UNPAD
Vol. 09, No. 01 (2025) 56 – 63
JIIF (Jurnal Ilmu dan Inovasi Fisika)
https://jurnal.unpad.ac.id/jiif/

EFFECT OF THERMOELECTRICS AS A COOLING SYSTEM ON PHOTOVOLTAIC EFFICIENCY AND ECONOMIC ANALYSIS

MUHAMMAD FUAD ABDUL HAKIM[1], OTONG NURHILAL[2*]

[1]*Mechanical Engineering, Institut Teknologi Nasional Bandung*
Jl. Phh. Mustofa No. 23 Neglasari, Cibeunying Kaler, Kota Bandung, Jawa Barat, Indonesia
[2]*Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran*
Jl. Raya Bandung-Sumedang km 21 Jatinangor, Sumedang, Jawa Barat, Indonesia

**Corresponding author*
Email: otong.nurhilal@unpad.ac.id

Diserahkan: 02/01/2025
Diterima: 21/01/2025
Dipublikasikan: 06/02/2025

Abstract. Photovoltaics (PV) offer a method to harness sunlight as a renewable energy source. However, commercially available PV systems currently achieve only around 15% efficiency in converting sunlight into electrical energy, with the remaining energy converted into heat, which raises the PV temperature. Increased PV temperature leads to a reduction in output power and overall efficiency. Therefore, efforts to reduce PV temperature are essential to improve its performance, including the use of cooling systems. One emerging PV cooling method is the thermoelectric cooler (TEC). However, the implementation of TEC involves additional costs for the components. This research aims to evaluate the impact of using TEC as a cooling system on PV efficiency and its economic feasibility. Two PV units were tested: one equipped with a TEC cooling system and the other without a cooling system as a reference. The experiments were conducted outdoors under direct sunlight. The results showed that the TEC cooling system improved PV efficiency by 6.45%. However, based on an economic analysis using the levelized cost of energy (LCOE) method, it was found that while TEC enhances PV efficiency, its LCOE is IDR 15,871/kWh, significantly higher than the LCOE of the PV without a cooling system, which is only IDR 5,350/kWh.

Keywords: cooling system; efficiency; LCOE; photovoltaic; thermoelectric

Abstrak. *Fotovoltaik (PV) menawarkan metode untuk memanfaatkan sinar matahari sebagai sumber energi terbarukan. Namun, sistem PV yang tersedia secara komersial saat ini hanya mencapai efisiensi sekitar 15% dalam mengubah sinar matahari menjadi energi listrik, sedangkan energi sisanya diubah menjadi panas, sehingga meningkatkan suhu PV. Peningkatan suhu PV menyebabkan penurunan daya keluaran dan efisiensi secara keseluruhan. Oleh karena itu, upaya penurunan suhu PV sangat penting untuk meningkatkan kinerjanya, termasuk penggunaan sistem pendingin. Salah satu metode pendinginan PV yang muncul adalah pendingin termoelektrik (TEC). Namun penerapan TEC memerlukan biaya tambahan untuk komponennya. Penelitian ini bertujuan untuk mengevaluasi dampak penggunaan TEC sebagai sistem pendingin terhadap efisiensi PV dan kelayakan ekonominya. Dua unit PV diuji: satu dilengkapi dengan sistem pendingin TEC dan satu lagi tanpa sistem pendingin sebagai referensi. Percobaan dilakukan di luar ruangan di bawah sinar matahari langsung. Hasilnya menunjukkan bahwa sistem pendingin TEC meningkatkan efisiensi PV*

DOI: https://doi.org/10.24198/jiif.v9i1 *e-ISSN: 2549-7014*

sebesar 6,45%. Namun, berdasarkan analisis ekonomi menggunakan metode levelized cost of energy (LCOE), ditemukan bahwa meskipun TEC meningkatkan efisiensi PV, LCOE-nya adalah Rp 15.871/kWh, jauh lebih tinggi dibandingkan LCOE PV tanpa sistem pendingin, yaitu hanya Rp 5.350/kWh.

Kata Kunci: sistem pendingin; efisiensi; LCOE; fotovoltaik; termoelektrik

1. Introduction

Photovoltaics (PV) offer a method to harness sunlight as a renewable energy source. However, commercially available PV systems currently achieve only about 15% efficiency in converting sunlight into electrical energy [1]. The remaining energy is converted into heat, which raises the temperature of the PV modules. Operating temperature is a critical factor influencing PV performance, alongside the amount of solar irradiation [2]. An increase in PV temperature negatively impacts the output power, thereby reducing overall efficiency. Experimental findings [3] indicate that a 1 ºC rise in PV temperature results in a 0.586% drop in efficiency. Similarly, another study [4] reported that the highest output power, 17.03 W, was achieved at the lowest PV temperature of 36.73 ºC, while the lowest output power, 14.78 W, occurred at the highest PV temperature of 45.10 ºC. Consequently, efforts to lower PV temperature are essential for improving efficiency, with one approach being the integration of a cooling system into PV modules.

Research [5] found that incorporating a cooling system increased PV output power from 186.42 W to 195.94 W. Another study [6] compared PV systems with and without cooling, showing that the efficiency of PV with cooling improved by 0.66% compared to those without cooling. Several other studies have explored methods to reduce PV temperature using cooling systems, including water, wind, DC fans, and heatsinks. In research [7], water was applied directly to the PV surface as a cooling mechanism, resulting in a 20% increase in output power. The use of heatsinks or fins as a cooling system was investigated in research [8], where a heatsink attached to the back of the PV reduced the temperature by approximately 3 ºC. A combination of DC fans and heatsinks was examined in research [9], which revealed that PV efficiency increased by 16.04% with DC fans alone and by 32.08% when DC fans were combined with heatsinks. A relatively novel PV cooling approach involves using a thermoelectric cooler (TEC).

The use of thermoelectric devices as a PV cooling system was investigated through simulations in the study [10]. The results demonstrated that PV efficiency could be improved with a maximum temperature reduction of 10 ºC. Similarly, in research [11], simulations were conducted to evaluate the performance of thermoelectric cooling systems under various conditions, combining thermoelectric modules with a heatsink. The study concluded that the increase in PV efficiency was influenced by ambient temperature, wind speed, and solar irradiation. Sumbodo et al. [12] utilized a thermoelectric cooler (TEC) as a PV cooling system in their research, reporting an 18.59% increase in output power and an 18.53% improvement in efficiency. In another study, Amelia et al. [13] employed a TEC combined with a water block heatsink attached to the bottom surface of the PV, achieving an increase in output power from 8.59 W to 9.03 W. Lastly, Praveenkumar et al. [14] explored the use of aluminum plates combined with four TECs as a cooling system mounted on the underside of the PV.

Their findings revealed a temperature reduction of 12.23 ºC and a 5.07% increase in efficiency.

The cooling area provided by four TECs is still relatively small compared to the total PV surface area. Therefore, the number of TECs used can be increased to achieve broader cooling coverage. However, employing more TECs as a PV cooling system entails additional costs. Consequently, it is essential to evaluate whether the incurred costs are justified by the resulting improvements in PV power output and efficiency.
In this research, experimental testing will be conducted to assess the effect of increasing the number of TECs in the cooling system to six units, building upon previous research [14], which used four TECs. Additionally, an economic analysis will be performed using the levelized cost of energy (LCOE). The aim of this study is to evaluate the impact of using six TECs on PV efficiency and assess whether the additional costs are justified by the increase in output power.

2. Method

This experiment was conducted using two PVs. The first PV served as a reference and was left without any additional cooling system. In the second PV, a thermoelectric cooler (TEC) was attached to the bottom surface. By utilizing the Peltier effect, when a voltage is applied to the TEC, it causes temperature differences on each side, creating a cold side and a hot side [14]. The cold side of the TEC is attached to the bottom surface of the PV. The heatsink and DC fan form a combined unit with the TEC to dissipate heat from the hot side. The PV used is a 30-watt peak (WP) monocrystalline type, with the overall dimensions of the cell being 590 x 320 mm. For the cooling components, a brushless DC fan with a 12-volt voltage rating and dimensions of 40 x 40 mm was used. The heatsink is made of aluminum, with the same 40 x 40 mm dimensions. The TEC used is type 12706, with a voltage of 12 volts. The PV, along with the other components, is assembled as shown in Figure 1. The output cable from the PV is connected to a wattmeter, which then links to a solar charge controller (SCC) and ultimately to a battery. The DC fan and TEC for cooling are connected to a power supply to ensure their operation.

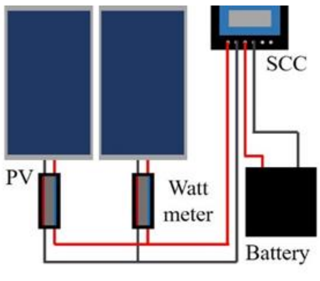

Figure 1. PV circuit

The experiment was conducted outdoors in Tanjungsari, Sumedang, West Java, Indonesia. Each PV, connected to a wattmeter, was then linked in parallel to the solar charge controller (SCC) and placed on a stand. Data collection took place from 11:00 AM to 1:00 PM, with measurements taken every 15 minutes.

The efficiency (η) of the PV is calculated by dividing the output power (P_{out}) by the solar irradiation (E) and the PV surface area (A) [5], as shown in equation (1). To determine the increase in efficiency of the cooled PV compared to the PV without cooling, equation (2) can be used.

$$\eta = \frac{P_{out}}{E \cdot A} \quad (1)$$

$$\eta_{\text{improvement}} = \frac{\eta_{\text{outcooled}} - \eta_{\text{outref}}}{\eta_{\text{outref}}} \cdot 100\% \quad (2)$$

The economics of the electrical energy produced by the four PV systems were analyzed using the levelized cost of energy (LCOE) method. LCOE generally compares the total costs of building and operating a power plant with the amount of energy it produces over its lifetime [15]. The LCOE method is commonly used to evaluate the economics of renewable energy power plants. The expenditure costs in LCOE include equipment investment costs (C_{inv}), operational and maintenance costs ($C_{O\&M}$), and fuel costs (C_{fuel}), which are then divided by the annual energy produced (E_{annual}), as shown in equation (3).

$$\text{LCOE} = \frac{LC_{inv} + LC_{O\&M} + LC_{fuel}}{E_{annual}} \quad (3)$$

The capital investment cost (LC_{inv}) is calculated by multiplying the equipment investment cost (C_{inv}) by the capital recovery factor (CRF), while the operational and maintenance cost ($LC_{O\&M}$) is calculated by multiplying the operational and maintenance cost ($C_{O\&M}$) by the constant escalation levelized factor (CELF). The values of CRF and CELF are determined using equations (4) and (5).

$$\text{CRF} = \frac{i_{eff} \cdot (1 + i_{eff})^n}{(1 + i_{eff})^n - 1} \quad (4)$$

$$\text{CELF} = \left(K_{O\&M} \cdot \frac{1 - (K_{O\&M})^n}{1 - K_{O\&M}}\right) \cdot \text{CRF} \quad (5)$$

where i_{eff} is the effective discount rate and n is the service life in years. The value of $K_{O\&M}$ is obtained from equation (6), where r_n represents the nominal escalation rate.

$$K_{O\&M} = \frac{1 + r_n}{1 + i_{eff}} \quad (6)$$

3. Results and Discussion

The irradiation and ambient temperature during the experiment are presented in Table 1. The average irradiation was 814.8 W/m², with the highest value of 865.8 W/m² recorded at 11:45 AM WIB.

Table 1. Irradiation and ambient temperature (T_a)

Time	Irradiation (W/m^2)	T_a (ºC)
11.00	827.9	29.6
11.15	855.6	32.2
11.30	862.7	32.7
11.45	865.8	33.1
12.00	811.3	33.4
12.15	763.1	31.4
12.30	774.9	32.6
12.45	786.1	33.1
13.00	786.1	33.1
Average	814.8	32.4

The average ambient temperature was 32.4 ºC, with the highest value reaching 33.4 ºC. Based on direct observation, the weather conditions during the testing were generally sunny, with occasional clouds partially covering the sun.

The average temperature data for the two PV systems are presented in Table 2. The PV with TEC cooling exhibits a lower average temperature compared to the PV without cooling. Therefore, it can be concluded that the TEC successfully reduced the PV temperature.

Table 2. Average PV temperature

PV	Average Temperature (ºC)
Without cooling	45.4
TEC cooling	44.0

A comparison of the output power produced by the two PV systems over time is presented in Figure 2. The PV with TEC cooling consistently generates higher output power than the PV without cooling. This is consistent with the average temperature data for each PV, where lower temperatures correspond to higher power output.

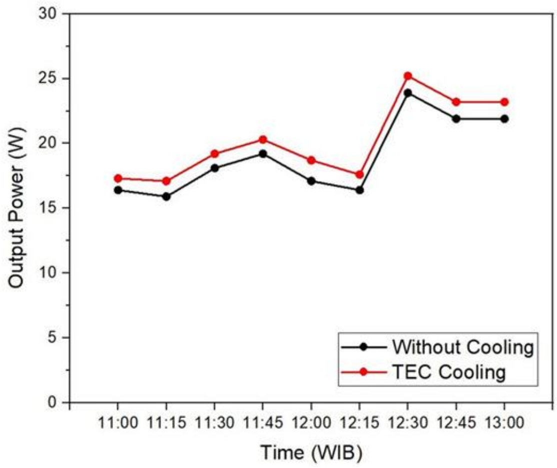

Figure 2. PV output power

Figure 3 presents the average output power of the two PV systems. It can be observed that cooling with TEC increases the output power of the PV, making it higher than that of the PV without cooling.

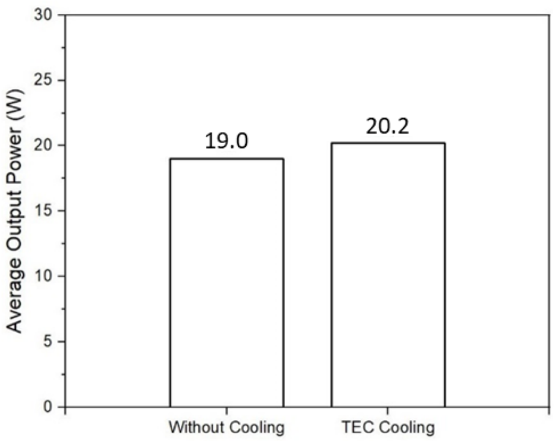

Figure 3. PV average output power

The efficiency of each PV system is calculated using equation (1). Figure 4 presents a comparison of the average efficiency for the two PVs. It can be observed that the PV with TEC cooling exhibits higher efficiency than the PV without cooling.

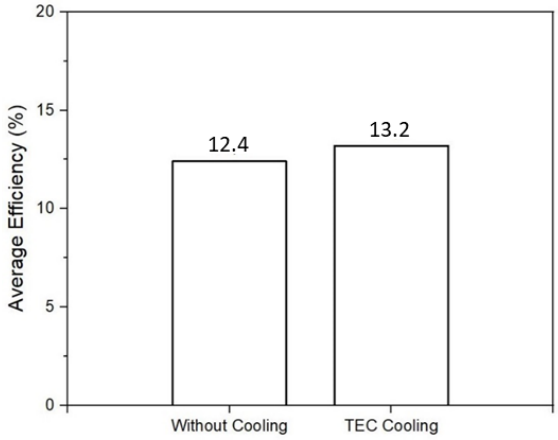

Figure 4. Average PV efficiency

The increase in PV efficiency with cooling, compared to the PV without cooling, is shown in Table 3. This increase is calculated using equation (2). The efficiency improvement with the TEC cooler is higher than that reported in research [14], where the increase was only 5.07%.

Table 3. Increased PV efficiency

PV	Increased efficiency (%)
TEC	6.45
TEC [14]	5.07

The cost of the PV without cooling is IDR 441,300, while the cost of the PV with TEC cooling is IDR 706,800. In calculating the levelized cost of energy (LCOE), several assumptions are made based on values referenced from research [15], including an effective discount rate (i_{eff}) of 5% and a nominal escalation rate (r_n) of 1%. The service life is assumed to be 10 years, corresponding to the warranty period of the PV system.

Using equations (4), (5), and (6), the values for LC_{inv} and $LC_{O\&M}$ are determined. For operational and maintenance ($C_{O\&M}$) costs, the PV without cooling is assumed to incur a basic fee of IDR 50,000 per year. For the PV with TEC cooling, the $C_{O\&M}$ includes the basic cost as well as the annual cost of replacing the cooling components. Therefore, the $C_{O\&M}$ for PV with TEC cooling is IDR 242,000. For comparison, $C_{O\&M}$ in research [15] was $3.50, or approximately IDR 50,000. LC_{fuel} is considered zero, as PV does not require fuel. The amount of electrical energy produced, or E_{annual}, is calculated assuming the PV is used for six months each year, which corresponds to the dry season in Indonesia. Each day is assumed to have 6 hours of effective PV use. With a service life of 10 years, the E_{annual} for each PV is calculated and presented in Table 4.

Table 4. The electrical energy produced by PV

PV	E_{annual} (kWh)
Without cooling	20.52
TEC cooling	21.82

The LCOE for each PV is then calculated using equation (3), and the comparison is presented in Figure 5. Although TEC as a cooling system can increase PV power and efficiency, the associated costs are not proportionate to the benefits. PV without cooling has an LCOE of IDR 5,350/kWh, which is lower than that of the PVs with cooling.

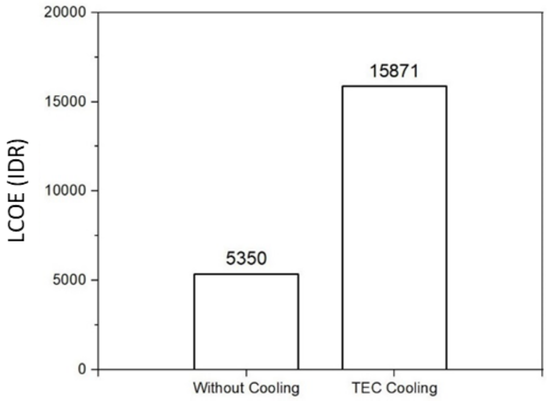

Figure 5. LCOE of PV

4. Conclusion

The PV with 6 TECs as a cooling system managed to increase efficiency by 6.45%, as it was able to reduce the average PV temperature by 1.4°C compared to the PV without a cooling system. The use of 6 TECs provided a higher efficiency increase (6.45%) compared to the use of 4 TECs (5.07%). The results of the economic analysis using the levelized cost of energy (LCOE) showed that, although it can increase output power and efficiency, the use of 6 TECs as a PV cooling system has a higher LCOE of IDR 15,871/kWh compared to the LCOE of PV without cooling, which is IDR 5,350/kWh. This indicates that the use of TECs as a PV cooling system, while effective in improving output power and efficiency, is not proportional to the costs incurred.

References

1. M.Y. Zulakmal, A. Fudholi, N.S. Rukman, S. Mat, H.Y. Chan, K. Sopian (2019). Solar photovoltaic/thermal-thermoelectric generator performance review. *IOP Conference Series: Earth and Environmental Science*, *268*(1), 012120.
2. Hashim. Emad Talib, & Abbood, A. A. (2016). Temperature Effect on Power Drop of Different Photovoltaic Modules. *Journal of Engineering*, *22*(5), 129–143.
3. M.K. Al-Ghezi, R.T. Ahmed, M.T. Chaichan (2022). The Influence of Temperature and Irradiance on Performance of the photovoltaic panel in the Middle of Iraq. *International Journal of Renewable Energy Development*, *11*(2), 501–513.
4. H. Assiddiq, M. Bastomi (2019). Analisis Pengaruh Perubahan Temperatur Panel Terhadap Daya dan Efisiensi Keluaran Sel SUrya Polycrystalline. *Dinamika: Jurnal Ilmiah Teknik Mesin*, *11*(1), 33–39.
5. M. Sani, A. Sule (2020). Effect of Temperature on the Performance of Photovoltaic Module. *International Journal of Innovative Science and Research Technology*, *5*(9), 670–676.
6. S. Utami, A. Daud (2020). Pengaruh Temperatur Panel Surya Terhadap Efisiensi Panel Surya. *Jurnal Energi*, *10*(1), 7–10.
7. W. Luboń, M. Janowski, G. Pełka, P. Reczek (2020). Analysis of the cooling of PV modules with water on their efficiency. *E3S Web of Conferences*, *154*, 05006.

8. S.S. Al-Azawiey, M.M. Mohamed, A.B. Arifin (2023). Effectiveness of PV/T Passive Natural Air Cooling by Backside Attached Fins. *International Journal of Energy Production and Management*, *8*(2), 55–62.
9. M.F.A. Hakim, M.A. Putra, O. Nurhilal (2023). Comparing the Effect of Using DC Fans and Heatsinks As Cooling Systems on Photovoltaic Efficiency. *Turbo : Jurnal Program Studi Teknik Mesin*, *12*(2).
10. A. Kane, V. Verma (2013). Performance Enhancement of Building Integrated Photovoltaic Module using Thermoelectric Cooling. *INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH*, *3*(2), 320–324.
11. H. Moshfegh, M. Eslami, A. Hosseini (2018). *Thermoelectric Cooling of a Photovoltaic Panel* (pp. 625–634).
12. J.S. Sumbodo, M.R. Kirom, P. Pangaribuan (2018). Efektivitas Pendingin Menggunakan Termoelektrik Pada Panel Surya. *E-Proceeeding of Engineering*, *5*(3), 3895–3902.
13. A.R. Amelia, M. Jusoh, I.S. Idris (2017). Effect of Thermoelectric Cooling (TEC) module and the water flow heatsink on Photovoltaic (PV) panel performance. *EPJ Web of Conferences*, *162,* 01077. https://doi.org/10.1051/epjconf/201716201077.
14. S. Praveenkumar, E.B. Agyekum, N.T. Alwan, M.A. Qasim, V.I. Velkin, S.E. Shcheklein (2022). Experimental Assesment of Thermoelectric Cooling on the Efficiency of PV Module. *International Journal of Renewable ENergy Research*, *12*(3), 1670–1681.
15. E.B. Agyekum, S. PraveenKumar, N.T. Alwan, V.I. Velkin, T.S. Adebayo (2021). Experimental Study on Performance Enhancement of a Photovoltaic Module Using a Combination of Phase Change Material and Aluminum Fins—Exergy, Energy and Economic (3E) Analysis. *Inventions*, *6*(4), 69.