Journal of Naval Sciences and Engineering
2025, Vol. 21, No. 1, pp. 51-71 *DOI: **.****/***.****.*******
Electrical-Electronics Engineering/Elektrik-Elektronik Mühendisliği

RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

INVESTIGATION OF THERMAL DISTRIBUTION AND THERMOELECTRIC COOLING PERFORMANCE IN A PHOTOVOLTAIC PANEL

Sevgi ALTINKÖK[1]
Meral ALTINAY[2]*

[1]*Kocaeli University, Graduate School of Natural and Applied Sciences, Kocaeli, Turkey, sevgicelen@gmail.com*

[2]*Kocaeli University, Department of Energy Systems Engineering, Kocaeli, Turkey, meral.altinay@kocaeli.edu.tr*

Received: 05.03.2025 **Accepted: 09.04.2025**

ABSTRACT

Photovoltaic (PV) panels, while generating energy from solar radiation, may experience a loss in efficiency due to excessive heating of the module surface. This heating negatively impacts the performance of the PV module, reducing the energy efficiency derived from solar radiation. In this study, the thermal behavior of a PV module integrated with a thermoelectric generator (TEG) is thoroughly investigated through experimental and simulation approaches. The PV-TEG integration not only minimizes the efficiency loss by cooling the PV modules but also provides additional energy generation through the TEG. These hybrid systems, especially in regions characterized by high ambient temperatures and intense solar radiation, offer a promising approach to improving the efficiency of photovoltaic systems and optimizing energy production. This study highlights the dual functionality of PV-TEG systems, demonstrating their capability to simultaneously provide cooling and generate electrical energy, thereby enhancing overall system performance.

Keywords: *Photovoltaic (PV) panels, Thermoelectric Generator (TEG), PV-TEG integration.*

FOTOVOLTAİK PANELDE TERMAL DAĞILIM VE TERMOELEKTRİK SOĞUTMA PERFORMANSININ İNCELENMESİ

ÖZ

Fotovoltaik (PV) panelleri, güneş ışınımı ile enerji üretimi gerçekleştirirken, modül yüzeyinin aşırı ısınması nedeniyle verimlilik kaybına uğrayabilir. Bu ısınma, PV modülünün performansını olumsuz yönde etkileyerek, güneş ışınımı ile elde edilen enerji verimliliğini düşürmektedir. Bu çalışmada, PV modülünün termoelektrik jeneratör (TEG) ile entegre edilmiş termal davranışı, deneysel ve simülasyon yaklaşımlarıyla detaylı bir şekilde incelenmiştir. PV-TEG entegrasyonu, yalnızca PV modüllerinin soğutulmasını sağlayarak verimlilik kaybını en aza indirgemekle kalmaz, aynı zamanda TEG sayesinde ek enerji üretimi de sunar. Bu hibrit sistemler, özellikle yüksek sıcaklıkların ve güneş ışınımının yoğun olduğu iklim bölgelerinde, fotovoltaik sistemlerin verimliliğini artırarak daha verimli enerji üretimi sağlama potansiyeline sahiptir. Çalışma, PV-TEG sistemlerinin her iki fonksiyonu, yani soğutma ve enerji üretimini aynı anda sağlama potansiyelini ortaya koymaktadır.

Anahtar Kelimeler: *Fotovoltaik (PV) paneller, Termoelektrik jeneratör (TEG), PV-TEG entegrasyonu.*

1. INTRODUCTION

Renewable energy sources are gaining significant importance in contemporary times as a critical means to address the escalating global energy demand and mitigate the reliance on fossil fuel consumption. PV panels play a pivotal role in this transformation, owing to their capability to directly convert solar energy into electrical power. Nevertheless, the efficiency of PV panels is dependent on various environmental and physical factors. Among these, temperature is one of the most significant factors.

When PV panels are exposed to solar radiation, their surface temperature increases, which negatively affects their electrical efficiency. For most semiconductor materials, as the temperature rises, the bandgap narrows and internal resistance changes, leading to a decrease in overall power output. Therefore, understanding temperature variations in PV panels and implementing efficient cooling strategies are essential for improving their performance and longevity.

Thermoelectric (TE) devices, comprising n-type and p-type semiconductor materials as illustrated in Figure 1, serve as significant instruments in the progression of sustainable energy Technologies. These devices are primarily divided into two categories: thermoelectric coolers (TECs) (Cheng T.C., 2011; Chen W.H. et al., 2012) and thermoelectric generators (TEGs) (Champier D. et al., 2010; Martinez A., 2011). TECs function based on the Peltier effect, transforming electrical energy into thermal energy to enable active cooling, whereas TEGs utilize the Seebeck effect to convert thermal energy, particularly from waste heat sources, into electrical power.

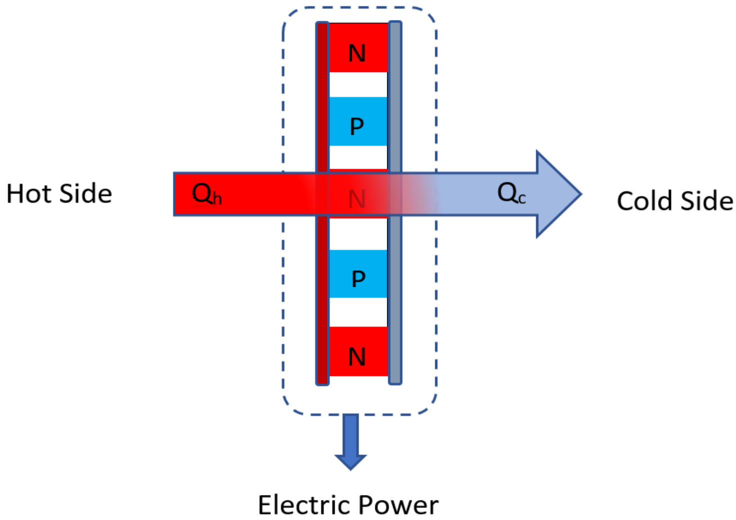

Figure 1. *Thermoelectric (TE) devices.*

TEGs operate by transforming the temperature gradient across the two surfaces of a module into electrical energy, utilizing the principles of the Seebeck effect. The fundamental components of a thermoelectric system consist of a heat exchanger, a TE module, and a cooling unit. The electrical power output of the TEG module is determined by several factors, including the temperature gradient between the hot and cold surfaces, the dimensions of the thermoelements, and the Seebeck coefficient of the material. An effective thermoelectric material must exhibit a high Seebeck coefficient, elevated electrical conductivity, and reduced thermal conductivity. Among the most commonly utilized thermoelectric materials today is bismuth telluride (Bi_2Te_3), which functions at temperatures of up to 380°C and demonstrates exceptionally low electrical resistance coupled with high material conductivity (Champier D. et al., 2011).

The efficiency of photovoltaic (PV) cells significantly decreases as their operating temperatures increase. Therefore, various methods for cooling PV cells are extensively discussed in the literature (Royne A. et al., 2005). Thermoelectric technology, with its ability to convert heat into electrical energy, offers an alternative solution to active cooling methods. Kane and Verma (Kane A., et al., 2017) developed a mathematical model aimed at optimizing the performance of PV-TEG integrated systems by considering the temperature-dependent material properties of thermoelectric generators (TEGs). This model proposes a temperature-based maximum power point tracking (MPPT) method to ensure the optimal operation of PV systems at the ideal temperature. Simulations performed in MATLAB have validated the effectiveness of this method and highlighted the potential benefits of PV-TEG integration.

This study is a comprehensive investigation into the integration of TEGs with PV panels to enhance their efficiency and address overheating issues. The efficiency of PV panels significantly decreases at high temperatures, as the performance of semiconductor materials is inversely proportional to temperature. To address this issue, TEGs operating based on the Seebeck effect have the potential to generate additional electrical energy by utilizing the temperature differences on the surface of PV panels. At the same time, TEGs can contribute to the cooling of PV panels, thereby enhancing the overall efficiency of the system.

Another key aspect of the study is the comprehensive analysis conducted using both experimental work and the ANSYS simulation program. These analyses examine the surface temperature variations of PV panels and the impact of these variations on system efficiency in detail. Additionally, the potential for enhancing the cooling of PV panels through the strategic integration of TEG modules and thus increasing efficiency is evaluated.

Throughout the day, surface temperature variations of PV panels were investigated through simulation-based analyses, and TEG modules were placed in the regions of highest temperature. This allowed for testing both the cooling effect and the additional electricity generation capacity of TEGs using both experimental and simulation methods. The results obtained demonstrate that TEGs can play a significant role in increasing the efficiency of PV panels and managing heat.

This study reveals the potential of PV-TEG integration to improve efficiency and reduce energy losses in renewable energy systems. In the future, such integrated systems are expected to become more widespread, offering sustainable solutions for energy production. Further research and development in this field will enhance the applicability of this technology by improving the efficiency of thermoelectric materials.

2. ENERGY BALANCE OF PV PANEL

The energy balance of PV panels represents the relationship between the energy entering and exiting the panel. This balance is modeled by considering solar irradiation, electrical energy generation, thermal losses, and other energy transformations.

For a closed system, the First Law of Thermodynamics states:

$$U = U_{final} - U_{initial} = Q - W \tag{1}$$

Here, U represents the total internal energy, Q is the heat transfer rate, and is W the work done on the system. If internal energy is expressed using the temperature difference between the initial and final states along with the heat capacity, the equation is formulated as follows:

$$Q_{in} = Q_{sun} - P_{PV} - Q_{loss} \quad (2)$$

Here, Q_{in} represents the internal energy stored in the panel, Q_{sun} is the solar radiation absorbed by the PV module, Q_{loss} accounts for heat transfer losses, and P_{PV} represents the electrical power output.

Heat transfer within PV panels plays a pivotal role in determining their performance and overall efficiency. While PV panels transform solar energy into electrical energy, a significant portion of the absorbed energy is dissipated as heat. This thermal energy increases the panel's surface temperature, thereby reducing its electrical efficiency. The heat loss in PV modules primarily occurs through three mechanisms: conduction, convection, and radiation.

$$Q_{loss} = Q_{cond} + Q_{conv} + Q_{rad} \quad (3)$$

Here, Q_{cond} conduction heat transfer, Q_{conv}convection heat transfer, and Q_{rad}radiation heat transfer are the primary mechanisms. These mechanisms are the key factors determining the panel's temperature.

2.1. Convection

The hot air formed on the panel surface transfers heat to the surrounding atmosphere, facilitating cooling. For a PV module in an air environment, the total convective energy exchange on the module surface is given by:

$$Q_{conv} = A.h.(T_{PV} - T_{\infty}) \quad (4)$$

Where h represents the convective heat transfer coefficient, T_{∞}denotes the ambient temperature, and A corresponds to the surface area. The magnitude of the convective heat transfer coefficient is determined by the prevailing physical conditions. Convection arises due to both natural (free) and forced convection mechanisms. On calm days and on the sheltered backside of the array, natural convection will be the primary cooling mechanism. However, when the exposed front side of the array is subject to wind, as is often the case, forced convection becomes dominant.

2.2. Radiation

The PV panel dissipates thermal energy into the surrounding environment through electromagnetic radiation. The radiative heat exchange between the PV module and its surroundings is mathematically represented using the view factor. The net radiative heat transfer between the PV module and the sky is given by:

$$Q_{rad} = \varepsilon.\sigma.A.F_{PV,\infty}.(T_{PV}^4 - T_\infty^4) \tag{5}$$

where *F* represents the view factor, σ is the Stefan-Boltzmann constant, and ε denotes the emissivity of the PV panel. Emissivity quantifies a material's efficiency in radiating thermal energy. The emissivity value of the front glass surface is considered to be 0.91, whereas the back surface of the PV module has an emissivity of 0.85 (Notton, G. et al., 2005; Bazilian, M. D. et al., 2002). This equation characterizes radiative heat dissipation from the PV module to the surrounding environment. The magnitude of radiative heat transfer is influenced by the temperature gradient between the panel and its surroundings, as well as the emissivity properties of the materials used in the module.

2.3. Conduction

Conduction pertains to the transfer of thermal energy within a material as a result of temperature gradients, driven by the random motion of atoms or molecules.In a PV system, a TEG module installed on the rear surface of the PV panel utilizes this heat transfer to generate electrical energy. The process of heat conduction between the PV panel and the TEG module can be described using Fourier's law of heat conduction:

$$Q_{cond} = k.A.\frac{\Delta T}{d} \quad (6)$$

Here, Q_{cond} represents the heat transferred from the PV panel to the TEG module, k denotes the thermal conductivity of the material, A signifies the conduction surface area, ΔT is the temperature difference between the PV panel and the TEG module, and d represents the thickness of the TEG module. This equation quantifies the efficiency of conductive heat transfer, which is critical for optimizing the thermoelectric conversion process.

3. SIMULATION STUDIES

In this study, the variations in surface temperature of PV panels and the cooling influence of TEG modules were investigated through both experimental measurements and numerical simulations. The thermal performance of the system was evaluated by measuring the PV panel surface temperature, ambient temperature, and solar radiation levels. Furthermore, numerical simulations were conducted to examine the heat transfer dynamics and assess the cooling efficiency of the TEG module.

3.1. Model Creation in ANSYS

Numerical analysis techniques were applied to examine the surface temperature distribution of the PV panel and the influence of the TEG module. In this regard, heat transfer simulations were performed utilizing the finite element method (FEM) within the ANSYS software environment. A three-dimensional (3D) model was constructed based on the actual dimensions of the PV panel and the material properties detailed in Table 1. To ensure precise thermal analysis across the cells, the surface of the PV panel was discretized into smaller regions through a meshing process.

Table 1. Different layers and their properties in a PV panel (Barroso et al., 2016*;* Kant et al., 2016: das *et al., 2019)*

Properties	**Glass**	**EVA**	**Silicon Cells**	**Tedlar**
Thickness (m)	0,003	0,0005	0,0003	0,0005
Thermal Conductivity (W/mK)	1,8	0,35	148	0,2
Density (kg/m^3)	3000	960	2330	1200
Specific Heat (J/kgK)	500	2090	677	1250
Absorptivity (α)	0,01	-	0,93	-
Transmissivity (τ)	0,95	0,85	-	-
Emissivity (ε)	0,95	-	-	-

Meshing is a computational approach that divides a complex geometry into simpler, smaller elements, thereby enhancing the accuracy of the simulations. A finer mesh structure provides more accurate thermal analysis by capturing localized temperature fluctuations with greater precision.

The rear and front views of the PV panel, as simulated in ANSYS, are depicted in Figure 2. Boundary conditions were defined to replicate the panel's response to external environmental factors. Defining these conditions accurately is essential for modeling heat transfer processes, which ensures more reliable thermal simulations and a thorough understanding of temperature variations. Additionally, the simulation incorporated dynamic environmental factors, such as solar irradiation and wind speed, to evaluate the system's performance under varying conditions. By including time-dependent solar irradiation data, the model was adjusted to better reflect actual operational scenarios.

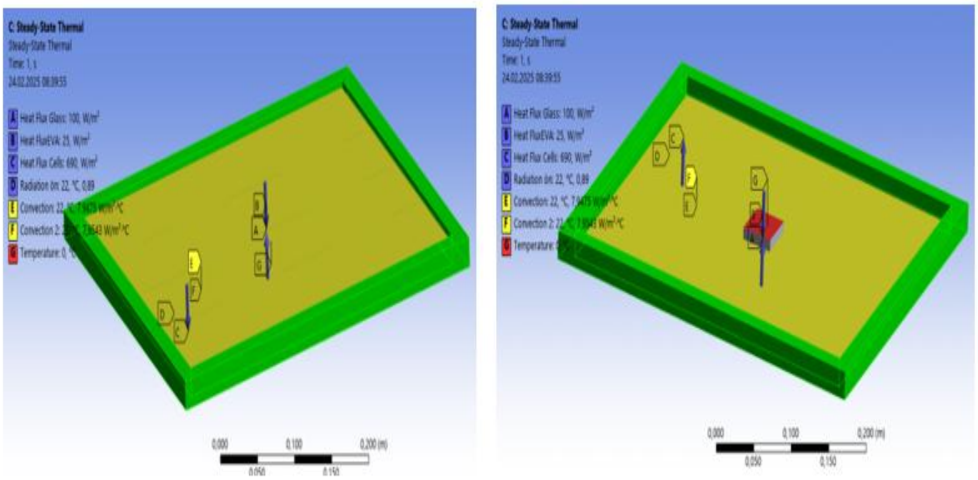

Figure 2. *Front and rear view of the PV module in the ANSYS simulation.*

In this study solar irradiation, ambient temperature, wind speed, and material properties were modeled based on experimental data to ensure realistic simulation results. As solar irradiation varies throughout the day, time-dependent irradiation values were incorporated into the simulations. The ambient temperature was set to align with experimental measurements and was integrated into the model to accurately represent the system's thermal behavior. This approach ensures that the simulation results closely reflect the real-world performance of the photovoltaic system under varying environmental conditions.

Heat loss from the outer surfaces of the PV module occurs due to airflow, and this heat transfer is modeled based on Newton's law of cooling. To calculate the convection coefficient for both the upper and lower surfaces, formulas were developed in Excel, and the resulting values were incorporated into the ANSYS software. This method facilitated a more precise representation of heat transfer from the PV panel surface to the surrounding environment. Additionally, Material properties, including density, specific heat capacity, and thermal conductivity of the PV cells, were modeled using data derived from literature and experimental studies, thereby enhancing the accuracy and reliability of the system’s thermal analysis.

3.2. Analysis of the Time-Dependent Thermal Behavior of the PV Panel

The time-dependent thermal behavior of the PV panel is analyzed and illustrated in Figure 3. This simulation study was carried out to evaluate the thermal performance of the PV module over the course of a day, with a specific focus on the temporal variation of its surface temperature. The findings highlight the influence of varying solar radiation on the temperature distribution across the panel's surface. As solar radiation intensifies, the surface temperature of the PV panel increases, resulting in a distinct heat distribution pattern. These temperature changes are directly influenced by the intensity and angle of solar irradiation, which vary throughout the day. Furthermore, the observed thermal behavior is crucial for evaluating the efficiency and durability of the PV panel under changing environmental conditions. This analysis offers valuable insights into the dynamic thermal response of the PV panel, enhancing our understanding of its performance in real-world conditions.

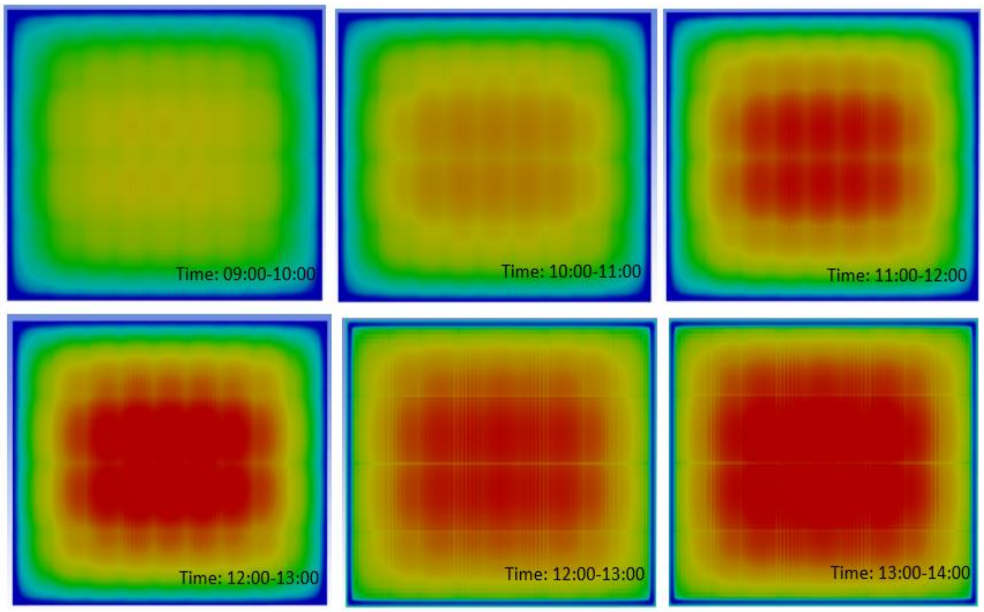

Figure 3. *Analysis of the time-dependent thermal behavior of the PV panel.*

In the initial time intervals of the simulation, the surface temperature of the PV panel is relatively low and close to the ambient temperature. Since the solar radiation is still at low levels, the surface temperature of the panel remains near the ambient temperature, resulting in no noticeable temperature gradient. At this stage, the panel has not yet reached thermal equilibrium, and the increase in temperature due to solar radiation has not yet commenced. As the simulation progresses, the panel begins to absorb more solar energy, leading to an increase in surface temperature and the development of a clear temperature gradient.

With the increase in solar radiation, an increase in the surface temperature of the PV panel has been observed. The temperature rises at the center of the panel, and heat accumulates in specific areas. Heat transfer occurs based on the material properties of the panel, environmental factors, and convective cooling conditions. The higher temperature at the center of the panel indicates limitations in the heat transfer toward the edges, with heat accumulation particularly concentrated in the central regions. The increase in green and yellow tones in the visuals indicates the rise in surface temperature due to the effect of solar radiation.

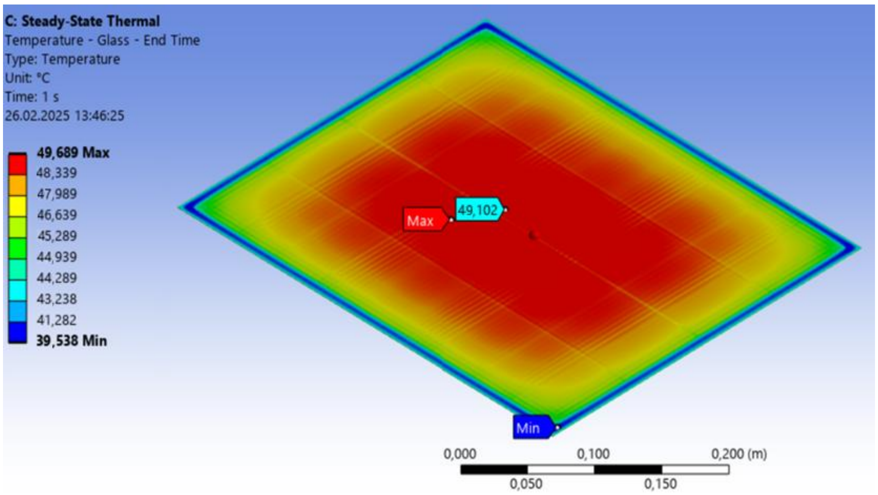

Figure 4. *Surface temperature distribution of the PV panel with TEG module.*

During the midday period, the temperature increase on the panel's surface becomes more pronounced, and the center of the panel reaches its highest temperature. This suggests that as the panel approaches thermodynamic equilibrium, heat transfer becomes stable at a certain point. Thermal accumulation on the surface of the panel increases, and the temperature becomes more concentrated in the central regions. The prominence of red tones indicates the formation of hot spots and the heat accumulation reaching its maximum level. At this stage, where heat accumulation has peaked, the temperature effect on the panel's energy conversion efficiency becomes a significant parameter.

The simulation results demonstrate that the surface temperature of the PV panel experiences substantial temporal variations and that the temperature distribution is non-uniform. The temperature increase in PV modules can lead to efficiency losses, and therefore effective heat management strategies are required. To control the panel temperature, the application of Peltier cooling systems or alternative thermal management methods can enhance system performance.

Figure 4 presents the surface temperature distribution of the PV panel simulated in this study. The highest temperature measured at 13:46 was 49.689 °C, while the lowest temperature was 39.538 °C. The temperature at the location where the TEG module was placed, at the exact center of the PV panel, was measured at 49.102°C. It was observed that the temperature at the location of the TEG module was 0.587°C lower than the maximum temperature value.

4. EXPERIMENTAL STUDY

Figure 5 and Figure 6 illustrate the experimental setup, where the PV panel is positioned at a 45° tilt angle to ensure maximum exposure to solar radiation. In the simulation studies, it was observed that the highest temperature accumulated in the central region of the panel. Based on this finding, the TEG module was mounted at the cener of the PV panel. The TEG module was affixed to the rear surface of the panel using thermal paste, and an aluminum heatsink was placed on its cold side to maintain the temperature differential.

Figure 5. *Experimental setup for PV panel with TEG modüle*

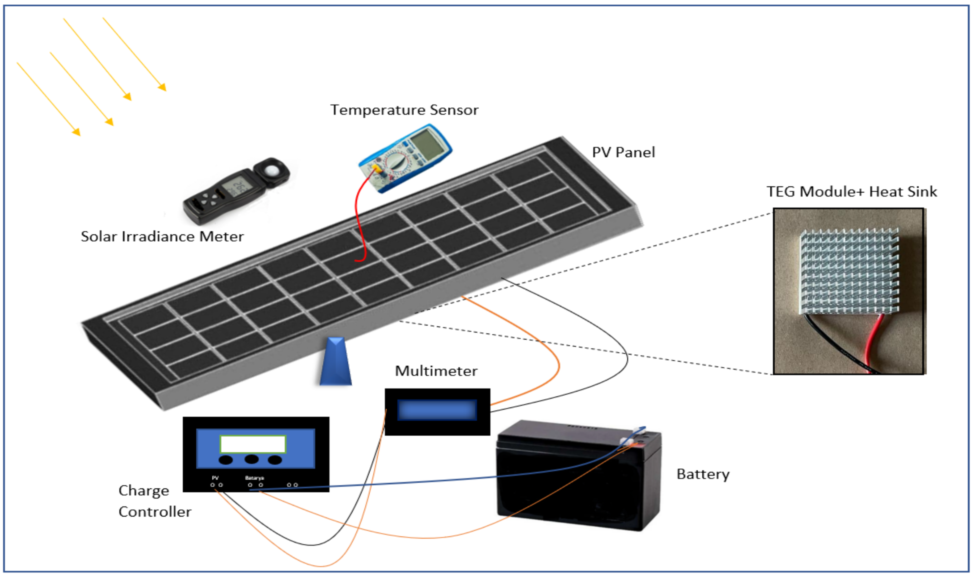

Figure 6. *Schematic representation of the PV-TEG experiment*

During the experiment, temperature measurements were recorded at specific time intervals using thermocouple temperature sensors, and the solar radiation level was monitored using a radiometer. The experimental results were compared with the simulation data to assess the system's performance. All materials used in this experiment are listed in Table 2. The materials used in this experiment were selected to analyze the thermal distribution and thermoelectric cooling performance of the photovoltaic panel. The monocrystalline photovoltaic panel generates electrical power, while TEG modules create a temperature gradient, enabling both cooling and additional power generation.

Table 2. *List of materials used in the experiment.*

Material	**Specification**	**Purpose**
PV Panel	12W	Monocrystaline power generation
TEG Module	TEC1-27145, SP1848	Thermoelectric cooling and power
Heat Sink	143 Fin Aluminum	Heat dissipation
Solar Irradiance Meter	Luxmeter (1-200000 lx)	Measures solar radiation
Battery	12V 12 Ah	Stores or supplies power
Charge Controller	10 Ampere 12V	Regulates power from PV to battery
Thermal Paste	6W/mK High conductivity compound	Improves heat transfer between surfaces
Multimeter	Digital, measures voltage & current	Electrical parameter measurements
Temperature Sensor	Thermocouple	Measures system temperature

The aluminum heat sink and thermal paste optimize heat transfer, enhancing system efficiency. Measurement devices such as temperature sensors, a solar irradiance meter, an anemometer, and a multimeter ensure precise data collection throughout the experiment. Additionally, the charge controller regulates energy management and storage processes. The electrical characteristics of the PV panel provided by the manufacturer are detailed in Table 3, offering crucial information for evaluating the panel's performance under different operating conditions.

Table 3. *Electrical Characteristics of the PV Panel Provided by the Manufacturer*

Parameters	**Values**
Maximum Power (P_{max})	12 W
Power Tolerans	0 to %5 W
Open Circuit Voltage (V_{oc})	24,62 V
Short Circuit Current (I_{mp})	0,64 A
Maximum Power voltage (V_{mp})	20,84 V
Maximum Power Current (I_{mp})	0,61 A
Dimension	355x255x20 mm

4.1. Experimental Measurements and Results

The temperature variations recorded during the experiment demonstrated that the surface temperature of the PV panel changes dynamically throughout the day and reaches its maximum level, particularly during midday, in response to solar radiation. Figure 7 illustrates the solar radiation levels measured during the experiment. It can be observed that solar radiation increases from the morning hours, reaching its peak around midday (approximately 900 W/m²).

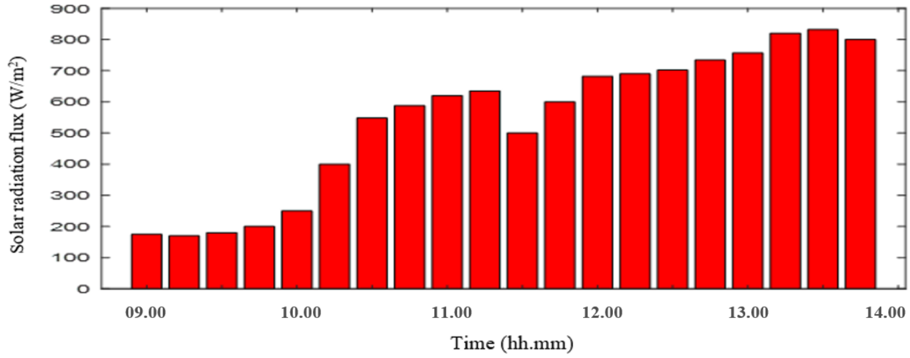

Figure 7. *Solar radiation levels throughout the day.*

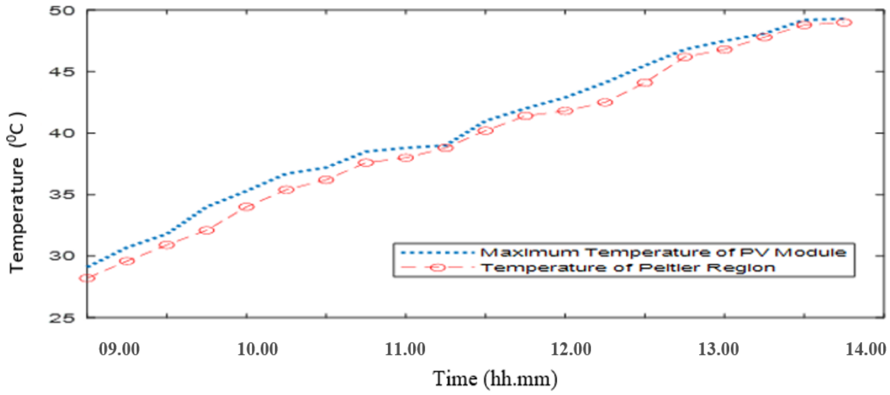

Figure 8. *Temperature variation in the hottest region of the PV panel and the area where the peltier module is mounted.*

The graph in Figure 8 shows the temperature variation between the hottest region of the PV panel and the area where the Peltier module is mounted. The observed temperature changes indicate that a slight cooling effect has occurred in the Peltier region. The difference between the experimentally obtained maximum temperature values and the temperature values at the location where the TEG module is mounted was calculated.

$$T_{av} = \frac{1}{n}\sum_{i=1}^{n}\left(T_{max,i} - T_{TEG,i}\right) \qquad (7)$$

Where $T_{max,i}$ is the maximum temperature measured in the hottest region of the PV panel, $T_{TEG,i}$ is the temperature measured at the location where the TEG module is mounted and n is the total number of measurements taken during the experiment. The average temperature difference, T_{av} calculated using the formula is found to be 0,94°C.

The experimental results show that the PV-TEG system achieved a surface temperature reduction of approximately 0,94°C. This value is higher than the predicted 0,55°C reduction in the simulation phase, indicating that the TEG module provides somewhat more effective cooling under real-world conditions.

These findings suggest that the Peltier module and heat dissipation system could potentially be an effective method for reducing the PV panel temperature. However, further investigation is required to enhance efficiency, including the integration of multiple TEG modules and the exploration of advanced cooling techniques.

5. RESULTS AND DISCUSSION

This study investigated the temperature variations in PV and the cooling potential of TEG modules through both experimental and numerical methods. The research focused on analyzing the daily temperature fluctuations on the PV panel surface and modeling the corresponding temperature distribution. Additionally, a TEG module was integrated into the regions experiencing excessive heating to assess its effectiveness in cooling.

The findings from simulations and experimental analyses revealed that the surface temperature of the PV panel exhibits dynamic variations influenced by solar radiation, wind speed, and ambient temperature. In the morning hours, the panel temperature remained relatively low but peaked around noon, particularly under high irradiation conditions, significantly surpassing the ambient temperature. This increase in temperature adversely affects the efficiency of PV panels and leads to localized heat accumulation, particularly in the central regions of the panel.

To mitigate this thermal issue, the study evaluated the impact of a single TEG module placed at the panel's central region. Simulation results indicated a temperature reduction of 0,55°C, while experimental measurements showed a decrease of 0,94°C. However, the cooling effect of a single TEG module was found to be limited, providing only marginal improvements in the overall temperature distribution. This result underscores the necessity of integrating multiple TEG modules to achieve effective cooling across a larger surface area of the PV panel.

The results obtained demonstrate that temperature variation in PV panels plays a critical role in efficiency, and these variations are concentrated in different regions over time. While TEG modules have the potential to improve panel performance by providing cooling along with electricity generation, it was observed that a single module was insufficient in terms of cooling. Therefore, further research should focus on the integration of multiple TEG modules and additional thermal management strategies.

This study addresses the initial stages of PV and TEG integration, and more comprehensive analyses and optimization efforts are required in future research. Work on multiple TEG systems and advanced cooling techniques will contribute to improving temperature management in PV panels and minimizing efficiency losses.

ACKNOWLEDGEMENT

The authors declares no conflict of interest.

REFERENCES

Barroso, J.C.S., Barth, N., Correia, J.P.M., Ahzi, S., Khaleel, M.A. (2016) "Solar Energy Materials & Solar Cells A computational analysis of coupled thermal and electrical behavior of PV panels". *Solar Energy Mater* Vol. 148, pp. 73-86. doi:10.1016/j.solmat.2015.09.004

Bazilian, M.D., Kamalanathan, H., Prasad, D.K. (2002) "Thermographic analysis of a building integrated photovoltaic system". *Renewable Energy* Vol. 26, Issue 3, pp. 449-461. doi: 10.1016/S0960-1481(01)00142-2.

Champier, D., Bedecarrats, J. P., Kousksou, T., Rivaletto, M., Strub, F., Pignolet, P. (2011). "Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove". *Energy*, Vol 36, Issue 3, Vol 1518-1526. doi: 10.1016/j.energy.2011.01.012

Champier D., Bedecarrats J.P., Rivaletto M., Strub F. (2010) Thermoelectric power generation from biomass cook stoves. *Energy* Vol. 35, pp. 935-942. doi: 10.1016/j.energy.2009.07.015

Chen, W.H., Liao, C.Y., Hung, C.I. (2012) "A numerical study on the performance of miniature thermoelectric cooler affected by Thomson effect". *Appl Energy*, Vol.89, pp:464-473. doi: 10.1016/j.apenergy.2011.08.022

Cheng T.C., Cheng CH, Huang ZZ, Liao GC. Development of an energy-saving module via combination of solar cells and thermoelectric coolers for green building applications. Energy 2011; 36:133e40. doi: 10.1016/j.energy.2010.10.061

Das, D., Kalita, P., Dewan, A., and Tanweer, T. (2019) . "Development of a novel thermal model for a PV/T collector and its experimental analysis". *Solar Energy* Vol. 188 pp. 631-643. doi: 10.1016/j.solener.2019.06.005.

Kane, A., Verma, V., & Singh, B. (2017). Optimization of thermoelectric cooling technology for an active cooling of photovoltaic panel. *Renewable and Sustainable Energy Reviews*, *75*, 1295-1305.

Kant, K., Shukla, A., Sharma, A., Biwole, P.H. (2016) "Heat transfer studies of photovoltaic panel coupled with phase change material". *Solar Energy*, 140, pp. 151-161, doi:10.1016/j.solener.2016.11.006

Martinez A., Astrain D., Rodriguez A. (2011) “Experimental and analytical study on thermoelectric self cooling of devices”. *Energy*, Vol.36, pp. 5250-5260. doi: 10.1016/j.energy.2011.06.029

Notton, G., Cristofari, C., Mattei, M., Poggi, P. (2005) “Modelling of a double-glass photovoltaic module using finite differences”. *Applied Thermal Engineering* Vol.25, pp. 2854-2877. doi: 10.1016/j.applthermaleng.2005.02.008.

Royne, A., Dey, C. J., & Mills, D. R. (2005). Cooling of photovoltaic cells under concentrated illumination: a critical review. *Solar energy materials and solar cells*, *86*(4), 451-483.