# STUDENT DECLARATION

This is to certify that the thesis entitled, **"PERFORMANCE STUDY OF PV PANEL WITH WATER COOLING"** is an outcome of the investigation carried out by the author under the supervision of **A.K.M. Sadrul Islam, Ph.D.,** Former Professor, Department of Mechanical Engineering, Bangladesh University of Engineering and Technology. This thesis or any part of it has not been submitted to elsewhere for the award of any other degree or diploma or other similar title or prize.

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I wish their ever success in life.

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# Abstract:

In photovoltaic system energy conversion efficiency is low. Furthermore, during the long operational period of solar cells, their energy conversion efficiency decreases even more due to increase in operating cell temperature over a certain limit. One way of improving the efficiency of photovoltaic system is to maintain a low operating temperature by cooling it down during its operation period. This study compares the effects of cooling on the performance of photovoltaic system. Experiments are performed on the solar panel inclined at fixed 23.45° angle with the horizontal due south without active cooling initially to have a set of reference performance parameters for comparison. Afterwards, cooling of the solar panel is carried out by using water at three steps. The three steps include normal water spray on the front surface, wet woolen material and wet Jute material on the back surface. I-V tests and temperature tests, for all the cases, are performed for comparative analysis. The results showed that the cooling of photovoltaic system using water over the front surface and back surface enhances the performance and gives better output than undisturbed panel.

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# 1 CHAPTER 1- INTRODUCTION:

Electricity can be produced by solar energy using an electronic device called “Solar Cell”. This process is known as Photovoltaic effect. The cells are connected and assembled together forming a PV module or panel that absorbs the solar radiation and generates electrical energy.

The solar panel is also known as PV module and the inverter is the core of a solar system. The panels generate direct current electricity (DC) and the inverter converts it in alternating current (AC) usable to make the household electrical appliances work normally or to feed the electrical grid. PV systems can be grid connected or work as stand-alone systems.

Solar energy in one form or another is the source of nearly all energy on the earth. Humans, like all other animals and plants, rely on the sun for warmth and food. However, people also harness the sun's energy in many other different ways. For example, fossil fuels, plant matter from a past geological age, is used for transportation and electricity generation and is essentially just stored solar energy from millions of years ago. Similarly, biomass converts the sun's energy into a fuel, which can then be used for heat, transport or electricity. Wind energy, used for hundreds of year to provide mechanical energy or for transportation, uses air currents that are created by solar heated air and the rotation of the earth. Today wind turbines convert wind power into electricity as well as its traditional uses. Even hydroelectricity is derived from the sun. Hydropower depends on the evaporation of water by the sun, and its subsequent return to the Earth as rain to provide water in dams. Photovoltaic (often abbreviated as PV) is a simple and elegant method of harnessing the sun's energy. PV devices (solar cells) are unique in that they directly convert the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long lasting. Solar cells are based on the same principles and materials behind the communications and computer revolutions, and this CDROM covers the operation, use and applications of photovoltaic devices and systems.

## 1.1 Mechanism of PV cell:

A solar cell is an electrical device that uses photovoltaic effect to convert the light Energy directly into electrical energy. The photovoltaic effect is the creation of voltage or current in a material due to exposure of material to sunlight. The solar cells are capable of producing electric current without being connected to any external voltage source.

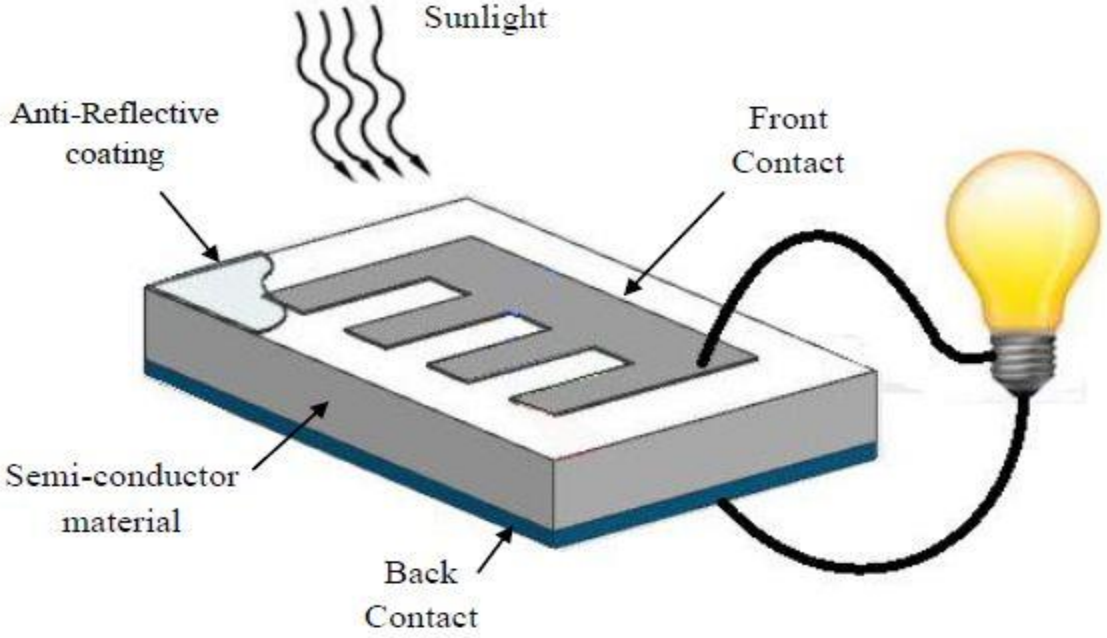

Figure 1: Illustration of photovoltaic cell operation

The figure above shows the operation of a photovoltaic cell which is also called a solar cell. Solar cells are made of semiconductor materials, such as silicon. Solar cells are made up of thin semiconductor material which is specially treated to form a positive and negative electric field on each side. When the photons of light incident on the solar cells, electrons of the semiconductor material get excited, and are released from the atoms in the semiconductor material. These free electrons can be captured in the form of electricity by connecting electrical conductors to the positive and negative sides of the solar cells. This electrical energy can then be used to operate tool or any other equipment. A number of solar cells can be connected in series or parallel and mounted in a frame structure which is called a photovoltaic panel/module. The current produced by the solar panel depends upon how much light is received by the solar cells.

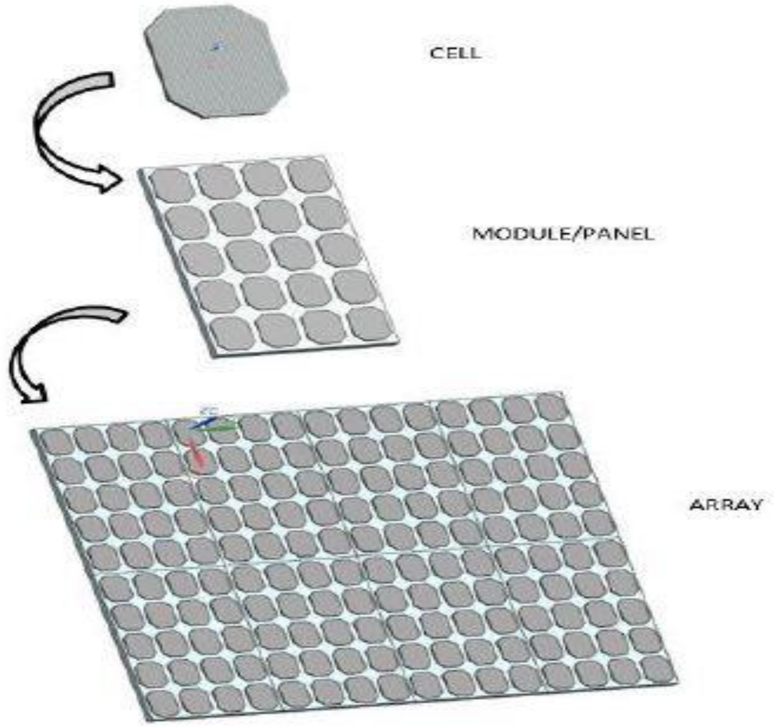

Figure 2: Cells combined together to form module and module combined together to form array

A number of modules can be put together and connected to form an array. In general, the larger area of a module or array gets strike by more light and thus produces more electricity. Photovoltaic modules produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce desired voltage and current. The most common semiconductor material used in the development of solar cells is silicon. Materials other than silicon used for the construction of solar cells are copper indium diselenide, cadmium telluride and gallium arsenide.

Solar energy is clean and is the most available renewable energy on earth. As non-renewable power sources are decreasing day by day and increases the pollution which is a threat to our mankind, it is becoming more widely used to generate electrical power, heat, light etc. for domestic and industrial applications.

For generating solar energy PV cell is used. Here, the energy potential of the sun is vast and immerse where harvesting it enough for our need is a challenge. The best conversion of efficiency of most commercially available of PV cell is in the range 10-20%.So, a lot of improvement in a PV cell is needed to increase the efficiency.

By I-V curve it can be determined the relation between I and V. [1]

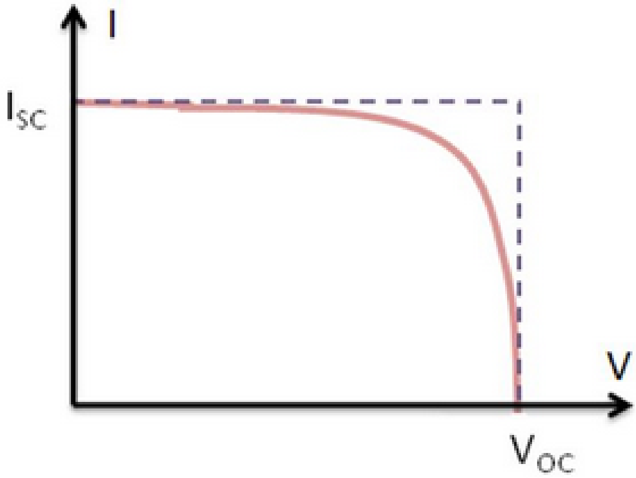

Figure 3: I versus V Curve

As PV cell input power is solar radiation and output power is voltage. So, temperature is a main factor for increasing and decreasing efficiency. PV module converts only 4-17% of the increasing solar radiation in electricity. From that 50% is used to produce heat which increase temperature. The Panel will lose efficiency if the temperature is above 25°C efficiency increases. So, maintaining 25°C is must to maintain the efficiency in a good range.

## 1.2 Introduction to energy consumption and production:

Any change that takes place in the universe is accompanied by a change in a quantity that we name energy. We do not know what energy exactly is, we use this term to describe a capacity of a physical or biological system for movement or change. Energy comes in many forms, such as electrical energy, chemical energy, or mechanical energy, and it can be used to realize many forms of change, such as movement, heating, or chemical change. Any activity, and human activity as well, requires energy. Human beings need it to move their bodies, to cook, to heat and light houses, or to drive vehicles. Human being is a greedy consumer of energy. An active young man needs about 2500 kcal (2.9 kWh) per day to fulfil his daily energy requirements. This means the energy of about 1060 kWh per year. The present global energy consumption is around 19 000 kWh per inhabitant per year. It means that on average a man consumes about 19 times more energy than is needed for his survival and satisfactory health.

The mankind has witnessed an enormous increase in energy consumption during last 100 years. While in 1890 the energy use per inhabitant per year was around 5800 kWh it reached 20200 kWh in 1970. Since 1970 the energy use has dropped to the present level of 19000 kWh per inhabitant per year. The increase in energy use in the 20th century can be related to an evolution process that has started about five centuries ago. The underlying motivation of this process was formulated during the Enlightenment period in the 18th century as the philosophy of human progress. The aim of the process was an examination of the surrounding world and its adaptation to the needs of people whose life would become more secure and comfortable. This process was accompanied by growing industrialization and mass production, which were demanding more and more energy. At the end of the 19th century coal was the main source of energy. In this period electricity was introduced in the industrialized countries as a new and elegant form of energy. This form of energy was quickly applied on a large scale. The widespread growth of electricity use led to construction of hydroelectric plants and hydropower became an important source of energy in the first half of the 20th century.

In the period after the World War II much effort was put into the reconstruction of the society. The emphasis was directed on the growth and efficiency of the mass production. New technologies and new materials, such as plastic, were applied in the production. The energy demand was tremendously growing in this period .Oil and gas started to play an important role as energy sources in the second half of the 20Th century. Coal, oil, and gas form today dominant sources of energy. These three energy sources, also known as fossil fuels, are called the traditional energy sources. In this period nuclear energy was introduced as a new source of energy. Increasing and more efficient mass production resulted in the low price of many household products. The consumption of the products grew enormously and therefore it is not surprising that we characterize today society as a consumption society. Nevertheless, it has become evident at the end of the 20thcentury that the philosophy of human progress that has manifested itself in a huge production and consumption of goods has a negative side too. It has been recognized that a massive consumption of fossil fuels in order to fulfil the present energy demands has a negative impact on the environment. The deterioration of environment is a clear warning that the present realization of human progress has its limitations. The emerging international environmental consciousness was formulated in a concept of a sustainable human progress. The sustainable human progress is defined as: "... to ensure that it (sustainable development) meets the needs of the present without compromising the ability of future generations to meet their own needs". A new challenge has emerged at the end of the 20thcentury that represents a search for and a utilization of new and sustainable energy sources. The urge of this challenge is underlined by limited resources of the fossil fuels on the Earth and increasing demand for energy production. This is the reason why the attention is turning to the renewable energy sources .Energy is an essence of any human activity. When we are interested in how the human civilization has been producing and using energy, we can describe it in terms of an energy system. The main characteristics of the energy system are: the population, the total consumption of energy, and the sources and forms of energy that people use. The energy system at the beginning of the 21st century is characterized by six billion people that live on the Earth and the total energy consumption of approximately 1.3 × 1010kWn.

## 1.3 Primary energy sources:

The primary energy sources can be divided in two groups. The first group includes those energy sources that will be exhausted by exploiting them. These energy sources are called the depleting energy sources and they are the fossil fuels and nuclear energy. The fossil fuels and nuclear power are the main source of energy in today’s energy system and they supply 78% of the energy demand. Under the assumption that the population of mankind does not change drastically and it consumes energy at the current level, the fossil fuel reserves will be exhausted within 320 years and the nuclear energy within 260 years. This can seem a very long time for us. However, when we compare this period of time to the time span of existence of the Earth or the human civilization, it is a negligible fraction of time. We have to be aware that the reserves of fossil fuels on the Earth are limited and will be exhausted. The energy of solar radiation is directly utilized in mainly two forms:

i) Direct conversion into electricity that takes place in semiconductor devices called solar cells

ii) Accumulation of heat in solar collectors. Therefore, do not confuse solar cells with solar collectors. The direct conversion of solar radiation into electricity is often described as a photovoltaic (PV) energy conversion because it is based on the photovoltaic effect. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The whole field of solar energy conversion into electricity is therefore denoted as the “Photovoltaic”. Photovoltaic literally means “light-electricity”, because “photo” is a stem from the Greek word “phõs” meaning light and "Volt” is an abbreviation of Alessandro Volta’s (1745-1827) name who was a pioneer in the study of electricity. Since a layman often does not know the meaning of the word photovoltaic, a popular and common term to refer to PV solar energy is solar electricity. The oil company Shell expects that PV solar energy will become the main energy source for the "post-fossil-era". Developing the PV solar energy as a clean and environmentally friendly energy source is considered at present noble mission. In this mission, the sun is consciously given an additional function to the one that it has had: to provide energy for life on the Earth. The sun’s additional function will be to provide the Earth with energy for people’s comfort and wellbeing by producing the solar electricity. The motifs that were behind the development and application of the PV solar energy were in general the same as for all renewable energy sources. The motifs were based on the prevention of climate and environment and providing clean energy for all people. The current motifs can be divided into three categories: energy, ecology and economy. There is a growing need for energy in the world and since the traditional energy sources based on the fossil fuels are limited and will be exhausted in future, PV solar energy is considered a promising energy source candidate. Large-scale of PV solar energy will also contribute to the diversification of energy sources resulting in more equal distribution of energy sources in the world. Ecology Large-scale use of PV solar energy, which is considered environmentally friendly source of energy, can lead to a substantial decrease in the emission of gases such as CO and SO and NOX that pollute the atmosphere during burning of the fossil fuels. When we closely look at the contribution of the PV solar energy to the total energy production in the world we see that the PV solar energy contribution is only a tiny part of the total energy production. At present, the total energy production is estimatedtobe1.6 × 1010kW compared to 1.0 × 106kWpthat can be delivered by all solar cells installed worldwide. By W (Watt peak) we understand a unit of power that is delivered by a solar cell under a standard illumination. When PV starts to make a substantial contribution to the energy production and consequently to the decrease in the gas emissions depends on the growth rate of the PV solar energy production. When the annual growth of PV solar energy production is 15% then in year 2050 solar cells will produce 2.0 × 108kWp. The annual growth of 25% will result in the solar electricity power production of7.5× 109kWpin 2040 and the annual growth of 40% will lead to power productionof2.4 × 1010kWpin 2030. This demonstrates that there must be a steady growth in solar cells production so that PV solar energy becomes a significant energy source after a period of 30 years. The solar cells and solar panels are already on the market. An advantage of the PV solar energy is that the solar panels are modular and can be combined and connected together in such a way that they deliver exactly the required power. We refer to this feature as “custom-made” energy. The reliability and very small operations and maintenance costs, as well as modularity and expandability, are enormous advantages of PV solar energy in many rural applications. There are two billion people in mostly rural parts of the world who have no access to electricity and solar electricity is already today the most cost effective solution. Bringing solar electricity to these people represents an enormous market. Some companies and people have realized that solar electricity can make money already now and this fact is probably the real driving for a widespread development and deployment of the PV solar energy. We can roughly estimate how much money is already involved in the production of solar cells. The total production of solar cells has achieved more than 1200 MWp. An average cost-prize of 1 Wp. Was approximately 3.5 €. This means that the money involved in production of solar cells reached 4.2 milliard €. Assuming that a complete PV system is roughly two times the cost of the cells, a total money involved PV in 2004 can be estimated to 10 milliard €.

The advantages and drawbacks of the PV solar energy, as seen today, are summarized.

## 1.4 Advantages:

•Environmentally friendly

•No noise, no moving parts

•No emissions

•No use of fuels and water

•Minimal maintenance requirements

•Long lifetime, up to 30 years

•Electricity is generated wherever there is light, solar or artificial

•PV operates even in cloudy weather conditions

•Modular or “custom-made” energy, can be designed for any application from watch to a multi-megawatt power plant Drawbacks:

•PV cannot operate without light

•High initial costs that overshadow the low maintenance costs and lack of fuel costs

•Large area needed for large scale applications

•PV generates direct current: special DC appliances or inverters are needed in off-grid applications energy storage is needed, such as batteries.

## 1.5 Wick Structures:

| Textile Fiber | Moisture Regain (MR %) | Moisture Content (MC %) |
|---|---|---|
| 1.Cotton | 8.5 | 7.34 |
| 2.Jute | 13.75 | 12.1 |
| 3.Silk | 11.0 | 9.91 |
| 4.Viscose | 11.0 | 9.91 |
| 5.Wool | 16.0 | 13.8 |

Table 1-1, Wick Structures

### 1.5.1 Moisture Regain:

It is defined as the weight of water in a material as a percentage of the oven dry weight.

### 1.5.2 Moisture Content:

It is the ratio of the mass of water in a sample to the mass of solids in the sample.

### 1.5.3 Moisture in Wool:

Wool has a great affinity for moisture. In general terms 1 tonne of wool at normal room conditions contains about 160kg of water. However, the amount of water depends very much upon the atmospheric humidity:-a 10% change in humidity can result a 1% change in weight. It is this dependence on humidity that has a significant impact on Yield. [2]

### 1.5.4 Moisture in Jute:

Jute can contain moisture. It has the 2nd highest moisture regain and moisture content percentage. It is this dependence on humidity that has a significant impact on Yield.

### 1.5.5 Yield:

Yield is the amount of useful fiber that can be obtained from a known weight of wool. Clearly the yield depends on the form of the wool at the time of measurement, the moisture content and the method of processing.

## 1.6 Applications:

### 1.6.1 Agriculture:

Solar water pumps are electrically driven pumping systems, powered by photovoltaic panels. Usually the need for water is greatest during the hot sunny days. During these peak times the PV panels also produce most power and most water will be pumped into the storage tank. [3]

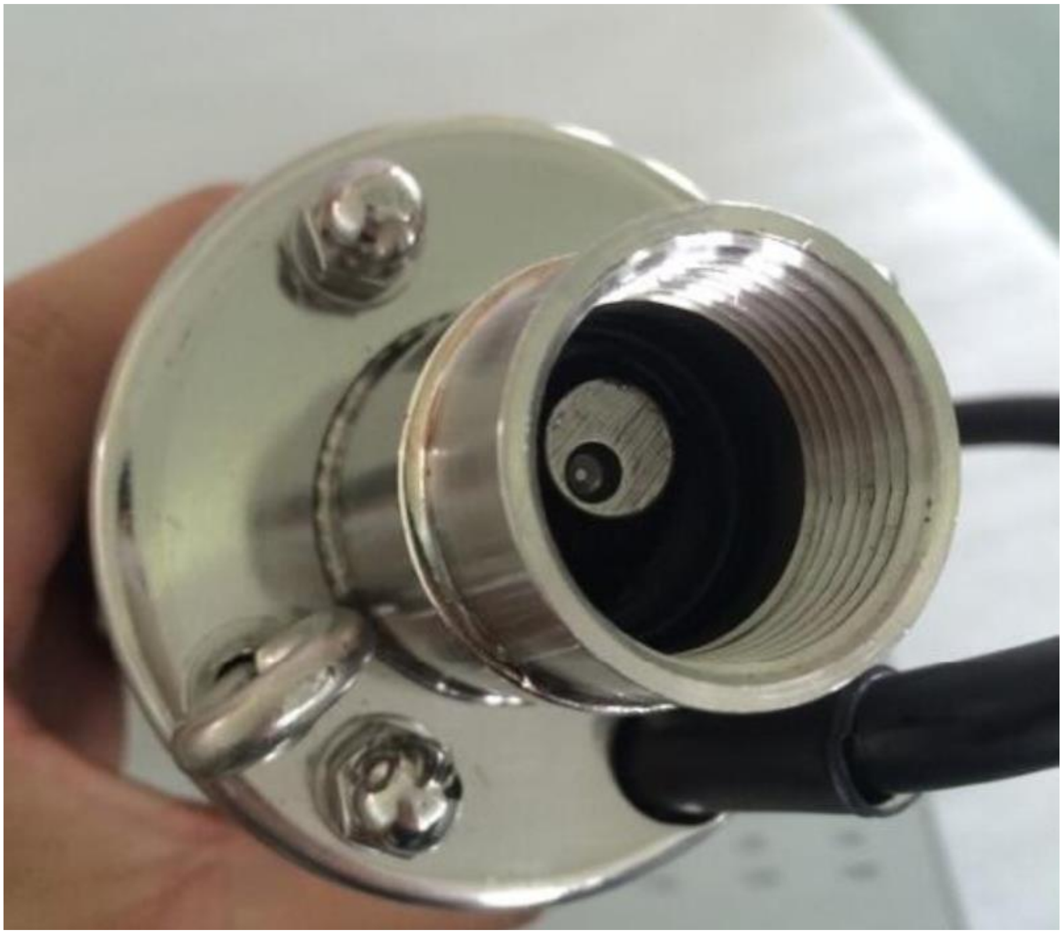

Fig.1.4: Solar Water Pump

### 1.6.2 Industry, Telecommunication and Public Services:

Cathode protection of gas, oil pipelines and other types of piping; provision of power in general, in particular for limited electric charges (in the order of a few KW) always in areas far from the grid or where power is unreliable (discontinuous electrical supply).Radio/Television relay stations: telephone devices; stations for data surveying and transmission. Often it is very useful for civil protection services, lighting of streets gardens and public transportation stops; street signaling.

Fig. 1.5: PV Panels in Industries

### 1.6.3 Health:

Especially for refrigeration, it is very useful particularly in developing countries for the conservation of vaccines and blood.

### 1.6.4 Residential:

Power supply for houses and mountain refuges. Consider very significant in developing countries. PV systems are easy to install and do not require any special maintenance.

Fig.1.6: PV Panels in Residential Area

### 1.6.5 Free Time:

Can be used for charging boat and camper batteries.

Fig.1.7: Boat with Solar Panel.

### 1.6.6 Building integrated photovoltaic system:

The PV system is composed of a number of individual PV modules that can be connected in series to form a string. It is done to increase the dc output voltage up to the desired value. Then, multiple strings are connected in parallel to increase the output current. The possibility of using multiple strings ensures the PV system modularity, which is one of the most important features of the PV technology. The arrangement is done in the PV modules in strings also allows for using different solutions for the dc/ac conversion. Centralized inverter is included in the available solutions, collecting the dc output from the whole array of PV modules, string inverters. It is with one inverter for each string or module-integrated inverters with a mono inverter for each PV module. The centralized inverter is a solution for PV systems with rated power indicatively above 20kW, it is connected to the supply system through a three-phase inverter. The other solutions are typical of residential installations, where the power is usually not higher than 5–10kW and the inverters are mono-phase. The adoption of module-integrated inverters requires the installation of a relatively high number of inverters, each one with its protections, directly on the field, paying attention to the fact that the inverters have to withstand different climatic conditions. Building-integrated photovoltaic (BIPV) systems incorporate photovoltaic properties into building materials such as roofing, siding, and glass and thus offer advantages in costand appearance as they are substituted for conventional materials in new construction. Moreover the BIPV installations are architecturally more appealing than roof-mounted PV structures. Yoo et al. (2002) proposed a building design to have the PV modules shade the building in summer, so as to reduce cooling loads, while at the same time allowing solar energy to enter the building during the heating season to provide daylight and conducted an analysis of the system performance, evaluation of the system efficiency and the power output. Bakos et al. (2003) described the installation, technical characteristics, operation and economic evaluation of a grid-connected building integrated photovoltaic system (BIPV) and the technical and economical factors were examined using a computerized renewable energy technologies (RETs) assessment tool. Xu etal. (2008) developed and evaluated the performance of an Active Building Envelope (ABE) systems, a new enclosure technology with the ability to regulate their temperature (cooling or heating) by interacting with the sun which integrates photovoltaic (PV) and thermoelectric (TE) Technologies. Chow et al. (2003) described effectiveness of cooling by means of a natural ventilating air stream numerically based on two cooling options with an air gap between the PV panels and the external facade: (i) an open air gap with mixed convective heat transfer, and (ii) a solar chimney with buoyancy induced vertical flow and found that effective cooling of a PV panel can increase the electricity output of the solar cells. Wong et al. (2008) proposed semi-transparent PV top light material for residential application with 50% radiation transmission rate contributing to a maximum of 5.3% reduction in heating and cooling energy consumption when compared with a standard BIPV roof. Cheng etal. (2005) developed an empirical approach for evaluating the annual solar tilted planes irradiation with inclinations from 0 to 90◦and azimuths from 0 to 90◦ on building envelopes for BIPV applications in Taiwan. Ruther et al (2008) studied the behavior of grid connected, building integrated photovoltaic (BIPV) solar energy conversion in the urban environment of a metropolitan area in a Brazilian state capital, aiming at maximizing the benefits of the distributed nature of PV generation. Jardim et al. (2008) studied the behavior of grid-connected, building integrated photovoltaic solar energy conversion in the built environment of ametropolitan area in Brazilian state capital, aiming at maximising the benefits of the distributed nature of PV generation.

### 1.6.7 Space:

A trade-off study in the field of space solar arrays and concentration that defines the parameters to evaluate whether a given concept (cell type, concentrator) becomes appropriate as two different trough concentrators, and a linear Fresnel lens concentrators are compared to rigid arrays and thermal and optical behaviors are analyzed. Seboldt et al. a developed a new design for an Earth-orbiting Solar Power Satellite (SPS) called “European Sail Tower SPS” featuring an extremely lightweight and large tower-like orbital system with the capability to supply Europe with significant amounts of electrical power generated by photovoltaic cells and subsequently transmitted to Earth via microwaves (Parida et al., 2011). Girish (2006) studied the possibility of nighttime photovoltaic power generation in planetary bodies like moon using reflected light energy flux from nearby planetary objects based on latest low-intensity low-illumination (LILT) solar cell technology

### 1.6.8 Desalination plant:

Lamei et al. (2008) discussed electricity price at which solar energy can be considered economical to be used for RO (Reverse Osmosis) desalination that is independent of RO plant capacity and proposed an equation to estimate the unit production costs of RO desalination plants that can be used to calculate unit production costs for desalinated water using photovoltaic (PV) solar energy based on current and future PV module prices. A simple mono-effect solar still plant with a capacity of 5.8m3 per day for the treatment of reject brine obtained from Sadous PV-powered RO desalination plant that can be configured as a 100% solar powered desalination system for any location and quality of brackish water and found that the mono effect solar stills for small scale plants is more viable to use in remote area, where the land value is negligible as solar stills are easy to install and maintained and can be fabricated with locally available materials (Parida et al., 2011). El-Sayed modeled desalination by spiral-wound RO membrane modules driven by solar to power photovoltaic converter panels with the purpose of revealing the economic potential of the combination. Weiner et al. (2001) presented the designing, erection and operation process of a stand-alone desalination plant powered by both solar photovoltaic and wind energy.

### 1.6.9 Solar home systems:

Bond et al. (2007) described current experience and trials in East Timor with solar photovoltaic (PV) technology by introduction of solar home systems (SHS). Posorski et al. (2003) proposed Solar Home Systems (SHS) that are commercially disseminated and used them cost efficiently to substitute kerosene and dry cell batteries to reduce. GHG emissions and thus make a significant contribution to climate protection. (Feyza Akarslan, 2012)

## 1.7 Efficiency:

Several technological approaches seek to boost the efficiency of solar cells. Improvements in power electronics and hardware technologies are possible by making distributed PV to supply an increasing share of power, without impairing the reliability of electricity supply. It is important to gather the solar energy in an efficient and cost effective manner. Maximizing the solar cells efficiency is very much necessary.

6 ways to improve solar cells efficiency are given below:

1. **Informed Decision should be made:** Making informed decision while purchasing solar panel. It can be found out that which system is offering the best value as

well as ensuring the best output from the solar system. Checking out new model of solar panel to improve the level of energy conversion. These models incorporate at least two layers of materials that are not similar with dissimilar sensitivities of wavelength.

2. **Using a Solar Concentrator:** It concentrated the solar light. The purpose is to concentrate the solar light from larger area to smaller area. Large mirrors or other devices is used to facilitate the task. The overall efficiency of solar cells, which are generally very expensive, can be increased.
3. **Installing the Photovoltaic Panel Correctly:** PV panel should be installed correctly. The orientation and the angle of tilt should be right. This would ensure that the panel will get optimal sunlight all day through and also all the year. For northern hemisphere, the panel should be faced south and the tilt should be 23.45°.The panels should be tilted in such a way that they receive sunshine directly without any obstruction from 9 am to 3 pm.
4. **Avoiding Shaded Areas:** Ensuring than the solar panel is not shaded as this would have an adverse effect on the power output. When solar cells are connected in a series, if a photovoltaic cell is shaded, it causes the energy that is generated by its neighbors to be drained. This is because it acts as a resistor and helps in determining the total current.
5. **Keeping the solar panel clean:** Dust reduces the solar panel efficiency. As a result, the sunlight that would normally reach the photovoltaic cells gets dissipated. It is therefore important to ensure that no dust and dirt collects on surface of the cell.
6. **Prevention of Increase In temperature:** Temperature levels affect the PV panel efficiency. Temperature gets higher with the drop of Efficiency. Care should be taken that there is a sufficient gap between the solar panels and the roof, as this would allow easy movement of air and prevent the heat from affecting the photovoltaic panels.[4]

## 1.8 Effect of Temperature:

Solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, which effects most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is then needed to break the bond. In the bond model of a semiconductor band gap, reduction in the bond energy also reduces the band gap. That is why, increasing the temperature reduces the band gap.

In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below. [5]

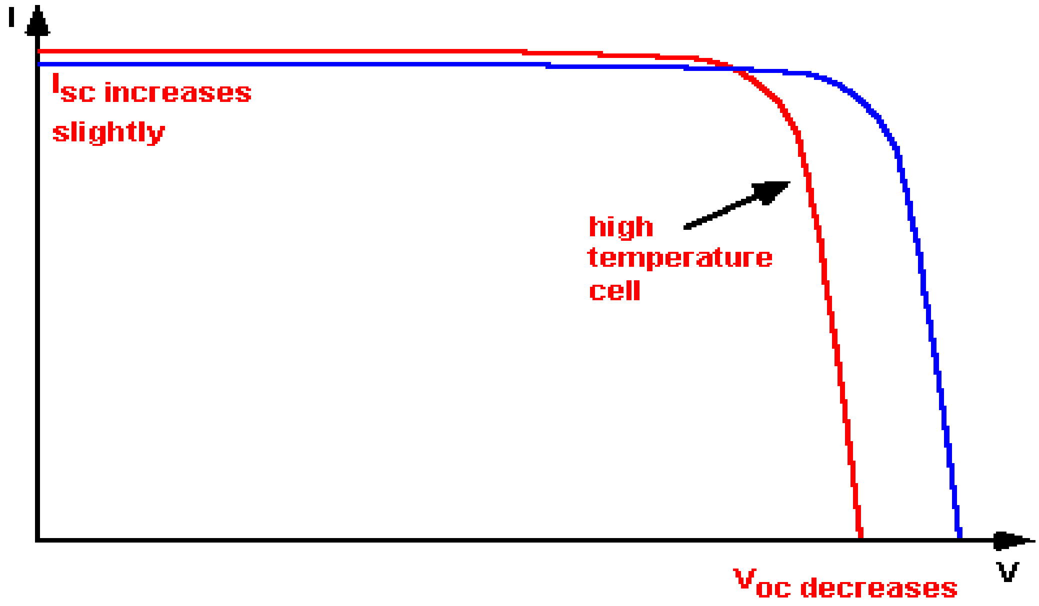

Figure 4: The effect of temperature on the IV characteristics of a solar cell.

Solar cells vary under temperature changes. The change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in temperature will decrease the voltage.

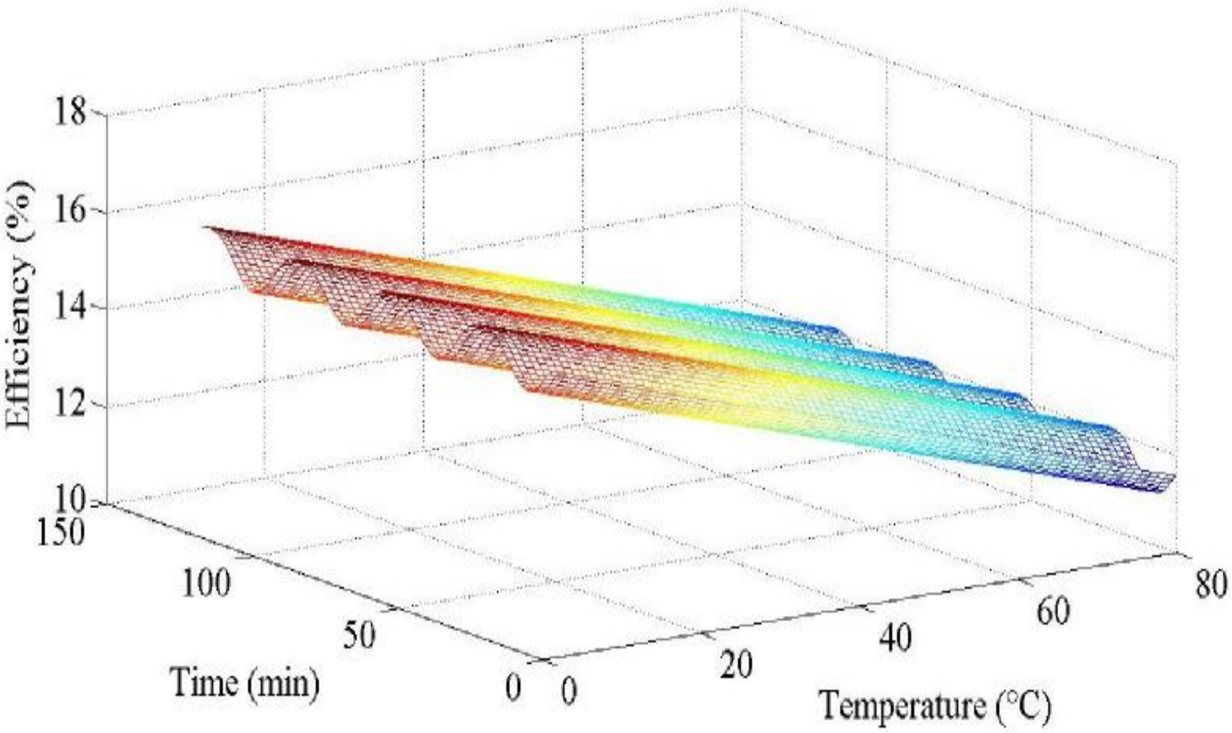

Figure 5: Variation of efficiency with different temperatures [6]

# 2 CHAPTER 2-LITERATURE REVIEW:

Krauter [7] demonstrated one of the methods to increase the electrical efficiency of PV module. Different designs were studied earlier which used water as cooling fluid to cool down the surface. The cooling design presented in this paper involved flow of water over the front side of the PV module. Reflection of sun light from PV module surface reduces electrical yield by 8–15%. The voltage and power also decreases by 0.4%/K when the solar cell temperature increases. Different methods to reduce reflection have been developed but most of them have constraints like durability of antireflective coatings, cost and cleaning of structured surface. Since water has refractive index of 1.3 which is almost the mid of refractive index of glass and air, hence water was used. The experimental setup involved two water tanks, one large tank under the module and the small one on the top of module. Pump was used to pump water from larger tank to smaller tank. Smaller tank had 12 small nozzles which drips water over the top face of module. This setup was capable of reducing reflection by 2-3.6% while decreasing the solar cell temperature up to 22°C and increasing electrical yield by 10.3% excluding the power required to run the pump. The comparison of module with and without water flow on top surface is shown below:

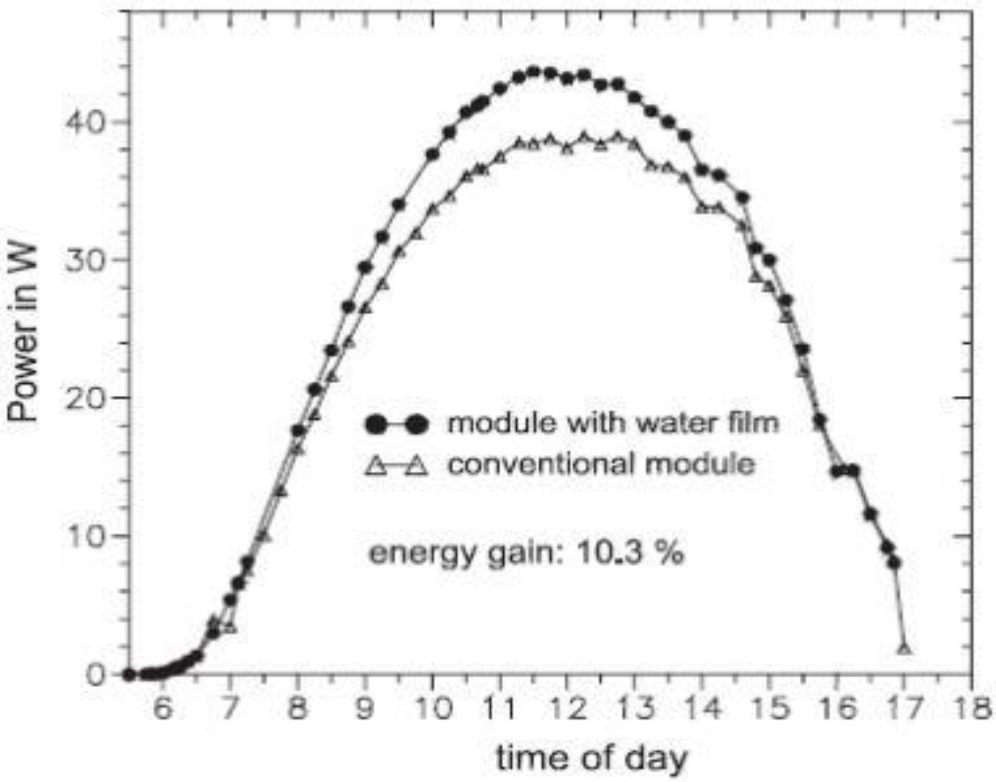

Figure 6: Graph between power and time of day for conventional module and module with water film [7]

The temperature of PV surface equipped with concentrator lens increases more rapidly as compared to normal PV surface. The increase in surface temperature reduces conversion efficiency of concentrator PV. In a research work by Kawahara et al. [8], glass cover having selective transmission thin film was used with the concentrator PV module which prevents infrared red portion of sun rays to transmit and incident on PV module. Films having different ratios of transmittances of cut off bands were attached to the concentrator PV module and their effects on the conversion efficiency were noted. The film having transmittance of cut off bands of 10% showed the maximum change in conversion efficiency by 1.1% after 20 minutes of irradiation.

The conversion efficiencies for different transmittance ratios were plotted as follows:

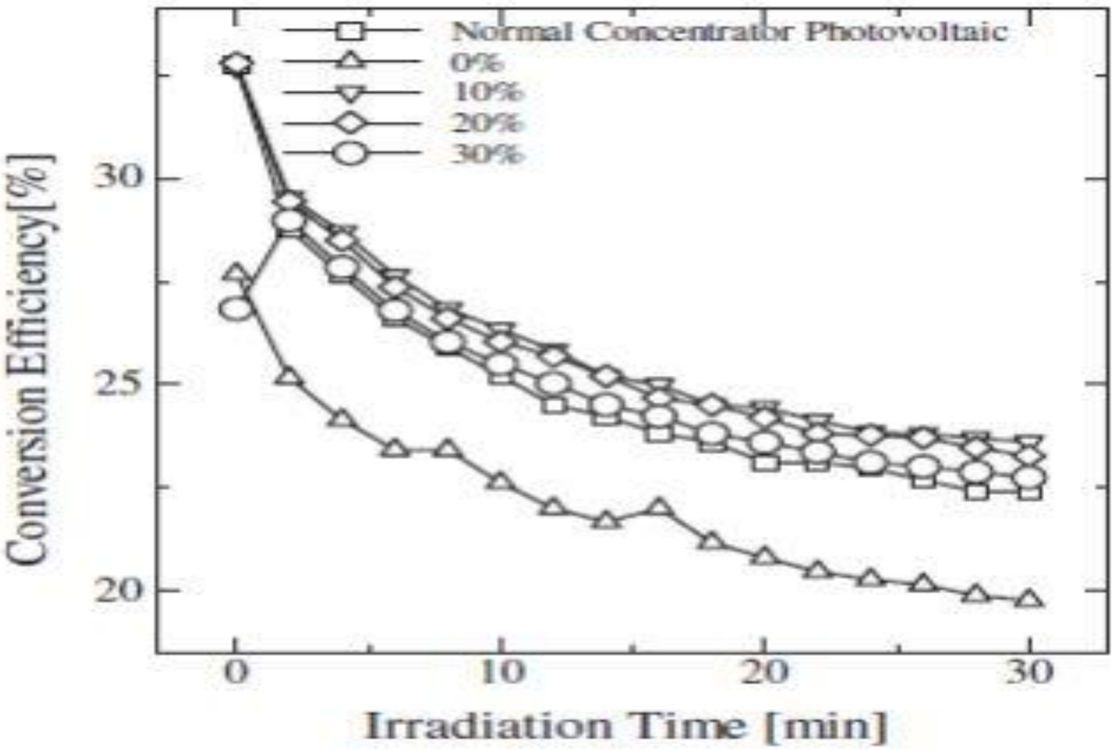

Figure 7: Graph between irradiation time and conversion efficiency [8]

The study by Zhao et al. [9] presents the optimized photovoltaic/thermal system for both concentrated and non-concentrated solar radiation. The system consists of photovoltaic module and direct absorption collector (DAC) based thermal unit. This system works in a way that initially the working fluid of thermal unit absorbs solar infrared radiation, and then the leftover visible light is absorbed by the solar cell and converted into electricity afterwards. This setup prevents the solar cells from excessive heating due to solar radiation. Different models and algorithms were used for analysis and investigation. The results of these analysis shows that the system can effectively use the visible and infrared part of solar radiation. 89% of infrared radiation was absorbed by thermal unit for photo thermal conversion and 84% of visible light by solar cells for photoelectric conversion. Also, the system generates 196°C of working fluid when the solar irradiation over the system is increased from 800 to 8000 W/m2 with thermal efficiency of 40%.

The performance of solar collector depends on many parameters, one of which is the amount of solar radiation reaching the collector surface. In this regard, Skeiker [10] observed that the tilt angle and the orientation of the solar collector with the horizon, is of great importance. Based on the mathematical model, solar radiation on a tilted surface was estimated and optimum tilt angle and orientation of solar collectors in selected Syrian zones were computed on daily basis and for specific period as well. The optimum angle at which the collector surface is showing maximum output was computed which indicates that at that angle, collector surface is receiving maximum solar radiations and thus producing maximum output. The results revealed that by setting up the optimum angle recorded for each month round the year maintains the total amount of solar radiation that can be achieved by changing the tilt angle daily to its optimum value. Using these optimum angle values for each month, there is a gain of approximately 30% more than the case of fixed solar collectors on horizontal surface.

During the recent years, the advancement in photovoltaic technology made it possible to be used in grid connected and stand-alone applications particularly in the areas having high solar potential. In this context, recent studies were carried out by Kaldellis and Zafirakis [11] to determine the optimum operating conditions of PV systems in Greece. Since summer only applications are more common in Greece, therefore local solar potential needs more exploitation during this period. For this purpose, an experimental study was carried out at Athens during summer period to determine the performance of solar panels at different tilt angles. The experimental results showed that the tilt angle 15 (± 2.5) is the optimum angle for almost the entire summer period. These experimental results were validated theoretically by means of solar geometry equations.

The amount of solar energy received by the photovoltaic (PV) panel is affected by many factors, the important ones are the orientation and tilt angle of the solar panel with the horizontal plane. An experimental study was carried out by Kacira et al. [12] to estimate the total solar radiation incident on tilt solar PV surface and to determine the optimum tilt angle for a solar panel installed in Sanliurfa, Turkey. The optimum angles were computed by looking for the tilt angles which give the maximum solar radiation on PV surface for the period studied. The study also highlighted the difference between the energy gain from the fixed solar panel and two axis sun tracking solar panel. The results showed that the optimum tilt angle for solar panel changes throughout the year from minimum 13° to maximum 61° in June and December, respectively. The gain in solar radiation received by solar panel mounted at optimum tilt angle based on the seasonal optimum angles and tilt angle equal to latitude were equal to 1.1% and 3.9% respectively. Furthermore, the average daily gain in the solar radiation by 29.3% resulted in daily average of 34.6% in generated power with two axis solar tracking as compared to fixed solar panel tilted at 14° angle on a particular day in July in Sanliurfa.

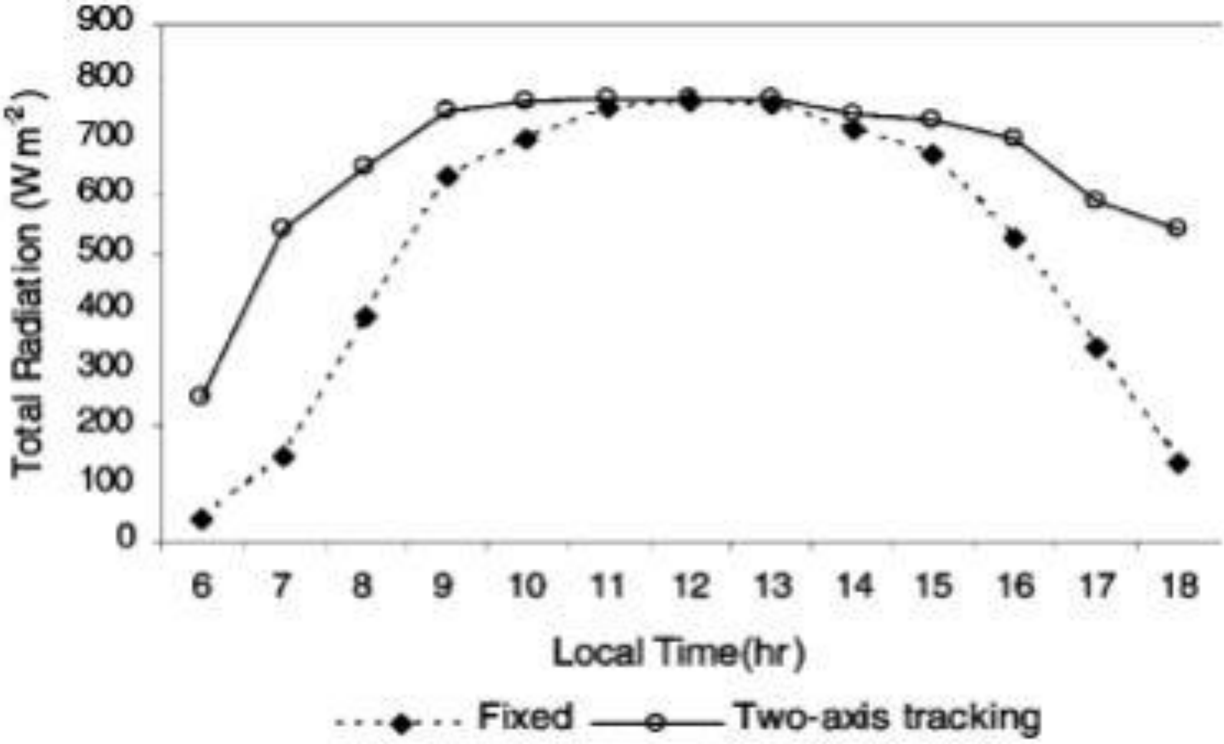

Figure 8: Hourly total radiation received by fixed and two axis tracking panel in Sanliurfa [12]

In order to maximize the electrical energy output by using solar panels, Chang [13] carried out a research work in Taiwan which used particle swarm optimization method with nonlinear time varying evolution (PSO-NTVE) to determine the optimum tilt angle for PV modules. Research included seven Taiwanese cities for analysis. Initially, the Sun's position at any time was predicted by mathematical model of Julian dating then solar irradiation was estimated for clear sky at each site. A number of experiments with statistical error analysis were performed for four PSO methods and the results of these experiments were compared. The results showed that the annual optimal angle for the Taipei area 18.16°; for Taichung, 17.3°; for Tainan, 16.15°; for Kaosiung, 15.79°; for Hengchung, 15.17°; for Hualian, 17.16°; and for Taitung, 15.94°. This study showed that the authorized Industrial Technology Research Institute (ITRI) recommended tilt angle of 23.5° was not an appropriate for use over Taiwan's seven cities and that PV modules tilt angles should be adjusted as per different locations. Rosell et al. [14] studied the combination of photovoltaic/thermal (PV/T) collectors and low solar concentration technologies into a PV/T system to increase the rate of conversion of solar energy into electrical energy. A prototype 11X concentration rate and two axis solar tracking system has been used in this study. The unusual thing about this study is the use of linear Fresnel concentrator with a channel photovoltaic/thermal collector. The thermal behavior of the prototype has been simulated with the help of analytical model which has been proposed and validated as well. The energy analysis of the system was performed. The PV/T system efficiency depends on the flow rate and concentration ratio. However, the measured thermal efficiency of the system gives values above 60%. The analysis showed that the thermal conduction between PV cells and the absorber plate is a critical parameter.

A study has been performed by Tripanagnostopoulos et al. [15] on hybrid solar system which consists of photovoltaic modules and thermal collectors (hybrid PV/T systems). The solar radiation increases the temperature of PV modules thus resulting in the decrease in electrical yield. In this study, heat is extracted from the PV modules by circulating a fluid with low inlet temperature resulting in increase in electrical yield. This extracted heat increases the thermal output of the system and can be utilized in several ways in different applications. The main application of hybrid PV/T systems is in buildings for the production of electricity and heat. The experiments have been performed on commercial PV modules of typical size and the results of the system is presented and discussed. The results showed that cooling of the PV modules can improve its electrical efficiency. In another study, Tonui and Tripanagnostopoulos [16] observed that the efficiency of photovoltaic module decreases as the temperature of the PV module increases. Cooling of the solar panel with the help of air presents a non-expensive method and the preheated air could be utilized in building, industrial and agricultural sectors. However, systems with heat extraction by air circulation have limited thermal efficiency due to low density, small heat capacity and small thermal conductivity of air and measures for improving heat transfer through panel is necessary. In this study, thin flat metallic sheet was suspended at the middle or fins at the back wall of PV module to improve the thermal and electrical performance of the system. The steady state thermal efficiencies of the modified system are compared with the typical PV/T system. Temperature profiles of the outlet air, PV rear face and channel back are presented which showed the contribution that resulted in increased system's electrical and thermal efficiencies.

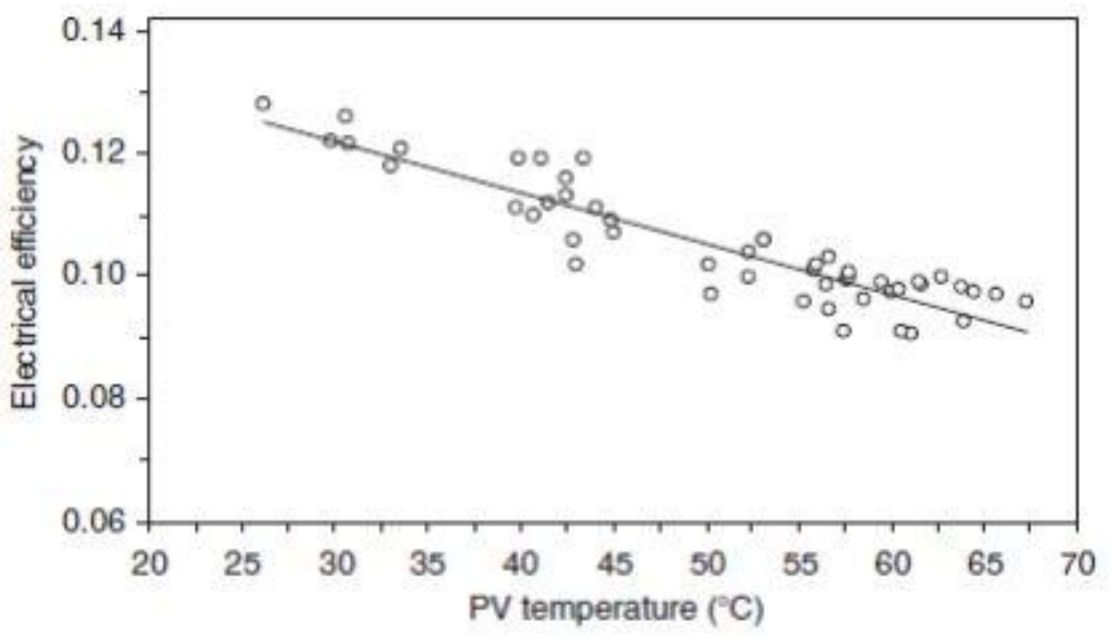

Figure 9: Electrical efficiency as function of PV [16]

The study by Eke and Senturk [17] involves one year operating performance comparison of a fixed tilt and a double-axis sun tracking PV system. The two identical 7.9 kWPV systems with similar modules and inverters were installed in October 2009 at Mugla University campus in southwestern Turkey. The performance measurements for fixed tilt PV system and double axis sun tracking PV system were carried out. Measured data of both systems were compared with the simulated data. The electricity yield is 11.53 MW-h with 1459 kWh/kWp energy rating for fixed tilt PV system and 15.98 MW-h with 1908 kWh/kWp energy rating for the double axis sun tracking PV system for the time period starting from April 2010 to March 2011. Double axis sun tracking system produces 30.79% more electricity as compared to the latitude tilt fixed PV system. The results showed that the difference between the simulated energy and the measured energy is less than 5%. Following graph shows the electricity yield for both the systems round the year.

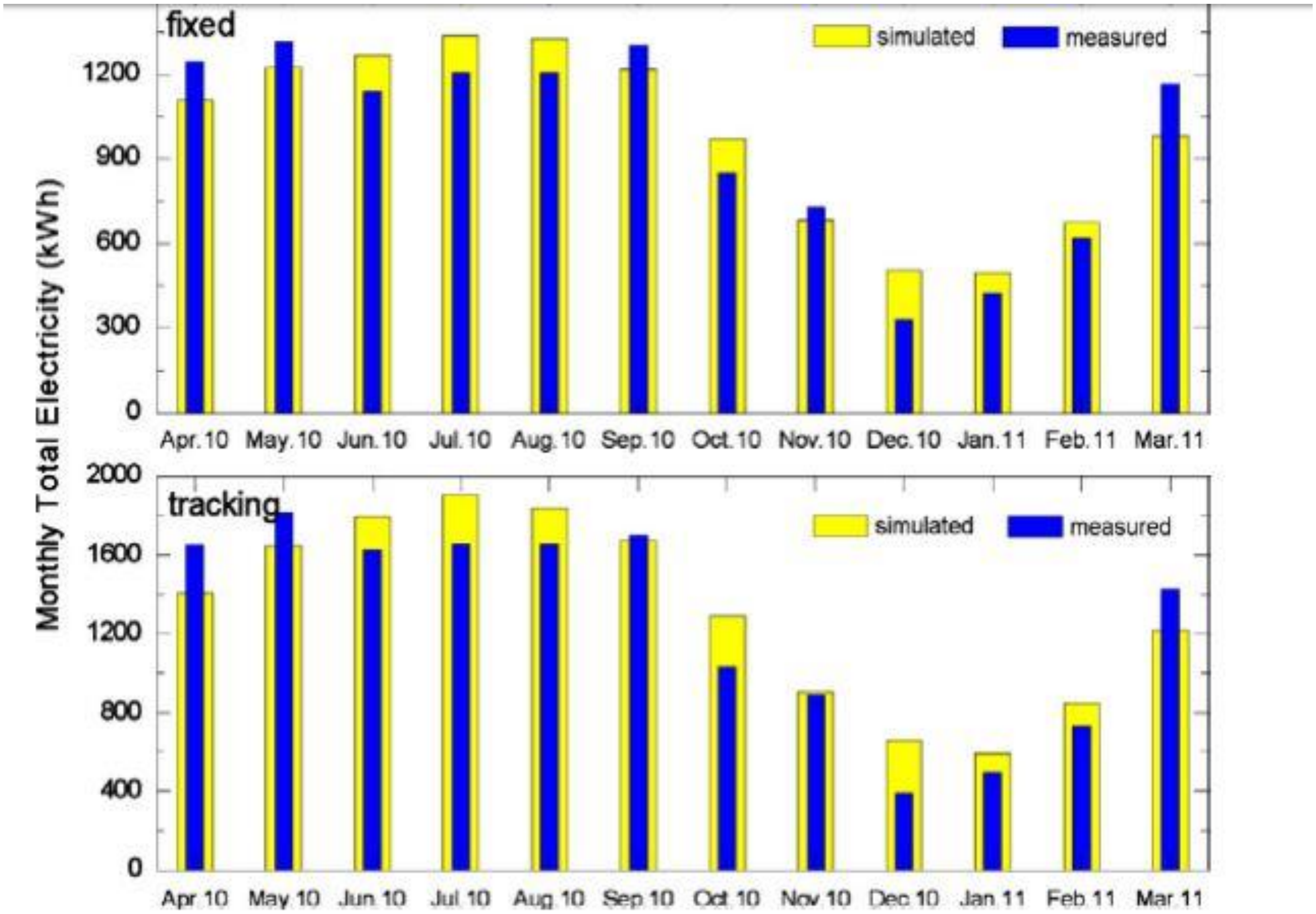

Figure 10: Simulated and measured energy differences for fixed and tracking PV systems [17]

The electrical efficiency of photovoltaic systems is affected by the operating temperature. Increase in temperature of PV system reduces its electrical yield. Many studies have been carried out regarding photovoltaic/thermal (PV/T) systems which involved a circulating fluid of lower temperature that cools down the system by taking away its heat and improves the power output. This study performed by Tonui and Tripanagnostopoulos [18] presents the cooling of PV system is by natural air flow and two low cost techniques to improve the heat transfer to air stream in the air channel are studied. The experimental setup involved reference PV/T system tilted at 40 degrees angle, the other PV/T systems were incorporated with thin metal sheet suspended at the middle and fins attached to the back wall of the air channel to improve heat transfer from module. A numerical model was developed and compared with the experimental data for both glazed and unglazed PV/T systems. The validation results showed good correlation between the anticipated values and measured data obtained from the experimental results thus performance of these PV/T air collectors can be studied analytically with respect to several design and operating conditions. This study conducted by Bakirci [19] deals with finding the optimum tilt angle of solar panels that affects the electrical efficiency of the photovoltaic (PV) system. The research was carried out in eight major provinces of Turkey. The data of solar irradiation on PV surface was measured for tilt angles starting 0° to 90° with the increment of 1° for each measurement. The results showed that the optimum tilt angle varies from 0 to 65°throughout the year in Turkey. Optimum tilt angle was at its minimum value of 0° in June and July and monthly average total irradiation was at its maximum at that tilt angle. The tilt angle came out to be maximum in the month of December for all the provinces. In addition, general correlations were derived and used to estimate the optimum tilt angle of photovoltaic module used in Turkey. The results were compared on the basis of statistical error tests of mean bias error (MBE), root mean square error (RMSE), t-statistic and correlation coefficient. Rosa-Clot et al. [20] studied the effects and behavior of photovoltaic panel submerged in shallow water. The experiments have been performed on monocrystalline silicon panel and noticeable increase in the electricity yield has been observed. This increase in electricity output of PV module is due to the submerged condition which helped in the reduction of sun light losses due to reflection and maintained normal surface temperature of the module by heat dissipation to water in contact from panel’s surface. The experimental setup has been made to test the solar panel in different water depths. For this purpose, three identical panels are used. One panel is exposed directly to sunlight, the other two panels are submerged under water at 4 cm and 40 cm depth respectively. The changes in solar panels‟ efficiencies have been observed and noted.

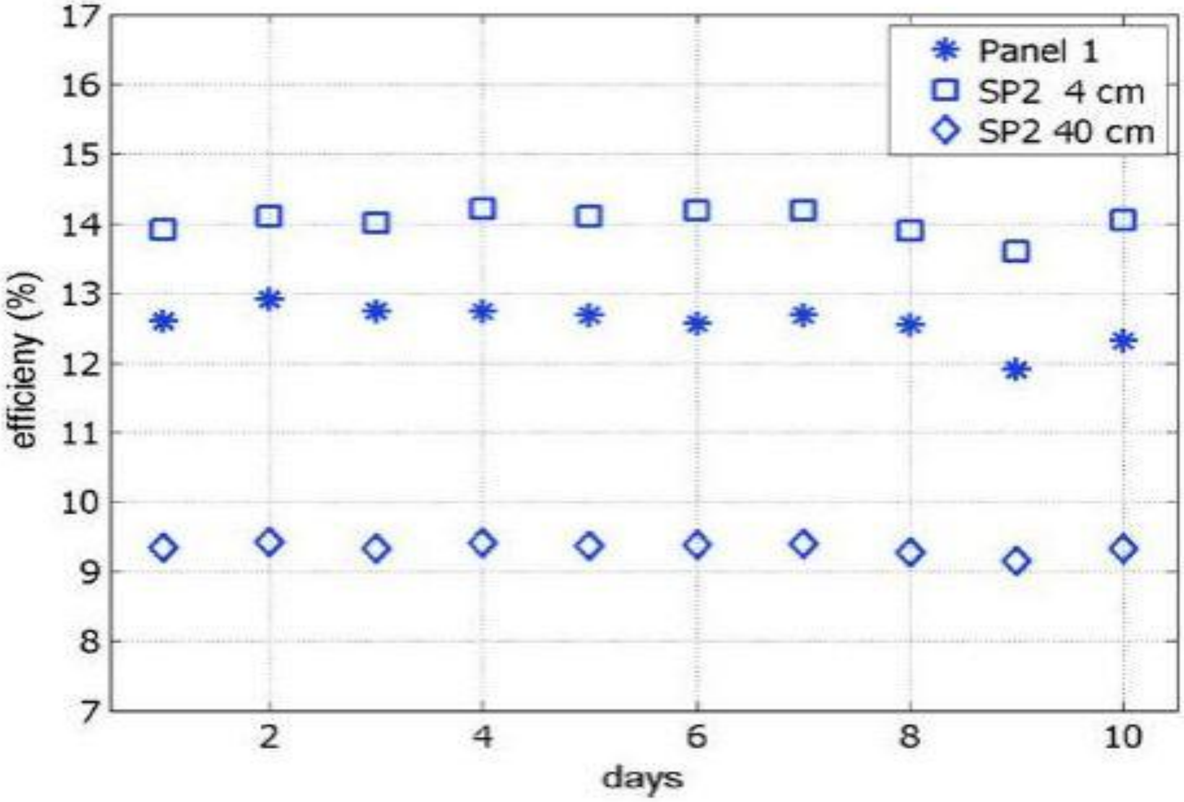

Figure 11: Graph between efficiency and number of days [20]

The study conducted by Moharram et al. [21] includes the steps to minimize the amount of water and electrical energy required to cool the solar panels particularly in hot regions such as Egypt. In this study, the cooling of solar panels has been done using water spray over the front surface of the photovoltaic (PV) panels. A mathematical model has been developed to determine trigger point to start the cooling of solar panels as the temperature of panels reaches to maximum allowable temperature (MAT). Related to cooling of solar panels, a model has been developed which showed the time required to cool down the solar panels to its normal operating temperature i.e. 35°C based on the proposed cooling system.The models for heating and cooling of solar panels were validated experimentally. The experimental results showed that the electrical energy output is maximum when the cooling of solar panels is performed as its temperature reaches maximum allowable temperature (MAT) of 45°C. The MAT is a temperature balance which gives a good agreement between output energy from solar panels and energy required for cooling of panels.

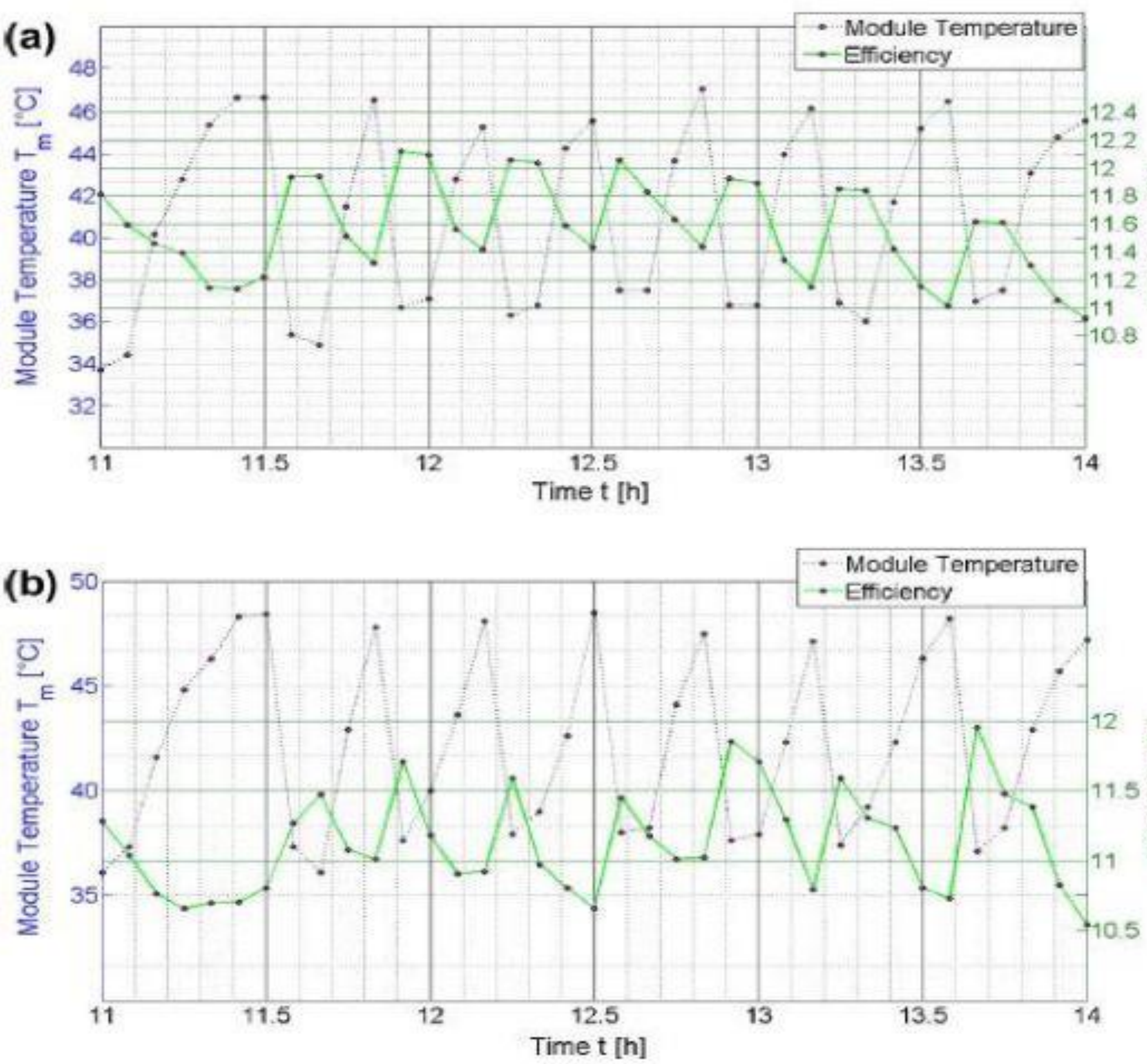

Figure 12: Experimental measurements of the module temperature and efficiency versus time in (a) June and (b) July 2012 [21]

The research work performed by Du et al. [22] focuses on improving the efficiency of photovoltaic (PV) system using concentrator and water cooling system. Two axis solar tracking system is used to maximize the solar irradiation over the PV surface. This concentrated water cooled system was developed at the Institute of Energy and Environment, Southeast University, China. The concentrated photovoltaic (CPV) system was used to get more power output by using less expensive semiconducting PV material required for the same output. This CPV system was used for testing the performance of system based on different parameters such as operating temperatures, power output and efficiency. In order to compare results, a fixed PV module of same characteristics was mounted at a tilt angle of 35° facing south. The experimental results showed that the maximum power output from CPV system and fixed PV system was 71.13W and 16.55W. The concentrating ratio of solar radiation on CPV system was 8.5, however the power output was comparatively less due to imperfection in design and material of the CPV system. The effect of cooling water flow rate over the electrical efficiency is shown in graph as follows:

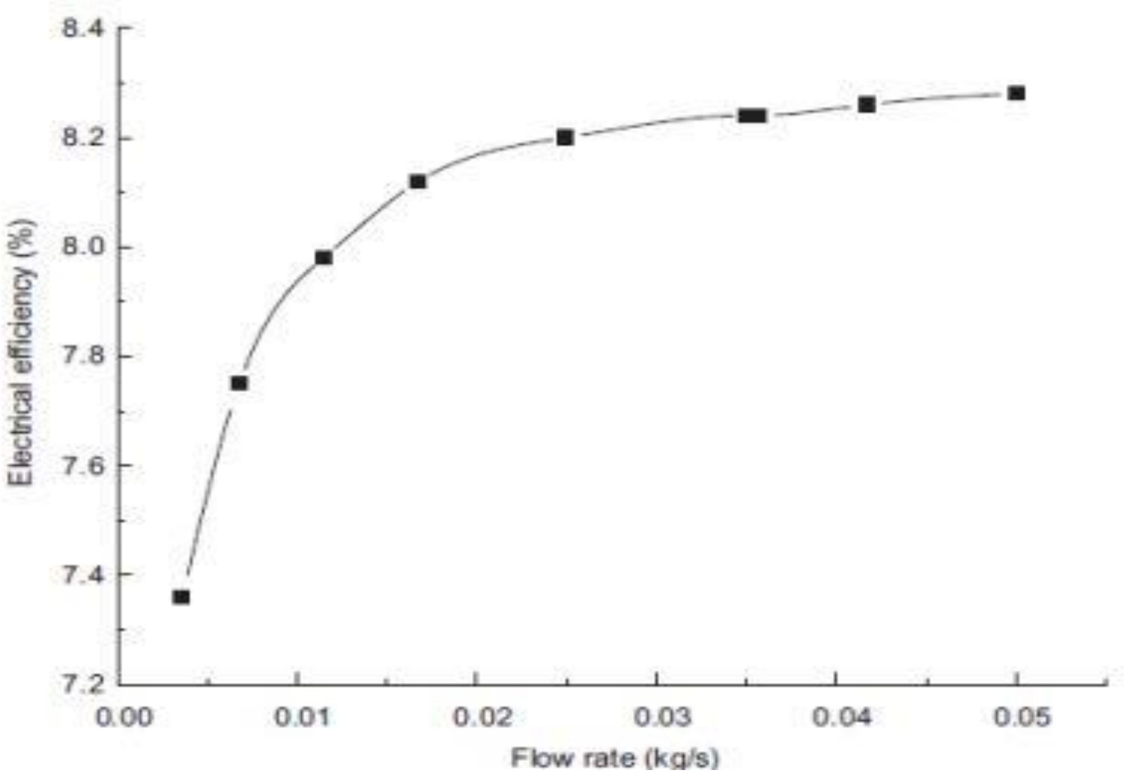

Figure 13: Effect of water flow rate on electrical efficiency[22]

The performance of photovoltaic module is affected by its operating temperature. Higher operating temperature of PV module significantly reduces the electrical output of the system thus reducing the overall electrical efficiency of the PV module. To overcome this problem, a

hybrid water cooled PV system is developed by Bahaidarah et al. [23] which incorporated a heat exchanger on the rear surface of the panel. A numerical model using Engineering Equation Solver (EES) software is developed to predict parameters affecting the performance of hybrid PV module. The effect of cooling down rear surface of hybrid PV module is investigated experimentally. The experimental results are in good conformity with the results of numerical model for the climate of Dhahran, Saudi Arabia. This cooling setup of PV module resulted in a significant drop of module temperature to about 20% leading to an increase in PV module efficiency by 9%.

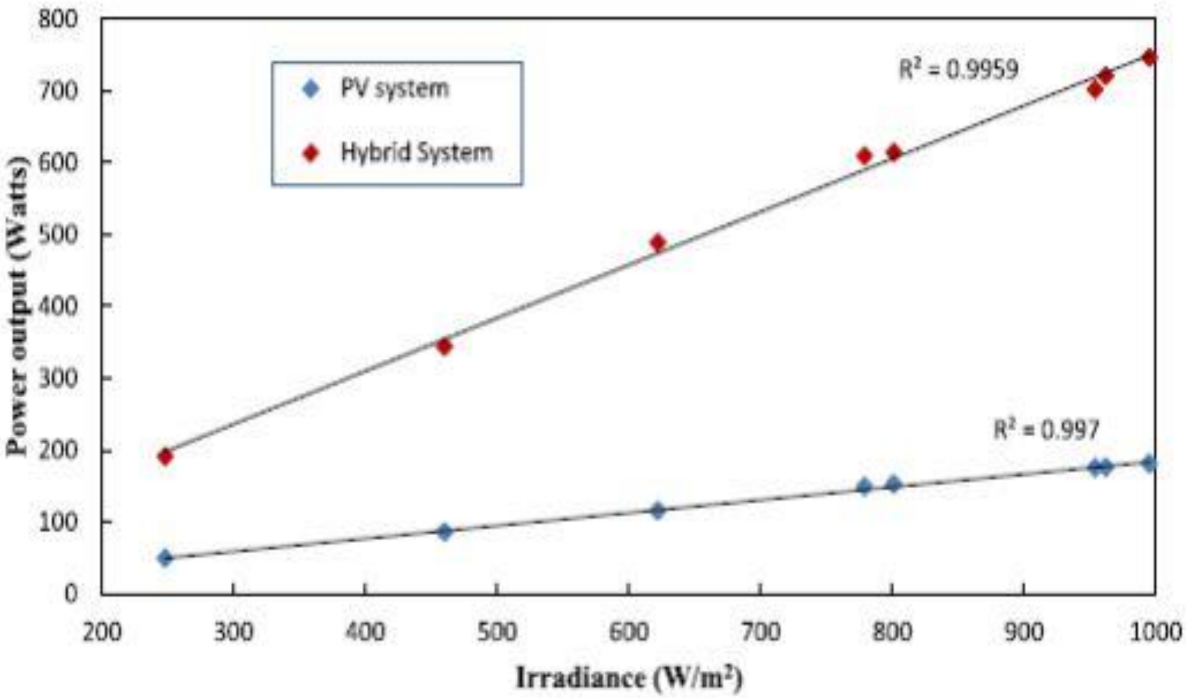

Figure 14. : Graph between irradiance and power output for PV system and Hybrid system[23]

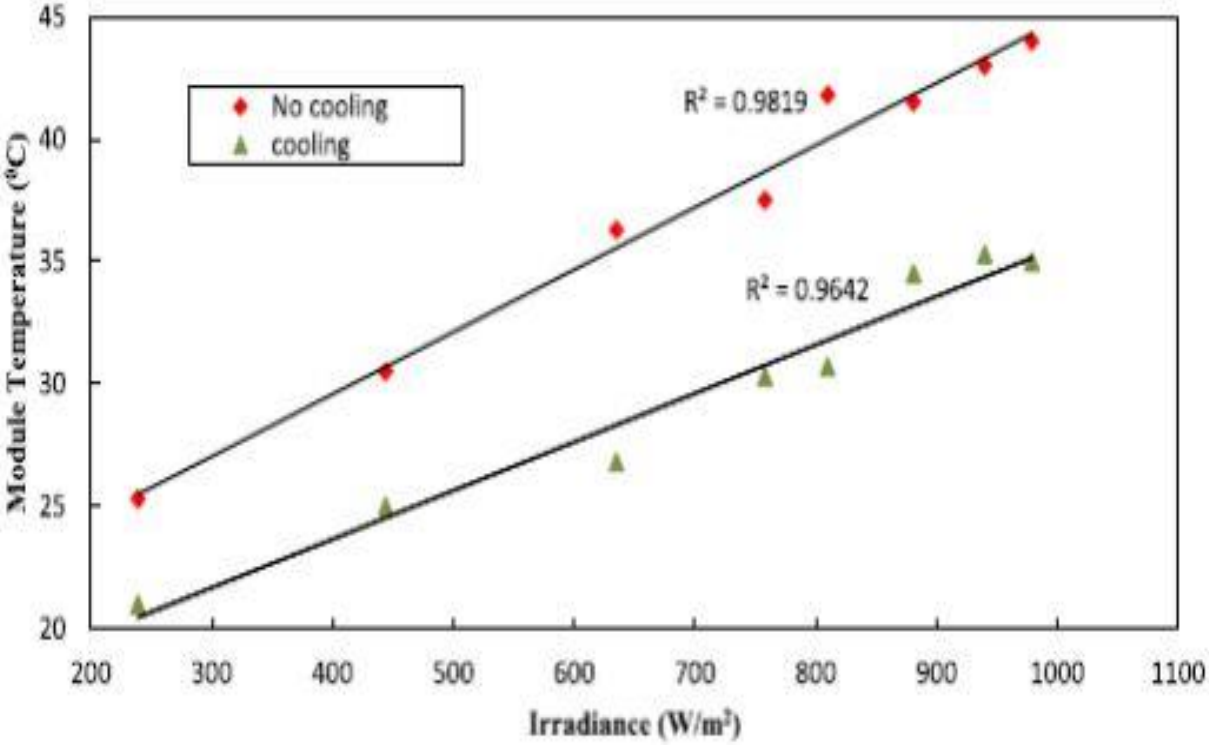

Figure 15: Graph showing relation between irradiance and module temperature for no cooling and cooling case[23]

Solar radiations have significant impact on the electrical efficiency of the photovoltaic (PV) cells. The solar radiations cause an increase in the cell operating temperature which in result reduces the electrical efficiency of the system. In order to actively cool down the solar cells, a hybrid photovoltaic/thermal (PV/T) system was developed by H.G. Teo et al. [24] which consisted of parallel array of ducts, attached to the back of solar panel, with inlet/outlet manifold for uniform air distribution. The system was tested experimentally with and without active cooling. The results showed that electrical efficiency of solar panel without active cooling and with active cooling came out to be 8-9% and between 12-14%, respectively. With active cooling, significant temperature drop of the solar cells was observed. The experimental results were compared and verified with the simulation results which showed good agreement between them.

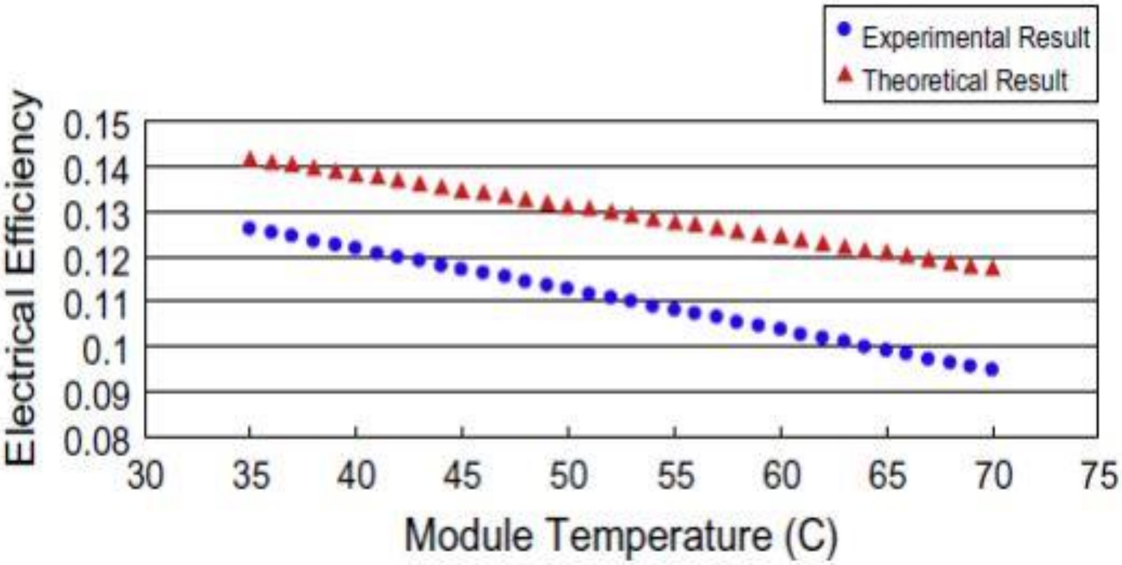

Figure 16: Relation between module temperature and electrical efficiency for experimental and theoretical result [24]

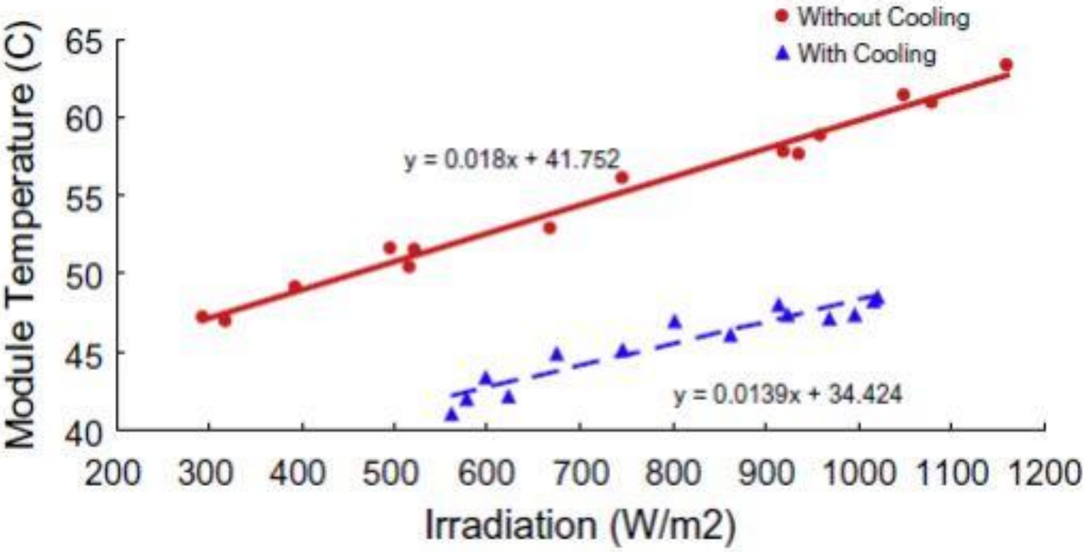

Figure 17: Relation between irradiation and module temperature for without cooling and cooling case [24]

The performance of photovoltaic cells is adversely affected if its operating temperature exceeds certain limit. In order to get maximum output from the solar panels and increase photovoltaic water pumping system efficiency, it is important to maintain the PV cell temperature and reflection as low as possible. Abdolzadeh and Ameri [25] investigated the improvement in the performance of photovoltaic water pumping system when water is Fig2.11. Relation between module temperature and electrical efficiency for experimental and theoretical result [26] Fig2.12. Relation between irradiation and module temperature for without cooling and cooling case [26] 21 sprayed over the PV cells. The results of this study are compared with the traditional PC systems. The experimental results show increase in power generated by the system due to water spray over the PV cells. The maximum PV cell efficiency of 13.5% was achieved with this modification. The spraying of water over PV cells also increased the efficiency of the subsystem and the pump flow rate when operating under different heads.

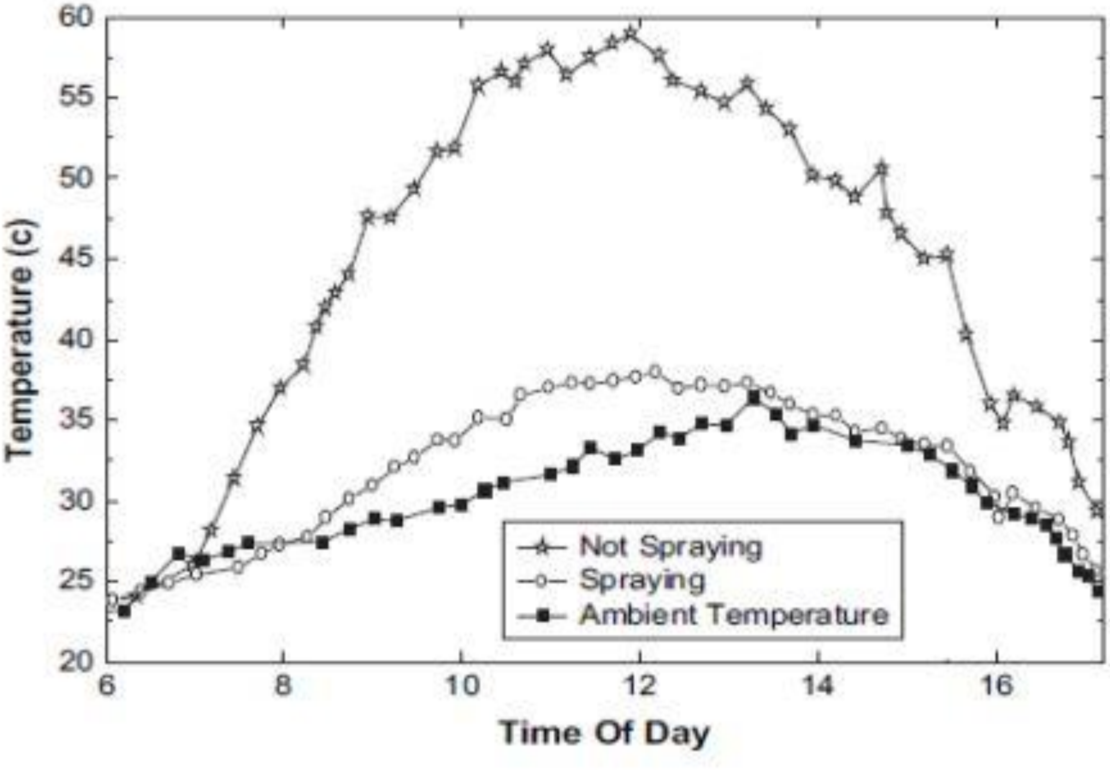

Figure 18: Temperature variation with respect to time of the day [25]

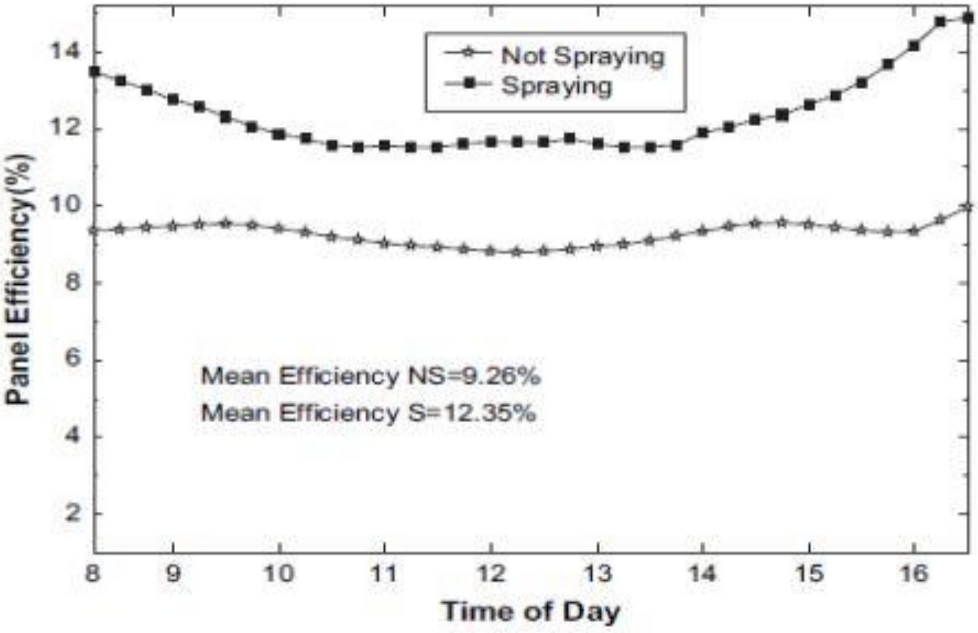

Figure 19: Time of day vs. panel efficiency for not spraying and spraying cases [25]

The energy conversion efficiency of photovoltaic panel depends on many factors, one of which is the operating temperature of PV cells. Studies clearly indicate that increase in operating temperature significantly decreases the electrical yield of PV cells. To overcome this problem, the PV cells need to be cooled down. A study by Kordzadeh [26] involves cooling of PV cells with thin film of water flown over PV surface with the help of water pumping system installed in Kerman, Iran. The purpose of this research is to study the effect of this cooling system on the nominal power of array and system head on the operation of system. The result of experiments show that array power generation increases significantly with the decrease in array nominal power and increase in system head. As a result, the panel and total efficiency increases along with pump flow rate.

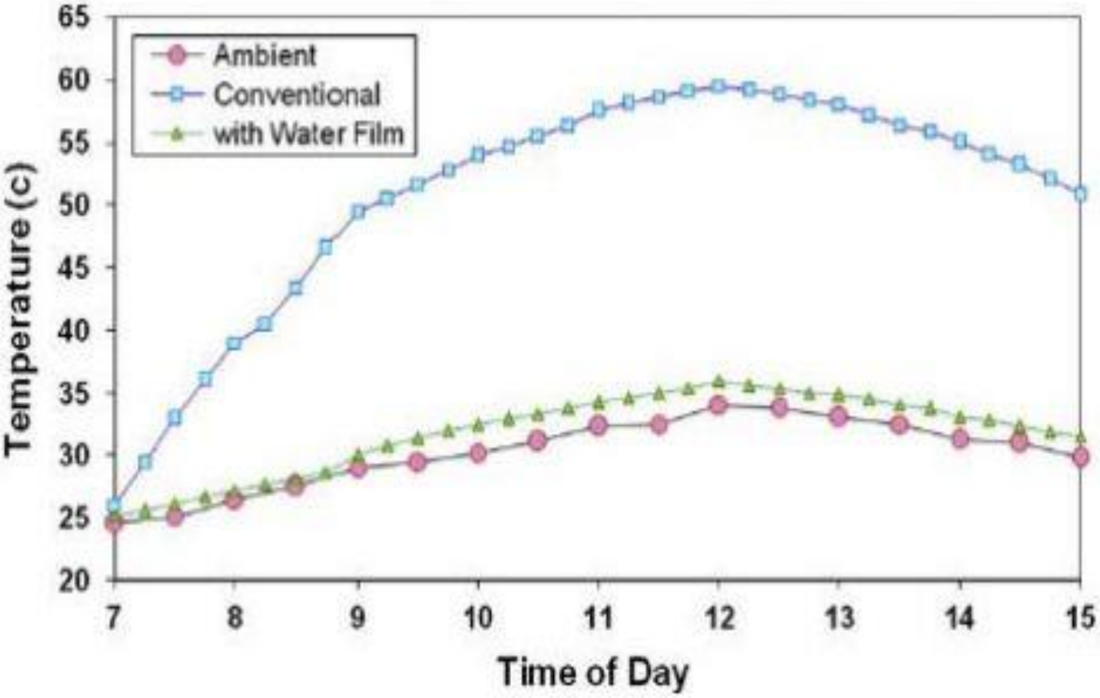

Figure 20: Time of day vs. temperature for ambient, conventional and water film case [26]

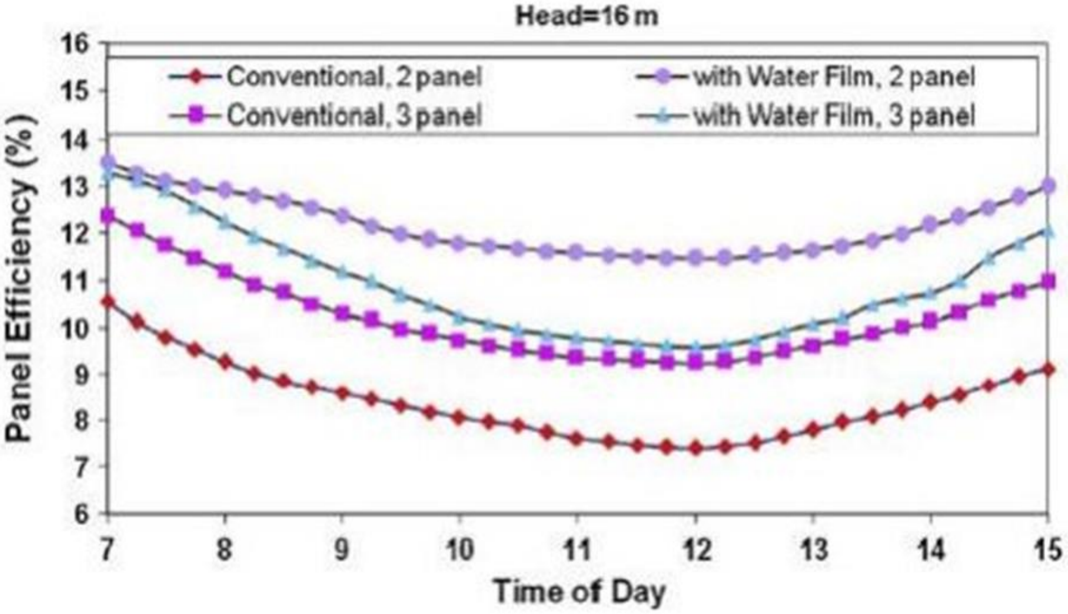

Figure 21: Relation between panel efficiency and time of the day for all cases [26]

This research, carried out by H.M.S. Hussein et al. [27], involves the performance study of mono-crystalline silicon type PV modules at different orientations and tilt angles. The performance analysis of PV was predicted using FORTRAN and TRNSYS for a year. The analysis program results were experimentally validated using different meteorological conditions of Cairo, Egypt, and design parameters. The results showed that the maximum output power can be obtained using PV modules facing south and mounted at angle between 20° – 30°. Furthermore, the horizontal PV modules can generate 95% of the yearly maximum output power as generated by PV modules mounted at optimum angles. A study conducted by Lave and Kleissl [28], deals with the determination of optimum tilt and azimuth angles of solar panels in the United States. For coastal states such as Florida, Texas, New Mexico and Colorado, the optimum tilt and azimuth angles changes by up to 10°from rule of thumb of latitude tilt and due south azimuth. The comparison was done for the yearly global solar irradiation incident on flat horizontal panel, panel at optimum tilt angle and 2 axis tracking panel. The irradiation on optimum tilt panel increased by 10% to 25% per year with increasing latitude as compared to horizontal fixed panel. Also, there was 25 to 45% more irradiation received by 2 axis tracking panel as compared to optimum tilt angle panel. The highest irradiation of over 3.4 MWh/m2 was observed in southwestern states using 2-axis tracking panel. Dike et al. [29] presented the optimum inclination angles for the solar panel mounted at fixed tilt angle without the use of mechanized tracking system for some of the African cities. The purpose of determining the optimum inclination angles of solar panel is to exploit and use maximum solar irradiation. The results of the solar panel mounted at optimal inclination angles were compared with the horizontally mounted solar panel. The comparison shows that the northern African cities like Algiers, Rabat and Tripoli have high levels of unused solar irradiation of 780 Wh/m2, 760 Wh/m2 and 680 Wh/m2 respectively whereas the cities like Bangui, Abidjan and Mogadishu have quite low levels of unused solar irradiation of 40 Wh/m2, 70 Wh/m2 and 10 Wh/m2 respectively when PV modules are mounted on horizontal plane. The energy generating potential of the region can be increased if these unused irradiations are harnessed.

The increase in solar panel operating temperature reduces its electrical yield. Therefore the necessary requirement was to reduce the solar panel temperature by effective cooling method in order to minimize its influence on power generation system. The experimental setup was prepared by Jianqiang et al. [30] for cooling of solar panel which used water as a cooling agent. The variation in the solar panel temperature has been studied while changing factors such as flow of cooling water, radiated power etc. The variation of panel temperature, with the amount of cooling water, has been studied using heat exchanger mathematical model which was established using Sieder-Tate formula. The analysis and calculations were done under different power and inlet water temperature. The experimental results were in good agreement with the theoretical results. A study carried out in the Middle East by Eveloy et al. [31] investigates the effects of cooling the module using water flow experimentally, to improve the energy output of the stationary and sun tracking PV modules. The experiments showed that the operating temperature of PV module was lowered up to 30° using water cooling system. For water cooled South facing stationary PV module, power output get increased by 13% at 2 p.m. whereas the power output of sun tracking PV module came out to be 20% more relative to passive cooling. The incorporation of sun tracking system and water cooling with the PV module increases the power output by up to 40% as compared to passively cooled stationary PV module.

# 3 CHAPTER 3-METHODOLOGY:

## 3.1 Equipments:

For preparing the experimental setup of this thesis, there are some particular equipments which were used.

1.Two 50 Wp polycrystalline solar PV panels

- ❖ Specification :
- Maximum power(Pmax) - 50watt
- Voltage at Pmax (Vmp) - 17.3 volt
- Current at P max – 2.9A
- Warranted Minium Pmax- 45watt
- Short circuit current (Isc) – 3.17A
- Open circuit voltage (Voc) – 21.8 volt
- Dimensions – 839L X 537W X 50D mm
- Weight - 6kg
- Bought from : Synergic Bangladesh Limited

2. Two rechargeable sealed Lead acid batteries

- ❖ Specification :
- BT-12M7.5AC (12V7.5Ah/20HR)

| Constant Voltage charge at 25 °C | Voltage Regulation | Initial Current |
|---|---|---|
| Standby Use | 13.62V-13.8 V | 1.875A |
| Cycle Use | 14.1V -14.4V | 1.875A |

- Made in China

3. Two solar charge controllers

- ❖ Specification :
- Model –SN1000 (IDCOL Approved)
- Rated Voltage -12 V
- Rated Current -10A (max)
- Microcontroller Based
- Manufactured by – Supernova Engineering

4. Six Thermocouples

- ❖ Specification :
- k-type Thermocouple
- Positive leg is Chromel based (90% nickel , 10% chromium) and Negative leg is Alumel based (95% nickel, 2% manganese, 2% aluminium and 1% silicon )
- Made in USA

5. Digital Thermometer

- ❖ Specification :
- MASTECH , MS6514
- Conform to IEC61010-1,Pollution degree -2

6. Multimeter

- ❖ Specification :
- GWINSTEK ,GDM-356

7. Glue gun

- ❖ Specification :
- 100-240V
- 50-60Hz

8. Woolen material

- ❖ Specification :
- Weight: 33gm or 0.033kg
- Length: 68cm or 0.68m
- Width: 46cm or 0.46m
- Covered Area: 3128cm² or 0.3128m²
- MR= 16%
- MC= 13.8%

9. Jute material:

- ❖ Specification :
- Weight: 78.71gm or 0.07871kg
- Length: 73cm or 0.73m
- Width: 47cm or 0.47m
- Covered Area: 3431cm² or 0.3431m²
- MR= 13.75%
- MC= 12.1%

Figure 22: Solar PV cell

Two solar panels were setup side by side and they were parallel to each other.

Figure 23: 12V 7.5 Ah/20HR Battery

Due to irradiation, solar panel produces electrical energy that needs to be stored therefore a 12 V solar battery was also used along with solar charge regulator whose function was to limit the rate at which electric current was added to or drawn from the battery.

Figure 24: Charge controller

Charge controller was also connected to the battery terminals so that load can be operated.

Figure 25: Experimental setup

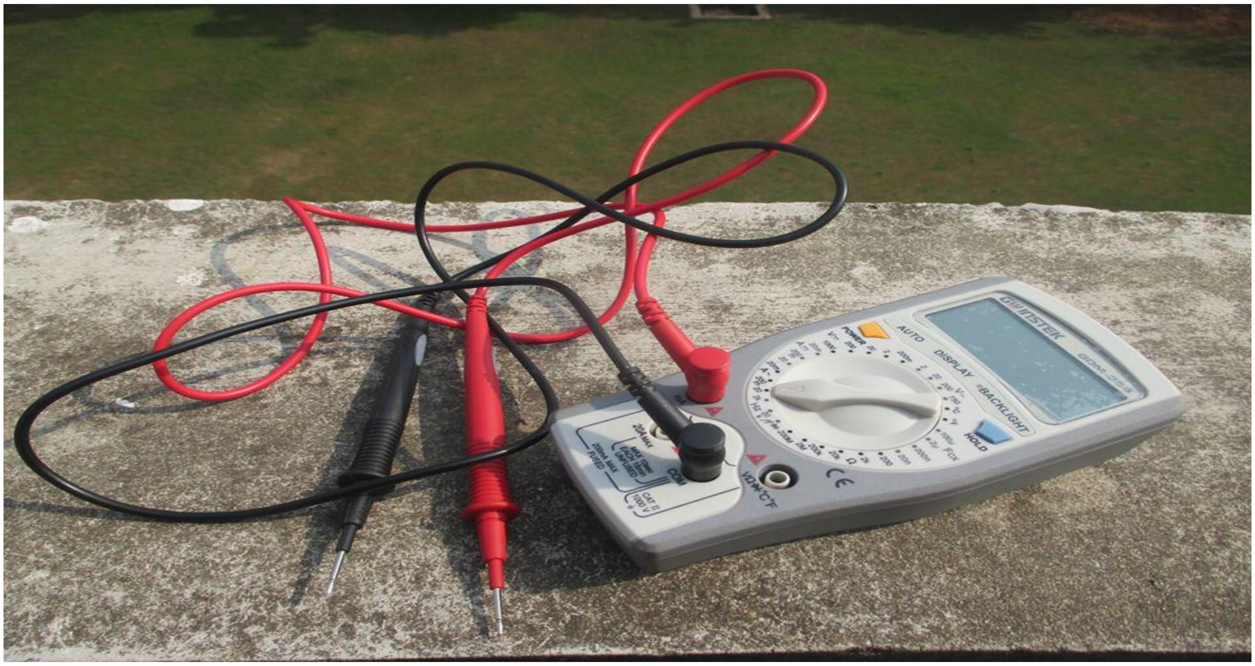

Figure 26: Multimeter

With the Multimeter, the voltage and current of the PV panel were determined.

Figure 27: Digital Thermometer

Digital Thermometer has been used to measure the temperature by inserting thermocouples into it.

Figure 28: Glue Gun

Glue gun was used to attach the woolen material on the back surface of the panel.

Figure 29: Thermocouples

The continuous irradiation of light from flood lamp increases the surface temperature of solar panel. In order to monitor those surface temperatures, thermocouples were used.

Figure 30: Woolen Material

Wet woolen material was used to cool the back surface of the panel to increase the output.

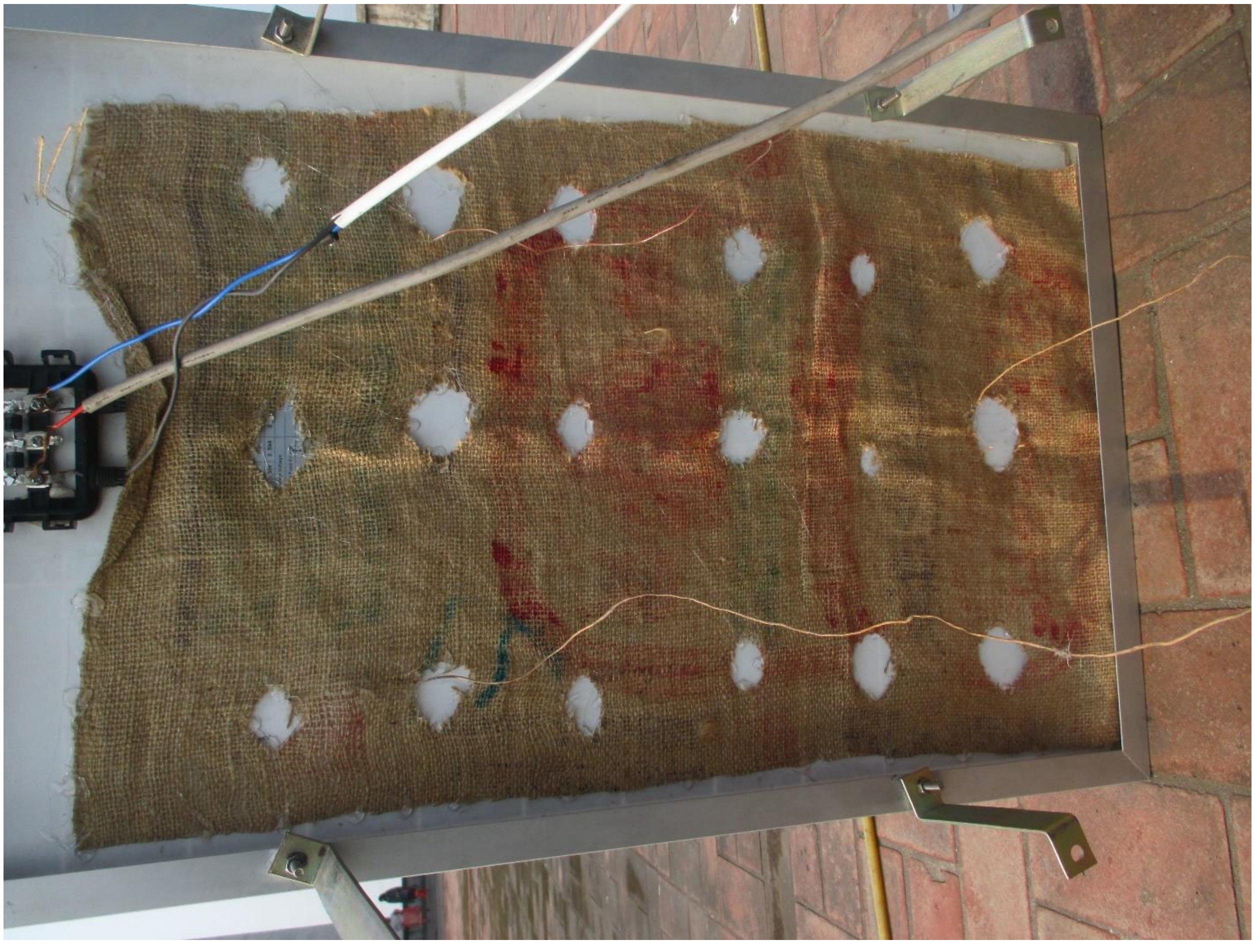

Figure 31: Jute Material

Wet jute material was used to cool the back surface of the panel to increase the output.

## 3.2 Experimental Procedure

Due to continuous irradiation on the surface of solar panel, the surface temperature increases. The increase in cell temperature reduces the electricity output of the solar panel. Therefore monitoring the surface temperature of the solar panel is of great importance. For measuring the front and back surface temperature of solar panel, a data acquisition unit is used which utilizes thermocouples for getting continuous measurements.

The output of the PV panel was compared at 3 stages:

1) By water spraying over the front surface of the panel

2) By attaching wet woolen material over the back surface of the PV panel

3) By attaching wet jute material over the back surface of the PV panel

### ❖ By water spraying over the front surface of the panel

At first two panels were kept to the sun for at least 1 hour and the inclination angle of the panels is 23.45 degree to the south. Since all the setup and equipments were same and both panels were kept parallel so both panels gave similar result. The thermocouples gave the surface temperatures of the panel. We used three thermocouples at three different places and the digital thermometer gave the reading of temperatures. The multimeter gave the reading of voltage and current across the panel.

Then one panel was kept normal and over the other panel water was sprayed. Due to the water spray, the temperature of the surface of the panel got decreased and similarly all the data were taken for this wet panel. This process was repeated then after 30 mins, 20 mins and 10 mins respectively. By comparing these two data it is seen that, the power output of the water sprayed panel get increased.

## ❖ By attaching wet woolen material over the back surface of the PV panel

one panel again kept normal and over the back surface of the other panel Woolen material was attached by glue gun and water was sprayed over the wool. After spraying a certain amount of water, both the panels were kept to the sun for 30to 40 minutes and the readings were taken. It has been seen that the temperature of the panels get decreased and the output get increased even more than the normal water spraying.

## ❖ By attaching wet jute material over the back surface of the PV panel

one panel again kept normal and over the back surface of the other panel jute material was attached by glue gun and water was sprayed over the jute fabric. After spraying a certain amount of water, both the panels were kept to the sun for 30to 40 minutes and the readings were taken. It has been seen that the temperature of the panels get decreased and the output get increased even more than the woolen material.

# 4 CHAPTER 4-RESULT AND DISCUSSION:

## 4.1 Experimental Data:

Two solar panels of 50 watt are used for the experiment. 1st we have examined if two panels give us the same power output or not without water spray. So for this we put two panels parallel one after another at 23.5° angle south faced.

### 4.1.1 Examined data if two panels give same power without spray:

#### 4.1.1.1.1 Reading 1:

Date: 21/08/2017

Setup time: 1:40pm

Reading time: 2:15pm

Ambient temp. : 34 °C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 | PANEL 2 |
|---|---|---|
| T1 (°C) | 35.4 | 35.9 |
| T2 (°C) | 36.2 | 36 |
| T3 (°C) | 35.4 | 36.2 |
| I (AMP) | 0.49 | 0.52 |
| V (VOLT) | 14.71 | 15.09 |
| P=IV (WATT) | 7.21 | 7.85 |

Table 4-1, Examined data if two panels give same power without spray

#### 4.1.1.1.2 Reading 2:

Date: 12/09/17

Setup time: 12:50pm

Reading time: 1:55pm

Ambient temp.: 30°C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 | PANEL 2 |
|---|---|---|
| T1 (°C) | 25.7 | 32 |
| T2 (°C) | 25.8 | 34 |
| T3 (°C) | 39.2 | 41 |
| I (AMP) | 0.6 | 0.7 |
| V (VOLT) | 20.84 | 18.5 |
| P=IV (WATT) | 12.50 | 12.95 |

Table 4-2, Examined data if two panels give same power without spray

#### 4.1.1.1.3 Reading 3:

Date: 12/09/17

Setup time: 12:50pm

Reading time: 2:20pm

Ambient temp.: 30°C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL1 | PANEL2 |
|---|---|---|
| T1 (°C) | 36.2 | 38.2 |
| T2 (°C) | 37.4 | 38.7 |
| T3 (°C) | 41.5 | 41.8 |
| I (AMP) | 0.67 | 0.62 |
| V (VOLT) | 19.2 | 19.9 |
| P=IV (WATT) | 12.86 | 12.34 |

Table 4-3, Examined data if two panels give same power without spray

#### 4.1.1.1.4 Reading 4:

Date: 12/12/17

Setup time: 10:05 am

Reading time: 11:00 am

Ambient temp.: 29°C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 | PANEL2 |
|---|---|---|
| T1 (°C) | 43 | 44.6 |
| T2 (°C) | 41.7 | 43 |
| T3 (°C) | 35.6 | 36.6 |
| I (AMP) | 1.68 | 1.63 |
| V (VOLT) | 20.1 | 20.0 |
| P=IV (WATT) | 33.768 | 32.926 |

Table 4-4, Examined data if two panels give same power without spray

#### 4.1.1.1.5 Reading 5:

Date: 12/12/17

Setup time: 10:05 am

Reading time: 12:10 am

Ambient temp.: 29°C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 | PANEL 2 |
|---|---|---|
| T1 (°C) | 44.2 | 44.9 |
| T2 (°C) | 45.7 | 46.5 |
| T3 (°C) | 41 | 42.8 |
| I (AMP) | 1.80 | 1.84 |
| V (VOLT) | 20.4 | 20.1 |
| P=IV (WATT) | 36.72 | 36.984 |

Table 4-5, Examined data if two panels give same power without spray

So from the data we can see that output is approximately same.

Now we can move to our real experiment by using water spray. We have sprayed water by three methods. They are:

1) Water spray on the front surface of the panel
2) Water spray on the back surface of the panel with wool
3) Water spray on the back surface of the panel with jute.

### 4.1.2 Type 1: Water spray on the front surface of the panel

#### 4.1.2.1 Day 1:

##### 4.1.2.1.1 Reading 1:

Date: 18/09/17

Setup time: 11:35am

Ambient temp.: 32°C

Reading Time: 2:00pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | Panel 1 (without water spray) | Panel 2 (with water spray) |
|---|---|---|
| T1 (°C) | 53.5 | 34.3 |
| T2 (°C) | 51.5 | 40 |
| T3 (°C) | 50.7 | 39.4 |
| I (AMP) | 3.01 | 3.05 |
| V (VOLT) | 17.45 | 17.63 |
| P=IV (WATT) | 52.53 | 53.77 |

Table 4-6, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (53.77-52.53) watt

= 1.24 watt

#### 4.1.2.1.2 Reading 2:

Date: 18/09/17

Setup time: 11:35am

Ambient temp.: 32°C

Time: 2:15pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | Panel 1 (without water spray ) | Panel 2 (with water spray) |
|---|---|---|
| T1 (°C) | 39.3 | 36.9 |
| T2 (°C) | 41.2 | 37.1 |
| T3 (°C) | 41.1 | 37.7 |
| I (AMP) | 1 | 1.13 |
| V (VOLT) | 19.36 | 19.93 |
| P=IV (WATT) | 19.36 | 21.91 |

Table 4-7, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (21.91-19.36) watt

=2.55 watt

#### 4.1.2.2 Day 2:

Date: 25/09/2017

Setup time: 12:30pm

Reading Time: 2:10pm

Ambient temperature: 31°C

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray) | Panel 2 (with water spray ) |
|---|---|---|
| T1 (°C) | 37.9 | 35.2 |
| T2 (°C) | 39.7 | 37.6 |
| T3(°C) | 40.1 | 37.9 |
| I (AMP) | 2.97 | 3.01 |
| V (VOLT) | 19.52 | 19.49 |
| P=IV (WATT) | 57.97 | 58.66 |

Table 4-8, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (58.66-57.97) watt

=0.69 watt

#### 4.1.2.3 Day 3:

Date: 12/10/2017

Ambient temp.: 33°C

Setup time: 11:55am

Reading time: 1:35pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | Panel1 ( without water spray) | Panel2 (with water spray) |
|---|---|---|
| T1 (°C) | 48.2 | 35.9 |
| T2 (°C) | 46.3 | 32.1 |
| T3 (°C) | 49.4 | 36.6 |
| I (AMP) | 1.03 | 1.19 |
| V (VOLT) | 19.23 | 19.18 |
| P=IV (WATT) | 19.81 | 22.82 |

Table 4-9, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (22.82-19.81) watt

= 3.01 watt

#### 4.1.2.4 Day 4:

##### 4.1.2.4.1 Reading 1:

Date: 10/11/17

Set up time: 12:00pm

Ambient temp.:30°C

Reading Time: 1:00pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 34.6 | 29.8 |
| T2 (°C) | 37.1 | 32.2 |
| T3 (°C) | 39.8 | 32.7 |
| I (AMP) | 1.59 | 1.62 |
| V (VOLT) | 18.9 | 19.1 |
| P=IV (WATT) | 30.05 | 30.94 |

Table 4-10, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (30.94-30.05) watt

= 0.89 watt

#### 4.1.2.4.2 Reading 2:

Date: 10/11/17

Set up time: 12:00pm

Ambient temp.:30°C

Time: 1:30pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 33.9 | 30.1 |
| T2 (°C) | 38.5 | 31.7 |
| T3 (°C) | 40.2 | 30.9 |
| I (AMP) | 2.03 | 1.97 |
| V (VOLT) | 19.05 | 19.81 |
| P=IV (WATT) | 38.67 | 39.03 |

Table 4-11, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (39.03- 38.67) watt

= 0.41 watt

#### 4.1.2.4.3 Reading 3:

Date: 10/11/17

Set up time: 12:00pm

Ambient temp.: 24°C

Time: 2:05pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 35.8 | 29.6 |
| T2 (°C) | 36.1 | 31.2 |
| T3 (°C) | 38.9 | 32.7 |
| I (AMP) | 0.98 | 0.87 |
| V (VOLT) | 18.55 | 19.62 |
| P=IV (WATT) | 18.18 | 17.07 |

Table 4-12, Water spray on the front surface of the panel

NOTE: As ambient temperature suddenly decreased because of cloudy sky, the temperature of panels also decreased and so after cooling power output decreases.

Increase of power output in panel 2 compared to panel 1= (17.07-18.18) watt

= -1.11 watt

= decreases by 1.11 watt

#### 4.1.2.4.4 Reading 4:

Date: 10/11/17

Set up time: 12:00pm

Ambient temp.:30°C

Reading Time: 2:40pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 32.9 | 28.9 |
| T2 (°C) | 32.7 | 30.2 |
| T3 (°C) | 37.6 | 32.7 |
| I (AMP) | 1 | 1.15 |
| V (VOLT) | 19.24 | 18.98 |
| P=IV (WATT) | 19.24 | 21.83 |

Table 4-13, Water spray on the front surface of the panel

NOTE: Again suddenly temperature increases because of the removal of cloud from the sky and power output of panel 2 after cooling increases.

Increase of power output in panel 2 compared to panel 1= (21.83-19.24) watt

=2.59 watt

#### 4.1.2.5 Day 5:

##### 4.1.2.5.1 Reading 1:

Date: 11/11/2017

Set up time: 10:00am

Ambient temp.: 31°C

Time: 11:00am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 36.7 | 32.3 |
| T2 (°C) | 34.9 | 29.8 |
| T3 (°C) | 39.5 | 30.2 |
| I (AMP) | 1.69 | 1.73 |
| V (VOLT) | 17.82 | 19.7 |
| P=IV (WATT) | 30.12 | 34.08 |

Table 4-14, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (34.08-30.12) watt

=3.96 watt

#### 4.1.2.5.2 Reading 2:

Date: 11/11/2017

Set up time: 10:00am

Ambient temp.: 31°C

Time: 11:35am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 39.2 | 32.8 |
| T2 (°C) | 35.9 | 29.7 |
| T3 (°C) | 37.4 | 27.6 |
| I (AMP) | 0.98 | 1.09 |
| V (VOLT) | 19.13 | 20.3 |
| P=IV (WATT) | 18.75 | 22.23 |

Table 4-15, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (22.23- 18.75) watt

= 3.48 watt

#### 4.1.2.5.3 Reading 3:

Date: 11/11/2017

Set up time: 10:00am

Ambient temp.: 31°C

Time: 12:05pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 40.8 | 38.7 |
| T2 (°C) | 39.9 | 36.5 |
| T3 (°C) | 42.4 | 39.3 |
| I (AMP) | 1.94 | 2.28 |
| V (VOLT) | 20.6 | 18.64 |
| P=IV (WATT) | 39.96 | 42.64 |

Table 4-16, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (42.69-39.96) watt

= 2.73 watt

#### 4.1.2.5.4 Reading 4:

Date: 11/11/2017

Set up time: 10:00am

Ambient temp.: 31°C

Time: 12:25pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 41.7 | 39.5 |
| T2 (°C) | 39.2 | 39.2 |
| T3 (°C) | 43.1 | 35.9 |
| I (AMP) | 1.26 | 1.27 |
| V (VOLT) | 19.6 | 19.9 |
| P=IV (WATT) | 24.70 | 25.27 |

Table 4-17, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (25.27-24.70) watt

= 0.57 watt

#### 4.1.2.6 Day 6:

##### 4.1.2.6.1 Reading 1:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Time: 01:45pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 29.1 | 27.5 |
| T2 (°C) | 27.3 | 28.9 |
| T3 (°C) | 29.7 | 28.3 |
| I (AMP) | 0.97 | 1 |
| V (VOLT) | 19.62 | 18.54 |
| P=IV (WATT) | 19.03 | 18.54 |

Table 4-18, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (18.54-19.03) watt

= -0.49 watt

= decreased by 0.49 watt

#### 4.1.2.6.2 Reading 2:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Reading Time: 02:05pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 29.1 | 27.4 |
| T2 (°C) | 27.6 | 31.5 |
| T3 (°C) | 29.3 | 24.3 |
| I (AMP) | 1 | 1 |
| V (VOLT) | 20.2 | 19.6 |
| P=IV (WATT) | 20.2 | 19.6 |

Table 4-19, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (19.6-20.2) watt

= -0.6 watt

= decreased by 0.6 watt

NOTE: As ambient temperature was too low so after cooling the power output of panel 2 in reading 1 and reading 2 decreases.

#### 4.1.2.6.3 Reading 3:

Date: 28/11/2017

Set up time: 11:00am

Ambient temperature: 28°C

Reading Time: 2:35pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 30.2 | 26.7 |
| T2 (°C) | 29.9 | 25.9 |
| T3 (°C) | 32.7 | 28.1 |
| I (AMP) | 1.02 | 1.1 |
| V (VOLT) | 19.93 | 20.08 |
| P=IV (WATT) | 20.33 | 22.09 |

Table 4-20, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (22.09-20.33) watt

=1.76 watt

#### 4.1.2.7 Day 7:

##### 4.1.2.7.1 Reading 1:

Date: 05/12/2017

Panel set up time: 10:20am

Ambient temperature, T= 26°C

Reading Time: 11:45am

Volume of Water sprayed: 100ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 37.5 | 33.4 |
| T2 (°C) | 36.8 | 31.0 |
| T3 (°C) | 26.5 | 33.0 |
| I (AMP) | 1 | 1.2 |
| V (VOLT) | 19.9 | 20.1 |
| P=IV (WATT) | 19.9 | 24.12 |

Table 4-21, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (24.12-19.9) watt

= 4.22 watt

### 4.1.2.7.2 Reading 2:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Reading Time: 12:15am

Volume of water required: 80ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 42.5 | 39.8 |
| T2 (°C) | 43 | 32.8 |
| T3 (°C) | 31.6 | 36.5 |
| I (AMP) | 1.1 | 1.3 |
| V (VOLT) | 20.1 | 20.4 |
| P=IV (WATT) | 22.11 | 26.52 |

Table 4-22, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1 = (26.52-22.11) watt

= 4.41 watt

#### 4.1.2.7.3 Reading 3:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Reading Time: 12:35am

Volume of water required: 50ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 35.1 | 33.7 |
| T2 (°C) | 37.8 | 30.9 |
| T3 (°C) | 31.8 | 32.8 |
| I (AMP) | 1 | 1.1 |
| V (VOLT) | 18.8 | 19.5 |
| P=IV (WATT) | 18.8 | 21.45 |

Table 4-23, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (21.45-18.8) watt

= 2.65 watt

#### 4.1.2.7.4 Reading 4:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Reading Time: 12:50am

Volume of water required: 40ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 30.9 | 28.3 |
| T2 (°C) | 35.3 | 34.8 |
| T3 (°C) | 31.0 | 28 |
| I (AMP) | 0.86 | 0.9 |
| V (VOLT) | 19 | 19.8 |
| P=IV (WATT) | 16.34 | 17.82 |

Table 4-24, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (17.82-16.34) watt

=1.48 watt

#### 4.1.2.7.5 Reading 5:

Date: 28/11/2017

Set up time: 11:00am

Ambient temp.: 22°C

Reading Time: 12:55am

Volume of water required: 30ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 30.9 | 26.7 |
| T2 (°C) | 32.7 | 27.2 |
| T3 (°C) | 31 | 26.9 |
| I (AMP) | 1 | 1.1 |
| V (VOLT) | 19.1 | 20.0 |
| P=IV (WATT) | 19.1 | 22.0 |

Table 4-25, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (22.0-19.1) watt

=0.9 watt

#### 4.1.2.8 Day 8:

##### 4.1.2.8.1 Reading 1:

Date: 05/12/2017

Set up time: 10:25am

Ambient temp.: 27°C

Reading Time: 12:25pm

Volume of water required: 20ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 33.3 | 31.1 |
| T2 (°C) | 44.3 | 39.7 |
| T3 (°C) | 26.6 | 31.3 |
| I (AMP) | 1.75 | 1.99 |
| V (VOLT) | 20.3 | 20.5 |
| P=IV (WATT) | 35.53 | 40.795 |

Table 4-26, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (40.795-35.53) watt

= 5.265 watt

#### 4.1.2.8.2 Reading 2:

Date: 05/12/2017

Set up time: 10:25am

Ambient temp.: 27°C

Reading Time: 12:35pm

Volume of water required: 20ml

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 30.9 | 37.3 |
| T2 (°C) | 43.3 | 39.7 |
| T3 (°C) | 43.4 | 36.3 |
| I (AMP) | 1.75 | 1.99 |
| V (VOLT) | 20.1 | 20.4 |
| P=IV (WATT) | 35.175 | 40.596 |

Table 4-27, Water spray on the front surface of the panel

Increase of power output in panel 2 compared to panel 1= (40.596-35.175) watt

= 5.421 watt

Note: So from type 1 observation we can say that the power output after cooling increases about 5.421 watt maximum.

## 4.1.3 Type 2: Water spray on the back surface of the panel with wool

### 4.1.3.1 Day 1:

#### 4.1.3.1.1 Reading 1:

Date: 06/12/2017

Setup time: 11:25am

Ambient temp.: 28°C

Water spray time: 12:30pm

Volume of water sprayed: 300ml

Required time of water spray: 120sec

Reading time: 12:32pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 44.5 | 41.3 |
| T2 (°C) | 46.3 | 30 |
| T3 (°C) | 44 | 39 |
| I (AMP) | 1.83 | 2.13 |
| V (VOLT) | 19.9 | 20.6 |
| P=IV (WATT) | 36.42 | 43.88 |

Table 4-28, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (43.88-36.42) watt

= 7.46 watt

#### 4.1.3.1.2 Reading 2:

Date: 06/12/2017

Setup time: 11:25am

Ambient temp.: 28°C

Water spray time: 12:30pm

Volume of water sprayed: 300ml

Required time of water spray: 120sec

Reading time: 12:44pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 34.5 | 35.7 |
| T2 (°C) | 36.1 | 27.5 |
| T3 (°C) | 38.1 | 33.6 |
| I (AMP) | 0.45 | 0.46 |
| V (VOLT) | 18.5 | 19.1 |
| P=IV (WATT) | 8.33 | 8.79 |

Table 4-29, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (8.79-8.33) watt

= 0.46 watt

#### 4.1.3.1.3 Reading 3:

Date: 06/12/2017

Setup time: 11:25am

Ambient temp.: 28°C

Water spray time: 12:30pm

Volume of water sprayed: 300ml

Required time of water spray: 120sec

Reading time: 1:00pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 37 | 40.2 |
| T2 (°C) | 32.2 | 32.1 |
| T3 (°C) | 36.8 | 34.3 |
| I (AMP) | 0.35 | 0.31 |
| V (VOLT) | 18.7 | 19.7 |
| P=IV (WATT) | 6.55 | 6.12 |

Table 4-30, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (6.12- 6.55) watt

= -0.43 watt

= decreased by 0.43 watt

NOTE: Because of decreasing in temperature power output of both panels decreases. And after a certain temperature the power output of panel 2 decreases compared to panel 1. So, these readings are avoided as it was not ideal condition to observe the increase of power output under cooling effect.

### 4.1.3.2 Day 2:

#### 4.1.3.2.1 Reading 1:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 11:00pm

Volume of water sprayed: 180ml

Required time of water spray: 150sec

Reading time: 11:12am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 44 | 41.6 |
| T2 (°C) | 41.8 | 36.3 |
| T3 (°C) | 35.6 | 36.6 |
| I (AMP) | 1.65 | 1.91 |
| V (VOLT) | 20.1 | 20.4 |
| P=IV (WATT) | 33.17 | 38.964 |

Table 4-31, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (38.964-33.17) watt

= 5.794 watt

#### 4.1.3.2.2 Reading 2:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 11:00pm

Volume of water sprayed: 180ml

Required time of water spray: 150sec

Reading time: 11:32am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 36.3 | 20.4 |
| T2 (°C) | 39.4 | 38.2 |
| T3 (°C) | 40.8 | 30.4 |
| I (AMP) | 1.7 | 1.97 |
| V (VOLT) | 20 | 20.1 |
| P=IV (WATT) | 34 | 39.56 |

Table 4-32, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (39.56-34) watt

= 5.56 watt

#### 4.1.3.2.3 Reading 3:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 12:08pm

Volume of water sprayed: 180ml

Time required for water spray: 150 sec

Reading time: 12:12pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 44.5 | 50.4 |
| T2 (°C) | 42.8 | 31.4 |
| T3 (°C) | 41.4 | 36.3 |
| I (AMP) | 1.78 | 2.12 |
| V (VOLT) | 19.8 | 20.1 |
| P=IV (WATT) | 35.24 | 42.61 |

Table 4-33, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (42.61-35.24) watt

=7.37 watt

#### 4.1.3.2.4 Reading 4:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 12:08pm

Volume of water sprayed: 180ml

Time required for water spray: 150 sec

Reading time: 12:30pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 43.7 | 42.1 |
| T2 (°C) | 40.1 | 36.5 |
| T3 (°C) | 43.5 | 35.2 |
| I (AMP) | 1.75 | 2.09 |
| V (VOLT) | 19.9 | 20.4 |
| P=IV (WATT) | 34.83 | 42.64 |

Table 4-34, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (42.64-34.83) watt

=7.81 watt

#### 4.1.3.2.5 Reading 5:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 12:08pm

Volume of water sprayed: 180ml

Time required for water spray: 150 sec

Reading time: 12:30pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 43.7 | 41.9 |
| T2 (°C) | 45.3 | 38.8 |
| T3 (°C) | 41.4 | 34.7 |
| I (AMP) | 1.72 | 2.05 |
| V (VOLT) | 19.8 | 20.2 |
| P=IV (WATT) | 34.06 | 42.03 |

Table 4-35, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1 = (42.03-34.06) watt

=7.43 watt

#### 4.1.3.2.6 Reading 6:

Date: 07/12/2017

Setup time: 10:00am

Ambient temp.: 28°C

Water spray time: 12:08pm

Volume of water sprayed: 180ml

Time required for water spray: 150 sec

Reading time: 12:40pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 42.1 | 43 |
| T2 (°C) | 42.9 | 40 |
| T3 (°C) | 40 | 38.1 |
| I (AMP) | 1.66 | 1.99 |
| V (VOLT) | 19.7 | 20.1 |
| P=IV (WATT) | 32.7 | 39.99 |

Table 4-36, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (39.99-32.7) watt

= 7.29 watt

#### 4.1.3.3 Day 3:

##### 4.1.3.3.1 Reading 1:

Date: 10/12/2017

Setup time: 11:45am

Ambient temp.: 24°C

Water spray time: 12:15pm

Volume of water sprayed: 180ml

Required time of water spray: 150sec

Reading time: 12:30 pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 35.1 | 34.1 |
| T2 (°C) | 37.1 | 32.6 |
| T3 (°C) | 34.9 | 29.2 |
| I (AMP) | 1.46 | 1.79 |
| V (VOLT) | 20.0 | 20.4 |
| P=IV (WATT) | 29.2 | 36.52 |

Table 4-37, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (36.52-29.2) watt

= 7.32 watt

#### 4.1.3.3.2 Reading 2:

Date: 10/12/2017

Setup time: 11:45am

Ambient temp.: 24°C

Water spray time: 1:00pm

Volume of water sprayed: 130 ml

Required time of water spray: 90 sec

Reading time: 1:20pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 39.9 | 40 |
| T2 (°C) | 38.5 | 33.1 |
| T3 (°C) | 37.2 | 32.7 |
| I (AMP) | 2.41 | 2.76 |
| V (VOLT) | 19.9 | 20.2 |
| P=IV (WATT) | 47.96 | 55.752 |

Table 4-38, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (55.752-47.96) watt

= 7.792 watt

#### 4.1.3.4 DAY 4:

##### 4.1.3.4.1 Reading 1:

Date: 11/12/2017

Setup time: 10:45am

Ambient temp.: 25°C

Water spray time: 11:45am

Volume of water sprayed: 210ml

Required time of water spray: 160sec

Reading time: 12:00pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 38.3 | 44.8 |
| T2 (°C) | 36.5 | 32.7 |
| T3 (°C) | 37.2 | 34.3 |
| I (AMP) | 1.59 | 1.91 |
| V (VOLT) | 19.8 | 20.2 |
| P=IV (WATT) | 31.48 | 38.582 |

Table 4-39, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (38.2-31.582) watt

= 7.102 watt

#### 4.1.3.4.2 Reading 2:

Date: 11/12/2017

Setup time: 10:45am

Ambient temp.: 25°C

Water spray time: 11:45am

Volume of water sprayed: 150ml

Required time of water spray: 160sec

Reading time: 12:30pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 38.3 | 38.4 |
| T2 (°C) | 36.5 | 29.8 |
| T3 (°C) | 37.2 | 31.1 |
| I (AMP) | 1.59 | 1.93 |
| V (VOLT) | 19.8 | 20.1 |
| P=IV (WATT) | 31.48 | 38.793 |

Table 4-40, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (38.793-31.48) watt

= 7.313 watt

#### 4.1.3.5 Day 5:

##### 4.1.3.5.1 Reading 1:

Date: 12/12/2017

Setup time: 10:10am

Ambient temp.: 29°C

Water spray time: 11:06am

Volume of water sprayed: 180ml

Required time of water spray: 120 sec

Reading time: 11:20am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 37.3 | 37.1 |
| T2 (°C) | 42 | 33.3 |
| T3 (°C) | 41.9 | 32.6 |
| I (AMP) | 1.98 | 2.34 |
| V (VOLT) | 20.0 | 20.2 |
| P=IV (WATT) | 39.6 | 47.268 |

Table 4-41, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (47.268-39.6) watt

=7.67 watt

#### 4.1.3.5.2 Reading 2:

Date: 12/12/2017

Setup time: 10:10am

Ambient temp.: 29°C

Water spray time: 11:06am

Volume of water sprayed: 180ml

Required time of water spray time: 120sec

Reading time: 11:50 am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 41.9 | 41.7 |
| T2 (°C) | 43.2 | 34.7 |
| T3 (°C) | 42 | 31.8 |
| I (AMP) | 2.36 | 2.72 |
| V (VOLT) | 19.8 | 19.9 |
| P=IV (WATT) | 46.728 | 54.128 |

Table 4-42, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (54.128-46.728) watt

= 7.4 watt

#### 4.1.3.5.3 Reading 3:

Date: 12/12/2017

Setup time: 10:10am

Ambient temp.: 29°C

Water spray time: 11:06am

Volume of water sprayed: 180ml

Required time of water spray: 120 sec

Reading time: 12:15pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 42.7 | 42.4 |
| T2 (°C) | 45.3 | 33.2 |
| T3 (°C) | 42.9 | 35.7 |
| I (AMP) | 2.47 | 2.79 |
| V (VOLT) | 20.0 | 20.4 |
| P=IV (WATT) | 49.4 | 56.92 |

Table 4-43, Water spray on the back surface of the panel with wool

Increase of power output in panel 2 compared to panel 1= (56.92-49.4) watt

= 7.52 watt

NOTE: So the effect of cooling with wool is long lasting. As the increase of power output stays same for 30 minutes. And also the power output of panel 2 increases more than panel 2 cooled with water spray only. The highest difference of power output of panel 2 compared to panel 1 is 7.81 watt.

## 4.1.4 TYPE 3: Water spray on the back surface of the panel with jute.

### 4.1.4.1 DAY 1:

#### 4.1.4.1.1 Reading 1:

Date: 13/12/17

Set up time: 9:45am

Ambient temp.: 28°C

Time of water spay: 11:20am to 11:25 am

Volume of water used: 300 ml

Reading Time: 11:35am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 30.5 | 30.5 |
| T2 (°C) | 36.6 | 32.7 |
| T3 (°C) | 35.9 | 31.5 |
| I (AMP) | 1.31 | 1.55 |
| V (VOLT) | 21.5 | 21.5 |
| P=IV (WATT) | 28.12 | 33.33 |

Table 4-44, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (33.33-28.12) watt

= 5.21 watt

#### 4.1.4.1.2 Reading 2:

Date: 13/12/17

Set up time: 9:45am

Ambient temp.: 28°C

Time of water spay: 11:20am to 11:25 am

Volume of water used: 300 ml

Reading Time: 11:45am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 31.3 | 34.6 |
| T2 (°C) | 37.3 | 33 |
| T3 (°C) | 35.8 | 33.2 |
| I (AMP) | 1.27 | 1.52 |
| V (VOLT) | 21.2 | 21.7 |
| P=IV (WATT) | 26.924 | 32.984 |

Table 4-45, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (32.984-26.924) watt

= 6.06 watt

#### 4.1.4.1.3 Reading 3:

Date: 13/12/17

Set up time: 9:45am

Ambient temp.: 28°C

Time of water spay: 11:20am to 11:25 am

Volume of water used: 300 ml

Reading Time: 11:55am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 32.7 | 35.8 |
| T2 (°C) | 35.6 | 34.4 |
| T3 (°C) | 37.2 | 33.8 |
| I (AMP) | 1.31 | 1.57 |
| V (VOLT) | 20.8 | 21.2 |
| P=IV (WATT) | 27.25 | 33.284 |

Table 4-46, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (33.284-27.25) watt

= 6.034 watt

#### 4.1.4.1.4 Reading 4:

Date: 13/12/17

Set up time: 9:45am

Ambient temp.: 28°C

Time of water spay: 11:20am to 11:25 am

Volume of water used: 300 ml

Time: 12:30am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 34.8 | 40 |
| T2 (°C) | 39.8 | 39.2 |
| T3 (°C) | 40.4 | 38.1 |
| I (AMP) | 1.21 | 1.44 |
| V (VOLT) | 19.7 | 20.1 |
| P=IV (WATT) | 23.84 | 28.944 |

Table 4-47, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (28.944-23.84) watt

= 5.104 watt

#### 4.1.4.2 Day 2:

##### 4.1.4.2.1 Reading 1:

Date: 14/12/17

Setup time: 10:10am

Ambient temp.: 29°C

Water spray time: 11:00am

Volume of water sprayed: 180 ml

Required time of water spray: 120sec

Reading time: 11:20am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 44.7 | 37.6 |
| T2 (°C) | 45.1 | 36.8 |
| T3 (°C) | 41.9 | 33.5 |
| I (AMP) | 2.31 | 2.57 |
| V (VOLT) | 19.8 | 19.9 |
| P=IV (WATT) | 45.738 | 51.143 |

Table 4-48, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (51.143-45.738) watt

= 5.405 watt

#### 4.1.4.2.2 Reading 2:

Date: 14/12/17

Setup time: 10:10am

Ambient temp.: 29°C

Water spray time: 11:00am

Volume of water sprayed: 180 ml

Required time of water spray: 120sec

Reading time: 11:45am

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 43.1 | 37.8 |
| T2 (°C) | 42.7 | 37.2 |
| T3 (°C) | 40 | 35.7 |
| I (AMP) | 2.07 | 2.37 |
| V (VOLT) | 19.8 | 20.2 |
| P=IV (WATT) | 40.986 | 47.87 |

Table 4-49, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (47.87-40.986) watt

= 6.89 watt

#### 4.1.4.3 Day 3:

##### 4.1.4.3.1 Reading 1:

Date: 21/12/2017

Setup time: 11:45am

Ambient temp.: 25°C

Water spray time: 12:40pm

Volume of water sprayed: 130ml

Required time of water spray: 120sec

Reading time: 12:55pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 43.1 | 36.5 |
| T2 (°C) | 42 | 38.4 |
| T3 (°C) | 42.5 | 35.7 |
| I (AMP) | 2.41 | 2.73 |
| V (VOLT) | 20.3 | 20.4 |
| P=IV (WATT) | 48.92 | 55.69 |

Table 4-50, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (55.69-48.92) watt

= 6.77 watt

#### 4.1.4.3.2 Reading 2:

Date: 21/12/2017

Setup time: 11:45am

Ambient temp.: 24°C

Water spray time: 12:40pm

Volume of water sprayed: 130ml

Required time of water spray: 120sec

Reading time: 1:15pm

Location: 2nd floor roof, Tower Building- 2, MIST

| | PANEL 1 (without water spray ) | PANEL2 ( with water spray) |
|---|---|---|
| T1 (°C) | 38.2 | 31.2 |
| T2 (°C) | 39.5 | 33.7 |
| T3 (°C) | 36.9 | 29.0 |
| I (AMP) | 0.97 | 1.09 |
| V (VOLT) | 18.8 | 19.5 |
| P=IV (WATT) | 18.24 | 21.255 |

Table 4-51, Water spray on the back surface of the panel with jute

Increase of power output in panel 2 compared to panel 1= (21.255-18.24) watt

= 3.015 watt

# 5 CONCLUSION AND RECOMMENDATION:

## 5.1 Conclusion:

- From the three procedures of cooling the PV panel and comparing the results between them it is seen that the power output get increased while the panel is being cooled.
- The power output gets increased most for woolen material, then jute material and finally normal water spray.
- The lifetime of Wool is better than Jute, while the cost of wool is greater than jute. But after all the comparisons, increase of power output and specially keeping the lifetime of both jute and wool in mind, we should recommend to use wool.

## 5.2 Limitations:

- For the experiment we must need proper sun light. But due to the weather of our country we could not get proper sun light as this year it was full of rainy days and gloomy days. As a result our most of the data is not accepted.
- Water spray was not uniformed as it was done manually.
- When we are doing normal water spray over the front surface of the panel and even when using woolen material over the back surface, we are spraying water once in a while, not at a constant rate. So a proper constant water flowing model can be introduced in this system.

- Due to the lack of solar meter we are not being able to measure the incident light energy and so the efficiency increase cannot be measured, we are just calculating the increased in output.
- The jute and woolen fabric used in our thesis work were not same type and they also differ in size and covered area. So by using same type fabrics more accurate result can be obtained.

## 5.3 Future Recommendations:

- Due to the bad weather and rains throughout the year, we couldn't take the readings in all months and seasons. So in future this experiment can be performed throughout the whole year and can be compared the results how power output changes from season to season.
- Cooling method with can be performed by using both wet woolen material or jute material at back side combined with water spray in the front side .

# 6 REFERENCES

[1] http://www.ni.com/white-paper/7230/en/

[2]http://textilecalculation.blogspot.com/2015/08/standard-moisture-regain-and-moisture.html

[3]http://sinovoltaics.com/learning-center/off-grid/solar-powered-water-pump-sizing-applications-benefit.

[4] https://www.doityourself.com/stry/6-ways-to-improve-solar-cell-efficiency

[5] http://www.pveducation.org/pvcdrom/effect-of-temperature

[6]Proceedings of the 1stInternational Conference on Emerging Trends in Energy Conservation-ETEC ,Tehran, Tehran, Iran, 20-21 November 2011 ,The Effect of Temperature on Photovoltaic Cell Efficiency

[7] StefanKrauter,"Increased electrical yield via water flow over the front of photovoltaic panels", Solar Energy Materials & Solar Cells, 82 (2004), pp. 131–137.

[8] Yuichiro Kawahara, Takanori Sasaki, Shigetaka Fujita, "Improvement of the conversion efficiency of the concentrator photovoltaic with the wavelength selective transmission thin film", *Current Applied Physics*, 11 (2011), pp. S8-S11.

[9] Jiafei Zhao, Yongchen Song, Wei-Haur Lam, Weiguo Liu, Yu Liu, Yi Zhang, DaYong Wang, "Solar radiation transfer and performance analysis of an optimum photovoltaic/thermal system", *Energy Conversion and Management*, 52 (2011), pp. 1343–1353.

[10] Kamal Skeiker, "Optimum tilt angle and orientation for solar collectors in Syria", *Energy*Conversion and Management, 50 (2009), pp. 2439–2448.

[11] John Kaldellis, Dimitrios Zafirakis, "Experimental investigation of the optimum photovoltaic panels‟ tilt angle during the summer period", *Energy*, 38 (2012), pp. 305-314.

[12] Murat Kacira, Mehmet Simsek, Yunus Babur, Sedat Demirkol, "Determining optimum

tilt angles and orientations of photovoltaic panels in Sanliurfa, Turkey”, *Renewable Energy*, 29 (2004), pp. 1265–1275.

[13] Ying-Pin Chang, “Optimal the tilt angles for photovoltaic modules using PSO method with nonlinear time-varying evolution”, *Energy,* 35 (2010), pp. 1954–1963.

[14] J.I. Rosell, X. Vallverdu´ , M.A. Lecho´ n, M. Iba´n˜ez, “Design and simulation of a low concentrating photovoltaic/thermal system”, *Energy Conversion and Management*, 46 (2005), pp. 3034–3046.

[15] Y. Tripanagnostopoulos, Th. Nousia, M. Souliotis, P. Yianoulis, “Hybridphotovoltaic/thermal solar systems”, *Solar Energy* Vol. 72, No. 3, pp. 217–234, 2002.

[16] J.K. Tonui, Y. Tripanagnostopoulos, “Improved PV/T solar collectors with heat extraction by forced or natural air circulation”, *Renewable Energy,* 32 (2007), pp. 623–637.

[17] Rustu Eke, Ali Senturk,”Performance comparison of a double-axis sun tracking versusfixed PV system”, *Solar Energy,* 86 (2012), pp. 2665–2672.

[18] J.K. Tonui, Y. Tripanagnostopoulos, “Performance improvement of PV/T solar collectors with natural air flow operation”, *Solar Energy,* 82 (2008), pp. 1–12.

[19] Kadir Bakirci, “General models for optimum tilt angles of solar panels: Turkey case study”, Renewable and Sustainable Energy Reviews, 16 (2012), pp. 6149–6159.

[20] M. Rosa-Clot, P. Rosa-Clot, G.M. Tina, P.F. Scandura, “Submerged photovoltaic solar panel: SP2”, *Renewable Energy,* 35 (2010), pp. 1862–1865.

[21] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil, H. El-Sherif, “Enhancing the performance of photovoltaic panels by water cooling”, *Ain Shams Engineering Journal*, 4 (2013), pp. 869–877.

[22] Bin Du, Eric Hu, Mohan Kolhe, “Performance analysis of water cooled concentrated photovoltaic (CPV) system”, *Renewable and Sustainable EnergyReviews,* 16 (2012), pp. 6732–6736.

[23] H. Bahaidarah, Abdul Subhan, P. Gandhidasan, S. Rehman, “Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions”, *Energy,* 59 (2013), pp. 445-453.

[24] H.G. Teo, P.S. Lee, M.N.A. Hawlader, “An active cooling system for photovoltaic modules”, *Applied Energy*, 90 (2012), pp. 309–315.

[25] M. Abdolzadeh, M. Ameri, “Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells”, *Renewable Energy*, 34 (2009), pp. 91–96.

[26] Azadeh Kordzadeh, “The effects of nominal power of array and system head on theoperation of photovoltaic water pumping set with array surface covered by a film of water”, *Renewable Energy*, 35 (2010), pp. 1098–1102.

[27] H.M.S. Hussein, G.E. Ahmad, H.H. El-Ghetany, “Performance evaluation of photovoltaic modules at different tilt angles and orientations”, *Energy Conversion and Management*, 45 (2004), pp. 2441–2452.

[28] Matthew Lave, Jan Kleissl, “Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States”, *Renewable Energy*, 36 (2011), pp. 1145-1152.

[29] V.N. Dike, T.C. Chineke, O.K. Nwofor, U.K. Okoro, “Optimal angles for harvesting solar electricity in some African cities”, *Renewable Energy*, 39 (2012), pp. 433-439.

[30] Gao Jianqiang , Zhang Ying , Liu Yanfeng, Gao Xin, “Study on the Temperature Variation of the Water-cooled Photovoltaic Solar Template”, *2010 International Conference* on Intelligent System Design and Engineering Application, Changsha / China, 10/13/2010, pp. 502-505.

[31] Valerie Eveloy, Peter Rodgers, Shrinivas Bojanampati, “Enhancement of Photovoltaic Solar Module Performance for Power Generation in the Middle East”, *28th IEEE SEMITHERM Symposium*, San Jose, CA, USA, March 18-22, 2012, pp. 87-97.