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Research Article

Investigation of Repurposed Material Utilization for Environmental Protection and Reduction of Overheat Power Losses in PV Panels

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Constant exposure of a photovoltaic (PV) panel to sunlight causes it to overheat and, consequently, its rated efficiency decreases leading to a drop in its generated power. In this study, a PV panel was tested under standard test conditions in a halogen lamp solar simulator at different solar irradiance values. The PV panel was then fitted with heat dissipating fins and measured under identical test parameters; thereafter, repurposed materials such as high-density polyethylene (HDPE) and plastic bags were, separately, added to the PV panel with fitted heat-extraction fins and the performance was evaluated again. Passively cooling the PV panel with fins and repurposed materials resulted in a 22.7% drop in the PV panel's temperature, while an 11.6% increase in power output occurred at 1000 W m^{-2}. Utilizing repurposed waste materials in PV cooling improves a panel's efficiency and saves the environment from the ecological effects of dumping these materials.

1. Introduction

Photovoltaic (PV) cells' efficiency for converting sunlight into electricity is low, and it drops even more as the cells are heated when exposed to a great deal of solar irradiance. There is an approximately 0.25% and 0.5% drop in efficiency for amorphous and crystalline silicon cells, respectively, for every 1°C increase in the cells' temperature [1]. Hence, cooling PV panels is essential in utilizing the maximum conversion efficiency. The two currently used PV panel cooling systems are active cooling and passive cooling. Active cooling is a system based on expending energy to cool the PV panel down, while passive cooling is a system that does not use any energy to cool off a PV panel.

PV cooling has been widely researched [2, 3]. Hybrid integrated PV/thermal systems are classified as (i) water based, (ii) air based, (iii) refrigerant based, (iv) heat pipe based, and (v) phase change material (PCM) based [4], while passive cooling systems are divided into air (heat sink), liquid (liquid immersion), and PCM [5]. Heat sinks, or fins, were also effective cooling additives to various applications [6–8]; PV panels can benefit from these properties to reduce their temperature and to increase their relative efficiencies, as was confirmed by multiple studies. There are plenty of uses for fins, such as in electronic equipment, heat exchangers, and turbine cooling. Increases of up to 0.3~1.8% and 1.8~11.8% in average electrical efficiency and average output power, respectively, were reported after the addition of passive cooling fins to a PV panel [9]. Installing aluminium fins to the backside of PV panels increased the electrical conversion efficiency by 1.75% [10] and the output power by 2% [11]. A study investigated a hybrid solar photovoltaic/wind system to maintain the cell's surface temperature, and according to the results, the system not only enhanced the PV cell's performance but also helped the wind turbine generate more electrical power [12].

PCMs have been extensively investigated as heat-extraction additive components to PV panels yielding favorable outcomes

in increasing the relative efficiency by reducing the PV panels' surface temperatures [13–16]. The advantages of adding PCMs to PV panels are their high heat transfer rate, passive heat exchange, no maintenance cost, among others, while some of the disadvantages are high cost, toxicity, fire safety, and corrosion issues [17]. Additional investigations of passive methods of PV panel cooling include the use of cotton wicks [18], rainwater [19], and radiative cooling [20].

State-of-the-art PV passive cooling reviews [21, 22] show a plethora of research on the subject but none look into the utilization of materials that would otherwise be discarded as passive cooling additives to PV panels. This work focuses on passive cooling and the repurposing of different materials to aid in reducing a PV panel's temperature. Repurposing of a material is defined as the utilization of a material, which was originally manufactured to serve a primary function, to serve a secondary purpose instead of being disposed of after its primary function is spent. An alternative to the disposal of particular materials or products is repurposing them to cool down a PV panel. Polyethylene is made from petroleum and considered as a thermoplastic (a plastic material that solidifies when it is cooled down and is easy to shape and bend when it is heated). High-density polyethylene (HDPE) is used for manufacturing plastic bags, plastic bottles, geomembranes, lumber plastic, and anticorrosion pipes. This work introduces a new hybrid passive cooling classification that combines air cooling using heat sinks (fins) under natural ventilation and no wind speed with repurposed materials. The repurposed materials that will be explored in this work are ground HDPE and plastic bags.

The disposal of plastic creates plenty of negative environmental impacts. Despite the fact that plastic is a durable material, it poses a considerable threat to the environment as it decomposes slowly and its incineration could lead to the emission of poisonous gases into the atmosphere. In addition to that, producing plastic proved to have a harmful effect on the environment as a large number of pollutants, together with enormous amounts of fossil fuels, are needed during the production process. Recycling is not always a viable option in many parts of the world; therefore, reducing the nonbiodegradable waste and using it for PV cooling can be beneficial to both the environment and to the efficiency and output power of PV panels. Renewable energy generation combined with environmental protection support the new trend of sustainable cities' design [23].

2. Methodology

The overheating problem in PV panels will be experimentally investigated. A PV panel will be prepared according to the test requirements; it will be tested under laboratory conditions. Halogen lights will be set to the required intensity, and the PV panel's front and back temperatures will be monitored. The temperature will be recorded after ensuring that a steady state was reached.

Heat loss from the PV panel is important for the fins' design. To estimate the heat loss from the PV panel, a mathematical model will be proposed and solved analytically. The following assumptions were considered:

(i) Steady state, one-dimensional problem in the direction of flow. Thus, the temperatures of the glass cover, solar cells, and plates vary only in the direction of working fluid flow

(ii) The capacity effects of the glass cover, solar cells, and back plate have been neglected

2.1. Heat Dissipation Rate by Convection, Q_{conv}. Q_{conv} is the degree at which heat dissipates through convection from the top and bottom surfaces of the PV panel and is assigned a function of convection coefficient and the temperature gradient between the surface and ambient temperature [24].

$$\begin{aligned} Q_{conv} &= Q_{conv,front} + Q_{conv,back}, \\ Q_{conv,front} &= A \times h_{front} \times \left(T_{pv} - T_{amb}\right), \\ Q_{conv,back} &= A \times h_{back} \times \left(T_{pv} - T_{amb}\right), \end{aligned} \tag{1}$$

where A is the surface area of the PV panel, h_{front} and h_{back} are the heat convection coefficients for the front and back surfaces of the PV panel in $\mathrm{W\,m^{-2}\,K^{-1}}$, and T_{pv} and T_{amb} are the PV panel and the ambient temperatures, respectively.

The convection coefficients are a mixture of both forced and free convections. They differ in velocity, air temperature, and geometry of the PV panel. In this research, not much attention was paid to forced convection. On the contrary, free convection is the main focus of attention. Free convection coefficients are derived from the base of a heated inclined plate for the entire range of Rayleigh numbers that were assigned to the Nusselt number (Nu). All equations were provided by [24].

2.2. Heat Dissipation Rate by Radiation, Q_{rad}. Q_{rad} is the degree to which the PV panel gives off heat. It relies on the emissivity of the PV panel as well as the temperature gradient between the PV panel and the environment. As for horizontal surfaces, the radiation heat transfer between the front and back surfaces of the panel and the surroundings was represented by the following:

$$\begin{aligned} Q_{rad,front} &= A \times \sigma \times \varepsilon_{pv} \times \left(\left(T_{pv} + 273.15\right)^4 - \left(T_{sky} + 273.15\right)^4\right), \\ Q_{rad,back} &= \frac{A \times \sigma \times \left(\left(T_{pv} + 273.15\right)^4 - \left(T_{ground} + 273.15\right)^4\right)}{1/\varepsilon_{pv} + 1/\varepsilon_{ground} - 1}. \end{aligned} \tag{2}$$

As for the tilted panels, the net heat, which is dissipated through radiation, was among the panel, the sky, and the ground and was given by the following:

$$Q_{\text{rad,front}} = A * \sigma * \left\{ \left(\varepsilon_{\text{pv}} * \left(T_{\text{pv}} + 273.15\right)^4 \right) - \left(\frac{(1+\cos\varnothing)}{2} * \varepsilon_{\text{sky}} * \left(T_{\text{sky}} + 273.15\right)^4 \right) - \left(\frac{(1-\cos\varnothing)}{2} * \varepsilon_{\text{ground}} + \left(T_{\text{ground}} + 273.15\right)^4 \right) \right\},$$

$$Q_{\text{rad,back}} = A \times \sigma \times \left(\varepsilon_{\text{pv}} \times \left(T_{\text{pv}} + 273.15\right)^4 \right) - \left(\frac{(1+\cos\varnothing)}{2} \times \varepsilon_{\text{ground}} \times \left(T_{\text{ground}} + 273.15\right)^4 \right) - \left(\frac{(1-\cos\varnothing)}{2} \times \varepsilon_{\text{sky}} \times \left(T_{\text{sky}} + 273.15\right)^4 \right), \quad (3)$$

where σ is the Stefan-Boltzmann constant at 5.67×10^{-8} W m^{-2} K^{-4}, PV is the panel's emissivity, and ε_{pv} is considered to be 0.9. Here, the sky's temperature of 15 K is lower than the ambient temperature and the ground temperature is presumed to be 10°C warmer than the ambient temperature.

2.3. Fin Design. The degree of heat transfer could be escalated through expanding the surface where convection takes place. This can be achieved through the application of fins, which stretch from end to end on the backside of the PV panel. The fin material's thermal conductivity could have a considerable impact on the circulation of temperature across the fin. Ideally, the fin material should possess a high level of thermal conductivity in order to diminish the variations in temperatures from top to bottom.

2.4. Selection of Fins' Shape. The fins' configurations were selected based on a few parameters such as weight, space, and cost. On one hand, fins can have simple designs such as rectangular, triangular, parabolic, annular, and pin shapes. On the other hand, fins' design can be complicated such as spiral shapes. In this study, rectangular fins were selected from three known and easy-to-install configurations. These configurations were (i) rectangular fins, (ii) parabolic fins, and (iii) pin fins. Table 1 shows the results of that calculation where each fin design produced a different efficiency; based on these results, the rectangular fin shape was selected.

The rectangular fin shape allows airflow in one direction only; if the air blows from a transverse direction, the fin will create high drag on the panel and will negatively affect the heat transfer. To overcome the flow direction problem, a perforated fin was used. Perforations in the rectangular fin allow the air to flow in all directions and reduce the amount of material used in the fin, thus making it lighter in weight. Perforated, lighter-weight fins are cheaper and exert less stress on the panel.

The perforated fin is shown in Figure 1. Under natural convection conditions, a perforated fin dissipated more heat than an identical solid fin. Perforated fins achieve better heat transfer than solid fins. In addition, light permeable fins reduce the cost of the fin material compared to solid fins. Furthermore, using a large number of permeable fins leads to an increase in the Nusselt number [25]. The permeable nature of perforated fins leads to a larger heat loss and a drop in the PV panel's temperature due to air passing through the fins freely. The fin's area, pores' area, and fin's weight were all calculated.

Table 1: Fin efficiency based on design type.

Design	Efficiency (η)
Rectangular fin	84%
Parabolic fin	78.4%
Pin fin	81.5%

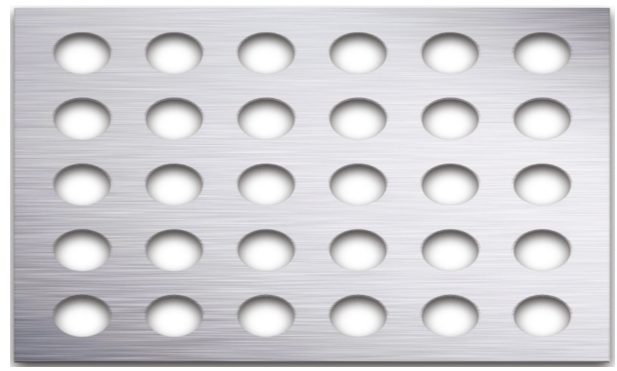


Figure 1: A perforated fin that was attached to the backside of a PV panel to act as a heat sink and to reduce the PV panel's temperature.

The fin's heat transfer rate was assessed using the q_{fin} rule on the fin's base as shown in equations (4)–(6) [24].

$$q_{\text{fin}} = M \frac{\sinh(\text{mL}) + (h/mk) * \cosh(\text{mL})}{\cosh(\text{mL}) + (h/mk) * \sinh(\text{mL})}, \quad (4)$$

$$M = \sqrt{hPkA_c}\,\theta_b, \quad (5)$$

$$m = \sqrt{\frac{hP}{kA_c}}, \quad (6)$$

$$\theta_b = T_{\text{base}} - T_\infty. \quad (7)$$

Fins were utilized to boost the heat transfer from a particular surface by expanding the surface area. Nevertheless, the fins installed were resistant to heat transfer through conduction from the designated surface. Therefore, any increase in the heat transfer rate could not be guaranteed. To address this issue, fin efficacy, ε_f, had to be evaluated. Accordingly, fins' effectiveness can be defined as the proportion of the heat transfer rate with fins to the heat transfer rate without the use of fins [24].

$$\varepsilon_f = \frac{q_{\text{fin}}}{hA_{c,b}\theta_b}, \quad (8)$$

where $A_{c,b}$ is the fin's cross-sectional area at the base. The results of the fins' effective calculations are shown in Table 2.

Table 2: Calculations of the fins' effectiveness.

Area of PV panel	0.156 m^2
Ambient temperature	25°C
Heat convection coefficient (h_{lower})	3.06 W m^{-2} K^{-1}
Length of the fin (l)	0.15 m
Width of the fin (w)	0.31 m
Thickness of fin (t)	0.001 m
Material's thermal conductivity (k)	237 W m^{-1} K^{-1}
Number of fins	21
Finned area	1.56 m^2
Unfinned area	0.15 m^2
Heat rate from the finned area (q)	110.8 W
Heat rate from the unfinned area (q)	10.117 W
Backside temperature of PV panel	47°C
Fin's cross-sectional area (A_{cs})	0.00031 m^2
The effectiveness of fin (ε_f)	11.455
The efficiency of the fin (η)	84.2%

2.5. Selection of Fins' Material. There were many factors considered when selecting the fins' material to guarantee maximum heat conduction through the fins. Those factors involved weight, thermal conductivity, and cost. Table 3 shows the benefits and drawbacks of three main and available materials: iron, aluminium, and copper; based on the table, aluminium was preferred to the other materials because of its good thermal conductivity, light weight, and medium cost. Therefore, a rectangular aluminium fin was designed.

3. Experimental Setup

The experimental investigation aimed at evaluating the PV panel after having been fitted with heat-extraction fins and later with fins and repurposed materials, as illustrated in Figure 2. The new PV cooling system's effects on the electrical performance of a PV panel and its efficiency were assessed. The PV panel's electrical performance is commonly determined according to the standard test conditions (STC) that correspond to 1000 W m^{-2} and 25°C cell temperature, with a reference solar spectral irradiance called Air Mass 1.5, as defined in IEC 60904-3 [26]. The testing conditions, including the nominal operating cell temperature (NOCT), STC, high-temperature condition, and low irradiance condition, together with irradiance and temperature measurement procedures are determined by this standard. Controlled indoor test conditions were preferred to fluctuations in temperature and to enable the repeatability of tests. A solar simulator was used to mimic solar irradiance for the indoor testing.

3.1. Solar Simulator. A locally designed solar simulator, shown in Figure 3(a), was utilized covering an area of $2 \times 2\,m^2$ using thirty-six 1000 W tungsten halogen lamps with a colour temperature of 3000 K.

3.2. PV Panel. A 30 W PV panel, shown in Figure 3(b), was first tested as is in the solar simulator. Then, it was fitted with aluminium perforated fins, as illustrated in Figure 3(c) (before attaching the fins) and in Figure 3(d) (after attaching the fins). Later, repurposed materials were added to the fin-fitted PV panel. The thermal behaviour was evaluated at the three stages to determine the fins' effects on the PV panel's temperature and efficiency, first without and then with repurposed materials. The data collected was used as a reference to compare the thermal and electrical behaviour of the PV panel at the different stages.

3.3. PV Analyser. The PVA-1000 PV Analyser Kit is a 1000-volt I-V curve tracer designed by Solmetric Corp., as shown in Figure 3(e). It has integral performance modelling and excellent wireless irradiance, and it detects tilt and temperature. This device can achieve measurement throughput along with accuracy. Both the I-V curve (current vs. voltage) and P-V curve (power vs. voltage) were measured using this device, and then a comparison was made between the measured results and the anticipated performance in terms of irradiance and PV panel temperature when carrying out the I-V measurement. The I-V unit communicated with the data acquisition computer wirelessly.

3.4. Measuring and Monitoring Devices. The ambient temperature, as well as the PV panel's temperature, was measured through the application of a Type K thermocouple (SE029) exposed junction and a 0.2 mm PTFE insulated twisted pair conductor. The thermocouples were positioned on the item's surface to measure its temperature. Consequently, the measured temperature was a mixture of the surface and the ambient temperatures. The measurements of the thermocouples were automatically recorded via a Pico Technology Environment Quad Temperature Converter together with a Pico Technology Environment DataLogger. The distribution of thermocouples is shown in Table 4. The device used to measure radiation was a silicon cell pyranometer (SP-212) with ±5% accuracy. The measurements of the pyranometer were automatically recorded by a Pico Technology Environment DataLogger.

4. Results and Discussion

All measurements were conducted in a laboratory setting to mimic the behaviour of the sun on a typical day; when the sun rises, its irradiance is low and when it is at its hottest, its irradiance reaches its peak and then starts to decrease until it diminishes. Hence, the PV panel was placed under the solar simulator with 500 W m^{-2} irradiance to simulate solar radiation in the morning (8 a.m.). The solar simulator's temperature started to rise gradually, and as it became stable, the irradiance of the solar simulator was adjusted to 750 W m^{-2}, late morning (10 a.m.). Similarly, when the temperature was stable once again, the irradiance was adjusted to 1000 W m^{-2}, noon (12 p.m.). Once the temperature reached a steady state, the irradiance was adjusted back to 750 W m^{-2}, afternoon (2 p.m.). Finally, irradiance was dropped to 500 W m^{-2}, late afternoon (4 p.m.). All

Table 3: Merits and demerits of common fins' materials.

	Advantages	Disadvantages
Aluminium	Relatively lightweight material (density = 2702 kg m^{-3}) Corrosion-resistant material Relatively high thermal conductivity Flexible and easy-to-install material	Relatively high cost
Copper	A high thermal conductivity of 401 W m^{-1} K^{-1} Corrosion-resistant material	Relatively heavyweight material (density = 8933 kg m^{-3}) High cost
Iron	Low cost	Relatively low thermal conductivity Corrosive material Heavyweight material (density = 7870 kg m^{-3})

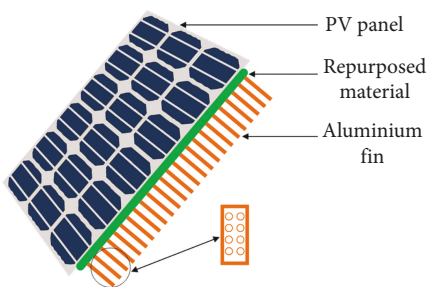


Figure 2: Schematic of a PV panel fitted with repurposed materials and fins.

tests were conducted under identical conditions and no wind speed.

4.1. As-Is PV Panel. The surface temperature and the output power of the PV panel measurements were recorded at different trials and consistently resulted in similar outcomes. The PV panel's surface temperature increased with the rise in solar irradiance until it reached a steady maximum of 106°C at 1000 W m^{-2}. As expected, the PV panel's output power increased with the increase in solar irradiance. Figure 4(a) shows the PV panel's temperature consistency over three trials, and Figure 4(b) shows the average surface temperature and the average output that were used for comparison.

4.2. Modified PV Panel. The PV panel was fitted with perforated aluminium fins as illustrated in Figure 3(d), and the thermal and electrical properties were measured. 19 cylindrically shaped wraps of ground HDPE grains weighing 70 mg each with an average diameter and height of 4.07 mm and 3.24 mm, respectively, were stuffed between the backside of the PV panel and the fins; two wraps are shown in Figure 5(a) before attachment to the PV panel. Plastic bags (PBs), as shown in Figure 5(b), were folded in a way that closely resembles the HDPE wraps and replaced HDPE wraps to evaluate their thermal and electrical effects on the PV panel.

The results in Figure 6 show that a significant drop in temperature occurred when the PV panel was modified. The as-is PV panel's surface temperature dropped by 23%, 22.7%, and 22% for the PV panel modified with fins, fins +HDPE, and fins+PBs, respectively, at a solar irradiance of 1000 W m^{-2}. Inversely, the as-is PV panel's output power increased with the cooling modifications by 11.5%, 12.1%, and 11.6% for the PV panel modified with fins, fins+HDPE, and fins+PBs, respectively, at a solar irradiance of 1000 W m^{-2}. For the other solar irradiance values, the trend was similar for the PV panel's surface temperature. As for the output power, the highest increase was recorded at 1000 W m^{-2} and was maintained, albeit at lower percentages, as the solar irradiance values dropped. As expected, less heat was received at lower solar irradiance values reducing the increase in output power compared to that observed at the maximum irradiance of 1000 W m^{-2}.

The certainty and reproducibility analyses were considered. The maximal difference in temperature measurements between the tests was 1.7°C, and the relative error between them was 1.6%. As a result, no corrections were required to determine the fins' effects on temperature. The maximum error for the measured PV panel was 2.4% with a maximum relative uncertainty of 0.32.

4.3. The Efficiency of As-Is and Modified PV Panels. The efficiency was calculated according to equation (9). The three different modifications that were applied to the PV panel all yielded higher efficiency than the unmodified one. The highest increase in efficiency was recorded at a solar irradiance of 1000 W m^{-2} where the as-is PV panel's measured efficiency was 8.67%, while the efficiency of the cooled PV panel with fins+PBs was 9.67% as shown in Figure 7. The highest overall efficiency, 10.15%, was measured at the morning solar irradiance of 500 W m^{-2} for the PV panel cooled with fins+HDPE. The efficiencies of the modified PV panels dropped as time went by, and solar irradiance values changed because the additives had retained some of the heat from the PV panel itself, essentially rendering them as thermal storage additives. Yet with that aforementioned decrease in efficiency, the modification aided in the reduction of the PV panel's surface temperature and resulted in higher efficiencies for all cooling cases.

$$\eta_{\max} = \frac{P_{\max}}{GA_c}. \tag{9}$$

5. Conclusions

The PV panels' conversion of solar radiation into electricity decreases with the rise in the panels' temperature. Therefore,

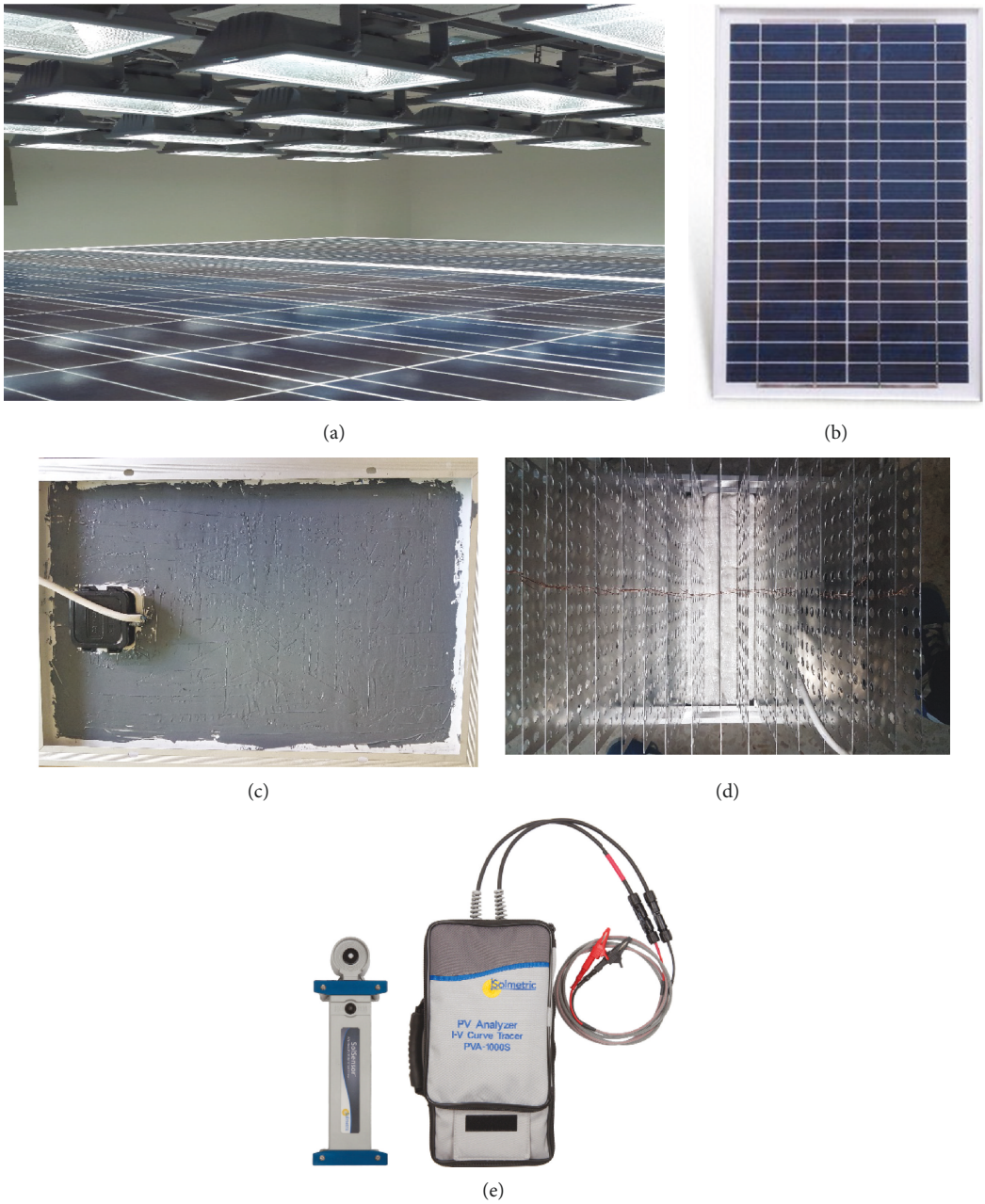


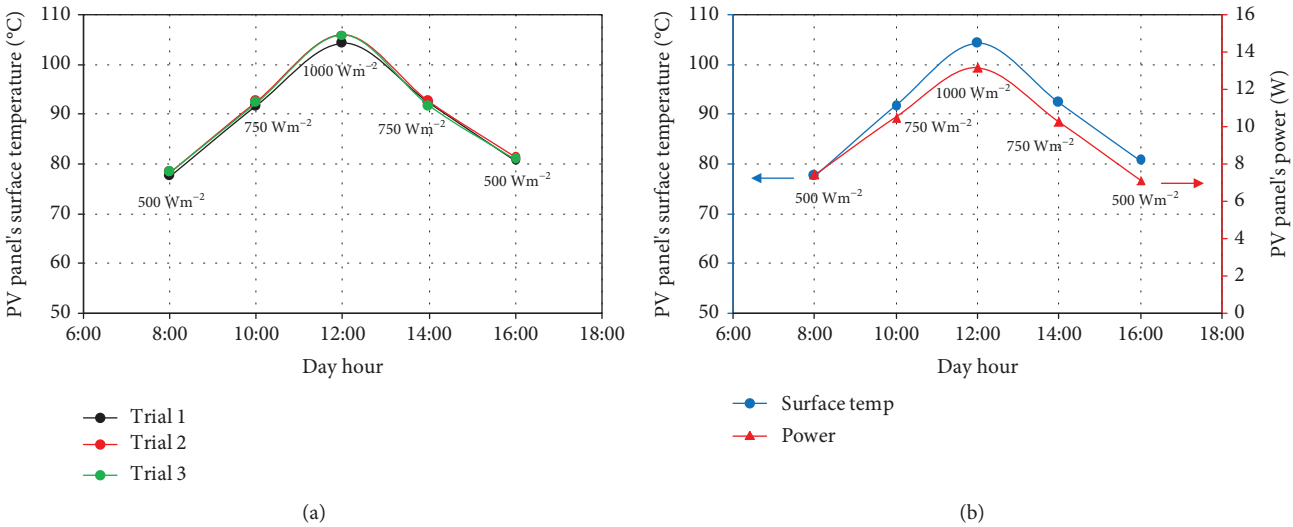
Figure 3: (a) Solar simulator, (b) PV panel used, (c) backside of the PV panel with paste for fin installation, (d) installed perforated aluminium fins, and (e) PV analyser.

Table 4: Distribution of thermocouples.

Thermocouple	Location
A	Ambient temperature
B, C	Backside temperature
D, E	Surface temperature
F	Frame temperature
J	Fin temperature
K	Repurposed materials temperature

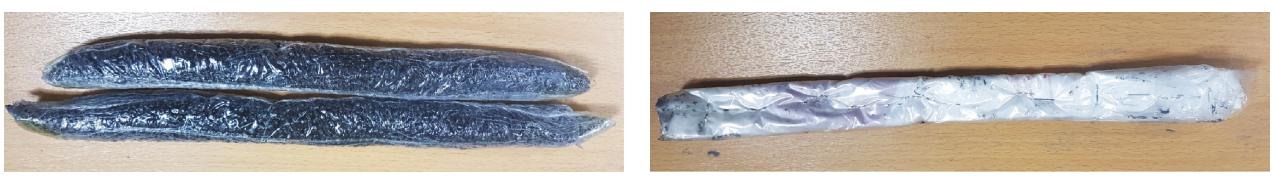
it is important to cool PV panels to maintain their rated conversion efficiencies. In this study, a hybrid passive cooling system was proposed that consisted of aluminium heat-extraction fins along with repurposed materials, i.e., HDPE and plastic bags. Recycling is not always an option, so repurposing certain materials can reduce nonbiodegradable waste and cool down PV panels.

The results obtained showed that modifying a PV panel with fins and repurposed materials reduced the temperature of the panel and increased its efficiency. Different solar irradiance values using a solar simulator, in a controlled laboratory setting, were utilized to mimic the sun's behaviour on a typical day. The highest temperature drop of 23.7°C at



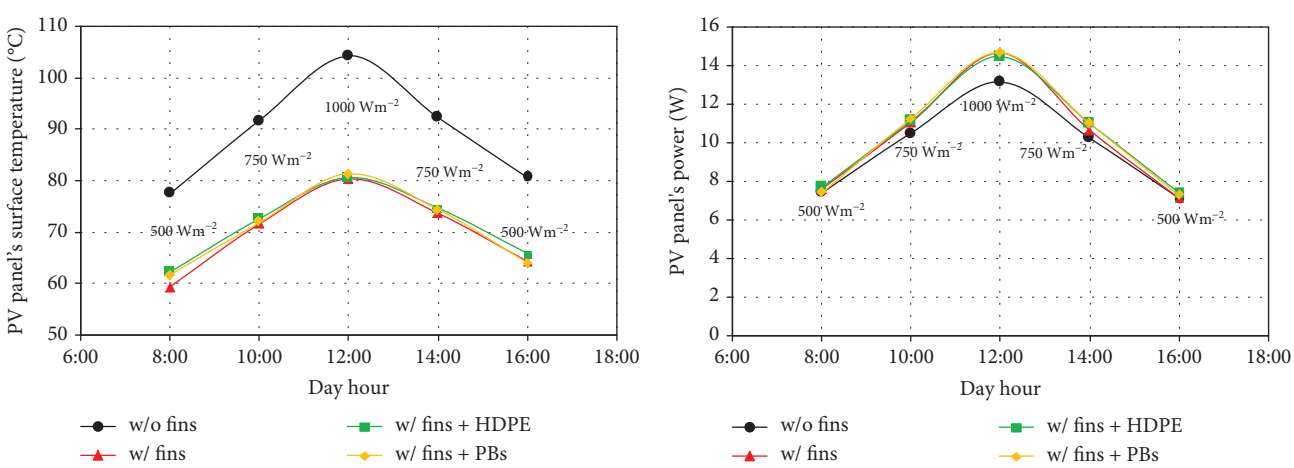
(a) (b)

Figure 4: Measurement of the PV panel at three different solar irradiances to simulate morning, late morning, noon, afternoon, and late afternoon (a) surface temperatures of three trials and (b) average surface temperature and average output power.



(a) (b)

Figure 5: Additives to the PV panel between its backside and the installed fins: (a) HDPE grain wraps and (b) folded plastic bags.



(a) (b)

Figure 6: Comparison of results for the as-is PV panel and the PV panel modified using fins, fins+HDPE, and fins+PBs for (a) a PV panel's surface temperature and (b) a PV panel's output power.

1000 W m^{-2} was observed when the PV panel was cooled with fitted fins and HDPE grain wraps. The highest output power was attained at 1000 W m^{-2} when the PV panel was cooled with fitted fins and folded plastic bags showing a rise of 11.6%. Lastly, the highest efficiency increase was recorded at 1000 W m^{-2} when fitted fins and folded plastic bags were used to cool down the PV panel; all those values were compared to the PV panel's measurements prior to making cooling modifications.

Passively cooling PV panels can effectively reduce their temperatures and enhance their thermal and electrical performance. Using repurposed materials that can otherwise be harmful to the environment if thrown away reduces the cost of raw cooling materials; at the same time passive

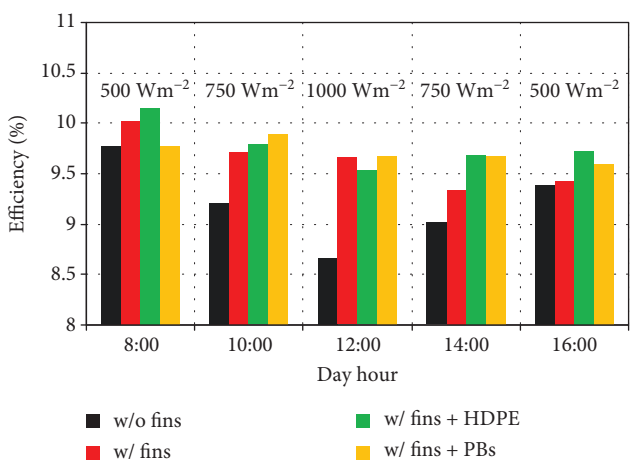


Figure 7: Measure efficiencies of the PV panel with no fins, fins, fins +HDPE, and fins+PBs.

cooling requires no energy input for the cooling process. The main drawbacks to the utilization of this repurposed material-based system are the collection of those materials before disposal and the possible labour cost of installation. However, if those disadvantages are addressed, the new PV panel cooling system could prove to be an important step in maintaining the rated efficiency and reducing negative environmental impact.

Nomenclature

A: Surface area of PV panel (m^2)
A_c: Cross-sectional area of fin (m^2)
$A_{c.b}$: Cross-sectional area of the fin at the base (m^2)
η_{max}: PV panel's maximum efficiency
ε_f: Fin's effectiveness
ε_{ground}: PV panel emissivity
ε_{pv}: Ground emissivity
G: Incident solar irradiance ($W\ m^{-2}$)
h: Conventional heat transfer coefficient around the fin ($W\ m^{-2}\ K^{-1}$)
h_{front}: Heat convection coefficient of the front of the PV panel ($W\ m^{-2}\ K^{-1}$)
h_{back}: Heat convection coefficient of the back of the PV panel ($W\ m^{-2}\ K^{-1}$)
HDPE: High-density polyethylene
k: Fin material's thermal conductivity ($W\ m^{-2}\ K^{-1}$)
L: Fin's length (m)
P: Fin parameter (m)
P_{max}: PV panel's maximum power output (W)
PV: Photovoltaic
PCM: Phase change material
$\varnothing$: PV panel's tilt angle (°)
Q_{conv}: Heat dissipation through convection (W)
$Q_{conv,front}$: Q_{conv} of the front of the PV panel (W)
$Q_{conv,back}$: Q_{conv} of the back of the PV panel (W)
q_{fin}: Fin's heat transfer rate rule
Q_{rad}: Heat dissipation through radiation (W)
$Q_{rad,front}$: Q_{rad} of the front of the PV panel (W)
$Q_{rad,back}$: Q_{rad} of the back of the PV panel (W)
T_{amb}: Ambient temperature (K)
T_{base}: Fin's base temperature (K)
T_{ground}: Ground temperature (K)
T_∞: Room temperature (K)
T_{pv}: PV panel temperature (K)
T_{sky}: Effective sky temperature (K)
σ: Stefan-Boltzmann's constant ($5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$).

Data Availability

The measured data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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