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A Comparative Analysis of the Efficiency of Monocrystalline and Polycrystalline Photovoltaic Modules: CTI-80 and YHM-205-27P

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ABSTRACT

This paper compares the theoretical and actual efficiency of two solar panels, CTI-80 and YHM-205-27P, using Engineering Equation Solver (EES) software. The comparison is based on specific parameters, and the rationale behind their selection is explained. The results show that the CTI-80 panel is more efficient than the YHM-205-27P panel due to the monocrystalline solar cells, which provide more efficiency than polycrystalline solar cells. Although the YHM-205-27P panel has more solar cells, the CTI-80 panel is still more efficient. The temperature affects the theoretical efficiency, as it assumes that all photons have the energy to break the bond in the n-type layer, while in reality, not all photons have sufficient power. Both theoretical and actual efficiencies are lower than the theoretical efficiency due to temperature. The conclusion emphasizes the importance of choosing the right type of solar panel for a particular application based on its efficiency and recommends using monocrystalline solar cells for higher efficiency.

1. INTRODUCTION

The detrimental impact of fossil fuels on global, economic, and environmental aspects poses significant threats to our planet. These threats manifest predominantly through harmful effects such as global warming, which contributes to an increase in the average planetary temperature. Subsequent repercussions include the expansion of desert regions, melting of polar ice caps, and a rise in sea levels. Additionally, the consumption of these conventional resources results in an escalation of gaseous pollutants such as carbon dioxide, a key player in the greenhouse effect. As reported by NASA, the concentration of atmospheric carbon dioxide has reached alarming levels of 411 parts per million [1]. In response to these challenges, scientists and engineers have been propelled to explore alternatives to traditional energy resources, leading to the emergence of renewable energy technologies. A significant stride in this direction was made in 1981 when the United Nations, during its thirty-third session, established a global conference for discussions on renewable energy resources [2]. Since then, a substantial expansion in the utilization of renewable energy resources has been observed [3]. This paper compares the efficiency of two solar panels, CTI-80 and YHM-205-27P, in converting sunlight into electrical energy. Solar energy is a sustainable and renewable energy source that has been widely used in Libya. The comparison of solar panels is crucial for choosing the right type of solar panel for a particular application.

When comparing two types of solar panels, such as the CTI-80 and YHM-205-27P, it is important to understand their advantages and disadvantages to make an informed decision. Here is a brief comparison of the two panels:

CTI-80: Advantages: High efficiency: CTI-80 panels are known for their high conversion efficiency, which means they can generate more electricity from the same amount of sunlight compared to other panels. Durability: These panels are typically built with high-quality materials and advanced manufacturing techniques, making them durable and long-lasting. Temperature tolerance: CTI-80 panels have good temperature tolerance, meaning they can perform well even in high-temperature environments, which is particularly beneficial in hot climates. Disadvantages: Higher cost: Due to their advanced technology and high efficiency, CTI-80 panels often come with a higher price tag compared to some other types of solar panels. Size and weight: These panels may be larger and heavier compared to other options, which can make installation more challenging, especially in limited space or on rooftops.

YHM-205-27P: Advantages: Cost-effective: YHM-205-27P panels are known for their cost-effectiveness, making them a popular choice for residential and commercial installations. Versatility: These panels are available in different sizes and configurations, allowing for flexibility in installation options. Good low-light performance: YHM-205-27P panels have good low-light performance, meaning they can generate electricity even in cloudy or shaded conditions. Disadvantages: Lower efficiency: Compared to higher-end panels like CTI-80, YHM-205-27P panels may have lower conversion efficiency, resulting in a slightly lower power output. Moderate durability: While YHM-205-27P panels are generally reliable, they may not be as durable or long-lasting as some higher-end panels, and their lifespan may be slightly shorter. Understanding these advantages and disadvantages is crucial because it allows consumers to consider factors such as budget, space availability, desired efficiency, and specific environmental conditions. By comparing the characteristics of these panels, individuals can make an informed decision based on their unique requirements and priorities.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

Renewable energy encompasses a diverse range of sources, including energy derived from the sun. This energy can be utilized in various ways. When analyzing the spectrum of the sun, it becomes evident that it has different regions, and the type of radiation changes as it passes beyond certain wavelengths. Therefore, as one moves down the solar spectrum curve, the use of solar energy also changes depending on the type of wave. One application of solar energy is using visible light from the sun, which has wavelengths ranging from 0.38 to 0.78 micrometers, to generate electricity using solar cells. Solar cells consist of several layers, including an anti-reflection layer, front and back contact layers, and N-type and P-type layers, which generate an electric current when exposed to photons. Solar cells consist of several layers of glass and an anti-vibration layer made of silicon dioxide, a front contact layer connected to terminals, an N-type layer, a P-type layer, and finally a back contact layer connected to terminals [4, 5]. N and P Junctions are the main components of solar cells that play a major role in generating electricity. To form both N and P contacts, semiconductors such as silicon are doped with other elements such as boron and phosphorus. The N-type contact consists of a crystal of silicon doped with phosphorus, which contains additional free electrons, while the P-type contact is a crystal of silicon doped with boron, which lacks an electron. When these two contacts are connected together, a thin layer called the N-P junction is formed in the middle of this contract, and an internal electric field is formed that prevents electrons from moving to the positively charged holes in the P-type layer. However, when a photon collides with the solar cell, it increases the electric voltage for electrons and holes to move across the N-P junction. If the two contacts (N and P) are connected together through a load, the circuit is closed, and the electrons complete the cycle [6]. A small-scale solar photovoltaic powered reverse osmosis purification system has been proposed to provide drinking water for domestic use or small groups in remote areas [7]. The results showed that it requires an energy consumption of approximately 216.5 watts with battery storage of up to about 38 hours, enabling the unit to operate continuously after sunset. A fan-cooling-based solar-powered ventilation technology was considered to provide ventilation under the solar unit [8]. There are different types of solar cells; however, in this study, a YHM-205-27P solar cell and a CTI-80 solar cell were evaluated in terms of theoretical and actual efficiencies. The reason for choosing the YHM-205-27P and CTI-80 solar cells is the availability of information on the I-V curve for different solar irradiance, in addition to specification tables. The YHM-205-27P solar cell, as shown in Figure 1, is a multi-crystalline solar cell, while the CTI-80 solar cell is a single-crystal type and is manufactured by Carmanah Technologies, as shown in Figure 2. A single-crystal means that the cell is made of monocrystalline, which is formed from silicon ingots [9, 10].

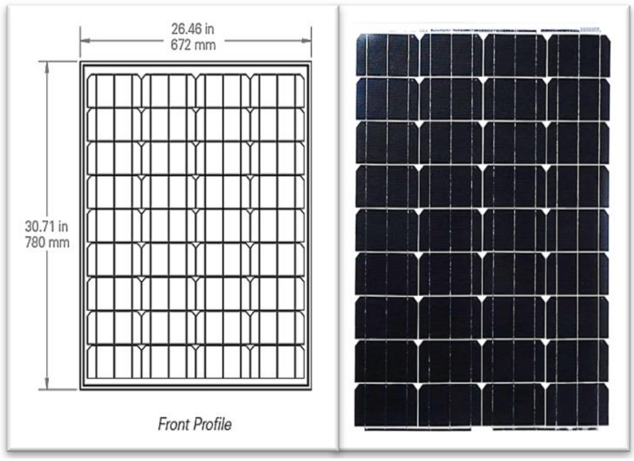

Figure 1. Polycrystalline YHM-205-27P module

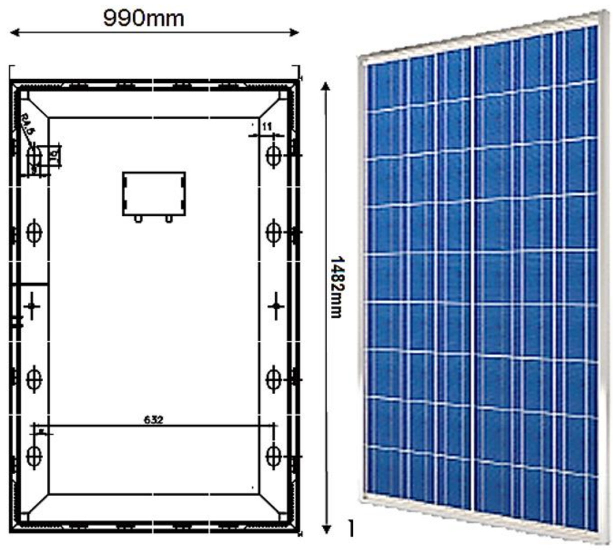

Figure 2. CTI-80 solar module

3. THE AIM AND OBJECTIVES OF THE STUDY

The aim of the study is comparison of the performance of several photovoltaic module technologies.

4. MATERIALS AND METHODS

The panels are tested outdoors, so the systems are exposed to wind and moisture as well as dust from daily vehicle movements or due to sand and dust storms. The photovoltaic system used is a fixed structure of two panels, one containing 36 cells and the other 54 photovoltaic cells. Commercially available photovoltaic technologies consist: monocrystalline silicon, and polycrystalline silicon. The main performance parameters of the PV modules (I-V curve, power, current and voltage at the maximum power point, open circuit voltage, short circuit current, efficiency, etc.) as well as solar radiation, ambient temperature and temperature of the modules were recorded every 5 minutes. By the central data recording computer to achieve synchronous data collection. The specifications of the photovoltaic modules are given in Table 1 and Table 2. To evaluate the performance of solar panels some specifications are needed to calculate both the theoretical and actual efficiencies, as listed in Table 1 for YHM-205-27P [10] and Table 2 for CTI-80 [11].

Table 1. YHM-205-27P solar module specifications

Rated Power (Pmax)	205 W
Maximum Power Voltage (Vmp)	26.3 V
Open Circuit Voltage (Voc)	33.6 V
Maximum Power Current (Lmp)	7.79 A
Short Circuit Current (Isc)	8.24 A
Dimensions	1482 × 990 × 50 mm^3
Cell Type	Polycrystalline

Table 2. CTI-80 solar module specifications

Rated Power (Pmax)	80 W
Maximum Power Voltage (Vmp)	18.4 V
Maximum Power Current (Lmp)	4.35 A
Open Circuit Voltage (Voc)	22.8 V
Short Circuit Current (Isc)	4.60 A
Cell Type	Monocrystalline
Module Efficiency	15.9%
Max System Voltage	1000 VDC
Dimensions	780×672×35 mm^3

The maximum power voltage and current power values for 600, 800, and 1000 W/m^2 for CTI-80 and YHM-205-27P are shown in Table 3 and Table 4 respectively.

Table 3. Maximum power voltage and maximum power current for CTI-80 module

Solar Radiation (W/m²)	Vmp (V)	Imp (A)
1000	18.4	4.35
800	17.73	3.64
600	16.90	2.75

Table 4. Maximum power voltage and current power maximum for YHM-205-27P module

Solar Radiation (W/m²)	Vmp (V)	Imp (A)
1000	26.3	7.79
800	26.21	6.40
600	26.10	4.70

4.1 EES programming

In the field of renewable energy, solar panels are widely used as a source of clean and sustainable energy. To assess the performance of different types of solar panels, it is important to compare their theoretical and actual efficiencies under different operating conditions. This comparison can be done using a variety of methods, including simulation and experimentation. One commonly used method is to utilize an Engineering Equation Solver (EES) program, which is a powerful tool for solving complex equations and performing thermodynamic and heat transfer analyses.

In this study, an EES program was used to compare the theoretical and actual efficiencies of two different solar panels, the YHM-205-27P and CTI-80. The calculations were all done at specific conditions, including irradiance values of 600, 800, and 1000 W/m² and a cell temperature of 77°F (25°C). The inputs required for these calculations include information on the spectral response of the solar cells, the temperature of the cells, and the irradiance level. The outputs of the EES program include the theoretical and actual efficiencies of the solar cells.

One major advantage of using an EES program for this type of comparison is the ability to solve complex equations quickly and accurately. The program can handle large sets of data and perform calculations under a range of different conditions. Additionally, the program allows for easy modification of input parameters and can quickly generate new results based on these modifications. This makes it an ideal tool for comparing the performance of different solar panels under different operating conditions.

4.1.1 Governing equations

The actual efficiency is calculated as the ratio between the actual peak power generated from a solar panel and the incident solar radiation on the surface area of the solar panel, shown in Eq. (1) [12, 13].

$$\eta_{act} = \frac{P_{max(actu)}}{P_{inc} \times A} \times 100 \quad (\%) \tag{1}$$

where,

$P_{max(actu)}$: Actual maximum power of the solar cell.

P_{inc}: Incident solar radiation.

A: Surface area of solar panel.

The theoretical efficiency is calculated as the ratio between the theoretical peak power generated of the solar panel and the incident solar radiation on the surface area of the solar panel, as noticed in Eq. (2).

$$\eta_{theo} = \frac{P_{max\,theo}}{P_{inc} \times A} \times 100 \quad (\%) \tag{2}$$

where,

η_{theo}: Theoretical efficiency

$P_{max\,theo}$: Theoretical maximum power

The theoretical generated power of a solar panel is calculated by the normalized voltage multiplied by the short circuit current times the theoretical fill factor, as seen in Eq. (3).

$$P_{\max(\text{theo})} = V_{oc} \times I_{sc} \times F.F_{theo} \quad (W) \tag{3}$$

where,

V_{oc}: Open circuit voltage

I_{sc}: Short circuit current

$F.F_{theo}$: Theoretical fill factor

The actual generated power of a solar panel is calculated by the open circuit voltage, short circuit current, and the actual fill factor, as seen in Eq. (4).

$$P_{\max(\text{act})} = V_{oc} \times I_{sc} \times F.F_{act} \quad (W) \tag{4}$$

where,

V_{oc}: Open circuit voltage

$F.F_{act}$: Actual fill factor

The actual fill factor can be calculated from Eq. (5).

$$F.F_{act} = \left(\frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}\right) \tag{5}$$

where,

V_{mp}: Maximum voltage power.

I_{mp}: Maximum current power.

The theoretical fill factor can be calculated from Eq. (6).

$$F.F_{theo}\left(\frac{V_{ocn} - Ln(V_{ocn} + 0.72)}{V_{ocn} + 1}\right) \qquad (6)$$

The normalized voltage is calculated as a ratio between the electron charge (q) times the open circuit voltage divided by the ideality factor (n) times Boltzmann constant (K) times the ambient temperature (T), as shown in Eq. (7). The normalized voltage is a good approximation of the ideal value of F.F for V_{ocn}>10. For a solar cell with an ideal diode behaviour the ideality factor n=1 [14, 15].

$$V_{ocn} = \frac{q}{nKT} \times V_{oc} \quad (V) \qquad (7)$$

where,

V_{ocn}: Normalized voltage.

q: Electron charge.

n: Ideality factor.

K: Boltzman constant.

T: Ambient temperature.

Normalized voltage in relation to semiconductor devices, such as solar cells, the ideality factor plays a significant role in its calculation. The ideality factor, often denoted as "n", represents the deviation from ideal behavior in a diode or a solar cell. The ideality factor is a parameter that quantifies the non-ideal characteristics of a device. In an ideal diode or solar cell, the current-voltage (I-V) curve would follow the theoretical Shockley diode equation, which assumes perfect behavior [16]. However, in reality, various factors contribute to deviations from this ideal behavior. The ideality factor takes into account these non-idealities, such as recombination, series resistance, and deviations from the ideal electron and hole transport. It is used to model and account for these deviations in the I-V characteristics of a diode or a solar cell. When calculating the normalized voltage in the context of solar cells, the ideality factor is used to adjust the voltage values to account for the non-ideal behavior. By normalizing the voltage, it allows for a fair comparison between different devices or experimental conditions. The significance of the ideality factor lies in its ability to provide insights into the underlying physical processes within a diode or a solar cell. It helps researchers and engineers understand the mechanisms that influence device performance and efficiency. The ideality factor is often determined experimentally by fitting measured I-V curves to the theoretical Shockley diode equation modified by the ideality factor term. The ideality factor is an important parameter in the calculation of normalized voltage as it captures the non-ideal behavior of a diode or a solar cell, allowing for accurate analysis and comparison of device characteristics.

5. RESULTS AND DISCUSSION

All aforementioned equations were programmed for both solar panels into EES in order to run the program and calculate the values of both actual and theoretical efficiencies for both panels, as shown in Figure 3 and Figure 4.

Using the program of EES to solve the equations, all results of actual and theoretical efficiencies for YHM-205-27P in different solar irradiance solar panel are included in Table 5.

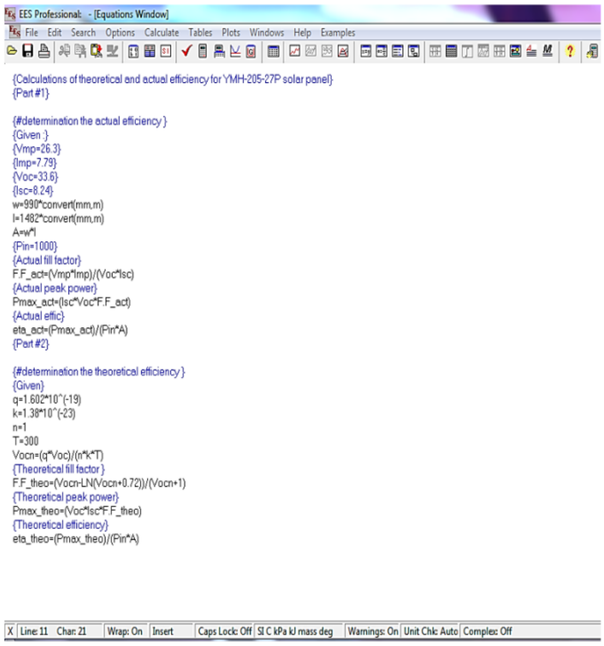

Figure 3. Programming the equations in EES for CTI-80 module

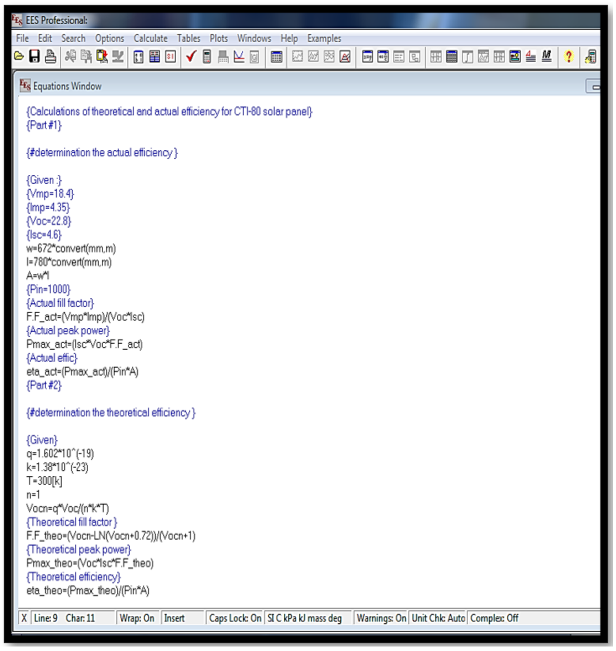

Figure 4. Programming the equations in EES for YHM-205-27P module

As shown in Table 5, both the theoretical and actual efficiencies of the YHM-205-27P solar module decrease as the solar incident power decreases. Figure 5 shows a comparison between incident power radiation and the efficiencies. By observing the curves of theoretical and the actual efficiencies, it is clear that they reach their maximum values when the solar incident power reaches 1000 W/m^2. While when the solar incident power reaches 600 W/m^2, both efficiencies hit their lowest values.

In addition, the YHM-205-27P solar panel with 600 W/m^2 incident solar radiation converts 13.9% of received photons to electrical power in actual manner. However, in case of the theoretical efficiency with 1000 W/m² incident radiation, the theoretical efficiency is 18.7%. That means, about 18.7% of the received radiation is converted to electricity.

Table 5. Results of the YHM-205-27P solar panel in different solar radiation

Trials	Pin (W/m^2)	Voc (V)	Isc (A)	Vmp (A)	Imp (A)	Vocn (V)	$Pmax_{act}$ (W)	$Pmax_{theo}$ (W)	$F.F_{act}$	$F.F_{theo}$	η_{act}	η_{theo}
Run1	1000	33.6	8.24	26.3	7.79	866.8	204.9	274.4	0.74	0.9911	0.1396	0.187
Run2	955.6	33.4	7.8	26.2	7.44	863.1	195.7	261.3	0.7423	0.991	0.139	0.186
Run3	911.1	33.3	7.5	26.2	7.1	859.3	186.6	248.2	0.7445	0.9910	0.139	0.1857
Run4	866.7	33.17	7.16	26.23	6.76	855.6	177.3	235.3	0.7468	0.9909	0.1395	0.1851
Run5	800	32.7	6.9	26.21	6.4	843.6	167.8	223.6	0.7435	0.9908	0.1429	0.1905
Run6	777.8	32.88	6.44	26.19	6.073	848.2	159.1	209.8	0.7512	0.9909	0.1394	0.1839
Run7	733.3	32.73	6.08	26.17	5.73	844.4	149.9	197.2	0.7534	0.9908	0.1394	0.1833
Run8	688.9	32.59	5.72	26.14	5.387	840.7	140.8	184.7	0.7555	0.9908	0.1393	0.1827
Run9	644.4	32.44	5.36	26.12	5.043	837	131.7	172.3	0.7576	0.9908	0.1393	0.1822
Run10	600	32.3	5	26.1	4.7	833.2	122.7	160	0.7596	0.9907	0.1393	0.1818

Table 6. Results of CTI-80 solar panel in different solar radiation

Trials	Pin (W/m^2)	Voc (V)	Isc (A)	Vmp (A)	Imp (A)	Vocn (V)	$Pmax_{act}$ (W)	$Pmax_{theo}$ (W)	$F.F_{act}$	$F.F_{theo}$	η_{act}	η_{theo}
Run1	1000	22.8	4.6	18.4	4.35	588.2	80.04	103.6	0.7632	0.9875	0.1527	0.1976
Run2	955.6	22.63	4.4	18.23	4.172	583.9	76.07	98.33	0.7639	0.9874	0.1519	0.1963
Run3	911.1	22.47	4.2	18.07	3.994	579.6	72.17	93.16	0.7648	0.9873	0.1511	0.1951
Run4	866.7	22.3	4	17.9	3.817	575.3	68.32	88.06	0.7659	0.9872	0.1504	0.1939
Run5	800	22.13	3.8	17.73	3.639	571	64.53	83.03	0.7672	0.9872	0.1539	0.198
Run6	777.8	21.97	3.6	17.57	3.461	566.7	60.8	78.06	0.7688	0.9871	0.1491	0.1915
Run7	733.3	21.8	3.4	17.4	3.283	562.4	57.13	73.16	0.7708	0.987	0.1486	0.1903
Run8	688.9	21.63	3.2	17.23	3.106	558.1	53.52	68.32	0.7731	0.9869	0.1482	0.1892
Run9	644.4	21.47	3	17.07	2.928	553.8	49.97	63.55	0.7759	0.9868	0.1479	0.1881
Run10	600	21	2.8	16.9	2.75	541.7	46.48	58.01	0.7904	0.9866	0.1478	0.1845

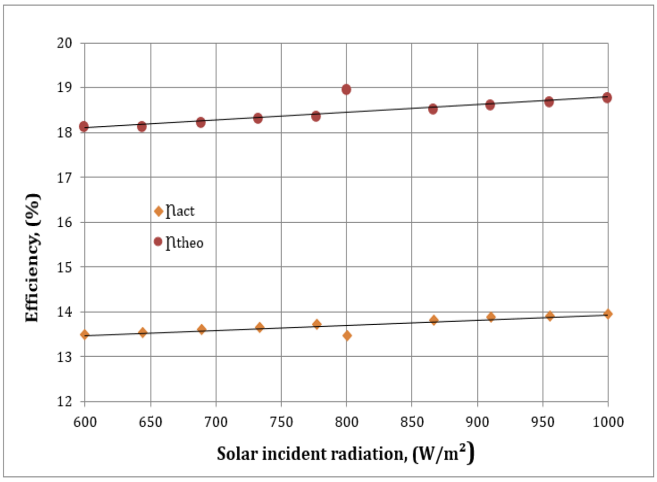

Figure 5. Actual and theoretical efficiencies against the incident solar radiation for YHM-205-27P solar module

By repeating the EES program with the CTI-80 solar module, all results included in Table 6, it is noticed that the efficiency of the panel of CTI-80 increases with the increasing of the solar incident radiation and decreases when the solar incident radiation decreases.

As illustrated in the Figure 6, the actual efficiency reaches its peaks when the solar incident radiation is at its highest values and the same goes for the theoretical efficiency.

Furthermore, the CTI-80 theoretical efficiency reaches a value of 19.7% when the solar incident radiation is equal to 1000W/m^2, and reaches 18.4% when the solar incident power is 600W/m^2. However, the CTI-80 actual efficiency gives a value of 15.2% when the solar incident radiation is 1000W/m^2. When the solar incident power is 600W/m^2, the actual efficiency is about 14.7%.

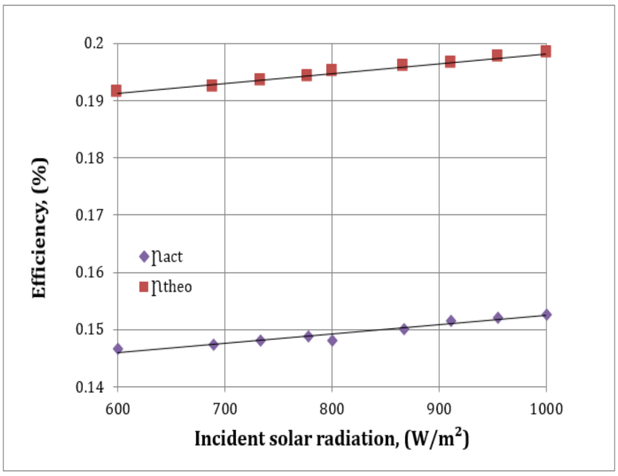

Figure 6. Efficiencies verses the power incident for CTI-80 solar module

By comparing the theoretical efficiencies for both solar panels (CTI-80 and YHM-205-27P), it is clear, from the Figure 7, that the YHM-205-27P panel has the lowest value with a value of 18.1%, while the highest value is for the CTI-80 panel with value of 19.7% at different solar incident radiations. However, when comparing the two efficiencies with the same solar incident radiation, it is noticeable that the YHM-205-27P panel has a lower value of 18.1% at 600 W/m^2, and the CTI-80 hits a value of 18.4% at the same incident power.

When comparing the two panels with a solar incident radiation of 1000W/m^2, the CTI-80 is ahead with a value of 19.7% and the YHM-205-27P gives a value of 18.7%, which is lower than CTI-80.

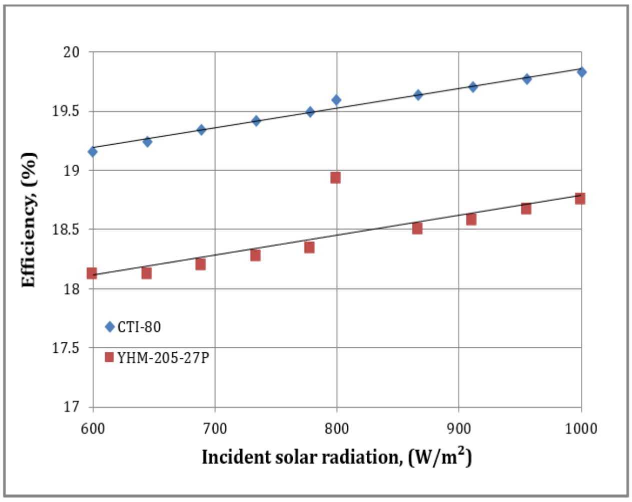

Figure 7. Theoretical efficiency for both CTI-80 and YHM-205-27P

In addition, when comparing the actual efficiency of both solar panels, Figure 8 illustrates the difference in values between YHM-205-27P and CTI-80. For an incident solar radiation of 1000 W/m², the CTI-80 panel has an efficiency value of 15.2% which is the highest for the panel, while the YHM-205-27P solar panel gives an efficiency value of 14% which the highest for the panel. For an incident radiation of 600W/m^2, YHM-205-27P gives the value with an efficiency of 13.9%, which is the minimum value for the panel, and CTI-80 gives an efficiency value of 14.7%, which is the lowest efficiency value for the panel.

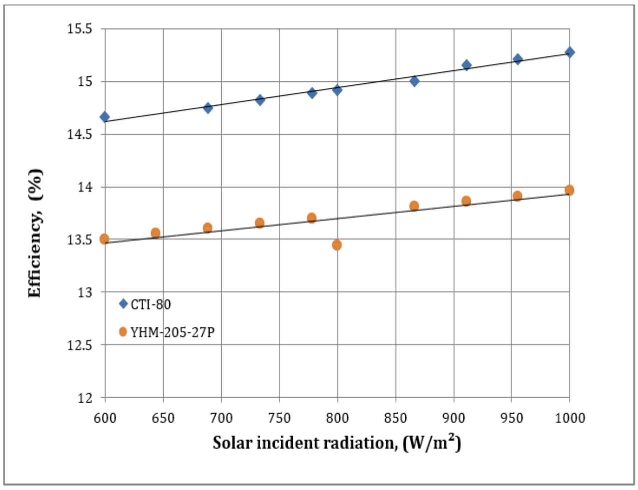

Figure 8. Actual efficiency for both CTI-80 and YHM-205-27P

When analyzing the results of a study comparing the efficiencies of two solar panels, such as the CTI-80 and YHM-205-27P, it is essential to provide context, interpretation, and discuss the significance of the findings. Let's delve into it: The study revealed that the CTI-80 panel exhibited higher efficiency compared to the YHM-205-27P panel. This disparity in efficiency can be attributed to several factors: Technological Advancements: The CTI-80 panel may incorporate advanced technologies and manufacturing processes that enhance its conversion efficiency. These advancements could include improved materials, optimized cell designs, reduced energy losses, or enhanced light-trapping mechanisms. Material Quality: Variations in the quality of materials used in the panels can contribute to differences in their efficiency. The CTI-80 panel might utilize higher-grade materials with better electron mobility, reduced recombination rates, or improved spectral response, resulting in enhanced performance. Manufacturing Processes: The manufacturing processes employed for the CTI-80 panel might ensure higher precision, tighter quality control, and reduced defects compared to the YHM-205-27P panel. These factors can influence the overall efficiency of the panels. Research and Development: The panels might have undergone different levels of research and development, with the CTI-80 panel benefiting from more extensive optimization efforts. This additional refinement could have led to higher efficiency levels. The implications of these findings for real-world applications are significant: Energy Output: The higher efficiency of the CTI-80 panel indicates that it can convert a greater amount of sunlight into usable electricity compared to the YHM-205-27P panel. This translates into higher energy output and increased power generation for the same surface area of installation. Space Limitations: Real-world applications often face space limitations, particularly in residential or urban environments. The higher efficiency of the CTI-80 panel can be advantageous in such scenarios, as it allows for greater power generation within a limited space. Cost Considerations: While the CTI-80 panel demonstrates superior efficiency, it may come at a higher cost compared to the YHM-205-27P panel. Therefore, the cost-effectiveness and overall financial viability of the panels must be considered when making decisions for specific projects or installations. Environmental Impact: Higher-efficiency panels, like the CTI-80, have the potential to reduce the environmental impact associated with energy production. They can contribute to reducing greenhouse gas emissions and reliance on non-renewable energy sources. In conclusion, the study's findings highlight the differences in efficiency between the CTI-80 and YHM-205-27P solar panels. The superior efficiency of the CTI-80 panel can result from technological advancements, material quality, manufacturing processes, and research and development efforts. These findings have significant implications for real-world applications, including increased energy output, optimal space utilization, cost considerations, and environmental impact.

6. CONCLUSIONS

Based on the analysis of the data, it can be concluded that the monocrystalline solar cell in the CTI-80 panel achieves a higher efficiency compared to the polycrystalline solar cell in the YHM-205-27P panel. Although the YHM-205-27P panel has more solar cells, the CTI-80 panel still achieves a higher efficiency due to the superior performance of the monocrystalline solar cells. The theoretical efficiency is higher than the actual efficiency for both solar panels, which is attributed to the temperature and the fact that not all photons in the incident radiation have the energy required to free the extra electron. It is important to note that this study was conducted under specific conditions, including irradiance values of 600, 800, and 1000 W/m^2 and a cell temperature of 77°F (25°C). There may be other factors that could affect the efficiency of solar panels, and further research could explore these factors to gain a more comprehensive understanding of the performance of solar panels.

In conclusion, the study comparing the efficiencies of the CTI-80 and YHM-205-27P solar panels has revealed that the CTI-80 panel exhibits higher efficiency. This difference can be attributed to technological advancements, material quality, manufacturing processes, and research and development efforts. The findings have important implications for real-world applications, including increased energy output, optimal space utilization, cost considerations, and environmental impact.

However, it is important to acknowledge certain limitations of the study. The research focused solely on efficiency and did not consider other factors such as cost-effectiveness, durability, or specific performance under varying environmental conditions. Moreover, the study may have been conducted under specific laboratory conditions, and the results may vary in different real-world scenarios. Despite these limitations, the findings provide valuable insights into the comparative performance of the two panels and contribute to the understanding of their suitability for different applications. Further research and analysis encompassing a broader range of factors would be beneficial for a more comprehensive evaluation of the panels' overall performance and their applicability to specific project requirements. In terms of limitations, the scope of this study was limited to comparing the YHM-205-27P and CTI-80 solar panels under specific operating conditions. Additionally, some assumptions were made in the calculations, which may affect the accuracy of the results. this study found that the monocrystalline solar cell in the CTI-80 panel achieves a higher efficiency compared to the polycrystalline solar cell in the YHM-205-27P panel under specific operating conditions. The limitations of the study should be considered when interpreting the results, and further research could explore additional factors that may affect the efficiency of solar panels. These limitations therefore include: Scope of Analysis: The study focused solely on the efficiency of the solar panels and did not consider other important factors such as cost-effectiveness, durability, reliability, or performance under varying environmental conditions. These additional factors are crucial for a comprehensive evaluation of the panels' overall suitability for different applications. Testing Conditions: The specific conditions under which the solar panels were tested can impact the results. The study may have been conducted under controlled laboratory conditions, which might not fully represent real-world scenarios. Factors such as temperature, irradiance levels, shading, and orientation can influence the performance of solar panels and may vary in different environments. Sample Size: The study may have analyzed a limited number of solar panels or samples, which might not provide a complete representation of the panels' performance. A larger sample size would contribute to more statistically significant results and increase the reliability of the findings. Assumptions: The calculations and comparisons made in the study might involve certain assumptions. These assumptions could pertain to the parameters used in efficiency calculations, data normalization methods, or other factors. The accuracy of the results depends on the validity of these assumptions. Timeframe: The study's results are based on the specific solar panels available at the time of the research. Solar panel technologies and models are continually evolving, and newer versions or alternative options may offer different efficiencies or performance characteristics. It is important to acknowledge these limitations as they can influence the generalizability and applicability of the study's findings. Future research and studies should aim to address these limitations and provide a more comprehensive analysis of the solar panels, taking into account a wider range of factors and real-world conditions.

For future research, it may be worthwhile to investigate the performance of other types of solar cells under different operating conditions. This could provide a more comprehensive understanding of the factors that affect the efficiency of solar panels and help identify ways to improve their performance.

Future research in the field of solar panels can explore various avenues to further enhance our understanding and improve the efficiency of solar cells. Here are some potential areas for future research: Environmental Factors: Investigate the impact of environmental factors, such as temperature, humidity, and dust accumulation, on the efficiency of solar panels. This research can help optimize panel performance under different climatic conditions. Advanced Materials: Explore the potential of new materials, such as perovskite or quantum dot materials, and their integration into solar cell designs. Research can focus on improving the efficiency, stability, and cost-effectiveness of these emerging materials. Novel Cell Architectures: Investigate innovative cell architectures, such as tandem cells, multi-junction cells, or bifacial cells, to enhance efficiency and energy output. These designs can enable better utilization of different portions of the solar spectrum and increase overall performance. Light Management Techniques: Explore advanced light management techniques, including nanostructured surfaces, photonics, or plasmonic, to improve light absorption, trapping, and conversion efficiency in solar cells. Stability and Longevity: Research the long-term stability and degradation mechanisms of solar cells to develop more durable and reliable panel designs. Understanding the factors that contribute to performance degradation over time can lead to improved longevity and maintenance strategies. Techno-economic Analysis: Conduct comprehensive techno-economic analysis that considers not only efficiency but also factors like manufacturing costs, installation costs, lifetime energy yield, and levelized cost of electricity. This research can guide decision-making processes by providing a holistic evaluation of solar panel technologies. Integration and System-level Research: Investigate the integration of solar panels into various applications, such as building-integrated photovoltaics (BIPV), solar farms, or smart grids. This research can focus on optimizing system-level performance, power management, and grid integration. Comparative Studies: Conduct comparative studies analyzing the performance of different types of solar cells, including thin-film technologies, organic photovoltaics, and emerging third-generation solar cells. Comparative research can help identify the most suitable technologies for specific applications and drive advancements in the field. By exploring these research avenues, we can further advance solar cell technologies, improve efficiencies, enhance durability, reduce costs, and accelerate the adoption of solar energy as a sustainable and viable power source.

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