

Comparative analysis of a hybrid Photovoltaic-Water Thermal solar system using monocrystalline, polycrystalline and amorphous silicon solar modules.

Alexis Kuefouet Lontsi ^{1*}, Boris Merlain Djousse Kanouo¹, Julius Kewir Tangka ¹, Claude Vidal Aloyem Kazé ¹, Henri Grisseur Djoukeng¹

University of Dschang, FASA, Renewable Energy Research Unit, Rural Engineering Department. P.O.Box: 222, Dschang, West-Cameroon

Abstract. The proposed work consists of a comparative analysis of a model of a hybrid solar PV/T waterborne system using monocrystalline, polycrystalline and amorphous silicon solar modules. In this work, we have highlighted that the design of a PV/T waterborne system depends on the type of solar module. We have chosen on the market the polycrystalline / monocrystalline silicon solar modules with a power of 100Wc each and 60Wc for the amorphous. Behind each solar module is glued a coil exchanger of respective dimensions: 22m, 32m length and 12 mm diameter for water circulation. The prototypes of the water PVTs as well as their control modules have been realized in the west of Cameroon. Tests were conducted and the data collected led us to optimize the production of the solar photovoltaic modules. We obtained an average daily electrical energy gain of 10.7% or 10.7Wc (mono-crystalline); 13.9% or 13.9Wc (polycrystalline) and 0.97% or 1.62Wc (amorphous) compared to conventional solar panels. For the thermal side, we obtained an average daily thermal power of 214.944 W or 4 liters of hot water (37°C) for the monocrystalline panel; 298.35 W or 5,6 liters of hot water (44.5°C) for the polycrystalline module and 304,57 W or 13.78 liters of hot water (48.6°C) for the amorphous. These tests were made on an average sunshine of 835.51W/m² between 7h30 min and 15h30 min. The analysis comparison of the developed models shows us that the PVT with poly water has a better electrical output followed by the mono then the amorphous and the PVT with amorphous water has a better thermal output followed by the poly and the mono. This approach allowed us to recover a quantity of the electrical power of the modules lost by Joule effect while determining the quantity of hot water that can be produced by a PV module

Keywords: PV/T hybrid solar system; efficiency; energy gain; hot water temperature

1 Introduction

Solar photovoltaic energy is one of the most important sources of renewable energy, which presents an end to our energy production problems Wolf et al. [1]. Moreover, this energy seems the most promising, non-polluting and inexhaustible energy source. The International Energy Agency in 2013, estimated that the share of photovoltaic solar energy in global electricity production would be about 2.1% in 2017 and could reach 16% by 2050 César kapseu, et al. [2]. The use of photovoltaic solar energy is increasing in Africa . However, the major drawback of photovoltaic cells is their low efficiency, which varies between 11 and 18% [3]. Indeed, only a small part of the power of the incident radiation can be converted into electricity. In addition, unconverted radiation heats the module inside, further reducing the yield that is inversely proportional to cell temperature Dahouéon et al. [4]

Hence the idea of developing a combined photovoltaic-thermal system that brings together solar thermal and solar photovoltaic on the same surface. The thermal energy recovered under the module via a coil exchanger can be used to heat water. Haithan et al. [5], have worked on a hybrid photovoltaic system cooled by water on the rear surface. The prototype has been realized and the electrical and thermal performances have been evaluated in Dhahran climatic conditions. The experimental results showed that with active water cooling, the module PV temperature dropped significantly to about 20% leading to an increase in panel efficiency of approximately 9%.The maximum value of efficiency without cooling was 15.8% at 9 am whereas with cooling the maximum value was 18% at 11am. With active cooling, the increase in the electrical power yield over the day was 9%. Baissi et al. [6], designed a hybrid photovoltaic thermal solar collector working on the thermo siphon principle.

They showed in their work that the efficiency of a thermo syphon water heater is around 40% or more, while in a photovoltaic installation only 10-20% of solar energy is used, and the rest about 80%, is lost. Saeed Abdul-Ganiyu et al [7]. conducted an experimental setup comprising a water-based monocrystalline silicon PVT system and an ordinary monocrystalline silicon PV. The main objective of their work is to experimentally evaluate the performance of a photovoltaic-thermal (PVT) module compared to a conventional photovoltaic (PV) module system in a hot and humid tropical climate in Ghana. The results showed that the highest combined monthly average measured electrical/thermal efficiency of the PVT was 56.1%. Previous work on PV/T systems has mostly been conducted with a single type of solar module, but there are several types on the market. The development of PV/T systems have been mostly approached on the thermosyphon principle, but in this principle, the emphasis is put on the production of hot water and less on electricity. More concretely in this paper, we propose to optimize the efficiency of three different types of PV solar modules by capitalizing on the heat produced underneath for water heating.

Within the framework of this work, it is a question for us to make a comparative analysis of a model of

hybrid photovoltaic-thermal solar system using monocrystalline, polycrystalline and amorphous silicon solar modules in the climatic conditions of Dschang in western Cameroon, in which we evaluated the electrical and thermal performance of systems such that: the variation of the current voltage, electrical and thermal efficiency, the I (V) curve and the electrical power for each type of solar module.

1.1 Description and operation principle of the system

The system consisted of solar PV sensors with monocrystalline, poly crystalline and amorphous placed on a metallic support tilted at 6° to the horizontal, a thermally insulated helical coil heat exchanger glued to the rear of the PV module, and a solenoid valve. Functionally, when the temperature below the solar modules is above 50°C , the solenoid valve is turned on and sends cold water which circulates through the coil through a water trap and when the temperature below solar modules is below 46°C , the solenoid valve is off.

The design of a hybrid PV-T water system gotten with solid Works computer-assisted design software is found in Figure 1 below.

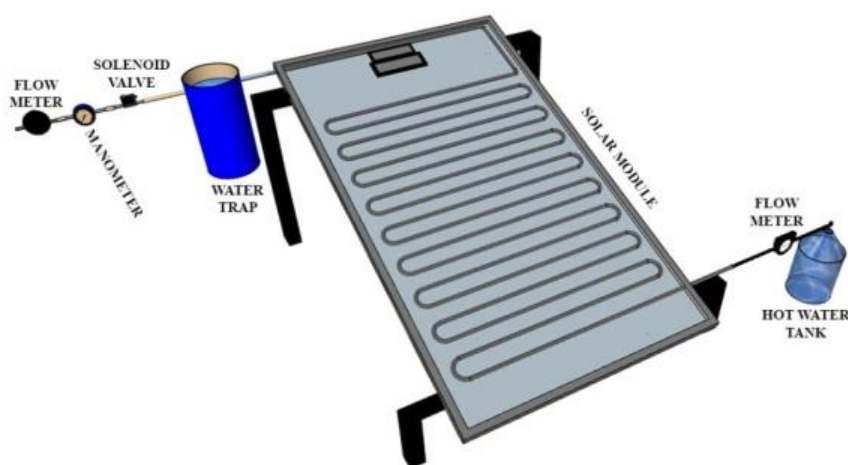


Fig.1. Designed hybrid PV-T solar system

2 Materials and Methods

2.1 Physical and Socio-Economic Environment

2.1.1 Physical environment

The site chosen for this work is in the western region of Cameroon specifically in Dschang, Menoua division with geographical coordinates;

latitude: 5-28'0" North, longitude: 10-25'0" East with an altitude of 1438m height.

2.1.2 Design of Heat Exchanger

Calculations were performed based on the dimensions of the solar module.

a) Determination of total tube length required

The total length of the coil was determined from the formula below:

$$L_T = \left(\frac{L}{a} \times l \right) + L \quad (1)$$

Where:

a : Spacing between coils

L_T : Total length of tube in m;

l : Width of solar module in m;

L : Length of solar module in m.

b) Sizing of the insulating surface

The insulation unit plays a very important role in the design of a heat exchanger. Its function is to minimize thermal losses. The determination of thermal insulation therefore depends on the ability of the material to withstand or prevent energy losses thus showing a certain level of energy reservation performance.

$$R = \frac{e}{\lambda} \quad (2)$$

With:

R : Thermal resistance ($\text{m}^2 \cdot \text{K}/\text{W}$);

e : Thickness of the insulation (m);

λ : Thermal conductivity coefficient ($\text{W}/\text{m} \cdot \text{K}$).

c) Sizing of solenoid valve

The water from the network was brought into the buffer tank naturally under good pressure, the solenoid valve was placed downstream of the coil and it sent water when the temperature below the module was quite high. The characteristics of solenoid valve was determined using the formulae 3 Sandberg et al. [7,8].

$$P_e = \frac{\Delta P \times Q}{\eta_{ev} \times 3600} \quad (3)$$

Where:

P_e : electric power of the solenoid valve (W)

Q : Fluid flowrate (m^3/h)

ΔP : Singular pressure drop at the solenoid valve (in Pa or N/m^2)

η_{ev} : overall performance of the solenoid valve

The Singular pressure drop at the solenoid valve formulae defined by formula 4 as seen;

$$\Delta P = K \times \frac{\rho \times V^2}{2} \quad (4)$$

2.2 Performance Evaluation of hybrid PV/T water system

The efficiency of the exchanger was evaluated by determining the usable thermal power it could produce.

d) Determining the thermal power of the system

This thermal power was deduced from the thermal balance on the hot fluid and is given by equation 6. Si Chaib and Sari. [8]

$$\phi = K \times S_l \times \Delta T \quad (5)$$

With:

ϕ : Total thermal power exchanged

S : Total exchange surface (m^2)

K : Global exchange coefficient

ΔT : Average logarithmic temperature

$$\text{Or } \Delta T = \frac{(T_{glass} - T_{fs}) - (T_{ted} - T_{fe})}{\ln \frac{(T_{glass} - T_{fs})}{(T_{ted} - T_{fe})}} \quad (6)$$

With

T_{fe} : Water temperatures at the inlet of the coil

T_{fs} : Water temperatures at the outlet of the coil

T_{glass} : Temperatures of the glass above the solar cells

T_{fs} : Temperatures of the tedlar below the cells

2.3 Determination of Global Exchange Coefficient

e) Layout of the different components of the heat exchanger in the PVT sensor

In this case, we will be interested in the conductive heat transfers between the glass, the PV cells, the tedlar, the copper tube and all of the rear insulators then convective between the movement of water inside the coil and above the glass due to the movement of the wind. The set of elements that

make up our sensor that can interact with each other thermally through convective exchange coefficients

and the different thicknesses of the materials used are shown in Figure 2 below.

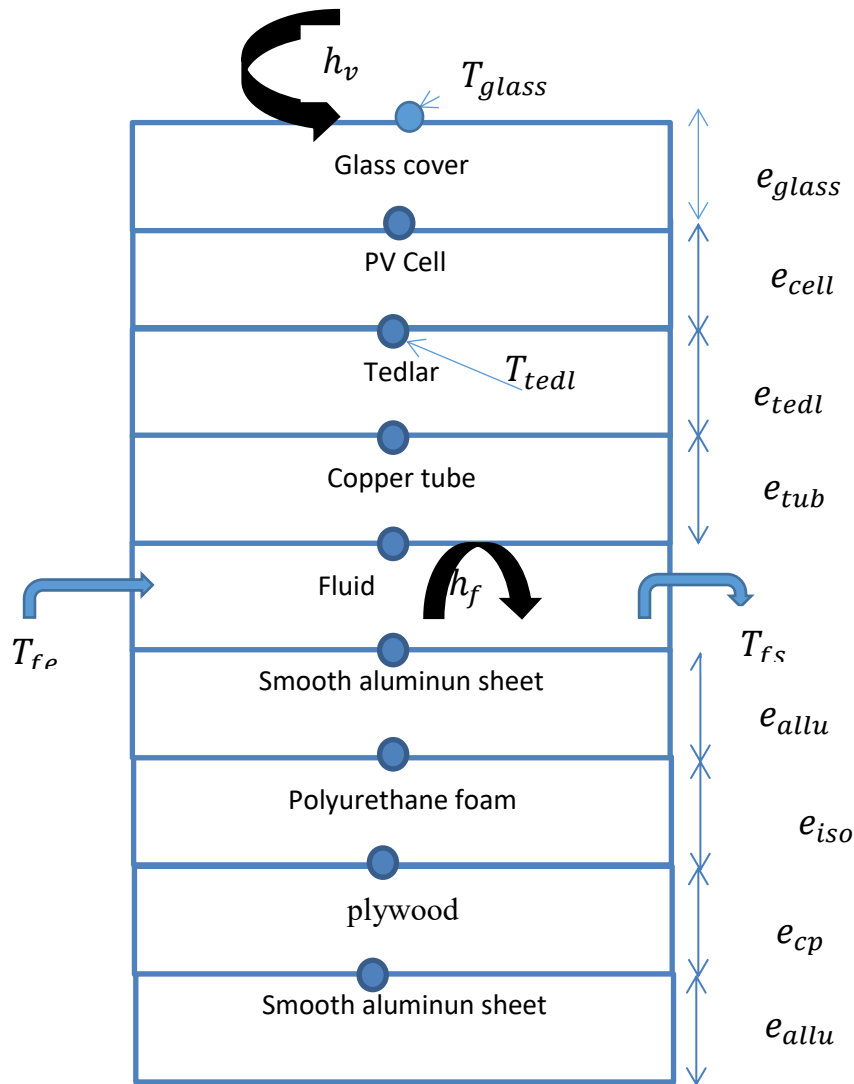


Fig.2. A Sketch of different heat exchangers on the PV/T water system

The equation governing the global exchange coefficient in the hybrid sensor is determined by the following formula while neglecting the crushing resistance Boureima et al, [11]

$$K = \frac{1}{\frac{1}{h_v} + \frac{e_{glass}}{\lambda_{glass}} + \frac{e_{cell}}{\lambda_{cell}} + \frac{e_{tedl}}{\lambda_{tedl}} + \frac{e_{tub}}{\lambda_{tub}} + \frac{1}{h_f} + \frac{e_{allu}}{\lambda_{allu}} + \frac{e_{iso}}{\lambda_{iso}} + \frac{e_{cp}}{\lambda_{cp}} + \frac{e_{allu}}{\lambda_{allu}}} \quad (7)$$

Where:

K= Global exchange Coefficient (m)

Table 1 Thermo-physical parameters of the studied hybrid PV/T water collector [17,21].

e_{glass} : Thickness of glass cover	0.003m
λ_{glass} : Thermal conductivity of glass	1W/mK
e_{cell} : Thickness of silicon the solar cell	5×10^{-6} m
λ_{cell} : Conductivity of silicon the solar cell	131W/mK
e_{tedlar} : Thickness of the tedlar	0.0002m
λ_{tedlar} : Conductivity of the tedlar	163W/mK
e_{tub} : Thickness of the pipe	0.0055m
λ_{tub} : Conductivity of the pipe	390W/mK
e_{allu} : Thickness of the aluminum sheet	0.003m
λ_{allu} : Conductivity of aluminum sheet	230W/m.K
i e_{iso} : Thickness of back insulation	0.03m
ii λ_{iso} : Conductivity of back insulation	0.025W/mK
e_{cp} : Thickness of the plywood	0.004
λ_{cp} : Conductivity of the plywood	0.025W/mK

cold water and heat below the solar module

Thermal transfer in between the rear of the solar module and the aluminum sheet, is characterized on one side by convection exchanges. To determine the internal convective thermal exchange coefficient, (h_f) in the case of rectangular pipes, we used the Colburn correlations [11] which is defined by[12, 20]:

h_v The convective heat flux depends on the wind speed Touafek et al. [10] et and can be calculated by : $h_v = 2.8 + 3V_w$ (W/m²K)

Where V_w is the average wind speed at Dschang 1m/s.

$$h_f = \frac{N_u \times \lambda_f}{D_t} \quad (8)$$

D_t : Tube Diameter (m)

h_f :Convection transfer coefficient between the rear of the solar module and the water inside the coil

λ_f : Thermal Conductivity of Water

N_u : Number of Nusselt

$$N_u = 0,023R_{ef}^{0,8}P_{rf}^{0,33}$$

Where:

R_{ef} : Number of Reynolds in the cold side,
 P_{rf} : Number of Prandtl in the cold side,

$$P_{rf} = \frac{\mu_f \times C_{pf}}{\lambda_f} \quad (9)$$

With:

C_{pf} : Specific Heat (J/Kg K) For Water $C_p = 4180$ J/Kg K ;

μ_f : Dynamic Viscosity of Heat Carrying Fluid (kg/m.s)

λ_f : Thermal Conductivity Coefficient of water (W/m.°C)

2.4 Design and simulation of the management module of the system using the Proteus

The management module consists of an information processing unit (microcontroller), temperature sensors, an LCD, power interface for the operation of solenoid valve. The temperature below the modules and the system is managed by a microcontroller that switches the different interfaces and two knobs that allow the adjustment of different temperature ranges. The control module works as follows:

- If the temperature below the solar module is above 50°C, the solenoid valve is turned on and the cold water circulates through the coil passing via a water trap.
- If the temperature below the solar module is less than 46°C, the solenoid valve is shut down.

2.5 Realization of the Hybrid PV/T Water System and the Management Module

The realization of the hybrid PV/T water system was based on dimensions made in the conception phase. The heat produced by PV cells on its rear was recovered by the passage of water in a coiled exchanger. The solar PV-T hybrid water system was made up of:

- Photovoltaic solar module;
- A blackened aluminum sheet glued to a plywood with the coiled copper tube heat exchanger;
- An insulating plate with a polyurethane foam, a plywood and a smooth sheet;
- An aluminum angle bar to attach the exchanger to the solar module;

2.5.1 Evaluation of system's electrical and thermal performance

Determination of Average daily power

Photovoltaic solar module when exposed to light, produces maximum power which is a function of maximum current and maximum voltage [12]. The equation below permits in determining the maximum power output;

$$P_j = \frac{\sum P_{max}}{n} \quad (10)$$

With:

P_{max} : Maximum power of the solar module

n : Number of measured value

P_j : Maximum daily average power of the solar PV module

Determining the performance of solar module

The formulae below was used to determine the performance solar module. [13,18].

$$\eta_j = \frac{\sum P_j}{S_p \times \sum IG} \quad (11)$$

S_p : Surface of the solar module. (m^2)

IG : global incident solar flux.(W/ m^2)

η_j : Average daily yield of the solar panel

g) Determination of the system's thermal performance

The thermal performance of a plane sensor was gotten by determining its instantaneous performance defined by the relationship below [9, 10]:

$$\eta_t = \frac{\phi}{(IG \times S_l) + P_e} \quad (12)$$

η_t : Collector thermal efficiency

S_l : Lateral surface of the tube (m^2)

IG : Global solar incident radiation (W/ m^2)

P_e : Electric power of the solenoid valve (W)

ϕ : Collector thermal power (W)

2.6 Data Processing

The software that was used to process data is Microsoft Office Excel software, which facilitated the graphically presentation of results, and the estimation of the electrical and thermal performance of the hybrid PV-T water system

3 Results and Discussions

This part presents the results obtained after the design, simulation and realization of the hybrid PV-T water system, it also presents the results gotten after performance evaluation of the system

3.1 Design of PV-T System

The modules used for this project were gotten from Euronet manufacturing industry (brand name) made in China. Poly-crystalline and monocrystalline (30

cells) modules having a surface area of 0.648 m^2 , peak power of $100\text{W}/20.36\text{V}/5.576\text{A}$, a length of 1.20 m and 0.54 m wide with 0.03m height and an amorphous silicon solar module from the same manufacturer with an area of 0.98 m^2 , peak power of $60\text{W}/60.36\text{V}/1.576\text{A}$, length 1m and 0.98m wide with 0.04m height were used. Figure 3 below shows the solar PV module used.



Fig.3. Solar PV module chosen

3.1.1 Characteristics of the helical coil heat exchanger

The spacing of the coils, a , was chosen as $= 0.006\text{m}$. The total length of the coiled copper tube were taken as follows for poly crystalline (L_T) 22m , for Monocrystalline (L_T) 22m and for amorphous module (L_T) is 32m .

From formula 7, we found a thermal resistance polyurethane foam with a thermal insulation of $R=4.65 \text{ m}^2.\text{K}/\text{W}$ with a thickness of 3 cm .

This solenoid valve power was determined by taking into account the pressure calculated from formula 7 which gave $\Delta P=8437.5\text{Pa}$.

we considered the thermos-physical parameters of the water at a temperature of 20°C where we set the number of Reynolds of the fluid at the outlet: $Re = 5000$ and in this case, $\lambda = 0.3164 Re^{-0.25}$. The optimal tilt angle of solar modules in Dschang is $\alpha=6^\circ$. From formula 4, we had a volumetric flowrate of water at the exit of the coil to be $Q_v=3.0772 \times 10^{-5} \text{ m}^3/\text{s}$. on the bases of this flowrate, we determined the power of the solenoid valve using Formula 6 to be $P_e=1.8\text{W}$ while fixing the overall efficiency of the solenoid valve at 75% . We obtained the volume of water in the coil to be $V_o=0.46$ liters for mono/poly crystalline modules and 0.653 liters for amorphous modules using formula 5.

We had determined the overall global exchange coefficient of the system to be $K= 37.8 \text{ W}/\text{m}^2.\text{C}$

using formula 9 while calculating the exchange coefficient by convection on the cold side $hf=3718.83 \text{ W}/\text{m}^2.\text{C}$ using equation 10 and The convective heat flux depends on the wind speed $h_v = 5.8\text{W}/\text{m}^2.\text{K}$. equivalent Thermal resistance by conduction is given as $e/\lambda=0.00921 \text{ W}/\text{m}^2.\text{C}$. The number of nusselt on the cold side were calculated from Colburn correlation equation and we obtained the value of the hydraulic diameter to be $D_h=0.05 \text{ m}$ from formula 11 which is the height of air blade on the rear of the solar module.

3.2 Design layout of the hybrid PV/T water sensor and the management module

The choice of module used for this project was gotten from Euronet manufacturing industry (brand name) made in China. We made use of poly-crystalline and monocrystalline (30 cells) modules having a surface area of 0.648 m^2 , peak power of $100\text{W}/20.36\text{V}/5.576\text{A}$, a length of 1.20 m and 0.54 m wide with 0.03m height and an amorphous silicon solar module from the same manufacturer with an area of 0.98 m^2 , peak power of $60\text{W}/60.36\text{V}/1.576\text{A}$, length 1m and 0.98m wide with 0.04m height.

The thermal exchanger is attached at the rear of solar modules and thermally insulated with a polyurethane foam and an aluminum sheet is used to block the insulator still at the rear of the module. Figure4 below shows the coiled exchangers.

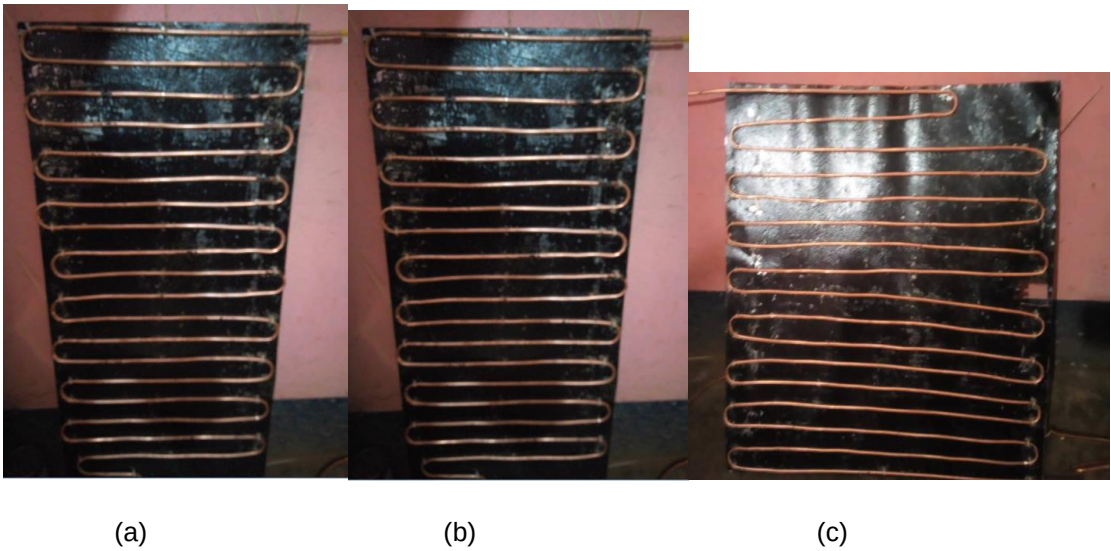


Fig.4. coiled thermal exchanger (a)mono, (b)poly, (c)amorphous

✓ Insulation

To insulate the outer surface of the exchanger, we used polyurethane foam as an insulator.

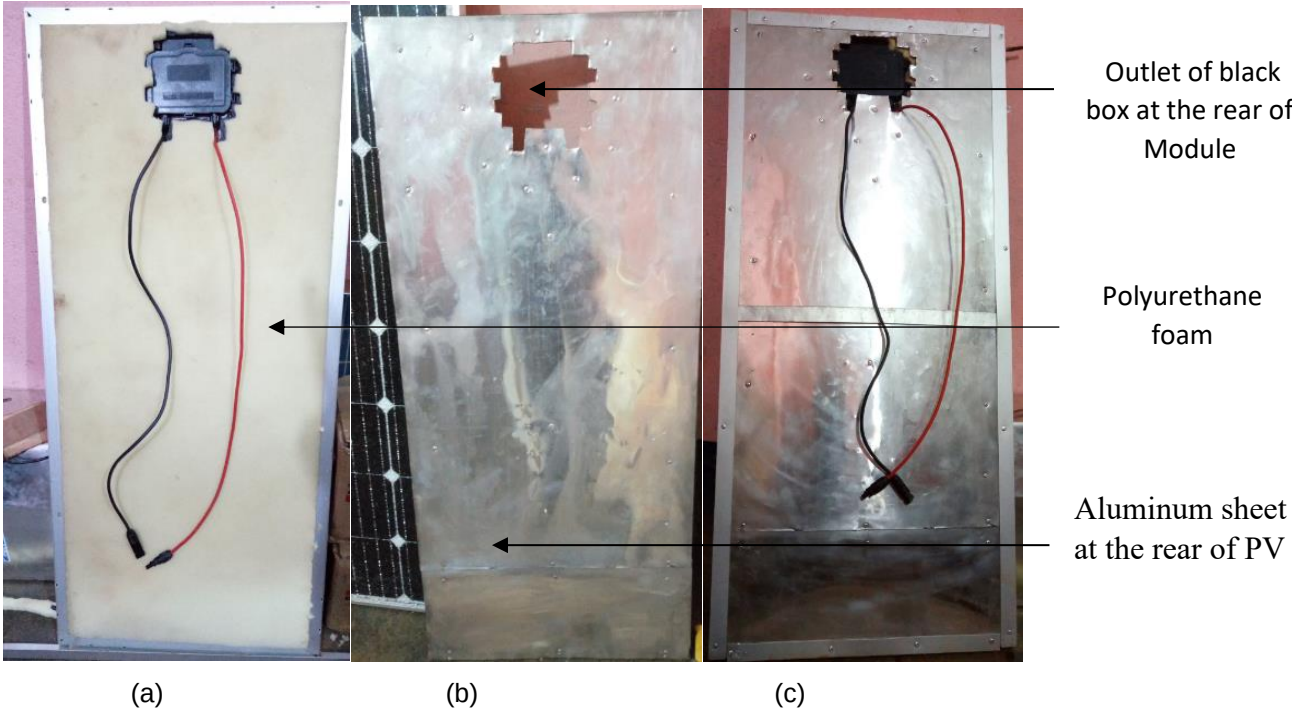


Fig.5. (a) thermal insulation of the exchanger, (b) Aluminum sheet at the rear of the module

Figure 6 shows a global view of the PV-T hybrid system realized, consisting of photovoltaic solar module and air collector below the module.



Fig.6. Hybrid PV/T water systems

- (1) PV solar module
- (2) solenoid valve
- (3)PVT solar module
- (4)Temperature sensor
- (5) Pyranom  ter
- (6)Flow meter at the outlet of hot water
- (7) Control module
- (8) load 120W (resistance)

3.2.1 Realization of the Management Module

Figure 7 represents a view of an electronic card for the management module of the system made on a pre-sensitized card and placed in a box to control of solenoid valve. It contains a set of electronic components, such as LCD display, temperature sensors (DS18S20), diodes (1N4001) and transistors (BC547) that allow the opening or closing of the solenoid valve at the desired time using signals sent by the temperature sensors to the microcontroller (ATMEGA328P). The data is collected and stored in an SD card.

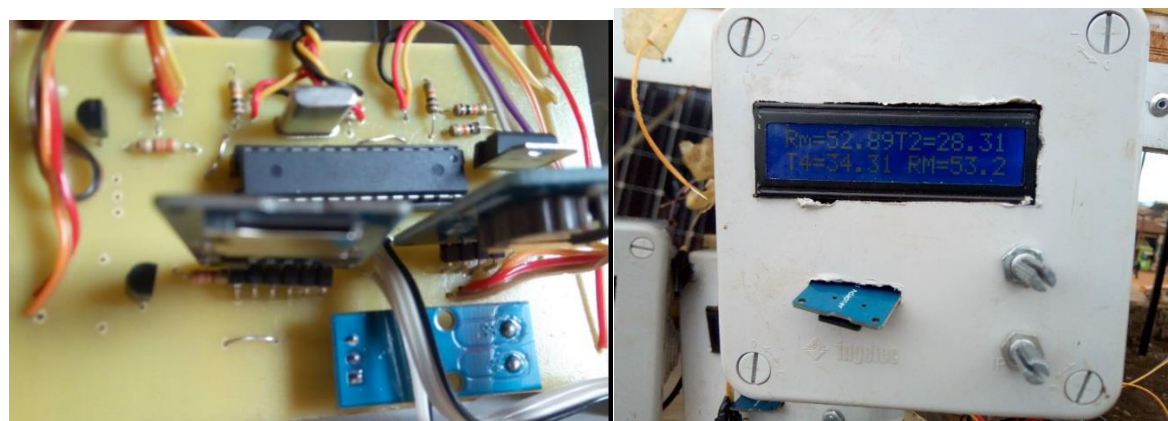


Fig.7. management module electronic card

The results obtained from test of different systems are presented in the form of graphs. The measurements were made for a period of five days

3.3 Results of the performance evaluation of the Hybrid PV-T Water System

in Dschang and the data collected was analyzed at the renewable energy laboratory in the department of Rural Engineering of the Faculty of Agronomy

and Agricultural Sciences(FASA) of the University of Dschang.

In order to come out with maximum power characteristic of the PV module with respect to sunlight and different temperatures, these measurements were done on the 5th October 2021 and recorded after every 5min.

- Performance according to module types

a) Monocrystalline modules

The following profile illustrates the variation of daily sunshine, temperature above and below the solar PV module and the variation of the maximum electrical power for the monocrystalline solar module.

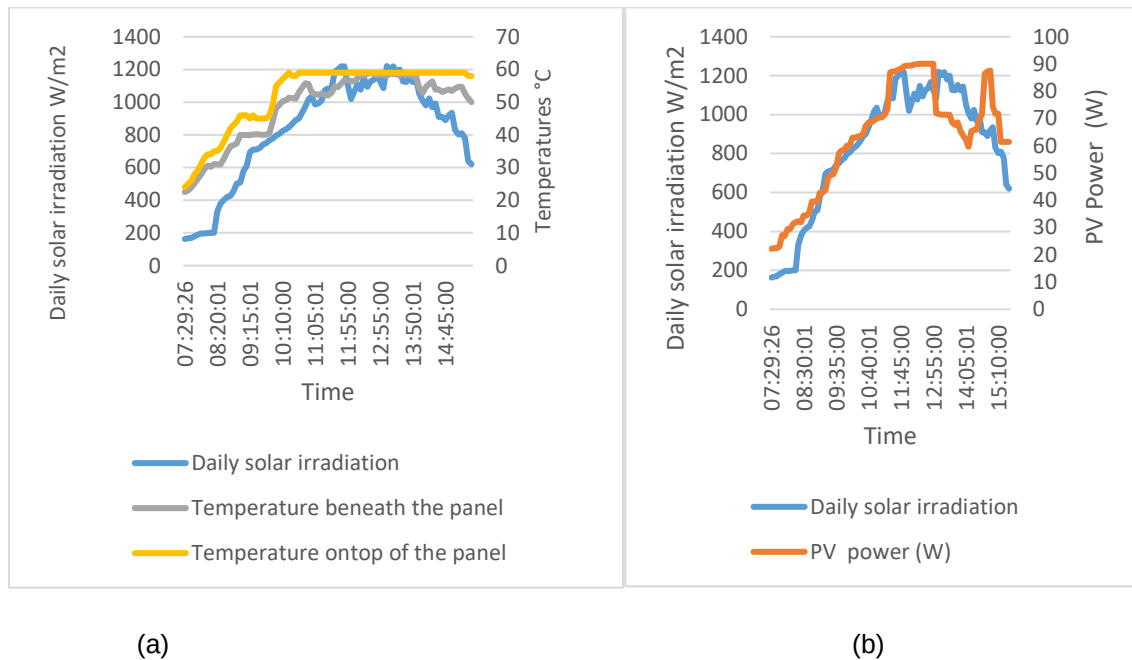


Fig.8. (a) Variation of daily solar irradiance, temperature above and below the conventional single-crystalline solar PV module also (b) the electrical power produced.

According to Fig 8, the single-crystalline solar PV module reaches a maximum power of 80.69W under a sunshine of 1077 W/m² at the turn of 12:10 min with a temperature below the module of 57.6 °C. This power decreases to 69.41W under a sunshine of 1221 W/m² around 13h35 min with a temperature below the PV oscillating between 58°C and 59.5°C and decreases again to 77.88 W around

14h 30 min with the temperature below the PV decreasing to 56°C.

To observe the behavior of the system under cooling in the case of a waterborne PV/T module of monocrystalline type, the data collected for a daily variation of the solar irradiance allowed to present the figure 9. It shows the evolution of the temperature above and below the solar PV/T module but also the electrical power produced.

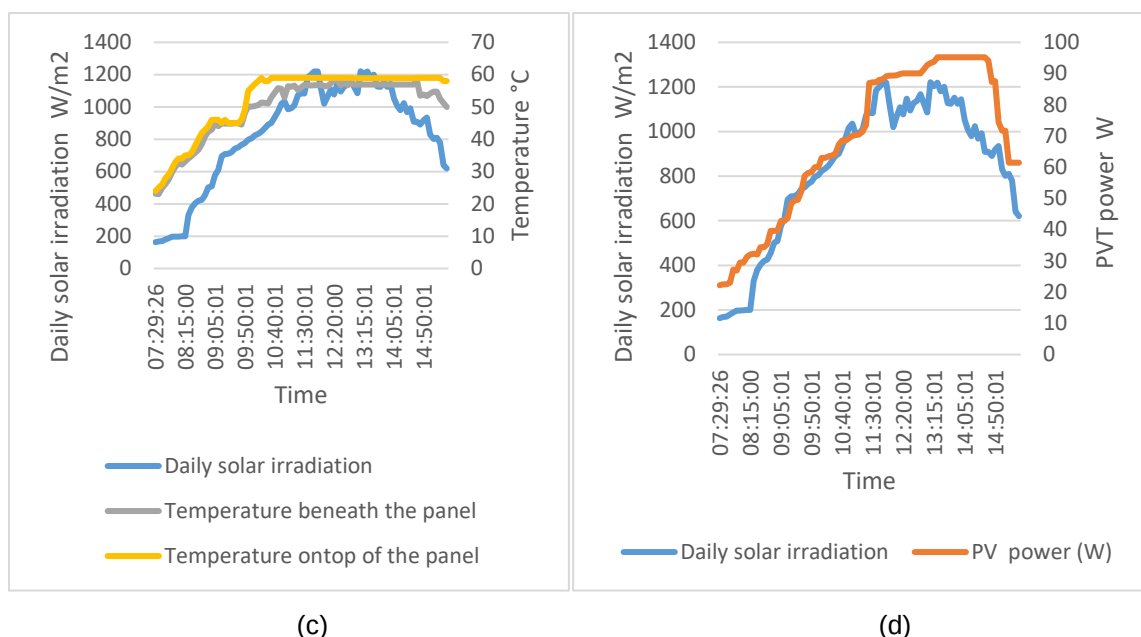


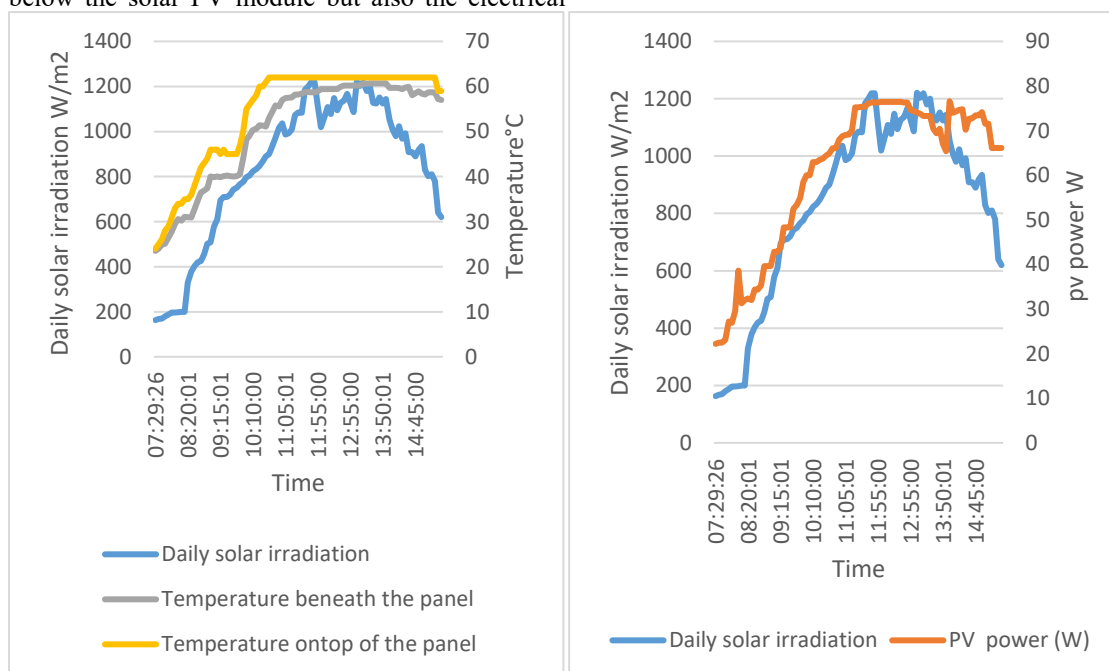
Fig.9. (c) Variation of daily solar insolation, temperature above and below the monocrystalline water-cooled PV/T solar module with cooling also (d) the electric power produced.

In Fig 9, the monocrystalline PVT solar module with water cooling via the coil exchanger reaches a maximum power of 95.21W under a sunshine of 1180 W/m² between 13:20 min and 14:55 with a temperature below the regulated module 58.1 °C.

b) Polycrystalline modules

The profile in Figure 10 illustrates the variation of solar irradiance for a one-day data collection for a polycrystalline solar PV module. We observe the variation over time of the temperature above and below the solar PV module but also the electrical

power produced. The power of the polycrystalline solar PV module reaches a maximum value of 76.45W under a sunshine of 1115W/m² at the turn of 11h 55 min for a temperature below the module of 58.2°C. The power profile decreases to 67.068W under an irradiance of 1221 W/m² at around 13:35 minutes under conditions where the temperature below the PV module oscillates between 59.9°C and 60.2°C. It decreases to 74.25 W around 14h15 min while the temperature below the PV decreases to 58.1°C.



(e)

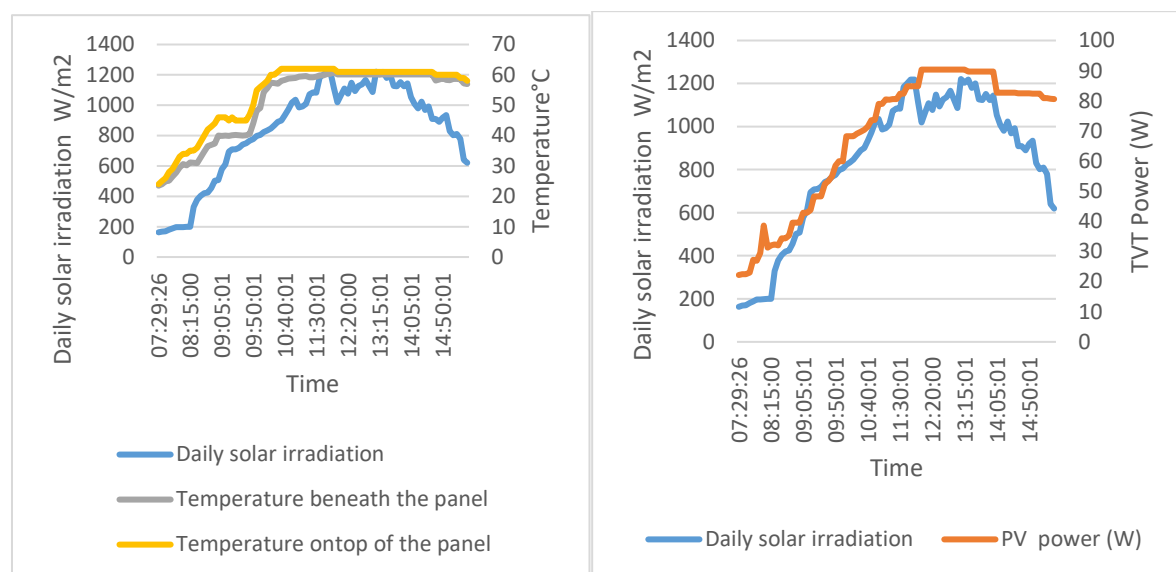
(f)

Fig.10. variation of sunlight, temperatures above and below the PV solar module and (f) the maximum power produced for poly-crystalline solar module.

From graph, the simple poly-crystalline PV solar module attends a maximum power of 76.45W when solar irradiation is 1115 W/m² at around 11:55am with a temperature below the module being 58.2 °C. This power drops to 67.068W when solar irradiation increases to 1221 W/m² around 1:30pm, at this time the temperature below the module varies between 59.9°C and 60.2°C and by 2:15pm, the power output of the module rises to 74.25 W

with the temperature below the module dropping to 58.1°C.

The profile shown in Figure 11 presents for one day of data collection the variation over time of sunshine, temperature above and below the water-cooled solar PV/T module in the case of the polycrystalline type module. The profile of the electrical power produced is also shown.



(g)

(h)

Fig.11. (g) Variation of daily solar insolation, temperature above and below the poly-crystalline water-cooled PV/T solar module with cooling also (h) the electric power produced.

From graph, a poly-crystalline PV/T solar module with water cooling via the coil exchanger reaches a maximum power of 90.35W when solar irradiation is 1127 W/m² between 12:10pm pm and 2:50pm with a temperature below the module regulated to 60.1°C.

c) Amorphous module

The profile of figure 12 shows the variation of the daily sunshine, the temperature above and below the solar PV module as well as the electrical power produced for the amorphous type solar modules. In this figure, the maximum power (19,328W) is reached under a sunshine of 1124W/m² at the turn of 13h 45 min with a temperature below the module of 61.6 °C. This power undergoes very weak variation until 15h 10 then, will undergo a decrease in the time in the same direction as the sunning.

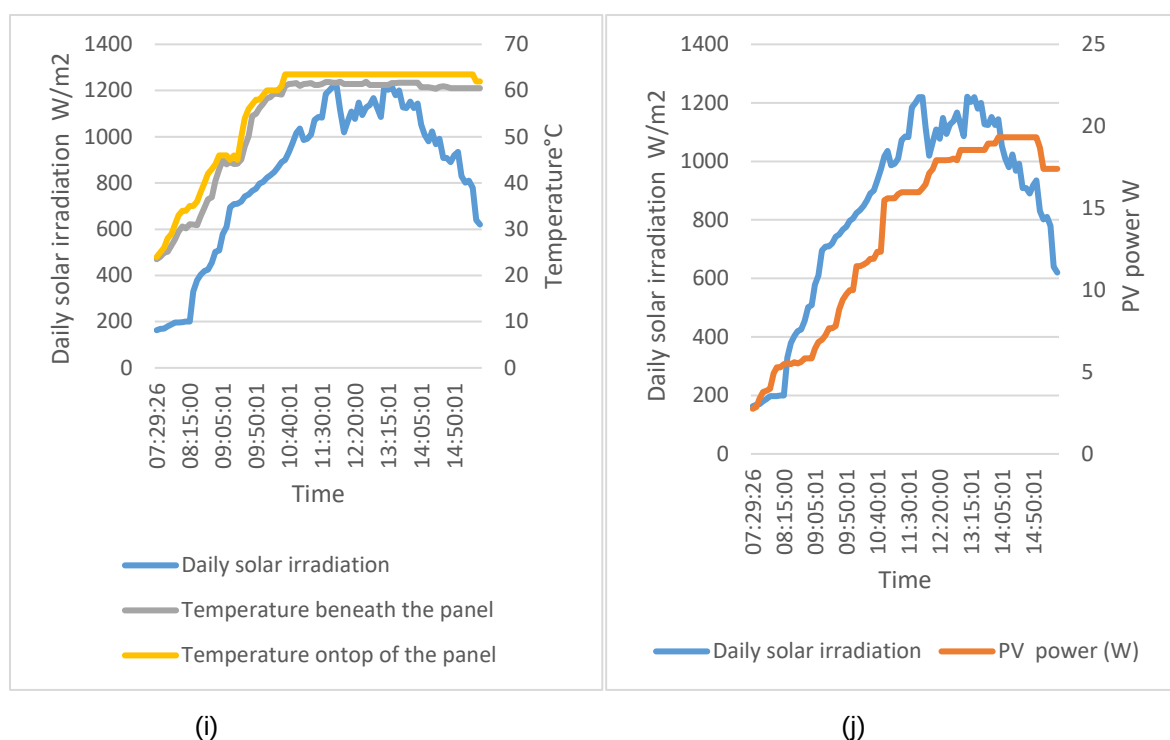


Fig.12. (i) Variation of daily insolation, temperature above and below the amorphous conventional PV solar module also of (j) the maximum electrical power produced.

The profile below shows the variation of daily insolation, temperature above and below the waterborne PV/T solar module with cooling also

the maximum electrical power produced for amorphous type solar modules.

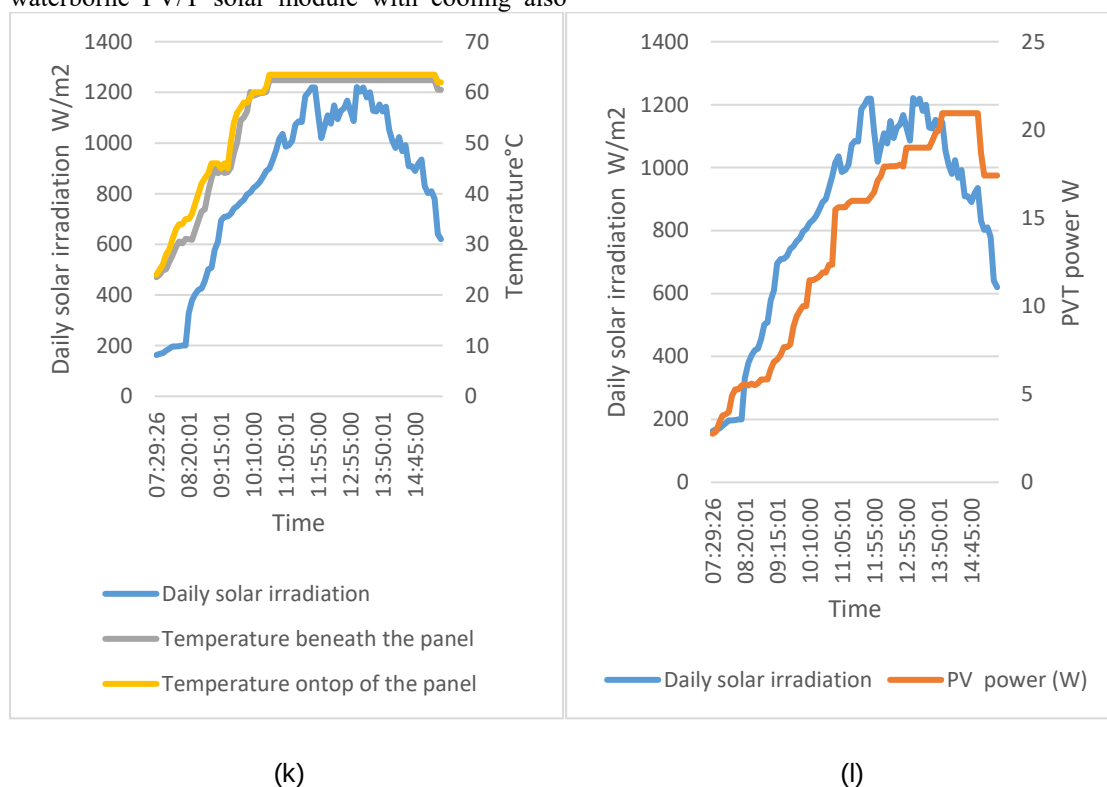


Fig.13. (k) Variation of daily sunshine, temperature above and below the amorphous water-cooled PV/T solar module with cooling also of (l) the maximum electrical power produced.

From Figure 13, the amorphous PVT solar module with water cooling via the coil exchanger reaches a maximum power output of 20,944W under a sunshine of 1127 W/m² between 12:10 min and 14:50 with a temperature below the regulated panel 61°C.

3.4.1 Comparative analysis of the thermal and electrical performance of the proposed model with the conventional solar photovoltaic module

Tables 2 and 3 present a comparative analysis of the results obtained.

Table 2 comparative analysis of the electrical performance of the proposed model with the conventional solar photovoltaic module

Types of solar modules	Average water thermal photovoltaic electric efficiency	Average electrical efficiency of the conventional solar module	Average electrical energy gain obtained compared to conventional solar modules	Average irradiation between 7h30 and 15h30
monocrystalline solar modules	15.33%	14%	10.7% is 10.7Wc	835.51W/m ²
poly-crystalline solar modules	14.33%	12%	13.9% is 13.9Wc	835.51W/m ²
amorphous solar modules	3.13%	3%	0.97% is 1.62Wc	835.51W/m ²

Table 3 comparative analysis of the thermal performance of the proposed model with the conventional solar photovoltaic module

Types of solar modules	Average water thermal photovoltaic thermal efficiency	Average thermal power of the water thermal photovoltaic collector	Average amount of hot water recovered	Average hot water temperature	Average irradiation between 7h30 and 15h30
monocrystalline solar modules	37.6%	214.95W	4 L	37°C	835.51W/m ²
poly-crystalline solar modules	42.7%	298.35W	5.1 L	44.5°C	835.51W/m ²
amorphous solar module	43.98%	304.57W	13.8 L	48.6°C	835.51W/m ²

These hot water temperatures obtained at the outlet of the exchanger are slightly higher than the results of the experimental study by CHOW et al. [3] on

PVT water systems with a parallel sheet exchanger therefore the temperature of the fluid at the outlet. is 43.28 ° C for the day of October 27.

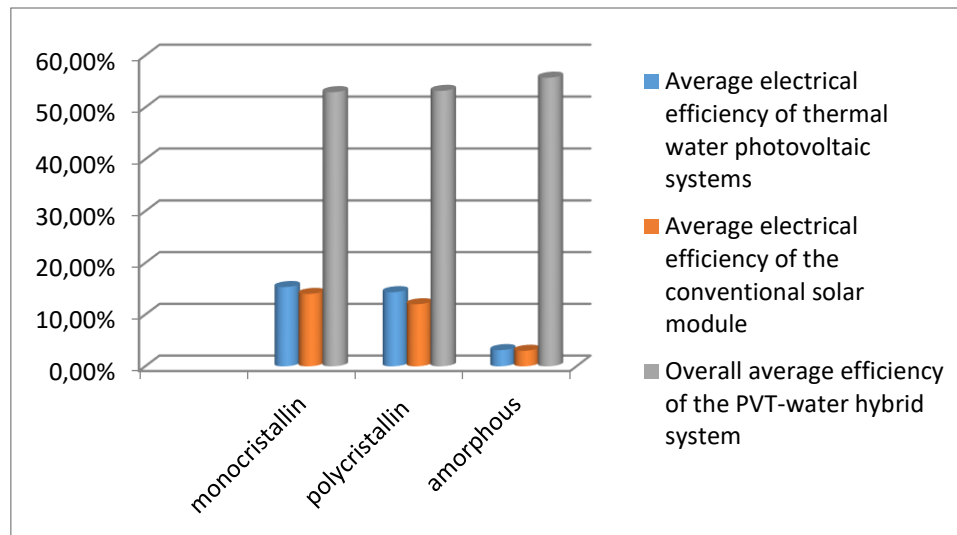


Fig.14. Histogram of the comparative analysis of the electrical and thermal performance of PVT systems of different type with the conventional solar photovoltaic module.

It was found that the waterborne PVT system with poly cristallin solar module gives a better overall efficiency (57.03%) compared to the other two. This efficiency is higher than that of Saeed Abdul-Ganiyu et al (56.1%).

The model is validated experimentally by comparing the results with some work from the previous literature.

The results indicated that the use of this proposed model gives a better electrical performance compared to the thermal photovoltaic systems with thermosiphon proposed by Baisssi (Algeria) and Chow (China). It is also found that the electrical and thermal production of the proposed model in the climatic conditions of Dschang (Cameroon) is higher than that of Haithan (Saudi Arabia) so their gain in electrical energy was 9% and Saeed Abdul-Ganiyu (Ghana).

4 Conclusions

Based on the methodology used in this study and the results obtained, it can be concluded that:

Solar modules chosen for this research are polycrystalline, monocrystalline and amorphous solar modules all from the same producer (Euronet made in china) with surface area and power respectively of 0.648 m², peak power of 100W/20.36V/5.576A, length 1.20 m and 0.54 m width with 0.03m height for both monocrystalline and poly crystalline. For amorphous module, peak power is 60W/60.36V/1.576A, length 1m and 0.98m width with 0.04m in height The coiled copper tube fixed beneath the modules have a total length of 22m for both poly and mono crystalline solar modules and 32m for amorphous solar module.

Tests were carried out on various PVT water systems and results analyzed with curves that explain the behavior of each system, indicating the optimization of power produced by photovoltaic solar modules. We obtained an average gain electrical energy for mono crystalline module of 10.7% (or 10.7Wc); for poly-crystalline modules, we obtained an average gain in electrical energy of 13.9% (or 13.9Wc) and 0.97% (or 1.62Wc) for amorphous solar modules compared to conventional solar modules. This approach helps in recovering a certain quantity of energy lost in the form of heat by the solar modules while making use of this heat for heating water for home use.

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