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Investigating the Impact of Water Cooling on the Performance of PV Modules in Palestine

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Abstract: The way that energy is produced across the world has altered recently. The use of renewable energy has increased because it does not harm the environment in the same way that other energy sources, such as fossil fuels, nuclear energy, etc., do because of the pollution they produce. In addition, the cost of producing renewable energy is lower than that of fossil fuels. Since the technologies used to convert solar radiation into a reliable power source have advanced significantly over the past few years and have demonstrated their high efficiency in energy production, demand for energy has recently increased significantly. Solar energy is one of the types of renewable energy. The most popular technique is photovoltaic (PV) modules since it generates energy directly. This study's main goal is to increase photovoltaic (PV) modules' operating capacity while also improving their overall efficiency. PV modules play a crucial part in the field of harvesting solar energy, serving as one of the most well-known ways to make use of the sun's unbounded potential as a leading source of renewable energy. The results of a thorough experimental investigation that examined the effects of PV module cooling and identified the most effective cooling techniques to optimize PV module performance within the particular context of Nablus City, located in Palestine, are revealed in this study. The horizontally divided box was discovered to be the most effective cooling technique, resulting in a 30% reduction in temperature and a 0.5% boost in efficiency.

Keywords: PV module, Photovoltaic, Palestine, PV cooling, PV efficiency.

Introduction

The expanding need for energy stimulates research into renewable energy for a variety of reasons, one of which is the negative environmental effect of fossil fuel usage; according to the Environmental and Energy Study Institute on the topic of fossil fuels posted in 2021, fossil fuels supply roughly 80% of the world's energy (1-2). The sun is the world's greatest and most important source of energy; solar energy is a free and clean resource that must be utilized, and photovoltaic (PV) modules may do so by directly creating electricity. Due to a lack of conventional energy sources and uncertain political situations. Palestine is completely reliant on neighboring nations for fuel. In 2014, the proportion of fossil energy utilized in Palestine was 68.6% (3, 4), on top of its 90% reliance on imported electricity (5). In 2020, the percentage of renewable energy in Palestine's energy consumption was 10.9% (6). Wood, solar energy, and olive cake are the three primary sources of renewable energy. Due to the political situation in Gaza, two areas with confirmed natural gas deposits have yet to be utilized; the reserves are estimated to be worth 1.1 trillion ft^3 (3, 7). Despite having 300 sunny days per year in Palestine PV systems are still underutilized (3, 7). In 2019 the amount of energy production from solar water heaters for water heating reached 1646 GW, as the percentage of families using solar heaters reached 56% in the year 2019, while the amount of electrical energy production from PV modules amounted to 120 GW (3, 7). The world needs more PV modules to generate more electricity, hence ongoing advances in the PV modules area are required to attain greater performance and generate more power at an acceptable initial cost. One of these advancements in PV systems is cooling, which aims to lower the temperature of the PV modules as much as possible. According to a study, the operating temperature of the PV modules influences the conversion process. The PV module's electrical efficiency and output power are linearly related to the operating temperature since the efficiency decreases with the increase in the module surface temperature (8-11).

Another article investigated cooling PV modules using a photovoltaic thermal system, which is one of the strategies for lowering the operating temperature of the PV module and improving the generated energy performance (12). Both studies found improvements in module performance and emphasized the necessity of such systems in areas with high sun intensity

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and high ambient temperatures (12,13). The papers examine elements of a photovoltaic/thermal (PV-T) system that are meant to cool the PV system, resulting in an increase in the PV modules' electrical efficiency (12,13).

It is clear that the operating photovoltaic temperature is a sensitive parameter, because of the determination of these characteristics, if the module temperature rises above the specified rated temperature which is usually between 40°C and 45°C results in decreasing the efficiency of the module the rise in temperature by one degree leads to a reduction in the efficiency by an estimated of (0.25%-0.45%), This percentage is considered high under the influence of high temperatures (14-16). The electrical efficiency of PV modules can be boosted by decreasing the temperature of the module, the module's high temperature is a problem module developers are interested in finding solutions to, such as air cooling and water cooling. Water is one of the most important methods of cooling PV modules because of the many properties water has, especially its heat capacity which is (4.180 KJ/kg.C°). Water cooling is divided into several methods, like; cooling the PV modules internally by pumping water into them, or externally by installing sprinklers on the glass surface of the module that cool the surface and get rid of any accumulated dust on it (13).

The use of PV cooling techniques in hot areas with high irradiance and ambient temperature has been extensively studied. This is more crucial to determine whether the PV cooling effect is perceptible at warmer temperatures (17). To optimize the energy yields obtained when running PV modules in Palestine weather, this experiment aims to determine if chilling PV modules with water can improve their operational characteristics.

Country	Main Findings
Saudi Arabia	Thermal efficiency was 65% while electrical efficiency was 13.7%. 2018 (18).
Indonesia	Efficiency improvement by 8.6%. 2019 (19).
Brazil	Increase by 22.69% in generated energy. 2017 (20).
Tampa	The input temperature was close to the ambient temperature, the output temperature was below 60 °C, and the thermal efficiency ranged from 6 to 46%. 2013 (21).
Singapore	The system's average thermal efficiency is 42.5%, while its average PV efficiency is 12%. 2013 (22).
Iran	The glazed photovoltaic/thermal system has better energy efficiency than the unglazed system. While the overall energy efficiency in a laminar regime is excellent, it is higher in a turbulent regime. 2016 (23).
Saudi Arabia	Operating temperature decreased to 20%, while electrical efficiency rose by 9%. 2013 (24).
Malaysia	The highest performance is presented by the spiral flow absorber. This led to a 13.8% PV efficiency, a 68.4% PVT efficiency, and a 54.6% thermal efficiency. Ranging from 79% to 91% efficiency at saving basic energy. 2014 (25).
Jordan	Increase in generated power by 5.77%, 2.14%, and 0.74% for (FN) PV, (N) PV, and finned PV respectively. (FN) PV has the lowest temperature of 31° followed by (N) PV and finally, the fined PV. 2022 (26).
Iran	Using steady-spray water cooling, pulsed-spray water cooling with DC=1 and 0.2, and air cooling with DC=1 and 0.2 enhances the solar panel's maximum electrical power production by about 33.3%, 27.7%, and 25.9%. 2021 (27).
Cyprus Greece	The system may provide 222-532 kWh of electrical energy depending on the location, and the solar contribution ranges from 29% to 72%. 2006 (28).
Poland	The temperature of the cooled PV decreased to 25°C while the temperature of PV non-cooled was 45°C and the power increased by 20.2 W/m^2. 2020 (17).
Cyprus	The system's mean annual efficiency grew from 2.8% to 7.7% on average and now provides 49% of a home's hot water needs, bringing the overall system's mean annual efficiency up to 31.7%. 2001 (29).
Saudi Arabia	The PV panel efficiency increased by 9% as a result of the module temperature dropping dramatically to around 20%. 2013 (30).
Brazil	With a surplus of 10.3%, electrical yield can recover. 2004 (31).
Jordan	System output increased by 15%. During dry and warm seasons produced energy increases by 5%. 2009 (32).
Iran	An improvement of 3.26%, 1.40%, and 1.35%, respectively, in the mean PV module efficiency, subsystem efficiency, and overall efficiency. 2009 (33).
Egypt	boosting efficiency by 12.5% while lowering the solar cell temperature by 10°C (from 45°C to 35°C). 2013 (34).
Saudi Arabia	PV panel temperatures were lowered by more than 20°C, while electrical efficiency rose by 14%. 2018 (35).
Saudi Arabia	From 71.2°C to 45.1°C in June and from 48.3°C to 36.4°C in December, the temperature dropped. The improvement in electricity efficiency was 35.5%. 2015 (36).
Iran	The energy efficiency for electrical, thermal, and total are increased to 12.3%, 49.4%, and 61.7%, respectively. 2019 (37).
Italy	28°C less module temperature and a 14% increase in module efficiency. 2019 (38).
Iran	In comparison to a design with no cooling system, the maximum produced power is raised by around 24.6% to 26.2%, and in comparison to paraffin wax, it is raised by 5.3% to 12%. 2019 (39).
Turkey China Saudi Arabia	The PV efficiency increased by 60% when using nanofluids in PVT, whereas PCM incorporation improved PVT efficiency by 32%. 2021 (40).
India	The output power increased to 20.9% in summer and to 18.32% in winter. Efficiency

Country	Main Findings
	increased to 52.70% in summer and 46.4% in winter. 2019 (41).
Brazil	The efficiency increases by 30%. 2020 (42).
Iran	Energy efficiency increased from 7.3% to 12.4%. Exergy efficiency increased from 13% to 19.6%. 2021 (43).
Croatia India	Electric power output increased by 16.3%. PV electrical efficiency increased by 14.1%. The photovoltaic temperature dropped from (54 to 24 °C.). 2016 (44).
Egypt	The PV module with cooling has a 19.8% efficiency compared to a 17.4% efficiency for the PV module without cooling, and its power rose by 14.1%. 2022 (45).
Iran	Power output rose by 21.2%, and the PV module's temperature dropped as well. 2021 (46).
Jordan	For backwater cooling and fins cooling, the daily energy recovered is increased by 10.2% and 7%, respectively. 2020 (47).
Jordan	The PV modules' electrical productivity and efficiency saw a roughly 14% increase. 2022 (48).

The objective of this study is to assess and choose the PV cooling technique that offers the maximum energy production intensity and is thus the most cost-effective. It is crucial to consider the discrepancy between a panel's nominal power, which is represented in kWp and is a standardized measure for all PV modules, and the power produced by a panel under actual conditions. Table 1 summarizes the results of scientific research related to PV cooling.

The electrical efficiency of the cooled PV module increased by (8.6-52.7%) and the amount of energy generated by (5-33.3%) compared to the uncooled PV module because the temperature of the cooled PV module was lower than the uncooled PV module (10-30°) C. The thermal efficiency of PVT systems, however, ranged from 6 to 64%.

In Palestine, solar energy is used in many applications, the most common one is a solar water heater which has been used since the mid-seventies of the last century. In this topic, Plans and studies have been established by the Palestine National Authority to boost the country's reliance on alternative energy sources to 10% during the following ten years (2015-2025) (5). For that PV cooling is an important subject to research. many studies conducted in Jordan which is close to Palestine and has similar climate conditions show that PV cooling is a valuable solution to decrease PV module temperature, which is the goal of this study.

The major objective of this study is to enhance the working capacity and overall efficiency of photovoltaic (PV) modules. PV modules are one of the most well-known ways to utilize the sun's limitless potential as a leading source of renewable energy, and they play a significant role in the field of collecting solar energy. This work presents the findings of a comprehensive experimental inquiry that investigated the impacts of PV module cooling and found the most efficient cooling strategies to enhance PV module performance in the specific environment of Nablus City, situated in Palestine.

Materials and Methods

Three boxes were made using galvanized steel (3 mm) thick and (35x29x5) cm in dimensions as shown in Figures 1, 2, and 3. A frame for the reference PV module was also made using galvanized steel (3 mm) thick as shown in Figure 4. The PV modules were placed at a 29° tilt angle on the rooftop of the Faculty of Engineering and Information Technology at An-Najah National University in Nablus – Palestine as shown in Figure 5 under Nablus climate conditions.

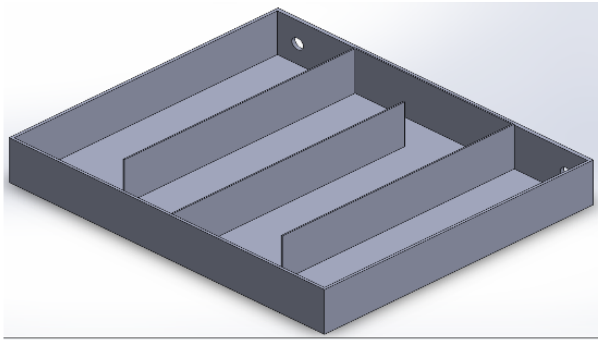

Figure (1): Horizontally divided box.

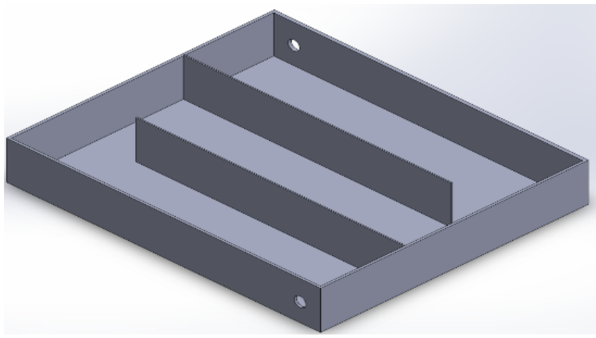

Figure (2): Vertically divided box.

The principle used in this system was dividing a box horizontally as shown in Figure 1 and vertically as shown in Figure 2. They were implanted into two PV modules; the first PV module had a horizontally divided box. The second PV module had a vertically divided box. The distance between the sections is equal. The goal of this design is to allow the water to stay in touch with the back surface of the PV module as long as possible to increase heat transfer from the PV module to the water as much as possible.

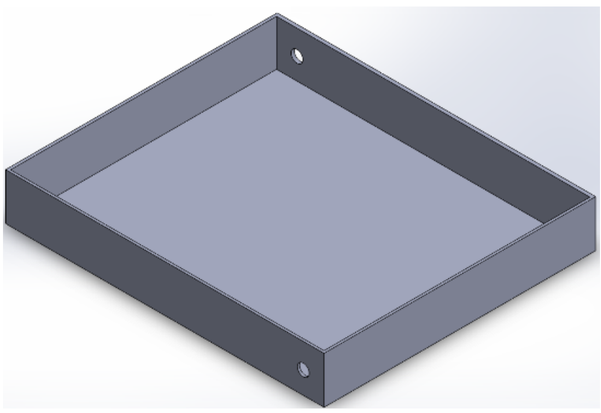

Figure (3): Box without fins.

The principle used in this system was installing a box at the back of the PV module as shown in Figure 3, which was completely full of water entering it, that allows the water to have contact with the PV module, and allow the water to stay in touch with the module long enough to effectively cool the module.

Figure (4): The frame used for the uncooled module.

The first PV module was installed without any cooling as shown in Figure 4 for one main purpose, to be used as a reference to compare it with other settings by measuring all the variables that can be recorded from the module under the experimental conditions. The module provided the output data like; voltage, current, module temperature, power, and irradiance, using this data, the efficiency of the module was calculated. Four identical PV modules of 10W and (34X24X1.7) cm dimensions as shown in Figure 6, were used in this project and the voltage, current, power, and temperature were measured.

Figure (5): The experimental setup used in this study.

The fill factor (FF) can be calculated from the following equation:

$$FF = (I_{mpp} * V_{mpp})/(I_{sc} * V_{oc}) \quad (1)$$

Where:

FF: Fill factor

I_{mpp}: Maximum power point current.

I_{SC}: Short circuit current.

V_{mpp}: Maximum power point voltage.

V_{OC}: Open circuit voltage.

The efficiency was calculated using the following equation

$$\eta = P_{out}/P_{in} * 100\% \quad (2)$$

Where:

P_{out}: Output power.

P_{in}: Input power.

The input power was estimated utilizing the following equation:

$$P_{in} = A * Irr \quad (3)$$

Where:

A: Module area.

Irr: Irradiance

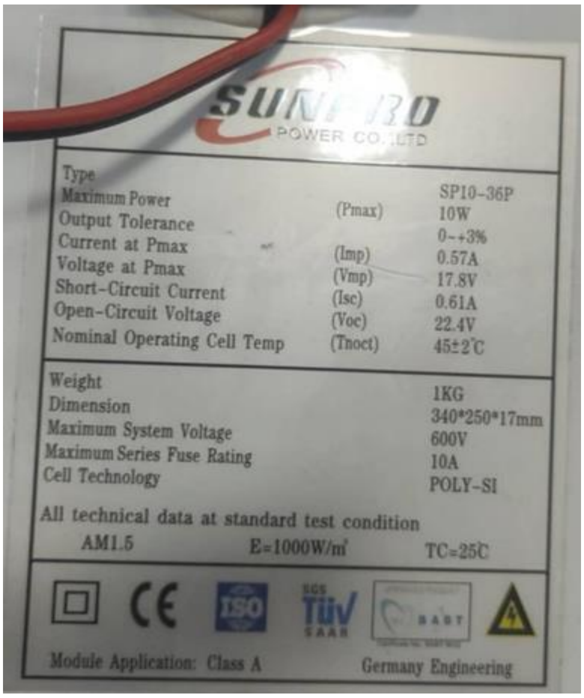

Figure (6): The data sheet for the PV module used.

Results and Discussion

The reading for temperature, solar radiation, and power was taken during the month of December 2022 in the following hours (9 AM – 1 PM). The temperature readings were taken for the four PV modules using an infrared thermometer 42510, the data shows that the uncooled module has the highest temperature as expected, followed by the vertically divided and the box with no addition, while the horizontally divided has the lowest temperature.

Figure 7 shows that the average daily temperature for the uncooled module is higher than the remaining modules by approximately (5-10)°C, the highest temperature recorded was for the uncooled module which is 41.4°C, and the lowest value was for the horizontally divided box which is 12.6°C.

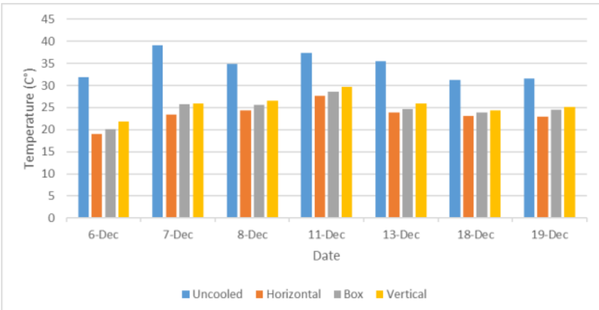

Figure (7): The average daily temperature for the four PV modules.

The solar radiation readings were taken using an IV-400 Device for the four PV modules, the results show that the values are close and often the value of the solar radiation for the cooling modules is higher than the value of the solar radiation for the uncooled. Figure 8 shows that the average daily irradiance for the uncooled module is sometimes equal to the remaining modules and sometimes a little higher. The highest solar radiation recorded was for the vertically divided box with a value of 934 W/m^2 at 11 AM, and the lowest solar radiation was for the unchanged box with a value of 436 W/m^2 at 9 AM.

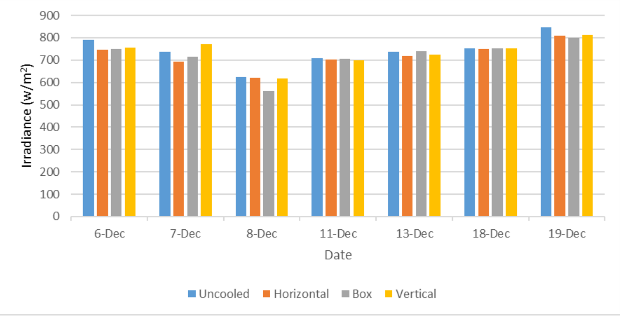

Figure (8): The average daily irradiance for the four PV modules.

The power readings were taken using the IV-400 device, the results show that the power values are either equal for all modules or the colled modules have a higher power than the uncooled module. But only with a difference of 1W.

Figure 9 shows that the average daily power for the four modules is either equal or with a small variation. The highest output power recorded was equal for all the modules with a value of 8 W, and the lowest output power was also equal for all modules with a value of 5 W.

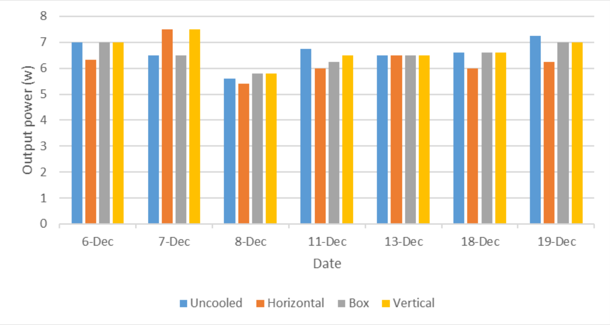

Figure (9): The average daily output power for the four PV modules.

V_{oc}, I_{sc}, and fill factor (FF) readings were taken using the IV-400 device, and the results show that V_{oc} values for the four modules vary between (19.9-20.8)V. The module that has the greatest value varies depending on whether it is cooled or not. The production capacity of the PV module is reduced as a result of the PV module's voltage steadily declining as the temperature rises. Moreover, the findings demonstrate that the Isc values of cooled modules are often greater than those of uncooled modules. It can be concluded that FF values vary from 0.6-0.77, and the values of the uncooled modules are often greater than those of the cooled modules.

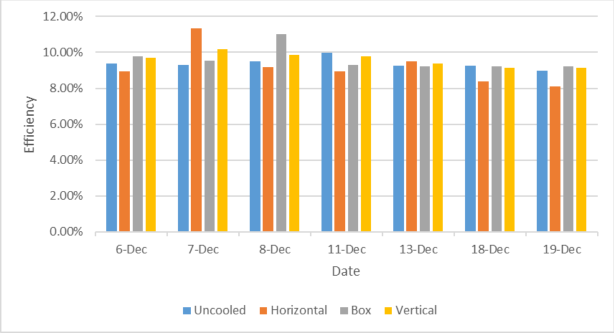

Figure (10): The average daily efficiency for the four PV modules.

Figure 10 shows that the efficiency values for the cooling modules are higher than the uncooled module, except for the 11th of December and 18th of December where the uncooled module had a slightly higher efficiency.

The study's findings demonstrate a large temperature decline in the horizontally divided water-cooled enclosure, with a shocking 30% fall in surface temperature. The enclosure without fins only succeeds in lowering the surface temperature by 21.5%, but the enclosure with vertical divides achieves a significant 22.5% decline. Despite these substantial temperature decreases, the efficiency increase is only 0.5%, which is quite modest.

Conclusion

This comparative experimental study examines the effect of water cooling on the electrical productivity and efficiency of PV modules in December 2022 in the climatic conditions of Nablus. Four identical PV modules were purchased for this test. One featured three distinct forms of water cooling whereas the other did not. The modules were tested outdoors simultaneously. The first module was fitted with a horizontally divided box, the second with a vertically divided box, and the third with an unchanged box, all made from galvanized steel (3 mm) thick and (35x29x5) cm in dimensions. The operating temperature of a photovoltaic (PV) module is the key determinant of its electrical output and efficiency. The results of this study show that the horizontally divided water-cooled enclosure has a significant temperature drop, with a startling 30% fall in surface temperature. Following closely after, the enclosure with vertical divisions shows a notable 22.5% drop in surface temperature, whereas the enclosure without fins only manages to lower the surface temperature by 21.5%. Despite these significant temperature drops, the measured improvement in efficiency only amounts to a negligibly small 0.5%. This minor gain can be ascribed to the PV modules used in our experiment having a relatively low power rating of 10 watts, which have intrinsic restrictions. Due to the module's naturally reduced power output, the effect of temperature reduction on total efficiency is thus somewhat limited.

While experimenting there was a problem with the increase in water temperature. Since the results mentioned in this experiment were obtained in winter. The water temperature did not increase in a way that affected the results. Future work will take place in summer to obtain better results in higher ambient temperatures and higher irradiance. For that the water will be cooled using a chiller, better equipment with instant data recording will be used and the period during which the data will be collected will increase. The power of the PV modules used in this experiment is 10W. Chosen to reduce cost. In future work, PV modules with higher maximum power will be used.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The authors confirm their contribution to the paper as follows: study conception and design: Ramez Abdallah, theoretical calculations and modeling: Ramez Abdallah, Aiman Albatayneh; data analysis and validation Ramez Abdallah, Aiman Albatayneh. draft manuscript preparation: Abdulaziz Sheikh Ali, Aseel Nasassrah, and Mahmoud Kashef. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

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List of Abbreviations

PV: Photovoltaic

PV-T: Photovoltaic/thermal

FF: fill factor

I_{mpp}: Maximum power point current.

I_{SC}: Short circuit current.

V_{mp}p: Maximum power point voltage.

V_{OC}: Open circuit voltage.

η: Photovoltaic efficiency

P_{out}: Output power.

P_{in}: Input power.

A: Module area.

Irr: Irradiance

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