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Effect of Using two storage Tanks as Heat-Exchanger System on the heating performance with economic study in a house solar heater

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ABSTRACT

A solar heating system is a set of combined components and subsystems whose main objective is to use solar energy and convert it into hot water for domestic use. In the present research, two cases of the solar system are compared. The first case is the traditional case, which is a solar heating system that contains only one storage tank. The second case utilizes two storage tanks. The study was performed by T*SOL software for both the solar performance analysis, and financial account. The results are discussed in both cases. A comparison between the results of the two cases is also discussed. It is concluded that the T*SOL is a suitable solar analysis software to be used in Egypt. The results indicated that the second case, containing the two tanks, is the best solution for the present solar-heating system.

1. Introduction

1.1. Motivation

Solar energy is naturally produced as a renewable energy source, and is obtained directly from one of the major celestial bodies called the Sun, I've been found since creation and humanity. Until recently, however, because of ignorance and lack of appropriate technology, their potential has not been used and cannot be used. Human demand for energy supplies is increasing, mainly for industrial, commercial and domestic purposes. The total amount of fossil fuel left on Earth does not reach the energy that can be saved within a few days under the Sun, which is the source of all energy. Therefore, given the high cost of oil and natural gas in electricity production and then impact of pollution on climate change (such as global warming and ozone depletion), there is a need to shift to renewable energy sources. Of course, in domestic and commercial hot water, solar energy can replace traditional hot water methods. One of the biggest consume of electricity, gas, and oil is water heating in homes, offices, schools, and hospitals. Solar water heaters are a simple and efficient way to use solar energy. Solar water heater concentrates and diffuses solar radiation into thermal energy. A solar heating system is a set of combined components and subsystems whose main objective is to use solar energy and convert it into hot water for domestic use. [1].

The use of solar energy comes first among renewable energies, followed by wind energy, and then biomass. The proposed system, in the present research, is a hybrid energy system of solar and wind energies. The production of the electrical energy was based on the use of both high-efficiency flat-solar panels and small wind-turbines to produce the highest possible energy in the available space for equipment

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installation. For many years, several researchers and companies worked on developing solar panels and raising their efficiency through the installation and manufacturing processes. Also, they focused on energy storage to make use of the most of the sun's rays during the daylight. Also, the use of wind energy, in this system, makes it highly efficient, especially during night [2-9].

*1.2. T*SOL Software*

T*SOL software was selected for the design and planning of the solar panel systems. It is considered a professional finite-element software that can be used for simulating temperature and energy performance, along a year down to a 6-minute resolution, with a wide range of solar systems and components [10].

1.3. Flat-plate collector (FPC)

A coated flat-plate absorber with a transparent cover was chosen as the solar collector. The absorber is protected by this cover, which also helps to decrease heat loss at the collector's top. There's also an operational fluid to harness the energy from the absorber, tubes for heat transfer fluid (HTF) circulation, an insulating system to prevent heat loss, and a protective case to keep the components safe from the weather. Fig. 1 shows the flat-plate collector with important angles that affect the performance and the efficiency in collecting sun rays such as tilt angle, zenith angle, and azimuth angle.

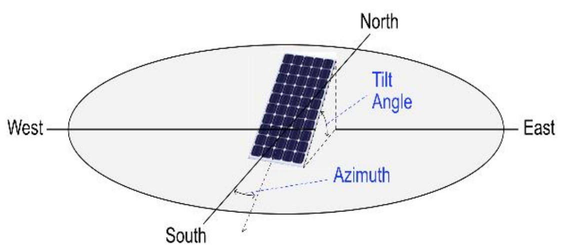


Fig. 1: Solar flat-plate collector with important angles [11]

1.4. Literature Survey

Since the beginning of the last century, many researchers have been interested in merging different types of renewable energies to obtain the largest sufficient amount of them to suit the actual operating requirements. The greatest emphasis was about the implementation of solar energy in operating residential buildings and providing them with the necessary electricity for lighting and heating. A lot of researches provided different designs and solutions that helped greatly to increase the efficiency of solar cells.

In 2006, Hessami [12] presented the methodology to combine wind and solar energies to meet the needs of operating a small rural residential-building and supplying it with the necessary electrical energy. The output power was assumed to be sufficient for heating the house, heating water, and lighting. A cost-analysis study was carried out to find the actual cost of the system to compare with the cost of connecting to the main grid. The results clearly showed that the cost was much higher than the connection to the public electricity network.

In 2008, a detailed study was presented on the importance of choosing the appropriate site for building a hybrid energy-system that relied on solar and wind energies [13]. However, the main focus was placed on the importance of choosing the appropriate site for the wind turbine depending on the area's wind speed. The research demonstrated that the efficiency of a wind turbine did not depend only on the wind speed, but also on the design of the turbine blades. Also, it was emphasized that the small size may be a big influencing factor in generating energy. The results of the research showed that the selection of the site was not that influencing, and that the dependence of determining the area on the wind speed was not appropriate in most regions.

There is a big difference between creating a network to produce electrical energy for a small house and wind farms to feed a large urban area. With the case of large-scale renewable energy systems, they must be permanently connected to the main grid to ensure a permanent supply of energy in the event of a problem or failure in the energy production to serve as a backup system of electrical energy. Excess power can also be sold to the main grid if it is produced in excess.

In addition, the use of appropriate equipment with hybrid power-systems, such as using diesel generators as a backup generator or using advanced storage systems (ESS), increases the efficiency and reliability of the system. Storage systems and taking the necessary precautions make the use of renewable energy a something that many do not fear, but rather motivates them to experiment and use [14, 15].

In 2016, Zhang et al. [16] presented a detailed study of a hybrid renewable-energy system that combined wind and solar energies and was designed to suit a low-rise residential building with net-zero energy consumption A water-based photovoltaic/thermal (PVT) collector and a ground water-source heat pump were included in their suggested hybrid system.. Their hybrid system was designed to provide the electrical energy for heating, lighting, and water heating purposes during the summer and winter. Their results proved the ability of their innovative system to supply energy for low/zero-energy low-rise residential buildings.

After that in 2018, Mohammadi et al. [17, 18] presented a study of the optimal planning to use renewable energy sources for supplying electricity for a residential building, taking into account economic and reliability considerations. Their system consisted mainly of PV solar systems combined with wind turbines. Their hybrid system proved its efficiency to produce the required sufficient power for heating and lighting.

Collectors, storage tanks, and, depending on the arrangement, electric pumps are common components of solar water heaters. Flat plate, evacuated tube, and concentrator are the three fundamental types of collectors. Solar water heaters are classified as active or passive based on their water circulation mechanisms. The active heaters use electric pumps to circulate the water, whilst the passive heaters do not. Flat-plate collectors, the most popular type of solar collector, are also separated into two types: thermo syphon and built-in storage. The built-in-storage solar water heaters are the most common of these [19].

After making this literature survey on the solar systems in addition to hybrid renewable systems, it is clear that there is a need to cover the gap of hybrid renewable energy systems for sustainability. This paper presents an important study to design a hybrid system that can supply a sufficient amount of renewable energy for a residential building. Cost analysis study was carried out to find the actual cost of using this system compared to the connection to the main grid. The paper structure starts with a discussion about solar data. After that, a general illustration of the requirement for hot water, space heating systems, and provision of power using the wind tree. Cost analysis is discussed showing the benefits of using this system and the economical merits achieved by applying it.

2. CASE STUDY

The storage tank's job is to balance peak demand and charging power in supplying hot water in all hot water systems, and in solar systems, it also balances for timing discrepancies between solar energy supply and hot water requirements. It usually has a heat exchanger at the bottom, where the collector's transfer medium (commonly a water-antifreeze mixture) transmits solar energy from the collector to the storage tank's contents. Where necessary, a conventional heating system is used to heat the upper section of the storage tank, ensuring that the hot water drawn from it is always at the desired target temperature, regardless of the available energy the sun's energy larger solar systems employ a sequence of storage tanks, the last of which is utilized for warming. [10]. In the present work, there is a comparison between the two cases of the solar system. The first case is the traditional case, which is a solar heating system that contains one storage tank, Fig. 2. The second case uses two storage tanks, Fig. 3.

The solar collectors' specifications were studied to correctly install and use them with a suitable tilt angle of 30 degrees. An under-floor heating system was studied to select the suitable pattern and calculate the thermal heat consumption required. Also, the weather data of the selected site were studied and imported to the finite-element software (T*SOL**)** to accurately calculate the total input energy to the system. Heat losses within the system were calculated such as heat losses due to windows, walls, taps, cables, and user outlets**.**

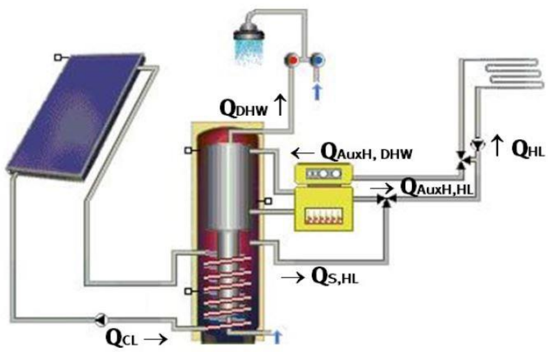


Fig. 2: First case of the study containing a single storage tank of the solar system [10].

The following are the calculations for a solar system with a single storage tank [10]:

$$Solar\ fraction - Total = \frac{Q_{CL}}{Q_{CL} + Q_{AUXH.DHW} + Q_{AUXHL}} \quad (1)$$

$$Solar\ fraction - \ DHW = \frac{Q_{CL} - Q_{S,HL}}{Q_{CL} + Q_{S,HL} + Q_{AUXH.DHW}} \quad (2)$$

$$Solar\ fraction - Heating = \frac{Q_{S,HL}}{Q_{S,HL} + Q_{AUXHL}} \quad (3)$$

where,

CL	: Collector loop
AUXHL	: Auxiliary heating
S	: Solar output based on the storage tank (net)
HL	: Heating loop
DHW	: Domestic hot water (including circulation)

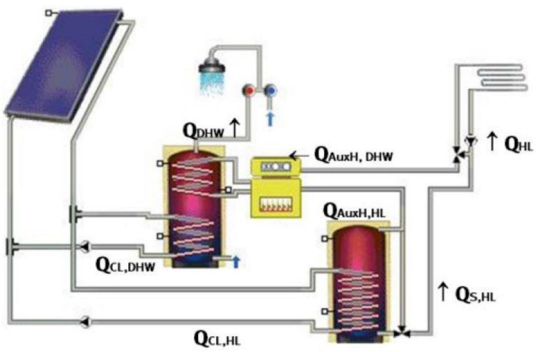


Fig. 3: Second case of the study containing two storage tanks of the solar system [10].

The solar savings fraction, also known as the solar fraction (f), is the amount of energy provided by solar technology as a percentage of total energy used.

The calculations for a solar system with a combined storage tank are as follows [10]:

$$Solar\ fraction - Total = \frac{Q_{CL,DHW} + Q_{S,HL}}{Q_{CL,DHW} + Q_{AUXH.DHW} + Q_{AUXHL}} \quad (4)$$

$$Solar\ fraction - DHW = \frac{Q_{CL,DHW}}{Q_{CL,DHW} + Q_{AUXH.DHW}} \quad (5)$$

$$Solar\ fraction - Heating = \frac{Q_{S,HL}}{Q_{S,HL} + Q_{AUXHL}} \quad (6)$$

- Calculation of Economic Efficiency

For the evaluation of the performance of solar water heater, its efficiency should be calculated. Collector efficiency is the ratio between the rates of useful heat (QU) transferred by solar radiation on the cover plate. Efficiency can be calculated as follows [20]:

$$\eta = (\text{Heat energy out})/(\text{Heat energy in}) = Qout/Qin \quad (7)$$

$$Q_{out} = m \times C_p \times \Delta T \quad (8)$$

where,

Q_{out}: Heat extracted from the collector (W)
m: Mass flow rate that is a measurement of the amount of water flowing around the hot water loop (kg/s)
C_p : Specific heat of water. (*J/kg. °C*)
ΔT: Difference in temperature before and after heat transfer (*°C)*

Equation (8) shows that the heat is extracted from the collector at a rate that can be measured by means of the amount of heat transmitted to the fluid passed inside the collector.

$$Q_{in} = A_c \times G_t \quad (9)$$

$$\eta = Qout/(Ac \times Gt) \quad (10)$$

where,

A_c: Size of the collector
G_t : Total solar radiation intensity (W/m^2)
η: Collector efficiency

- Heat removal factor

Heat removal factor (Fr) is the ratio of the useful energy calculated using (T_i – T_a) to that calculated using (T_{pm} – T_a).
The average absorber-surface-temperature can be replaced by the temperature of the fluid entering the collector (T_i) if the useful energy is divided by a 'heat removal factor' (Fr). The heat removal factor is a function of the flow rate of the heat transfer fluid [20]:

$$F_r = \mathrm{m} \times C_p \times (T_o - T_i)/(A_c \times \mathrm{G}_t - \mathrm{U}_L (Ti - T_a)) \quad (11)$$

The maximum possible available energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain (Q_u) is found by using the collector heat removal factor (F_r) to obtain the maximum possible useful energy gain. Thus, Equation (8) is rewritten as follows:

$$Q_{out} = F_R \times A \times \left(\mathrm{Gt} \times \tau \times \alpha - \mathrm{U}_L \times (T_i - T_a)\right) \quad (12)$$

Equation (14) is the most used relationship to calculate the energy gain in the collector with consideration of the flow rate of the heat transfer fluid.

$$\eta = F_r\,(\mathcal{T}\alpha) - F_R\,\mathrm{U}_L\,(Ti - Ta)\;/\mathrm{G}_t \quad (13)$$

$$\eta = \mathrm{m} \times Cp \times (T_{out} - T_{in})/(A_c \times \mathrm{G}_t) \quad (14)$$

Where,

Q_u: Energy absorbed by the collector (W/m^2)

A_c: Size of the collector (m^2)

F_r: Collector heat loss factor

U_L: Overall heat loss (W/m^2°*C)*

G_t: Total solar radiation intensity (W/m^2)

T_i: Temperature of incoming water(*°C)*

T_{out}: Temperature of the water out (*°C)*

$\mathcal{T}$: Transmissivity of glass cover

α: Absorptivity of absorber plates

C_p: Specific heat of water. (*J/kg. °C*)

T_a: Ambient air temperature. *(°C)*

2.1. Economics of Solar Systems

Solar systems are always bivalent since they can never be exclusively responsible for supplying thermal energy, at least not year-round. As a result, they are connected to conventional systems upstream and serve as "fuel savers" by conveying more or less preheated water to the downstream heating system. The investment costs of a solar thermal system are calculated over the system's lifespan, taking into account simple interest and a sum for maintenance and operational expenditures. The heating price in cents/kWh is calculated using the annual heating amounts supplied. The cost of heating a kilowatt-hour generated by solar energy is comparable to the cost of producing hot water from electrical current, however the latter is now far cheaper for bigger systems. In the next years, this advancement will permit and expand the usage of solar thermal systems in medium-rise housing construction. The money saved from not burning fossil fuels is not included in this calculation. However, as a result of an enhanced social image and a significant improvement to home surroundings with the obviously ecological "advertisement," many renters are now accepting slightly higher heating energy expenses [21].

3. Results and Discussions

The simulation software is T*SOL 2018 R3 and all calculations were carried out using this software for the solar heating system. The results were obtained by a mathematical model of the thermal system with variable time steps of up to 6 minutes.

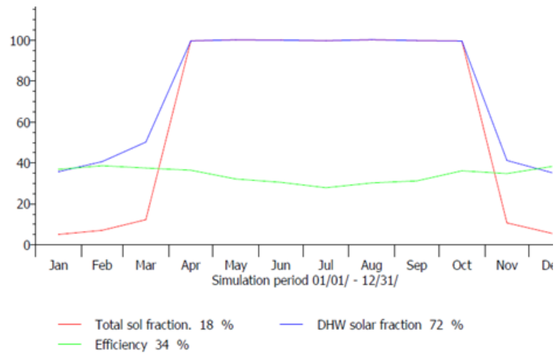
3.1. Results for first case study with one storage tank

The results include total solar fraction, DHW the proportion of solar energy, and the efficiency that are shown in Table 1. It is clear that the total solar fraction, from January to April, increases from 5% to 12%, and is constant from April to November, then it reaches 100%, and finally declines from November to December to reach 5.5%. Domestic hot-water solar fraction increases from January to April from 36% to 50%, and is constant from April to November, then it reaches 100%, and also declines from November to December to reach 35%. However, it is noted that the efficiency changes along the year, increasing and decreasing, until it reaches 34%.

Figs. 4-11 indicate the relation between total solar fraction, domestic hot water (DHW) solar fraction, and efficiency. It is seen that the total solar fraction, during the year, lowers in the winter and increases in the summer. Generally, it reaches 18 %. Domestic hot water solar fraction, during the year, lowers in the winter and increases in the summer. Overall, it reaches 72 %. Nevertheless, it is noted that the efficiency changes along the year, increasing and decreasing, until it reaches 34%.

Table 1: Output data of year-long variation of total solar fraction, domestic hot water (DHW) solar fraction, and efficiency for the first case study.

		Total solar fraction	**DHW solar fraction**	**Efficiency**
Daily value	**Total period**	**18 [%]**	**72 [%]**	**34 [%]**
from	to			
01/01/	02/01/	5.0	36	37
02/01/	03/01/	7.0	41	39
03/01/	04/01/	12	50	38
04/01/	05/01/	100	100	36
05/01/	06/01/	100	100	32
06/01/	07/01/	100	100	31
07/01/	08/01/	100	100	28
08/01/	09/01/	100	100	30
09/01/	10/01/	100	100	31
10/01/	11/01/	100	100	36
11/01/	12/01/	11	41	35
12/01/	01/01/	5.5	35	38



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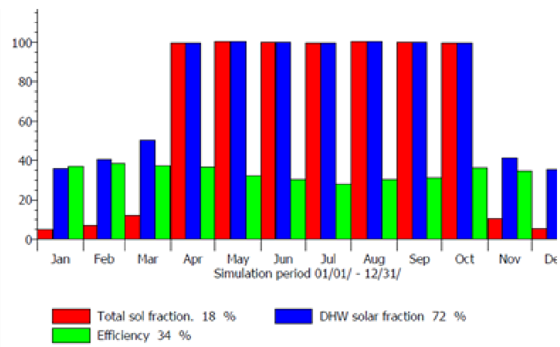


(b)

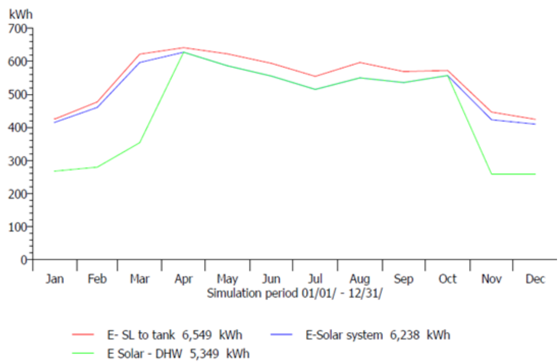
Fig. 4.: Year-long variation of total solar fraction, domestic hot water (DHW) solar fraction, and efficiency for the first case study; (a): line chart, (b): bar chart.

The results include solar energy to tank, energy-solar system, and energy-solar DHW as shown in Table 2. It is noted that the solar energy to tank, energy-solar system, and energy-solar DHW varies along the year; increasing and decreasing.

Table 2: Output data of year-long variation Energy solar (E-solar) to tank, Energy solar (E-solar) system, and Energy solar to domestic hot water (E-solar DHW) for the first case study.

		E- Solar to tank	E-Solar system	E Solar - DHW
Total period		6,459 [kWh]	6,238 [kWh]	5,349 [kWh]
from	to			
01/01/	02/01/	425	416	268
02/01/	03/01/	477	461	280
03/01/	04/01/	622	597	354
04/01/	05/01/	642	628	628
05/01/	06/01/	623	587	587
06/01/	07/01/	594	556	556
07/01/	08/01/	555	515	515
08/01/	09/01/	597	550	550
09/01/	10/01/	569	536	536
10/01/	11/01/	573	557	557
11/01/	12/01/	447	424	259
12/01/	01/01/	425	410	259

Figs. 5-a, and 5-b indicate the relation between Energy solar to tank, Energy solar system, and Energy solar (DHW). It is seen that, during the year, Energy solar to tank equals 6.459 kWh, Energy solar system equals 6.459 kWh, and Energy solar (DHW) equals 5.349 kWh. One of the most important output-data from the used software (T*SOL) is the usage of solar energy as a percentage of total consumption. It represents the monthly amount of the building's thermal needs that can be met by a solar water heater (SWH). As shown in Fig. 6, the total solar contribution from May to October is sufficient to meet all the requirements of the residential building and all the required energy is supplied by the solar collectors. But during the months from November to April, the total energy consumption is very high, and the solar collectors can't supply all the required energy.



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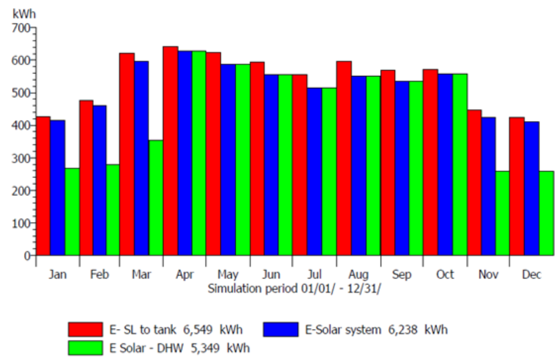


(b)

Fig. 5: Relation of solar energy to tank (kWh) and energy to solar tank versus simulation period for the first case study; (a): line chart, (b): bar chart.

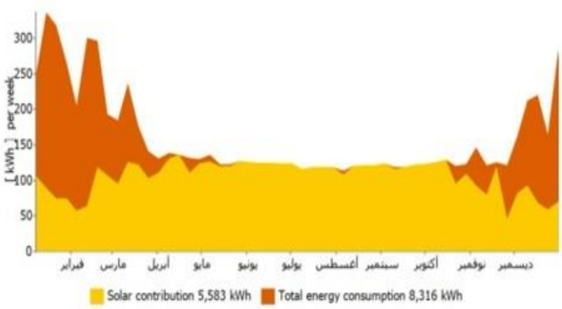


Fig. 6: Solar energy consumption as percentage of total consumption for the first case study.

Also, the highest need for the water heating system occurs in December and January and the collectors supply only about 15% of the total energy required. Actual yields can be deviated from these values due to the fluctuations in climate, consumption, and other factors as shown in Fig. 7.

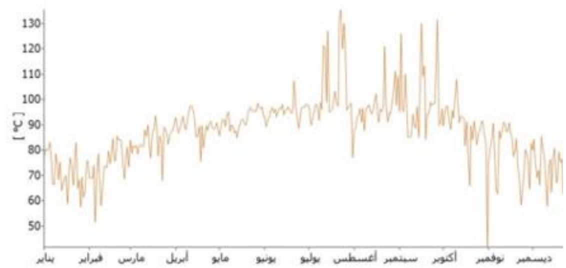


Fig. 7: Daily maximum collector temperature by the present study by T*SOL software for the first case study.

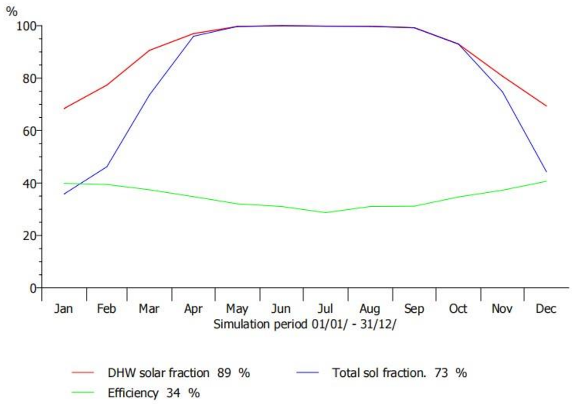
3.2. Results for the second case study with two storage tanks

The results include Total solar friction, DHW solar fraction, and the efficiency that are shown in Table 3. It is seen that the total solar fraction from January to May increases from 68% to 97%, and is constant from May to September. It reaches 100%, and declines from September to December to reach 69%. Domestic hot water solar fraction increases from January to May from 36% to 96%, and is constant from April to September. It reaches 100%, and also declines from September to December to reach 44%.But, it is noted that the efficiency changes along the year, increasing and decreasing, until it reaches 34%.

Table 3: Output data of Year-long variation of total solar fraction, domestic hot water (DHW) solar fraction, and efficiency for the second case study.

		Total solar fraction	**DHW solar fraction**	**Efficiency**
Monthly value	**Total period**	89[%]	73 [%]	35 [%]
from	to			
01/01/	01/02/	68	36	40
01/02/	01/03/	77	46	39
01/03/	01/04/	91	74	37
01/04/	01/05/	97	96	35
01/05/	01/06/	100	100	32
01/06/	01/07/	100	100	31
01/07/	01/08/	100	100	29
01/08/	01/09/	100	100	31
01/09/	01/ 10/	99	99	31
01/ 10/	01/ 11/	93	93	35
01/11/	01/ 12/	81	75	37
01/12/	01/01/	69	44	41

Figs. 8-a, and 8-b indicate the relation between total solar fraction, domestic hot water (DHW) solar fraction, and efficiency. It is seen that the total solar fraction, during the year, decreases in winter months and increases in summer months. It reaches 73 %. Domestic hot-water solar fraction, during the year, decreases in winter months and increases in summer months. It reaches 89 %. Nonetheless, it is noted that the efficiency changes along the year, increasing and decreasing, until it reaches 34%.



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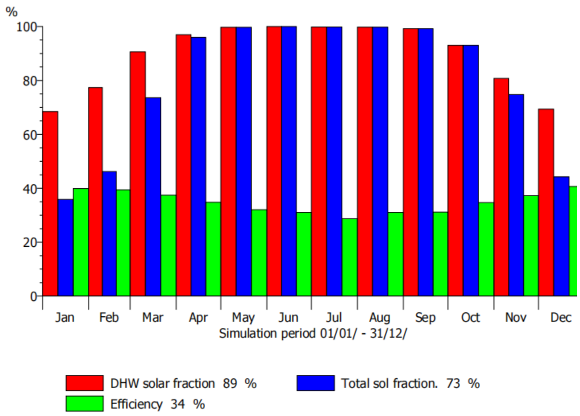


(b)

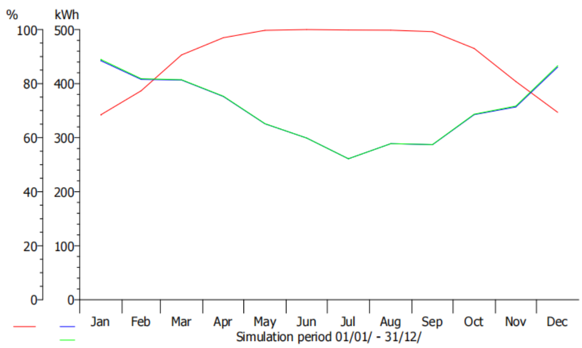
Fig. 8: Year-long variation of the percentage of the solar energy to tank (kWh), and energy to solar tank for the second case study; (a): line chart, (b):bar chart.

The results that include domestic solar fraction, energy domestic hot-water (DHW), and energy preset domestic hot-water (DHW) are shown in Table 4. It is noted that the domestic solar fraction, energy domestic hot-water (DHW), and energy preset domestic hot-water (DHW) vary along the year; increasing and decreasing.

Table 4: Output data of Year-long variation Energy solar (E-solar) to tank, Energy solar (E-solar) system, and Energy Preset to domestic hot water (E-Preset DHW), for the second case study.

		DHW solar fraction	E. DHW	E. Preset - DHW
	Total period	89[%]	4,225 [kWh]	4,235 [kWh]
from	to			
01/01/	01/02/	68	442	445
01/02/	01/03/	77	408	409
01/03/	01/04/	91	407	407
01/04/	01/05/	97	376	377
01/05/	01/06/	100	326	326
01/06/	01/07/	100	299	299
01/07/	01/08/	100	261	261
01/08/	01/09/	100	289	289
01/09/	01/10/	99	287	287
01/10/	01/ 11/	93	343	343
01/11/	01/ 12/	81	357	359
01/12/	01/01/	69	431	433

Figs. 9-a and 9-b indicate the variation of domestic solar fraction, energy domestic hot-water (DHW), and energy preset domestic hot-water (DHW). It is seen that the total solar fraction, during the year, lowers in the winter and increases in the summer. It reaches 89 %. Energy domestic hot-water (DHW) reaches 4.225 kWh, and Energy preset domestic hot-water (DHW) reaches 6.459 kWh.



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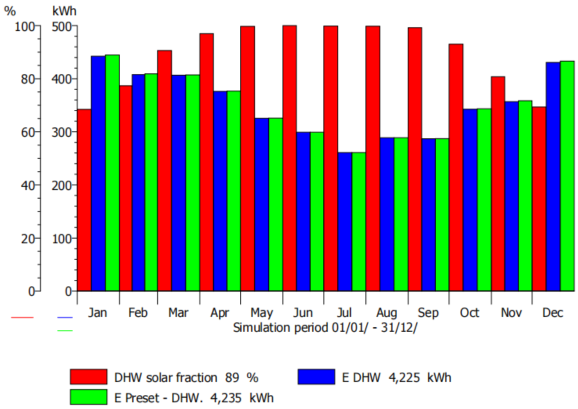

(b)

Fig. 9: Variation of the domestic solar fraction, energy domestic hot-water (DHW), and energy preset domestic hot-water (DHW) for the second case study; (a): line chart, (b): bar chart.

As shown in Fig. 10, the total solar contribution from May to October is sufficient to meet all the requirements of the residential building and all the required energy is supplied by the solar collectors. But during the months from November to April, the total energy consumption is very high, and the solar collectors cannot supply all the required energy.

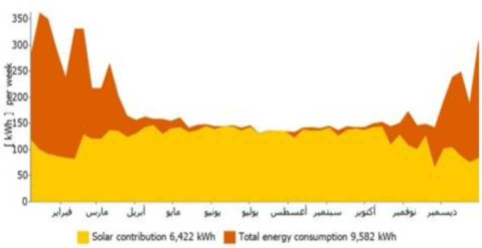

Fig. 10: Solar energy consumption as percentage of total consumption for the second case study.

Also, the highest need for the water heating system occurs in December and January and the collectors supply only about 15% of the total energy required. Actual yields can be deviated from these values due to fluctuations in climate, consumption, and other factors as shown in Fig. 11

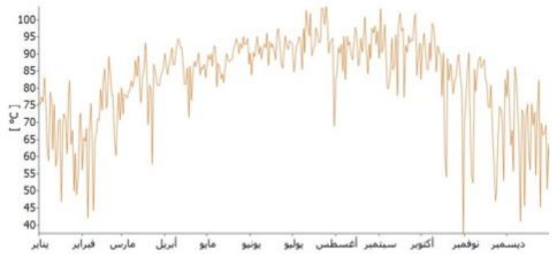

Fig. 11: Daily maximum collector temperature of the present study by T*SOL software for the second case study.

3.3. Financial Analysis

The results include relation between cash-flow, balance, and bank account in the next 20 years. The results stated that the total cost of installing and purchasing this hybrid system is very high compared with the cost of power from the main grid. But from an economic point of view, this system can last up to 20 years of operation and it can return its value after 14 years. So, the owner of this system can have free energy without any cost for more than 6 years. In addition to the clean energy out of the system, the positive effect is very beneficial on the environment as shown in Tables 5-a, and 5-b.

Table 5-a: Yearly results for the financial analysis for the first case study.

Year	**Cash flow**	**Balance**	**Bank account**
1	459	459	4032
2	468	938	4305
3	477	1439	4597
4	487	1962	4908
5	497	2507	5240
6	506	3076	5595
7	517	3670	5974
8	527	4289	6379
9	537	4933	6811
10	548	5605	7273
11	559	6304	7765
12	570	7032	8291
13	582	7790	8853
14	593	8578	9453
15	605	9398	10093
16	617	10250	10777
17	630	11136	11507
18	642	12057	12286
19	655	13013	13118
20	668	14007	14007

Table 5-b: Yearly results for the financial analysis for the second case study.

Year	Cash flow	Balance	Bank account
1	542	542	4066
2	553	1109	4377
3	564	1700	4713
4	575	2318	5075
5	587	2963	5464
6	599	3636	5883
7	611	4337	6334
8	623	5068	6820
9	635	5830	7343
10	648	6624	7906
11	661	7450	8512
12	674	8311	9165
13	688	9206	9868
14	701	10137	10625
15	715	11106	11440
16	730	12113	12317
17	744	13161	13262
18	759	14249	14279
19	774	15379	15374
20	790	16553	16553

Fig. 12 shows the financial analysis of the cash flow, balance, and bank account for the two case studies over 20 years.

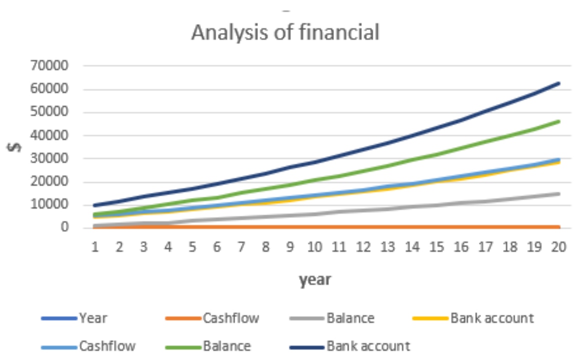

Fig. 12: Financial analysis of the cash flow, balance, and bank account for the two case studies.

4. Conclusions

The proposed system is used for space heating, and heating domestic water. The solar system comprises solar flat-plate collectors. The system heats water and stores the hot water in heat exchanger storage tanks.

Based on the previous results and discussions, the following concluding points can be stated:

- Using an efficient simulation software (T*SOL) with accurate data, including climate change of the selected site and all characteristics of the solar and wind turbine system, gives an accurate view of the benefits of using renewable energy.
- The solar water heating system is eco-friendly and may be used as an alternative water heating system to save money, reduce energy consumption, and reduce carbon emissions. Retrofitting the currently used conventional water heaters should be considered.
- From the economic point of view, this system could last up to 20 years of operation and could return its value after 14 years. So, this system gives free energy at no cost for over 6 years.
- Solar water heating (SWH) is a developed and marketed technology that is one of the most effective ways to transform solar energy into thermal energy. However, there are ways to improve the system's performance in order to improve its dependability and efficiency..
- Using a solar water heating system saves energy, which helps to minimise home energy demand from power providers. After the system has paid for itself, a solar water heater is a long-term investment that will save money on water heating.
- In the case of use two tanks, each tank has a temperature of 60°*C* for hot water and 55°*C* for heating, so hot water can run summer and winter and warm only winter. In this case, use is made of solar panels for heating when separated in the summer, leading to rapid heating of hot water on a summer highway.

Nomenclature

A_c:	the size of the collector (m)
Cp:	specific heat of water. (*J/kg. K*)
F_r:	collector heat loss factor
G_t:	total solar radiation intensity (W/m^2)
Q_u:	the energy absorbed by the collector (W/m^2)
T_i:	the temperature of incoming water (°*C)*
T_{out}::	the temperature of the water out (°*C)*
T_a:	ambient air temperature. *(°C)*
$\mathcal{T}$:	transmissivity glass cover
UL:	overall heat loss (W/m^2°*C)*
α:	absorptivity of absorber plates.

Abbreviations

AuxH	: Auxiliary heating
AC	: Alternating current
CL	: Collector loop
DHW	: Domestic hot water
ESS	: Energy storage systems
E-SOL	: Energy Solar

FPC : Flat-plate Collector
HTF : Heat Transfer Fluid
HL : Heating loop circulation
PVT : Photovoltaic/thermal
S : Solar yield as per the storage tank
SWH : Solar water heater
USD : United States dollars

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