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Increase the Efficiency of Solar Panel by surface cooling - A Review

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Abstract: Authors made a review to increase the efficiency of solar panel by decreasing surface temperature of the same. Approximately twenty-two different papers have been studied to get the detail information on the topic. Best on the past literatures different cooling media and process were used to lower the surface temperature of panel at peak hot period. Varying methods such as hybrid photovoltaic/thermal (PV/T) system, cooling by a novel micro heat pipe, water spray cooling technique and phase change material etc were the common techniques used in the process. All these techniques were used to decreases the temperature of the sonar panel by which increases the efficiency. The maximum efficiency was achieved by the cooling technique of novel micro heat pipe array with water cooling, in this process the efficiency increased by 13.5% compare to traditional one. Another technique where copper indium diselenide Photovoltaic module using an inorganic phase change material (PCM) which was able to decrease the temperature up to9^0C**.**The maximum power output was achieved by the technique of spraying water on the surface of solar PV channel where the efficiency was improved by 16.3%. The working temperature of another PV module attained as high as 68^0C at peak hot period and the efficiency drops 8.6% without cooling but by the application of blower the temperature was PV module, restricted within 38^0C and the electrical efficiency enhances by 12.5%.

***Index Terms* - photovoltaic cell, cooling temperature, solar panel, Efficiency, phase change material**

1. Introduction

The basic hindrance of the photo voltaic cell efficiency is the cause of varying day temperature, especially in the hot summer [1].The P-V characteristics of a ideal solar cell with the range of temperature from$0^0$to 75^0C was described by Rodrigues et al.[2]. The relation between the electrical power input P and the output voltage V of Solar cell is called the P-V characteristics of the cell also calculated by many researchers keeping module temperature (T_m) and E (Solar irradiance) kept constant throughout the experiment. In the trial they found if any of these two parameters E and T_m was changed then all characteristics changed accordingly and the total maximum electrical power gradually reduces as the solar cell temperature increases as it is shown in Fig. 1.In this examination temperature coefficient of the panel was maintained at 0.5%/C [3].

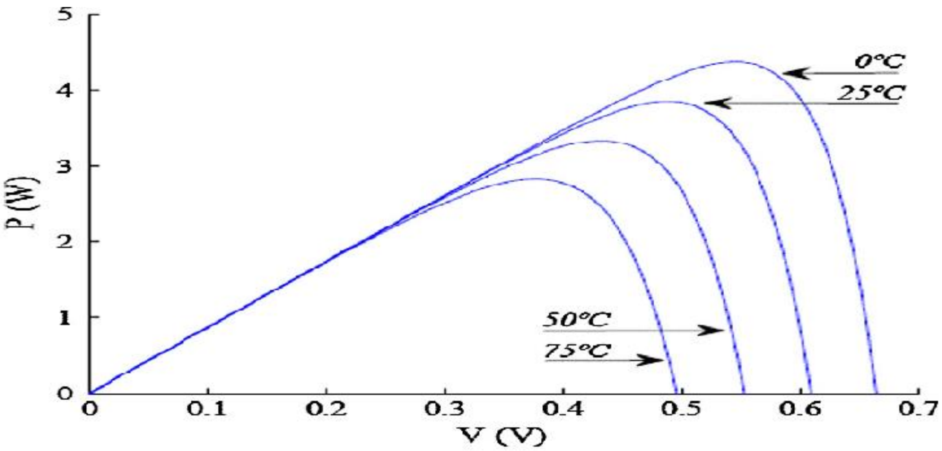

Fig. 1 P–V characteristics as a function of the module Temperature Tm, adopted from [2].
The module temperature varies between 0^0C to 75^0C.

a) The most popular methods for cooling the photovoltaic panels are Hybrid Photovoltaic/Thermal (PV/T) solar system. Currently, in hybrid system the solar photovoltaic system combined with cooling system are used to cool the surface of the solar photovoltaic cell.

b) Water or Air were also used as cooling agent that is spread on the surface of PV panels at high temperature and the discharge warm water or Air leaving the panels may be used for resident applications such as resident heating. Akbarzadeh and Wadowski [1] planned a combination of PV/T solar structure and found that the output power of the solar cells increases about 50% of the solar photovoltaic panel with water cooling. They also reported that the duration of cooling the temperature of solar photovoltaic panels does not shoot up beyond 46^0c when it exposed to solar radiation for a period of 4 hrs. Chaniotakis [4] planned combination of PV/T solar photovoltaic panels with both water and air as cooling agent. The literature clearly vivid that when solar photovoltaic panel is cooled by using water as cooling agent the performance of the solar cell enhances more than the air-cooled based system. Dubey and Tiwari [5] experimented with a hybrid solar photovoltaic system with thermal solar water heater. The combined PV/T solar water heater system has been planned and tried in open-air situations in New Delhi. They measured the efficiency of the solar PV panels under three dissimilar situations, Case A- solar collector is fully covered by the PV module, Case B – 50% covered by the PV module, and Case C –partially covered by PV module, i.e., 30%.Dubey and Tiwari [5] described that the increase in the efficiency is due to increase in glazing area of the panel. They depicted that the increase in the instantaneous efficiency of the solar collector from 33% to 64% was occurred as we move from Case A to Case C respectively. Tonui and Trip Anagnostopoulos [6] made their experiment with PVT/Air system to study the cooling effect of the solar photovoltaic panels with forced as well as natural convection. They found in the early afternoon during sunny days the PV module temperature could reach up to 12^0C under natural Convection. In the forced Convection, the experiments were done under three dissimilar situations, Case –I, fins are used in the PVT/Air, Case- II, Thin metallic sheet is used in PVT/Air, Case-III, normal PVT/Air is used. The efficiency of the PVT/Air with fins was increased by 30%, while metallic sheet was recorded as 28% and the normal panel knocks to 25% respectively. Based on the performance they declared that PVT/Air with fins proved best amongst all other cases. Kluth [7] studied water as cooling agent to improve the solar panel efficiency. For this purpose, two prototype solar panels were made. One prototype was cooled by spraying water by fan and other was left without cooling. He noticed that solar panel without cooling generates less energy than one with water cooling. Cooling by fans is mostly used in this method but spraying water is not efficient one to cool the solar panel as it creates a huge wastage of water, at the same time it is recommended by manufacturer that some part of the PV channel will not be cooled by water.

A novel micro heat pipe array is used for solar panel cooling by Tang et al. [8]. This cooling system was the combination of condenser section and evaporator section. Inside the evaporator section the input heat from the sun vaporizes the liquid and through the condenser section that vapor is passing to convert it again to water and finally by using either air or water condenser section then cooled down. Depending upon the system heat can be transferred by the heat pipe from solar panel to air or water. Conversion efficiency is the most important characteristic of the solar panel, which expresses the amount of solar radiation that is converted into wattage, in certain environments. In the case of mono crystalline silicon solar cells, the typical highest values of efficiency were found between the range 14 to 17%[9.] The solar radiation that is not transformed into electricity was totally converted into heat and consider as loss. Scientific literature papers [10], results of the following literatures[11, 12], and manufacturers of solar cells[13-16] confirm that while the temperature of the photovoltaic solar cells increases beyond certain value, the efficiency decreases. Most of the studies [10-16] describes that the maximum power produce in the solar panel differs linearly with the working temperature.

The value of the current formed by solar photovoltaic cell has an inconsequential growth when the temperature of the photovoltaic solar cell increases at the same time the voltage drops occurred causing ultimate losses of power produced. For the increment of each degree hike over 25 °C, the average reduction of efficiency is observed about 0.45% [17]. The idea of Standard Test Conditions (STC) is desired, for defining the performance of a Photovoltaic solar cell [18]. The reference electrical power produced by a photovoltaic panel is defined for an average temperature of the cell of 25 °C when the intensity of solar radiation was 1000 W/m². The maximum power generates in these situations by the photovoltaic solar cell is measured in Watt-peak (Wp). The power of photovoltaic solar cells dependent on the temperature changes and solar radiation level in actual operating conditions, but this value is mainly depending on the manufacturers as per materials of solar cell. Skoplaki et al. [19] present procedures and relationships for defining the dependence between conversion efficiency and temperature of Photovoltaic solar cells. A method for refining the temperature of photovoltaic panels by using air and passive cooling is studied by Cuce et al. [20]. Surveys concerning air cooling for photovoltaic panels are also projected by Tonui et al. [21]. This solution involves in cooling the solar photovoltaic panel by understanding a ventilated channel of 0.1 m width behind it. With the additional role of generating thermal energy, a solar photovoltaic/thermal (PV/T) system is created, which represents an adjusted solution of using solar photovoltaic panels. There were generating two types of energy: heat and electricity. Moreover, the optimal operational of each one brings paybacks to the other [22]. It is important to know the construction of the solar photovoltaic panel for finding exact results and realizing exact simulations. A typical structure is presented in the literature [23]. Therefore, the main layers are: Exterior glass, anti-reflexive coating (ARC), PV cells, ethylene-vinyl acetate (EVA), metal rear contact and polyvinyl fluoride (PVF) film. The thermo-physical properties of these layers are presented in Table 1 [23].

Table 1
Photovoltaic layer properties

Layer	Thickness t,(m)	Thermal conductivity k(W/mk)	Density ρ,(kg/m³)	Specific heat Capacity c (J/kg°C)
1.glass	0.003	1.8	3000	500
2.ARC	100*10-9	32	2400	691
3.PVCells	225*10-6	148	2330	677
4.EVA	500*10-6	0.35	630	2090
5.Rear Contact	10*10-6	237	2700	900
	0.0001	0.2	1200	1250

Here the authors are interested to look for the highest efficient solar panel that already used as photovoltaic radiation by the application of different cooling media. Therefore, the different cooling media on photo voltaic cells are considered for study. To find out the efficiency on the basis of changeable day temperature, the author also took pain to get data from different papers that are mentioned below. The literature reveled that water spraying technique is one of the most effective way of cooling of the surface of the solar panel which enhances the efficiency by16.3%.

2. Different Methodology used for cooling the panel

Sl. No.	Heading	Author's and Date	Methodology	Finding's
1	Heat-pipe-based cooling systems for photovoltaic cells under concentrated solar radiation	Akbarzadeh and T. Wadowski 1996	HEAT PIPE-BASED COOLING	Open circuit voltage, short circuit current, Maximum electric power output, efficiency
2	Modeling and Analysis of Water-Cooled Photovoltaic's'	Efstratios Chaniotakis 2001	water cooled PV, air cooled PV	Solar cell efficiency
3	Thermal modeling of a combined system of photovoltaic thermal (PV/T) solar water heater	Swapnil Dubey *, G.N. Tiwari 2008	(PV/T) solar water heater	Solar cell efficiency
4	Improved PV/T solar collectors with heat extraction by forced or natural air circulation	J.K. Tonui, Y. Tripanagnostopoulos 2006	heat extraction by forced or natural air circulation	Solar cell efficiency
5	Experimental investigation of solar panel cooling by a novel micro heat pipe array	Xiao Tang, Zhen Hua Quan, Yao Hua Zhao 2010	solar panel with heat pipe using air-cooling, heat pipe using air-cooling and water-cooling	Output power, Efficiency
6	Effects of passive cooling on performance of silicon photovoltaic cells	ErdemCuce*, Tulin Bali and Suphi Anil Sekucoglu 2011	aluminum heat sink used in order to dissipated waste heat from a photovoltaic (PV) cell	Maximum output power, efficiency, amount of heat dissipation

7	Hybrid photovoltaic and thermal solar-collector designed for natural circulation of water	Wei He a, Tin-Tai Chow b,*, Jie Ji a , Jianping Lu a , Gang Pei a , Lok-shun Chan b 2015	hybrid photovoltaic and thermal (PVT) collector technology using water as the coolant	Thermal efficiency
8	Advanced cooling techniques of P.V. modules: A state of art	Pushpendu Dwivedi a, K. Sudhakar a,b,c,* , Archana Soni a , E Solomin c , I Kirpichnikova c 2020	active water cooling, Natural and forced convection air cooling, Liquid immersion cooling	Efficiency, output power
9	Global advancement of cooling technologies for PV systems	M. Hasanuzzaman a, A.B.M.A. Malek a,b , M.M. Islam a,b , A.K. Pandey a , N.A. Rahim a, 2016	Active and passive water-cooling systems	Efficiency, output power
10	Experimental Assessment of PV Panels Front Water-Cooling Strategy 21	L. Dorobanțu, M. O. Popescu, C. L. Popescu, and A. Crăciunescu 2013	free flow front water cooling solutions	Open voltage, thermal resistance
11	Cooling of a photovoltaic module with temperature controlled solar collector	İlhan CEYLANa1 Ali EtemGÜRELbHüsamettinDEMİRCANcBahriAKSUd 2013	a spiral heat exchanger in order to provide active cooling	Solar efficiency
12	An active cooling system for photovoltaic modules	H.G. Teo a, P.S. Lee b ,M.N.A. Hawlader 2011	hybrid photovoltaic/thermal (PV/T) solar system	Thermal efficiency
13	Performance enhancement of PV array based on water spraying technique	Salih Mohammed Salih, Osama Ibrahim Abd, Kaleid Waleed Abid 2015	forced-water spraying and cooling technique with constant flow rate of water	Electric output power, solar irradiance
15	Water spray cooling technique applied on a photovoltaic panel: The performance response	S. Nizˇetic´ a, D. Cˇoko b, A. Yadav c, F. Grubišic´ -Cˇabo a 2015	Water spray cooling technique	peak solar irradiation, PV panel efficiency
16	Yearly energy performance of a photovoltaic-phase change material (PV-PCM) system in hot climate	A. Hasan a, J. Sarwar b, H. Alnomana , S. Abdelbaqi a 2017	A photovoltaic-phase change material (PV-PCM) system	Electric output power

17	Performance enhancement of copper indium dieseline photovoltaic module using inorganic phase change material	Alagar Karthick1 | Pichandi Ramanan2 | Aritra Ghosh3 | Balasubramaniam Stalin4 | Ramalingam Vignesh Kumar2 | IrusappanBaranilingesan 2020	PV-PCM system	Electric power gain

3. Result and discussion:

(3.1) Result as per A. Karthick et al.[24] the production of the solar photovoltaic module vary with respect to Geological and incident solar radiation climatic circumstances. The incident solar emission and ambient temperature at the site were shown in Fig.. 2 a, b. for the classic day of testing.

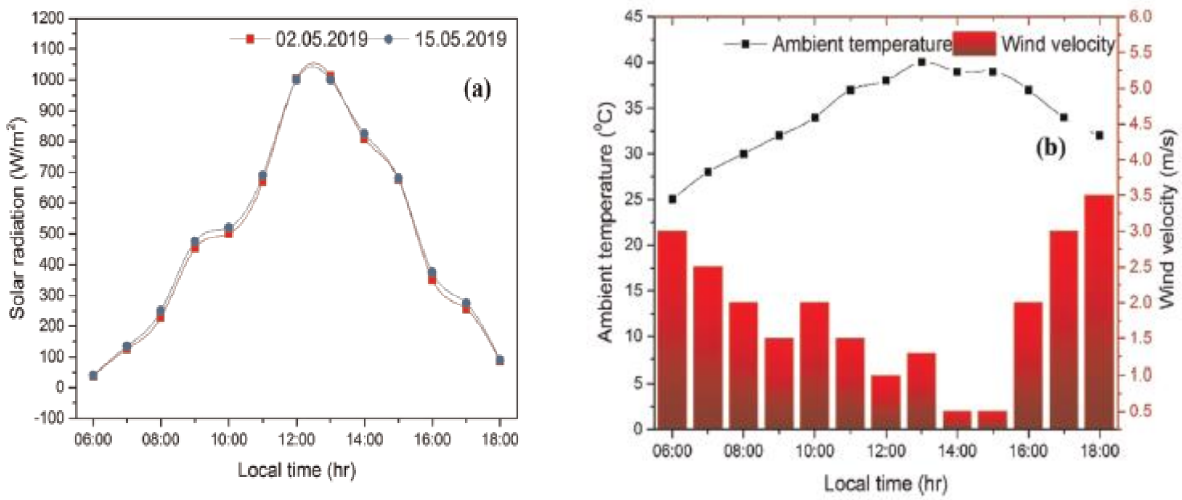

Fig. 2 Hourly variations of the ambient parameters of Typical day. (a) Solar radiation and (b) ambient parameters

(3.2) Result based on J. Sarwar Hasan et al.[25] investigational and simulated transient temperature progression on the front surface of PV panel for a distinctive day in January(The winter month) and July (The summer month). It can be seen that the peak T*PV* reached 53^{0}C in January and 72^{0}C in July representing a deviation of 36%. Result is shown in the Fig. 3.

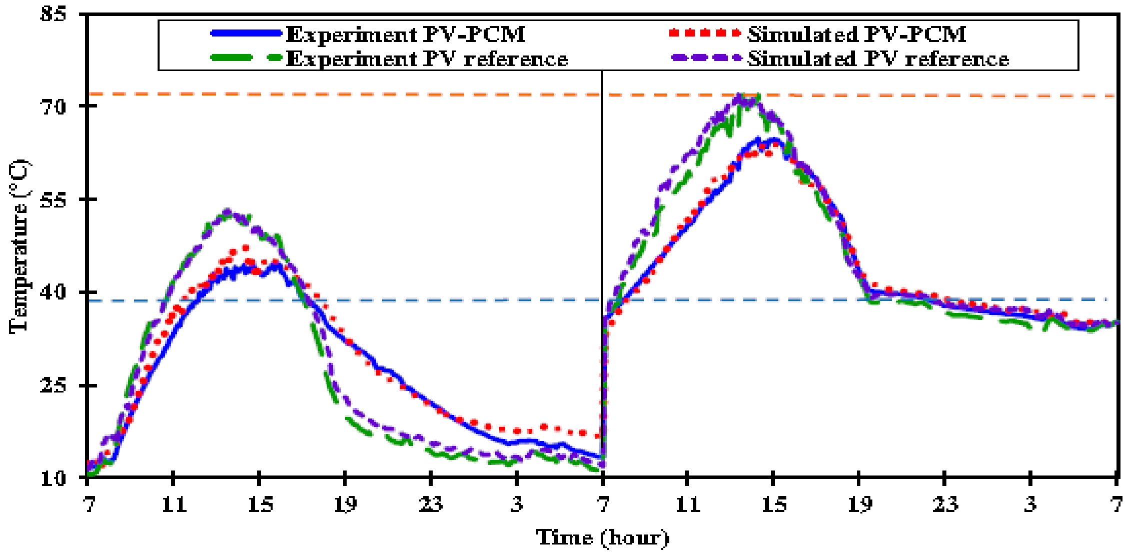

Fig. 3 The experimental and simulated transient temperature rise of the PV and PV-PCM system
For a typical day of the coolest (January) and warmest (July) months

The average and peak temperature drops on PV front surface achieved by insertion of the PCM. The winter and summer months produced less temperature drop compared to moderate months. The peak and average temperature drops of 13^{0}C and 6^{0}C respectively, were exhibited in April whom dropped to 8.6^{0}C and 2.3^{0}C respectively in January Fig 4.

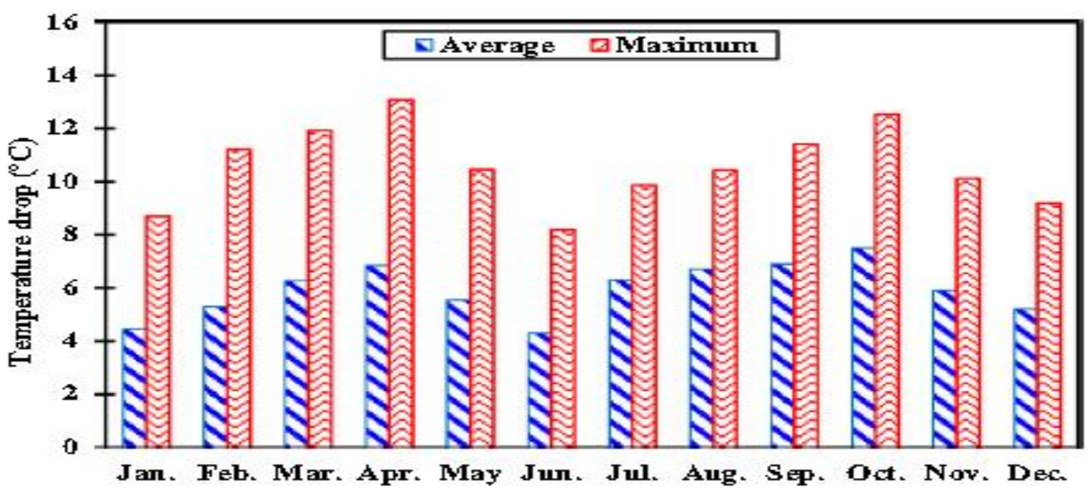

Fig. 4 average and peak temperature drop achieved by PV-PCM for a typical day of each month

To understand the melting and solidification behavior of the PCM, the temperature curves of the PCM
Over its thickness were plotted every 30 min for three selected months (April, July and December) shown in Fig. 5.

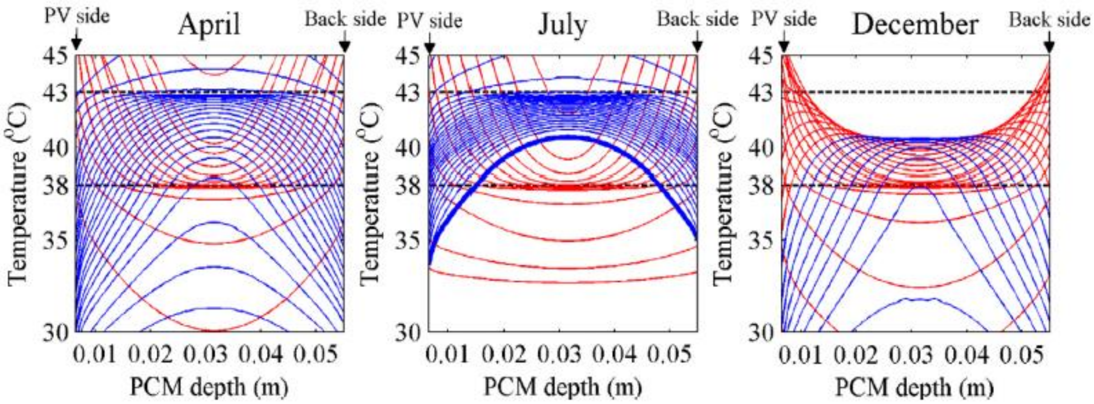

Fig. 5 temperature curves in the PCM for every 30 min during melting (red curves) and Solidification (blue curves) for a typical day in the month of April, July and December.

These three months are selected to show three different behaviors of the PCM which were

a) The PCM completely melts and solidifies in April.

b) The PCM completely melts but does not completely solidify in July

c) The PCM completely solidifies but does not completely melt in December.

(3.3) Result as per S. Nizetic et al. [26] Fig. 6 represents electric power output against voltage for dissimilar applied cooling conditions gain through a series of experiment in the period of maximum solar irradiation levels for the exact geographical location where the panel was tested.

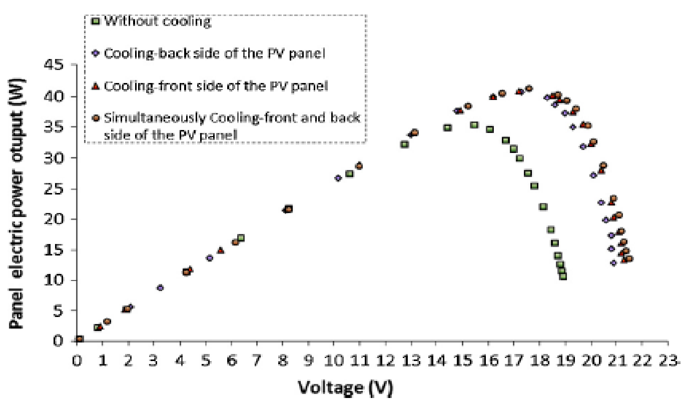

Fig. 6 Power output versus voltage for different investigated cooling Situation.

The effect of different experimentally tested water spray cooling regimes on the mean maximal PV panel Electrical efficiency is presented in Fig. 7

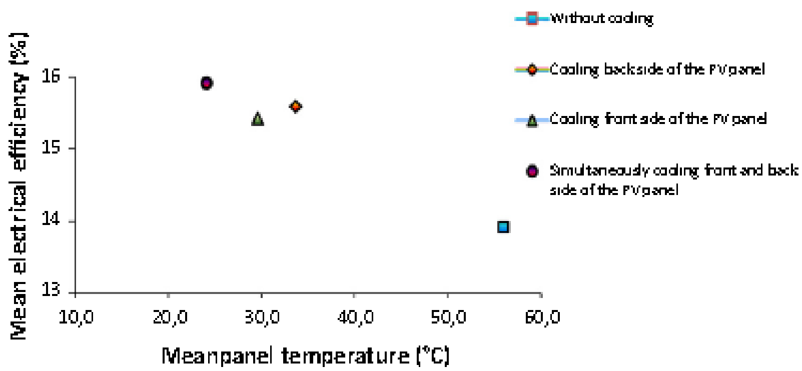

Fig. 7Mean maximal PV panel electrical efficiency as the function of the mean panel temperature for different applied cooling circumstances

(3.4) Result as per H.G. Teo et al.[27] The electrical efficiency of the solar photovoltaic module is existing in Fig.8 It can be observed that the electrical efficiency is a linear function of module temperature. The electrical efficiency of PV module declines with the raise in temperature of the solar photovoltaic module. For the period of the experiment, cooling and non-cooling cases were considered.

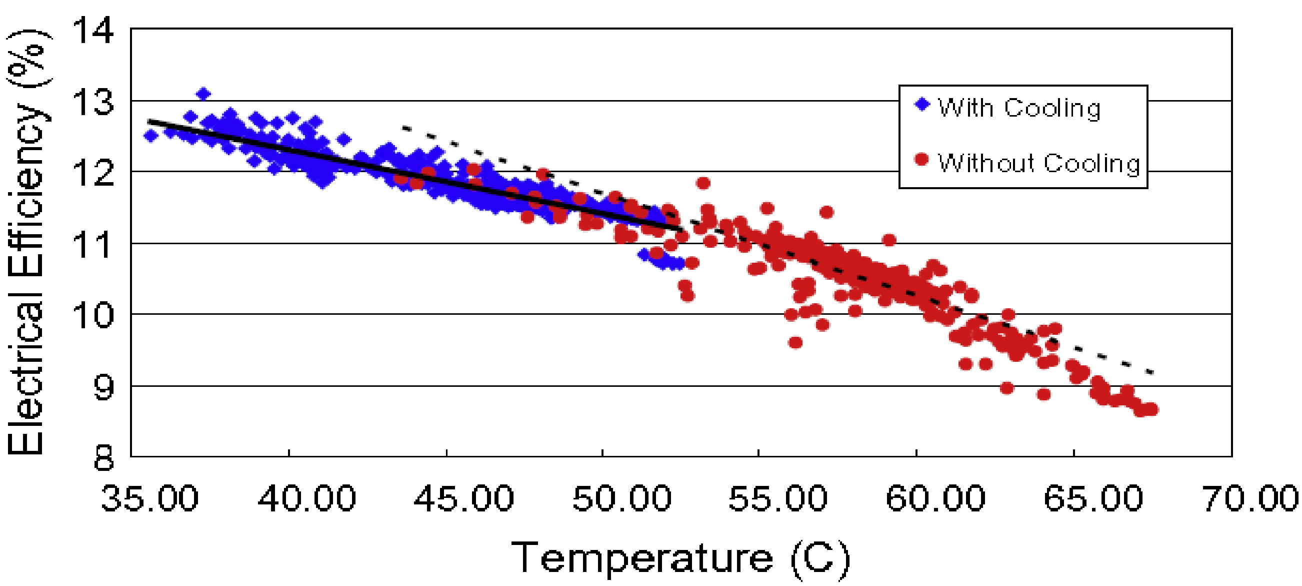

Fig.8 Electrical efficiency as a function of PV temperature Based on the experimental data,

Fig. 9 showed that the theoretical electrical efficiency is about 1–2% higher than experimental electrical efficiency.

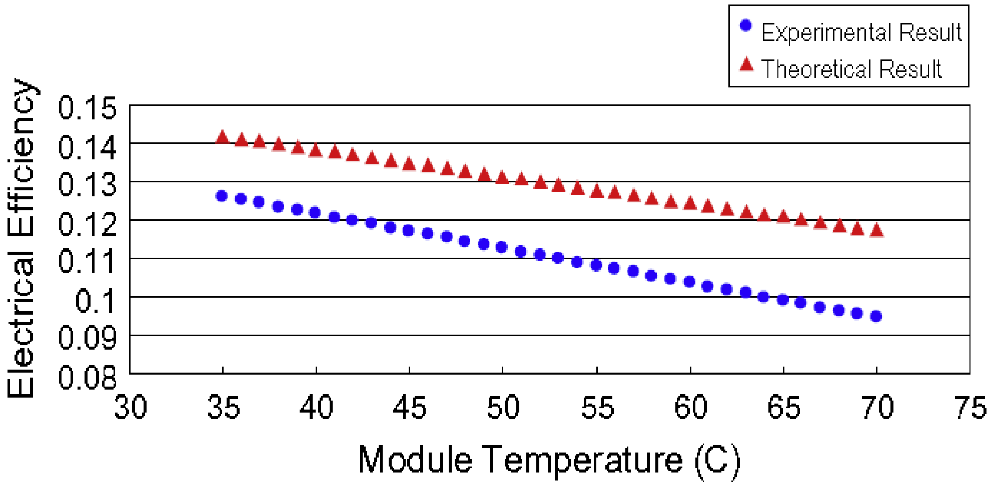

Fig. 9 a comparison between theoretical and experimental results.

(3.5) Result based on Xiao Tang et al [28] Fig. 10-12 show the comparing results between the ordinary solar panel without the heat pipe and solar panel with heat pipe using air-cooling in one day of May.

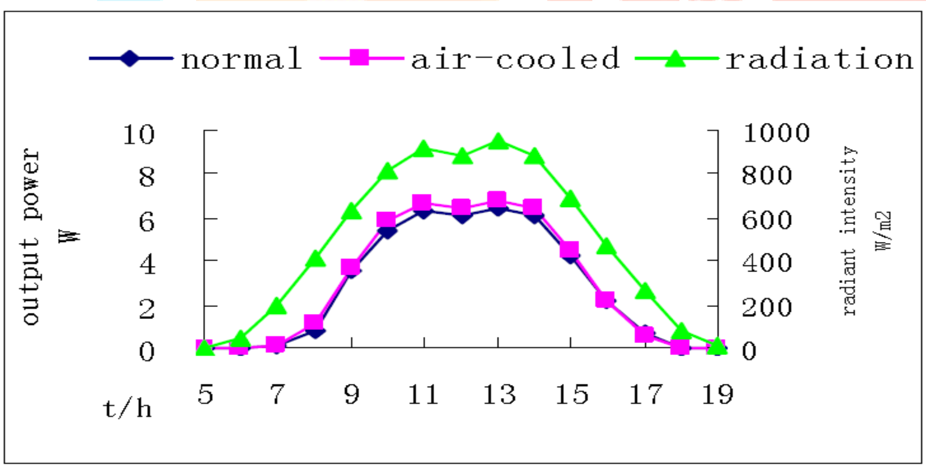

Fig.10 comparison of hourly output power of solar panel cooling by air with heat pipe and without cooling

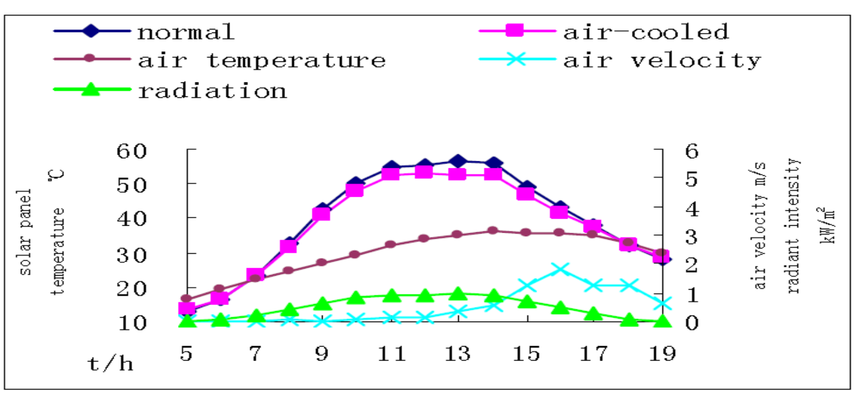

Fig.11. comparison of hourly temperature of solar panel cooling by air with heat pipe and without cooling

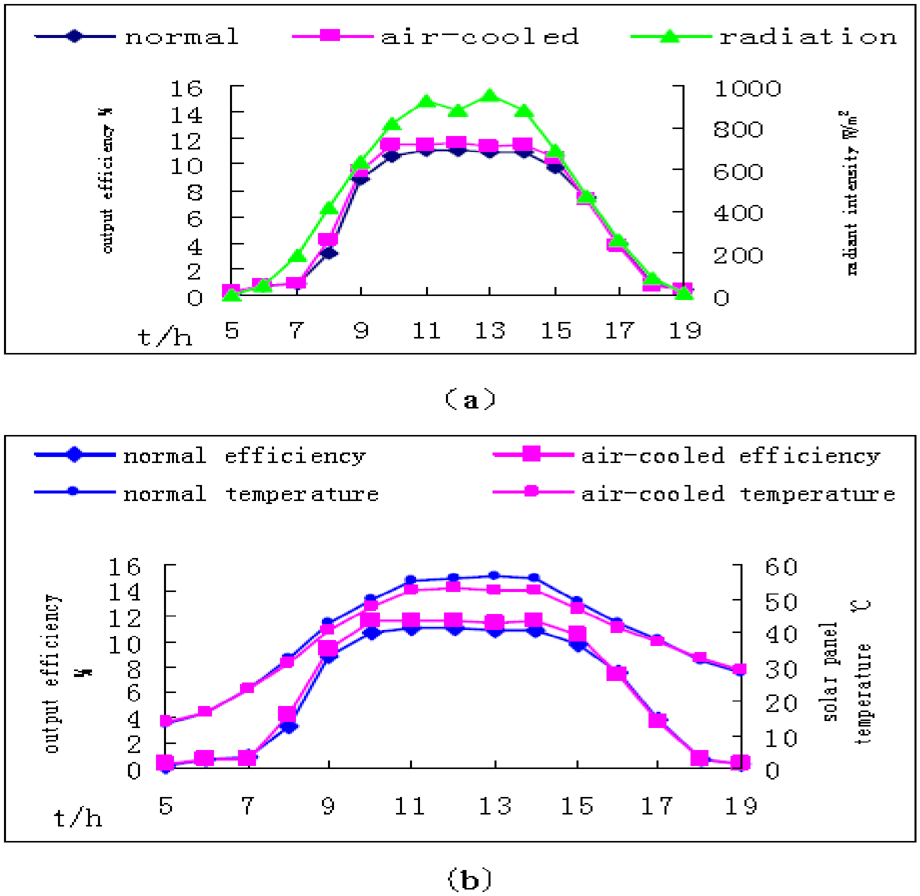

Fig.12. comparison of hourly efficiency of solar panel cooling by air with heat pipe and without cooling

A novel micro heat pipe array was used for solar panel cooling-

Compared with the common solar panel, the temperature of that using air-cooling reduces by 4.7^0c, hence the output power increase by 8.4% as well as the efficiency difference observed 2.6%,when the day

Maximum air temperature was recorded as 36^0Cand the wind speed maintained 5.32m/s respectively and the daily global radiation was 26.3 MJ. The temperature of the panel reduces by 8^0Cin water-cooling compared with the solar panel using air-cooling where the output power increases maximum by 13.9% and the efficiency difference took place 3%. In this way the maximum efficiency can be achieved 13.5%. (In that day when the data was collected, the maximal air temperature, Wind speed and the daily global radiation were 35^0C, 4.72 m/sand 21.9 MJ respectively.).

4. Conclusion and future scope of work:

The Author have covered large many research papers in the field of cooling of solar panel to increase the efficiency of the panel and the literature review clearly mentioned varying types of cooling media that increases the efficiency of solar panel. Based on the literature the following conclusions are made as given below-

- There are different methods/materials are used in the cooling system of solar panel
  a) Like hybrid PV/T system,
  b) Cooling by a novel micro heat pipe,
  c) Water spray cooling technique
  d) Phase change material

All these techniques are used to decreases the surface temperature of the sonar panel by which increases the efficiency of the same.

- The power efficiency is achieved by the cooling technique of novel micro heat pipe array with water cooling where efficiency increased by 13.5% compare to conventional panel.

- Degradation of temperature is achieved by copper indium dieseline Photovoltaic module using an inorganic phase change material which was capable to decrease the temperature up to by 9^0C.

- The maximum power output is achieved by technique of water spraying on the Solar PV channel and efficiency of the panel increases by 16.3% comparison with ordinary solar panel.
- The working temperature of PV module attained a as high as 68^0C and the efficiency drops significantly 8.6% without cooling but by the application of blower the temperature of PV module restricted within 38^0C and the electrical efficiency enhances by12.5%.

- The study has conducted based on the approximately twenty papers but to get more details about the number of papers could be increased.

- Only the few cooling media as well process has been taken care of but it also can be increased by using different phase change materials and by using nano-fluids etc.

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