Experimental analysis of thermal cooling of solar photovoltaic panel using PCM

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Abstract : The aim of this research paper is to investigate the effect of temperature on the solar photovoltaic panel (PV panel) efficiency. The efficiency of the solar PV panel is depending upon the cell temperature, as the temperature of the solar panel increases the efficiency of the cell decrease. A phase change material (PCM) cooling technique has been incorporated to cool solar panel. An experimental test setup was manufactured for indoor testing of the solar PV cell with different heat flux technique. Five different irradiations was selected for the analysis by varying the halogen lamp intensity. Voltage and current was recoded for every irradiation, electrical and thermal efficiency was calculated. The results shows that, the maximum electrical efficiency was found 0.56 for without cooling system while it was 0.6 with cooling solar system. There is a 4% of rise of the efficiency with the addition of the PCM cooling. Hence, it is concluded that, the cooling technique of the solar PV cell was beneficial to improve the performance of the system.

***IndexTerms* - Photovoltaic solar panel, electrical efficiency, phase change material, solar irradiations.**

I. INTRODUCTION

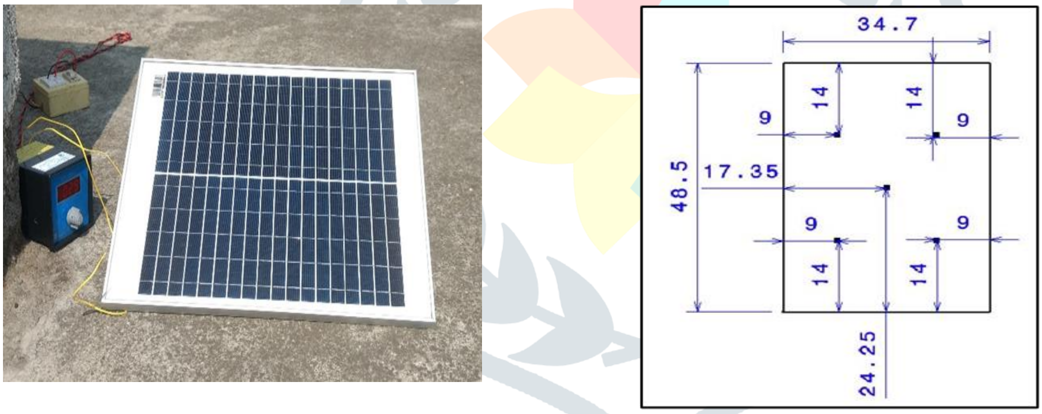
Environmental problems due to extensive use of fossil fuels for electricity production and combustion engines have become increasingly serious on a world scale in recent years. To solve these problems, renewable energy sources have been considered as new sources of clean energy. Solar energy is one of the most important sources among the renewable energies. Generally, solar energy conversion systems can be classified into two categories: thermal systems which convert solar energy into heat and photovoltaic systems which convert solar energy to electricity. Although, the usage of solar energy has been amplified, there are some difficulties that influence on the use of solar energy transporter among the other energy carriers, such as very high cost, low efficiency and electricity storing systems (batteries) due to the alteration between supply and demand. According to different PV cells materials, converting of solar irradiance into direct electricity can be achieved at several conversion efficiency between 7 and 40% [2,3]. A 80% of the total irradiation can be absorbed by the solar panel and only a minor percentage of the solar energy was converted into electrical energy with conversion efficiency of PV cell [4]. The rest of the energy was overheating the PV cells and other parts. Many researchers studied the operating temperature of the PV cells can rise above the atmospheric temperature of about ~40 °C [5–7]. The reason for overheating is due to fact that PV cells convert a certain band of the coming irradiance spectral wavelength that responsible of light direct converting into electrical energy, while the remaining of spectral wavelength is overheated the PV cells [8]. Raised temperatures of PV cells was considered as a critical issue particularly in hot climatic counties causing a series drop in PV electrical conversion efficiency by about 0.5%/1 °C f of the PV panel temperature [9]. Thus an integral cooling system of PV cells during operation is task of great significance to enhance the performance of the PV cells with an efficient conversion process particularly in sun- belt regions. Furthermore, the presence of the cooling system will help in decreasing the overall cost of solar cells, prolonging PV cells lifetime, encourage solar cells industries and ensuring maximum output power from the installed PV cells. Passive cooling technics involve eliminating or minimizing extra heat from the PV panel without consuming additional energy [12]. Diversities of passive cooling approaches are examined, elementary options suggest collection of metal fins with high thermal conductivity, or other surface formations to enhance dissipating overheating to the environmental surrounding [13]. More progressive systems comprise engaging heat pipes as well as phase change materials (PCMs) as passive cooling options.

Several experimental and theoretical studies about PV/T collectors have been carried out. Most studies have been conducted to improve PV electrical efficiency and its thermal efficiency. A comprehensive review on the hybrid PV/T solar collectors has been carried out by T. T. Chow . H. Saitoh et al. did experimental and analytical research on simultaneous power and heat generation with a hybrid solar collector. The result demonstrates that electrical conversion efficiency is around 10%- 13%. In case of brine temperate around 20C, the collector efficiency and overall efficiency (electrical conversion efficiency + collector efficiency) are obtained 40-50% and 50-60%, respectively, while if the brine temperature reaches 40C, the collector efficiency and overall efficiency decrease to 20% and 30%, respectively. The study shows that the hybrid collector has the advantage of higher exergy efficiency. M. Abdolzadeh and M. Ameri developed a PV/T water collector set up to increase the flow rate of a photovoltaic water pumping system that is performed by spraying water over the photovoltaic cells. Experimental results demonstrate that spraying water over the cells increases the performance indexes. The improvement of average PV cell efficiency, subsystem efficiency, and total efficiency are reported 3.26%, 1.40%, and 1.35%, respectively. Improving PV electrical efficiency transfers a higher power to the pump that means increasing water flow rate. Coupling a PV with the suggested cooling system, to a pump, can provide 644L/h flow rate at 16m head, while if the cooling system is inactive, the flow rate drops to 479L/h at 16m head. **Bhaskar B. Gardas et.al. [2]** were studied design of cooling system for PV panel for growing its electrical efficiency. They were obtained the aluminum fin at an irradiation of 1000 W/m^2 is showing maximum efficiency of 97.58 %, when water vapor is made to flow through the duct, maximum mass flow rate is for carbon dioxide and of the magnitude of 0.04559 kg/sec through the duct. Electrical efficiency drops when temperature of solar cells increases. For hydrogen, the system requires a mass flow rate of 0.00275 kg/s, which is the least of all other gas mass flow rate values & Number of fins required are 3.46. **Borkar et al. [3]** were investigated performance evaluation of PV panel using thermoelectric cooling. Mathematical model was developed to simulate thermoelectric system for cooling of PV panel, they reported that simulation shows at low temperature 25ºC of the PV panel there is improvement in efficiency of PV module. The detailed analysis of the model indicates that performance and life enhancement of PV module could be achieved with 25ºC cooling without loss of power. **Bhargava et al. [4]** were presented study of hybrid solar system- solar air heater combined with solar cells. Analysis of hybrid system (combination of an air heater and photovoltaic system) were investigated, they reported that the flow rate increases, then the solar cell efficiency increases, as duct depth increases, the thermal efficiency of the collector decreases. **Cuce et al. [5]** were studied effects of passive cooling technic on recital of silicon material PV panel. Effects of passive cooling on performance parameters of silicon solar cells and aluminum heat sink were investigated, they reported that energy, exergy and power conversion efficiency of the PV cell considerably increase with the proposed cooling technique. An increase of _20% in power output of the PV cell is achieved at 800 W/m2 radiation condition. Maximum level of cooling is observed for the intensity level of 600 W/m2. Performance of PV cells both with and without fins increases with decreasing ambient temperature. **Garg and Agarwal. [7]** were studied some aspects of a pv/t collector/forced circulation flat plate solar water heater with solar cells. They studied that system which combines thermal and photovoltaic systems in one-unit, conventional forced circulation type water heater, simulations of solar cell areas, mass flow rates, different water masses. They concluded that pump-on time is more or less independent of the total stagnant water mass in the collector unit, The average cell efficiency turns out to be more or less independent of the solar cell area on the absorber plate, A normal domestic solar water heater of about 2 m 2 generates sufficient electrical energy (after taking into account the various losses in storage, etc. and the energy required by the pump) to run 2 tube lights of 20 W each for 5 h and 1 television of 30 W for 4 h.

From the above extensive literature review, it shows that different cooling technique can help to increase the efficiency of the solar PV panel in a significant value. In this research work, a analysis of solar PV panel has been done with phase change material (PCM) cooling technique. An experimental study has been performed in indoor conditions with constant heat flux radiations from halogen lamp. The heat flux was varied by changing the distance between the solar panel and halogen lamp and respective observations has been recorded. A paraffin was material has been selected for cooling of the solar PV panel. An electrical efficiency was calculated for different heat flux.

II. Experiental setup and measurement

Solar photovoltaic panel of 20W nominal power output that is rated power. Photovoltaic panel is made of polycrystalline silicon. Figure 5.1 shows solar PV panel basic solar PV panel consists of connected PV cells, which contain a semiconductor material covered by protective glass connected to a load. The details of the solar PV panel were tabulated in table 1. A T-type thermocouple has been used for to record the temperature. Digital temperature indicator is used for the measurement of PV panel back side temperature. Paraffin wax selected for cooling of the solar panel with density 800 kg/m^3 and 43 ^{0}C melting temperature. Light Intensity Meter light meter or a flux meter is a device used to measure luminance flux per unit area. A digital multimeter was connected to the solar PV panel to record the voltage and current of the system. Halogen light lamp Light of capacity having 500watt used for constant irradiation conditions. Figure 2 shows the whole setup with connection of lamp. The Experiment test setup to carry out the test with constant heat flux variation and without cooling mechanism. The halogen lamp is kept at a fixed distance of 25 cm between solar panel and light source.



(a) Solar Panel (b) Thermocouple connection

Figure 1 solar PV panel of 20 W capacity and backside thermocouple arrangement.

Table 1 solar PV panel detail

P_{max}	20 w
Voltage(V_{max})	18.10 v
Current(I_{max})	1.10 A
Open Circuit voltage(V_{oc})	21.54 v
Short Circuit voltage(I_{sc})	1.18 A
System Voltage	1000 C

Figure 2 actual photograph of experimental set-up shows an experimental setup without cooling.

Table 2 shows the radiation intensity calculated by lux meter and light energy meter with different height of panel and the halogen lamp. Total five different height (25, 30, 35, 40, and 45 mm) has been selected for the analysis, and their corresponding radiation intensity was mentioned in table 6.3. Light intensity has been measured at five different locations of the solar panel, so that the average radiation can be calculated according to inlet light incident of the panel. All corners and the center of the panel was considered for the light measurement.

Table 2 Observation table of light intensity meter and their corresponding radiation.

Distance	1	2	3	4	5	Average	W	Radiations (W/m^2)
25	27400	7600	9300	11000	9200	12900	75.852	**686.1702**
30	19400	8000	9300	10700	9400	11360	66.7968	**604.2553**
35	15000	8000	8400	9300	8300	9800	57.624	**521.2766**
40	11300	6900	7100	7600	7200	8020	47.1576	**426.5957**
45	9200	6300	6600	6900	6700	7140	41.9832	**379.7872**

III. DATA ANALYSIS

Efficiency in photovoltaic solar panels is measured by the ability of a panel to convert sunlight into usable energy for human consumption. Knowing the efficiency of a panel is important in order to choose the correct panels for your photovoltaic system. For smaller roofs, more efficient panels are necessary, due to space constraints. How do manufacturers determine the maximum efficiency of a solar photovoltaic panel though? Read below to find out. Let us first start out by saying that the maximum power, also known as P_{max}, of a 20W panel is 20W regardless of the panel efficiency. The panel efficiency determines the power output of a panel per unit of area. The maximum efficiency of a solar photovoltaic cell is given by the following equation [22].

$$\eta_{solar\ panels} = \frac{p_{max}}{incident\ radiation\ flux \times A_c} \quad ....(1)$$

p_{max} =maximum power output (I_{max} x U_{max})

A_c = cross section area

III.I Electrical Efficiency

$$\eta_{thermal} = \eta_r[1 - \beta(T_C - T_r)] \quad ....(2)$$

η_r = Reference temperature efficiency

T_r = Reference temperature/ ambient temperature

T_C = Actual temperature

β= Temperature coefficient

III.II Thermal Performances

The thermal performance of the system is assessed through its daily thermal efficiency, which is calculated by the equation

$$\eta_{th} = \frac{mc_p\left(T_f - T_i\right)}{A_C G} \qquad \text{……………(4.3)}$$

M = fluid total mass
C_p = heat capacity
T_f = final temperatures
T_i = initial temperatures
A_C = collecting area
G = daily total incoming solar radiation/ radiation of the constant heat source.

Concerning the effects of the climatic conditions, in winter the low amounts of incident solar radiation limited the temperature reached by the PV modules. On particularly sunny but very cold and windy days, the convective heat losses from the modules surface to the exterior could also play an important role in reducing the thermal efficiency

III.III Electrical Performances

The system daily electrical efficiency η_{elec} is calculated by the equation

$$\eta_{elec} = \frac{\int_{day} I.U}{A_{pv}.G} \qquad \text{……………..(4.4)}$$

$$\eta_{elec} = \frac{I.U}{I_{max} U_{max}} \qquad \text{………………….(4.4 (a))}$$

I = current
U = voltage
I_{max} = maximum rated current capacity of the solar PV panel for 1000 W/m^2 solar radiation
U_{max} = maximum rated voltage capacity of the solar PV panel for 1000 W/m^2 solar radiation
A = surface area of PV module
G = daily total incoming solar radiation/ radiation from the constant heat source.

IV. Results and discussion

IV.I Effect of rise in temperature

The effect of rise in temperature of the solar PV panel on the voltage and current can be recorded with a constant heat source of halogen light. Figure 3 and figure 4 shows that, the variation of the generated voltage, current vs. increase in average solar panel temperature for different height of halogen lamp. The trends shows that, there is decrease in generated power with increase in solar panel temperature. The results of temperature and power produced with radiation. It is concluded that, the power is going to reduce with increase in temperature. There is a change in voltage with changing temperature. The voltage is going to reduce with increasing solar temperature and the miner rise in current. In the variation of the operating temperature of PV panel without cooling mechanism in the fixed solar radiation at height 30 cm. The maximum temperature reached 69.4 ^{0}C while a maximum power is reached 10.976 W. The variation of the operating temperature of PV panel with and without the water cooling mechanism in the fixed solar radiation at height 35cm. The variation of the operating temperature of PV panel with and without the water cooling mechanism in the fixed solar radiation at height 40 cm. Figure 4 shows the variation of the operating temperature of PV panel with and without the water cooling mechanism in the fixed solar radiation at height 45cm.

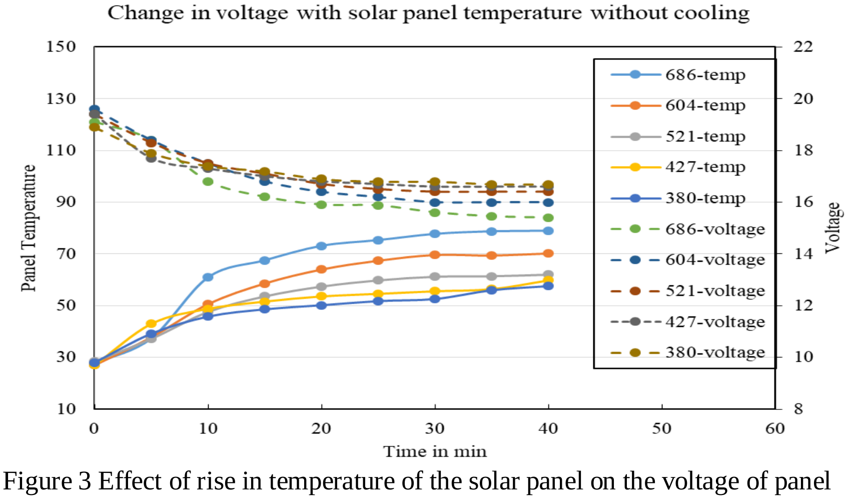


Figure 3 Effect of rise in temperature of the solar panel on the voltage of panel

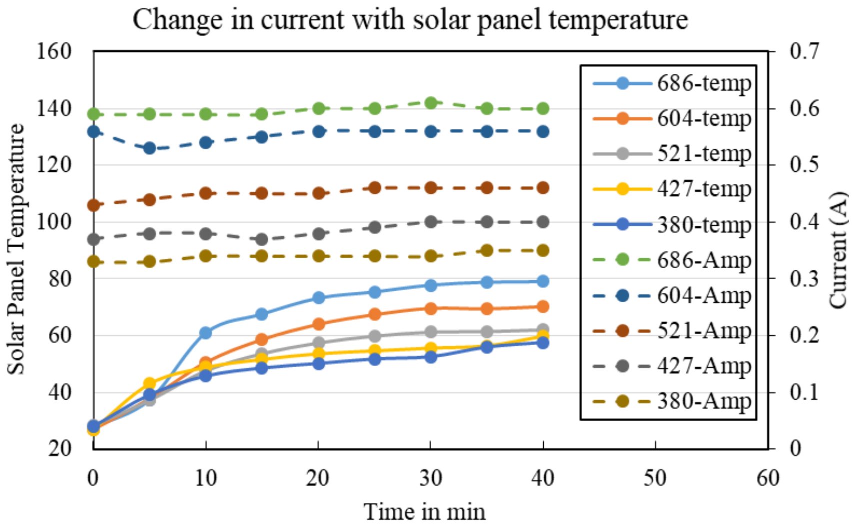


Figure 4 Effect of rise in temperature of the solar panel on the current of panel

Figure 5 shows the change in solar panel temperature with time and intensity of the light for with and without cooling system. A paraffin wax with 37.5 ^{0} C melting temperature was placed at the back side of the solar panel.

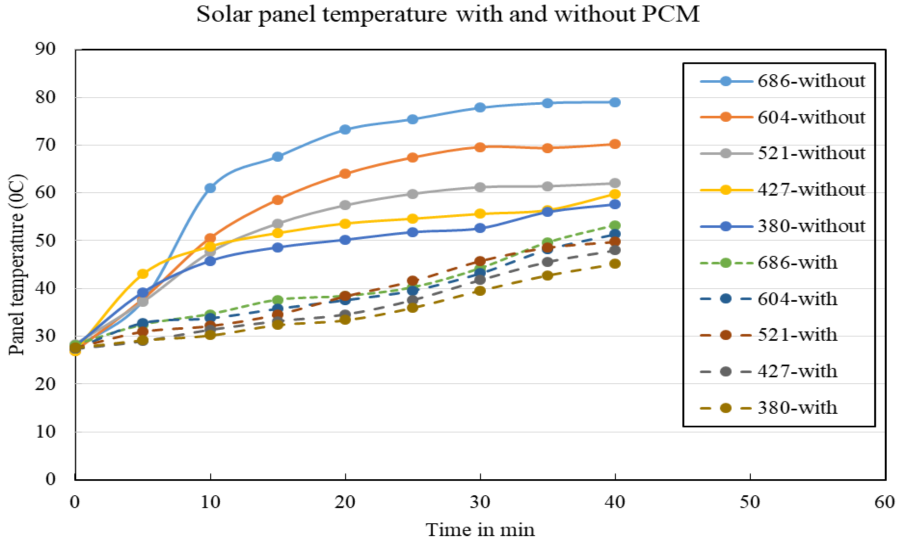


Figure 5 effect of rise in temperature on with and without PCM cooling technique.

IV.II Effect of PCM cooling system of the solar panel

IV.II.I Effect on the voltage

The effect of PCM cooling on the solar PV performance can be observed with different intensity of the radiation. PCM jackets can be fixed back side of the solar panel to absorb the heat. Figure 6 shows the change in voltage comparison with time for with and without PCM cooling. The voltage of without cooling system has fallen down significantly with rice in temperature, while in case of cooling system, the voltage will go down but the reduction rate is very low as compared with without cooling system. The maximum voltage at 40 min for 686 W/m^2 reading 15.4 V for without cooling system and that of for 15.9 V for with cooling system. The significant drop in voltage can found within 10 min as the highest temperature can be reached with 10 to 15 min span.

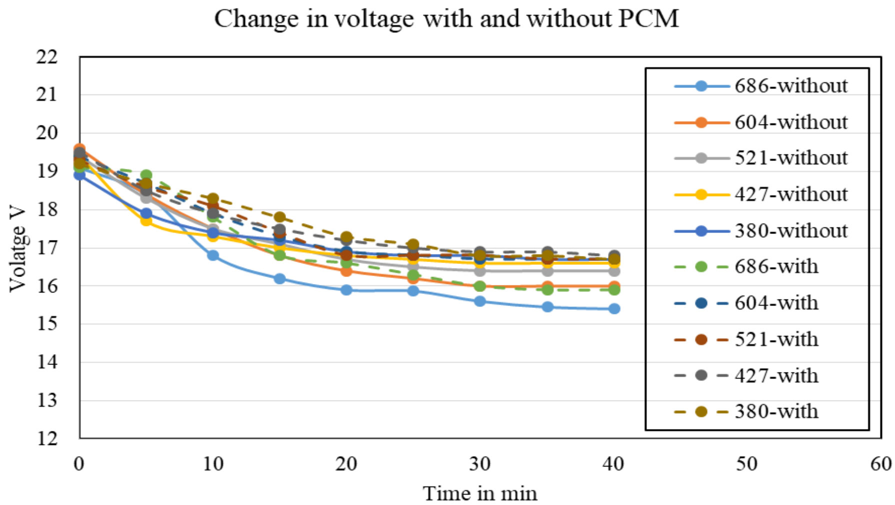


Figure 6 Graph of change with voltage for with and without PCM cooling system

Change in current for with and without system can be seen in figure 7. it can be seen that, there is not much significant affect of temperature on the current. The maximum current can be achieved with 686 W/m^2 radiation. There is a effect of addition of cooling system on the current. The current keeps higher with cooling system, hence the efficiency can be improved. The maximum current can be achieved is 0.61 A for 686 W/m^2 radiation. The maximum efficiency can be found with highest radiation 0.56 and 0.59 for with and without cooling system, respectively. The electrical efficiency for with and without cooling system is shown in figure 8.

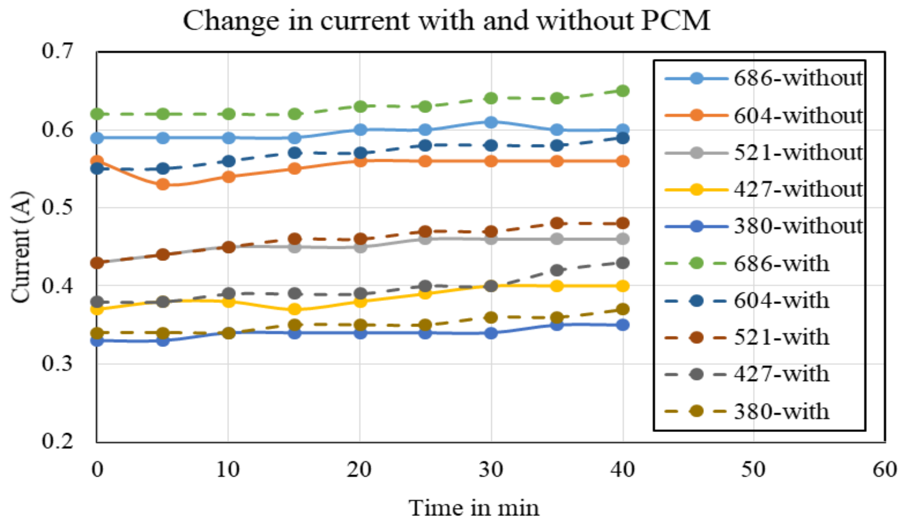


Figure 7 Graph of change with current for with and without PCM cooling system

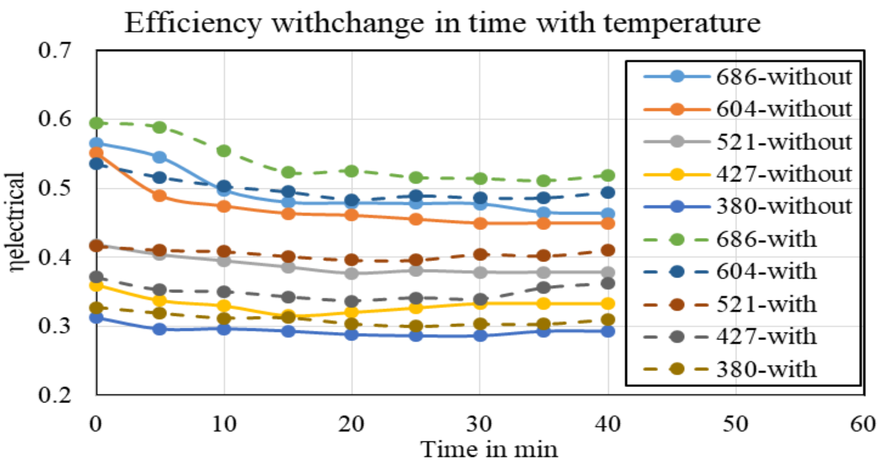


Figure 8 Graph of change with efficiency for with and without PCM cooling system

IV.II.II Effect on thermal efficiency:

A thermal efficiency can be calculated using equation 2 by considering the panel temperature. Figure 9 and 10 shows the thermal efficiency of with and without cooling system. The maximum thermal efficiency was found 0.26 at 40 min and for without cooling system. Similarly, the maximum efficiency of 0.31 was found for with cooling system for 686 W/m^2 radiation.

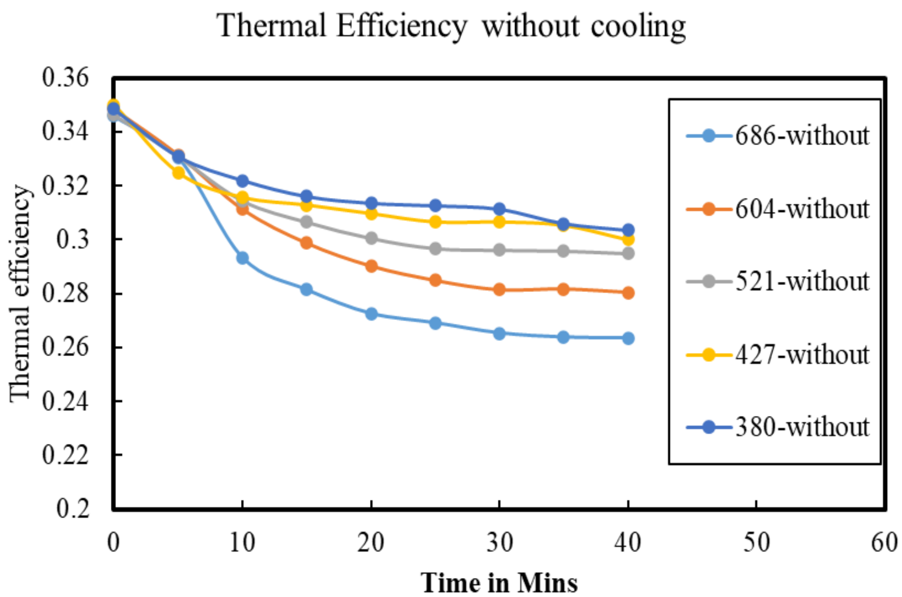


Figure 9 thermal efficiency plot with time for without cooling system and for different radiation intensity.

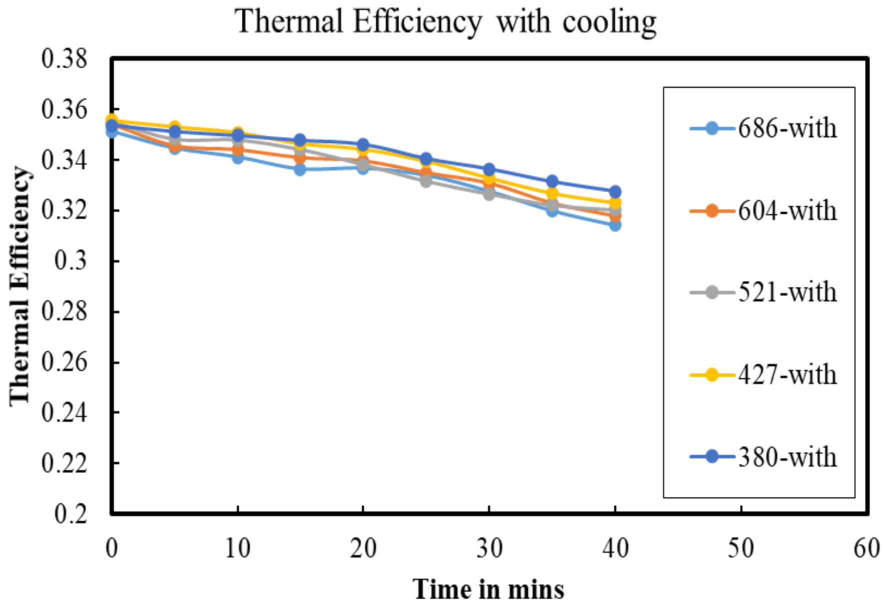


Figure 10 thermal efficiency plot with time for with cooling system and for different radiation intensity.

V. Conclusion

- The power generated from the solar PV panel is dependent on the temperature of the solar cell. The power generated is reduced with increase in solar cell.
- There is an effect on the temperature on the voltage of the panel. The voltage of the panel will decrease with increase in solar cell temperature.
- There is not a significant effect on the current of solar cell temperature.
- The maximum electrical efficiency was found 0.56 for without cooling system while it was 0.6 with cooling solar system. There is a 4% of rise of the efficiency with the addition of the PCM cooling.
- A thermal efficiency can be calculated and found maximum 0.26 for without cooling with highest temperature solar panel. Similarly, the maximum efficiency of 0.31 was found with cooling solar system.
- Hence, it is concluded that, solar PV panel can perform better with cooling system. The efficiency of the PV solar panel can be improved with the cooling system.

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