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Technical and Financial Assessment of Glazed and Evacuated Tubes Solar Collectors for Domestic Water Heating Application in Palestine

التقييم الفني والمالي للواقط الشمسية المسطحة المغطاة واللواقط الشمسية ذات الانابيب المفرغة في تسخين المياة للتطبيقات المنزلية في فلسطين

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Abstract

Palestine owns high potential of solar energy radiations at the same time it suffers from high prices and shortage of conventional energy sources. The exploitation of renewable energy sources especially solar energy is considered one of the robust alternatives. A passive open-loop domestic solar water heater (SWH) system for a typical house in Palestine using glazed and evacuated tubes solar collectors is technically and financially evaluated in this paper. Palestine territories (West bank and Gaza strip) are divided into five sites in order to study the performance of domestic SWH all over the country. The RETScreen® software solar water heating project model is utilized in this paper to perform simulations for different cases and conditions. The simulations approved that the optimal tilt angle of the solar collectors in all sites is the latitude of each site or latitude plus 15, therefore the tilt angle is adjusted to 45. Both types of solar collectors selected in the study are mostly similar to the brands available in the Palestinian local market with approximately similar gross collector area. The study assumes unified price rate of electricity all over Palestine. The solar fraction, financial indices and reduced greenhouse (GHG) emissions are estimated for each case and condition for comparative analysis. The gross area of glazed or evacuated tubes solar collectors required to achieve at least 50% solar fraction is about 4.6 m^2 of energy in all locations. This corresponds to payback ranging from 2 to 2.5 years. Installing one collector (~2.3 m^2) obtains less than 50% solar fraction while installing 2 collectors obtains more than 70%. The value of total annual GHG emissions reduction for glazed type collector of 2.31 m^2 gross area is ranging from 3.2 to 3.5 tons of CO_2 which is equivalent to 7.3 to 8.2 barrel of crude oil. Larger amount of reduced GHG emissions are gained in case of using evacuated tubes collectors. The performance of SWH systems is mostly similar all over Palestinian territories whether glazed or evacuated tubes are used. This is approved by estimating solar fractions and financial indices. Utilizing SWH technology in Palestine for water heating in domestic sector is feasible whether glazed or evacuated tubes are used.

Keywords: Solar Water Heating System; Evacuated Tubes And Glazed Solar Collectors; Retscreen; Solar Fraction; Palestinian Territories, GHG Emission, Financial Indices.

ملخص

تمتلك فلسطين إمكانات عالية من الطاقة الشمسية وفي نفس الوقت تعاني ارتفاعاً في اسعار الطاقة ونقصاً كبيراً في مصادر الطاقة التقليدية. إن استغلال مصادر الطاقة المتجددة وعلى وجه الخصوص الطاقة الشمسية يعتبر احد الحلول الناجعة للخروج من هذه المشكلة. في هذه الورقة العلمية تم عمل تقييم فني ومالي لأنظمة السخانات الشمسية المنزلية ذات النظام الحلقي المفتوح التي تعمل بالدفع الذاتي حيث تم تناول نوعين رئيسيين من اللواقط الشمسية وهما اللاقط الشمسي المسطح المغطى glazed type واللاقط الشمسي ذو الانابيب المفرغةevacuated tubes. تم تقسيم المناطق الفلسطينية (الضفة الغربية وغزة) الى خمس مناطق مختلفة وذلك لدراسة اداء السخان الشمسي في جميع انحاء البلاد. تم الاستعانة ببرناج RETScreen® وعلى وجه الخصوص الجزء الذي يُعنى بتحليل جدوى مشروع تسخين المياة بواسطة السخان الشمسي حيث تم القيام بعدة دراسات محاكاة حسب ظروف وخصوصية الدراسة. لقد أثبتت دراسة المحاكاة أن زاوية الميلان المثلى للواقط الشمسية هي زاوية خط العرض للموقع أو زاوية خط العرض مضافاً لها 15° وعليه تم تحديد الزاوية 45°. تم إختيار اللواقط الشمسية في هذه الدراسة لتكون مشابهة الى حد كبير للواقط الشمسية المتوفرة في السوق الفلسطيني المحلي مع مراعاة مساحة

مماثلة لكلا النوعين. كذلك افترضت الدراسة سعراً موحداً لبيع الكيلوواط ساعة في جميع انحاء المناطق الفلسطينية. يقوم البرنامج، حسب ظروف وشروط الدراسة، بحساب نسبة الطاقة التي يمكن تزويدها بواسطة السخان الشمسي (solar fraction) وكذلك المؤشرات المالية بالاضافة الى كمية الانبعاثات التي يمكن تقليلها. إن مساحة اللواقط الشمسية اللازمة لإنتاج على الاقل 50% من الطاقة اللازمة لتسخين المياة بواسطة الطاقة الشمسية من كلا النوعين المستخدمين هي 4.6م^2 في جميع المواقع علماً أن فترة الاسترجاع تتراوح ما بين 2-2.5 سنة. إن تركيب لاقط شمسي واحد من كلا النوعيين بواقع 2.3م^2 ينتج اقل من 50% من النسبة المطلوبة بينما تركيب لاقطين ينتج من كلا النوعيين يعطي ما نسبته 70%. إن قيمة الانبعاثات السنوية التي يمكن تقليلها جراء استخدام السخان الشمسي المنزلي ذو اللاقط الشمسي المسطح المغطى (مساحة 2.31 م^2) تتراوح ما بين 3.2 -3.5 طن ثاني اكسيد الكربون وهو ما يعادل 7.3 -8.2 برميل زيت خام .إن أداء انظمة السخانات الشمسية في فلسطين متشابه الى حد كبير سواء أُستخدم اللاقط الشمسي المسطح المغطى او اللاقط الشمسي ذو الانابيب المفرغة. ان هذه النتيجة تم تدعيمها من خلال حسابات المؤشرات المالية للحالات التي تم دراستها وكذلك حساب نسبة الطاقة المتولدة من السخان الشمسي solar fraction. إن استخدام تكنولوجيا السخان الشمسي في القطاع المنزلي في فلسطين يعتبر مجديا سواء أُستخدم اللاقط الشمسي المسطح المغطى او اللاقط الشمسي ذو الانابيب المفرغة.

الكلمات المفتاحية: أنظمة السخان الشمسي، اللواقط الشمسية ذات الانابيب المغرغة، اللواقط الشمسية المسطحة المغطاة، RETScreen®، المناطق الفلسطينية، الانبعاثات الغازية، المؤشرات المالية.

Introduction

The excessive usage of energy depending on conventional energy sources increases the concentration of carbon dioxide in our atmosphere. The expected depletion of fossil fuels is another catastrophic problem. The systematic exploitation of renewable energy sources is one of the solutions adopted by energy decision makers all over the world.

Palestine suffers from shortage and high prices of energy sources because of the political situation. Palestine purchases all its needs of petroleum products from Israeli market and about 92% of electrical energy from the Israeli Electric Corporation (IEC) which is considered one of the main problems to Palestinian economy.

Solar energy radiations is abundant in Palestine (5.46 kWh/m^2.day) which makes the exploitation of solar energy feasible.

Solar energy technologies use the sun's energy and light to provide heat, light, hot water, and electricity. Among those technologies is the solar water heating (SWH) technology which is defined as technology used to transform sunlight energy into heat energy used to heat water utilizing solar thermal collector.

Solar water heaters (SWH) are extensively used in the residential sector in Palestine, in which 68.2% of households use solar family systems, whereas, it is limited in the service and industry sectors (PCBS, 2010). The existing installed capacity in all sectors is totaled to 1,533,000 m² of which 7100 m² in the service sector, this can produce 650 GWh annually with corresponding CO_2 savings of 395,000 tons per year (PCBS, 2010 and PEC, 2007).

The energy consumption in service and building sectors in Palestine and in all other developing countries represents a major part of energy bill, approximately equal to 75% (PEA, 2010). The electric water heating consumes the most electric power and emits the most pollutants during its life cycle (Taborianski and Prado, 2004).

Palestine is represented by five areas: Gaza city represents the southern part and locates in the Mediterranean coast. Hebron is annexed to southern parts as well. Nablus city represents the northern part while Ramallah and Jericho represent the middle parts of Palestine.

The potential of SWH application for heating commercial greenhouses has been investigated in Iran and the project viability analysis is performed using RETScreen® software (Ramedani Z. and et.al. 2012). Techno-economic viability of SWH technologies for domestic purposes using different types of SWH collectors are simulated using RETScreen® software (Abd-ur-Rehman M. and Al-Sulaiman A. 2014).

Environmental, technical and financial feasibility study of solar power plants in Iran utilizing RETScreen® software has been analyzed (Mirzahosseini M. and Taheri T., 2012), while the same software is utilized to investigate the potential of SWH application in Oman (Gastli, and Charabi, 2011).

The feasibility analysis of domestic SWH systems has been investigated in Greece (Kaldellis et.al. 2005). The regional, technical, and economic performance of residential rooftop SWH technology in the U.S. has been examined and focuses on the application of SWH to consumers (Cassard H. et.al. 2011). The energy and CO_2 savings of an institutional collective SWH system in Palestine is evaluated (Yasin A., 2011).

This paper contributes in establishing comparative analysis between evacuated tube and glazed solar collectors for domestic SWH systems in Palestine which is considered very important for the researchers as well as the users. RETScreen® software SWH project model (RETscreen® manual, 2005) is utilized in this research which is considered another contribution. The software is used to assess the energy based on solar radiation on horizontal and tilted surface, energy delivered from SWH system, GHG emissions, and energy saving. Various financial indices are utilized in this study to evaluate the economic benefits like payback period, equity payback period and pre-tax IRR.

Geographical Context and Metrological Data

Palestine (West Bank & Gaza Strip) as shown in Figure 1.a lies on the western edge of the Asian continent and the eastern extremity of the Mediterranean Sea, between $34^o20'$– $35^o30'$ E and $31^o10'$– 32^o30 N. It includes two land areas; the West Bank 5800 km^2 and the Gaza Strip 365 km^2.

Palestine's elevation ranges from 300m below sea level in the Jordan Valley to sea level along the Gaza Strip seashore and it reaches 1000m above sea level in some locations in West Bank.

The climatic conditions are varying widely. The coastal climate in Gaza Strip is hot and humid during summer and mild during winter. In the hilly areas of West Bank (Nablus, Ramallah, Jerusalem and Hebron) a cold winter and mild summer weather are prevailed while hot summer and warm winter are prevailed in Jordan Valley.

Palestinian territories can be divided into five topography regions (Atlas, 2014):

- Jordan Valley Region: Its altitude varies between 200-300m below sea level to about 100–200m above sea level. The region is flat with terrain slopes up to 3 degrees.
- Eastern hills: it is extending along the eastern part of the West Bank. The altitude varies between 200 and 800m above sea level and terrain inclination reaches up to 15 and more degrees.
- Central Highlands: it is extending over 120km and comprising Hebron in the south to Tubas in the North. This region is mountainous, with some parts reaching over 1000m above sea level. It is considered the largest part of the West Bank.

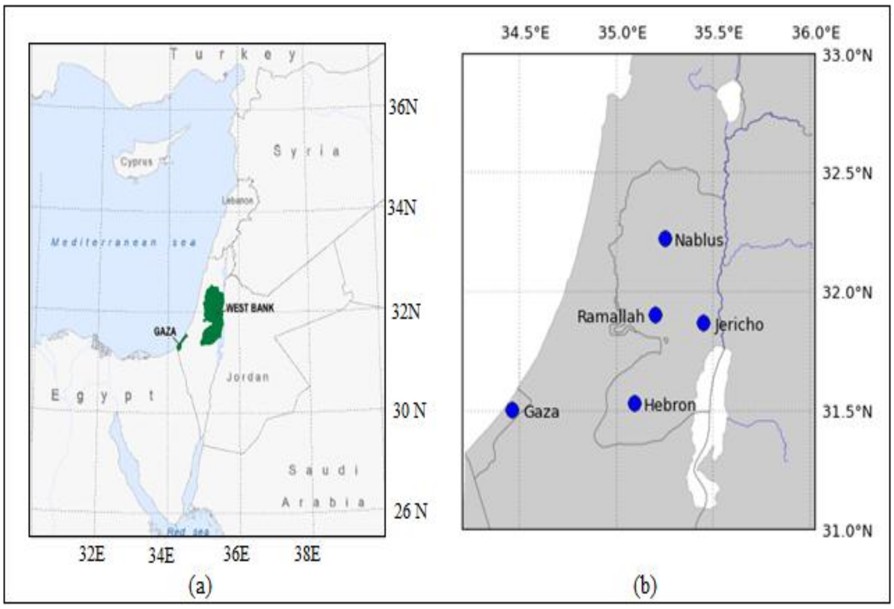

Figure (1): (a) Location the Palestinian Territories in the region, (b) Localization of representative sites within the Palestinian Territories (Atlas, 2014).

- Western West Bank, it includes the districts of Jenin and Tulkarem. The altitude is 100-300m above sea level and mostly low to medium inclined terrain.
- Gaza Strip is mainly flat, with dunes near the coast. The highest point has 105m above sea level.

The metrological data used in this study are mainly based on the Atlas of solar resources of Palestinian territories (Atlas, 2014), the local metrological stations of Najah Energy Research Center, and the database recorded by National Aeronautics and Space Administration NASA.

Five regions or zones are considered to represent all Palestinian territories. The five sites are Gaza, Jericho, Hebron, Nablus and Ramallah (refer to Figure 1.b). Table 1 shows the position of the representative sites.

Table (1): Position of the representative sites.

	Gaza	**Hebron**	**Jericho**	**Nablus**	**Ramallah**
Latitude	31° 30' 00"	31° 31' 46"	31° 52' 00"	32° 13' 16"	31° 53' 59"
Longitude	34° 28' 00"	35° 05' 38"	35° 27' 00"	35° 15' 16"	35° 12' 15"
Elevation	39 m	907 m	-233 m	569 m	875 m

The monthly variations of daily solar radiation on horizontal surface of the selected sites are presented in Figure 2. The data are imported from Atlas of solar resources of Palestine (Atlas, 2014). Figure 2 indicates that differences between sites are small as the variability in yearly averages of global horizontal irradiation (GHI) is only 1.5% while monthly averages have differences ranging from 1.1% in May to 5.2% in February (Atlas, 2014).

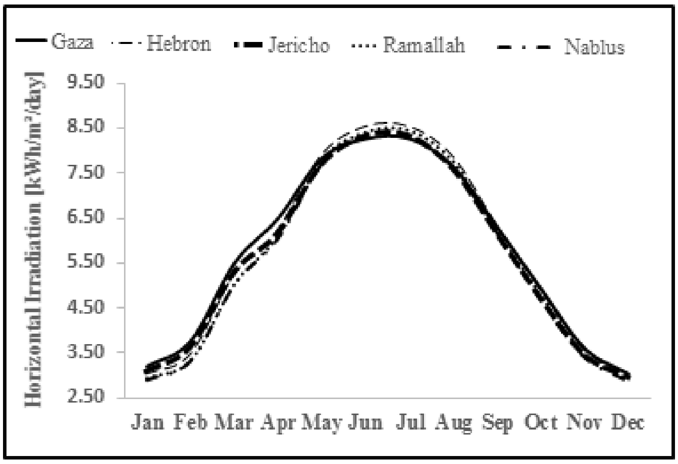

Figure (2): Monthly variation of daily solar radiation on horizontal surface**.**

Figure 3 shows the monthly average temperature all over the year for the selected sites. There are variations in average air temperature between the representative sites, therefore the analysis should be performed for each site in order to have accurate results even though the selected sites have approximately similar solar radiation potential.

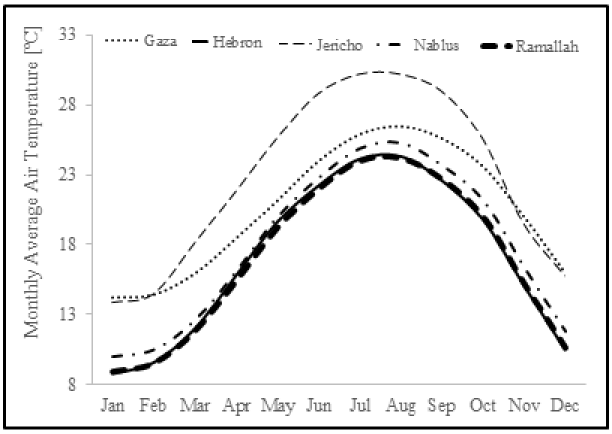

Figure (3): Monthly average air temperature.

To select the proper slope of the solar collector, comparative study for annual solar energy on horizontal and tilted surfaces are presented in Figure 4.

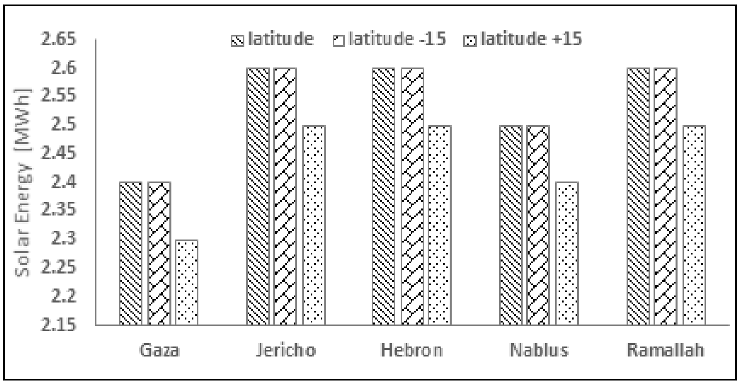

Figure (4): Solar energy on the collector with respect to three adjustments of tilt angle.

Generally speaking solar collector angle is set equal to the absolute value of the latitude of the site. In summer season, the slope is adjusted to latitude minus 15° and typical optimum value for slope adjustment in winter is latitude plus 15°. It is clear from Figure 4 that optimum slope of the solar collector is latitude of the site or latitude plus 15º as the solar energy increases for all sites at those slopes.

Description of the Solar Water Heater System and the RETscreen Model

The typical configuration of the domestic SWH used in this study is shown in Figure 5 which is called open loop passive solar water heater system. It is a roof mounted system that includes storage tank, solar collectors and auxiliary parts.

The Passive systems collect solar energy without direct recourse to any source of conventional power to support the collection while open-loop systems are defined as systems in which the collector performance is independent of the storage temperature (Goswami Y. and Kreith F., 2007).

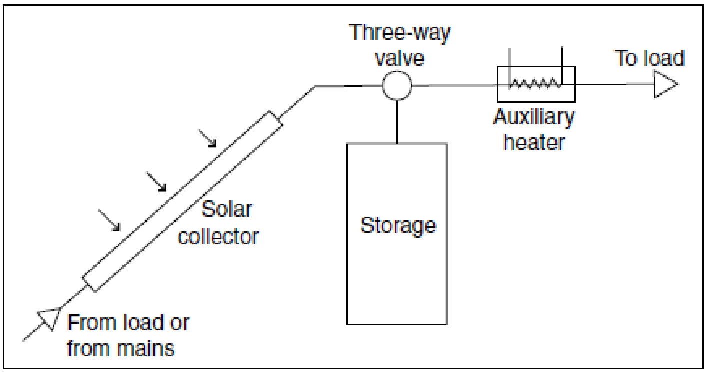

Figure (5): Open-loop passive SWH system.

The energy performance of SWH system for a specific site is predominantly depending on the collector type such as glazed, unglazed and evacuated tube solar collectors. The area, efficiency, solar tracking mode, tilt angle and azimuth of the solar water heater are playing significant role in the performance SWH system as well.

RETScreen® software is utilized in this study for simulation of evacuated tube and glazed SWH collectors. Glazed and evacuated tubes solar collectors share the same parameters and follow the same equations and relations in the energy model as both are wind-independent. Effects of angle of incidence, losses due dirt, loss of heat through the piping and the solar tank are considered through separate factors (RETScreen engineering & cases textbook, 2004).

The RETScreen's energy model shown in Figure 6 requires weather data which are supplied by users. These data are important to compute a number of environmental variables as the monthly average daily irradiance, cold water temperature and the amount of water required to be heated (load). In this study some data are imported from RETScreen Online Weather Database (RETScreen, 2015) but specifically the average daily irradiance are imported from Palestinian Atlas (Atlas, 2014). The fundamentals of solar energy are utilized by the software for calculating the environmental variables used throughout the model (Duffie and Beckman, 1991).

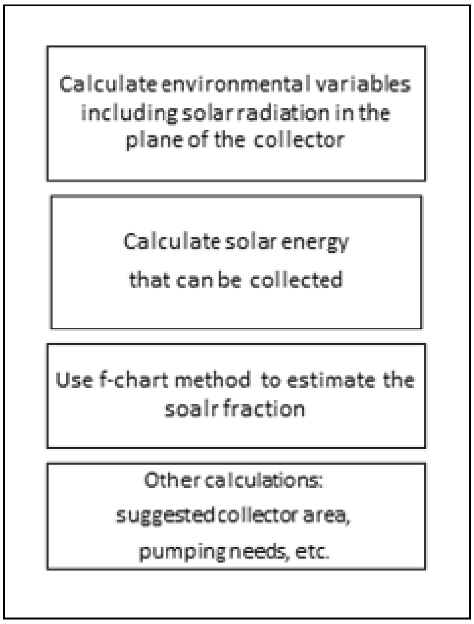

Figure (6): RETScreen® software Solar Water Heating Energy Model Flowchart.

According to the flow chart shown in Figure 6 the solar radiation in the plane of the solar collector is required to estimate the efficiency of the collector and the actual amount of solar energy collected. The RETScreen SWH Project Model uses Liu and Jordan's isotropic diffuse algorithm.

The monthly average radiation in the plane of the collector, $\bar{H}_T$ (Duffie and Beckman, 1991) is calculated using equation (1) assuming isotropic diffuse:

$$\bar{H}_T = \bar{H}_b \bar{R}_b + \bar{H}_d \left(\frac{1+\cos(\beta)}{2}\right) + \rho_g \bar{H}\left(\frac{1-\cos(\beta)}{2}\right) \quad (1)$$

Where $\bar{H}_b \bar{R}_b$ represents solar radiation coming directly from the sun in which $\bar{H}_b$ represents the monthly average beam radiation and $\bar{R}_b$ is the purely geometrical factor which depends only on collector orientation γ, site latitude $\emptyset$, and the time of the year n. The $0.5\overline{H}_d(1+cos\beta\ )$ term characterizes the contribution of monthly average diffuse radiation, $\overline{H}_d$, which depends on the slope of the collector, β . The $0.5\rho_g\overline{H}(1-cos\beta)$ term represents reflection of radiation on the ground in front of the collector, the slope of the collector and on ground reflectivity, ρ_g. Plots of the geometrical factor $\overline{R}_b$ are designed as a function of latitude, time of the year and the tilit angle β (Duffie and Beckman, 1991).

The monthly average daily diffuse radiation $\overline{H}_d$ is calculated from global radiation using equations (2) and (3) .

$$\frac{\overline{H}d}{\overline{H}} = 1.391 - 3.560\overline{K}t + 4.189\overline{K}_T^2 - 2.137K_T^3 \quad \text{at} \quad w_s \leq 81.4° \quad (2)$$

$$\frac{\overline{H}d}{\overline{H}} = 1.311 - 3.022\overline{K}t + 3.427\overline{K}_T^2 - 1.821K_T^3 \quad \text{at} \quad w_s \geq 81.4° \quad (3)$$

Where w_s is the sunset hour angle. The monthly average clearness index, $\overline{K}_T$, and monthly clearance index, K_T, can be estimated as shown in equation (4):

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_0} \quad \text{and} \quad K_T = \frac{H}{H_o} \qquad (4)$$

Where H_o and $\overline{H}_o$ are the monthly and average monthly solar radiation outside the earth's atmosphere (extraterrestrial), respectively and they can be calculated using equations (5) and (6):

$$H_o = \frac{24*3600}{\pi} G_{sc}\ (1 + 0.033\cos(\frac{360n}{365})\ ) *$$
$$(\cos\emptyset\ \cos\delta\ sinw_s + \ \sin\emptyset\ \sin\delta\ \ w_s) \qquad (5)$$

$$\overline{H}_o = \frac{24*3600}{\pi} G_{sc}\ (1 + 0.033\cos(\frac{360\ n_m}{365})\ ) *$$
$$(\cos\emptyset\ \cos\delta\ sinw_s + \ \sin\emptyset\ \sin\delta_m\ \ w_s) \qquad (6)$$

Both of the above equations depend on the latitude of the site $\emptyset$, the hour angle w_s ,the day of the year n and the declination angle of the sun δ considering that δ_m and n_m are the monthly mean declination and recommended day of the month respectively (Duffie and Beckman, 1991).

The monthly average daily beam radiation $\overline{H}_b$is simply equal to $\overline{H} - \overline{H}_d$. The energy required by the load is calculated using equation (7)

$$Q_{load} = C_p \rho V_l (T_h - T_c) \quad (7)$$

Where C_p is the heat capacitance of water (4.2 kJ/kg.°C), ρ is the water density (1 kg/L), T_c is the cold water temperature from mains and V_l is the required amount of water in liter (L). The power collected per unit collector area for glazed and evacuated tube collectors is described by equation (8) (RETScreen engineering & cases textbook, 2004):

$$\dot{Q}_{coll} = F_R(\tau\alpha)G - F_R U_L \Delta T \quad (8)$$

Where $\dot{Q}_{coll}$ is the energy collected per unit collector area per unit time, F_R is the collector's heat removal factor, τ is the transmittance of the cover, α is the shortwave absorptivity of the absorber, G (W/m^2), is the global incident solar radiation on the collector , and U_L ($W/m^2.°C$) is the overall heat loss coefficient of the collector and ΔT (°C) is the difference between the temperature of working fluid entering and leaving the collector.

The values of F_R (τα) and F_RU_L are dimensionless parameters that distinguish solar collectors from each other. The detailed specifications of the selected models of glazed and evacuated tubes solar collectors used in this study are shown in Table 2 in the next sections.

The performance of service hot water systems with storage is estimated with the f-Chart method. The derivation of *f* function is not presented here to avoid tedious mathematical equations. The method is explained in details in (Duffie and Beckman 1991). The purpose of this method is to calculate solar fraction *f* which is defined as the fraction of the hot water load that is provided by the solar heating system. Once *f* is calculated, the amount of renewable energy that displaces conventional energy for water heating can be determined (RETScreen engineering & cases textbook, 2004).

RETScreen® Software Simulation

The technical and financial assessment study is performed based on a typical house in Palestine with 6 occupants at occupancy rate of 80% without incentives offered by the local authority. The daily hot water use per typical house is assumed to be is 250L. The storage capacity per collector area is assumed 70L/m². The required load temperature is 60ºC with 7 operating days per week.

The study proposed fixed tracking mode and the latitude of location is taken as tilt angle of the collector. The proposed auxiliary heating system is electrical boiler with 95% efficiency and electrical price rate 0.17$/kWh. The price of electricity all over Palestine is assumed unified for the purpose of comparison.

The study proposed coal as a base fuel type for electricity generation especially electricity is purchased from Israeli Electrical Company (IEC). The greenhouse (GHG) emission factor is 0.84 tons of CO_2 per MWh excluding the transmission and distribution losses which is ranging from 5 to 10% in Palestine. The study does not estimate the GHG reduction income because the GHG emission reduction credit rate is not defined in Palestine.

The inflation rate in Palestine is 15% with 15 years project's life. The total initial cost consists of solar collectors, hot water storage tank, cold water makeup plastic tank, piping system, valves, fixtures and auxiliary heating system (electricity fueled boiler).

In this study simulations are performed to obtain at least 50 % solar fraction and the remaining need is fulfilled by backup fuel that is electricity in our case. The detailed specifications of the selected models of glazed and evacuated tubes solar collectors used in this study are shown in Table 2. Both types of solar collectors have approximately identical gross sectional areas for the purpose of comparison.

Table (2): Specifications of selected SWH collectors (RETScreen® software, 2015).

Manufacturer	Glazed Type	Evacuated Type
	Soltop Schuppisser	**Shangdong Linuo Paradigma**
Model	Cobra 2.3 m^2	CPC 1512
Collector gross area	2.31 m^2	2.28 m^2
Collector aperture area	2.05 m^2	2 m^2
F_r (τα) coefficient	0.71	0.56
F_rU_L coefficient	3.95 (W/m²)/°C	0.84 (W/m²)/°C
Temperature coefficient for F_r U_L	0.000 (W/m²)/°C	0.000 (W/m²)/°C

Results and Discussions

Different indicators were considered in order to study and compare the performance of glazed and evacuated tubes solar collectors implemented in Palestine. RETScreen® software estimates the solar fraction which is considered very important indicator that illustrates the percentage of solar energy delivered from the solar collector to the total energy required by the load. Figure 7 shows the solar fraction with respect to number of glazed SWH collectors.

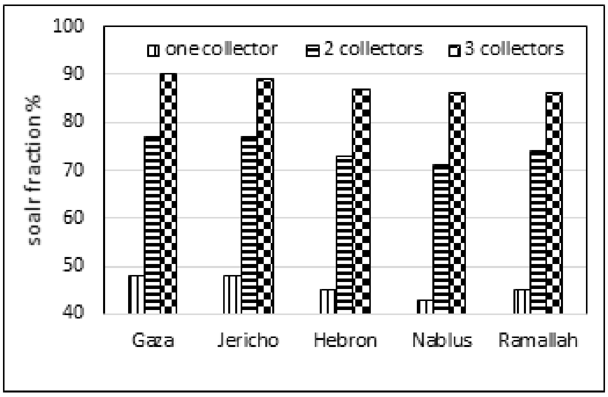

Figure (7): Solar fraction with glazed type collectors.

Figure 7 shows that the solar fraction reaches to about 90% if the number of collectors is three. The solar fraction is mostly similar for all sites considering that the maximum occurs in Gaza city and the minimum occurs in Ramallah and Nablus cities.

In order to obtain solar fraction equal to at least 50%, two solar collectors should be installed at all sites. The solar fraction with two glazed solar collectors in Gaza, Jericho, Hebron, Nablus and Ramallah city is 77%, 77%, 73%, 71%, and 74%, respectively. The required number of collectors and obtained solar fraction with evacuated tube SWH collectors is shown in Figure 8.

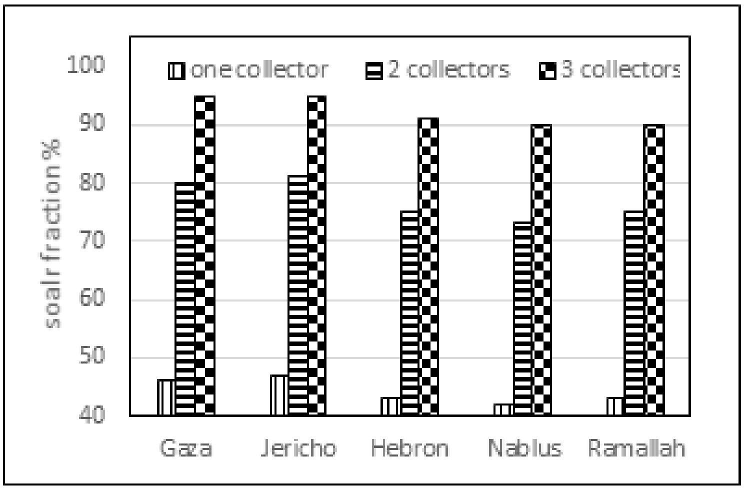

Figure (8): Solar fraction with evacuated tube type collectors.

The simulation shows that in order to obtain at least 50% solar fraction, two evacuated tubes solar collectors should be installed. The solar fraction in Gaza, Jericho, Hebron, Nablus and Ramallah city is 80%, 81%, 75%, 73%, and 75%, respectively. The lowest fraction is obtained in Nablus city but it is considered within the same range.

From the above discussion the solar fraction obtained from evacuated tubes is approximately the same as obtained from glazed solar collector which gives no justification of using evacuated tubes SWH collectors in

Palestine for domestic applications and conditions specified in the study specially the costs of installing evacuated tubes is higher than glazed solar collector.

The above result is approved by estimating the corresponding payback period for each case. The payback period is very important factor and it refers to the period of time required to recover the funds expended in an investment, or to reach the break-even point. The payback period and the solar fraction are used to compare the performance of SWH systems installed in different sites with different technologies.

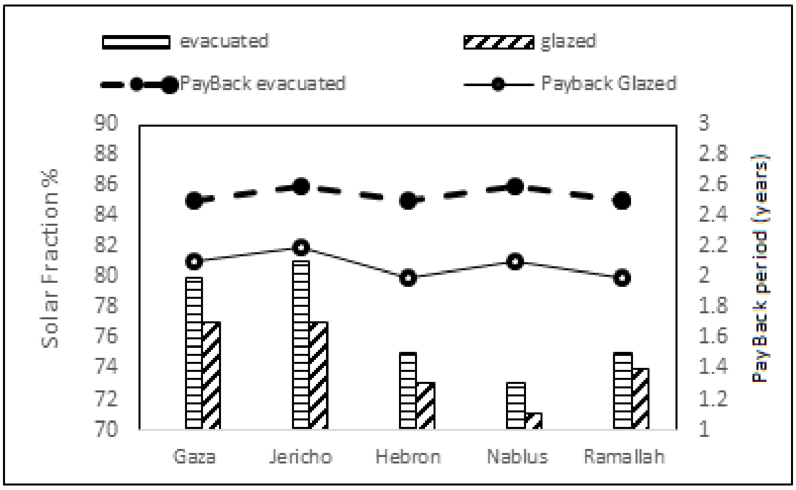

Figure (9): Solar fraction with evacuated tube type collectors.

Figure 9 illustrates the solar fractions obtained from installing two solar collectors (evacuated and glazed) at each site with the corresponding payback period. The payback periods obtained in case of installing glazed type solar collector for all sites are in the range of two years for all sites which is relatively small and considered feasible and cost effective. In fact there are small variations in the results but it is insignificant for this application.

The payback period in case of evacuated tubes solar collectors for all sites occurs in the range of 2.5 years which is small and considered feasible as well especially the life cycle of the project is at least 15 years.

Another financial indices considered in this study are the equity payback period and the pre-tax internal rate of return (IRR). The equity payback represents the length of time that it takes for the owner of a project to recover its own initial investment (equity) out of the project cash flows produced. The equity payback reflects project cash flows from its beginning as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback.

The pre-tax IRR on assets (%) represents the true interest yield provided by the project assets over its life before income tax. It is calculated using the pre-tax yearly cash flows and the project life. It is also referred to as the return on assets (ROA). It is calculated by finding the discount rate that causes the net present value of the assets to be equal to zero.

Figure 10 shows the values of pre-Tax IRR and equity payback periods for both separate sets of simulations: two collectors (~ 4.6m^2) of glazed solar collectors and two collectors (~ 4.6m^2) of evacuated tubes.

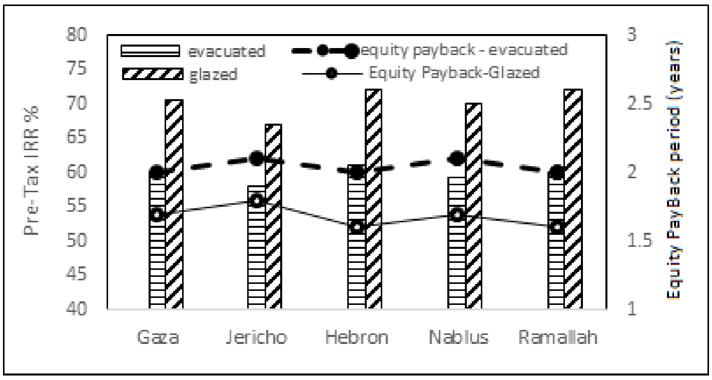

Figure (10): Pre-tax IRR index and equity payback period for glazed and evacuated tube type collectors.

The estimation of equity payback period index is mainly depending on the total annual saving and income. The greater the total annual saving and income the smaller the equity payback period.

Figure 10 shows that the equity payback period for glazed type collector is ranging from 1.6 to 1.8 years while it is ranging from 2 to 2.1 years in case of evacuated tube collectors.

The pre-tax IRR for equity in this study once installing glazed solar collectors for all sites is ranging from 67% to 72%. These percentages are greater than the inflation rate (15%) and then the project is financially justified so the larger the percentage the more it is feasible. The pre-tax IRR is ranging from 58% to 60% in case of installing evacuated tubes collectors for all sites which is less than obtained in case of installing glazed solar collector. The detailed results are shown in Figure 10.

From the simulation results as the solar fraction increases the amount of energy required from auxiliary heater decreases which is directly related to the amount of greenhouse gases (GHG) emitted to the atmosphere. Figure 11 shows the amount of electrical energy saved and the GHG reduction from using SWH system. The proposed auxiliary heating system is electrical boiler with 95% efficiency and electrical price rate 0.17 $/kWh. The coal is the base fuel type and the GHG emission factor is 0.84 tons of CO_2 per MWh excluding the transmission and distribution losses.

The value of total annual GHG emissions reduction for glazed type collector is ranging from 3.2 to 3.5 tons of CO_2 which is equivalent to 7.3 to 8.2 barrel of crude oil, respectively. Larger amount of reduced GHG emissions are gained in case of using evacuated tubes collectors. It is worthy to mention that in Palestine no credits are given for SWH owner's projects even those projects reduce GHG emissions.

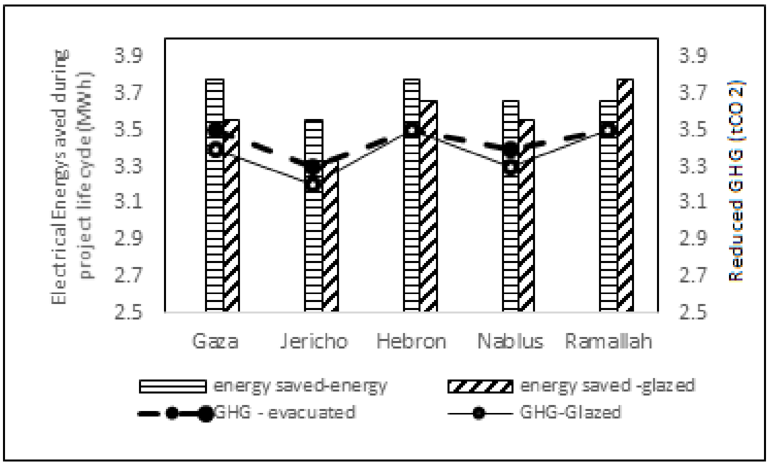

Figure (11): The electrical energy saved and GHG reduction for glazed and evacuated tube type collectors during project life cycle.

Conclusion

This study shows a technical and financial assessment of glazed and evacuated tubes solar collectors for residential SWH system in Palestine. Numerical comparisons were performed using RETScreen® Software. In order to perform the comparisons technical and economic indicators were defined.

Utilizing SWH technology in Palestine for water heating is feasible, efficient, and cost effective whether glazed or evacuated tubes are used. The performance of SWH systems are mostly similar all over Palestinian territories with slight variations.

Gaza and Jericho experience the highest solar fraction value while Ramallah city obtains the least solar fraction. The payback period for installing domestic glazed and evacuated SWH in Palestine is comparable as well as they approximately obtain same performance.

The study found that installing SWH systems can effectively contribute to reduce CO_2 emissions providing that more than 65% of Palestinians families install SWH systems. Utilizing SWH technology is considered one of the important measures to save fuel or reduce the amount of imported electricity from IEC.

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