TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

B-16-BME-2018/2023

DESIGN AND EXPERIMENTAL STUDY OF A SOLAR PV COOLING SYSTEM

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A TERMINAL REPORT SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN

PARTIAL FULFILLMENT OF THE REQIREMENT FOR BACHELOR DEGREE IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING PULCHOWK CAMPUS

MARCH, 2023

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled "Design and Experimental Study of a Solar Panel Cooling System" submitted by Niraj Kumar Kushwaha, Prashant R.D. and Sagar K.C in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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ABSTRACT

Solar PV systems suffer decrease in efficiency due to the increase in temperature as they operate. Hence, a cooling system was designed for an experimental study of the effects of temperature reduction on efficiency. Due to fabrication problems with the spiral collector design, a nozzle spray cooling system was used. The investigation discovered that, as predicted, the open circuit voltage of the solar panels rose with irradiance and fell with temperature. The panels' temperature was brought down by the cooling system, increasing performance efficiency from 50.44% to 58.76%, actual efficiency from 5.8323% to 7.467%, and maximum output from 60.528W to 70.518W. A contour of the solar panel's temperature distribution with and without cooling was made for the simulation component. The panel's maximum and minimum temperatures were determined to be 37.2467°C and 36.666°C, respectively, without cooling. The panel's maximum and minimum temperatures with cooling were found to be 27.127°C and 26.777°C, respectively. It should be noted, though, that the experiment's highest temperature of 44.3°C was higher than the irradiance utilized in the simulation. It was discovered that the panel's average temperature during the cooling experiment was 29.97°C at an irradiation of 738W/m2, which was lower than the temperature discovered in the simulation.

Despite its shortcomings and inconsistencies, the study offers insightful information regarding the potential advantages of cooling systems for enhancing the effectiveness and performance of solar PV panels. The effectiveness of various cooling methods, as well as the effects of panel ageing and wear and tear on their performance, require further study.

ACKNOWLEDGEMENT

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List of Abbreviations

3D	Three Dimensional
PV	Photovoltaic
V	Voltage
R	Resistance
Rh	Rheostat
E	Irradiance
I	Current
T	Temperature
ODE	Ordinary Differential Equations
PDE	Partial Differential Equations

1 INTRODUCTION

1.1 Background

Solar PVs are clean, renewable and relatively cheap energy sources. Solar PV technology works by using the energy absorbed from sunlight to excite the movement of electrons in semiconductor materials. It is a very environmentally friendly source of power as its operation causes no pollution of any natural aspect of the world. In the context of Nepal, hydropower remains the major source of energy however numerous off-grid systems are also incorporating Solar PV panels for the convenience of installation, operation, and maintenance and also due to increasing accessibility and decreasing costs. Due to these very reasons, solar PV panels are becoming popular day by day worldwide for home and commercial power generation purposes.

A significant inherent flaw in current photovoltaic technology is its inability to collect solar radiation from the entire solar spectrum. Due to the significant amount of solar energy that is rejected as heat, PV solar cells have relatively low electrical efficiency. Incident Photons with energies below the bandgap of a PV cell won't be absorbed; instead, they will reach the solar cell's rear surface, where they will be more strongly reflected by the metal contact before leaving the solar cell. The PV cell will absorb photons with energies over the bandgap, which will result in just one electron-hole pair being created per photon and the rest energy being converted to heat in the crystal lattice. Additionally, internal recombination and ohmic losses will turn some of the electron-hole pairs into heat.

The rise in temperature of the PV cell is proportional to the incident photons and ambient temperature, however, it has a detrimental impact on electrical efficiency, even though higher insolation values yield more current output. To reduce the temperature, the most often utilized cooling strategies are the less expensive air cooling and the more effective water cooling. But this increases the complexity and cost of the completed component. Nevertheless, the energy payback period and the annual energy output per unit area have substantial improvement.

Solar PV panels have a rating of their specifications like power, open-circuit voltage, short-circuit current, and efficiency available from the manufacturer with most panels having an efficiency rating of 12-15% (Cai et al., 2016). However, those data are recorded under standard laboratory conditions, which is defined as being 1000 W/m2 of solar irradiance with the cells and the panel being at a standard ambient temperature of $25^\circ C$ with a sea level air mass of 1.5. This data does not correspond to the real-life performance of these panels as numerous experiments and studies point out that the heat generated during the operation of these panels can raise the temperature and affect the voltage, current and performance. Rodrigues, Melicio and Mendez,(2011) illustrated in their study that as temperatures rise, the power generated per voltage developed in the PV module decreases significantly. This causes a drastic reduction of efficiency, especially in areas with an already high ambient temperature or those that don't have much wind which reduces the natural cooling of the panels due to natural convection. This reduces the payback period for the users opting to use alternative energy sources while also reducing the lifespan of

the panel. Hence a design of the cooling system for PV panels was deemed necessary for study.

To study the resulting improvement in efficiency, an experimental setup was assembled and a study was conducted at the location of the Centre For Energy Studies. The materials and methods used to achieve the setup were chosen in an iterative process according to the available resources within limitations.

1.2 Main Objective

The main objective of the project is to reduce the operating temperature of the PV panelusing an active cooling method.

1.2.1 Specific Objectives

- To generate I-V characteristics of PV module.

- To measure the increase in efficiency, power and performance efficiency

- To compare experimental data with simulated results

1.3 Assumptions and Limitations

- The effect of wind was random and was not accounted for.

- The effect of natural convection was unaccounted for in the experiment.

- The panels were old hence rated specification wasn't reliable

2 Literature Review

This section contains the contemporary information necessary to understand the effect of operating temperature on Solar PV panel output.

2.1 Solar Photovoltaic Module

2.1.1 History

The history of (PV modules or solar panels, can be traced back to its origins in the discovery of the photovoltaic effect in 1839 by French physicist Alexandre-Edmond Becquerel. However, it wasn't until the 1950s that Bell Labs developed the first practical silicon solar cell, which laid the foundation for modern PV technology. Bell Labs created the first PV module in 1954, using silicon as the semiconductor material. However, these early solar panels were costly and inefficient. Only in the 1970s did PV technology begin to be used in practical applications, such as powering space satellites and remote telecommunication systems. The 1980s saw significant advancements in PV technology, resulting in the development of larger and more efficient solar panels. As a result, the cost of PV modules began to decrease, making them more affordable for residential and commercial use. Since then technology has kept upgrading as the world transition to a state of renewable and emission-free energy being the main objective (Fraas, 2014).

2.1.2 Working Principle

A crystalline Silicon photovoltaic module converts 13% to 20% of incident solar radiation to electrical energy via photovoltaic action, while the remaining radiation is converted to thermal energy via infrared radiation of the solar spectrum and heat generated by the photovoltaic activity. (Bhubaneswori P. 2011).

Mathematically the process can be expressed as in equation 1

$$E = \frac{hc}{\lambda} \tag{1}$$

where where E is the energy given by the photon, h is Planck's constant, c is the speed of light and λ is the wavelength of the photon.

Chouder, Silvestre and Sadaoui,(2011) have shown that the PV modules can be modelled as an equivalent circuit current source. The current-voltage relationship developed in a PV module is given as :

$$I = I_{ph} - I_0(e^{\frac{(V + R_s I)}{A}} - 1) \tag{2}$$

where I_{ph} is the photocurrent generated in the material (Ampere), I_0 is the saturation current of the diode (Ampere), and $A = \frac{nkT}{q}$ is the modified ideality factor which is a factor that represents how much a diode follows the ideal diode equation, n is the diode ideality factor, k the Boltzmann constant ($1.38 * 10 - 23 J K^{-1}$), q the electronic charge

$(1.602 * 10^{-19}C)$, T being the cell temperature (K), V_t is the thermal voltage ($V_t = \frac{kT}{q}$), R_s the series resistance (Ohm) and R_{sh} is the shunt resistance (Ohm).
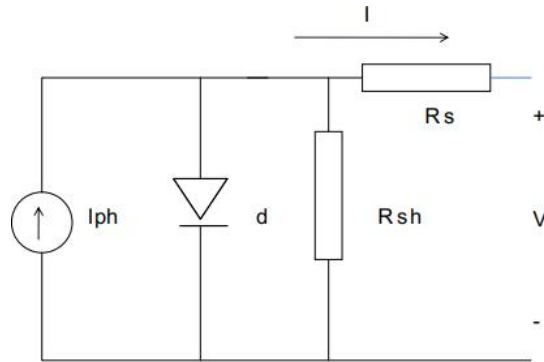
Figure 1: Equivalent Electrical circuit of the single diode model.(Chouder et al., 2011

2.1.3 Efficiency of Solar PV

Efficiency is a very important factor that determines how well the solar cell is working i.e to measure its performance. It is defined as the ratio of the output power that is generated by the solar cell to the input energy received due to solar radiation incident on the solar panel surface. It can be calculated with the formula:

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \tag{3}$$

where η is the efficiency of the panel, V_{OC} is the open-circuit voltage of the panel, I_{SC} is the short-circuit current of the panel and FF is the fill factor of the solar panel which is calculated by the formula in Equation 4

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}} \tag{4}$$

where V_{MP} and I_{MP} are the voltage and current respectively during maximum power in an I-V curve.

2.1.4 I-V and P-V Characteristics of Solar PV module

The IV curve of a solar cell is the superposition of the IV curve of the solar cell diode in the dark with the light-generated current.(Lindholm et al.,1979)
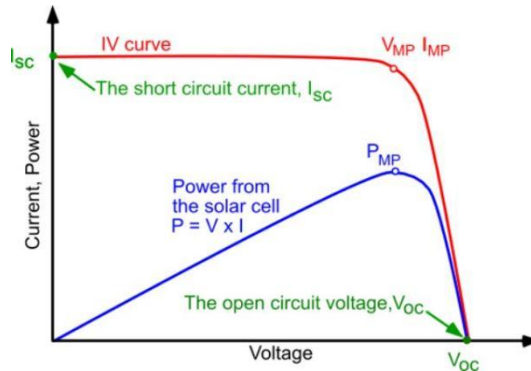
Figure 2: Current voltage (IV) cure of a solar cell. To get the maximum power output of a solar cell it needs to operate at the maximum power point, P_{MP})

2.1.5 Effect of Temperature on Solar PV Characteristics

Rodrigues, Melicio and Mendez,(2011). illustrated that as temperatures rise, the power generated per voltage developed in the PV module decreases significantly. Kumar, Sharma and Jain (2007) observed that with every 1°C rise in PV panel temperature its efficiency decreases by 0.5%. Various cooling active and passive cooling techniques can be used to reduce the temperature of the PV module. the efficiency of the PV module. The efficiency of the PV module depends on various parameters like solar irradiance, ambient temperature, wind speed over the module and the nature of the flow. Moreover, the most important parameter of solar irradiation depends on other factors like geographical location, time of day, local weather, air quality, local landscape etc.
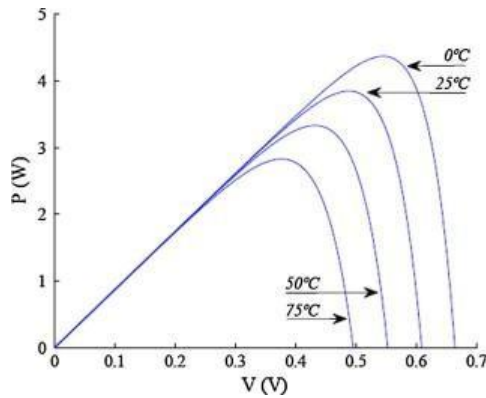
Figure 3: P–V characteristics as a function of the module temperature T. (Rodrigues et al 2011)

2.2 Relevant Past Studies

Solar energy is an important source of renewable energy with the potential to meet global energy needs. However, the efficiency of solar panels decreases with increasing temperature, leading to a reduction in power output. According to a study conducted by M. S. Suleiman and S. Mekhilef (Singh A. 2016), an increase in solar cell temperature from 25°C to 75°C results in a 40% decrease in power output. This decrease in efficiency is due to the increased recombination of electrons and holes and decreased carrier mobility.

To overcome the drop in efficiency due to temperature, various cooling methods have been proposed, including air-cooling, water-cooling, and passive cooling. In a study by S. S. Patel (2018), they investigated the use of air-cooling to improve the efficiency of solar panels. The study concluded that the use of air-cooling can improve the performance of solar panels, leading to an increase in power output.

Zeyad A.heidar(2016) worked on the experimental investigation of evaporative cooling for enhancing photovoltaic panels' efficiency. The heat generated from the body of the PV module was absorbed by the evaporation latent heat resulting in a reduction of module temperature. The experimental setup was tested under outdoor conditions. The back surface of a PV panel was wetted by water supplied from a tank and exposed to the surroundings. The experiment resulted in more than a 20°C reduction in PV module temperature and around a 14% increase in electrical efficiency was observed.

(Arcuri,2014) worked on Numerical solutions for PV module cooling using air and water as working fluids, in PV panels duct to increase the efficiency of power generation. He found the average annual efficiency of PVA Panels for cooling with water and air is 12.65% and 12.58%, and annual energy generation to be 270.93 kW/hr and 269.53 kW/hr, respectively. We can see that the efficiency of PV panels is higher with water cooling than air cooling though the difference is not that large.

Oden and Behnia(2009) worked on an experimental-numerical analysis of PV panel cooling by water flow. The results of their experiment showed that due to the flow of

water in the panel, a 15% increase in the performance of the system was normalized under irradiation conditions. Also, the 5% increase in annual energy generation in warm seasons is a result of numerical calculations.

Erdem cue,(2013) illustrated the optimized thermodynamic factors of solar PV cells through the use of air cooling. The author used a properly known and trusted CFD software to evaluate the cooling utilization in terms of betterment of energy conversion from one state to another in solar cells. In this research, air was used as a coolant in the numerical study. In the result section, the author found that the cooling applications are significant factors that can postively affect the efficiency and maximum power of the photovoltaic modules.

In a research conducted by Sargunanathan,(2016) active cooling by spraying the water over the front plane of a PV module was found to be instrumental raising solar efficiency and also the operating temperature was reduced to 26°C and the refraction losses of cell surface were reduced by 2-4%

Z.Farhana,(2012) studied experimentally the operating temperature variation for the PV module with and without an active cooling system to observe the electrical performance of the PV module. Two multi-crystal silicon solar modules with 13% of peak efficiency at standard conditions (25°C, 1000 W/m2) were used in the test. One of the modules was used as a reference and in case of the other, an aluminum heat sink was installed at the bottom of the PV panel and a DC brush-less fan was installed on the heat sink. The temperature for the PV module with and without a cooling system was higher than ambient temperature by 30% and 70%, respectively Hence, the open-circuit voltage of the PV module with a cooling system was a little higher than that of the photovoltaic module without a cooling apparatus.

S. Nizetic,(2016) experimentally investigated the impact of water spray cooling on the performance of the PV panel in the environment of highest solar irradiation level . Both sides of the PV panel were cooled at the same time by utilizing twenty nozzles, with ten on each side. The results were measured for three different cases of cooling: front-side cooling, rear-side cooling, and both sides together and compared with a case of control that is a non-cooling case. The research indicated that the water spray cooling has achieved a significant effect on the PV panel performance and the best case was the simultaneous or dual side; front and back, cooling of the PV panel.

Naimish Kumar Baranwal and Dr. Mukesh Kumar Singhal,(2020) performed CFD analysis of a PV/T spiral type water collector. This collector was found to be more efficient than other collector. For optimal power output, system should be operated between 33-66 L/h of flow rate.

2.3 Finite Element Analysis

Calculations, models, and simulations are used in finite element analysis (FEA) to forecast and comprehend how an item might react under various physical conditions. Computers are used by FEA softwares to analyse and simulate physical interaction.Governing equations used by FEA models include the continuity, momentum,stress-strain and energy equations etc.. Together, they all form the basis of FEA.For fluid flow i.e CFD (Computational Fluid Dynamics), the three fundamental physical laws of conservation of mass, momentum, and energy form the basis of fluid dynamics while for heat transfer problems, the Fourier law of heat transfer is the basis. These fundamental physical concepts are transformed into partial differential equations (PDEs), which are then solved numerically to create a mathematical model. Instead of PDEs, discretized algebraic equations are used, and these equations are then solved with the aid of powerful computers with a large amount of processing power and memory.

Finite Element Analysis through software, consists of three steps:

- Preprocessing

- Solver

- Post processing

Each step is discussed in further detail below.

2.3.1 Preprocessing

Preprocessing is known as the preliminary stage of any FEA simulation. In this step, the parameters regarding the analysis or simulation are defined. It also incorporates the work of geometric modeling of the physical problem with the help of a CAD(Computer Aided Design) software. The model so obtained is divided into finite elements and the result is called a mesh. The mesh generation is followed by the processes of defining the material property and the input of the boundary conditions. For the modeling of this geometry, CAD softwares like CATIA, Solidworks etc. can be used. Meshing can be done in ANSYS Steady State Thermal for thermal analysis and ANSYS Fluent or CFX for fluid flow analysis. For accurate results, the finer the mesh element sizes are, the better.

2.3.2 Solver

Solvers are the software packages like ANSYS Fluent or ANSYS Steady State Thermal provide user interface for selection of material, definition of properties, initial and boundary conditions and else parameters needed for the solving of the governing equations of any physical phenomenon to be analyzed. Different solvers may use different methods for the numerical discretization of a physical system. For this study ANSYS Fluent and ANSYS Steady State Thermal are used.

2.3.3 Post-processing

Postprocessing refers to the stage of FEA where the results obtained from the solver are analysed. For this purpose of analysis and to aid in understanding, various tools and visualisation techniques are made available.

3   Experimental Setup

3.1   Spiral Water Collector

A spiral water collector is a component used in a photovoltaic (PV) module cooling system designed to collect and transport water to cool the PV modules. The spiral water collector is typically made of a lightweight and durable material such as plastic or metal, and is designed to fit within the frame of the PV module.

The spiral water collector is composed of a series of spiraling channels that run parallel to each other. These channels are designed to collect water that is pumped through the system and distribute it evenly across the surface of the PV module. The spiral design of the water collector ensures that the water flows in a continuous and uniform manner across the surface of the PV module, maximizing the efficiency of the cooling system.

The water is typically pumped through the system using a small electric pump, which is powered by the PV modules themselves. The water is collected from a reservoir or other source and is circulated through the spiral water collector and over the surface of the PV module, where it absorbs heat and cools the module.

The water that is collected by the spiral water collector is typically returned to the reservoir or other source for reuse, minimizing waste and conserving water resources. The use of a spiral water collector in a PV module cooling system helps to increase the efficiency and lifespan of the PV modules, ensuring that they operate at peak performance for a longer period of time.
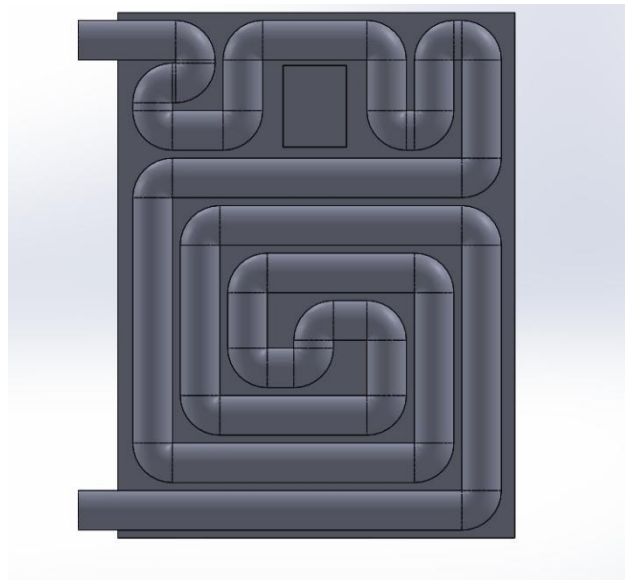
Figure 4: Spiral Collector Design

3.2 DC Pump

A device known as a DC pump is one that is designed to move fluids while being powered by a direct current (DC) power source. It's components normally include an impeller, motor,exit and inlet and exit ports, and a housing, among other important parts. The motor is in charge of transforming electrical energy from the source into mechanical energy as output, which is then applied to rapidly spin the impeller. A pressure difference caused by the impeller, in turn, causes fluid to be drawn into the input port and forced out the outlet port.

DC pumps are extensively employed in numerous applications, including the transfer of fuel, coolant, and water. In some situations, they are favoured over AC pumps because they provide superior control, efficiency, larger power densities, and less maintenance needs. In order to provide sophisticated functionality like variable speed control, flow monitoring, and fault detection, DC pumps can also be combined with electronic controllers and sensors. In this study a 12V DC pump is used to supply coolant i.e water through the nozzle spray.

Figure 5: DC Pump

3.3 Arduino

Arduino is an open-source electronics platform that consists of both hardware and software components. At its core, Arduino is based on a programmable circuit board, also called a microcontroller board, that can be programmed to perform a variety of functions. The board are equipped with numerous sets of both digital and analog input and output pins that allow it to interface with sensors, actuators, breadboards and other electronic components.

Overall, Arduino provides a low-cost, easy-to-use platform for prototyping and experimenting with electronic circuits and automation systems. Its open-source nature and large community of users make it a popular choice for a wide range of fields. It allows for the setup of a convenient, automated system for experiments that require a lot of data to be recorded at once and for long periods of time. For this study an Arduino UNO R3 was used to be at the helm of automating all the different sensors required to take the necessary data.
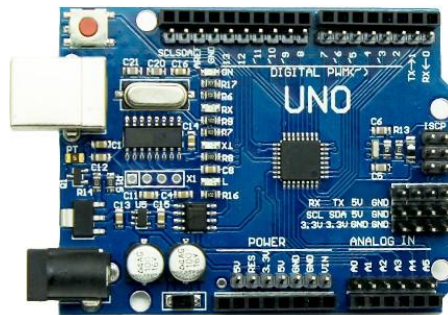
Figure 6: Arduino UNO R3

3.4   Voltage Sensors

An electronic device that gauges the potential difference between two locations in a circuit is called a voltage sensor. It works by transforming the voltage into an equivalent electrical signal that other electronic components can process and analyse.

Voltage sensors are used in a wide range of scientific and engineering applications, including power systems, industrial automation, and instrumentation. In this study voltage sensor was used in connection with Arduino so as to automate the voltage recording process.

Figure 7: Voltage Sensor

3.5   Current Sensor

An electronic tool that gauges the flow of current in a circuit is called a current sensor. It functions by transforming the current into an equivalent electrical signal that other electronic components can process and analyze.

To determine the current flowing across a circuit, current sensors typically employ one of several sensing methods, such as transformer, shunt resistor, or Hall effect sensing. Extra components might also be included, like filters or amplifiers, to boost the measurement's precision and dependability.

Current sensors are used in a wide range of scientific and engineering applications, including power systems, electric vehicles, and industrial automation. In this study, current sensor was used for the automation of recording data obtained by measuring the current flowing across the PV module.

Figure 8: Current Sensor

3.6 Rheostat

A rheostat is an electrical component used for varying the resistance in a circuit. It consists of a resistive element, typically a coil of wire or a carbon composition material, that can be adjusted to change the resistance of the circuit.

Rheostats operate by converting electrical energy into heat through the resistive element. As the resistance is increased, more electrical energy is converted into heat, and less is available for the rest of the circuit. This allows the current to be controlled and varied, which can be useful for regulating the load in a given circuit.

Hence rheostats are applicable in scientific and engineering applications, including electronics, electrical power systems, and laboratory experiments. In this study, a rheostat was used to vary the resistance in the circuit so as to measure voltage and current at different loads and generate the I-V curve.

Figure 9: Rheostat

3.7 Multimeter

A digital multimeter (DMM) is an electronic instrument used to measure multiple electrical parameters in a circuit, such as voltage, current, and resistance. It typically consists of a display screen, a selection knob, and probes or test leads.

The DMM works by using an analogue-to-digital converter (ADC) to convert the electrical signals being measured into digital values that can be displayed on the screen. The selection knob is used to choose the parameter to be measured, and the probes or test leads are connected to the circuit to make the measurement.

DMMs are hence widely suitable for scientific,industrial and engineering applications due to their versatility and capability of measuring a wide range of values of different parameters with high accuracy and their portability and durability for use in field applications.

Figure 10: Multimeter

3.8 Temperature Sensor

A digital temperature sensor is a piece of technology that accurately and precisely measures the temperature of the area around it. Typically, it consists of an output interface, a signal-processing module, and a temperature-sensing element.

Thermocouples, resistance temperature detectors (RTDs), and thermistors are only a few examples of the technologies that can be used as the temperature sensing element. The signal processing unit transforms the output signal from the sensing element into a digital signal using methods like analogue-to-digital conversion (ADC) or pulse-width modulation (PWM).

The output interface of the digital temperature sensor is typically in the form of a digital bus protocol, such as I2C or SPI, which allows it to communicate with other digital devices such as microcontrollers or computers.

Digital temperature sensors are widely used in scientific, engineering, industrial, and consumer applications for temperature monitoring. They provide high accuracy and stability, low power consumption, and ease of integration with other digital devices. Digital temperature sensors are also often more robust and less susceptible to noise and other environmental factors than analog temperature sensors. For this study, an HW 557 temperature sensor was used along with multiple other LM35 sensors to monitor the temperature of the PV module.

3.9 Pyranometer

An instrument known as a pyranometer is used to measure the total amount of solar radiation, or the amount of solar energy that reaches the surface of the Earth. It comprises of a flat, horizontally positioned sensor unit that faces the sky.

A thermopile, a device that produces a voltage in reaction to a temperature difference between its two surfaces, is commonly used as the sensor element in pyranometers. When solar energy hits the sensor, it alters the temperature across the thermopile and produces a voltage inversely proportional to the amount of radiation received.Pyranometers are calibrated to measure the total solar radiation across the entire spectral range of the sun's output, from ultraviolet to infrared wavelengths. They may also be designed to measure only a specific portion of the spectrum, such as the visible range, depending on the application.

Pyranometers are widely used in atmospheric science, meteorology, solar energy research, and agriculture. They are often used in conjunction with other meteorological instruments to monitor weather conditions and to estimate the amount of solar energy that can be captured by solar panels or used for agricultural purposes.

In this study, a pyranometer was used to monitor the solar irradiation on the Solar PV module.

Figure 11: Pyranometer

4 Methodology

Methodology is the process by which a goal or objective is accomplished. In methodology chapter, we have listed the process by which our project was completed. So, we started with literature review, selection of suitable cooling method (iterative process), then we performed test with and without cooling, and discussions and conclusion were done based on the data obtained from the two tests and finally documentation of the project was done
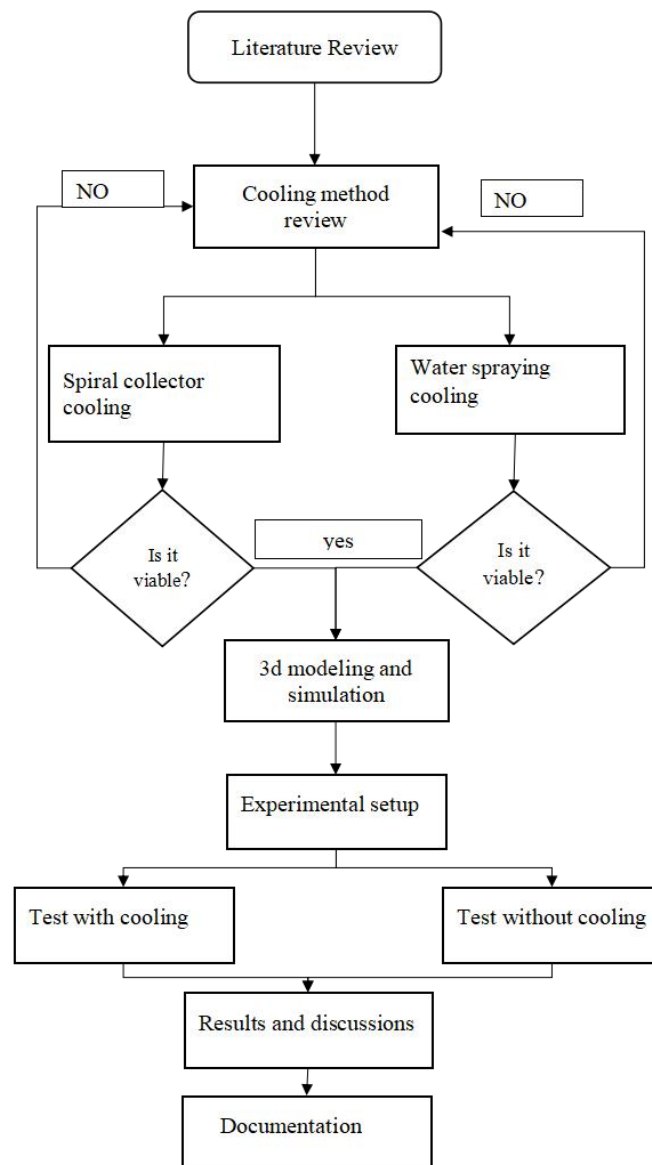
Figure 12: Methodology

4.1 Literature Review

Various research papers and journal relating to our project title were caerfully studied. These research papers and review papers were collected from both online and offline sources. For the cooling purpose we selected the water spray cooling technique for cooling of solar panel.

4.2 Cooling Method Review

The different cooling method were studied in literature review with some being cooling involving nanomaterials, cotton wick,water immersion of PV panel etc . Among them, cooling the PV panel by using spiral collector at the backside of PV panel and water spraying cooling method were chosen.

4.2.1 Spiral Water Collector

The spiral water collector is great for cooling PV panel. We needed to design a collector which was flat at one side and semi-circular in the other side. The flat nature of the pipe would helped in having greater surface area contact with the PV panel. The 3D print of the collector could not be made due to the overhanging of the collector which caused the structure to fail and also the bed of the available 3D printer was smaller than the required area so a compromise needed to be considered. Hence the spiral water collector was determined as not viable for our project.

4.2.2 Water Spray Cooling

Eventually, water spray cooling was selected as our main cooling method as it was easy to fabricate and relatively cheaper compared to spiral cooling method.

4.3 3D Modeling and Simulation

The dimension of solar PV panel selected for our project was 158mm*81mm. For the 3D modelling part , a panel of thickness 0.225mm and glass of thickness 3mm are considered. These two parts CAD model are created in and they are assembled in Solidworks 2022. The simulation was done in Ansys. The properties of solar panel and glass used in simulation are as follows():

S.N	Part	Thickness	Thermal Conductivity	Density	Specific heat
1	Solar PV	0.225mm	148W/mK	2330 kg/m^{-3}	677
2	Glass	3mm	1.8W/mK	3000kg/m^{-3}	500

Table 1: Material Properties

In our project water is sprayed on the glass so there is a fluid surface interaction between solar panel as a whole and water flowing over it. We use steady state subsystem to simulate the thermal distribution in solar panel and we used fluent subsystem to simulate the fluid flow.
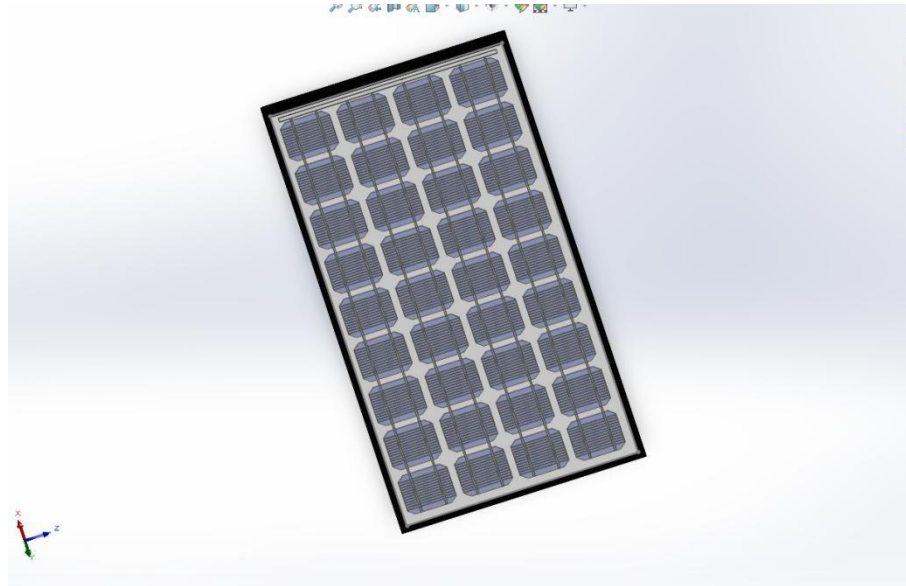
Figure 13: CAD Model of Solar PV Panel

Heat is transferred from the water to the glass with help of the convection and the heat of glass is also transferred to water so two way fluid surface interface is required. Two way FSI is done by linking fluent subsystem with steady state thermal subsystem by system coupling in Ansys. Steady state thermal analysis is done for solar panel and glass. Heat flux of 754 w/m^2 was incident upon the glass ,the ambient temperature was assumed to be 25 °C. The convection rate was assumed to $19 wm^{-2}k^{-1}$ .The nodes and elements in the mesh are: 2806 and 306 respectively. For fluent part a rectangular domain of thickness 2mm is assumed . A flow rate of 10l/min is supplied at the inlet(temperature 300K) and at the outlet of the domain was specified by static pressure which is equal to gauge pressure. . Reynolds number is given by: Re=ρul/μ Where ρ is the density of water which is equal to $1000 kg/m^3$, u is the velocity which equals 0.1029m l is the characteristic length equal to 2mm and μ is the kinematic viscosity which equals to 8.90×10^{-4} pa.s so the Reynolds number is 23 ,132 and therefore a turbulence flow regime is considered K epsilon model was used as turbulence model. The fluid surface interface portion of the domain is linked to system coupling and no slip condition condition is applied to remaining portion. Scaled residuals measure the convergence of the numerical model so all the residual values were set to 10^{-4} . The model was initialized from inlet and then solved until the solution converged.

4.4 Experimental Spray Cooling

A 120w rated power 21v open circuit voltage and 7.7 amps PV panel was chosen for this project. At first the different parameters were measured without cooling of solar panel. Voltage and current sensor were used to measure the output voltage and current of the panel. An Arduino was used to transfer the data from sensor to computer. By varying the resistance on a variable resistor different values of voltage current were recorded. Simultaneously, the temperature was also recorded by the temperature sensor

at the instant the value of voltage and current were taken. A pyranometer was used to measure the solar irradiance.

We used spray cooling technique for cooling of PV panel. The water was sprayed in the interval of 30s and current and voltage were recorded at varying resistance. Then the corresponding temperature was measured. Solar irradiance were also recorded.

Following were the test conditions:

- Both tests were conducted between 11:00 am to 1:30 pm.

- Water was used as the cooling medium

- The tests were conducted in a stable atmosphere and The sudden change of atmospheric condition was not preferred

- The test was conducted at the rooftop center for zero energy studies.

- Water was sprayed at the front side of the PV panel for every 30s.

- The reading were measured at every 30s time interval

4.5 Results and Discussions

After successfully conducting the experiment, data of the voltage and current parameters were obtained. To generate the I-V and P-V characteristics of PV module, the data was imported into MATLAB and plotted. Calculations were done for the The electrical efficiency of both cooled and uncooled studyand a comparison between these obtained efficiency and power was done and the results were interpreted to describe the experiment, implications and sources of error were discussed and recommendations were given to improve the study.

5 Results and Calculations

In this section of the report, we calculated the power and efficiency of solar panel with the help of experimental data obtained from the cooling and uncooling test. We also simulated the process and the temperature distribution contour so obtained from the simulation was used to show the variation in the panel and also to calculate the efficiency of solar panel.

5.1 Simulation Results
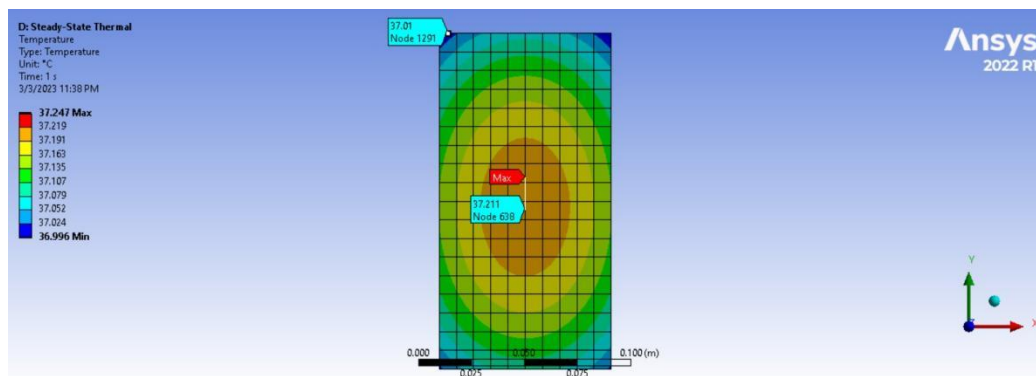
Figure 14: Temperature Distribution of Solar Panel Without Cooling

From the contour in figure 12 it can be understood that the temperature around the centre is the largest and it decreases farther away from the center. The maximum temperature of the panel is 37.247°C and the minimum temperature is 36.996°C. After cooling
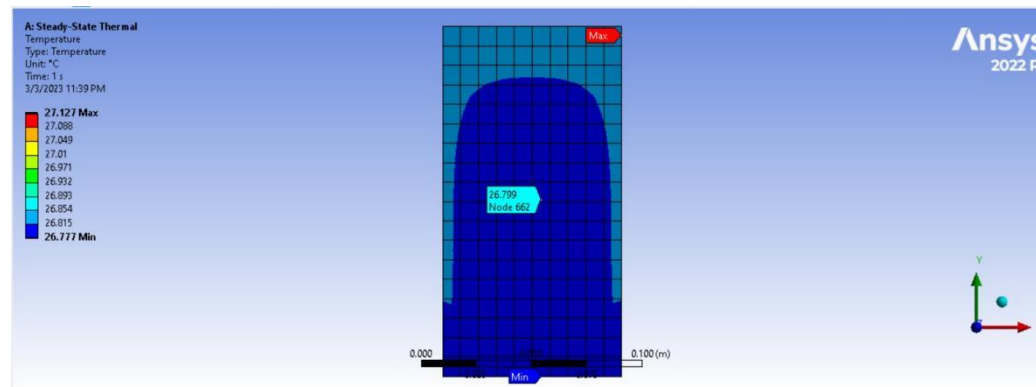
Figure 15: Temperature Distribution of Solar Panel After Cooling

by spraying the maximum temperature of the panel was observed to be 27.127°C and the minimum temperature was observed to be 26.77°C. let the average temperature be the average of two extreme temperature. Without cooling, the average temperature would be 37.127°C. With cooling , the average temperature would be 26.9485°C. So the reduction in average temperature is 37.127°C-26.9485°C=10.1785°C.This is nearer to reduction obtained in average temperature between cooling and without cooling condtion i.e. 12.125°C.

The temperature of water exiting the panel was found to be 27.368℃ and the efficiency of panel is calculated by: $\eta=\eta_{ref}(1-\beta*(Tc-Tref))=8.78\%$. (Tiwari and sodha ,2005)

5.2 Experimental Results

We performed experiments on the basis of previous studies in this field. The location of the experiment was chosen where there was the less chance of obstruction in incoming of solar irradiance. On this basis, the terrace of the Center for Energy Studies (CES) was suitable. The experiments were performed there and the results from the experiment is as below:

5.2.1 Without Cooling

The relationship between solar irradiance average and the generated open-circuit voltage was established with the data as displayed in the following table:

E	Voc
21.01	16.9
48.363	17.3
75.1908	18.28
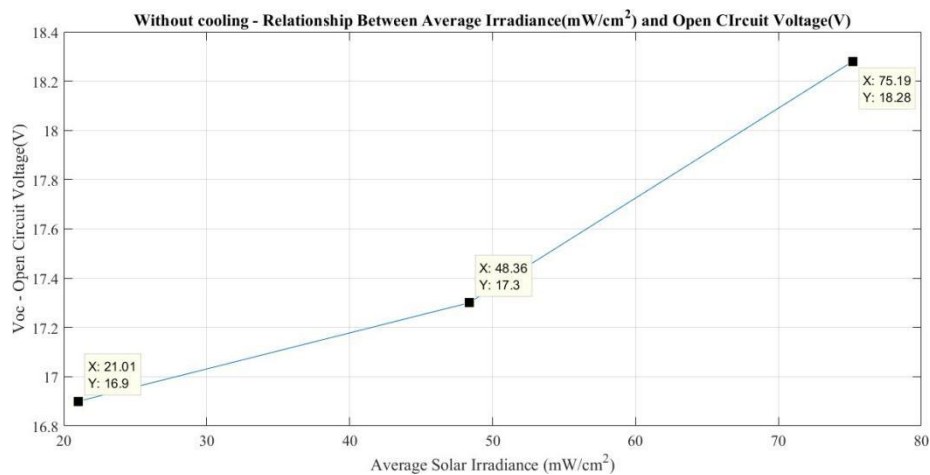
Figure 16: Relationship Between Solar Irradiance and Open Circuit Voltage

The I-V relationship during an average irradianceof $53mW/cm^2$:
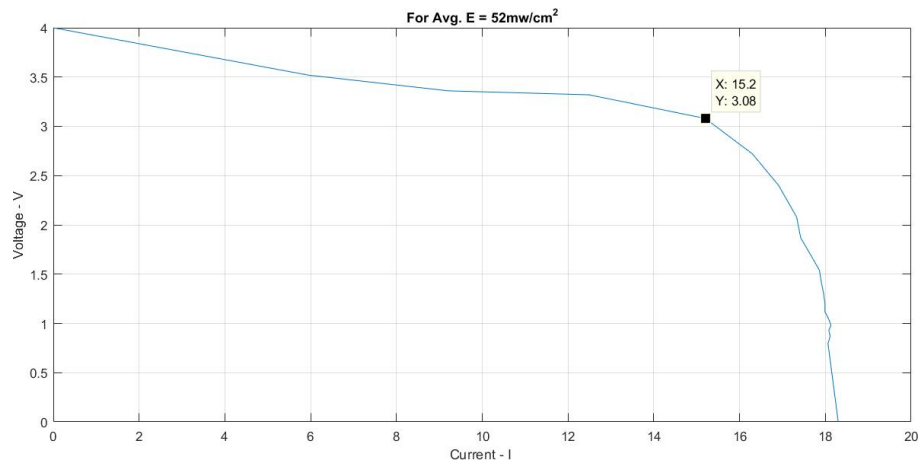
Figure 17: V-I Relationship at avg, irradiance is $53mW/cm^2$
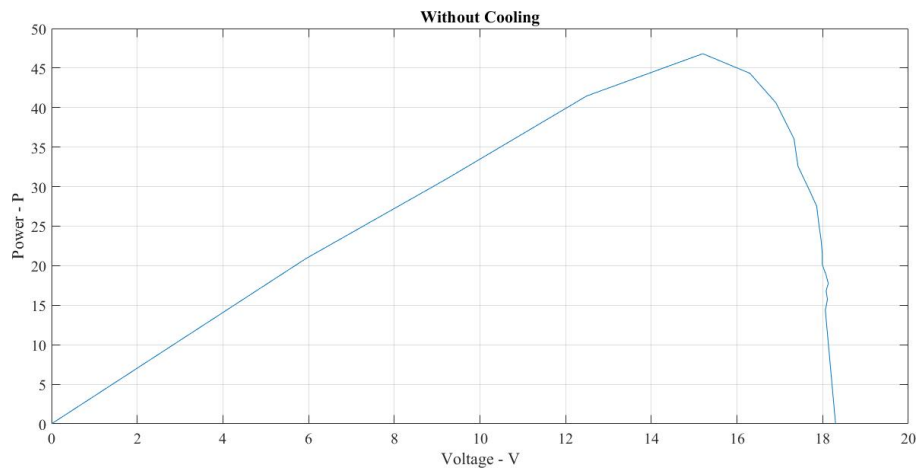
Figure 18: P-V Charasteristics at avg, irradiance is $53mW/cm^2$

The results from the experiment are shown in the graph as illustrated from the Table 2 in the Appendix section.
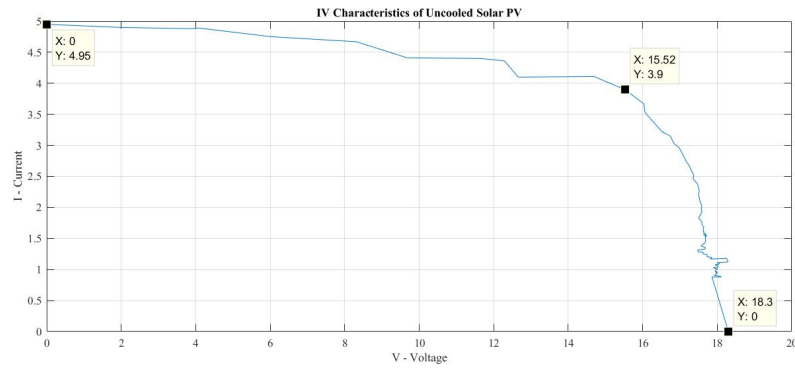
Figure 19: IV Characteristics of Uncooled Solar PV
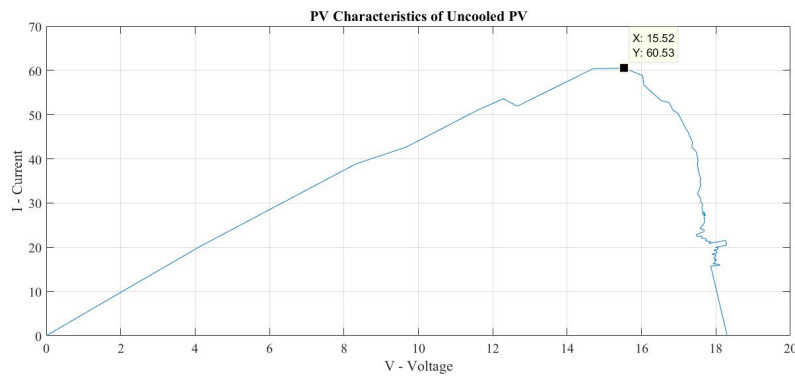
Figure 20: PV Characteristics of Uncooled Solar PV

	Without cooling
V_{oc}	18.3V
I_{sc}	5.03A
P_{max}	60.528W
Avg.solar radiation	81.094mW/cm^2
Fill factor	0.6575
P_{input}	1037.8W
overall efficiency	5.83%

rated power	tempearture	maximum power	temperature	performance efficinecny
120W	25℃	60.528W	41.71℃	50.44%

Where performance efficiency $= \frac{max\ power}{rated\ power} * 100\%$

and overall efficiency was calculated using formula 3.

5.2.2   With Cooling

The results from the experiment are shown in the graph as illustrated from the Table 3 in the Appendix section. From this table, we have observed the necessary data points for
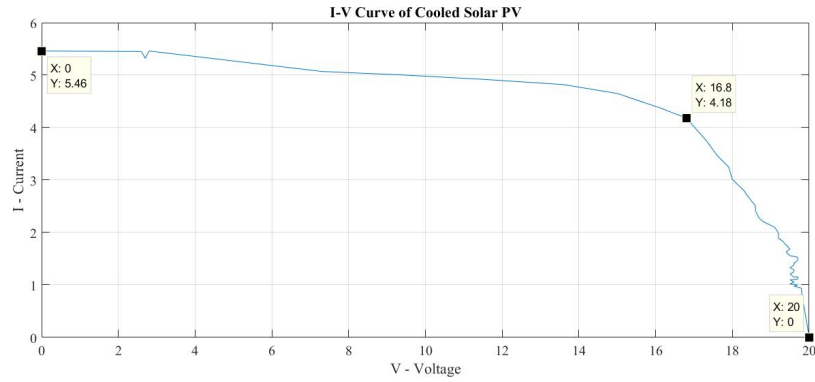
Figure 21: IV Characteristics of Cooled Solar PV
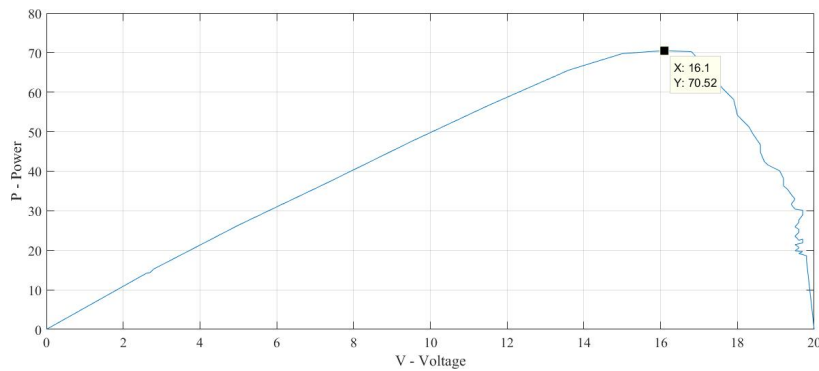
Figure 22: PV Characteristics of Cooled Solar PV

Efficiency calculation with cooling

	with cooling
V_{oc}	20V
I_{sc}	5.46A
P_{max}	70.518W
Avg.solar radiation	73.73mW/cm²
Fill factor	0.645765
P_{input}	944.4W
Overall efficiency	7.47%

rated power		maximum power	temperature	performance efficinecny
120W	25℃	70.518W	41.71℃	58.76%

Where performance efficiency $= \frac{max\ power}{rated\ power} * 100\%$

and overall efficiency was calculated using formula 3.

5.2.3   Comparison

The results from Table 2(Uncooled) in red and Table 3(With Cooling) in blue were compared in the same graph to see results.   From these graphs, it is illustrated that
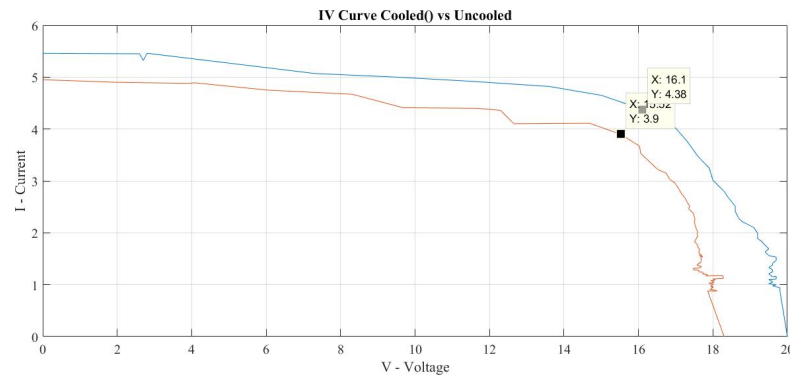
Figure 23: I-V Characteristics of Uncooled vs Cooled Solar PV
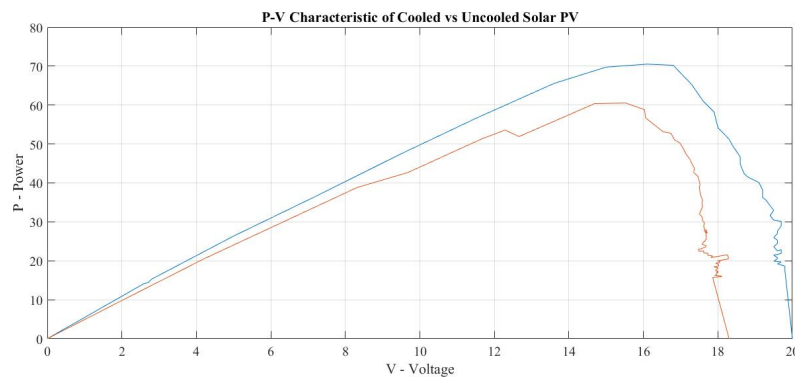
Figure 24: PV Characteristics of Uncooled vs Cooled Solar PV

through the cooling system usage, there was significant increase in overall power and also the maxium power output of the solar PV module.

6 Budget

S.N	Particulars	Specifications	Quantity	Rate	amount (NRs)
1	Panel	10W	1	1000	1000
2	Pump	9V	1	150	150
3	Temperature sensor	LM35	4	100	400
4	Battery	9V	2	50	100
5	Voltage sensor	Vcc25V	1	225	225
6	Temperature sensor	Digital	1	400	400
7	Resistors	4 *1KΩ, 100KΩ	5	1	5
8	Current sensor	ACS712	1	250	250
9	Battery	3V	1	120	120
10	Humidity sensor	HW036	1	250	250
11	Nozzle and Pipe				1190
12	Pump	12V	1	1000	1000
13	Arduino	UNO R3	1	2000	2000
14	Multimeter		1	1200	1200
15	Miscellaneous				300
				Total	8590

7   Challenges and Limitations

Solar panels can convert only a small part of incoming solar radiation into electricity. Most of the irradiance from sun is converted into either heat or it is reflected back to the environment which can be considered as a loss of energy. Furthermore, the increase in operating temperature of solar PV module decreases the solar efficiency and rated efficiency. However, the operating temperature of PV panel can be reduced by various cooling methods. We chose first of all Spiral water collector cooling, we made the design of spiral water collector which was supposed to be attached to the back of the panel and that design would have given us higher efficiency in our experiments as compared to the methods performed.

However, the problem arose in the manufacturing i.e. 3D printing. The printer available in our location was not able to print as the design was larger than the maximum printer capacity. Shrinking down the design was a choice to perform the experiment but according to the literatures we reviewed, the method would not have given us satisfactory results due to uneven cooling. This was the main reason behind the selection of water spraying method over the spiral water collector method of cooling. This experiment has not delved into the energy consumption due to the need of pumping the coolant due to the limitations of time, which is an area of improvement.

8   Discussions and Conclusions

For the simulation part contour of temperature distribution of solar panel with and without cooling was created. Without cooling, the maximum temperature of panel was found to be 37.2467°C and the minimum temperature of the panel was found to be 36.666°C.With cooling, the maximum temperature of the panel was found to be 27.127 and the minimum temperature of the panel was found to be 26.777°C. Without cooling , a maximum temperature of 44.3°C was observed during the experiment. This temperature was observed at the irradiance of 860W/m2 while for simulation a 738 W/m2 irradiance was used. A constant irradiance was assumed for the simulation while for the experiment constant irradiance was not observes. With cooling a average temperature of 29.97°C at 738W/m2 was measured during experiment. The temperature reduced by 14°C which lies is between 5-23°C (Zubeer, Mohammed, & Ilkan, 2017) using water spraying method over the front of the panel. This value is less than the value found in simulation. The reason might be the fact the water sprayed over the front surface of the panel in the simulation was assumed to completely wetted the front cover while in the experiment the water sprayed from the nozzle did not completely wet the front cover.

With the conclusion of the experiment, an increase in performance efficiency by 8.76% in terms of absolute percentage of performance efficiency. As expected due to the temperature coefficient of efficiency of a solar PV module, the decrease in efficiency in the PV module without cooling system was dropped to 5.8323% and a significant increase to the efficiency was observed by the application of cooling system, 7.467%. The maximum power was observed to have increased by 10W. This corresponds to a 16.67% increase in the maximum power output of the PV cells. Irwan et al.(2015) found that the power output was increased by 9–22%.

Cooling a solar panel surface helps increase its efficiency by reducing the temperature of the panel and thus minimizing the negative impact of temperature on the photoelectric properties of the materials used in the solar panel. At high temperatures, the thermal energy causes the atoms or molecules in the material to vibrate more intensely, which results in increased electron-hole pair recombination rates and reduced carrier mobility. This ultimately leads to a decrease in the panel's power conversion efficiency.
Cooling the panel reduces the thermal energy of the materials, decreasing the vibration of atoms or molecules in the panel, and thus reducing electron-hole pair recombination rates and increasing carrier mobility. This results in higher efficiency of the solar panel.

Although the rated power was 120W, with the open circuit voltage being 21V and short circuit current being 7.7A. The results were significantly less. Even under cooled conditions, the open circuit voltage only reached 20V and the short circuit current reached 5.46A. This reduction is likely due to the old age and wear of the panels and also with the contribution of temperature as both age and temperature rise are known to contribute to the reduction of performance parameters of a Solar PV module.

9 Recommendations

The following suggestions and recommendations are provided to aid and enhance any related study in the future:

- Only a single nozzle was used for the experiment as such the whole front side of the panel was not applied with coolant simultaneously. Increasing the number of nozzles would aid in the cooling process.

- Experiments can be done at different flow rates to obtain the varying result. So a flow controller attached to the nozzle would be helpful.

- Sprayed water should be not be wasted. The water exiting from the surface can be recirculated for various use.

- Cooling technique optimization can be used to further optimize the cooling process.

- Water was used as the cooling fluid in this project as water is inexpensive and easy to use. Nanofluid can be used as fluid for the cooling process for further study..

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A Tables

Table 2: I-V Characteristics of PV without cooling

R%	R	V	P	I	T	E
0	0	0	0	4.95	42.1	84
2	0.4	2	9.8	4.9	43.4	84
3	0.6	3.89	18.9832	4.88	43.7	84
4	0.8	4.08	19.9512	4.89	43.7	84
5	1	6.04	28.69	4.75	44.3	86
6	1.2	8.31	38.8077	4.67	43.4	86
8	1.6	9.68	42.6888	4.41	44	88
10	2	11.66	51.304	4.4	43.9	84
11	2.2	12.29	53.5844	4.36	43.1	84
12	2.4	12.66	51.906	4.1	34.66	76
14	2.8	14.69	60.3759	4.11	34.9	76
16	3.2	15.52	60.528	3.9	35.7	76
18	3.6	16.03	58.8301	3.67	36.4	78
19	3.8	16.06	56.6918	3.53	36.5	78
20	4	16.37	54.3484	3.32	36.3	78
21	4.2	16.52	53.1944	3.22	36.7	78

22	4.4	16.74	52.731	3.15	36.8	78
23	4.6	16.84	51.0252	3.03	37	78
24	4.8	16.98	50.2608	2.96	37.7	80
25	5	17.08	48.678	2.85	38.4	80
26	5.2	17.15	47.334	2.76	38.9	80
27	5.4	17.25	46.0575	2.67	39.3	80
28	5.6	17.3	44.98	2.6	39.5	80
29	5.8	17.37	43.7724	2.52	39.9	80
30	6	17.35	42.681	2.46	40.3	80
31	6.2	17.47	41.5786	2.38	40.2	84
32	6.4	17.5	40.425	2.31	40.7	84
33	6.6	17.52	39.5952	2.26	41.4	84
34	6.8	17.5	38.85	2.22	42.1	80
35	7	17.52	37.668	2.15	42	80
36	7.2	17.55	36.504	2.08	42.1	82
37	7.4	17.59	35.5318	2.02	42.5	82
38	7.6	17.57	34.7886	1.98	42.7	82
39	7.8	17.59	34.1246	1.94	42.6	82
40	8	17.55	32.994	1.88	42.7	84
41	8.2	17.5	32.025	1.83	43.2	84
42	8.4	17.55	31.59	1.8	42.9	84
43	8.6	17.59	30.9584	1.76	43	84
44	8.8	17.59	30.2548	1.72	43.2	84
45	9	17.64	29.8116	1.69	43.4	86
46	9.2	17.62	28.8968	1.64	43	84
47	9.4	17.64	28.224	1.6	43.1	82
48	9.6	17.64	27.8712	1.58	42.8	80
49	9.8	17.64	27.5184	1.56	42.6	80
50	10	17.72	27.1116	1.53	42.8	80
51	10.2	17.67	28.0953	1.59	42.6	80
52	10.4	17.69	25.6505	1.45	42.7	z
53	10.6	17.64	24.8724	1.41	42	82
54	10.8	17.64	25.0488	1.42	42.3	82
55	11	17.57	24.2466	1.38	42.5	82
56	11.2	17.69	23.8815	1.35	43.1	82
57	11.4	17.67	23.5011	1.33	43.7	82
58	11.6	17.47	22.8857	1.31	43.8	82
59	11.8	17.5	22.4	1.28	43.7	82
60	12	17.62	22.5536	1.28	43.9	82
61	12.2	17.62	22.025	1.25	44.1	80
62	12.4	17.72	21.9728	1.24	44	80
63	12.6	17.74	21.6428	1.22	43.3	78
64	12.8	17.72	21.4412	1.21	42.9	78
65	13	17.86	21.2534	1.19	43.1	78
66	13.2	17.81	20.8377	1.17	42.7	78
67	13.4	18.25	21.535	1.18	41.9	80

68	13.6	18.28	21.022	1.15	41.6	81
69	13.8	18.28	20.4736	1.12	42.2	82
70	14	17.99	19.9689	1.11	41.9	82
71	14.2	18.06	19.866	1.1	41.7	82
72	14.4	18.03	19.4724	1.08	42.8	80
73	14.6	17.94	19.3752	1.08	42.7	80
74	14.8	18.01	19.0906	1.06	42.1	82
75	15	18.03	18.7512	1.04	41.9	80
76	15.2	17.89	18.4267	1.03	42	80
77	15.4	17.94	18.2988	1.02	42	84
78	15.6	18.01	18.1901	1.01	42.3	84
79	15.8	17.96	17.7804	0.99	42.5	84
80	16	17.94	17.4018	0.97	42.4	84
81	16.2	18.01	17.2896	0.96	42.6	80
82	16.4	17.96	17.062	0.95	43	80
83	16.6	18.01	17.1095	0.95	42.6	80
84	16.8	17.96	16.7028	0.93	42.6	80
85	17	17.96	16.5232	0.92	42.6	80
86	17.2	17.96	16.3436	0.91	42.8	78
87	17.4	17.91	16.2981	0.91	42.1	78
88	17.6	18.08	16.0912	0.89	42.7	78
89	17.8	18.11	15.9368	0.88	42.7	76
90	18	17.86	15.7168	0.88	42	76
91	20	18.3	0	0		

Table 3: I-V and P-V Characteristics of PV Module After Cooling

Rh%	R	V	P	C	T	E
0	0	0	0	5.46		80
1	0.2	2.6	14.17	5.45	30.9	80
2	0.4	2.7	14.364	5.32	31	82
3	0.6	2.8	15.288	5.46	31.8	82
4	0.8	5	26.35	5.27	31.2	84
6	1.2	7.3	37.011	5.07	31	84
8	1.6	9.5	47.5	5	29.8	76
10	2	11.5	56.58	4.92	31.1	76
12	2.4	13.6	65.552	4.82	31.5	76
14	2.8	15	69.75	4.65	31.7	76
16	3.2	16.1	70.518	4.38	32.1	76
18	3.6	16.8	70.224	4.18	31.8	72
20	4	17.3	65.221	3.77	31.5	72
22	4.4	17.6	61.072	3.47	31.3	72
24	4.8	17.9	58.175	3.25	31	72
26	5.2	18	54.18	3.01	30.9	72

28	5.6	18.3	51.24	2.8	31.4	72
30	6	18.4	49.496	2.69	31.1	72
32	6.4	18.6	46.686	2.51	31.3	72
34	6.8	18.6	44.826	2.41	30.1	72
36	7.2	18.7	42.449	2.27	28.9	72
38	7.6	18.8	41.548	2.21	30.5	72
40	8	19.1	40.11	2.1	29.2	72
42	8.4	19.2	38.208	1.99	30.5	72
44	8.8	19.2	36.288	1.89	30.5	74
46	9.2	19.3	35.512	1.84	31	74
48	9.6	19.4	34.144	1.76	29.8	74
50	10	19.5	32.955	1.69	31	76
52	10.4	19.4	31.622	1.63	31.3	72
54	10.8	19.5	30.42	1.56	29.6	72
56	11.2	19.7	30.141	1.53	29.2	72
58	11.6	19.7	28.959	1.47	28.9	72
60	12	19.6	27.636	1.41	28	72
62	12.4	19.6	27.048	1.38	28.6	72
64	12.8	19.5	25.935	1.33	29.6	72
66	13.2	19.6	25.284	1.29	28.9	72
68	13.6	19.6	24.5	1.25	27.4	72
70	14	19.5	23.595	1.21	28.9	72
72	14.4	19.6	22.54	1.15	29.7	74
74	14.8	19.7	22.852	1.16	30.3	74
76	15.2	19.7	21.867	1.11	30.8	74
78	15.6	19.5	21.45	1.1	31.1	74
80	16	19.6	20.776	1.06	28.9	72
82	16.4	19.6	20.58	1.05	29.8	72
84	16.8	19.5	19.89	1.02	30.2	72
86	17.2	19.7	19.7	1	27.6	72
88	17.6	19.6	19.208	0.98	28.7	72
90	18	19.7	18.912	0.96	27.2	74
92	18.4	19.8	18.612	0.94	28.2	74
94	18.8	19.8	18.216	0.92	28.3	74
96	19.2	19.8	17.82	0.9	28.9	70
98	19.6	19.8	17.424	0.88	26.3	70
100	20	19.8	17.424	0.88	27.7	70
		20	0	0		

B   Code

A.1   Arduino Code For Current Sensor

```
int offset =20;// set the correction offset value
void setup() {
  // Robojax.com voltage sensor
  Serial.begin(9600);
}

void loop() {
  // Robojax.com voltage sensor
  int volt = analogRead(A0);// read the input
  double voltage = map(volt,0,1023, 0, 2500) + offset;// map 0-1023 to 0-2500 a

  voltage /=100;// divide by 100 to get the decimal values
  Serial.print("Voltage: ");
  Serial.print(voltage);//print the voltage
  Serial.println("V");

delay(500);


}
```

A.2　Arduino Code for LM35 Temperature Sensor

```
void setup()

  { Serial.begin(9600);
}
void loop() {

  float sensorValue = analogRead(A0);
  float temperature = (sensorValue *500)/1023;

  Serial.println(temperature);
  delay(500);
}


}
```

A.3 Arduino Code for Current Sensor ACS712

```
#ifdef ARDUINO_SAMD_VARIANT_COMPLIANCE
  #define RefVal 3.3
  #define SERIAL SerialUSB
#else
  #define RefVal 5.0
  #define SERIAL Serial
#endif
#define Pin A5


const int averageValue = 500;

long int sensorValue = 0;

float sensitivity = 1000.0 / 200.0; //1000mA per 200mV


float Vref = 1508;

void setup()
{
  SERIAL.begin(9600);
}

void loop()
{
    for (int i = 0; i < averageValue; i++)
  {
    sensorValue += analogRead(Pin);

        delay(2);

  }

  sensorValue = sensorValue / averageValue;


      unitValue= 5.0 / 1024.0*1000 ;
  float unitValue= RefVal / 1024.0*1000 ;
  float voltage = unitValue * sensorValue;

   SERIAL.print("initialValue: ");
```

```
SERIAL.print(voltage);
SERIAL.println("mV");

 float current = (voltage - Vref) * sensitivity;

/*
voltage = unitValue * sensorValue-Vref;
SERIAL.print(voltage);
SERIAL.println("mV");
*/

// Print display current (mA)
SERIAL.print(current);
SERIAL.println("mA");

SERIAL.print("\n");

// Reset the sensorValue for the next reading
sensorValue = 0;
// Read it once per second
delay(1000);
}
```

A.4   Arduino Code for Environment Temperature and Humidity Sensor HW036

```
#include "dht.h"

#define TIMEOUT 10000

/////////////////////////////////////////////////////
//
// PUBLIC
//


// return values:
//  0 : OK
// -1 : checksum error
// -2 : timeout
int dht::read11(uint8_t pin)
{
// READ VALUES
int rv = read(pin);
if (rv != 0) return rv;

// CONVERT AND STORE
humidity    = bits[0]; // bit[1] == 0;
temperature = bits[2];  // bits[3] == 0;

// TEST CHECKSUM
uint8_t sum = bits[0] + bits[2]; // bits[1] && bits[3] both 0
if (bits[4] != sum) return -1;

return 0;
}

// return values:
//  0 : OK
// -1 : checksum error
// -2 : timeout
int dht::read22(uint8_t pin)
{
// READ VALUES
int rv = read(pin);
if (rv != 0) return rv;

// CONVERT AND STORE
humidity    = word(bits[0], bits[1]) * 0.1;
```

```cpp
int sign = 1;
if (bits[2] & 0x80) // negative temperature
{
bits[2] = bits[2] & 0x7F;
sign = -1;
}
temperature = sign * word(bits[2], bits[3]) * 0.1;



// TEST CHECKSUM
uint8_t sum = bits[0] + bits[1] + bits[2] + bits[3];
if (bits[4] != sum) return -1;

return 0;
}

/////////////////////////////////////////////////////
//
// PRIVATE
//

// return values:
//  0 : OK
// -2 : timeout
int dht::read(uint8_t pin)
{
// INIT BUFFERVAR TO RECEIVE DATA
uint8_t cnt = 7;
uint8_t idx = 0;

// EMPTY BUFFER
for (int i=0; i< 5; i++) bits[i] = 0;

// REQUEST SAMPLE
pinMode(pin, OUTPUT);
digitalWrite(pin, LOW);
delay(20);
digitalWrite(pin, HIGH);
delayMicroseconds(40);
pinMode(pin, INPUT);

// GET ACKNOWLEDGE or TIMEOUT
unsigned int loopCnt = TIMEOUT;
while(digitalRead(pin) == LOW)
if (loopCnt-- == 0) return -2;
```

```
loopCnt = TIMEOUT;
while(digitalRead(pin) == HIGH)
if (loopCnt-- == 0) return -2;

// READ THE OUTPUT - 40 BITS => 5 BYTES
for (int i=0; i<40; i++)
{
loopCnt = TIMEOUT;
while(digitalRead(pin) == LOW)
if (loopCnt-- == 0) return -2;

unsigned long t = micros();

loopCnt = TIMEOUT;
while(digitalRead(pin) == HIGH)
if (loopCnt-- == 0) return -2;

if ((micros() - t) > 40) bits[idx] |= (1 << cnt);
if (cnt == 0)   // next byte?
{
cnt = 7;idx++;
}
else cnt--;
}

return 0;
}
```

A.5 Arduino Code for Environment Temperature and Humidity Sensor HW036 - Second Version

```
#ifndef dht_h
#define dht_h

#if ARDUINO >= 100
 #include "Arduino.h"
#else
 #include "WProgram.h"
#endif

#define DHT_LIB_VERSION "0.1.00"

class dht
{
public:
int read11(uint8_t pin);
    int read22(uint8_t pin);
double humidity;
double  temperature;

private:
uint8_t bits[5]; // buffer to receive data
int read(uint8_t pin);
};
#endif
//
// END OF FILE
//

Executable code on Arduino:
#include "dht.h"
#define dht_apin A0 // Analog Pin sensor is connected to

dht DHT;

void setup(){

  Serial.begin(9600);
  delay(500);//Delay to let system boot
  Serial.println("DHT11 Humidity & temperature Sensor\n\n");
  delay(1000);//Wait before accessing Sensor

}//end "setup()"
```

```
void loop(){
  //Start of Program

    DHT.read11(dht_apin);

    Serial.print("Current humidity = ");
    Serial.print(DHT.humidity);
    Serial.print("% ");
    Serial.print("temperature = ");
    Serial.print(DHT.temperature);
    Serial.println("C  ");

    delay(5000);//Wait 5 seconds before accessing sensor again.

  //Fastest should be once every two seconds.

}// end loop()
```

A.6 Matlab Code for Data Plotting For Uncooled PV

```
T = readtable('ExperimentalData.xlsx');
plot(V,I)
plot(V,P)
```

A.7 Matlab Code for Data Plotting For Cooled PV

```
T = readtable('ExperimentalData.xlsx');
plot(V2,I2)
plot(V2,P2)
```

A.8   Matlab Code for Data Plotting For I-V Comparison of Uncooled and Cooled PV

```
T = readtable('ExperimentalData.xlsx');
plot(V, I)
hold on
plot(V2, I2)
hold off
```

A.9 Matlab Code for Data Plotting For I-V Comparison of Uncooled and Cooled PV

```
T = readtable('ExperimentalData.xlsx');
plot(P,V)
hold on
plot(P2,V2)
hold off
```

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