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Comprehensive Study on Exergy and Energy Efficiencies of Photovoltaic Thermal System

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Abstract:- Photovoltaic cells are widely used in harvesting solar energy. Photovoltaic cells convert solar light energy to electric energy. At higher temperature, efficiency of photovoltaic cells decreases drastically. Proper cooling can be used to circumvent this limitation. We intend to introduce a system which will cool the photovoltaic cell while working in high temperature. The project includes a comprehensive study of photovoltaic cells under high temperature with and without cooling system and analyzing it.

Solar energy can be converted into electrical or thermal form. We are using 4 types of cooling,

- **Air Cooling**
- **Forced Air Cooling.**
- **Water Cooling.**
- **Peltier Cooling.**

Using these 4 cooling system we are comparing the efficiencies of solar panel.

***Keywords*:-** *Exergy Analysis; Energy Analysis; Peltier Module; Photovoltaic thermal systems; Solar radiation.*

I. INTRODUCTION

Today fossil fuels are the main energy supply depended by the world. About 84% of worlds energy supply is fossil fuel itself. Natural processes of buried dead organisms help to form fossil fuel. Now world is seem to be known the importance to answer to lot of problem with climate change. Increased consumption of fossil fuels face issues and it take millions years to rebuild, and this is known the reserves are being much faster than new ones also it being made to cause dangerous environmental issues.

Environmental issues include the following

- Green House Effect
- Air pollution
- Acid Rain

A. Greenhouse Effect

The major environmental issues caused by fossil fuel are Greenhouse effect. Rapid increases in the concentration of CO2, methane, chlorofluorocarbons (CFCs), nitrous oxide and ozone in the atmosphere is acting to ambush heat radiated from the earth's surface and causing increase in the surface temperature of the earth.

50 percent of the greenhouse gases constitute the Carbon dioxide. From the fossil fuel Co2 is the major releasing gas. A greenhouse gas is a gas which absorbs and emits radiation between the thermal infrared limit. The primary gases of greenhouse in the earth’s atmosphere are carbon dioxide, water vapor, methane, nitrous oxide and ozone. The greenhouse effect is done by which the thermal radiation from earthly surface is absorbed by atmospheric greenhouse gases and is re-radiated in every directions. The re-radiation is back towards the surface and the lower atmosphere; results in an elevation of the average surface temperature above what it would be in the absence of the gases.

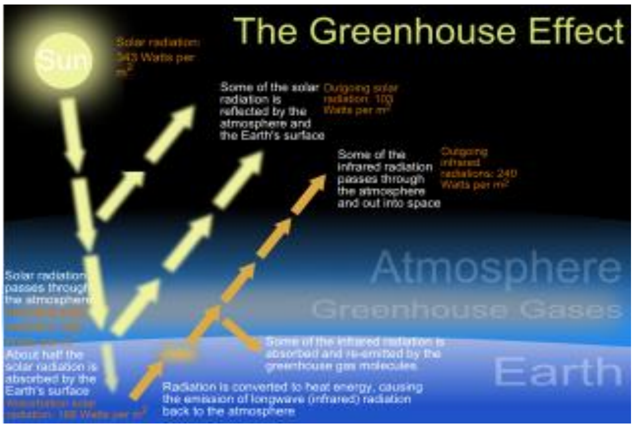

Fig 1:- A representation of the exchanges of energy between the source (the Sun), the Earth’s surface, the Earth’s atmosphere and the ultimate sink outer space.

Through the atmosphere the solar radiation at the frequencies of visible light largely passes to warm the planetary surface, which emits energy at the lower frequencies of infrared thermal radiation. Infrared radiation is absorbed by greenhouse gases, which help to re-radiate much of the energy to the surface and lower atmosphere. Effect of solar radiation passing through glass and warming a greenhouse is the mechanism but the way it retains heat is fundamentally different as a greenhouse works by reducing air flow, isolating the warm air inside the structure so that heat is not lost by convection.

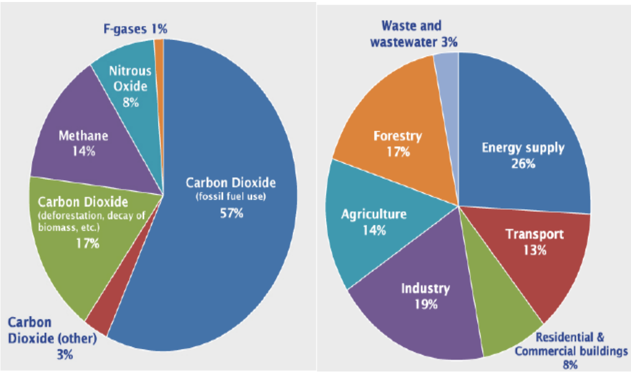

Fig 2:- Annual Greenhouse gas emissions.

- *Air Pollution*

The main reason for the air pollution is burning the fossil fuel like gasoline, coal, oil in presence of insufficient supply of oxygen liberates carbon monoxide and unburnt hydrocarbons cause dangerous health problems. The combustion of fossil fuel release carbon dioxide into the atmosphere. CO_2 has the ability to absorbs infrared radiation emitted by the earth surface and re-radiate back. The fossil fuel become dangerous pollutant when spilled during transport. It is severe and negative environmental impact when it happens. It leach toxins into ground water and soil.

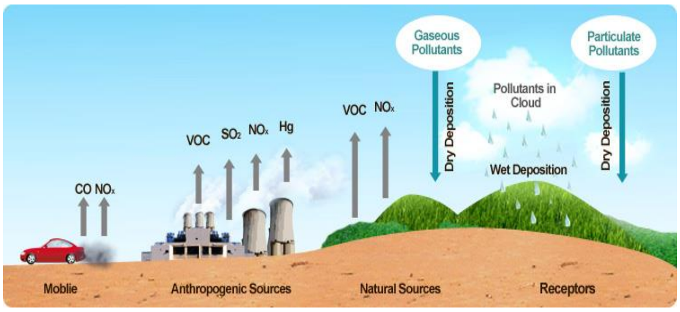

Fig 3:- Gases Causing of Air pollution

- *Acid Rain*

Acid rain can carry sulfur and nitrogen compounds from the atmosphere to the ground. Fossil fuel contains sulphur. When fossil fuel burns, sulphur then reacts with oxygen to form oxides of sulphur. They are added to environment where they react with rain water to form sulphur acid or sulphurous acid. This is called Acid rain

Acid rain pointed to the mixture of deposited materials, both wet and dry, coming from the atmosphere containing huge amounts of nitric acids and sulfuric acids. Simply put, it refers the rain that is acidic in nature due to the presence of certain pollutants in the air due to vehicles and industrial processes. It may easily defined as rain, fog, sleet or snow that has been acidic by pollutants in the air by the fossil fuel and industrial combustions that mainly emits Nitrogen Oxides (NOx) and Sulfur Dioxide (SO2). Acidity can be determined on the basis of the pH level of the water droplets. Normal rain water is shows pH range of up to 5.3-6.0, because of carbon dioxide and water present in the air it react together to form carbonic acid, normally weak acid. When the pH level of rain water falls below normal range, then it becomes acid rain.

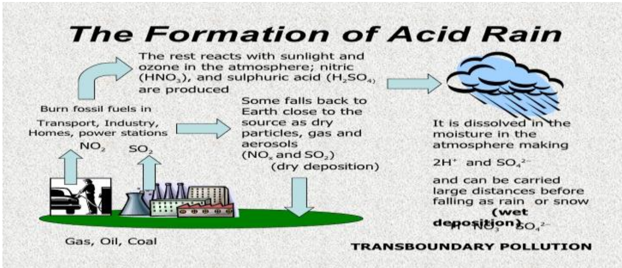

Fig 4:- Formation of Acid Rain.

These gases react with water molecules and oxygen by other chemicals found in the atmosphere, mild acidic chemical compounds such as sulfuric and nitric acid are formed resulting the acid rain. Acid rain generally leads to destruction of buildings, corrosion of metals, and peeling of paints on surfaces. Erupting volcanoes also contains some chemicals that causes acid rain. Apart from this, burning the fossil fuels, running of factories, automobiles due to human activities are few other reasons behind this acid rain.

B. *Solar photovoltaic*

Solar power is the transferring of sunlight into electricity, either using directly the photovoltaic (PV), or indirectly using concentrated solar power (CSP). By using lenses or mirrors concentrated solar power can track to focus a large area of sunlight into a small beam. In 1980s Commercial concentrated solar power plants were first developed. By the photoelectric effect photovoltaic convert light into electric current. Photovoltaic are an important and relatively less expensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable. All though as the cost of solar panel decreasing nowadays, the use solar panel is increasing day by day. Sunlight is a total frequency spectrum of electromagnetic radiation given by the Sun, particularly infrared, visible, and ultraviolet light. The sunlight is filtered through the Earth's atmosphere, and is same as day light when the sun is above the horizon. The amount of incoming solar electromagnetic radiation per unit area that may incident at a distance of one astronomical unit (AU) on a plane perpendicular to the rays, known as solar constant.

A solar panel is a packaged connected assembly of photovoltaic cells. The solar panel can be used as components of a larger photovoltaic system to generate and supply electricity in residential and commercial sector. Each panel is a Dc output power under standard test conditions, and generally from few watts to kilo watts. A photovoltaic system typically includes an array of solar panels, an inverter, and a battery or solar tracker and interconnection wiring.

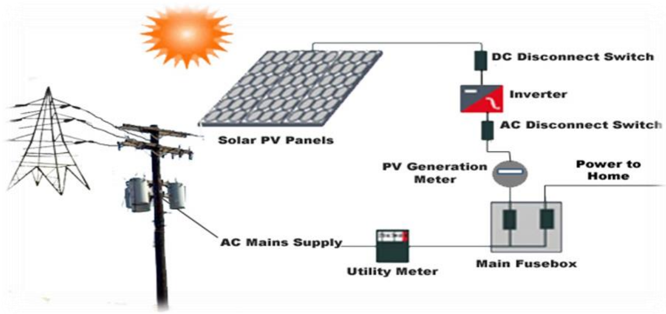

Fig 5:- Photovoltaic System

C. Working of PV

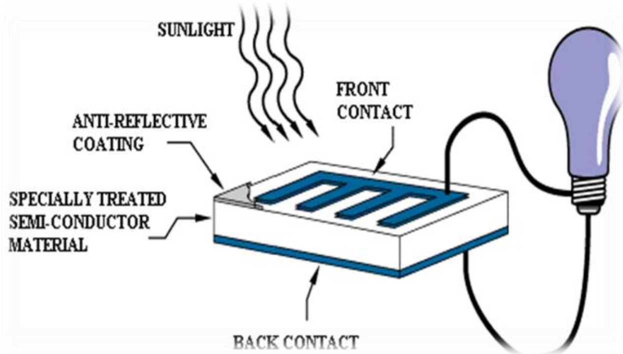

Fig 6:- Working of photovoltaic cell,

The diagram above emphasizes the process of a basic photovoltaic cell, also called a solar cell. Solar cells make light into electricity directly. When sunlight hits, electrons are liberated in the p-type region and holes produced in the n-type region; as a result it lowers the potential energy barrier at the junction. A current flows and establishes an external potential difference. Solar cells act in a way similar to the diode, because of that current can flow in only one direction when the cell is exposed to light. The first solar cell was made in 1954 but Becquerel discovered the photoelectric effect in 1839.

Solar cells are made with the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. A thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are swiped loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

Many solar cells electrically connected to each other forms a panel like structure or a frame called photovoltaic module. Each module gives a certain voltage to the system. How much sun light strikes to the module that much output will gain or depend to the output from the panel.

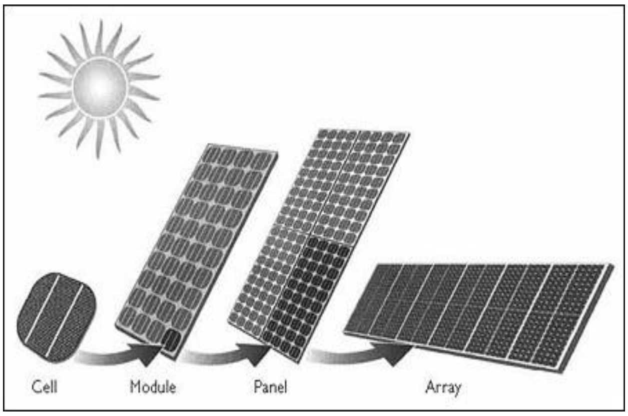

Fig 7:- solar panel components,

A photovoltaic array (solar array) consists of multiple photovoltaic modules, normally called as solar panels, here it convert the radiation from the sun light (or sun) into applicable direct current (DC) electricity. A photovoltaic system for industrial ,commercial or residential energy supply normally contains an array of photovoltaic (PV) modules, one or more DC to alternating current (AC) power converters (also known as inverters), a delightful system that supports the solar modules, electrical wiring and interconnections, and mounting for other components. The modules in the system determine the total DC watts capable of being generated by the solar array; Even though the inverter ultimately governs the amount of AC watts that can be distributed for consumption. Huge grid-connected photovoltaic power systems are capable of giving an energy supply for multiple consumers. The electricity generated can be stored, used directly, fed into a large electricity grid powered by central generation plants (grid-connected or grid-tied plant), or combined with one, or many, domestic electricity generators to feed into a small electrical grid (hybrid plant). PV systems are generally designed to ensure the highest energy yield.

D. Solar Cell Efficiency And Temperature

Theoretically, the maximum possible efficiencies of a typical solar cell of silicon at a temperature of 0ºC is about 25%. Bus as the operating temperature increases this maximum efficiency drops rapidly, and is only 13% at 100ºC. Beyond that, because of the presence of other loss mechanisms such as the edge losses, the efficiency of a good quality photovoltaic (PV) panel is only ranged from 9% to 13%. Most of the case solar energy striding a PV panel is converted into heat. This heated water can be used for water heating, space heating or other household purposes other than wasting it. As a result this can lead to higher efficiencies and reduced life cycle cost.

Electricity flows through an electrical circuit can be change by the temperature causing its speed at which the electrons travel. This is due to the increase in resistance of the circuit that when increase in temperature, Vice versa.

Solar panel only work best in certain whether conditions, Engineers are installing solar panel all over the world in different climatic region, most panel do not operate under ideal conditions. By this knowledge they can improve the efficiency of solar panels in non-optimal conditions

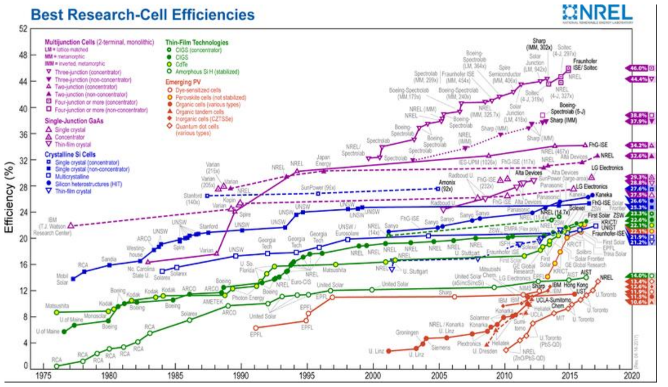

Fig 8:- Research cell efficiencies around the world (NREL)

- *Solar Pv/T Systems*

Photovoltaic thermal hybrid solar collectors, or known as hybrid PV/T systems or PVT, which convert solar radiations into thermal and electrical energy. This system combines a PV cell that converts electromagnetic radiations (photons) into electricity, with a solar thermal collector, which capture remaining energy and removes heat from PV module. By removing heat these devices becomes more overall energy efficient than solar photovoltaic (PV) or solar thermal alone.

The most two important collectors are,

- PV/T Liquid collector
- PV/T Air collector

- *PV/T Liquid Collector*

The basic design is that a plates is attached to the back of a PV module (Box type with glass). The working fluid, typically water, mineral oil or glycol is then piped through these plate chillers. The heat from the PV cells are sends to (conducted) through the metal and absorbed by working fluid which is cooler than the operating temperature of the cells. In closed systems this heat is either exhausted to cool or transferred to a heat exchanger, in open loop systems, this heat is used, or exhausted before the fluid returns to the PV cells. Two liquid collectors that is Active and Passive. In Active system there in need of external force to flow. In Passive the flow of the fluid will occur naturally.

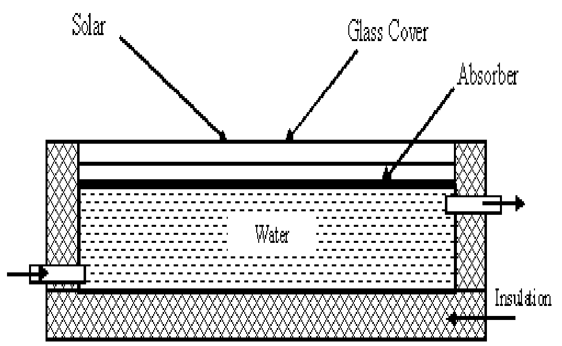

Fig 9:- Liquid solar collector.

- *Thermosiphon Pv/T System*

The principle of the thermosiphon system is that cold water has a higher specifics density than warm water, and so being heavier will sink down. Therefore the water storage tank is always mounted above the collector, so that cold water from the tank reaches the collector via a descending water pipe. When the collector heats up the water, the water rises and reaches to the tank through the water pipe at the upper end of the collector. Collector ensures the water is heated up until it achieves an equilibrium temperature. Now the hot water from top of the tank can be used for other purposes, with any water that replaced by the cold water at the bottom. Again the collector heats up the cold water. As a result the higher temperature differences at higher solar irradiances, warm water rises faster than it does at lower irradiances. Hence, the circulation of water prepares itself almost perfectly to the level of solar irradiance. The storage tank must be positioned well above the collector for the smooth working of thermosiphon system, otherwise the cycle can run backward during the night and all the water will cool down. Moreover, the cycle does not work properly very small height differences.

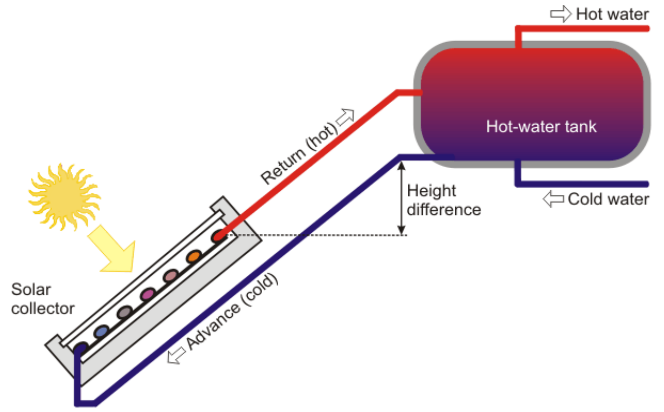

Fig 10:- Thermosiphon effect

- *PV/T Air Collector*

In Air cooled PV/T instead of water here air is passed below the PV cells. The heat from the solar cells is carried away by the air so decrease in temperature. Heat carrying capacity of air is less than that of water. So its normally used in active mode using blowers.

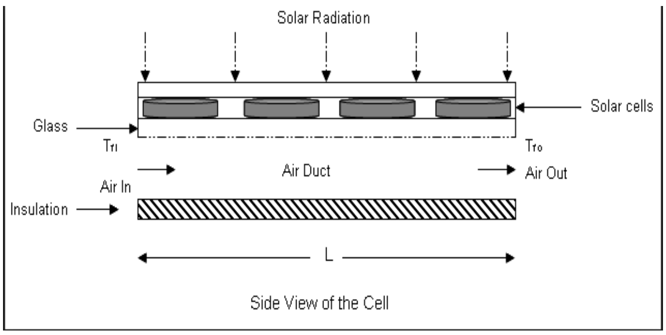

Fig 11:- PV/T Air collector

Peltier Module

The Peltier effect is the temperature difference generated by applying a voltage between two electrodes connected to a unit of semiconductor material. This phenomenon can be effective when it is necessary to transfer heat from one medium to another on a small scale. When electricity is passed through a circuit consisting of two different conductors, a cooling effect is observed in one junction whereas another junction senses a rise in temperature. This change in temperatures at the junctions is called the Peltier effect. The effect is found to be stronger when two different semiconductors are used in place of conductors in the circuit.

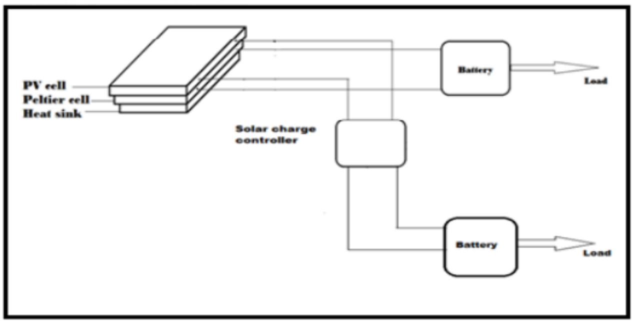

Fig 12:- Block diagram of Solar Panel with Peltier Module

E. Types of PV Technology

Many types of PV cells are available today. Some details on the current types and an overview of the cells that are currently in the research and development stage are mentioned below.

- *Mono crystalline silicon cell*

This is made from pure mono crystalline silicon. The efficiency is about 16% and this is quite higher efficiency than comparing to other technologies. Complicated manufacturing process is the main drawback of this type. So the cost is high than other technologies.

- *Multi crystalline silicon cell*

These cells are made from producing number of grains together of mono crystalline cell. Very less cost than the Mono crystalline silicon cell. Its efficiency is about 12%.

- Amorphous silicon

As the name suggesting here amorphous silicon is using instead of crystalline silicon. It absorbs light quite efficiently. The advantage of these types is silicon give wide range of essentials. But the efficiency is just about 8%. With the help of this type can replace solar plate.

F. Need for Cooling

The major application of solar energy is classified into two; they are solar thermal system and photovoltaic (PV) system. Solar thermal system converts solar energy into thermal energy whereas PV system converts solar energy into electrical energy. In the PV system, electrical efficiency of the system decreases rapidly due to temperature increment in the PV module. Similarly for solar thermal system, external electrical energy is required to circulate the working fluid through the system. So in order to increase or obtain higher electrical efficiency its mandatory to cool the PV module by removing the heat from it. Therefore to eliminate this heat from the PV module, it should be combined with the solar air/water heater collector. This method is called solar photovoltaic thermal (PV/T) collector.

In current thesis, the performance of air cooled, water cooled and most importantly Peltier cooled solar panel is performed. Here the evaluation is based on first and a second law of thermodynamic. The performance of a PV/T of all these collectors parametrically depends up on climate, operating and design parameters such as solar radiation intensity, solar ambient temperature, back surface temperature, solar cell temperature, inlet and outlet air temperature, open-circuit voltage, short-circuit current, maximum power point voltage, maximum power point current, overall heat transfer coefficient the length and width of PV/T collectors, etc. Mainly, the concept of energy is never a conscious with respect to the direction of the process. There is no differentiating the quality of energy. Analysis on energy by their own not sufficient translates some processes. It does not give any internal irreversibility's. This is not sufficient method to evaluate the performance of photovoltaic collectors.

II. LITERATURE REVIEW

The modeling of a channel type PVT collector for the cases of both air (100-300kg/h) and water (40-120 kg/h) has been carried out by Prakash (1994) and He has observed that decreasing the duct depth increases the thermal performance of air and water heater. Garg and Adhikari (1997) have presented a variety of results regarding the effect of the design and operational parameters on the performance of PVT air collectors. Brinkworth et at. (1997) have presented a variety of results regarding the effect of the design and operational parameters on the performance of PVT air collectors. Brinkwortth et al. (1997), Moshfegh and Sandberg (1998), Schroer (1998) and Brinkworth et al. (2000) have carried out design and performance studies regarding air type hybrid PVT system. Kalogirou (2001) has studied the monthly performance of the unglazed hybrid PVT system under forced mode of operation for climatic condition of Cyprus and he observed that an increase of the mean annual electrical efficiency of PV solar system from 2.8% to 7.7% with thermal efficiency of 49%, respectively. Similar study has also been carried out by Zondag et al. (2002) and they have referred hybrid PVT system as a combi-panel that converts solar energy into both electrical and thermal energy.

Paisarn Naphon (2004) in his study presented a mathematical model for predicting the heat transfer characteristics, the performance, and entropy generation of the double pass solar air heater with longitudinal fins. Effect of the height and number of fins on the performance and entropy generation were considered. It was found that the thermal efficiency increases with increasing the height and number of fins. The entropy generation is inversely proportional to the height and number of fins.

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Aravind Tiwary and M.S Sodha develop a thermal model of an integrated photovoltaic and thermal solar (IPVTS) system developed by previous researchers. Based on energy balance of each component of IPVTS system, an analytical expression for the temperature of PV module and the water have been derived. Numerical computations have been carried out for climatic data design parameters of an experimental IPVTS system. The simulations predict a daily thermal efficiency of around 58%, which is very close to the experimental value (61.3%) obtained by Huang et al.

Design of an Aluminum- alloy flat-box type hybrid solar collector (PV/T) functioned in thermosiphon mode has presented by He et al. and found that the daily thermal efficiency of the system is around 40%.

Chow et al. has done an experimental study of façade-integrated photovoltaic/thermal water-heating system and found the thermal efficiency as 8.56% during the summer of 2006 (Hong Kong) . They have compared both forced as well as natural mode of water circulation and found that the latter is more preferable and suggested that the system can serve as a water preheating system.

Tiwary et al. have developed an analytical expression for the water temperature of an integrated photovoltaic thermal solar (IPVTS) water heater under constant flow rate hot water withdrawal has been obtained. Analysis is based on basic energy balance for hybrid flat plate collector and storage tank, respectively, in terms of design and climatic parameters. Further, an analysis has also has been extended for hot water withdrawal at constant collection temperature. Numerical computation have been carried out for the design and climatic parameters of the system used by Huang et al. It is observed that the daily overall thermal efficiency of IPVTS system increase with increase constant flow rate and decrease with increase of constant collection temperature. The exergy analysis of IPVTS system has been carried out. It is further to be noted that the overall exergy and thermal efficiency of an integrated photovoltaic thermal solar system (IPVTS) is maximum at the hot water withdrawal flow rate of 0.006 kg/s. The hourly net electrical power available from the system has also been evaluated

III. METHODOLOGY AND EXPERIMENTATION

A. *Governing Equation*

In cooled PV panels heat transfer associate a fluid. A separation of solid domain for each material layer in the PV panel and for the heat exchanger body. Equations (1) and (2) is the heat transfer equations for solid and fluid domains respectively.

$$\rho i\, Cp,i \frac{\partial Ti(x,y,z)}{\partial t} = \nabla.(\boldsymbol{q}i) + Qi \qquad i = 1, 2, 3 \ldots n \tag{1}$$

$$\rho\, Cp \frac{\partial T}{\partial t} + \rho\, Cp\boldsymbol{u}.\nabla T(x,y,z) = \nabla.(\boldsymbol{q}) + Qvh \tag{2}$$

Where q = $K_{cond}\,\nabla T$ (3)

Where ρ is the density, Cp known specific heat capacity, T temperature, *Kcond* is the thermal conductivity, **q** is the heat transferred by conduction, t time, Q is the internal heat generation, u is the velocity of the fluid.

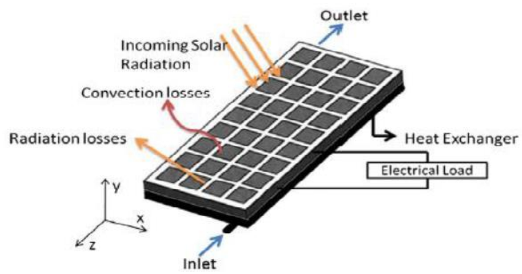

Fig 13:- Energy transfer through solar plate.

The momentum and continuity equations governing the fluid flow inside the heat exchanger are given by Equations (4) and (5).

$$\rho\frac{\partial u}{\partial t} + \rho(\boldsymbol{u}.\nabla)\,\boldsymbol{u} = \nabla.[-p\boldsymbol{I} + (\mu+\mu_T)(\nabla\boldsymbol{u} + \nabla\boldsymbol{u}^T) - \frac{2}{3}\rho k\boldsymbol{I}] \tag{4}$$

$$\rho\nabla.\boldsymbol{u} = 0 \tag{5}$$

Where ρ is the pressure, μ is the viscosity, is the turbulent viscosity and k is the turbulent kinetic energy. The turbulence model used is the k–ε model given by Equations (6) - (9).

$$\rho\frac{\partial k}{\partial t} + \rho(\boldsymbol{u}.\nabla)\,k = \nabla.\left[\left(\mu + \frac{\mu^T}{\sigma_k}\right)\nabla k\right] + P_k - \rho\varepsilon \tag{6}$$

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho(\boldsymbol{u}.\nabla)\varepsilon = \nabla.\left[\left(\mu + \frac{\mu^T}{\sigma_e}\right)\nabla\varepsilon\right] + C_{el}\frac{\varepsilon}{k}P_k - C_{e2}\,\rho\frac{\varepsilon^2}{k} \tag{7}$$

$$\mu_T = \rho\, C_\mu\frac{k^2}{\varepsilon} \tag{8}$$

$$P_k = \mu_T[\nabla\boldsymbol{u} : (\nabla\boldsymbol{u} + (\nabla\boldsymbol{u})^T)] \tag{9}$$

Where Pk is production term and ε is the turbulent dissipation rate. The values of the model constants are Cμ = 0.09, Cε1 = 1.44, Cε2 = 1.92, σk = 1.0 and σε = 1.3.

B. *Experimental Setup*

Fig 14:- Solar panel with (i) Water cooling (ii) Peltier cooling (iii) Air cooling, (iv)Without cooling.

Type	Polycrystalline solar module
Rated maximum power (Pmax)	20W
Voltage at Pmax (Vmp)	18.25V
Current at Pmax (Imp)	1.10A
Open-circuit voltage (Voc)	21.96V
Short-circuit current (Isc)	1.17A
Maximum system voltage	800VDC
Operating temperature	-40ºC to +85ºC
Dimensions (mm)	510 X 355 X 20

Table 1. Solar panel specifications

The calibrated K type thermocouple we are using to find the temperature, current and voltage.

Fig 15:- Multimeter reading showing the temperature value

Latitude	11.1336º N
Longitude	76.1855º E
Time zone	+5 hours. 30 minute
Tilt to horizontal	30
Ambient dry bulb temperature	35ºC
Surface pressure	1013(mbar)
Solar constant	1367(w/m^2)

Table 2. Test site details for all four setup

- *Forced Cooling*

Fig 16:- DC fan

Four solar panels of the same dimension were used, one with air cooling (forced) second with water cooling third with Peltier cooling and finally without cooling. For forced air cooling the setups were subjected to experiment at same time and environmental conditions. The specification of PV panel is mentioned. The rated output is 20W and having surface area of 0.181 m2.The highest value of open circuit voltage 21.96V. The highest short circuit current is 1.17Amps.

Fig 17:- Partition of air flow circulation

Experimental setup of PV/T air collector and instrument is shown in figure.. For easily circulate throughout the panel it has been portioned as shown in figure.

- *Water Cooling*

The PVT made from solar panel of 20W power and having surface area of 0.181 m2. The maximum open circuit voltage is 21.96V and maximum short circuit current is 1.17Amps.

Fig 18:- Water cooling system

A 8 liter water tank is used as the water storage. The header and the footer pipes are connected to the water tank by means of heat resistance plastic pipe. A steel stand for holding the water tank is used. The whole system is placed in the test location in such a way that PVT from surface facing south direction and having an inclination of 30° with the horizontal.

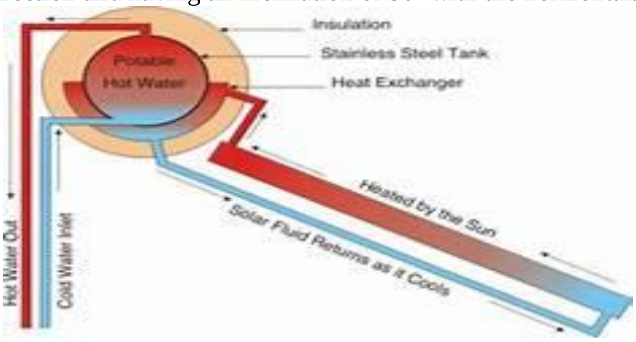

Fig 19:- Thermosiphon setup

Here the cooling is done by Thermosiphon principle, the cold water reaches the collector through water pipe. The water rises in the tank through the water pipe at the collector upper end. The water is heated up to an equilibrium temperature. So the hot water from top of the tank can be used for other purposes. Again it heats up. As a result the warm water rises faster than it does at lower irradiances.

The hourly based parameters that are measured in given below

- Ambient temperature
- Cell temperature of PVT
- Water temperature in tank

- *Peltier Cooling*

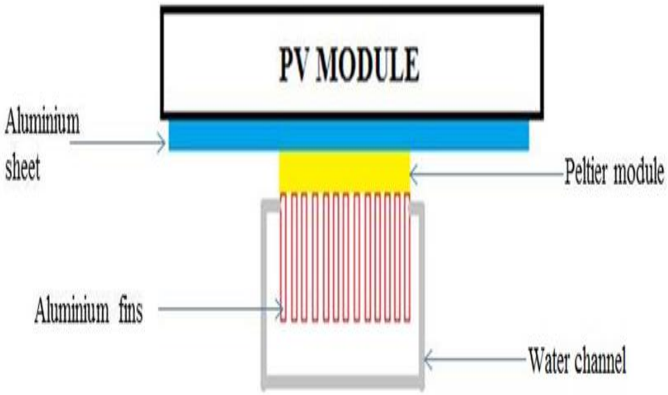

Fig 20:- Design of peltier module cooling

When the photons strike on the PV module generates high temperature, it is found that efficiency drops with rising temperature. Several cooling technique have been tried. Here we have introducing a new kind cooling system by using Peltier module. The peltier modules have a property, at a time one phase of peltier module will be cool and the other phase will be hot. Here we placed an Aluminum sheet between PV module and Peltier module, to transmit the cooling effect all over the PV module, because Aluminum is a good conductor. A water circulating system is provided near to hot side of the peltier module to absorb the heat from it. This hot water can be used for further domestic uses. Here instead of water using fan to cool.

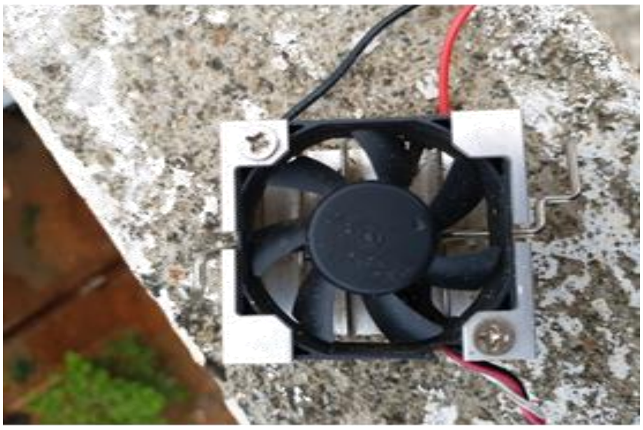

Fig 21:- Peltier module with Fan and heat sink

The hourly based parameters that are measured in given below

- Ambient temperature
- Cell temperature of PVT

C. *Energy Analysis*

Accumulated energy + Energy gain = Absorbed energy – Lost energy

Accumulated Energy	= M.C_P.((dTp,avg)/dT)	(10)
Energy gain	= m.C_p.(Tout-Tin)	(11)
Absorbed energy	= η.I.Ac	(12)
Lost energy	= Uc.(Tp,avg-Te).Ac	(13)

The thermal efficiency of solar collector is defined as the ratio between the energy gain and the solar radiation incident on the collector plane, given by

$$\eta=(m.Cp.(Ta,out-Ta,in))/(I.Ac) \quad (14)$$

D. *Exergy Analysis*

Following assumptions are made to form exergy equations

- It is a steady state steady flow operation.
- No chemical or nuclear reactions
- Here Air is an ideal gas. Specific heat of the gas is constant.
- The heat transfer to the system is negative also the transfer from the system is positive

Mass balance equation is

$$\sum \dot{m}in = \sum \dot{m}out \quad (15)$$

Energy and exergy balance are represented as

$$\sum E\ in = \sum E\ out \quad (16)$$

$$\sum E\ x\ in - \sum E\ x\ out = \sum E\ x\ dest \quad (17)$$

Exergy efficiency is given as

$$\Psi = \frac{\dot{m}(hout-hin-Te(Sout-Sin))}{(1-\frac{Te}{Ts})Qs} \quad (18)$$

IV. RESULT AND DISCUSSION

The hourly variations of different parameters were taken for 3 days (27/03/2018 to 29/03/2018) The readings on 28/03/2018 were considered as those readings were with more solar intensity and further calculations were done based on the readings on 28/03/2018. Following are the results obtained from the experiment.

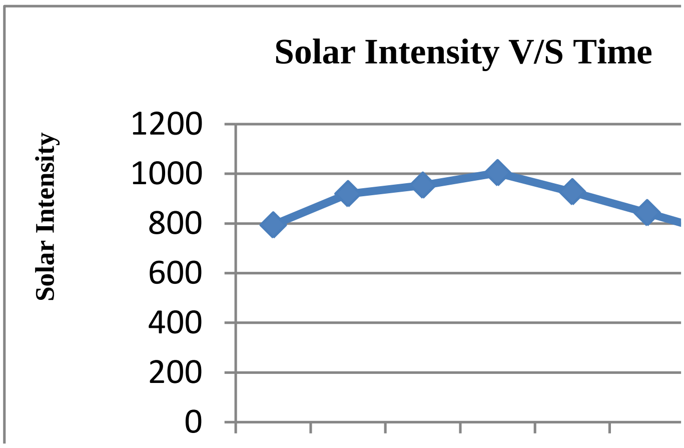

Fig 22:- Solar Intensity v/s Time graph for a typical day on 28/03/2018

From the above graph it is clear that the solar intensity value increases till noon and then decreases as the position of Sun changes throughout the day and more temperature is felt during noon which satisfies the result. The maximum value obtained was found to be 953.504 W/m2 at 12pm and the minimal value was found to be 773.187 at 4pm.

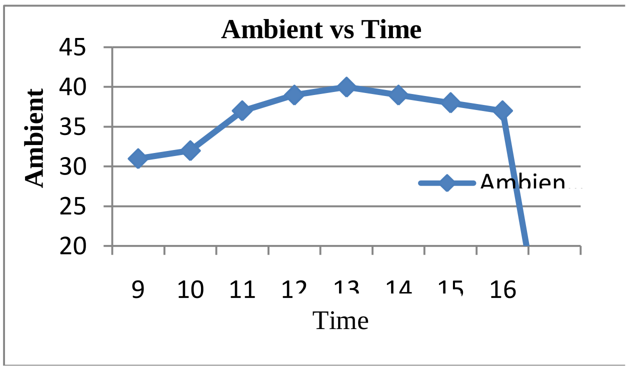

Fig 23:- Ambient temperature v/s Time graph for a typical day on 28/03/2018

Ambient temperature, in a similar manner to solar intensity, initially increases till noon and then decreases. This is because as time reaches to 12pm the solar intensity increases and hence the temperature. The value decreases after noon as the solar intensity decreases. The maximum temperature was found to be 40ºC at 1pm. From the graph it can be viewed that the first half of the graph has a somewhat steeper slope compared to the second half. This is because early morning the temperature is comparatively low and the temperature increases only due to the radiation from sunlight. But after 12pm even though the sunlight amount is low the temperature does not decrease with initial slope. This is due to terrestrial radiation. The ground gets heated in the early morning period and later this heat is liberated out which accounts for the less steep sloop curve for the second half.

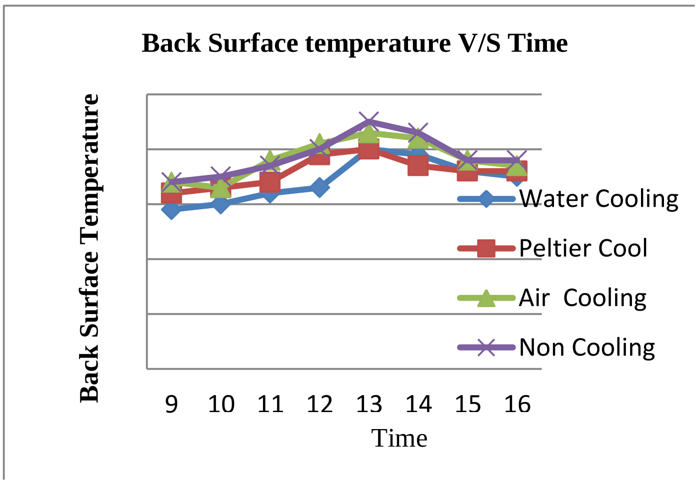

Fig 24:- Back surface temperature v/s Time graph for a typical day on 28/03/2018

Hourly variations of back surface temperature with respect to time for solar panels with water cooling, Peltier cooling, air cooling and without any cooling, are plotted. Back surface temperature initially increases for every panels, reaches a maximum value and then decreases. From the graph it can be clearly seen that the back surface temperature is very low for panel with water cooling and peltier cooling compared with other cooling. The maximum value was found to be 40ºC for water cooled PV/T, 40ºC for peltier cooling, 43ºC for Air cooling and 45º Non cooling system at 1 pm. These temperature differences are aids to an increase in the efficiency of solar panel.

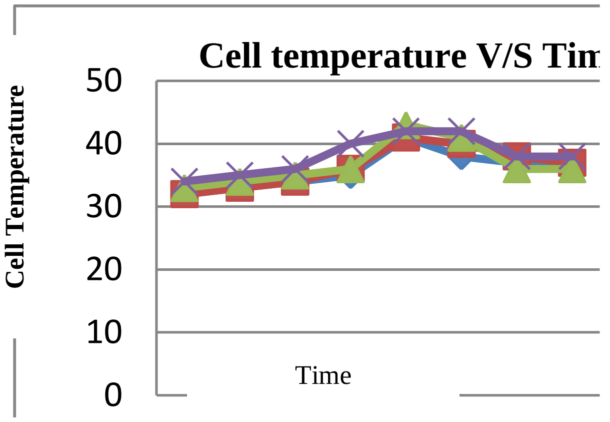

Fig 25:- Cell temperature v/s Time graph for a typical day on 28/03/2018

The above graph represents the variation of cell temperature with respect to time for solar panels with water cooling, Peltier cooling, air cooling and without any cooling. Cell temperature for panel with water and peltier cooling was found to be very much less compared to that of other two cooling. This decrement achieved in the solar panel aids in the increase in efficiency of the panel. The maximum temperature was found to be in water cooling is 41ºC, Peltier cooling is 41ºC, Air cooling it is 43ºC and 42ºC in Non

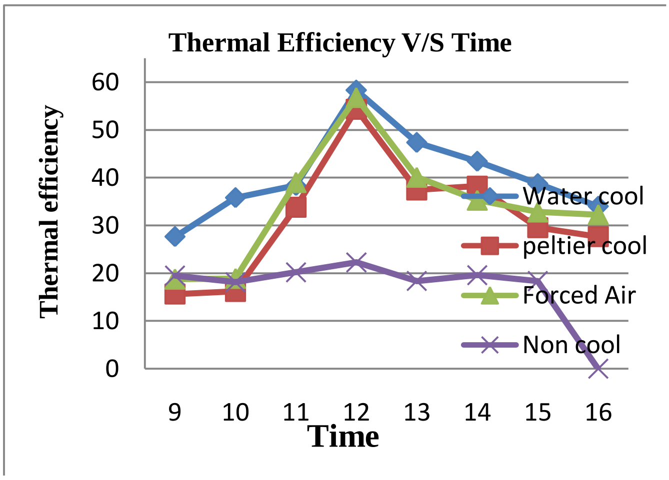

Fig 26:- Thermal Efficiency v/s Time graph for a typical day on 28/03/2018

Time	Solar Intensity w/m^2	Ambient temp ºC	Cell temp ºC	Back Surface temp ºC	Inlet air temp ºC	Outlet air temp ºC	Voltage V	Current A
9	794.006	31	33	34	32.2	32.7	19.88	1.1
10	919.915	32	34	33	33.5	34.2	19.54	1.22
11	954.255	37	35	38	34.4	35.9	19.23	1.13
12	1004.50	39	36	41	35.3	37.6	19.14	0.83
13	927.75	40	43	43	37.8	39.3	18.8	0.49
14	843.4	39	41	42	39.1	40.3	19.1	0.71
15	755.62	38	36	38	38.4	39.4	18.3	0.48
16	538.42	37	36	37	37.8	38.5	19.32	0.72

Thermal efficiency was found to be more for the panel with water cooling. This is because more heat gain was attained

from the panel with cooling and hence the thermal efficiency increased. For peltier cooling it seem to be same as the air cooling, But here we using just one peltier so the effect will be accordingly. More the peltier using higher will be Thermal Efficiency. The maximum value of thermal efficiency for water cooling it was 17.14%. For peltier cooling it was found to be 3.32% .and for air cooling it was 3.32% at 12pm.

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Time	Thermal efficiency %	Electrical efficiency %	Overall efficiency %	Exergy efficiency %
9	18.75	16.37	35.12	2.97
10	18.888	15.44	34.32	2.935
11	39.00	15.01	54.01	4.02
12	56.81	14.88	71.69	5.067
13	40.12	15.01	55.13	4.213
14	35.30	15.43	50.73	4.277
15	32.841	16.33	49.171	4.627
16	32.6	18.35	50.61	7.74

Table 3. Observation values and experimental readings for photovoltaic thermal air collector system

Time	Solar Intensity w/ m^2	Ambient temp °C	Cell temp °C	Inlet temp °C	Outlet temp °C	Voltage V	Current A
9	794.006	31	32	33.2	33.8	20.5	.31
10	919.915	32	33	34.4	35.3	20.61	.47
11	954.255	37	34	35.5	36.5	20.67	.8
12	1004.50	39	35	37.3	38.9	20.28	.9
13	927.75	40	41	38	39.3	20.38	.831
14	843.4	39	38	40.2	41.2	19.64	.5
15	755.62	38	37	39.5	40.3	19.74	.72
16	538.42	37	37	38.8	39.3	19.61	.71

Time	Thermal efficiency %	Electrical efficiency %	Overall efficiency %	Exergy efficiency %
9	27.67	16.37	44.04	3.954
10	35.82	15.44	51.26	3.960
11	38.37	15.01	53.38	3.964
12	58.33	14.88	73.21	5.166
13	47.36	15.01	62.37	4.771
14	43.42	15.43	58.55	4.944
15	38.77	16.33	55.07	5.196
16	34	18.35	52.35	8.935

Table 4. Observation values and experimental readings for photovoltaic thermal water collector system

Time	Solar Intensity w/m^2	Ambient temp °C	Cell temp °C	Inlet temp °C	Outlet temp °C	Voltage V	Current A
9	794.006	31	32	32.1	32.6	19.61	.35
10	919.915	32	32	33.3	33.9	19.38	.48
11	954.255	37	35	34.2	35.5	19.4	.8
12	1004.50	39	35	35.7	37.9	19.2	.96
13	927.75	40	41	38	39.4	19.39	.84
14	843.4	39	40	39.5	40.8	19.44	.59
15	755.62	38	36	39.6	40.5	19.97	.78
16	538.42	37	35	38.8	39.2	19.1	.71

Table 5. Observation values and experimental readings for photovoltaic thermal peltier cooling system

Time	Thermal efficiency %	Electrical efficiency %	Overall efficiency %	Exergy efficiency %
9	15.62	16.37	31.99	2.862
10	16.18	15.44	31.62	2.44
11	33.80	15.01	48.81	3.62
12	54.34	14.88	69.22	4.9
13	37.44	15.01	52.45	4
14	38.24	15.43	53.67	4.513
15	29.55	16.33	45.88	4.318
16	27.65	18.35	46	6.061

Table 6. Observation values and experimental readings for photovoltaic system

Time	Solar Intensity	Ambient temp	Cell temp	Inlet temp	Outlet temp	Voltage	Current
	w/ m^2	°C	°C	°C	°C	V	A
9	794.006	31	34	33.2	33.3	19.77	.31
10	919.915	32	36	34.5	34.6	19.88	.44
11	954.255	37	35	35.2	35.4	20.4	.81
12	1004.50	39	40	37.5	37.8	19.67	.94
13	927.75	40	42	38.7	38.9	19.74	.827
14	843.4	39	42	40.4	40.5	19.78	.55
15	755.62	38	38	39.3	39.4	20.12	.782
16	538.42	37	38	38.5	38.5	20.01	.71

Time	Thermal efficiency %	Electrical efficiency %	Overall efficiency %	Exergy efficiency %
9	3.125	16.37	19.945	1.736
10	2.697	15.44	18.137	1.39
11	5.200	15.01	20.21	1.5
12	7.41	14.88	22.29	1.572
13	5.349	15.01	20.359	1.554
14	2.942	15.43	18.372	1.542
15	3.284	16.33	19.614	1.832
16	0	18.35	18.35	2.413

Table 6. Observation values and experimental readings for photovoltaic system

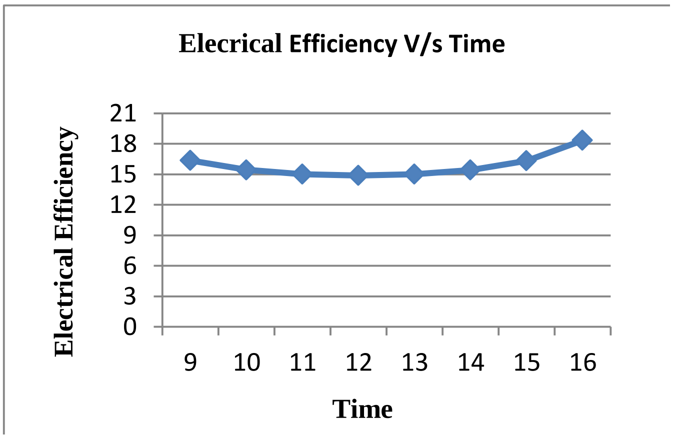

Fig 27:- Electrical efficiency v/s Time graph for a typical day on 28/03/2018

The above graph reveals the hourly variations of electrical efficiency of solar panel and solar panels under consideration. The electrical efficiency was found to be varying with intensity of solar radiation. As the temperature increases or in other words as the noon approaches, electrical efficiency decreases with time till noon and then increases. This is because the temperature increases till noon and hence the electrical efficiency decreases and later increases due to the decrease in temperature. The minimum value of electrical efficiency for was found to be 14.88% at 12pm.

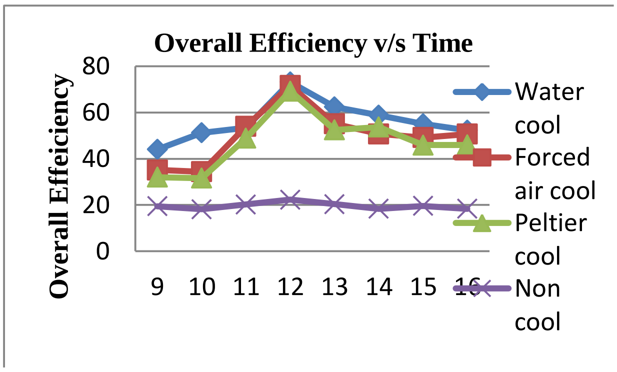

Fig 28:- Overall efficiency v/s Time graph for a typical day on 28/03/2018

Overall efficiency was found to be more for the PV/T than PV which implies that it is much more economical in using a PV with water cooling than Peltier and Air cooling. But as we say previously if we apply more than two peltier cooling the result will be different. The maximum value of overall efficiency was found to be 32.02% for water cooling. For air and peltier cooling it was 18.2 % for PV/T at 12pm.

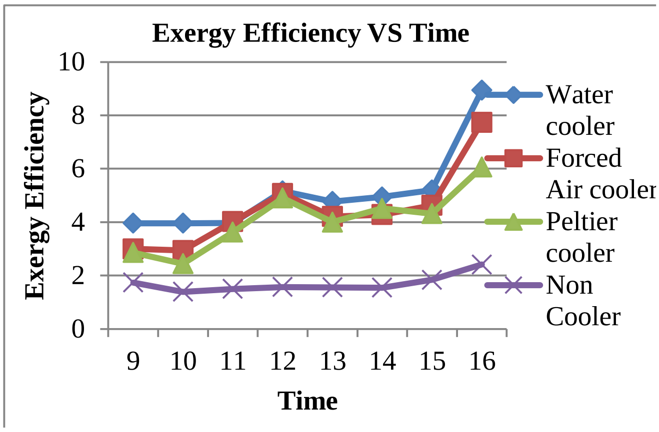

Fig 29:- Exergy Efficiency v/s Time graph for a typical day on 28/03/2018

Exergy efficiency was found to be more for the PV/T than PV which implies that it is much more economical in using a PV with water cooling than Peltier and Air cooling. The maximum value of exergy efficiency was found to be 5.116% for water cooling. For air it was 5.064 and peltier cooling it was 4.9% for PV/T at 12pm.

V. CONCLUSION

Energy crisis is a problem faced by both developed and developing nations. Solar energy plays a crucial role in this scenario. The presently manufactured solar panels converts only a fraction of the solar energy falling on it, along with this the decrease in voltage with increase in cell temperature further reduces the efficiency of the system.

In this study, four solar panels of the same dimension and packing factor were considered one provided with water cooling another with forced air cooler another with peltier cooler and last one just PV cell. From the results obtained we can conclude that the efficiencies, both energetic as well as exergetic efficiencies were far more prominent for cooled solar panel than that without cooling. This was because the cooling provided beneath the solar panel helped in the removal of heat from the solar cell and the tedlar surface. Hence the cell temperatures reduced considerably when compared to that without cooling.

The project can be further extended by providing new and efficient methods of heat removal from the solar panel. Instead of using air, water, peltier as the fluid medium, any other nano fluids can be used for heat removal and the comparisons of these can be made pointing out which fluid medium is the best option among all the available options.

A light absorbing coating can be applied on the surface of the solar panel so that rays of more frequencies from the Sun can be absorbed and hence increase the efficiency of the panel.

Instead of using one peltier module in the center, introduce 3 to 5 peltier modules different sides of the solar panel brings more cooling to the panel. So the efficiencies can be increased.

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