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Experimental Performance and Comparison of Sustainable Cooling Techniques for Solar (Photovoltaic) Panel

Sagar Wankhede[1*], **Pralhad Pesode**[2], **Dhanaji Jadhav**[3], **Yogesh Mane**[4] **and Manoj Mugale**[5]

[1] *School of Mechatronics Engineering, Symbiosis Skills and Professional University, Pune, Maharashtra, India*

[2] *School of Mechanical Engineering, Dr. Vishwanath Karad MIT-World Peace University, Pune, Maharashtra, India*

[3] *Department of Mechanical Engineering, Nutan Maharashtra Institute of Engineering and Technology, Pune, Maharashtra, India*

[4] *National Institute of Technology, Tiruchirappalli, Tamil Nadu, India*

[5] *Cleveland State University, Cleveland, Ohio, USA*

***Correspondence to:**
Sagar Wankhede
School of Mechatronics Engineering,
Symbiosis Skills and Professional University,
Pune, Maharashtra, India.
E-mail: svw8890@gmail.com

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Abstract

Solar panels are necessary for capturing renewable energy, but extreme heat can shorten their lifespan and reduce their effectiveness. Sustainable cooling techniques have been investigated as a solution to this problem. In order to improve solar panel performance, this study compares various cooling techniques, including watermelon rind, banana leaves, wet soil, green net, coir, and jute bags. The study intends to assess how well these methods work in lowering panel temperature and raising overall effectiveness. Key performance indicators used in the controlled studies were voltage output and temperature. The outcomes of the experiment show that various cooling methods have variable effects on solar panels' ability to regulate temperature. Due primarily to its evaporative cooling abilities, watermelon rind displayed the highest voltage output and significant temperature reduction. Watermelon rind surpassed banana leaves, wet soil, green net, coir, and jute sack in terms of voltage output and temperature reduction. The comparative analysis shows how each method works well in reducing temperature rise and enhancing solar panel efficiency. These results offer useful information to solar panel system stakeholders, assisting in the selection of appropriate sustainable cooling methods based on their effectiveness and suitability for certain environmental circumstances. Overall, by enhancing the effectiveness and dependability of solar panel systems, the experimental performance and comparison of these cooling strategies advance renewable energy technology.

Keywords

Renewable energy, Solar panel, Sustainable, Cooling, Technique, Power

Introduction

Due to their limitations, traditional sources of energy cannot be trusted [1, 2]. Solar energy is one of the renewable energies that are expanding the quickest. Solar radiation is converted into electricity by solar cells and collectors, which is then utilized to produce energy. Solar energy can not only be utilized to generate electricity but also for heating and cooling purposes. Although solar photovoltaic (PV) and thermal collectors have made great strides, they still need auxiliary parts, including energy storage that drives up the cost of the system as a whole [3]. The effectiveness of solar PV systems has been thoroughly examined in order to produce higher energy per unit area [4]. Researchers [5] have also shown the value of the local climate for solar PV installations. The adoption of these technologies has increased as a result of government initiatives to promote solar energy [6]. Only

5% to 20% of the solar energy received by a typical PV module is converted into electrical power, depending on the solar cell type and environmental factors. Higher current or voltage settings often improve the electrical performance properties of a PV cell or module. Current characteristics can be enhanced by maximizing incoming solar radiation using conventional concentrators. Cuce et al. [7] has investigated the connection between G and I_{SC} under various humid environments. The level of humidity has no effect, according to the results [8].

Shockley's ideal diode equation needs two resistors in order to accurately and realistically describe the electrical behavior of a PV cell or module. The five-parameter technique is the name of this technique. Researchers are aware that the cell temperature, which is frequently observed in warm and humid environments, has a significant impact on the energy performance characteristics of PV modules [9]. When all the advantages and disadvantages are considered, solar cells may end up winning out. For example, a solar updraft tower starts off significantly more expensively and is less effective than PV [10]. Solar cells allow for the direct conversion of the photon energy of light into electrical power. For solar thermal collectors or solar updraft towers, on the other hand, expensive auxiliary equipment such turbines, generators, pipes, etc. is required [11, 12]. Despite whatever advantages crystalline silicon solar cells could have, there are still a number of challenges that may hinder us from utilizing these attractive devices as much as we would like. The device's fragility and sensitivity to dust collection [13], poor efficiency (between 15% and 25%) [14], and sensitivity to its operating temperature [15] are just a few of the challenges faced by researchers. To address these problems and pave the way for the subsequent generation of scientific articles, thousands of publications based on these criteria have been produced.

The effects of operating temperature on PV modules are examined in this study. The sensitivity of PV modules to operational temperature decreases by 0.4% to 0.65% with each degree of temperature rise [16]. The explanation for this phenomenon is given in detail by Bernardo et al. [17]. According to his paper, PV modules short-circuit current (I_{SC}) increases noticeably as its temperature rises. However, both the power output and the open-circuit voltage (V_{OC}) reduce dramatically. For example, crystalline silicon cells demonstrate that the maximum power achievable and V_{OC} decrease by 0.5% and 0.3%, respectively, with each degree of temperature increase. This drop is significant compared to the I_{SC} rise of 0.05% per °C. Taking everything into account, it's probable that PV modules will operate more effectively on cold days than on hot ones. Because deserts are suitable beginning places for solar installations, it is vital to study their weather [10]. For example, during the summer months, the "Lut Desert" in Iran experiences daytime highs of 50 °C and nighttime lows of 10 - 20 °C. PV modules can heat up to 35 °C above ambient temperature on sunny days, according to van Helden et al. [18], putting the laminates under extreme thermal pressures day and night. Additionally, if the temperature of solar cells rises above a certain point, they will degrade for a long period [19]. These elements make creating a cooling field for a PV module necessary. Renewable energy is defined as energy that can be renewed spontaneously over a brief period of time. Solar, wind, hydropower, geothermal, wave energy, biomass, hydrogen, etc. are a few possibilities for renewable energy sources [20].

Solar energy has become a prominent option among renewable energy sources since it provides a number of advantages, such as: It is feasible to collect this significant amount of renewable energy since it is continuously accessible, even on overcast days. Most solar energy conversion methods require only a little initial expenditure [21]. Given that PV modules have an exceptionally longer time span of more than 30 years, maintenance expenses are practically non-existent. The flexibility to assemble PV modules in any arrangement, from modest residential setups to huge solar farms. In terms of aesthetics, in comparison with alternative renewable energy sources, PV modules have the least adverse ecological effects. solar energy is becoming more and more common due to the aforementioned benefits, in addition to in tropical areas where sun intensity is substantial adequate to support solar farms with capabilities ranging from 10 to 150 MW [22, 23]. Solar updraft towers, solar thermal collectors, and solar cells are typically the three methods used to transform this pure energy into usable electrical and thermal forms of energy. Each technique has benefits and drawbacks. When all benefits and drawbacks are taken into account, solar cells could tip the scales in their favor. For example, a solar updraft tower has a much higher initial investment need and is less effective than PV.

Solar cells may directly transform the photon energy of light into electrical power in the case of producing electricity. The use of solar thermal collectors or solar updraft towers, in contrast, necessitates several expensive auxiliary components, including turbines, generators, pipes, etc. [11, 12]. The PV panels and solar thermal collectors are the two primary solar energy technologies. In order to transform solar radiation into thermal energy that can be used by humans, it is usual practise to use a heat transfer fluid whose temperature (and, consequently, enthalpy) rises as the fluid moves through the solar thermal collector [24]. A PV panel, on the other hand, converts the solar energy that directly hits its surface into electrical energy by means of the photovoltaic effect. A commercial solar PV panel's efficiency typically falls between 10% and 23% [25, 26]. The three most common forms of PV panels are mono-crystalline, poly-/multi-crystalline, and amorphous, and they are all based on silicon cells. Thin-film technologies, including CdTe and CIGS, have also lately made their way into the market [24], as well as silicon hetero-junction cells. The PV action in a PV panel is supported by photons with energies over the band gap energy; the outstanding photon energy, however, is primarily transformed into heat, raising the temperature of the cell. The open-circuit voltage (V_{OC}), fill factor, and output power all suffer from temperature increases, which eventually reduce the panel's electrical efficiency.

Environmental elements including relative humidity, ambient temperature, and wind speed, along with particles like collected dust on the panel are common variables which affect a solar cell's operating temperature along with to the local sun irradiation. Any method for cooling a PV panel that involves dissipating some of the excess or collected thermal energy is significant in this case because it can lower cell temperatures, increase the panel's electrical capacity, and guard against irreparable harm to the panel brought on by the temperature rise of the cells and their regular thermal cycling throughout daytime and night-time operation. Over the years, a variety of thermal management strategies have been put forth, created, and tested with the goal of cooling PV panels, and there are currently a number of commercial systems available on the market that do so. Both active and passive temperature control techniques are available. Forced convective heat transfer is used in the first category, whereas free convective, conductive, and/or radiative heat transfer control is used in the second. Numerous thorough and instructive evaluations may be found while searching the literature for research that pertains to this field. For instance, Siecker et al. [27] gave an in-depth description of different hybrid cooling methods, covering methods like (i) floating tracked concentrated cooling systems; (ii) PV-thermoelectric systems cooled by a heat sink; (iii) PV panels with integrated phase change materials (PCMs); (iv) immersion cooling of PV panels; (v) PV panels with transparent coatings; and (vi) hybrid PV-thermal (PV-T) systems cooled by water spray. Additionally, Maleki et al. [28] and Hasanuzzaman et al. [29] given a summary of both passive and active methods of cooling readily accessible for modifiable PV panel temperatures and concluded that passive cooling methods are extra beneficial for commercial-scale systems due to the higher costs and higher electricity demands whereas active cooling methods are more feasible for small-scale deployment. A full discussion of several cooling solutions was presented by Sargunanathan et al. [30], including active cooling using water flowing over the front surface of PV panels or using air/water/fin cooling systems. Ali [31] clarified the latest advances in PV cooling, especially for PCM systems. On how these techniques affect lowering operating temperatures for PV panels, an analysis was given [32-37]. In their state-of-the-art evaluation of PV performance enhancement methods, Kandeal et al. [38] place a special emphasis on convection, conduction, and radiation-based cooling methods. A summary of several thermal management techniques was also provided by Bahaidarah et al. [39] and Hamzat et al. [40], based on the use of (i) heat pipes, (ii) microchannels, (iii) liquid immersion, (iv) heat sinks, (v) impingement jets, and (vi) PCMs. The use of nano-liquid cooling, cutting-edge techniques for radiative thermal management, or new advancements in the arena of integrated hybrid PV-T collectors, that additionally entail the removal of thermal energy from PV cells, are examples of present-day research.

The fluid and newly defined properties of the solute are included in the science of nano-liquid. This nanotechnology suggests a possibility of increasing the properties of the base fluid's thermal conductivity in the nano-liquid. According to the research of [41], Al_2O_3 water nano-liquid with a 0.5% concentration has the ability to increase convection current in a twin pipe heat exchanger while just slightly lowering pressure. Similar to [42], who used Al_2O_3, CuO, and TiO_2 nano-fluids of varying concentrations to cool the solar panel, it was surprise to find that Al_2O_3 nanoparticle greatly increased the solar panel's power output. In addition, when carbon nanotube and $AgSiO_2$ were appropriately integrated, the effectiveness of the solar panel was increased by 30% [43]. Additionally, the sophisticated simulator was used to test the applicability of CuO, SiC, and Al_2O_3 in boosting solar panel efficiency, with the result that SiC was recommended as the best nano-fluid [44]. A scientific comparison of Bohemite water and water used as a heat extractor in PVT was also done. As a result, Bohemite and water were preferred over water for increasing PVT's output power. Recently, [45] investigated the effects of concentration, water, and nanoparticles on the electrical and thermal efficiency of the PV. According to [46], copper-water nanoparticles were more efficient electrically and thermally than copper-ethylene glycol. The best cooling candidate, according to a comparison of several cooling techniques including forced air, natural, SiO_2-water, water, and Fe_3O_4, was nano-liquid (SiO_2- water). A further notable finding is that nanofluid is a better coolant than water-PVT and uncooled-PV, as demonstrated by the experimental results of 13% efficiency and a 16 °C drop in PV temperature reached by [47]. As a result of the solar panel's high irradiance and surface area sensitivity to heat dissipation, the unpredictable temperature rise can be managed with this nano-fluid technique.

The overviews stated above offer extremely fascinating details about the advancement of these technological advances. The efficient performance of solar panels is crucial for harnessing solar energy effectively. However, solar panels are susceptible to temperature increases, which can negatively impact their performance and longevity. To mitigate this issue, various sustainable cooling techniques have been explored and implemented. The objective of this study is to systematically assess comparing the effectiveness of several environmentally friendly cooling methods for solar panels.

Materials and Method

The experiment utilizes commercially available solar panels of a specific 40 W and size (Table 1). The following cooling techniques are tested and compared:

- Watermelon rind: Watermelon rinds are collected and prepared as a cooling material.
- Banana leaves: Fresh banana leaves are selected and prepared for use.
- Wet soil: Soil with high moisture content is used as a cooling medium.
- Green net: A shade net or green mesh material is employed to limit heat absorption.
- Coir: Natural coir material is used for insulation and temperature regulation.
- Jute sack: Jute sacks are used for their insulation properties and heat reduction capabilities.

Table 1: Solar PV panel specifications and electrical ratings.

Module Type	NSA40
P_{max}	40 W ± 2
Voltage (V_{max})	17.84 V
Current	2.26 A
Open circuit voltage (V_{oc})	21.95 V
Short circuit current (I_{sc})	2.44 A
System voltage	1000 V DC

The solar panels are mounted in a controlled environment that closely resembles real-world conditions. The panels are exposed to sunlight at a predetermined intensity and temperature. High-precision temperature sensors are strategically placed on the solar panels to monitor the surface temperature accurately (Figure 1).The voltage output of the solar panels is measured using appropriate equipment and the following components (Table 2).

The cooling techniques are individually tested in separate experimental runs. For each technique, the cooling material (watermelon rind, banana leaves, wet soil, green net, coir, or jute sack) is placed below the solar panels. The surface temperature of the solar panels and the corresponding voltage output are recorded at regular intervals during experiment (Figure 2). The collected data is analyzed to evaluate the performance of each cooling technique.

Statistical methods may be employed to determine any significant differences in temperature reduction and voltage output between the techniques. The results from each cooling technique are compared to identify the most effective methods in terms of temperature regulation and voltage generation. To ensure the reliability of the results, the experiments are repeated multiple times, and the average values are calculated.

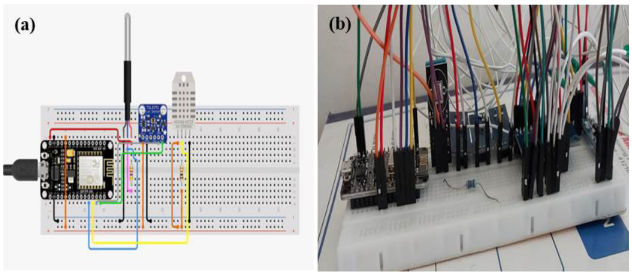

Figure 1: Basic circuit configuration diagram **(a)** from software and **(b)** at actual.

Table 2: Circuit components with specifications.

Component	Specifications
NodeMCU ESP8266	• Tensilica 32 bit RISC CPU Xtensa LX106. • Wifi supported. • Digital IO pins with 3.3V input.
4.7K OHM resistor	• Variable resistor with resistance 4.7 and 5% tolerance
Voltage sensor	• Range from DC 0 V to 25 V
Temperature sensor	• 100 K NTC, with one-meter cable temperature sensor. • Temperatures range from -40 °C to 270 °C.
Step-down buck converter	• LM 2596 adjustable step-down buck converter.
Power supply module	• 3.3 V power supply module. • Input 4.5 V to 12 V and output of 3.3 V.
Breadboard	• Withstanding voltage of 1000 V AC. • Rating is 5 Amps.
Arduino board	• 22 Digital IO pins • 6 PWM output pins.

Figure 2: Experimental setup for sustainable cooling technique utilizing circuit boards as intermediaries and standard panel.

Results and Discussion

Case-1

The use of watermelon rind and banana leaves as cooling materials has a positive impact on the voltage output of the solar panels. Watermelon rind contains a significant amount of water, which has contributed in evaporative cooling. Placing watermelon rind below the solar panels allows for the evaporation of water, which helps to dissipate heat and potentially lower the panel temperature. This cooling effect may positively impact the voltage output and overall performance of the panels. Similarly, Banana leaves offer natural insulation properties. By using banana leaves below to the solar panels, limits the heat absorption. This result improves the voltage output of the panels and helps with maintaining lower operating temperatures. By reducing the operating temperature of the panels, these cooling techniques helped maintain a higher voltage output. Lower temperatures result in reduced resistive losses within the solar cells, allowing for improved electron flow and increased voltage generation. The voltage enhancement was particularly notable during peak sunlight hours when temperature raised and leads to decreased efficiency (Figure 3 and figure 4).

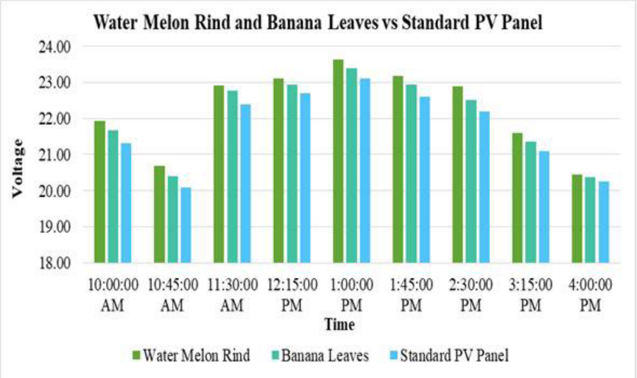

Figure 3: Water melon rind and banana leaves vs standard PV panel for voltage.

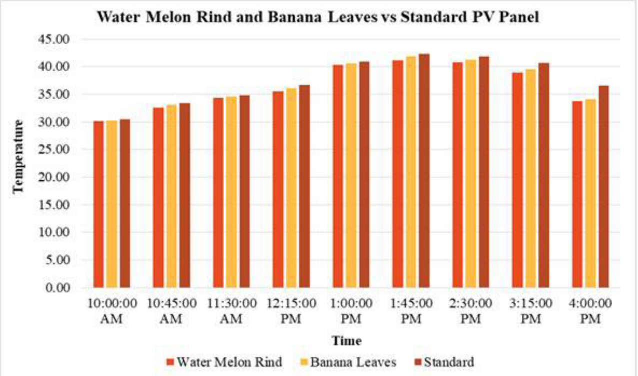

Figure 4: Water melon rind and banana leaves vs standard PV panel for temperature.

The use of watermelon rind and banana leaves aligns with the principles of sustainability and environmental responsibility. These materials are readily available, low-cost, and biodegradable, making them accessible and eco-friendly options for cooling solar panels. It is worth noting that while the experimental results highlight the effectiveness of watermelon rind and banana leaves as cooling materials, their durability and longevity may pose certain challenges. Regular replacement or maintenance may be required to sustain their cooling efficiency over extended periods.

Case-2

Wet soil acts as an effective cooling medium by absorbing and dissipating heat, thereby reducing the temperature of the panels. It utilizes the high heat capacity and thermal conductivity of the soil to transfer the heat away from the panels, maintaining lower operating temperatures. Green net provided to reduce heat absorption. These cooling techniques contributed to maintaining a more stable and optimal operating temperature for the solar panels. Both wet soil and green net offer sustainable and cost-effective solutions for cooling solar panels and also utilizes natural elements and do not require additional energy consumption. These cooling techniques are particularly beneficial in regions with high ambient temperatures or limited access to conventional cooling methods. Further study is needed to optimize the implementation of wet soil and green net, considering factors such as the ideal depth and moisture content of the soil, as well as the shading efficiency and durability of the green net. Additionally, long-term studies are required to assess their effectiveness and practicality in different climates and solar panel installations (Figure 5 and figure 6).

Case-3

Coir exhibits good insulating properties, which helps to reduce heat transfer from the ground to the solar panels. By placing coir underneath the panels, it acts as a thermal barrier, preventing the direct transfer of heat from the surface. It has the ability to retain moisture, which is aid in cooling. Jute sacks have relatively good breathability, allowing for airflow around the solar panels. Adequate airflow has aid in dissipating heat from the panel surface, preventing overheating and improving overall performance. Coir and jute sack effectively regulated and reduced the operating temperature of the solar panels, mitigating the negative impact of high temperatures (Figure 7 and figure 8).

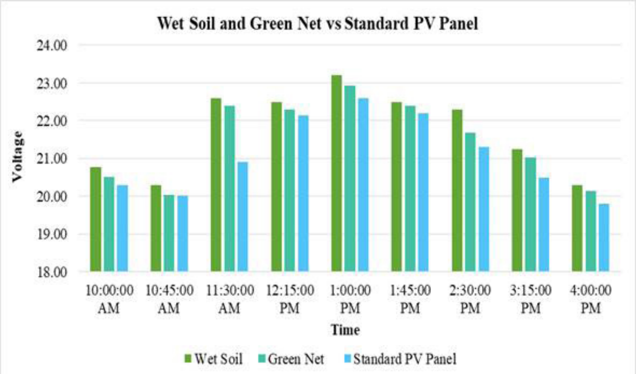

Figure 5: Wet soil and green net vs standard PV panel for voltage.

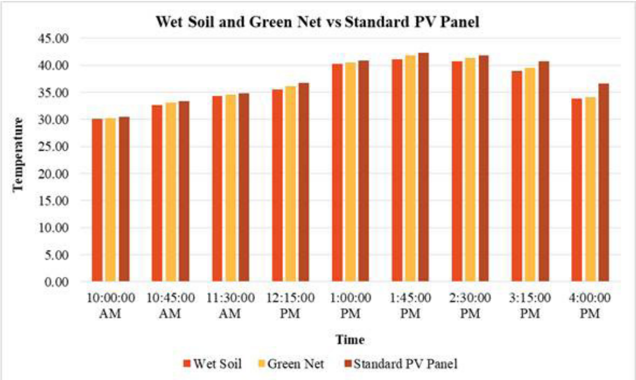

Figure 6: Wet soil and green net vs standard PV panel for temperature.

Among the various cooling techniques (Figure 9 and figure 10), the experimental results indicate that watermelon rind exhibits the highest and improved voltage output compared to other methods. This has been attributed to the effective evaporative cooling effect of watermelon rind, which aids in dissipating heat from the solar panels. Following closely behind, banana leaves demonstrate their capability to reduce heat absorption, thereby maintaining a more stable operating temperature and enhancing voltage generation. After banana leaves, wet soil proves to be a reliable cooling technique as it acts as a heat sink, effectively regulating the temperature of

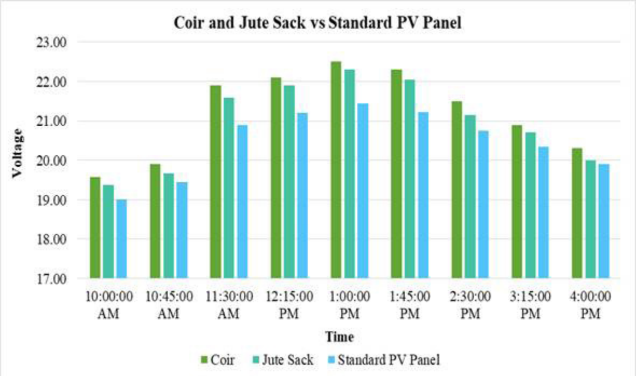

Figure 7: Coir and jute sack vs standard PV panel for voltage.

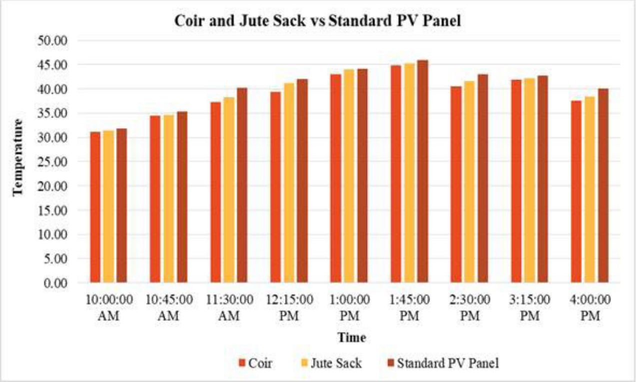

Figure 8: Coir and jute sack vs standard PV panel for temperature.

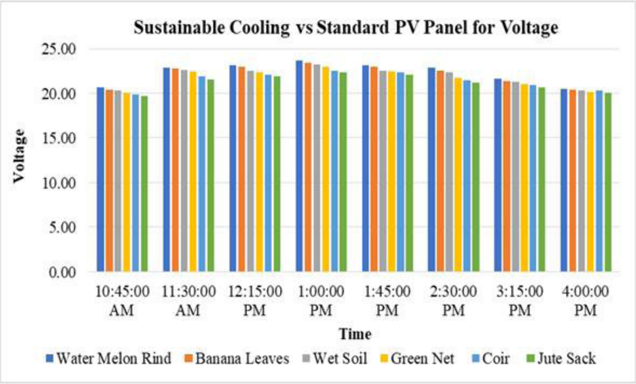

Figure 9: Comparison of sustainable cooling vs standard PV panel for voltage.

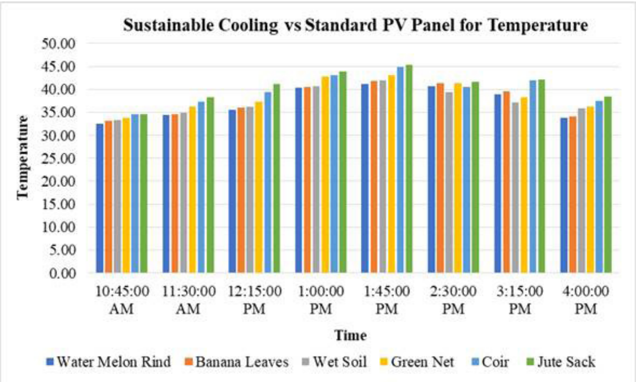

Figure 10: Comparison of sustainable cooling vs standard PV panel for temperature.

the panels. This regulation helps in minimizing resistive losses and potentially improving the voltage output of the solar panels. Additionally, the green net shows promise by limiting heat buildup, which positively influences the voltage generation and overall performance of the panels. Moreover, the insulation properties of coir and jute sacks contribute to maintaining lower operating temperatures, further enhancing the voltage output of the solar panels. These materials act as effective barriers, reducing heat transfer and ensuring improved performance.

Conclusions

The experimental performance and comparison of sustainable passive cooling techniques for solar (PV) panels has demonstrated promising results and significant potential for improving the efficiency and longevity of solar panel systems. Through rigorous testing and analysis, the following key findings have emerged:

- The implementation of sustainable cooling techniques has shown a notable increase in the overall efficiency of solar panels. By reducing the operating temperature, the panels are able to maintain higher levels of output, maximizing electricity generation.
- The implementation of these sustainable cooling techniques has demonstrated a significant reduction in the operating temperature of solar panels. The natural properties of watermelon rind, banana leaves, wet soil, green net, coir, and jute sacks, such as high-water content, evaporation, and shading, have effectively cooled the panels, preventing overheating and improving their overall performance.
- Advantage of these cooling techniques is their affordability and accessibility. Watermelon rind, banana leaves, wet soil, green net, coir, and jute sacks are widely available and relatively inexpensive materials, making them a cost-effective solution for cooling solar panels, particularly in regions with limited resources or budget constraints.
- The use of these natural cooling techniques aligns with environmental sustainability principles. Unlike conventional cooling methods that require additional energy consumption, these techniques rely on renewable resources and have minimal environmental impact and contribute to a more sustainable energy production process by reducing carbon emissions associated with traditional cooling methods.
- The experimental performance has highlighted the adaptability of these cooling techniques to different geographical locations and climates. Watermelon rind, banana leaves, wet soil, green net, coir, and jute sacks can be easily sourced and tailored to suit specific regional conditions, making them suitable for a wide range of solar panel installations.
- The experimental results have shown promising outcomes, there is still a need for further research and optimization of these cooling techniques. Factors such as material durability, maintenance requirements, and long-term effectiveness need to be investigated to ensure their practicality and reliability over extended periods.

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Conflict of Interest

Author(s) do not have any conflict of interest

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