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A Noval Solar Simulator to Explore Environmental Impacts On Panel Efficiency

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Abstract:

The paper provided a complete hardware design for a solar simulator for versatile environmental conditions.These conditions include shading, humidity, dust, and temperature. The full design of the solar simulator is proposed and fabricated to analyze the performance of PV panels with and without air cooling mechanisms in indoor tests. The halogen bulbs with built-in reflector support by the steel structure holder act as natural sunlight. The challenge for a solar simulator is stable, uniform solar irradiance and illumination. The uniform solar irradiance of 7,575 candela was measured in the test area. Several units of PV panels were tested on variable environmental conditions. PV panels with an air-cooling mechanism experience a 2.3 ˚C decrease in surface temperature when driven at 200 km/h..This increases the panel's efficiency by 6.11 % of the maximum power output based on different fixed solar irradiance. They also compared it using hardware and simulation methods. An overall method and procedure of the measurement by the solar simulator are discussed and proposed.

Keywords: s*olar simulator; solar panel testing; environmental testing; shading effects; humidity effects; dusting effects; temperature effects; photovoltaic (PV) performance; multi-variable testing*

1. Introduction

There are various ways to generate electrical energy. Most of these techniques (e.g., burning coal and fossil fuel) pollute the environment[1]. An environment-friendly method uses solar panels to generate energy. The lifespan of solar cells is short. Solar energy is a viable alternative to traditional methods of producing fuels and power from decreasing natural resources, but its distributed and intermittent nature presents issues. The scattered nature of sunlight restricts the acceptable thermal flux density to 1000 W/m^2 [2]and prevents processes from reaching high temperatures needed for large-scale fuel manufacture or power generation. This method generates electricity without pollution. Our project is also renewable—our solar simulator tests solar panel life and performance.

Traditional power generation methods that rely on fossil fuels contribute to global environmental degradation [3]. Due to the rapid depletion of fossil fuel resources and their detrimental effects on the environment, there is an increasing demand for power generation methods that are less harmful to the environment and more sustainable. Direct power generation from the sun is made possible by solar photovoltaic cells, which use solar energy,[4] a renewable resource that never runs out. The cost-effectiveness of power generation is affected by environmental

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conditions, cell operation and maintenance, and the solar PV cell's optimal output, energy conversion efficiency, productivity, and longevity[5]. This article summarizes current studies that have examined how operational and environmental variables affect solar PV cell performance. Research has shown that environmental factors such as humidity, temperature, dust allocation, and soiling affect PV module performance significantly. Also, the wind is a significant dust and sand source, especially in remote areas. Compounding the problem, dust accumulates in damp environments, turning the PV cell into stubborn, sticky mud that reduces power output by 60–70%. Modern approaches to mitigating these factors' impacts are discussed in this article, along with their relative merits and shortcomings. In addition to discussing the efficiency analysis, this paper delves into the parameters that play a role in solar power production. Additionally, the article delves into the effectiveness and capability of semiconducting materials to convert energy into power. The overall advantages of solar PV power generation are also covered.[6]

The solar simulator is the leading indoor laboratory for studying solar thermal collectors, photovoltaic cells, spacecraft, and concentrated solar power systems. Space solar simulators, conventional PV cell testing, collector testing, and high-flux solar simulators are the four types outlined in this study, with each type's attributes and design goals considered. Solar simulator improvements are evaluated based on state-of-the-art improvements in light sources and optical concentrators. As the most essential part of a solar simulator, the light source is carefully selected to meet the design objective. Some examples of light sources include carbon arc lamps, mercury xenon lamps, argon arc lamps, quartz tungsten halogen lamps, xenon arc lamps, and light-emitting diode (LED) lamps.[7]

Watts per square meter (W/m^2) are the universally accepted units for solar irradiance measurements. The inability to measure low irradiance values and the high cost of irradiance meters are two of their main limitations. Light meters take readings in lumens per square meter, or lux, a measure of luminous flux per unit area (illuminance). They are inexpensive and susceptible in low-light circumstances. Light meters might be used to assess photovoltaic performance even when solar irradiance is low if there is an efficient conversion factor between W/m^2 and lx. Despite much research, there is still no accepted "rule of thumb" for converting solar irradiance to illuminance. For 1000 W/m^2 (1 Sun) of solar irradiation, easily accessible online sources provide conflicting and substantially different estimates, spanning from 688449 to 21000 lx [8]. Values for Luminous Efficacy equivalents between 21 and 131 lx per W/m^2 are found in peer-reviewed literature. The connection between solar irradiance and illuminance is investigated in this publication, which also provides a theoretical and experimental measurement guide. Standards data, accuracy estimates for equipment calibration, and uncertainty estimations are all part of the conversion factor. The solar irradiance for an outside sunlight source (122 ± 1) klx and an LED-based solar simulator (116 ± 3) is 1000 W/m^2.

The architecture of a solar simulator that uses 19 different wavelengths controlled individually by high-power LEDs, covering the 250-1000 nm standard sun spectrum of AM1.5Global, is described in this article. The simulator is tunable, adaptable, and built on light-emitting diodes (LEDs). The focal points of the design process were covered, including the placement of the LEDs, regulation of their intensity, handling of heat, and secondary optics [9]. The solar simulator's rating, spectral match, irradiance non-uniformity, and temporal instability were examined by the International Electrotechnical Commission's (IEC) and ASTM's requirements. At an 8.7 cm distance from the LEDs, the suggested solar simulator satisfies the Class AAA requirements in all three categories for the 2.3×2.3 cm test plane. Class AAA is a standard defined by the IEC 60904-9 for solar simulators, which ensures high-quality performance in terms of spectral match, spatial uniformity, and temporal stability. Meeting this requirement is crucial as it guarantees that the solar simulator provides consistent and accurate simulation of sunlight, which is essential for reliable testing and evaluation of solar panels. This solar simulator is excellent for evaluating newly developed photovoltaic technologies with extended spectral responsivity in the UV region, including ultraviolet-responsive solar cells, thanks to its spectral tunability and extended spectrum. It is valuable for research studies in a variety of sectors.[10]

Solar cells and modules are the building blocks of solar power plants, and the solar simulator is an essential tool for testing their efficiency. Designing an accurate, cost-effective solar simulator relies heavily on precise measurements of solar cell performance. A unique solar simulator method that is both exact and quantifiable is suggested in this work. With the addition of a reflector system, the developed solar stimulator becomes a continuous type, allowing for a 6-inch sun cell measuring with improved result uniformity. Furthermore, one side of the reflector has 2 to 6 light-emitting diodes (LEDs). The uniformity, temporal instability, and spectrum values were matched in a 1000 W/m^2 light intensity condition using the standard measurement of IEC60904-3, ensuring a trustworthy evaluation. Utilizing an Al reflector and LED, the solar simulator achieved a uniformity of 1.43%, which is very close to the 3.06 achieved before using the reflector. This suggests that the planned stimulator achieved class A results in enhancing spectral match and temporal instability levels.[11]

An apparatus that produces light similar to that of sunlight is called a solar simulator. Creating a regulated indoor testing environment in a controlled laboratory setting is the primary objective of the solar simulator. It may also test the various solar cells' performance to the fullest extent. In a solar simulator, the three parameters that govern the light output are spectral content, spatial uniformity, and temporal stability. There are three distinct categories into which it falls: Class A, Class B, and Class C. Class U solar simulators are those that do not meet the requirements of Classes A, B, and C. The spectral match, spatial non-uniformity, and temporal instability of irradiance values are higher in Class U, which stands for unclassified.

TABLE I. Solar Simulator Classification

Class	Spectral Match	Spatial Non-Uniformly of irradiance	Temporal instability of irradiance
A+	0.875-1.125	1%	1%
A	0.75-1.25	2%	2%
B	0.6-1.4	5%	5%
C	4.0-2.0	10%	10%
U	>2.0	<10%	>10%

Table I compares the classification of solar simulators. This way, we learned that class A+ is the best classification for solar simulators and performs better than other classes A, B, and C. If a solar simulator is absent in these conditions, it will be unclassified class U.

2. Literature Review

People began to generate electricity using thermal because, although there are different methods, the electricity generated by heat is fundamental and straightforward. The scientists learned that many pollination will occur due to burning processes[5]. Therefore, they seek an alternative approach that does not result in environmental degradation. Additionally, researchers are attempting to find a way to regulate pollution. In this project, we will go over the various solar plate phenomena that may be accomplished without polluting the environment and yet produce a respectable amount of electricity. Some examples of such ways include piezoelectric sensors [5], solar plates, wind turbines, and many more..

The use of conventional fossil fuel-based power generation is one of the main contributors to global environmental pollution. They learned solar energy is an unlimited and immeasurable renewable source for direct electricity production through a solar PV cell. They understood that ecological conditions also affect solar PV cell performance. It was also found that dust allocation is affected along with humidity and temperature, which affect solar PV performance. They found that due to this environmental condition, power generation will be reduced by up to 60-70%.[12]

Although this study's primary objective is solar simulators for the thermal sector, its results apply to the PV industry. An optical element, a power source, and a source of light are the three main components of these models. The result would have to meet these standards. Thus, each component was hand-picked for that reason. This research aims to analyze the outcomes of laboratory tests on solar panels.[13].

To facilitate spacecraft testing on Earth, the National Aeronautics and Space Administration (NASA) funded the development of solar simulators in the 1960s [14, 15]. Building more accurate representations of the radiation environment on Earth has been a primary focus of recent research. Sunscreen clinical testing, photovoltaic (PV) cell calibration and characterization, and other applications are all possible with these tools.[14].

Daniel et al. developed and tested a solar simulator with great success. Combined with a cluster of seven 1500 W metal halide lamps, achieving over 60 kW/m^2 fluxes at their peak and 45 kW/m^2 on average was possible. A 38-centimeter-wide output aperture yielded these results. This method has been used to study molten salts' optical melting point and light absorption behavior. Qinglong et al. constructed a large-scale solar simulator using 188 400W metal halide lamps. The average radiation changes from 150 to 1100 W/m^{2}when the number of lamps and the distance from the lamps to the region are changed.[15].

A pulsed solar simulator, which mitigates the typical power and temperature swings caused by prolonged light exposure, was also considered throughout the construction of the standard PV solar simulator. Continued research focused on improving the spectrum output of multisource simulators. Simulators have shifted their focus to light-emitting diode (LED) technology since its rapid development at the end of the 1990s. This new light source has numerous advantages, such as low cost, compact size, longer operational life, and good energy efficiency. Recent developments in high-power LED technology have solved the main challenge of entirely LED solar simulator designs; Fig. 1 shows a sample design. The entirely LED solar simulator, developed by UIUC researchers in 2012, covers the AM1.5G sun spectrum and achieves Class C uniformity across a 100mm × 50mm region. As time passes, LED solar simulators will overtake their more-traditional counterparts.[16].

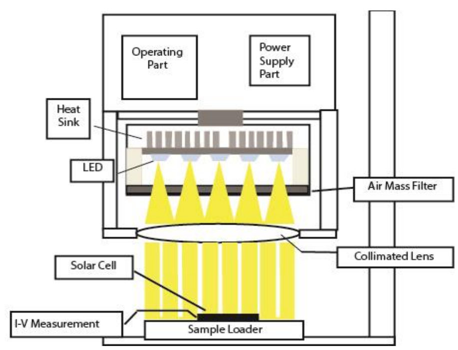

Fig. 1. Schematic of a typical LED Solar Simulation [16]

The main emphasis of this research is on measuring solar energy using Arduino Board technology. Light intensity, temperature, voltage, and current are the four variables that will be measured in this paper. With the use of sensors, we can quantify these things. A thermometer was used to record the temperature. Due to the high output from the solar panel, which surpasses the capacity of the Arduino, a voltage divider was used to measure voltage in the project. In contrast, an LDR sensor was used to gauge light intensity. The output current of the solar panels was also measured using a current sensor module. An LCD panel showed the results, including temperature, light intensity, voltage, and current readings, which were inputted into the Arduino. In this setup, the analog inputs were converted into digital displays on the LCD using the Arduino. In addition, the project's design centered on developing a portable device case.[17]

The importance of solar simulators, which allow for the controlled testing of solar-related components, has grown in tandem with the proliferation of renewable energy sources. In this review, we will explore various light sources used in solar simulators and compare them based on criteria such as intensity, cost, spectrum match, and the types of lamps used, including metal halide, xenon arc, and tungsten halogen. While xenon arc lamps are more intense and stable, metal halide is preferred for modern simulators due to its balanced performance and safety. Both xenon and metal halide arc lamps are recommended for their similarity to sunlight.[18]

In this study, we look at how dust, water, bird droppings, and shadowing affect the performance of solar panels. This is the first study that evaluates all three at once. The results show that dust, shade, and droppings significantly affect the power output, with shading having the most negative effect. Shade can reduce power output by 33.7%, 45.1%, and 92.6% when applied to solar panels at 25%, 50%, and 75% coverage levels, respectively. Conversely, a few drops of water can cool the panel and increase power output by 5.6%. In addition to impacting overall efficiency, dust reduces power by 8.80% and droppings by 7.4%. [19]

The impact of dust on massive solar power facilities and the efficacy of different cleaning procedures are examined in this research. Environmental variables, especially dust, which differs by region and can drastically diminish power production and efficiency, significantly impact solar panels' performance. According to the study, dust might cause a 1% daily power loss and an 80% monthly efficiency decline. For individuals involved in solar power systems, it gives a comprehensive overview while critically analyzing dust-related problems and cleaning methods from a technical and economic perspective. [20]

As fossil fuels continue to dwindle in supply, this article looks at the pressing need for alternative energy sources. It uses a MATLAB model of a parabolic solar collector to investigate the possibilities of solar energy. It evaluates its performance in five cities around Iran, each with its unique environment. According to the results, the thermal efficiency of the collectors in Shiraz is 71.97%, whereas the exergy efficiency in Sanandaj is 22.01%. Rasht also has the lowest yearly cost when the analysis takes CO2 emissions into account. [21]

There has been a concerted effort in the last 20 years to find energy sources that do not release greenhouse gases, the culprits behind climate change and extreme weather. Despite its reduced efficiency owing to various losses, renewable energy, particularly solar photovoltaic (PV), is a critical component in the puzzle for environmentally friendly power generation. Dust, temperature, and shadowing are just a few operational and environmental variables that can reduce solar PV performance. This review examines these issues and how solar cell materials and system designs have evolved to address them. [22]

The optimal size and placement of Hybrid Renewable Energy Systems (HRES) for energy consumption is the focus of this study.

Using a case study in a rural location, it employs the Generalized Reduced Gradient Method to size HRES components. A comparison is made between grid-connected and independent HRES; the former can reduce carbon emissions and create jobs, while the latter provides more significant economic advantages and reliability. Comparisons of HOMER software support the study's methodology. [23]

Using layers of GaInP, GaInAs, and Ge to capture a broad spectrum of solar photons efficiently, this research investigates the performance of a triple-junction solar cell. The J-V curve was used as a critical indicator in a developed model to evaluate the cell's performance. From 25 to 125°C, the efficiency reduces by 17%, the open circuit voltage by 15%, and the fill factor by 4.5 %, but the current density increases by 5.5 %, according to the study. This research highlights the significance of thermal management in solar CPV systems for improving efficiency and avoiding thermal damage.[24]

More and more people are noticing perovskite solar cells because of their efficiency and cheapness. However, it has been challenging to ensure their stability in practical settings. Recent breakthroughs have revealed that integrating hexamine into the perovskite structure enhances stability, resulting in high-efficiency solar cells that function effectively even in humid environments. These cells are a huge step towards commercially practical perovskite solar cells; they reach a power conversion efficiency of 16.83% and remain stable for 1500 hours in humid environments [25].

This research breaks new ground by systematically testing the impact of Iranian desert dust on solar panel efficiency. Modern tools such as elemental mapping and scanning electron microscopy have allowed scientists to determine better how dust affects solar systems. The study discovered that when dust, which mainly consists of silicon, oxygen, aluminum, and calcium, accumulates at high densities, it can significantly decrease the power output of solar panels—by as much as 98%. The fill factor is unaffected by the dust's even distribution throughout the panels.[26]

The energy mechanisms of interfacial solar desalination, a technique that has increased the efficiency of sun-thermal evaporation, are explored in this work. The article showcases the advantages of interfacial evaporation over conventional approaches by presenting a heat and mass transport model. The study shows that environmental factors still influence evaporation rates even after adjusting solar flux and surface area, and it also looks at how efficiency is affected by these adjustments. The article argues that solar stills need interfacial evaporation at total efficiency, but that better system design could improve performance. The results provide light on how to enhance interfacial solar desalination systems.[27]

In the Alborz province of Iran, it evaluates PV and PV/T systems for greenhouse strawberry production using TRNSYS software. Sc-1 is the status quo of energy practices, Sc-2 is PV systems, and Sc-3 is a PV/T system. Sc-3 reduces environmental harm by 6% and Sc-2 by 16%, respectively, while Sc-1's primary energy user is diesel fuel, according to the study. According to the survey, sc-2 lowers energy consumption by 50% compared to Sc-1, making it the most environmentally beneficial alternative. In contrast, Sc-3 is less efficient because of additional equipment and local climate circumstances. Based on the findings, solar power has the potential to drastically change patterns of energy usage and their effects on the environment. [28]

3. Methodology

As part of our research, we design a model resembling a solar simulator which is look like

Class A solar Simulator. Using the specifications indicated in Fig 2, we selected a wooden box.The cost of the solar simulator of class A is $25,834 US dollar and the price of the solar simulator we design is $613.81 US dollar.

The two advantages are, initially, the electrical short. Additionally, we know that wood is an electrical insulator, which means we can readily handle a short circuit in our circuit. As for the second reason, wood has a lower thermal conductivity than iron. Artificial suns made from fluorescent bulbs generate heat; without a wood eternal simulator, the heat will become intolerable. Therefore, we opted for a wooden box. An aluminum sheet covers the wooden container.

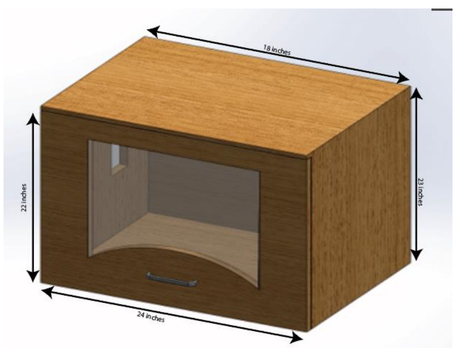

Fig. 2. Wooden Box

TABLE II. Wooden Box Parameters

Name	Inches
Chamber Length	18
Chamber Width	23
Door Length	24
Door Width	22
Glass Width	18
Glass Length	14

The dimensions of the wooden crate are displayed in Table II.

The following parameters, taken from Table III, are applied to a mono solar panel. After that, set that panel inside the wooden container.

TABLE III. Solar Panel Parameters

Name	Voltage/ Ampere
Max Power	30W
Optimum Operating Voltage (V)	17.1 V
Optimum Operating Current (Im)	1.75A
Open Circuit Voltage (Voc)	21.2V
Short Circuit Current (Isc)	2.01A
Name	Voltage/ Ampere

The efficiency of the solar panel, housed in a wooden box, is tested with a halogen bulb.

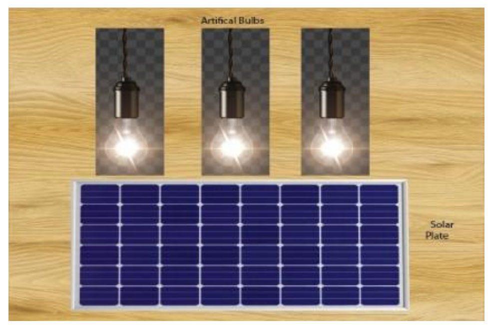

Fig. 3. Halogen bulbs in the simulator

The three halogen lights and solar panels are housed within the wooden box, as shown in Figure 3. The solar panel's output can be obtained by turning on the Heliogen lamps.

3.1. Types of Testing

Type of task will be done quickly, i.e., Heating, dusting, lighting, and raining testing.

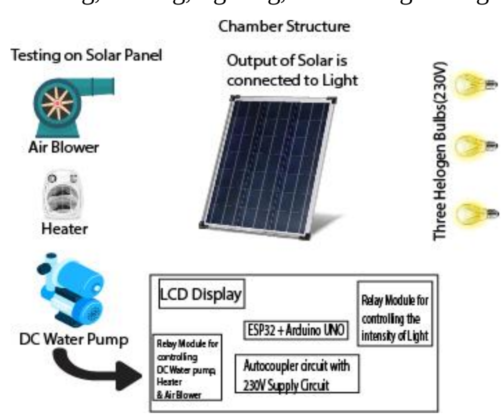

Fig. 4. Chamber Structure

3.2. Working process

At this point, we will go over how our project operates. By running it through a battery of tests, this gadget can determine the solar panel's maximum voltage, which is its primary function. Here, we harness the power of artificial solar panels, similar to a halogen lamp, which transforms sun rays into usable heat or electricity. Solar panels collect energy from the sun's rays and convert it into usable electricity. A relay is the third part. The only two requirements are that it be generally closed and normally open. If they specify that our relay must remain open under typical circumstances, and they subsequently achieve this state, it will also be closed. Fourth, there's the EPS32, which controls everything through its connection to the Arduino UNO. We need to know how to toggle the light, warmth, and blower on and off. We utilized a single solar plate with a 30W power rating for this project.

All three of the 230W halogen light bulbs and the electric heater. A wooden box can be heated using an electric heater. The water pump is utilized to clean the solar panel for training reasons. A 12 DC charger is used to power the water pump, which operates on 12 DC. Turning on the halogen lights is the first step in testing the solar panel's illumination impact and output. Additionally, use the formula to verify the Light Intensity. The length in meters, the power in watts, and the light intensity in W/m^2 are all given here.

Which electrical generation occurs once the lighting test is successfully executed? The following step is to do the test in a rainstorm. We have a 12V DC motor attached to our device, which may be used to draw water from a tank, and the water is connected to the tank. The water will then be thrown onto the solar plate, simulating rain. The following step is to dust the solar panel using the air blower to simulate a real-life blower. We continued by taking note of the solar panel's readings after we watched how dust, rain, and lighting affected them. A heating test is the ultimate test. The heater attached to our project is on one side of the wooden box. They need to think about heat resistance since solar panels can produce much heat from the sun, and the efficiency of these panels might fluctuate based on how much heat is absorbed.

Proceed to describe the model's associated circuit. Describe the initial circuit that incorporates the auto coupler and rectifier. Protecting our circuit from the 230 V AC supply is the primary function of the auto coupler. After that, To change 12V DC into 4V, you can adjust the voltage of our 12 DC bucker converter. The ESP 32 and Arduino UNO are both powered by a 4V source. To power the Arduino, ESP 32, and relay module, we will send the auto coupler's first right-side signal to the converter network, transforming the 12-volt DC signal into a 3.7-volt DC. The other signal from the auto coupler will go to the second buck converter, which is directly connected to the LCD. The halogen lights' high/low intensity can be controlled with the dimmer, while the bulbs, heater, fan, and water pump may be controlled with the rally. This is the finished circuit layout.

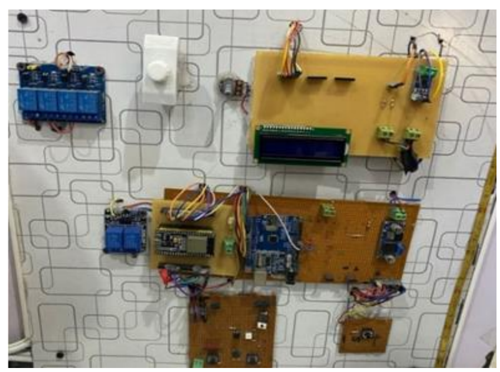

Fig. 5. Final hardware structure of Circuit

4. Results and Discussions

4.1. Results

For measuring the solar output we have used the Digital Multitmeter. The Digital multimeter exhibits about 0.06% additional error.The Table IV demonstrates that the panel's surface temperature gradually decreases when humidity increases. The panel surface temperature was reduced by 11.40%, representing a 32.8% increase in associated humidity from 65.40% to 98.20%. A decrease in the panel's surface face temperature occurs due to the formation of water droplets surrounding the panel's surface at a high humidity level, which serves as a cooling agent.

TABLE IV. Measured values of PV panel surface temperature under varying humidity levels

Sr. No	Relative Humidity (%)	Temperature of PV Panel(deg)
1.	65.40	39.50
2.	70.20	39.10
3.	73.50	38.60
4.	76.40	38.30
5.	80.60	38.10
6.	85.60	37.40

See below for my explanation of this table about Fig 6. The graph clearly shows that the temperature drops as humidity rises. The formula can determine the difference between the PV panel's relative humidity and temperature. The equation also indicates this: -

$$\phi(\xi)=\alpha1*\sigma\iota\nu(\beta1*\xi+\chi1) + \alpha2*\sigma\iota\nu(\beta2*\xi+\chi2) \quad (1)$$

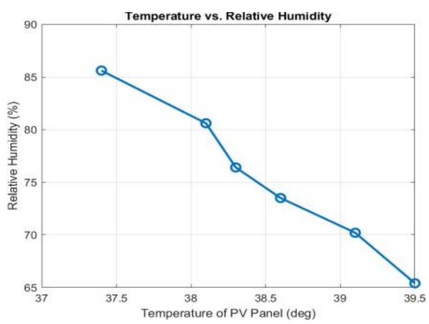

Fig. 6. Graph of Temperature and Humidity

Table V shows that we have used a halogen lamp. This application is preferred due to its high light intensity, low cost, and spectral interval approximately equal to natural sunlight. In the test, conducted under four different light intensities, as the light intensity increased, the efficiency of the load also increased, and the desired efficiency was obtained, equal to 18V.

The usage of the halogen bulb is indicated by Table V. The inexpensive price, wide spectral interval (almost identical to that of natural sunshine), and intense light intensity make this application a top pick. The test was conducted under four different light intensities; the load's efficiency grew directly proportional to the light intensity, reaching the target efficiency of 18V. Using the same technique, we can also determine the voltage-to-temperature ratio. The equation also shows it:

$$\phi(\xi) = \alpha1*\sigma\iota\nu(\beta1*\xi+\chi1) + \alpha2*\sigma\iota\nu(\beta2*\xi+\chi2) \quad (2)$$

TABLE V. Change of Intensity of Light

V_{out} (V)	About (A)	Temp (deg)	Humidity (%)	Candela (cd)
7.73	0.04	36	44	5561
12.96	0.46	36.2	44	6456
13.96	0.51	36.4	44	6570
16.5	0.77	36.5	44	6970
18.3	1.11	36.5	44	7575
7.73	0.04	36.5	44	5561
8.03	0.15	36.6	44	5760
9.46	0.2	36.6	44	6150

Fig 7 shows This shows that turning the heater on will also increase the temperature, which will decrease the voltage of the solar panel.

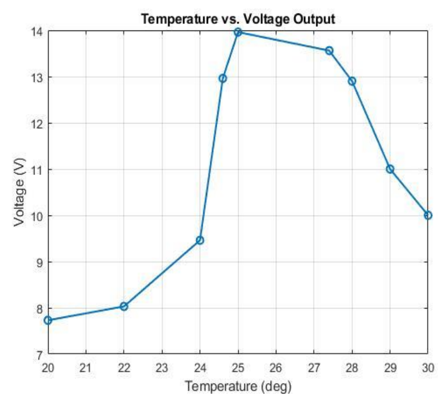

Fig. 7. Temperature and Voltage Graph

In Fig 8 it shows that by increasing the intensity of light.The output of solar panel will also increase. Table VI shows the impact of rain on Solar panel performance. Rain is also beneficial due to dust and heat. It helps to cool down the solar panel's temperature.

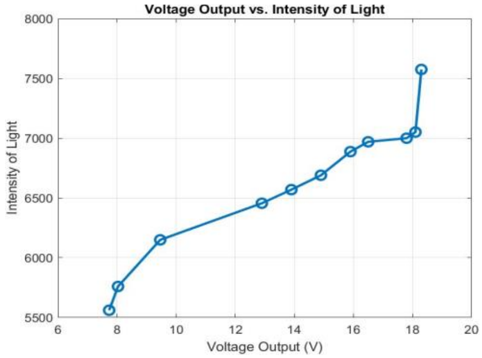

Fig. 8. Voltage and Intensity of Light Graph

TABLE VI. Testing of Solar Panels on raining

V_{out} (V)	**About** (A)	**Humidity (%)**	**Candle** (cd)	**Water Fall**
7.73	0.04	44	5561	2
8.03	0.15	44	5760	4
9.46	0.2	44	6150	5
12.9	0.46	44	6456	6
13.9	0.51	44	6570	8
14.9	0.61	44	6690	10
15.9	0.75	44	6888	12
16.5	0.77	44	6970	14
17.8	0.79	44	7000	15
18.1	0.81	44	7051	17
18.3	1.11	44	7575	20

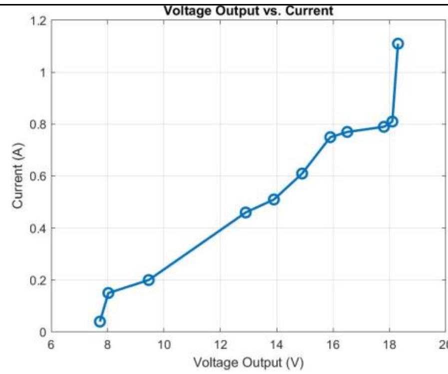

Fig. 9. Current and Voltage Graph

Fig 9 shows the output voltage will increase by increasing the intensity of light, so the current will be increased. The max voltage is 18V, and the max current is 1.11A

4.2. Discussion

The manufactured solar simulator can provide consistent solar irradiance levels in an indoor test at any time of day or night, regardless of the weather outside. The solar meter has been used to measure the average sun radiation for four groups. This experiment effectively determined the design and production of the solar simulator using halogen lamps.Using halogen lamps in solar simulators presents limitations due to spectral mismatch and heat generation, impacting accuracy and temperature control. Desipte cost effectiveness addressing these limitations is crucial for reliable solar-related research. The solar simulator system produces more reliably reproducible solar irradiance. Within the confines of the available test space, this solar simulator system can accurately simulate the behavior of PV panels. Using a solar simulator, one may compare the efficiency of a PV panel with and without an air-cooling system in a controlled laboratory setting. The electrical efficiency of a PV panel is primarily affected by the amount of solar irradiance and the operating temperature. Increases solar irradiance cause photovoltaic panels to operate at greater temperatures, lowering their electrical efficiency and speeding up their depreciation. The most significant amount of electricity produced by PV panels dropped as solar irradiance. This is due to a shortage of photons inside semiconductor cells. The panel can only operate within a specific temperature range, so the air-cooling system was built as it is. If you look at how well PV panels function with and without an air cooling system, you'll see that the latter has less of an impact from heat and generates more electricity. As a bonus, PV panels with an air cooling system have a lower operating temperature than the PV panel standard. According to testing data, the power output of a PV panel equipped with an air cooling mechanism may be increased by 14% and decreased by 6%. This is because a reduction in operating temperature of only 3oC increases efficiency. The increased generation of electricity will significantly benefit the PV system's utility.

5. Conclusion

We design a model that simulates a solar simulator to test temperature, rain, and dusty impacts inside. Our indoor simulator can run all tests, including illumination, warmth, rain, and dust.[29] The operation and effectiveness of solar panels in different environments will be examined. Solar panels lose efficiency as temperature rises and rain exceeds a specific amount. In this research, we try to simulate all experiments in one simulation to increase solar panel efficiency due to lighting. We also discuss blower dust. Increased dust on the solar panel reduces its efficiency.[30] Electrical devices and microcontrollers can control all parameters. All experiments can be done simultaneously and measured with a digital multimeter to determine solar panel efficiency. At the solar simulator, the solar panel reached 18V. This method produced an energy- and resource-efficient solar panel test box. Due to their energy efficiency, we chose halogen lights and aluminum paper for the walls. Changing the number of controlled bulbs changes light intensity. A 12.34% homogeneity problem and 0.8% irradiance stability make the test solar simulator unsuitable. The light qualities of the solar simulator may meet the standards for evaluating solar panels this way. This experiment used sunlight to test an SST solar panel[31]. In the same experiment, a solar simulator replaced the Sun. Using solar simulator radiation, we got an excellent solar panel reading. The solar simulator excels at thermal solar collector testing because it mimics real-world conditions as closely as possible.

References

[1] J. Zhang, "Energy access challenge and the role of fossil fuels in meeting electricity demand: Promoting renewable energy capacity for sustainable development," *Geoscience Frontiers*, p. 101873, May 2024, doi: 10.1016/J.GSF.2024.101873.

[2] H. Gürbüz, S. Demirtürk, H. Akçay, and Ü. Topalcı, "Thermal stabilization and energy harvesting in a solar PV/T-PCM-TEG hybrid system: A case study on the design of system components," *Energy Convers Manag*, vol. 294, p. 117536, Oct. 2023, doi: 10.1016/J.ENCONMAN.2023.117536.

[3] K. Addai, D. Kirikkaleli, G. O. A. Ampong, and M. Yufenyuy, "Assessing long run asymmetric effect of urbanization, fossil energy consumption and regulatory quality on environmental degradation in the Black Sea Region: A dynamic analysis," *World Development Sustainability*, vol. 4, p. 100153, Jun. 2024, doi: 10.1016/J.WDS.2024.100153.

[4] J. Zhang, F. Lv, and L. Zhang, "Discussion on Environment Impact Assessment in the Lifecycle of PV Systems," *Energy Procedia*, vol. 16, pp. 234–239, Jan. 2012, doi: 10.1016/J.EGYPRO.2012.01.039.

[5] H. F. Mateo Romero *et al.*, "Optimized estimator of the output power of PV cells using EL images and I–V curves," *Solar Energy*, vol. 265, p. 112089, Nov. 2023, doi: 10.1016/J.SOLENER.2023.112089.

[6] F. Shaik, S. S. Lingala, and P. Veeraboina, "Effect of various parameters on the performance of solar PV power plant: a review and the

experimental study," *Sustainable Energy Research*, vol. 10, no. 1, Apr. 2023, doi: 10.1186/s40807-023-00076-x.

[7] L. B. Wang Wujun, "Simulate a 'Sun' for Solar Research: A Literature Review of Solar Simulator Technology," *Digitala Vetenskapliga Arkivet*, 2014.

[8] J. L. Torres and I. García, "Analytical expressions for estimating sky diffuse irradiance and illuminance on tilted planes for the CIE Standard General Skies," *Renew Energy*, vol. 174, pp. 320–335, Aug. 2021, doi: 10.1016/J.RENENE.2021.04.059.

[9] C. Sun *et al.*, "LED-based solar simulator for terrestrial solar spectra and orientations," *Solar Energy*, vol. 233, pp. 96–110, Feb. 2022, doi: 10.1016/J.SOLENER.2022.01.001.

[10] M. Tavakoli, F. Jahantigh, and H. Zarookian, "Adjustable high-power-LED solar simulator with extended spectrum in UV region," *Solar Energy*, vol. 220, pp. 1130–1136, May 2021, doi: 10.1016/j.solener.2020.05.081.

[11] I. S. Jung, J. Choi, D. K. Shah, and M. S. Akhtar, "Development and Characterization of Solar Simulator for Solar Cells," *Journal of Nanoelectronics and Optoelectronics*, vol. 15, no. 6, pp. 720–724, Aug. 2020, doi: 10.1166/jno.2020.2802.

[12] K. Hasan, S. B. Yousuf, M. S. H. K. Tushar, B. K. Das, P. Das, and M. S. Islam, "Effects of different environmental and operational factors on the PV performance: A comprehensive review," *Energy Science and Engineering*, vol. 10, no. 2. John Wiley and Sons Ltd, pp. 656–675, Feb. 01, 2022. doi: 10.1002/ese3.1043.

[13] A. Namin, C. Jivacate, D. Chenvidhya, K. Kirtikara, and J. Thongpron, "Construction of tungsten halogen, pulsed LED, and combined tungsten halogen-LED solar simulators for solar cell i - V characterization and electrical parameters determination," *International Journal of Photoenergy*, vol. 2012, 2012, doi: 10.1155/2012/527820.

[14] H. Kawamoto, "Electrostatic cleaning equipment for dust removal from soiled solar panels," *J Electrostat*, vol. 98, pp. 11–16, Mar. 2019, doi: 10.1016/j.elstat.2019.02.002.

[15] Y. H. Seo, Y. Lee, D. Y. Jeon, and J. I. Han, "Enhancing the light utilization efficiency of microalgae using organic dyes," *Bioresour Technol*, vol. 181, pp. 355–359, 2015, doi: 10.1016/j.biortech.2015.01.031.

[16] D. S. Codd, A. Carlson, J. Rees, and A. H. Slocum, "A low cost high flux solar simulator," *Solar Energy*, vol. 84, no. 12, pp. 2202–2212, 2010, doi: 10.1016/j.solener.2010.08.007.

[17] S. A. Jumaat and M. H. Othman, "Solar Energy Measurement Using Arduino," in *MATEC Web of Conferences*, EDP Sciences, Feb. 2018. doi: 10.1051/matecconf/201815001007.

[18] M. Tawfik, X. Tonnellier, and C. Sansom, "Light source selection for a solar simulator for thermal applications: A review," *Renewable and Sustainable Energy Reviews*, vol. 90. Elsevier Ltd, pp. 802–813, Jul. 01, 2018. doi: 10.1016/j.rser.2018.03.059.

[19] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah, and H. Rezk, "Environmental impacts on the performance of solar photovoltaic systems," *Sustainability (Switzerland)*, vol. 12, no. 2, Jan. 2020, doi: 10.3390/su12020608.

[20] H. A. Kazem, M. T. Chaichan, A. H. A. Al-Waeli, and K. Sopian, "A review of dust accumulation and cleaning methods for solar photovoltaic systems," *Journal of Cleaner Production*, vol. 276. Elsevier Ltd, Dec. 10, 2020. doi: 10.1016/j.jclepro.2020.123187.

[21] S. F. Moosavian, D. Borzuei, and A. Ahmadi, "Energy, exergy,

environmental and economic analysis of the parabolic solar collector with life cycle assessment for different climate conditions," *Renew Energy*, vol. 165, pp. 301–320, Mar. 2021, doi: 10.1016/j.renene.2020.11.036.

[22] A. D. Dhass, N. Beemkumar, S. Harikrishnan, and H. M. Ali, "A Review on Factors Influencing the Mismatch Losses in Solar Photovoltaic System," *International Journal of Photoenergy*, vol. 2022. Hindawi Limited, 2022. doi: 10.1155/2022/2986004.

[23] S. A. Memon, D. S. Upadhyay, and R. N. Patel, "Optimal configuration of solar and wind-based hybrid renewable energy system with and without energy storage including environmental and social criteria: A case study," *J Energy Storage*, vol. 44, Dec. 2021, doi: 10.1016/j.est.2021.103446.

[24] A. O. M. Maka and T. S. O'Donovan, "Effect of thermal load on performance parameters of solar concentrating photovoltaic: High-efficiency solar cells," *Energy and Built Environment*, vol. 3, no. 2, pp. 201–209, Apr. 2022, doi: 10.1016/j.enbenv.2021.01.004.

[25] N. Alias *et al.*, "Air-Processable Perovskite Solar Cells by Hexamine Molecule Phase Stabilization," *ACS Omega*, vol. 8, no. 21, pp. 18874–18881, May 2023, doi: 10.1021/acsomega.3c01236.

[26] S. Ali Sadat, J. Faraji, M. Nazififard, and A. Ketabi, "The experimental analysis of dust deposition effect on solar photovoltaic panels in Iran's desert environment," *Sustainable Energy Technologies and Assessments*, vol. 47, Oct. 2021, doi: 10.1016/j.seta.2021.101542.

[27] X. Luo, J. Shi, C. Zhao, Z. Luo, X. Gu, and H. Bao, "The energy efficiency of interfacial solar desalination," *Appl Energy*, vol. 302, Nov. 2021, doi: 10.1016/j.apenergy.2021.117581.

[28] F. Hosseini-Fashami, A. Motevali, A. Nabavi-Pelesaraei, S. J. Hashemi, and K. wing Chau, "Energy-Life cycle assessment on applying solar technologies for greenhouse strawberry production," *Renewable and Sustainable Energy Reviews*, vol. 116, Dec. 2019, doi: 10.1016/j.rser.2019.109411.

[29] G. Editors *et al.*, "Indoor Testing of Solar Systems: A Solar Simulator for Multidisciplinary Research on Solar Technologies," in *CHEMICAL ENGINEERING TRANSACTIONS*, 2014. [Online]. Available: www.aidic.it/cet

[30] A. E. COŞGUN and H. DEMİR, "The Experimental Study of Dust Effect on Solar Panel Efficiency," *Politeknik Dergisi*, vol. 25, no. 4, pp. 1429–1434, Dec. 2022, doi: 10.2339/politeknik.903989.

[31] A. Halim, A. Rahman, I. M. Sofi, I. Adam, and M. Yaakop, "The Development of Smart Solar Tracker (SST) and Charging System by Using Microcontroller," 2016. [Online]. Available: https://www.researchgate.net/publication/352977452