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# Assessment of the Thermal Performance of Hybrid PVT Collector by Integrating It with a PCM Storage Unit

Hulya S. Sulaiman*, Ehsan F. Abbas**‡, Tahseen A. Tahseen***

*Master student at the Power of Mechanics Techniques Engineering, Kirkuk Technical College, Northern University, Kirkuk city-Iraq

**The Power of Mechanics Techniques Engineering, Kirkuk Technical College, Northern University, Kirkuk City-Iraq

*** Mechanical Engineering Dept.- Engineering College/ Kirkuk University

( hulya1993h@ntu.edu.iq, ehsanfadhil@ntu.edu.iq, tahseen@uokirkuk.edu.iq )

‡Ehsan F. Abbas, Kirkuk Technical College, Tel:+9647706102846, ehsanfadhil@ntu.edu.iq

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**Abstract-** Photovoltaic (PV) modules convert solar energy directly to electricity whereas solar thermal collectors absorb solar energy to heat air or water. Over several years, photovoltaic/thermal (PV/T) systems, in which, during daytime, each PV module generates electricity and forms the absorbing surface of a solar thermal collector with heat generated transferred to air or water for space or water heating applications, where the objective in such systems is to achieve an optimal simultaneous useful electrical and heat output, were designed, constructed and tested. The current study aims to evaluate the thermal performance of a hybrid PVT system by integrating it with an external PCM storage unit. Two similar hybrid PVT systems simultaneously conducted experiments to achieve the desired goal, one integrating with a PCM volume and the other without it, using a water flow rate ranging from (0.72 to 1.2) LPM. Simulations of both systems compared for the extent to which PCM contributes to improving the performance of PVT collectors. Experiments have been conducted on both hybrid PV/T collectors simultaneously under actual weather condition of the city of Kirkuk - Iraq for four months, starting from January until the end of April 2021. The simulation results showed that the addition of the PCM storage unit to the PV/T collector had contributed to increasing the thermal performance of the WPVT collector by twice the thermal performance of the TPVT collector. The result obtained from the present study agrees well with other similar works.

**Keywords** PVT collectors; solar hybrid collector; thermal efficiency of PVT; collector efficiencyof PVT collectors

**Nomenclature**

| | | | |
|---|---|---|---|
| A | Area of PV panel (m$^2$) | $\alpha$ | Absorptivity |
| $C_P$ | Specific heat of water ( J/kg.$^o$C) | $\rho$ | Density of the water (kg/m$^3$) |
| $\dot{E}$ | Energy (W) | | |
| G | Incident solar radiation intensity (W/m$^2$) | ***Subscript*** | |
| $h$ | Convection heat transfer coefficient (W/m$^2$.$^o$C) | a | Ambient |
| HE | Heat exchanger | b | Bulk |
| $\dot{m}$ | Water mass flow rate (kg/s) | c | Cell |
| u | Wind speed (m/s) | i | Inlet |
| T | Temperature ($^o$C) | o | Outlet |
| ***Greek symbols*** | | PV | Photovoltaic panel |
| $\eta$ | Efficiency | th | Thermal |

## 1. Introduction

In most countries globally, population growth and economic development contribute to a rise in international energy demands. International energy agencies have shown that the energy consumption increases in developing countries are higher than in industrialized nations, requiring almost twice their current capability to meet the demand for energy by 2020. The world's overall energy consumption is also expected to rise by 44 % between 2006 and 2030 [1] . Renewable energy explanations are being guided by the decreased supply of non-renewable energy and the harmful impact of CO2 emissions in the atmosphere. Therefore, generally and in particular solar power is a tempting alternative to collect energies, which offers one of the best options for clean energy demand [2]. This led to using an alternative energy source to satisfy our energy needs and preserve conventional fossil fuels. Solar energy is a source of renewable power. Photovoltaic (PV) modules convert solar energy directly to electricity whereas solar thermal collectors absorb solar energy to heat air or water. Over several years, photovoltaic/thermal (PV/T) systems, in which, during daytime, each PV module generates electricity and forms the absorbing surface of a solar thermal collector with heat generated transferred to air or water for space or water heating applications, where the objective in such systems is to achieve an optimal simultaneous useful electrical and heat output, were designed, constructed and tested. The PV/T system becomes attractive when the generated thermal energy is stored temporarily in a phased change material (PCM), thermal energy system (TES). This kind of systems was modeled and tested experimentally in [3][4]. These systems were studied theoretically and experimentally. Typically, 15–18% of solar radiation incident on a PV module is converted to electricity and 82–85% is converted to heat. For practical applications, a variety of types of solar energy systems exist, including photovoltaic cells. Depending on its sort, the performance of a PV panel is not more than 20%, as more than 80% of the solar radiation from the PV panel does not become usable energy[5].More than 80% of waste is reflected in or turned into thermal energy by the solar panel, and worse than this. The latter decreases the performance of the PV module as the operating temperature increases[6]. Jazayeri et al.(2013) [7] analyzed the effect of experimentally different values of the solar irradiance intensity and electrical connections type on the PV panels' performance. Aste et al. (2013) [8] have presented a mathematical model to estimate an unglazed hybrid PVT's electrical and thermal production with water as heat transfer fluid. The present study shows a detailed performance prediction model applicable to uncovered PVT collectors and the experimental validation carried out on a commercial module. Mosalam (2018) [9] the design and operation of photovoltaic panels has been studied experimentally. The aim of this study was to include the effect of panel orientation and tilt angle on their power generation and were tested for different inverter- maximum power point tracking (MPPT). Elsir et al. (2019) [10]have analyzed the cost optimization of the PV panels based on the declination angle and power generation. The present studied solar storage energy system on the distributed generators unit. Ghasemzadeh et al.(2020)[11] studied the effect of temperature challenges on PV efficiency. The current study was conducted on several parameters, such as the variable density method, different from the monolayer bismuth, including the structural, optical, and electronic properties under various stresses biaxial in a homogeneous manner the amplified plane waves of the linear voltage system.The thermal and photovoltaic system was implemented with the progression of studies in this area. An integrated solar collector and photovoltaic system. Device. The solar panel absorbs solar radiation, while the thermal device extracts heat from the cell to maintain the panel temperature, thereby preventing the heat condition during the panel's operation. The panel is used to regulate the panel temperature. Therefore, from an integrated system, this system generates electric and thermal energy from one integrated system. These systems are classified as follows [12].

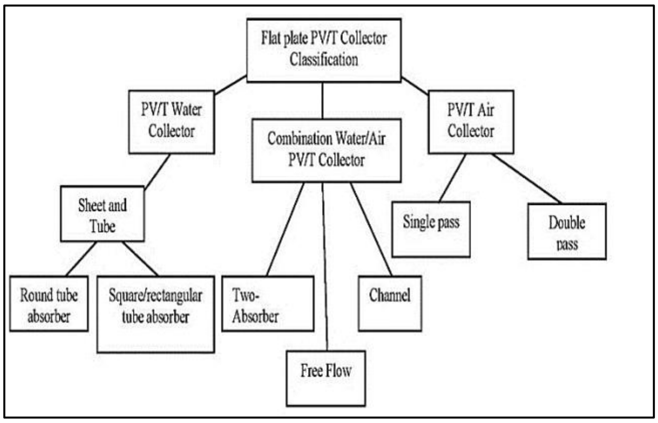


**Fig. 1.** Flat plate PVT collector classification [12].

Several techniques can be advantageously applied to harness and harvest more thermal energy from PVT systems; among them are thermal potential energy storage methods using PCM where the material can store energy at a temperature a certain heat by changing its phase. The sensitive heat is absorbed in a solid state of PCM, and then its temperature increases from the ambient temperature to the melting temperature. During melting, PCM absorbs latent heat at a constant temperature. It then eventually melts, and the temperature continues to rise, as, in the final stage, PCM absorbs sensitivity to heat. Many forms of PCMs are available such as organics, inorganic products, and eutectics. Several studies of organic phase change materials have been used in hybrid PVT systems[13][14][15], and their results



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have been compared with nanofluids to know which is better during the tests. Kazanci et al. [16]. have examined the PCM performance in the PVT system, and they found that PCM can increase the PV panels power output by 15.5%. Sarhaddi et al. [17] studied verification of the use of a PCM in the hybrid PVT system. They have also investigated that if PCM is capable or not on sunny days. They found that the energy performance and energy available to the system containing the covered tank with PCM Best on waking days. Gaur et al. [18] different PCMs used, such as the organic material (OM37), to determine the extent of its impact on the energy performance and the energy available for a typical day, the summer and winter seasons. Respectively for PVT / PCM and PVT in the summer season.The winter season found that the same percentage was 16.87% and 16.78%, respectively. Hosseinzadeh et al. [6] used paraffin wax as a phase-variable material in their system and found that the maximum available energy output and total energy efficiency were 114.99 W / m2 and 13.61%, respectively. Mousavi et al. [19] used several different PCMs to store thermal energy in a hybrid PVT system. They concluded that paraffin C22 was the best in enhancing the system's thermal efficiency by up to 83%. Hossain et al.[20] changed the flow level using volume flow rates ranging from (0.5-4) LPM. The study results indicated that the collector obtained maximum thermal efficiency at a flow rate of 2LPM at 87.72%. The highest energy efficiency available for PVT-PCM is 12.19% at 0.5 LPM. Kazemian et al.[21] investigated the effect of using a mixture of pure water and ethylene glycol on the performance of both vitrified and unglazed thermoelectric systems. The results indicated that the percentage of energy loss decreased when it was vitrified, and the refrigerant was used by 23.33% compared to the non-vitrified systems. Thermal performance assessment and variance analysis of the design and data analysis by Ren.et al. [22] by Taguchi method. In terms of useable energy stored in the thermal energy storge TES system for the proposed system. The results indicated that the temperature at the outlet air of the TES unit during the vacuum process on the specified test day was at least 2°C higher than that at the inlet air. The main elements that determine the useable energy stored in TES were PCM type, charging air flow rate and PCM air flow rate. Browne et al [23] has compared a new PV/T/PCM power-generating, heating and water preheating system in Dublin, Ireland, in outside conditions. A photovoltaic unit is combined with a heat collector; the thermal flow is extracted from a heat exchanger in the PCM. The system performance was compared with (a) a PCM-free system, (b) a PCM-free system, and (c) thePV module alone. In comparison to the PV/T system without PCM, it was observed that the temperature reached by the water was 5.5 °C greater. PCM is an effective form of heat storage in a PV/T system for subsequent heat removal

The present study aims to assess thermal performance for the hybrid PVT system by integrating it with an external PCM storage unit. Two similar hybrid PVT systems simultaneously have performed experiments to achieve the desired goal, one of them integrating with PCM storage unit and the other without it, using water flow rate varying from (0.72 to 1.2) LPM. The simulation of both systems is compared to get the extent of PCM's contribution to improving the performance of PVT collectors.

## 2. Experimental Setup

Built an experimental test rig from two PV panels with technical specifications illustrated in Table 1. Each one was integrated with a thermal collector, made from a flat heat exchanger, and it was fixed on the backside of the PV panel and covered with insulated glass wool, Table 2 shows the specifications of the flat plate. One integrated solar collector with a thermal storage unit is made of a wooden box with dimensions (length 158 width 140 thickness 25) cm. It consists of a copper tube with a diameter of 1 mm and a length of 10 meters, immersed in 16.2 kg wax; Table 3 shows the used wax's physical properties. Both solar collectors are mounted on the iron frame and installed at 30º with a horizontal axis. Both collectors were located in Kirkuk city (Iraq) in the south direction (35.4666 °N, 44.3799 °East). The hybrid photovoltaic collector system with a thermal storage unit was symbolized (MPVT) and the other (PVT); Fig. 2 shows test rig photos in detail. Both PVT collector systems were operated with open-cycle water circulation separately through two pipelines; each one consisted pump with a water flow rate of (1.83) LPM and a rotameter with an accuracy of ±1%. Various measuring devices are used to record the required data, such as, the ammeter device is connected in series to an electrical circuit and the voltmeter in parallel to measure electrical power generation from each PV panel, a temperature recording data logger 16 channel type (AT4516) and accuracy of 0.2%+1ºC used to record temperature from 16 optional locations in both collectors by thermocouple wire type K as shown in Fig.1, an anemometer type DA40 with an accuracy of ±1%. Is used to measure wind speed, and a solar radiation meter with an accuracy of ±10 W/m$^2$ is used for solar radiation incident on the PV panels. Both PVT collectors underwent hands-on trials beginning in January 2021 and lasting for three months. During these periods, the experiment started at 8 a.m. and ended at 6 p.m. every day, and temperatures, solar radiation, wind speed and power generation were recorded in sync every 15 minutes.The two systems were identical, with two water flow regulators known as the rotameter, connected by a piping system to heat the water by a heat exchanger for domestic application. 16 K-type thermocouples were placed in different places in the system to measure the temperature. These thermocouples were connected to the temperature data logger device to record and store data. A Solar Power Meter type (TES-1333) was also used to measure the intensity of solar radiation, and a Digital Anemometer type (DA40) was used to measure wind velocity. All devices were set up to record data from the devices every 15 minutes, starting from 8 a.m. to 6 p.m. four days a week during the testing period in March 2021. The system was operated in two cases, the first when the water flow was at 0.72 LPM and the second on 1.2 LPM to see the extent effect of the flow to the system.

**Table 1.** technical specifications of the photovoltaic panel

| | |
|---|---|
| Mobil Solar | PolycrystallineSolar Model: SLP135-12 |
| Open circuit voltage (Voc) | 21.6V |
| Optimum operating voltage (Vmp) | 17.2V |
| Short circuit current (Isc) | 8.74A |
| Optimum power at STC (Imp) | 7.85A |
| Maximum power at STC (Pm) | 135Wp |
| Standard test condition | 1000W/m$^2$,AM1.5 and 25°C |
| Electric efficiency [24] | $\eta_{el} = \eta_{ref} - 0.0045(T_{pv} - T_{ref})$ |

**Table 2.** Specifications of the flat plate

| Specification | Dimension |
|---|---|
| Length (cm) | 126 |
| Width (cm) | 58 |
| Thickness (cm) | 0.1 |

**Table 3.** Thermo-physical properties of paraffin wax [25].

| | |
|---|---|
| Melting temperature | 44 °C |
| Latent heat of fusion | 190 (kJ/kg) |
| Solid density | 930 (kg/m$^3$) |
| Liquid density | 830 (kg/m$^3$) |
| Thermal conductivity | 0.21 (W/m °C) |
| Solid specific heat | 2.1 (kJ/kg °C) |
| Liquid specific heat | 2.1 (kJ/kg °C) |

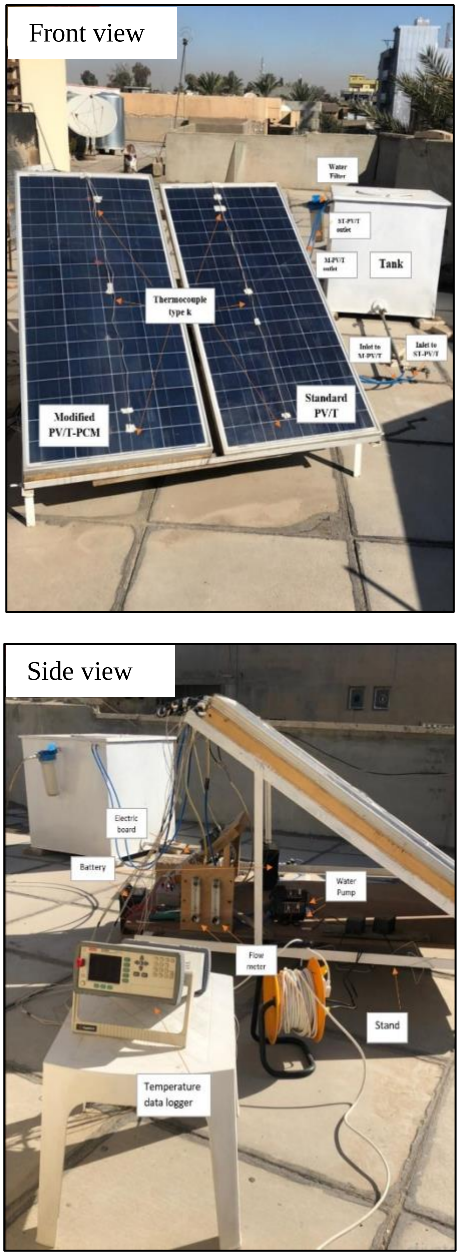


**Fig. 2.** Photograph of the experimental device

## 3. Analysis of PVT Hybrid System Efficiency

a) Energy analysis

To calculate the useful energy from TPVT and WPVT, we make energy balance on a model of both hybrid collectors under the transient condition as shown in Fig.3, expressed as in Eq. 1 [26]:

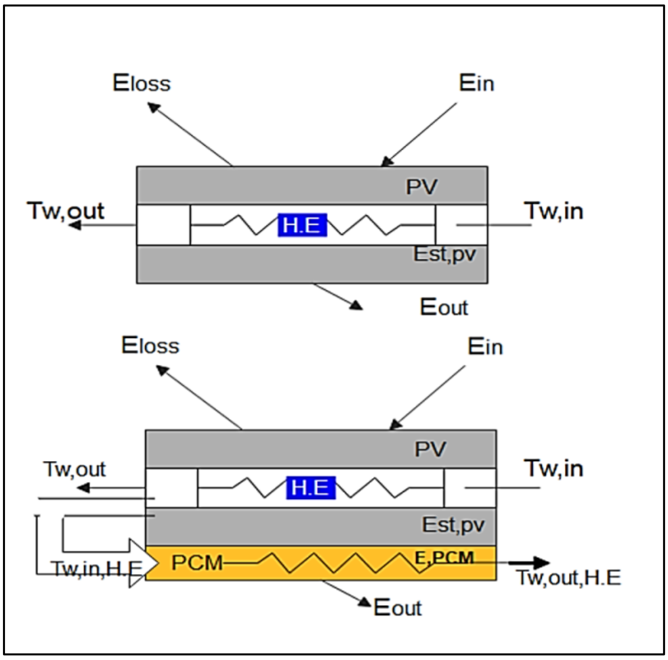


**Fig. 3.** The system's energy balance process

$$\dot{E}_{in} - \dot{E}_{out} - \dot{E}_{loss} = \dot{E}_{st,pv} \quad (1)$$

where $\dot{E}_{in}$ is the thermal energy input into the PV panel, and is gives as [27][28]:

$$\dot{E}_{in} = G\, A_{pv}\, \alpha \quad (2)$$

and the useful thermal energy ($\dot{E}_{out}$) obtained from the PV collectors was calculated as follows:

$$\dot{E}_{out} = \dot{m} \times C_p \times (T_{w,out} - T_{w,in}) \quad (3)$$

Therefore, due to the difference in temperature between the body of the photovoltaic collectors and the ambient temperature, part of its energy lose into the ambient and is calculated from [2]:

$$\dot{E}_{loss} = h \times A_t \times (T_{pv} - T_\infty) \quad (4)$$

where

$$A_t = A_{pv} + A_{side} \quad (5)$$

And Equation (6) shall measure the coefficient of heat transfer h, which in turn is incorporated in the calculation of waste energy $\dot{E}_{loss}$ [29]:

$$h = 5.7 + 4.1u \quad (6)$$

The present study simulates the photoelectric collector's energy in the timer, which was expressed in Equation 1; the difference between these energies represents the change in the internal energy. In the hybrid WPVT system, stored the internal energy in the collector and the wax.Whereas water's physical properties, such as $C_p$ and ρ are evaluated at the bulk temperature $T_{b.}$

b) The efficiency of the hybrid PVT systems

The efficiency of a hybrid PV system is defined as the ratio of the useful energy to the thermal energy absorbed by the system, and it is expressed as[30];

$$\eta_{thermal} = \frac{\dot{E}_{out}}{\dot{E}_{in}} \quad (7)$$

### 4. Experimental Analysis of Uncertainty

The Gaussian distribution law calculated experimental uncertainty. Uncertainty (R) is estimated based on the x1, x2, ......, xn, and w1, w2, ...., wn independent variables. uncertainty in the separate variables Thus, the uncertainty in the result ($w_n$) can be computed as follows[31][32]:

$$W_R = \left[\left(\partial R/\partial x_1 \times w_1\right)^2 + \left(\partial R/\partial x_1 \times w_2\right)^2 + \cdots + \left(\partial R/\partial x_1 \times w_n\right)^2\right]^{\frac{1}{2}} \quad (8)$$

The uncertainty of measuring devices used in the present study was calculated based on Eq. 8, and the result illustrated in Table 2. The maximum uncertainty of thermal efficiency is ±3.44%.

**Table 4.** Uncertainty of the measuring devices

| Device name | Resolution | Accuracy | Uncertainty (%) |
|---|---|---|---|
| Temperature data logger | 0.1 °C | 0.2%+0.1 °C | ± 0.1117 °C |
| Digital Anemometer | 0.01 MPS | ±1.0% of reading ±1 digit | ±0.014388 MPS |
| Solar Power Meter | 1 W/m$^2$ | W/m$^2$±10 | ±12.78775 W/m$^2$ |
| Voltmeter | 0.01 V | ±(0.8+5) V | ±0.1341 V |
| Ammeter | 0.01 A | ±(0.2+5) A | ±0.0269 A |
| Rotameter | - | ±0.04 LPM | ±0.061 LPM |

## 4. Results and Discussion

Experimental data obtains throughout four months from the two-hybrid TPV collectors started from January to April 2021 under actual weather conditions. Through this period, both systems exposed to different weather of sunny and cloudy days. In this study, two water flow rates have been chosen, which are 0.7 and 1.2 LPM. Table 4 illustrates the details of the experiment period weather at both flow rates. Discussing the results will focus on the following.

**Table 5**. Details of experimental days in each month.

| Month | No. of Experiment days | No. of sunny days | No. of Cloudy days | Number of days to experiment with a 0.72 LPM flow rate | Number of days to experiment with a 1.2 LPM flow rate |
|---|---|---|---|---|---|
| January | 17 | 11 | 6 | 8 | 9 |
| February | 14 | 8 | 6 | 7 | 7 |
| March | 16 | 8 | 8 | 8 | 8 |
| April | 16 | 11 | 5 | 8 | 8 |

### 4-1 Weather conditions

Weather conditions (Ta, G, and u) are simultaneous with other data recorded each day from 8 am up to 6 pm. Carrying the experiment encountered different weather conditions, from cold to hot weather. Data simulation was performed based on average weather data conditions, as shown in Figs 5-8. They indicated that the weather in January was cooler than in other months, and Ta did not exceed 18 ºC and G was also not exceeding 700 W/m$^2$, while you fluctuated ranged from 0.95 to 1.3 m/s. In February, the weather conditions became warmer, ***Ta*** ranged from 13.8 °C to 20.8 ºC, the change in ***u*** was apparent during the day for a short time in the middle of the day, and most of the time, there was almost stagnation. As for the G, it reached approximately 800 W/m$^2$ at midday. In March, the weather changed significantly compared to February, when the temperature increased by around 2 °C, solar intensity 100 W/m, and the wind was apparent most times a day, ranging from 0 to 1.5 m/s. In April, the weather became warmer, with the average ambient temperature ranging from 25 °C to 33 °C, which is during most of the day, the wind was blowing at speed ranging from 0.55 to 0.82 m/s, while the solar intensity did not exceed 800 W/m$^2$.

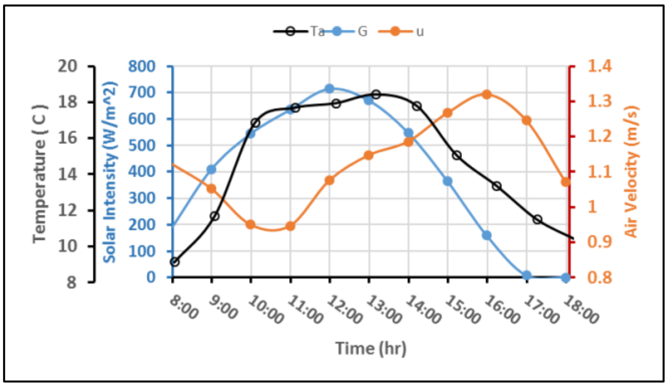


**Fig.4**. Average weather data in January, 2021

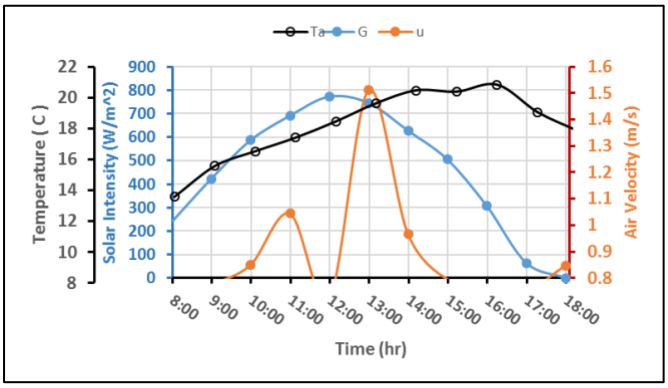


**Fig.5**. Average weather data in February, 2021

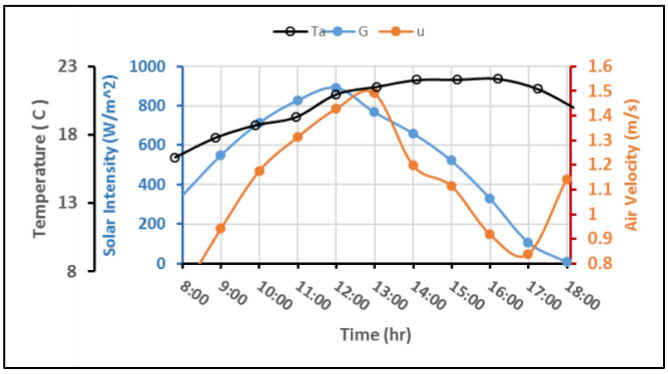


**Fig.6.** Average weather data in Match, 2021

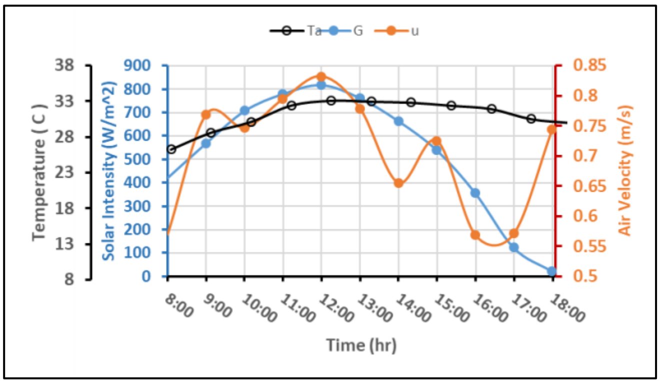


**Fig.7**. Average weather data in April, 2021

4-2 Thermal energy simulation.

The experiments were performed with both hybrid PVT collector systems at a volume flow rate of 0.7 and 1.2 LPM , respectively; Data acquisition from these experiments was simulated based on average values for each month. The energy absorbed by these systems depends mainly on solar radiation; it reaches its maximum in the middle of the day, especially on a clear weather day, as shown in Figs 8 to 11. They indicated that the average daily solar energy that reached both TPVT and WPVT collectors was determined based on the area integration under the input energy curve, estimated as 270.8, 332.9, 427.04 355.09 W.hr for January, February, March and April, respectively. On the other side, energy losses from collectors to their surroundings depend on the temperature difference between the collectors' bodies and the ambient. The previous figures showed that the highest energy losses have occurred at a time afternoon, where at these times, the collector body temperature has become much higher than ambient temperature. In the same method as the energy entering the systems was calculated, the daily average of the lost energy was calculated and estimated as 193.16, 188.83, 220.72, 167.87 W.hr for January, February, March and April, respectively. The result showed that most of the energy loss occurred from the upper surface of the PV panel because it is in direct contact with the surrounding environment. It is hotter than ambient and other sides were tightly thermally insulated. Previous figures indicated that the WPVT collector gave higher useful energy than another collector in all weather conditions at both flow rates. Part of the thermal energy coming from the collector by circulating water was stored in the paraffin layer during the day and released when needed when the sun was not available. The experimental results of the WPVT complex showed that produced the highest average useful energy was in March due to the solar energy density exceeding 860 W/m$^2$ in it, which is the highest solar intensity among the testing months. Also, the result showed that a volumetric flow rate of 1.2 LPM for each of the collectors had transported the highest applicable energy rate from the collector to the storage water tank.

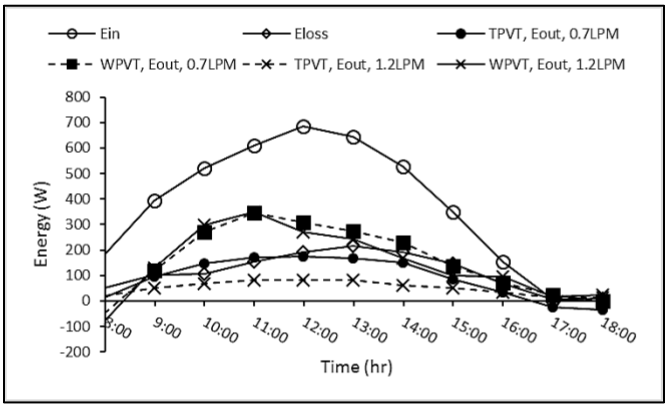


**Fig.8**. Average energy vs time simulation for both hybrid PVT collectors.in January.

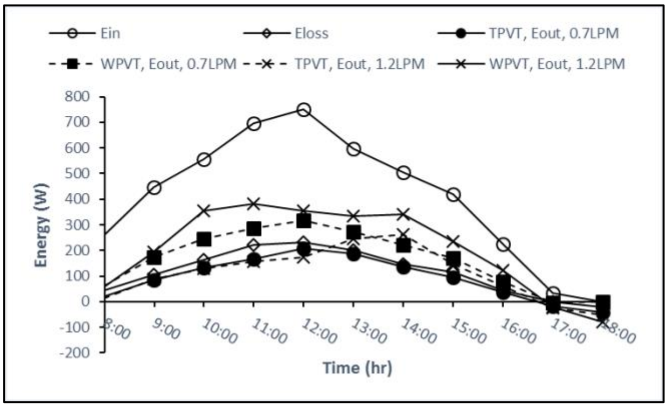


**Fig.9**. Average energy vs time simulation for both hybrid PVT collectors.in February.

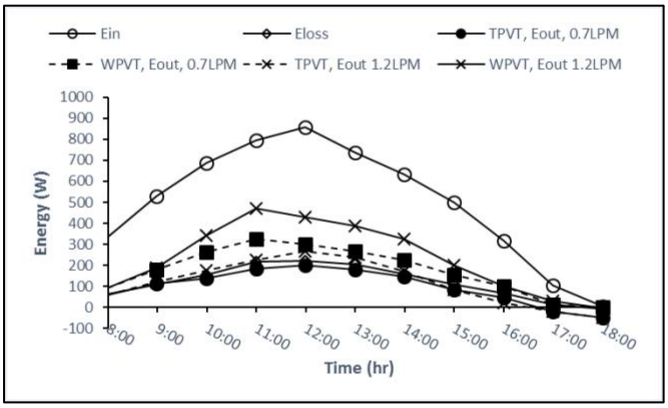


**Fig.10**. Average energy vs time simulation for both hybrid PVT collectors.in March.

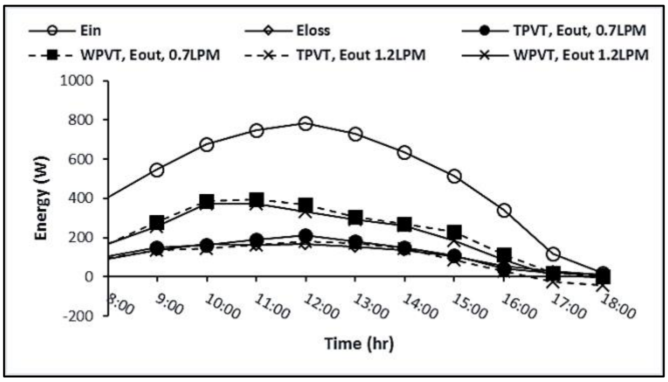


**Fig.11**. Average energy vs time simulation for both hybrid PVT collectors.in April.

4-3 Thermal efficiency

The thermal efficiency of the collectors TPVT and WPVT was calculated from the analysis of the practical data recorded during the testing period in two volumetric flow rates, LPM 0.7 and LPM 1.2, and expressed in Figures (12 to 15) for the months of January to April, respectively. These figures indicate that the WPVT collector gives a higher thermal efficiency than the TPVT collector for both flow rates and over the test period, as a storage unit that contains paraffin wax had a good contribution to improving the thermal efficiency of the collector. The figures also indicated that the water flow in the two collectors has an important role in improving the efficiency, as the flow 1.2 LPM gave a higher efficiency than the other flow 0.7 LPM in most of the times. Figure.12 shows the analysis of the thermal efficiency of the two collectors in January, where it was noticed that the efficiency increases with the increasing progress of the test time until it reaches its highest value for the collector WPVT of the two LPM flows (0.7 and 1.2) and it was estimated (53.5 and 60) % to respectively at 11:00 a.m. and then gradually decreased until it reached 16.3% and 33.2% of the aforementioned flow, respectively, at 17:00 p.m. While the efficiency of the TPVT unit during the same test period in general at best did not exceed 50% of the efficiency of WPVT, in addition, the benefit of paraffin wax appeared after the solar energy decreased at sunset hours, as it provided the collector with stored thermal energy until 18:00 p.m. in When the TPVT collector has exhausted all its stored internal energies at 17:00. Figure.13 shows the capacitive thermal efficiency of the two collectors in February, as the efficiency of the collector WPVT was the highest in the two flows than the other collector and at a rate of double for the two flows, where the thermal efficiency of the collector WPVT at the flow rate of 1.2 LPM ranged between (25to 63) %, and at a flow rate of 0.7 LPM, it ranged from (23 to 45) %, while the TPVT collector in the best case did not exceed 43% at a flow of 1.2 LPM and 33% at a flow of 0.7 LPM. It is noticed from the figure that the efficiency of the TPVT collector is very similar in the two flows (0.7 and 1.2) LPM, and the reason is that the environmental conditions for most of the month were cloudy and cold. It is noticed from Figures 14 and 15 that the thermal efficiency with mild weather conditions and their transformation to warmer than the past two months is less volatile and that the change in efficiency with time is more regular, as it was mentioned previously that the efficiency of the WPVT complex is the highest The performance of the efficiency with the flow rate is similar to the previous two months, but with different values from them, as the efficiency of the WPVT collector ranged from (29 to 59) % for 1.2 LPM flow and (27.5 to 41) % for 0.7 LPM flow in March, while the efficiency of the TPVT collector did not exceed From 17% to 33% at a flow of 1.2 LPM and less than it at a flow of 0.7 LPM. The thermal efficiency level for the month of April for the collectors was less than the months of March, and the reason for this was that the average intensity of the sun's rays for the month of April was less than 800 $W/m^2$, although the temperatures in it were higher than the month of March. Figure (16-4) indicates that the highest efficiency of the WPVT collector did not exceed (55 and 57) % for the two flows (0.7 and 1.2) LPM, respectively, while the efficiency of the TPVT collector was in the range of (25 to 27) % for the aforementioned flows, respectively, until before midday and from Then it dropped to zero at 17:00 p.m.

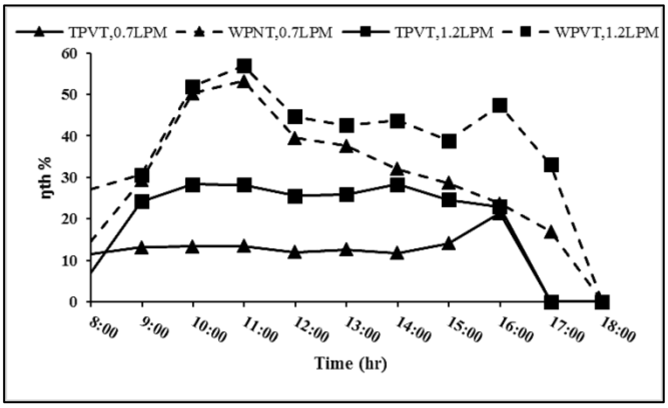


**Fig.12**.The hourly variation of average thermal efficiency vs. time for both hybrid collectors in January.

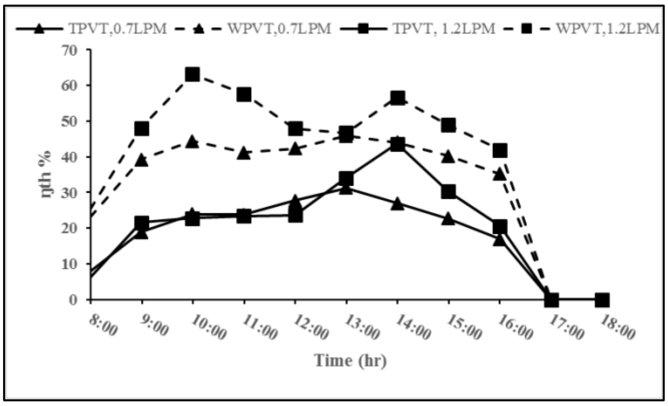


**Fig.13**.The hourly variation of average thermal efficiency vs. time for both hybrid collectors in February.

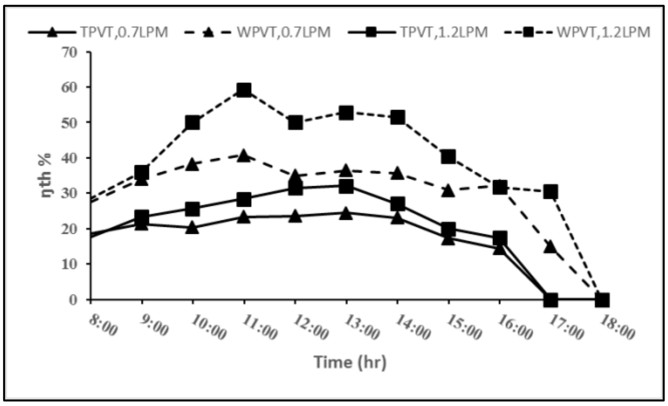


**Fig.14**.The hourly variation of average thermal efficiency vs. time for both hybrid collectors in March.

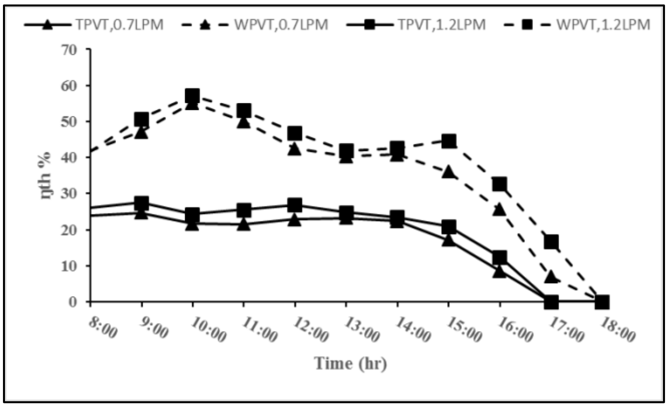


**Fig.15**.The hourly variation of average thermal efficiency vs. time for both hybrid collectors in April.

## Conclusions

The transient result simulation of two hybrid PVT collectors for four months, which started from January 2021 up to April, indicated that the use of a hybrid collector contributed to rising PV panel performance efficiency in good form. When using TPVT collectors, performance efficiency can add approximately 30% to the electrical efficiency of the PV panel. Still, when adding paraffin wax storage unit to the hybrid collector system (WPVT), its performance efficiency was increased more than the efficiency of the TPVT by twice adding to the electrical efficiency, in addition to that, the time of energy supplying to the water tank storage from WPVT collector increased to time longer than another collector. When comparing the current study results with similar work performed in the same geographical area [3], they showed a good agreement. So the following conclusion have been achieved:

- Increase thermal efficiency of less than 60% by adding paraffin wax to the hybrid PVT collector.
- Paraffin wax was viewed as a useful source of thermal energy, especially when the intensity of solar radiation falls in times of dusk and afternoon.

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