International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 11 (2019), pp. 1901-1906

Experimental Analysis of Different Solar Water Heating Systems According to Palestinian Environmental Conditions

Dr. Imad Ibrik[1], Dr. Abdelrahim Abu-Safa[2], Eng. Linda Mansour[3]

[1, 3] An-Najah National University, Energy Research Centre, Nablus-Palestine.

[1]E-mail ID: iibrik@najah.edu & ORCID: 0000-0002-1743-912X

[2]Chemical Engineering Department, An-Najah National University, Nablus, Palestine.

Abstract

The application of solar energy in the form of solar water heating (SWH) system is most popular and useful for domestic, commercial and industrial purposes in Palestine, but it is found that the application of its depends on using different types of SWH systems. This paper investigates experimentally the performance of flat plate collectors (FPC) and evacuated tube collectors (ETC), which are the most common use in Palestine. A three locally made solar water heating systems, with 0.48m^2 serpentine type flat plate collector(S-FPC), 0.48m^2 parallel type flat plate collector(P-FPC) and 0.31m^2 U-Pipe evacuated tube collector (ETC) were installed on the rooftop of Energy Research Center building at Al-Najah National University, in Nablus (32.227099N, 35.222209E), Palestine. The data were gathered in 3 months of the same weather conditions during May , June and July 2019. Then the performance of each system was studied and compared with others. The results show that the daily energy collected by S-FPC is 1015 Wh/m^2, 1415 Wh/m^2 for P-FPC and 1854 Wh/m^2 for ETC. The system efficiencies were 26%, 38% and 49% respectively for S-FPC, P-FPC and ETC.

Keywords: Solar water heating, performance analysis, weather conditions, economical analysis .

1. INTRODUCTION

Unlike other World countries, and because the political situation Palestine suffers from the shortage and high cost of all energy sources. This had negative effects on the economic and social life of Palestinians.

Sun is the way to overcome the problems of conventional energy sources. Palestine has high potential of solar radiation, where the average annual sunshine hours exceeds 3000 hour and the average global solar radiation is 5.4 kwh/m^2/day. This makes solar energy a reliable source can be utilized in electrical and thermal applications.

The most familiar application for solar energy in Palestine is heating water by means of Solar Water Heating Systems (SWHS) which have been used extensively , such that 56.5% of Palestinian families are used it, (PCBS, 2015). Palestine is ranked sixth among the top ten countries in the world in the use of SWHS.

Two types of SWHS are commonly used in Palestine. The first and the most widespread type is with FPC, which is extensively used not only on household but also in schools, hospitals, factories and many other facilities. The total flat plate collector area in operation by the end of 2016 was 1,826,625 m^2 (Weiss, 2018).

The second type is with ETC. ETC have started to gain market shares with total collectors area in operation by the end of 2016 was 8,225 m^2 (Weiss, 2018).

We notice a big difference in the total installed area between the two types of collectors, this was because the ETC considered as new technology entered the Palestinian market and because of its high initial cost. But in some cases it has become obvious that low prices were also accompanied by low quality in different respects. Unfortunately, the low quality wasn't always revealed due to the absence of quality and performance tests for the collectors which available in the market even for the installed systems.

High quality , good performance and high efficiency of SWHS means more energy production and less dependency on conventional energy sources for heating water , and due to the fact that 18% of our total used energy goes for water heating (Ibrik,2019),we must perform all required tests to insure that we installed SWHS with the highest efficiency.

This study, therefore, aims to build two types of collectors systems (FPC & ETC) installed side by side, then to be tested under the weather conditions of West Bank in order to evaluate the performance of each system using thermodynamic equations.

2. LITERATURE REVIEW

A number of studies have investigated the performance of SWHS with ETCs and FPCs. (Ayompe et al, 2011) conducted a field study to compare the performance of 4 m^2 flat plate and 3 m^2 heat pipe evacuated tube collectors for domestic water heating system in Dublin, Ireland. (Nájera-Trejo et al, 2016) determined in their study the economic feasibility of using flat plate vs evacuated tube solar collectors for domestic hot water and radiant floor heating (combisystem). (Zambolin and Del Col, 2010) presented experimental analysis for the thermal performance of flat plate and evacuated tube solar collectors in their paper. (Yasin, 2017) evaluated the performance of glazed and evacuated tubes solar collectors technically and financially using RETScreen software. (Hernández and Guzmán, 2016) made a comparison between three water heating systems; two flat plate collectors (one with copper coil, the other with stainless steel coil) and one vacuum tube heater, all of them are on top of the "Universidad Pontificia Bolivariana" in Bucaramanga, Colombia. (Hayek et al, 2011) investigated the thermal performance of two types of evacuated tube solar water collectors namely, the water-in-glass tubes and the heat-pipe designs under Eastern Mediterranean climatic conditions. (Yasin et al, 2011) used the SWHS of main cafeteria in Birzeit University-Palestine which consists of 148 m^2 of solar collectors and 3000 Liter storage tank as a case study to determine the utilized energy and CO_2 saving.

This study, therefore, aims to build two types of collectors systems (FPC & ETC) installed side by side, then to be tested under the weather conditions of West Bank in order to evaluate the energy delivered to the hot water tank and system efficiency.

3. EXPERIMENTAL SETUP AND TEST DEVICE

The layout of the comparative experimental prototype for flat plat and evacuated tube collectors is shown in Figure 3.1.

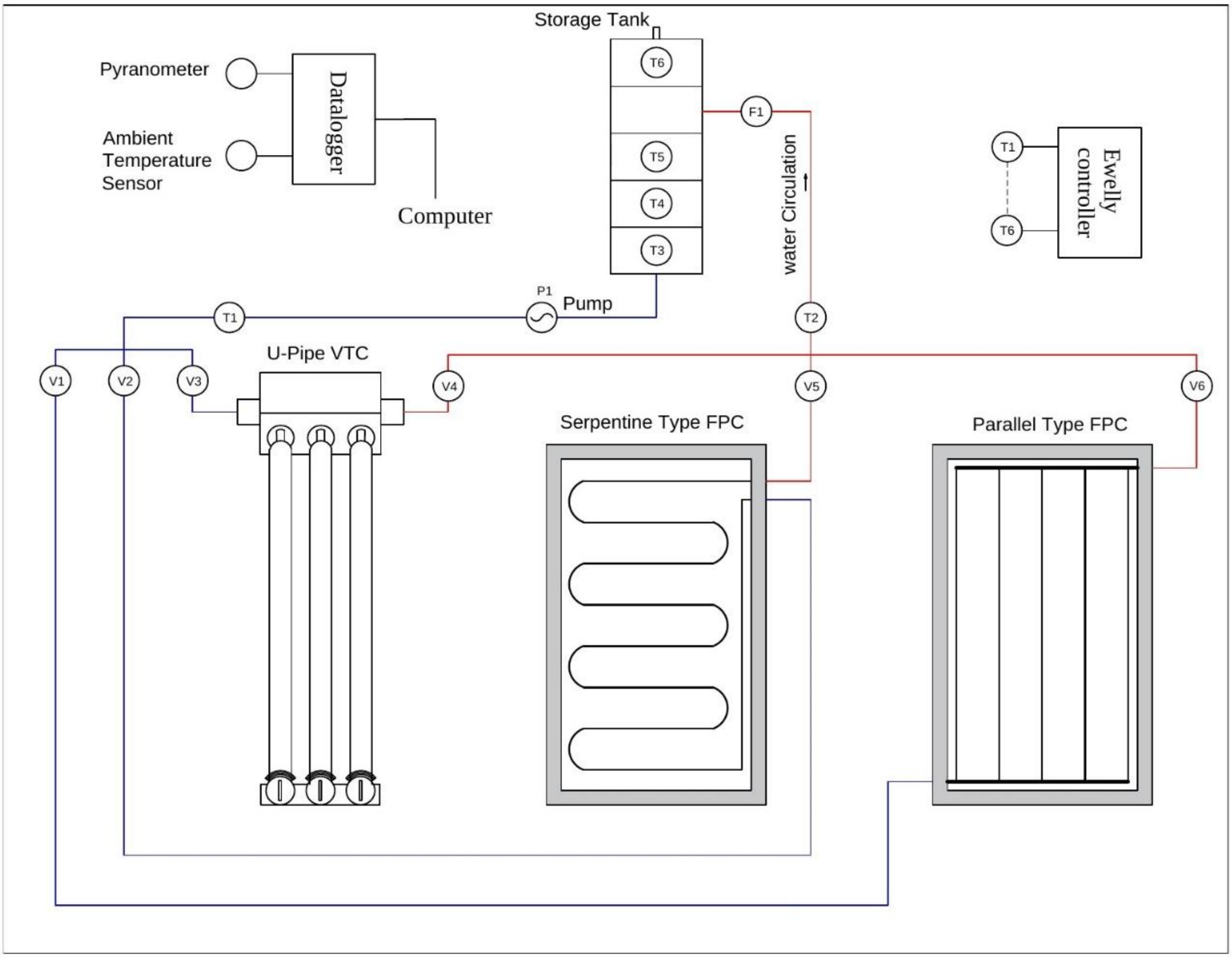

Figure 3.1: Layout of experimental prototype.

The experimental set-up consists mainly of 0.48 m^2 Parallel type FPC(P-FPC), 0.48 m^2 Serpentine type FPC(S-FPC), 0.31 m^2 U-Pipe ETC and one cylindrical tank with 30 Liter storage capacity.

The two flat plate and the evacuated tube collectors were in parallel, and water was circulated between the collectors and the storage tank.

Figure 3.1 shows also the position of the thermocouple sensors. These sensors were used to measure water temperature at the collectors inlet (T1), water temperature at the collector outlet (T2), water temperature at the bottom of the water tank (T3), water temperature at the middle of the water tank (T4 and T5) and the water temperature at the top of the water tank (T6).

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 11 (2019), pp. 1901-1906

The global solar radiation incident on the collector surface and the surrounding air temperature were measured by Meteocontrol weather station, connected to a datalogger, which records the data every 15 minutes.

The experimental set up appears in Figure 3.2, it consists of the following items:

Figure 3.2: Experimental set up

1) FPC s:

The S-FPC and P-FPC are in rectangular shape with 1.0 m long and 0.6 m wide. Both collectors have 0.48m^2 effective area. The collector box is made of powder-coated aluminum of 2 mm layer thickness and covered by transparent glass with 4mm thickness. Internally, a thermal insulating sheet (Rockwool) of 3 cm thickness covers them. A layer of steel sheet 1 mm thickness painted with selective coating was used as the absorber plate. The internal pipes of S-FPC are made of copper with diameter 3/8" and total length 5.5 m, arranged in serpentine back model. While the P-FPC has a five parallel copper pipes, 1/2" diameter each, are connecting at the bottom and top with 1" copper headers.

2) U-Pipe ETC:

The evacuated tube collector is U-pipe type composed of three tubular glasses. Each evacuated tube has 1.8 m length and 58 mm outer diameter with total effective area 0.31 m^2. The copper pipes inside the evacuated tubes have 9.4 m length and 3/8" diameter.

Water tank:

Vertical storage water tank was used in the experiment. Its length 65 cm and diameter 25 cm, with total capacity 30 Liter. The tank is well insulated by Rockwood.

3) Connection pipes:

16 mm^2 PVC pipes were used to connect the solar collectors with the storage tank.

4) Temperature sensors:

Six temperature sensors were used in the experiment. They are K-Type thermocouple with measuring temperature range (-270° C to 1260° C) and accuracy +/-2.2° C.

Temperature readings are collected and showed using Ewelly controller (EW-181)

5) Weather station:

Meteocontrol weather station was used to measure the ambient temperature and the global solar radiation at the tilted collector surface. The data were collected and stored every 15 minutes by datalogger.

4. DATA COLLECTION AND ANALYSIS

The three prototypes of solar water heating systems are installed side by side on the rooftop of Energy Research Center building at Al-Najah National University, in Nablus (32.227099N, 35.222209E), Palestine.

To make a comparison between the three types of collectors in term of daily performance, a three days of similar environmental parameter where chosen for that purpose.

These three days have been chosen to test the three types of collector individually. The P-FPC was tested in 28/5/19, the ETC was tested in 23/6/2019 and the S-FPC was tested in 24/6/19.

Throughout the tests period, the collectors faced south at fixed tilt angle 32 degree. A measurement for global irradiation on collector plane, collector's inlet temperature, collector's outlet temperature, storage tank temperature and surrounding air temperature were acquired every 15 minutes from 9:00 AM until 1:45 PM.

4.1 Energy analysis:

The collected data from field experiments were used to evaluate the energy performance indices, which are the received energy, energy delivered and system efficiency.

1- Received energy:

If G_t is the intensity of solar radiation, in W/m^2, incident on the tilted plane of the solar collector having a collector surface area of A_c, in m^2, then the amount of energy received by the collector is:

$$Q_{in}= A_c\, G_t$$

2- Energy delivered:

The useful thermal energy that has been collected by the solar collector is given by the following equation.

$$Q_u= m\, C_p\, (\overline{T}_{2tank}-\overline{T}_{1tank})$$

Where;

m: Water mass inside the tank (kg).

C_p: Specific heat capacity of water (kJ/kg.K).

$\bar{T}_{2tank}$: Final average tank temperature.

$\bar{T}_{1tank}$: initial average tank temperature.

3- System efficiency:

For the entire system, the useful heat energy obtained by the water in the tank is as follows (Pie et al, 2012):

$$Q_u = m\, c_p \frac{d\bar{T}}{dt}$$

Where $\bar{T}$ is the average water temperature in the tank.

The overall system thermal efficiency η_{sys} is calculated by:

$$\eta_{sys} = \left(\int_{t1}^{t2} Qu\, dt\right) / \left(Ac \int_{t1}^{t2} Gt\, dt\right)$$

5. RESULTS AND DISCUSSIONS

5.1 Enviornmenal conditions:

Figure 5.1 shows that the three days nearly have the same solar radiation and Figure 5.2 shows that the ambient temperature in 24/06/19 is slightly higher than 23/06/19, which also has a slightly higher temperature than 28/05/19. The average solar radiation and ambient temperature for the test period of 28/05/19, 23/06/19, 24/06/19 are (804 w/m^2, 29° C), (791 w/m^2, 31° C) and (796 w/m^2, 32° C) respectively.

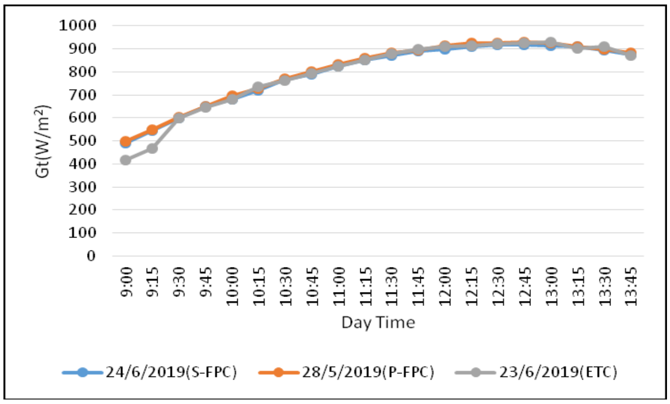

Figure 5.1: In-plane solar radiation for three comparison days

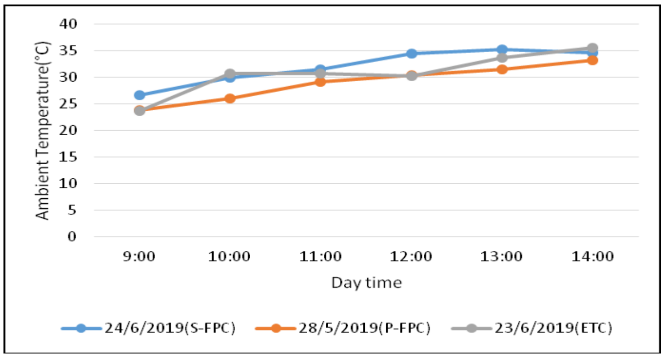

Figure 5.2: Ambient Temperature for three comparison days

5.2 Collector inlet-outlet temperatures:

The max outlet temperature and the min inlet temperature of the collectors, where 51° C/27° C for ETC, 49° C/31° C for S-FPC and 48° C/24° C for P-FPC. The P-FPC raised the water temperature 24° C while S-FPC raised it by 18° C Only. So it is obvious that the P-FPC is more efficient than S-FPC and ETC is the most efficient one especially that it could raise the water temperature by 24° C while as the P-FPC while it has less area.

Figure 5.3 shows the difference between the inlet and the outlet temperatures for the three types of collectors. The ETC has the higher temperature difference up to 12:00 pm then it starts in decreasing due to the decrease in solar radiation. The S-FPC has less temperature difference than the P-FPC up to 10:30 then it starts in having more temperature difference.

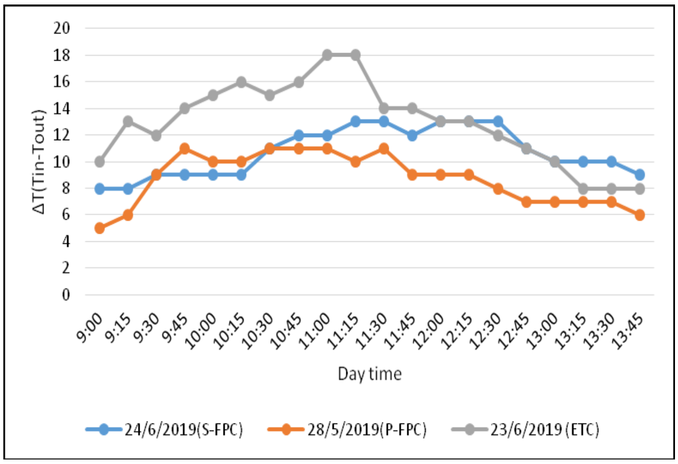

Figure 5.3 : ΔT for S-FPC, P-FPC and ETC

5.3 Average tank temperature:

Figure 5.4 shows the average tank temperature for the three collectors during the three days. The average tank temperature is nearly the same for the three collectors.

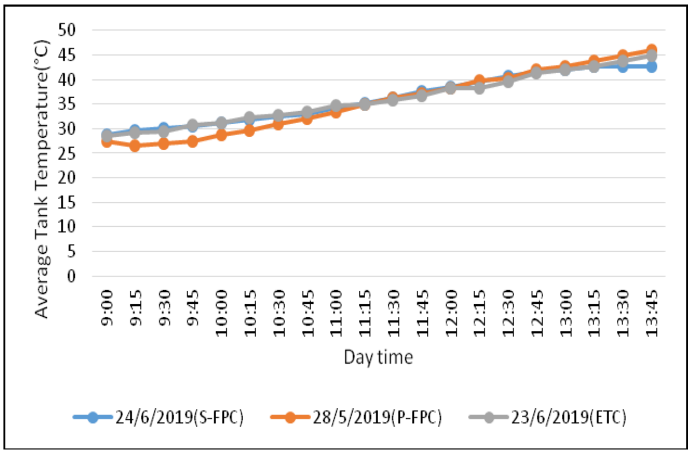

Figure 5.4: Average tank temperature for S-FPC, P-FPC and ETC

5.4 Collected energy:

Figure 5.5 shows the hourly energy collected by each collector. The ETC attained more energy than the P-FPC and the P-FPC attained more energy than the S-FPC. The total Energy collected by ETC in 23/6/19 from 9:00Am to 1:45 pm was 1854 Wh/m^2 and the useful energy collected by P-FPC was 1415 Wh/m^2 in 28/5/19 while it was 1015 Wh/m^2 for S-FPC in 24/6/19.

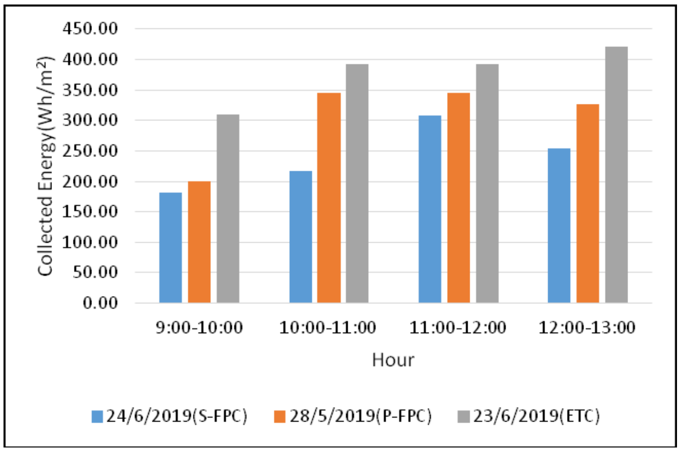

Figure 5.5: hourly energy collected by S-FPC, P-FPC and ETC.

5.5 System efficiency:

The ETC was the most efficient collector of the three. For the period from 9:00 AM and 1:45 PM, the ETC has 49% average efficiency on 23/6/19. 38% is the efficiency of P-FPC in 28/5/19 and 27% for S-FPC in 24/6/19.

Figure 5.6 shows the average hourly efficiency for the three collectors in the three test days.

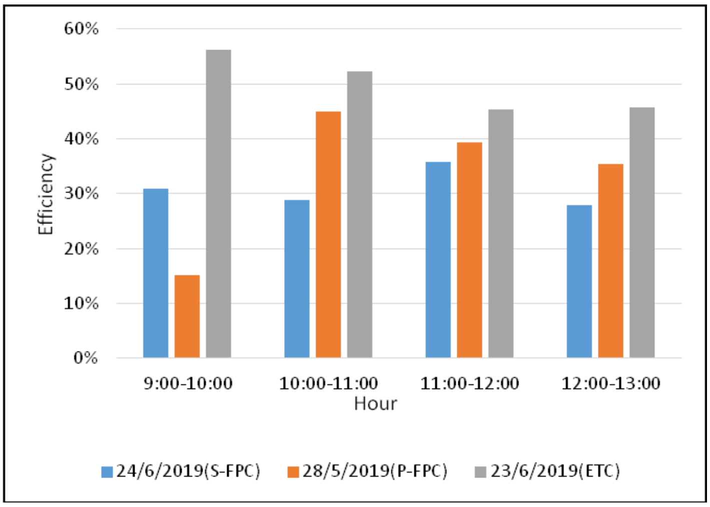

Figure 5.6: Hourly efficiency collected by S-FPC, P-FPC and ETC.

6. CONCLUSIONS

A comparison of the experimental prototype of solar water heating systems with ETC, S-FPC and P-FPC was conducted. The results of the comparative tests were presented.

This study compares between the performance of ETC, S-FPC and P-FPC systems under the same weather conditions. Results show that the daily energy collected by S-FPC is 1015 Wh/m^2, 1415 Wh/m^2 for P-FPC and 1854 Wh/m^2 for ETC. The system efficiencies was 26%, 38% and 49% for S-FPC, P-FPC and ETC respectively.

In Palestine, most people chose the FPC for household applications because of its cheap price and its effectiveness in covering hot water demand of houses.

But the commercial and industrial facilities start in using the ETC system since it can give water at very high temperature for different applications such as heating water, pool heating and space heating even in winter and then it reduces the huge electrical bills come from using fossil fuels for heating water. This make the ETC more economically feasible to be used commercial and industrial applications than residential applications.

REFERENCES

[1] Weiss, W., Spörk - Dür, M., Mauthner, F. 2018. Solar Heat Worldwide. Austria: AEE INTEC.

[2] Palestinian Central Bureau of statistics (PCBS). Percentage Distribution of Households by Region, Availability and usage of Solar Heater, 2015. Retrieved from PCBS website: https://www.pcbs.gov.ps/Portals/_Rainbow/Documents/HE-%20EA4%202015.htm

[3] Ibrik Imad, 2019. An overview of electrification rural areas in Palestine by using micro-grid solar energy, Journal Cogent Engineering, Volume 6, 2019 - Issue 1, 1-13.

[4] Ayompe, L., Duffy, A., McCormack, S., McKeever, M., Conlon, M. 2011. Comparative Field Performance Study of Flat Plate and Heat Pipe Evacuated Tube Collectors (ETCs) for Domestic Water Heating Systems in a Temperate Climate. Energy, Vol. 36, Issue 5, pp. 3370-3378.

[5] Nájera-Trejoa, M., Martin-Domíngueza, I., Escobedo-Bretadoa, J. 2016. Economic feasibility of flat plate vs evacuated tube solar collectors in a combisystem. Energy Procedia 91, 477 – 485.

[6] Zambolin, E., Del Col, D. 2010. Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Solar Energy 84, 1382–1396.

[7] Yasin, A. 2017. Technical and Financial Assessment of Glazed and Evacuated Tubes Solar Collectors for Domestic Water Heating Application in Palestine. An - Najah Univ. J. Res. (N. Sc.) Vol. 13(1).

[8] Hernández, E., Guzmán, R. 2016. Comparison of three systems of solar water heating by thermosiphon. Journal of Physics: Conference Series 687, 012007.

[9] Hayeka, M., Assaf, J., Lteif, W. 2011. Experimental Investigation of the Performance of Evacuated- Tube Solar Collectors under Eastern Mediterranean Climatic Conditions. Energy Procedia 6, 618–626.

[10] Yasin, A., Alsayed, M., Yasin, B., Arafat, H. 2011. Evaluation of energy and CO_2 saving of an institutional collective solar water heating system in Palestine. Resouk 2011, Emuni student research multi-conference.

[11] Pei, G., Li, G., Zhou, X., Ji, J., Su, Y., 2012. Comparative Experimental Analysis of the Thermal Performance of Evacuated Tube Solar Water Heater Systems With and Without a Mini-Compound Parabolic Concentrating (CPC) Reflector(C < 1). Energies, *5*, 911-924; doi:10.3390/en5040911.