and renewable resource, has emerged as a promising solution. Libya, with its high solar radiation and favorable climate, offers an ideal environment for harnessing solar energy for domestic water heating. This study evaluates the performance of a flat-plate solar collector designed to supply hot water for a typical household in Brega, Libya. The system was optimized for local climatic conditions to maximize efficiency. In Brega, solar radiation intensity reaches 980 W/m², and the collector has an area of 1.80 m² with a 45°C tilt angle. The absorber incorporates copper pipes, and the water storage tank, utilizing the thermosyphon principle, has a capacity of 40 liters. A 10-hour performance test conducted on June 15th 2024 yielded positive results, demonstrating the potential of solar water heating in the region.

Keywords: Flat Plate Solar Collector; Design; Water Heating; Environment.

Nomenclatures			
At	Area of tank(mm²)	Tmain	main temperature (K)
Di,Do	inner and outer diameter tube(mm)	t	tank thick (cm)
DT	diameter of tank (mm)	Ue	Edges heat loss coefficient(W/m².k)
F′	collector efficiency factor	Ub	Bottom heat loss coefficient(W/m².k)
FR	removal efficiency factor	Ut	Top heat loss coefficient(W/m².k)
Gt	heat loss (W)	UL	heat loss coefficient(W/m².k)
HT	length of storage tank (m)	v	volume (m³)
K	fiber glass insulation conductivity (w/m.oc)	VT	capacity of tank (m³)
Mf	mass flow rate (kg/s)	Ws	width of collector (mm)
M	hot water mass for 30 sec (kg)	σ	steel Strength(psi)
Ns	Number of pipes(mm)	σt	stress of tangential cold water (Mpa)
N_u	Nusselt number	σ′t	stress of tangential hot water (Mpa)
Pr	Prandtl numbers	$σ_l$	Longitudinal stress of cold water (Mpa)
Pt_1	pressure at cold water (Pa)	$σ_2$	Longitudinal stress of hot water (Mpa)
Pt_2	pressure at hot water (Pa)	σt	tangential stress of cold water (Mpa)
Q_{max}	heat from pipes to water(w/m²)	γ	coefficient of cubic expansion of water
Q_u	useful gain from the collector (w/m²)	ϱ	density (kg/m³)
Ra	Rayleigh number	$ϱ_1$	density of hot wate (kg/m³)

Re	Reynolds	ρ_{w1}	density of cold water (kg/m^3)
S	absorber solar radiation (w/m^2)	ρ_{w2}	density of hot water (kg/m^3)
To	outlet temperature (K)	γ	coefficient of cubic expansion of water (K^{-1})
Tg	glass cover temperature (K)		

1. Introduction

Since rising carbon dioxide (CO_2) emissions are widely regarded as a significant contributor to climate change, addressing emissions from buildings will inevitably become a critical priority [1-4]. In addition to that, the increasing global emphasis on sustainable energy solutions has brought solar energy to the forefront of renewable energy technologies [5-9]. Among its various applications, solar water heating has gained substantial attention for its ability to reduce energy consumption in residential and commercial buildings. Water heating typically accounts for a significant portion of energy usage in buildings, making it an essential target for implementing energy-efficient technologies [10,11]. Solar collectors, designed to capture and utilize solar radiation, present a practical and eco-friendly solution for meeting this demand [12-14].

The rationale for selecting a single-cover design lies in its adaptability to varying environmental conditions, structural simplicity, and reduced maintenance requirements. The design process incorporates essential factors such as optimal material selection, geometric configuration, and thermal insulation to maximize energy capture and minimize losses [15-17]. By harnessing solar energy, this system offers a sustainable alternative to traditional energy-intensive water heating methods, aligning with global efforts to reduce greenhouse gas emissions and mitigate climate change [18,19].

Water heating represents a significant portion of energy consumption globally. For example, water heating accounts for approximately 11% of total residential energy usage in the USA, 14% in Europe, 22% in Canada, 25% in Australia, 29% in Mexico, 27% in China, and 32% in South Africa [20]. Various domestic hot-water production systems are available, each differing in operating costs, environmental impact, and performance based on factors such as energy source, climate, system type, and design. Consequently, selecting the most appropriate domestic hot-water system can lead to substantial energy savings, reduced environmental impact, and lower operational costs.

To achieve these goals, a thorough review of existing water-heating systems is essential. Such an analysis helps in identifying the most efficient system from current options or in developing innovative designs that can further minimize energy consumption, environmental pollution, and operating expenses. Solar water-heating systems, in particular, offer a promising solution by harnessing renewable energy to meet water heating demands sustainably [21-24]. Despite the widespread implementation of various solar heating systems, relatively few studies have focused on the design of a single-cover solar collector for water heating applications. This gap highlights the need for targeted research to explore and optimize single-cover designs, which balance simplicity, cost-effectiveness, and thermal efficiency. By addressing this need, the present work aims to contribute to the body of knowledge in solar water-heating technologies, emphasizing the practical design and implementation of single-cover solar collectors to meet the demands of typical buildings. This study not only evaluates the performance and feasibility of such systems but also aims to advance their adoption as an energy-efficient alternative to conventional water-heating methods.

This design represents an important step towards sustainability and reducing electricity consumption, and is the ideal solution, especially in remote areas, as it focuses on using solar collectors to heat water, thus reducing dependence on traditional energy sources and reducing carbon emissions. Relying on solar energy not only enhances environmental protection, but also contributes to saving costs in the long run.

2. Description of the System

Active systems utilize electrical components to operate; however, the storage tank in these systems is often exposed to external temperatures. This exposure can lead to significant heat losses during cold days and pose a risk of water freezing at night, potentially damaging system components. In contrast, passive systems offer higher efficiency and cost-effectiveness compared to active systems. These systems rely on gravity and the natural convection of water as it heats, forming the basis of passive solar water heaters. The absence of electrical components in passive systems makes them inherently more reliable, easier to operate, and potentially more durable than their active counterparts. Figure 1 illustrates passive solar water heating system. Figure 2 displays flat plate sheet and tube configuration.

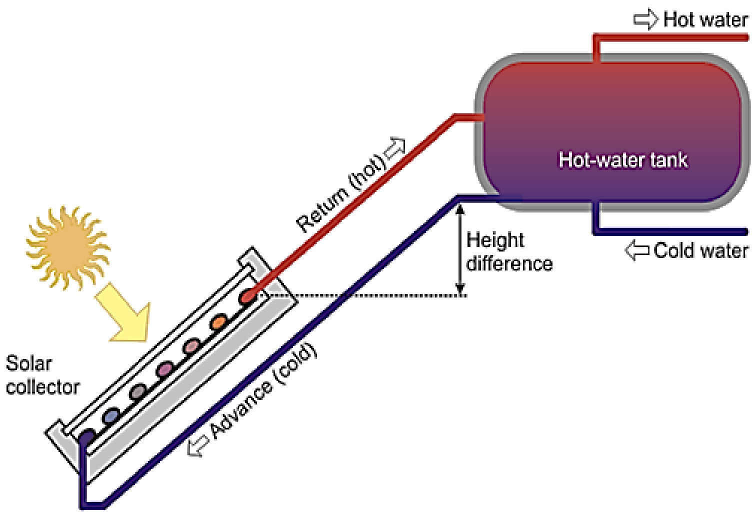

Figure 1. Passive solar water heating system.

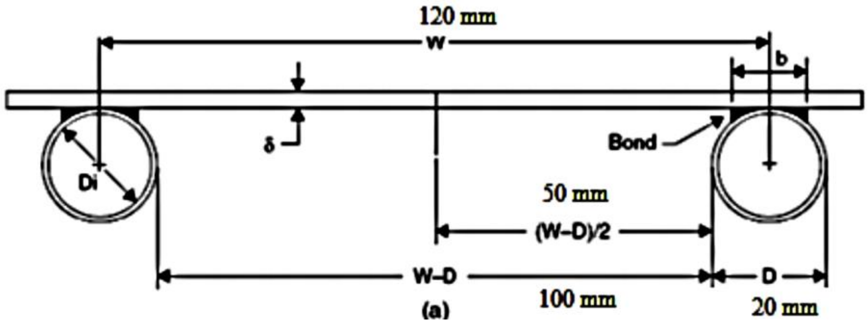

Figure 2. Flat plate sheet and tube configuration.

3. Methodology

A. Collector Energy Losses

The majority of the solar radiation that strikes a collector's surface is absorbed, transferred to the transport fluid, and then taken away as full energy utilization. However, heat losses to the environment due to different forms of heat transfer are unavoidable, just like in all thermal systems.

B. Details And Dimensions of The Collector

The collector long is 2m and 0.9m wide, 0.16 high and the depth of channel is 0.010m. The glass cover is 3.5mm thick with a gap of 30mm, the fiber glass insulation thick at the back is 0.08m and the fiberglass insulation thick at the edges is 0.03m.

C. The Collector Emissivity:

The coating of copper tubes and sheets is achieved through a specialized black powder coating that provides an absorbability exceeding 0.92 and an emissivity below 0.2, thereby maximizing solar energy capture while minimizing thermal losses. In this configuration, the absorber's emissivity (εp) is approximately 0.92, the glass cover's emissivity (εg) is about 0.88, and the backing layer (εb) has an emissivity of around 0.92. These carefully selected properties, combined with an effective collector transmittance–absorptance product ($\tau{\cdot}\alpha$) of 0.95, ensure optimal performance of the solar collector by maintaining high energy absorption and reducing heat dissipation.

D. Calculate the overall heat loss coefficient

To determine the overall heat loss coefficient UL for the solar collector in Albrega city, we first note the local ambient temperature of about 28 °C (301 K), an absorber plate temperature of 70 °C (343 K), a glass cover temperature of 45 °C (318 K), and a back temperature of 65 °C (338 K). The collector's overall heat loss coefficient is composed of three main components: top loss (Ut), bottom loss (Ub), and edge loss (Ue). The top loss typically includes both convective and radiative heat transfer between the absorber plate, glass cover, and the surroundings; the bottom loss depends on conduction through the back insulation layer; and the edge loss accounts for heat conduction through the collector's frame or sidewalls. By calculating each of these components based on the given temperature differences and material properties, and then summing them, we obtain the total UL, which is essential for evaluating the collector's thermal performance.

$$U_L = U_t + U_b + U_e \quad (1)$$

The radiation heat transfer coefficient ($h_{r_{p-g}}$) between absorber plate and glass cover is given by [25].

$$h_{r_{p-g}} = \frac{\sigma(T_p + T_g)(T_p{}^2 + T_g{}^2)}{\left(\frac{1}{\varepsilon_p}\right) + \left(\frac{1}{\varepsilon_g}\right) - 1} \quad (2)$$

The radiation heat transfer coefficient ($h_{r_{g-a}}$) between the glass cover and the ambient is given by [26]:

$$h_{r,g-a} = \epsilon_g \, \sigma(T_g + T_a)(T_g^2 + T_a^2) \quad (3)$$

The following properties of air obtained for $0.5\,(T_P + T_g)$.The Rayleigh number, Ra can be obtained by following equations.

$$Ra = \frac{g\grave{\beta}P_r}{v^2}(T_p - T_g)L^3 \quad (4)$$

$$\grave{\beta} = 1/T_{main} \quad (5)$$

The convection heat transfer coefficient ($h_{c_{p-g}}$) between absorber plate and glass cover, can be estimated from correlations for Nusselt number suggested by following reference [25].

$$h_{c_{p-g}} = \frac{k}{L}\left[1 + 1.446\left(1 - \frac{1708}{Ra \times Cos\,\theta}\right)\right] \times \left[1 - \left(\frac{1708\,[Sin(1.8\theta)]^{1.6}}{Ra \times Cos\,\theta}\right)\right] + \left[\left(\frac{Ra \times Cos\,\theta}{5830}\right)^{0.333} - 1\right] \quad (6)$$

The convection heat transfer coefficient from glass to the ambient is the wind loss coefficient (hw) [24-27].

$$h_{c_{g-a}} = h_w = \frac{8.6\,v^{\,0.6}}{L^{0.4}} \quad (7)$$

U_{top} Can be calculated from Eq (8).

$$U_{top} = \left(\frac{1}{h_{c_{p-g}} + h_{r_{p-g}}} + \frac{1}{h_{c_{g-a}} + h_{r_{g-a}}}\right) \quad (8)$$

$$U_b = \frac{1}{\frac{t_b}{k_b}} \quad (9)$$

$$U_e = \frac{1}{\frac{k_e}{t_e}} \quad (10)$$

The value assumed are Tp=343k and back temperature Tb=338k

$$T_{main} = \sqrt[3]{\frac{(Tp + Tb)\,(Tp^2 + Tb^2)}{4}} \quad (11)$$

The radiation heat transfer coefficient from the absorber to the back plate [28-30].

$$h_{r_{p-b}} = \frac{\sigma\,(T_p + T_b)\,(Tp^2 + Tb^2)}{\left(\frac{1}{\varepsilon_p}\right) + \left(\frac{1}{\varepsilon_b}\right) - 1} \quad (12)$$

hydraulic diameter of the air channel from fluid mechanics [12]:

$$D = 4\left(\frac{\text{flow cross} - \text{sectional area}}{\text{Wetted perimeter}}\right) = 2S \quad (13)$$

The values of Nusselt number, Reynolds and Prandtl numbers, respectively.

The Reynolds number is given by:

$$Re = \frac{\dot{m}D}{A\mu} \quad (14)$$

$$Nu = 0.0158\,(Re)^{0.8} \times \frac{K}{D} \quad (15)$$

Convection heat loss coefficient, absorber-ambient is equal to convection heat loss from back- ambient.

$$h_{C_{p-a}} = h_{C_{b-a}} = \frac{0.0290}{0.12} \times 0.0158\,(6601)^{0.8} \quad (16)$$

The collector efficiency factor can be calculated from the equation [4]:

$$\acute{F} = \frac{h}{h + U_L} \quad (17)$$

The absorber solar radiation

$$S = Gt\,(\tau\alpha) \quad (18)$$

The outlet air temperature

$$T_0 = T_i + \frac{1}{U_L}[s - U_L(T_i - T_a)]\left[1 - \exp\left(-\frac{A_c U_L \dot{F}}{\dot{m}C_p}\right)\right] \quad (19)$$

The removal efficiency factor can be calculated from the equation [4]:

$$F_R = \frac{\dot{m}\dot{C}_p}{A_c U_L}\left[1 - \exp\left(-\frac{A_c U_L \dot{F}}{\dot{m}C_p}\right)\right] \quad (20)$$

The performance of a flat-plate solar collector can be described by the useful gain from the collector [29,30].

$$Qu = A_c F_R[S - U_L(Ti - Ta)] \quad (21)$$

E. Solar Collector Efficiency:

The solar collector efficiency is defined as the ratio of the useful heat gain over any time period to the incident solar radiation over the same period.

$$\eta_c = \frac{Qu}{A_c I_t} \quad (22)$$

F. The Solar Water Heating System Efficiency:

The SWH system efficiency is defined as the ratio of the useful heat gain over any time period to the incident solar radiation over the same period.

$$\eta_{th} = \frac{Qu}{Q_{in}} \quad (23)$$

The mass flow rate of water through the collector plate area is given by:

$$M_f = \frac{m}{t} \quad (24)$$

where t = 1/2 minute required to drain 4 liters of water through the collector [30-32].

$$m = \frac{\rho}{V} \quad (25)$$

G. The Design of storage tanks for cold and hot water

The Cold-water tank for 40 liter is a single thin-walled cylinder and the height (length 746 mm) where 40 liter = 4×10−3 m³.

$$V = A_T x H_T \quad (26)$$

$$A_T = \frac{\pi D^2 T}{4} \quad (27)$$

$$V_T = \frac{\pi D^2 T}{4} H_T \quad (28)$$

$$D_T = \sqrt[3]{\frac{4V_T}{H_T \pi}} \quad (29)$$

The pressure in a cold-water tank at full capacity is determined by.

$$P_{T_1} = \rho W_1 x g x H_T \quad (30)$$

The pressure in a hot water tank at full capacity is determined by following equations [33-37].

$$P_{T_2} = \rho W_2 x g x H_T \quad (31)$$

$$\rho W_2 = \rho W_1 x [1 + \gamma \Delta T]^{-1} \quad (32)$$

γ from [40 –70] = 4.58×10^{-4}

$$\sigma_t = \frac{P_T D_T}{2t} \quad (33)$$

$$\dot{\sigma}_t = \frac{\dot{P}_T \dot{D}_T}{2t} \quad (34)$$

$$\sigma_1 = \frac{P_T D_T}{2t} = \frac{1}{2}\sigma_t \quad (35)$$

$$\dot{\sigma}_t = \frac{\dot{P}_T \dot{D}_T}{2t} = \frac{1}{2}\dot{\sigma}_t \quad (36)$$

H. The Sizing of Pipes

The pipe spacing is set at 0.10 m, and the data presented in Table 1 is incorporated into the design process.

Table 1. Time, temperature and solar radiation intensity data.

Time	Ta	Gt
8	28	430
9	30	600
10	32	800
11	34	900
12	35	980
13	34	850
14	32	800
15	30	600
16	28	500
17	27	427

Table 1 shows the average of usual data on June 15 for the climate in Brega region, including hours, ambient temperature and solar radiation intensity at each hour, which the performance rate of the solar collector was evaluated, the results obtained for a period of 10 hours starting from 8 am to 5 pm, thus determining the amount of heat and the temperature of water exiting from the system. Number of pipes can be calculated as following equation (37). Equations (38) and (39) used to calculate useful energy and output temperature as following [34-37]:

$$N_s = \frac{W_c}{0.10} \quad (37)$$

$$Qu = \eta \times A_c \times G_t \quad (38)$$

$$T_o = \frac{Q}{\dot{m}\, C_p} + T_i \quad (39)$$

Table 2. Explanation all the results which have been collected of data.

Time	T_a	G_t	To	Q_u
8	28	430	70.897	117.55
9	30	600	72.933	384.34
10	32	800	75.295	694.04
11	34	900	76.567	860.74
12	35	980	77.531	986.98
13	34	850	76.022	789.23
14	32	800	75.295	694.04
15	30	600	72.933	384.34
16	28	500	71.661	217.65
17	27	427	70.774	101.41

Through Table 2, can see the results obtained from the previous climate data from 8 am to 5 pm, where the lowest water temperature coming out of the solar collector ranges from (69 - 70) degrees Celsius, the average water temperature is (73-74) degrees Celsius, and the highest temperature is (76-77) degrees Celsius. It also shows the lowest, average, and highest amount of heat obtained, respectively: 101.41 w/m^2, 694.04 w/m^2, 986.98 w/m^2.

4. Results and Discussions

In this research, the results depend on the area of the solar collector, the angle of inclination, and the method of designing the storage tank. Several results were obtained, the most important is the out temperature of the water which is 76 degrees Celsius, and the efficiency of the collector is 51% for 10 hours during the day. The results were good depending on the intensity of solar radiation, climate conditions, and the surrounding environment.

Table 3. The final results of the equations.

Prefix	Result	Prefix	Result
$h_{r_{p-g}}$	6.5559 $w/m^2.k$	Ns	8
$h_{r_{g-a}}$	5.7771 $w/m^2.k$	Ws	9
R_a	44615.28	D	0.02
$h_{c_{p-g}}$	2.9973 $w/m^2.k$	Re	14446
$h_{c_{g-a}}$	11.294 $w/m^2.k$	U_t	6.1254
$h_{c_{p-a}}$	48.734 $w/m^2.k$	U_b	0.475
H	55.329 $w/m^2.k$	U_e	1.266
h_{fg}	2318.1 KJ/Kg	Ḟ	0.8755
$h_{r_{p-b}}$	7.6274 $w/m^2.k$	S	931
UL	7.8670	To	349.7
f	0.6677	FR	0.8363

C	316.6	Qu	904.09
U_t empirical	6.637	Qw	227.4
M	4	Mf	0.13
T_{main}	340.5	ηc	0.51 %
tank thick	0.06	Steel Strength	26000

Table 3 explains the most important results obtained by all the previous equations and laws, can calculate the total heat transfer coefficient U_L (7.8670w/m^2. k), and the out temperature of the water for the solar collector up to (349.7k), as well as the amount of heat Q(904.09w/m^2) and the efficiency (0.51%) of the collector which shows the optimal performance for the final design of solar heater. Table 4 illustrates the configuration of the water storage tank that is linked to the solar collector. It provides details regarding the tank's height, the surface area of the storage tank, and the diameter of the tank.

Table 4. The final results of storage tank design and pipe sizing

Prefix	Result	Prefix	Result
Ht	746	σ_1	0.7967
Dt	261.27	σt2	1.6742
At	53619	σl	0.8371
Pt	7318.3	Ns	8
ρ1	979.81	Number of headers pipes	2
Pt2	7170.5	Number of riser pipe	6
σt	1.5934	Qmax	1819.4
Di,Do	18.5, 20		

Additionally, it presents the longitudinal and tangential stresses for both cold and hot water, along with the quantity of tubes and the diameter of each tube. Furthermore, it indicates the total heat transferred from the pipe headers and risers to the water within the solar collector. In this regard, Figure 3 shows the degree of gradual increase in the amount of heat with the increase in daylight hours. Its average rate was at 10 in the morning and 3 in the afternoon, and it reaches its highest value at 12 noon, and begins to decrease until it reaches its lowest value at 5 in the evening. Figure 4 presents the temperature gradient coming out of the solar collector, it is the important and primarily depends to the design the solar collector. Figure 5 illustrates the increase in radiation intensity linked mainly to the increase in daylight hours.

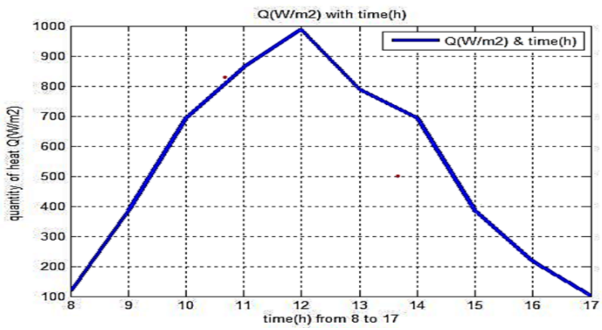

Figure 3. Variation of quantity of heat transfer with time.

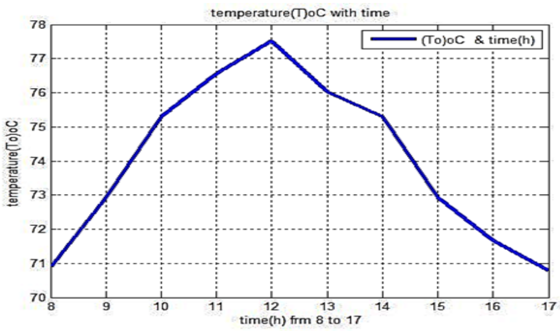

Figure 4. Variation of out Temperature with time.

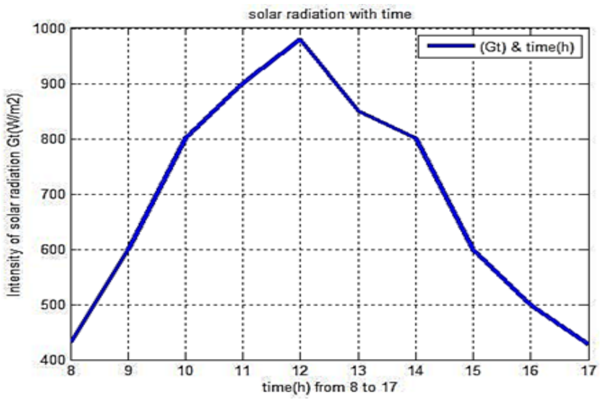

Figure 5. Variation of the intensity of solar radiation with time.

Figure 4 shows the temperature gradient coming out of the solar collector, it is the important and primarily depends to the design the solar collector. It shows the increase in temperature, which begins to increase with the increase in daylight hours. The average temperature was at 10 and 3 o'clock, and the highest temperature was at 12 and 1 o'clock. The temperature begins to decrease until it reaches the lowest temperature at 5 o'clock in the evening. Moreover, Figure 5 demonstrates the increase in radiation intensity linked mainly to the increase in daylight hours and it increases significantly and reaches its average value which is about 600 w/m2 at 9 and 10 o'clock and its highest value is approaching 1000 w/m2 at 12 noon and the radiation intensity begins to decrease with sunset until it reaches its lowest value which exceeds 400 w/m2 at 5 o'clock in the evening.

5. Conclusion

Over the past few years, research into renewable energy has expanded markedly, with Solar Water Heating (SWH) systems emerging as a highly efficient means of capturing and converting solar radiation into thermal energy. SWH is a mature, commercially viable technology that plays a crucial role in improving energy efficiency by providing sustainable, renewable alternatives for residential, commercial, and industrial hot water needs. Solar collectors contribute to reducing carbon emissions, thereby mitigating climate change, while also lowering energy costs by replacing fossil-fuel-based heating systems. Furthermore, they promote energy independence and offer long-term cost savings over their lifespan. This study highlights key findings based on a solar collector area of 1.80 m^2, an inclination angle of 45°C, and a thermosyphon-based storage tank design. Notable results include an output water temperature of 76°C, a collector efficiency of 51%, and a total heat absorption of 1819.4 W/m^2 from the pipes to the water. The number of headers and riser pipes was calculated, along with the tangential and longitudinal stresses acting on the walls of the storage tank due to the cold and hot water flows. Performance testing over a 10-hour period demonstrated that system efficiency is influenced by solar radiation intensity, local climate conditions, and the surrounding environment. Overall, the results confirm that the proposed solar water heating system, optimized for regions with high solar radiation, is highly effective and offers a successful and sustainable solution for water heating in areas like Brega, Libya.

Author Contributions: Author has contributed significantly to the development and completion of this article.

Funding: This article received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to express their sincere gratitude to the University of Bright Star-Albrega, Libya, for their invaluable support and resources throughout the course of this research.

Conflicts of Interest: The author(s) declare no conflict of interest.

ORCID
Yahy M. Othman https://orcid.org/0009-0001-4873-261X
Mohammed. A. M. Haweel https://orcid.org/0009-0006-9925-8942
Kamal Mohamed Saied https://orcid.org/0009-0007-7861-9611
Abdelgader. A. S. Gheidan https://orcid.org/0000-0003-4713-6047
Ashraf J. Meelad https://orcid.org/0009-0007-7988-1013

References

[1] R. W. Moss, P. Henshall, F. Arya, G. S. F. Shire, P. C. Eames, and T. Hyde, "Simulator testing of evacuated flat plate solar collectors for industrial heat and building integration," *Sol. Energy*, vol. 164, pp. 109–118, 2018.

[2] A. A. Eidan, A. AlSahlani, A. Q. Ahmed, M. Al-fahham, and J. M. Jalil, "Improving the performance of heat pipe-evacuated tube solar collector experimentally by using Al2O3 and CuO/acetone nanofluids," Sol. Energy, vol. 173, pp. 780–788, 2018.

[3] Y. F. Nassar, H. J. El-khozondar, A. A. Ahmed, A. Alsharif, M. Khaleel, and R. J. El-Khozondar, "A new design for a built-in hybrid energy system, parabolic dish solar concentrator and bioenergy (PDSC/BG): A case study – Libya," J. Clean. Prod., vol. 441, no. 140944, p. 140944, 2024.

[4] M. Khaleel, Z. Yusupov, A. Ahmed, A. Alsharif, Y. Nassar, and H. El-Khozondar, "Towards sustainable renewable energy," Appl. Sol. Energy, vol. 59, no. 4, pp. 557–567, 2023.

[5] Y. Nassar and M. Khaleel, "Sustainable development and the surge in electricity demand across emerging economies," Int. J. Electr. Eng. and Sustain., pp. 51–60, 2024.

[6] M. Khaleel et al., "Evolution of emissions: The role of clean energy in sustainable development," Chall. Sustain., vol. 12, no. 2, pp. 122–135, 2024.

[7] Y. Nassar et al., "Simulating the energy, economic and environmental performance of concentrating solar power technologies using SAM: Libya as a case study," jsesd, vol. 12, no. 2, pp. 4–23, 2023.

[8] A. H. Alsharif et al., "Mitigation of dust impact on solar photovoltaics performance considering Libyan climate zone: A review," vol. 1, no. 1, pp. 22–27, 2023.

[9] Y. F. Nassar et al., "Solar and wind atlas for Libya," International Journal of Electrical Engineering and Sustainability (IJEES), vol. 1, no. 3, pp. 27–34, 2023.

[10] O. Hlaváček and A. Vagenknechtová, "Reduction of water consumption for heating plant cooling with an indirect cooling system," Water Conserv. Sci. Eng., vol. 9, no. 2, 2024.

[11] H. Karimi, M. Monemi Bidgoli, and S. Jadid, "Optimal electrical, heating, cooling, and water management of integrated multi-energy systems considering demand-side management," Electric Power Syst. Res., vol. 220, no. 109353, p. 109353, 2023.

[12] Y. Wu, Y. Jiang, B. Gao, Z. Liu, and J. Liu, "Thermodynamic analysis on an instantaneous water heating system of shower wastewater source heat pump," J. Water Reuse Desalination, vol. 8, no. 3, pp. 404–411, 2018.

[13] D. Guest Editor Jianping, "Analysis of the current situation and design principles to use solar energy for the integral combination of heating water and buildings in China," Int. J. Simul. Syst. Sci. Technol., 2016.

[14] A. Maraj, A. Londo, C. Firat, and A. Gebremedhin, "Comparison of the energy performance between flat-plate and heat pipe evacuated tube collectors for solar water heating systems under Mediterranean climate conditions," J. Sustain. Dev. Energy Water Environ. Syst., vol. 7, no. 1, pp. 87–100, 2019.

[15] J. M. Sangoi and E. Ghisi, "Energy efficiency of water heating systems in single-family dwellings in Brazil," Water (Basel), vol. 11, no. 5, p. 1068, 2019.

[16] D. Fugarov, O. Purchina, I. Popova, and A. Purchina, "Modeling of the temperature profile when heating fuel oil with water vapor in a single-pass tubular heat exchanger," in Springer Proceedings in Materials, Cham: Springer Nature Switzerland, 2024, pp. 587–595.

[17] A. Tripathi, C. Swaroop Meena, A. Saxena, G. Pant, and V. Sharma, "Review on: Study and analysis the effect of single glazing and double glazing on the performance of Flat Plate Collector in solar water heating system," International Journal of Energy Resources Applications, pp. 14–24, 2022.

[18] Y. Marif, A. Benazzouz, and B. Hebbal, "The effect of single and hybrid nanofluids in the performance of Solar Water Heating System," Asian J. Res. Chem., pp. 489–494, 2022.

[19] L. da S. Maia, W. P. Miranda, and É. C. N. M. Pinheiro, “Sizing of a water heating system in a single-family residence through solar energy capture: Case study,” Int. J. Adv. Eng. Res. Sci., vol. 8, no. 6, pp. 134–144, 2021.
[20] O. Ibrahim, F. Fardoun, R. Younes, and H. Louahlia-Gualous, “Review of water-heating systems: General selection approach based on energy and environmental aspects,” Build. Environ., vol. 72, pp. 259–286, 2014.
[21] S. Abdulwahab, Y. F. Nassar, H. J. El-Khozondar, M. Khaleel, A. A. Ahmed, and A. Alsharif, “Meeting solar energy demands: Significance of transposition models for solar irradiance,” International Journal of Electrical Engineering and Sustainability (IJEES), vol. 1, no. 3, pp. 90–150, 2023.
[22] Y. Nassar et al., “Optimum number of glass covers of thermal flat plate solar collectors,” RENEWABLE ENERGY, vol. 2, no. 1, 2024.
[23] Y. F. Nassar et al., “Thermoelectrical analysis of a new hybrid PV-thermal flat plate solar collector,” in 2023 8th International Engineering Conference on Renewable Energy & Sustainability (ieCRES), 2023, pp. 1–5.
[24] S. A. Kalogirou, “Solar water-heating systems,” in Solar Energy Engineering, Elsevier, 2024, pp. 265–327.
[25] T. T. Chow, G. Pei, K. F. Fong, Z. Lin, A. L. S. Chan, and J. Ji, “Energy and exergy analysis of photovoltaic–thermal collector with and without glass cover,” Appl. Energy, vol. 86, no. 3, pp. 310–316, 2009.
[26] L. Hu, A. Narayanaswamy, X. Chen, and G. Chen, “Near-field thermal radiation between two closely spaced glass plates exceeding Planck’s blackbody radiation law,” Appl. Phys. Lett., vol. 92, no. 13, p. 133106, 2008.
[27] K. Maatouk, “Non-gray radiative and conductive heat transfer in single and double glazing solar collector glass covers,” Int. J. Therm. Sci., vol. 45, no. 6, pp. 579–585, 2006.
[28] S. Kumar and S. C. Mullick, “Glass cover temperature and top heat loss coefficient of a single glazed flat plate collector with nearly vertical configuration,” Ain Shams Eng. J., vol. 3, no. 3, pp. 299–304, 2012.
[29] R. Alvarado-Juárez, J. Xamán, G. Álvarez, and I. Hernández-López, “Numerical study of heat and mass transfer in a solar still device: Effect of the glass cover,” Desalination, vol. 359, pp. 200–211, 2015.
[30] M. Rubin, “Calculating heat transfer through windows,” Int. J. Energy Res., vol. 6, no. 4, pp. 341–349, 1982.
[31] A. M. Abdel-Ghany and T. Kozai, “On the determination of the overall heat transmission coefficient and soil heat flux for a fog cooled, naturally ventilated greenhouse: Analysis of radiation and convection heat transfer,” Energy Convers. Manag., vol. 47, no. 15–16, pp. 2612–2628, 2006.
[32] C. Mahboub and N. Moummi, “Calculation of the glass cover temperature and the top heat loss coefficient for 60° vee corrugated solar collectors with single glazing,” Sol. Energy, vol. 86, no. 2, pp. 804–808, 2012.
[33] H.-T. Chen and S.-K. Lee, “Estimation of heat-transfer characteristics on the hot surface of glass pane with down-flowing water film,” Build. Environ., vol. 45, no. 10, pp. 2089–2099, 2010.
[34] S. Kumar and S. C. Mullick, “Wind heat transfer coefficient in solar collectors in outdoor conditions,” Sol. Energy, vol. 84, no. 6, pp. 956–963, 2010.
[35] A. Al-Mahdouri, M. Baneshi, H. Gonome, J. Okajima, and S. Maruyama, “Evaluation of optical properties and thermal performances of different greenhouse covering materials,” Sol. Energy, vol. 96, pp. 21–32, 2013.
[36] H. Mao, Q. Meng, S. Li, P. Ren, J. Wang, and M. Santamouris, “Convection heat transfer coefficient of building glasses under salt deposition conditions,” Build. Environ., vol. 224, no. 109571, p. 109571, 2022.
[37] N. Akhtar and S. Mullick, “Computation of glass-cover temperatures and top heat loss coefficient of flat-plate solar collectors with double glazing,” Energy (Oxf.), vol. 32, no. 7, pp. 1067–1074, 2007.