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A COMPARATIVE STUDY OF THE INFLUENCE OF SUNLIGHT AND TEMPERATURE ON THE PERFORMANCE OF A LOW-CONCENTRATION FIXED PV SYSTEM AND A NON-CONCENTRATING FIXED PV SYSTEM IN A SAHELIAN ENVIRONMENT

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ABSTRACT

Our study compares the performance of a low-concentration photovoltaic (LCPV) system and a non-concentrating PV system under the influence of solar irradiance and temperature in a Sahelian environment (Burkina Faso). The systems used are fixed-axis systems with monocrystalline modules of identical specifications. To determine the most suitable system for the Sahelian context, mathematical and electrical models were developed for the concentrator and the PV module. Based on these models, the concentrator system was sized, and an experimental setup was constructed. The experimental study was conducted in Ouagadougou, the capital of Burkina Faso, over a one-month period (from the first (01) to the twenty-eighth (28) of February 2026). The results showed that the currents and voltages of both systems vary in tandem with irradiance. However, the low-concentration system exhibits higher efficiency during periods of high sunshine than the non-concentrating system. Furthermore, temperature has a negative impact on the modules' electrical parameters. This effect is more pronounced in the low-concentration system than in the non-concentrating system. Overall, the LCPV system exhibits higher energy efficiency than the simple system with , given Burkina Faso's climate, with a relative gain of approximately 32%. Its use will thus reduce the number of modules required and, consequently, the amount of space needed.

Keywords: Solar Photovoltaic System; Monocrystalline; Low Concentration; Fixed-Axis; Irradiance; Temperature.

1 INTRODUCTION

Today, renewable energy—particularly solar photovoltaic energy—represents an effective alternative to fossil fuels. Indeed, it is less polluting and widely available worldwide. The Sahel region enjoys particularly high levels of sunshine, with a total solar potential ranging approximately from 4.71 to 6.24 kWh/m²/day [1], [2], [3]. Nevertheless, despite this abundant resource, the conversion efficiency of photovoltaic systems remains relatively low, generally ranging between 15% and 22% [4], [5], [6], [7]. The low energy output of the modules is primarily due to climatic and environmental factors, as well as technical limitations [8], [9], [10]. This situation leads to an increase in the number of PV modules required to ensure sufficient energy conversion, which in turn requires the use of larger areas. Consequently, for powering telecommunications systems in urban environments, where available space is often limited, it becomes essential to consider alternative solutions that reduce the footprint of photovoltaic installations.

The objective of this study is to compare the electrical performance of a fixed, low-concentration photovoltaic system with that of a fixed, non-concentrating photovoltaic system, in order to identify the most suitable solution for telecommunications applications in the Sahelian context.

Numerous studies have already examined low-concentration photovoltaic systems on an international scale. The study by Youssef et al. [11], conducted in a hot, arid climate in Egypt, highlights an increase in electrical power of approximately 33% compared to a conventional system. Similarly, the work by Reis et al. [12] indicates that in Portugal, the use of a solar concentrator can lead to an improvement in annual efficiency of up to 50%. However, in the Sahel region, studies have generally focused on thermal concentration systems [13]. In this region—and more specifically in Burkina Faso—the month of February is characterized by intense sunshine, high temperatures, a dry climate, and high levels of dust [14]. These specific conditions justify the relevance of this study, which aims to analyze the influence of these climatic parameters on the performance of a CSP system during this period. This is the first investigation of its kind in the region.

2 MATERIALS AND METHODS

2.1 Modeling of the concentrated flux on the module

A low-concentration photovoltaic (LCPV) system typically consists of two flat mirrors arranged symmetrically on either side of the photovoltaic module.

The geometric concentration is given by the ratio of the area of the concentrator’s aperture to the area of the module [15] [16] [15], [16], [17].

$$C_r = \frac{Air\ de\ l'ouverture}{Air\ de\ l'absorbant}\ . \qquad (1)$$

Based on Figure 1 [18] [19], this is expressed by equation (2) :

$$C_r\ \frac{L_1.(l_1+2x)}{L_1.l_1} \qquad = (2)$$

Where C_r is the geometric concentration, and l_1 ; l_2 ; L_1 are, respectively, the module width, the mirror width, and the module length.

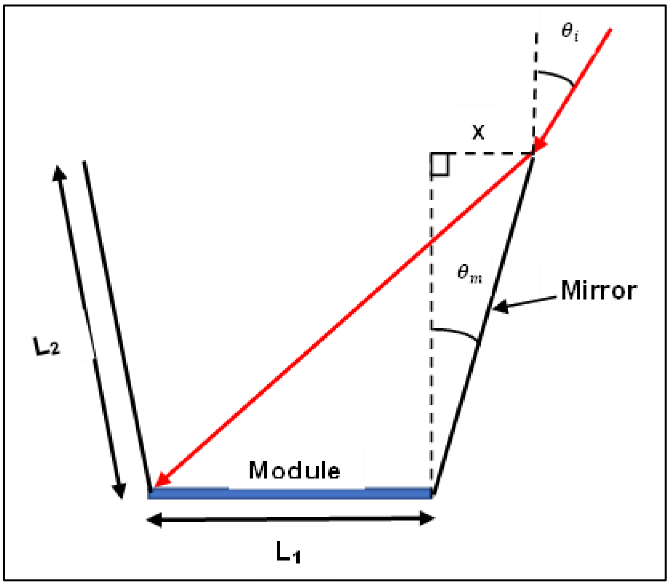

Figure 1: Diagram for determining the geometric concentration of the system.

From Figure 1:

$$x = l_2 \sin(\theta_m) \tag{3}$$

Applying the law of sines, we have [20]:

$$l_2 = \frac{l_1 \sin(90° - (\theta_i + 2\theta_m))}{\sin(\theta_i + \theta_m)} \tag{4}$$

Substituting equation (3) into (2) and then into (1), we find:

$$C_r = 1 + \frac{2 \sin \theta_m \cos(\theta_i + 2\theta_m)}{\sin(\theta_i + \theta_m)} \tag{5}$$

When θ_i = 0 and the mirrors are practically perpendicular to the plane of the PV module—that is, $\theta_m \approx 0$—then the geometric concentration factor is maximal and equals 3.

The flat mirrors in our system are sized based on the configuration shown in Figure 2, where θ is the angle of inclination of the mirrors, and L_1 and L_2 represent the lengths of the module and the mirror, respectively. Their ratio is given by Equation (6) [Malki Ahmed]:

$$\frac{L_2}{L_1} = -\frac{\cos 2\theta}{\sin \theta} \tag{6}$$

The optical efficiency of the system is given by Equation 7.

$$\eta_{op} = \frac{\textit{radiation incident on the absorber}}{\textit{radiation incident on the aperture}} \tag{7}$$

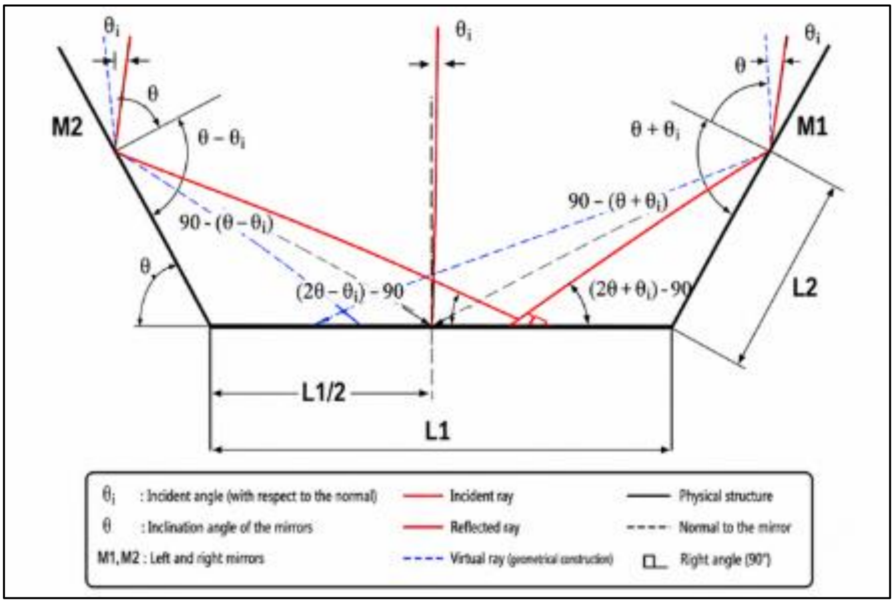

Figure 2: Geometric model of a V-trough CSP system

2.2 Electrical Modeling of the PV Module

The operation of a photovoltaic cell is based on an N-P junction. Each cell is represented by an electrical model consisting of one or more diodes [21] [22]. However, the single-diode model is more widely used due to its simplicity. Figure 3 shows the electrical schematic of a single-diode PV cell [22].

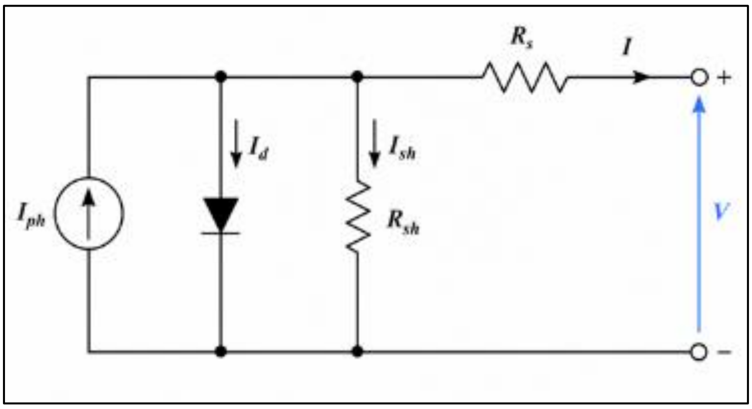

Figure 3: Electrical diagram of a single-diode photovoltaic cell [22]

Using the cell's electrical diagram and applying the node rule, the current I flowing through the load is obtained from Equation 1 :

$$I = I_{ph} - I_s \left[\exp\left(\frac{q(V+IR_S)}{nkT}\right) - 1\right] - \left(\frac{V+IR_S}{R_{sh}}\right) \tag{8}$$

Where: k is the Boltzmann constant, q is the electron charge, n is the ideality factor I_{ph} is the photonic current, I_s is the saturation current, and I_d is the current flowing through the diode.

The short-circuit current, open-circuit voltage, maximum power, form factor, and efficiency are given by equations 2, 3, 4, 5, and 6, respectively [23].

$$I_{cc} = I_{ph} - I_s \left[\exp\left(\frac{q(I_{cc}R_S)}{nkT}\right) - 1\right] - \left(\frac{I_{cc}R_S}{R_{sh}}\right) \tag{9}$$

$$V_{co} = \frac{nkT}{q} \ln\left(\frac{I_{ph}}{I_s} + 1\right) \tag{10}$$

$$P_{max} = I_m V_m \tag{11}$$

$$FF=\frac{P_{max}}{I_{cc}V_{co}}=\frac{I_m\,V_m}{I_{cc}V_{co}} \quad (12)$$

$$\eta=\frac{P_{max}}{P_{in}}=\frac{I_m\,V_m}{G\,S}=\frac{FF\,I_{cc}\,V_{co}}{G\,S} \quad (13)$$

O$\grave{u}$ G is the solar irradiance and S is the module area [23] [24].

The current delivered by a module is given by Equation 14 [24].

$$I=N_p.I_{ph}-N_p.I_s\left[exp\left(\frac{q\left(\frac{V}{N_S}+\frac{R_S.I}{N_p}\right)}{nk_BT}-1\right)\right]-N_p\left[\frac{\frac{V}{N_S}+\frac{I.R_S}{N_p}}{R_{sh}}\right] \quad (14)$$

where:

$$I_s=I_{s,n}\left(\frac{T_n}{T}\right)^3\exp\left[\frac{qE_g}{nk_B}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right] \quad (15)$$

Where :E_g the energy of the semiconductor's bandgap (in eV) , and$I_{s,n}$, is the nominal saturation current (A), $N_S$is the number of cells in series, and $N_P$is the number of branches in parallel [24].

Irradiance and temperature influence the electrical parameters of PV cells. Indeed, increased irradiance positively affects module performance, while rising temperature reduces their performance [25].

The cell temperature varies as a function of ambient temperature and irradiance. It is expressed by the following equation [26] [27] [28]:

$$T=T_a+\frac{NOCT-20}{800}\times G \quad (16)$$

Where NOCT is the nominal operating cell temperature andT_a is the ambient temperature.

2.3 Experimental Setup and Measurements

For the experimental study, we used two identical monocrystalline PV modules, each with a power output of 10 W. The characteristics of the modules under standard test conditions (1000 W/m^2, AM 1.5 at 25°C) are listed in Table 1. We also used two plane mirrors of the same dimensions. The length and width of each mirror, as determined after system sizing, are 55.3 cm and 37.8 cm, respectively. The modules are placed on a 30° inclined plane. For data acquisition and processing, we used a data acquisition system, a computer, shunt resistors, connecting wires, and a solarimeter. Lamps of 10 W each were used as loads.

Table 1: Module specifications

Specifications	Values
Maximum power (Pmax)	10 W
Voltage at maximum power (Vm)	19.0 V
Current at maximum power (Im)	0.53 A
Open-circuit voltage (Vco)	22.8 V
Short-circuit current (Icc)	0.57 A
Operating temperature	-40°C to 85°C

Prototypes of the concentration-based system and the non-concentration-based system were built based on the electrical schematics shown in Figures 4 and 5.

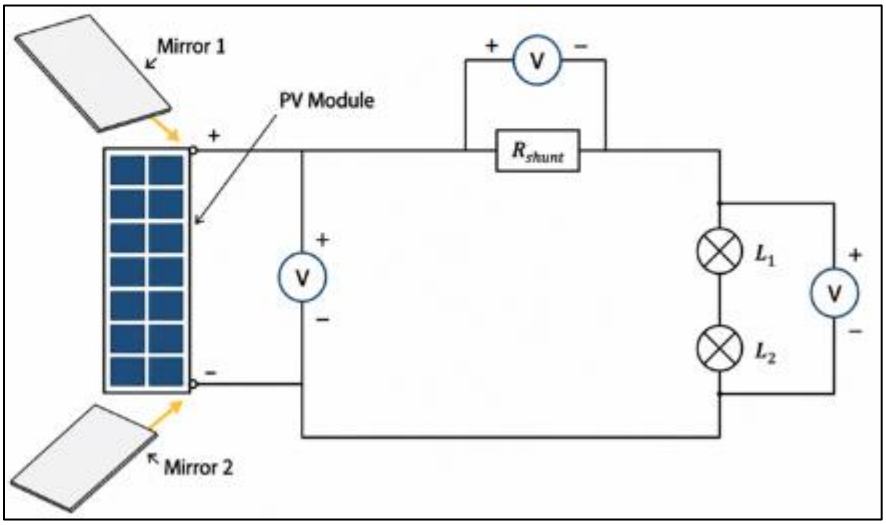

Figure 4: Electrical diagram of the system designed with mirrors

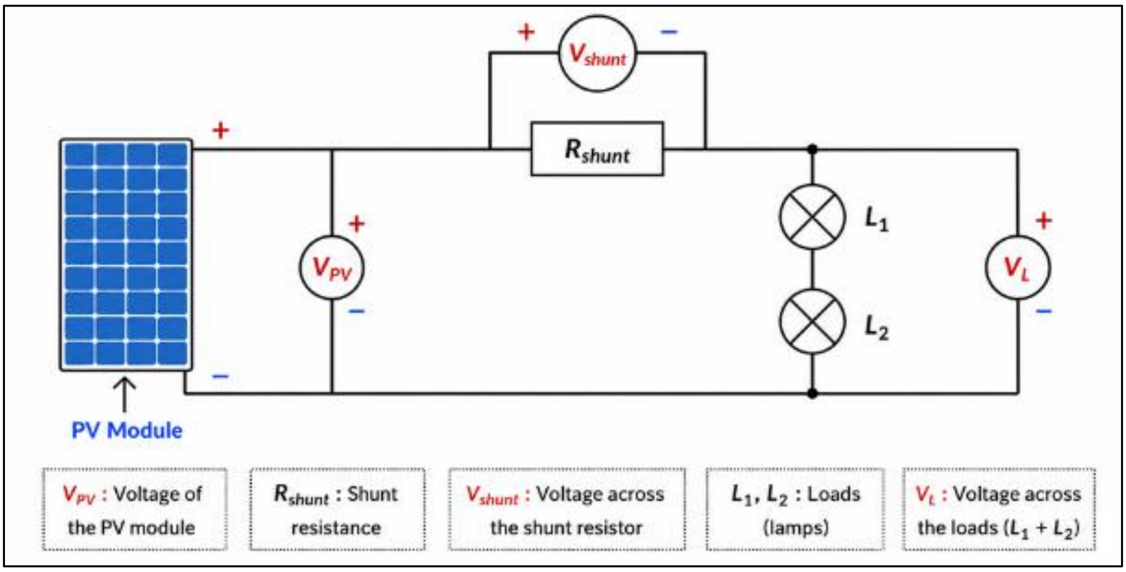

Figure 5: Electrical diagram of the system designed without mirrors

These schematics allowed us to collect data from both systems in order to compare their performance. Data collection took place throughout the month of February 2026 over a period of 28 days, from 6:00 a.m. on Sunday February 1 to 6:00 p.m. on Monday, February 28, with a 10-minute data-logging interval. Data were collected simultaneously from both systems.

3 RESULTS AND DISCUSSION

To better analyze the influence of temperature and sunlight on energy yield, we calculated the daily average values of the various electrical parameters during the month of February 2026 in order to create graphs using Matlab software.

3.1 Comparison of Electrical Power

Figure 6 shows representative curves of the power output of the standard PV system, the LCPV system, and solar irradiance as a function of time.

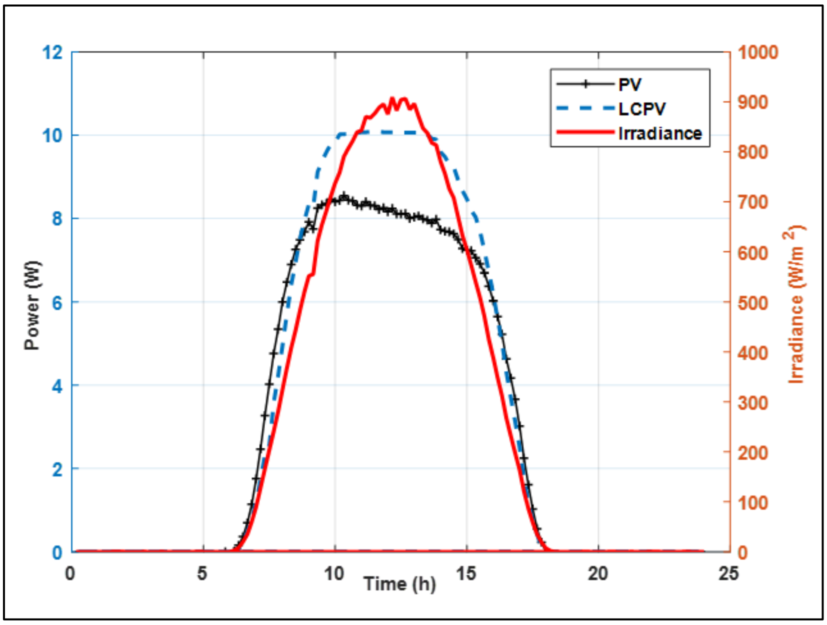

Figure 6: Power and solar irradiance curves

In general, the power curves vary with solar irradiance. In the morning from 6:30 a.m. to 8:00 a.m. and in the afternoon from 4:00 p.m. to 6:00 p.m., the power curve of the standard PV system is very slightly higher than that of the concentrated system. This may be due, among other factors, to the shading effect of the mirrors on the LCPV module. Indeed, during these periods, the angle of incidence of the sun is quite high, and some of the rays reflected by the mirrors are no longer directed toward the module. This results in optical losses that reduce the module's electrical power.

However, between 8 a.m. and 4 p.m., the power curves reach their peaks; this period also corresponds to when irradiance is at its maximum (sunlight rays are nearly perpendicular to the PV module's surface). The power output of the concentrating system is significantly higher than that of the conventional system. A maximum power of approximately 10 W is recorded for the concentrating system, compared to a maximum power of approximately 8.5 W for the conventional system. This increase in power for the concentrating system can be explained by the use of the solar concentrator, which redirects an additional portion of solar radiation toward the PV module. This concentration increases the power incident on the module's active surface, which explains this result.

This confirms the results of studies conducted by *Paul et al.* and *Tan et al.*, which showed that the angle of incidence directly influences the electrical performance of the V-trough system [29] [30].

3.2 Comparison of Temperature and Energy Efficiency

Figures 7 and 8 show, respectively, representative curves of the temperatures and efficiencies of the two systems as a function of time.

Figure 7 shows that the ambient temperature and the temperatures of the two photovoltaic systems evolve similarly throughout the day. Between 8 a.m. and approximately 4 p.m., temperatures reach their maximum values: approximately 47 °C for the ambient temperature, 55 °C for the conventional PV system, and 62 °C for the LCPV system. The observed difference between the ambient temperature and the module temperatures is primarily due to the absorption of solar radiation by the photovoltaic cells, where a portion of the incident energy is converted into heat, thereby causing their temperature to rise. Furthermore, the higher temperature of the LCPV system compared to the conventional system can be attributed to the concentrating effect of solar radiation reflected by the mirrors onto the module surface. These observations are consistent with the results reported by *Haitham et al*. [31].

The efficiency curves for the conventional system and the LCPV system are plotted as a function of time in Figure 8. During the periods from 6 a.m. to 10 a.m. and from 3 p.m. to 6 p.m., the efficiency curves show peaks that can exceed 14.5% for the LCPV system and 12% for the conventional system. These peaks correspond to periods when module temperatures are not very high. However, a drop-in efficiency is observed for both systems between 10:00 a.m. and 3:00 p.m. These drops in efficiency correspond to the period during which module temperatures are high. Thus, rising temperatures negatively affect the energy efficiency of both systems. Since the modules used are made of monocrystalline silicon, the open-circuit voltage decreases as the temperature rises, leading to a decrease in electrical efficiency.

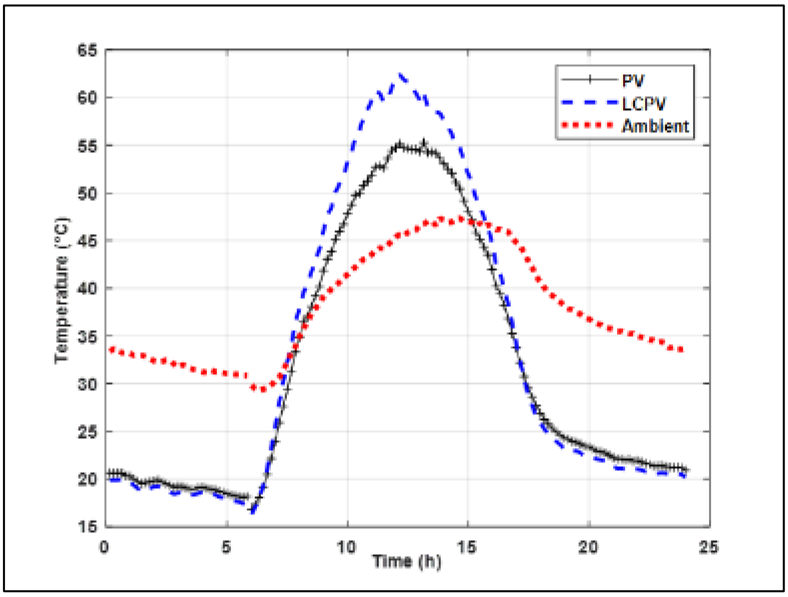

Figure 7: Temperature Curves as a Function of Time

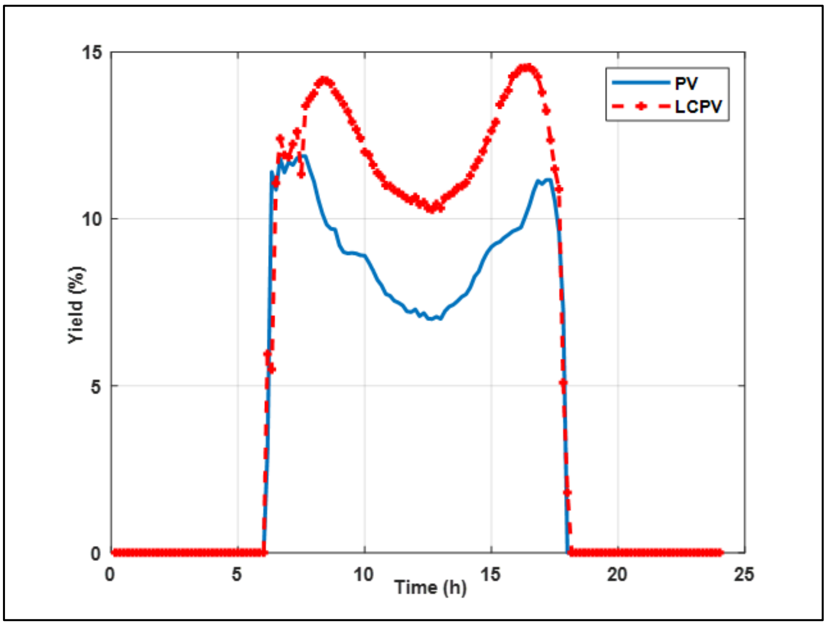

Figure 8: Efficiency curves as a function of time

In general, analysis of the curves shows that the efficiency of the LCPV system is overall higher than that of the conventional PV system during periods of sunlight. The average efficiency is estimated at approximately 11.9% for the LCPV system compared to 9.0% for the conventional PV system, representing a relative gain of about 32%. These results confirm the studies conducted by *Bahaidarah et al*. and *Ustaoglu et al*. [31] [32], which highlight the benefits of low concentration in improving the energy performance of photovoltaic systems.

4 CONCLUSION

This study focused on a comparative analysis of the influence of solar irradiance and temperature on the electrical performance of a low- -concentration photovoltaic (PV) system and a conventional PV system under Sahelian climatic conditions. To this end, models of the concentrator, the photovoltaic module, and the thermal behavior of both systems were developed, and their respective configurations were designed.

Experimental data were collected in Ouagadougou during the month of February 2026. Analysis of the daily average values highlights a positive influence of solar irradiance on the electrical power and efficiency of both systems. This influence is, however, more significant in the case of the LCPV system, which makes better use of incident solar radiation.

Conversely, an increase in module temperature leads to a decrease in the efficiency of both systems, particularly when the temperature reaches approximately 40 °C.

In general, the results show that the low-concentration photovoltaic system has a higher efficiency than the conventional PV system under the conditions studied. These results thus highlight the benefits of using low-concentration photovoltaics to improve solar energy conversion in a Sahelian environment.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflict of interest to be disclosed.

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