Performance's improvement methods of PV solar panel by different cooling systems: A review of Experimental and Numerical studies

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Hafid EL KHARAZ[1,a)], Kaoutar KHALLAKI[1, b)], M. Saddik KADIRI[1, c)], Khadija.CHOUKAIRY[1]

[1]*Process Engineering, Computer Science and Mathematics laboratory (LIPIM), National School of Applied Engineering-Khouribga, Sultan Moulay Slimane University.*

[a)] Corresponding author: hkharaz@gmail.com

[b)] k.khallaki@usms.ma

[c)]s.kadiri@usms.ma

Abstract. In order to enhance the performance of the PV solar panel, many studies was carried out. Several recent works of different cooling techniques using experimental and numerical methods are presented. Three materials are tested: Water, Air and Phase Change Material (PCM). PV, PVT (photovoltaic thermal) and CPV (concentrating photovoltaic) systems are cooled by passive and active cooling techniques. The effects of some structural parameters on PV cell temperature and electrical efficiency were studied and analyzed. The most important parameters are summarized on various solar irradiation, inlet air temperature, air mass flow rate, water mass flow rate, channel numbers, depth of the channel, wind speed, fins length, fins tilt, numbers of the fins, spacing between successive fins, fin thickness, container depth, Reynolds number and Prandlt number. The results showed that the photovoltaic performance enhanced when the cooling system is installed.

Keywords: photovoltaic panel, cooling, water, air, PCM, heat pipe, heat transfer, passive and active methods, heat exchanger.

INTRODUCTION

In the last years, many works became centered on researches about renewable energy sources and how could to improve its efficiency and to reduce energy production cost. One of those clean energy sources is photovoltaic cells. The PV is based on solar irradiance where it converts solar energy into electrical energy using semiconducting materials. It can use this kind of electrical energy in different domains, for example, to supply electricity to a smart grid system, to power water pumps in isolated farm fields, or to power residential in remote areas. Actually from 4% to 20% of the solar energy is converted to electricity and the rest is converted to heat [1]. It is able to be used in different fields, for heating and cooling Buildings, in the water heater, and it can be used to dry some foods. This heat surplus causes an increase in the temperature's PV surface which reduces the PV efficiency. Hence, when the surface temperature rises by 1°C the PV panel efficiency decreases by 0.5% [2]. The surface temperature increasing is related to external climate variables such as solar irradiation, wind speed, humidity, ambient temperature and accumulated dust on the PV surface.

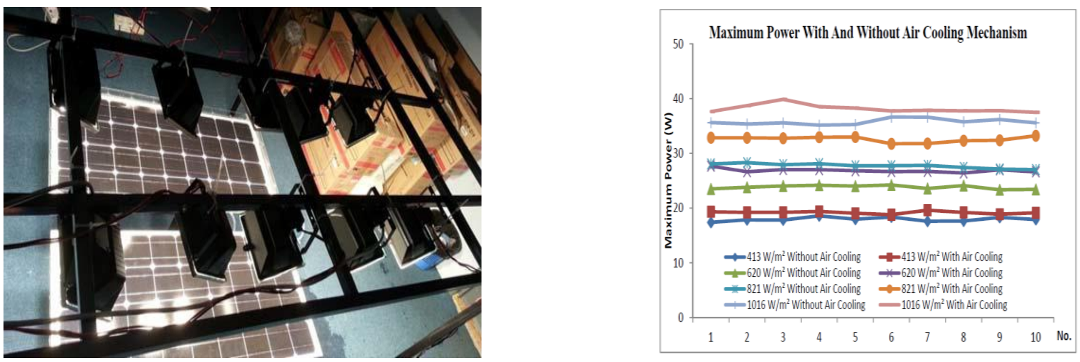
In order to enhance the performance of the photovoltaic by avoiding the problem of increasing the temperature, many cooling techniques were carried out and were reviewed in several works of literature. Zondag [3] made an exhaustive review on Flat-plate PV thermal collectors which were carried out over the last 30 years studies. Gilmore et al [4] studied the microchannel cooling methods of concentrator photovoltaic (CPV) at a solar concentration ratio of up to 2000 suns to 4000 suns (1 sun=1000 w/m²). Edaris et al [5] presented a review that covered different configurations and experimental designs of passive and active water cooling methods of Photovoltaic/Thermal (PV/T) and their performances in terms of electrical efficiency. Grubišić-Čabo et al [1] compared various cooling techniques such as passive and active cooling techniques, heat pipe cooling, nanofluids cooling and thermoelectric cooling.

In [2], [6] and [7], the highlights, contributions, advantages and disadvantages of different PV module cooling technologies were reviewed and discussed.

The purpose of this paper is to identify different cooling methods and results for existing project researches when using the water, air or PCM cooling systems and their effects on the PV pannel performances.

REVIEW OF AIR COOLING SYSTEMS

Irwan et al [8] used 20 halogen lamps of 500 W as a light source to manufacture a solar simulator (Figure 1a). The experiments were carried out to two units of the photovoltaic. They were tested under four sets uniformity of solar radiation, which are 413 W/m², 620 W/m², 821 W/m² and 1016 W/m². By using DC brushless fans installed at back surface of the panel, the experimental results were indicated that the operating temperature of the PV panel with air cooling system can be decreased by 2.56 °C from 37.09 °C to 39.65 °C under 413 W/m² of solar radiation. Similar results were found for the three solar radiations above. The average operating temperature with the air cooling system was reduced by 6% (from 56.4 °C to 53.11 °C) under 1016 W/m². Also, the same results were found for the average maximum voltage, current and power output of the PV panel. Thus, the maximum power output of the PV panel with the air cooling mechanism can be increased from 6% to 14 % when was measured below different solar radiation (Figure 1b).



(a) (b)

FIGURE 1. (a) PV panel cooling mechanism by using solar simulator. (b) The variation of maximum power of PV panel with and without air cooling mechanism [8].

Crăciunescu et al [9] realized experimental study to investigate the extracted heat from the air-cooled PV panel (BP SX 40U with the frontal area is 0.38 m^2). The results show that, in the absence of the air cooling system, the open circuit voltage of the PV panel decreasing (from 20.80 V to 19.33 V) and the PV panel average temperature increasing (from 35 °C to 52 °C), during 10 minutes and under 900 W/m^2. While, when the air cooling system was used, the open circuit voltage of the PV panel increasing (from 18.9 V to 19.65 V) and the PV panel average temperature decreasing (from almost 64 °C to 36 °C) in the same conditions.

Revati and Natarajan [10] made an experimental study to analyze the effect of the temperature on the solar cell's performance with three different conditions such as solar panel with air cooling, solar panel placed in a grass field and solar panel without cooling. Cell surface temperature, panel temperature, ambient temperature, open circuit voltage and short circuit current were presented. The authors observed that the high values open circuit voltage and short circuit current were achieved when air cooling was used. This is due to the panel temperature reduction. Also, the solar panel with air cooling give a substantial efficiency over the whole day (from 26.77% to 10.86% between 7 am and 5pm) that allows improving power generation (Figure 2).

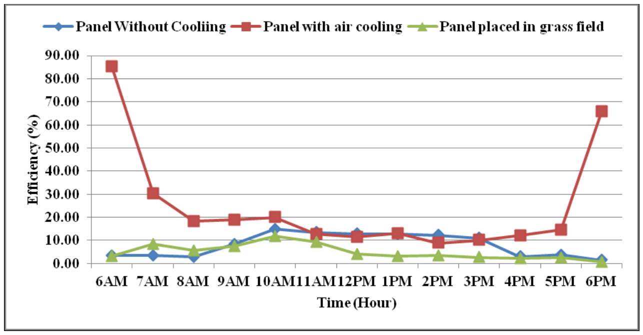
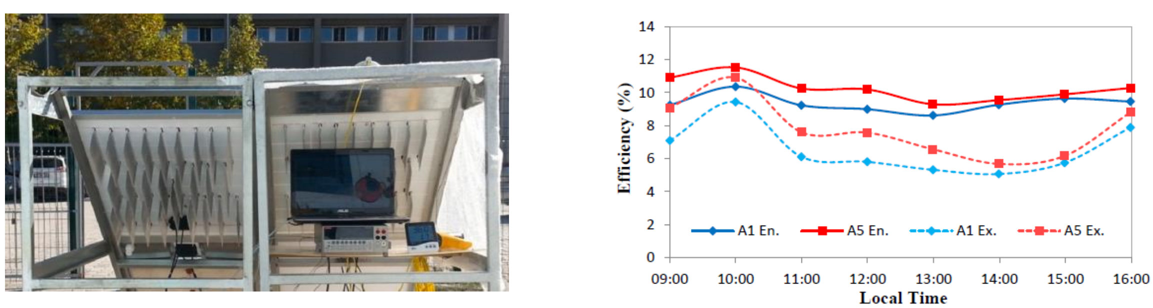


FIGURE 2. Comparative analysis of variation of efficiency with respect to time [10].

Amelia et al [11] realized a cooling system based on forced convection, controlled by fans attached at the back side of the photovoltaic. The fans are monitored by micro controller (PIC18F4550), which is depending on the average value of PV temperature. The experiments were evaluated four cooling mechanisms (PV panel with one, two, three and four units of fan) and compared them with the reference PV system (no cooling). They showed that the number of the fan for a PV panel depends on the total amount of heat needed to be removed, the size of the PV panel and ambient temperature. When it takes into account thermal and electrical results, two units fan PV panel is enough to get a good output performance.

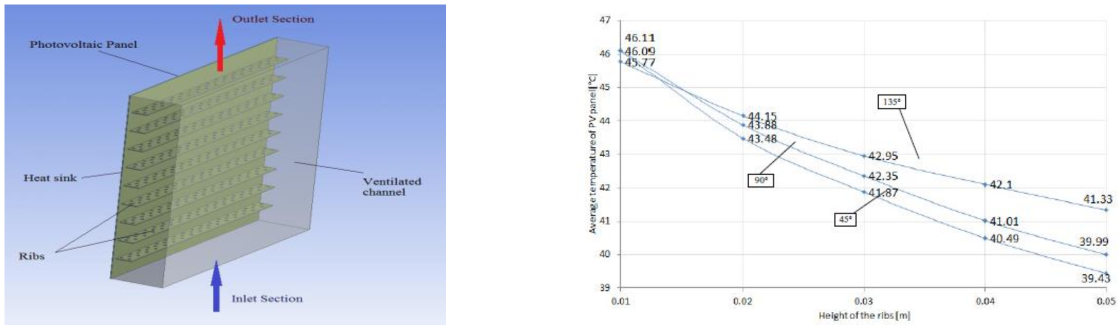
Bayrak et al [12] used an experimental study of the PV panels with polycrystalline cell structure of 75 W under Elazig, turkey climatic conditions. Aluminum fins were fabricated and ten different fin parameters A1-A10 (length, sequences) were installed at the back surface of the PV panel to analyze their effects on the PV system performance: temperature, power and efficiencies. They used 10 T-type thermocouples of OMEGA brand placed on the back surface of photovoltaic to determine the variations in temperature between the hot and cold spots. The cell temperature, output power, power loss ratios and exergy-energy efficiencies of the PV panel were calculated and presented during the day (from 09:00 am to 04:00 pm). The results show that the increases in the temperature value reduces the output power of the PV panel. As energy and exergy efficiencies are a function of power, the negative change in power negatively affects the efficiency values. The fin lengths and sequences have been tested and the results demonstrated that reducing the surface temperatures, increases the output power. The best results were noticed when the fins (A5) were used with the highest energy and exergy efficiencies values: 11.55 % and 10.91 % respectively.



(a) (b)

FIGURE 3. (a) A views of the experimental set-up, (b) Energy and exergy efficiency according to time of photovoltaic panels (A1:7 cm of size and 60 cm of length, A5: 7 cm of size and 20 cm of length) [12].

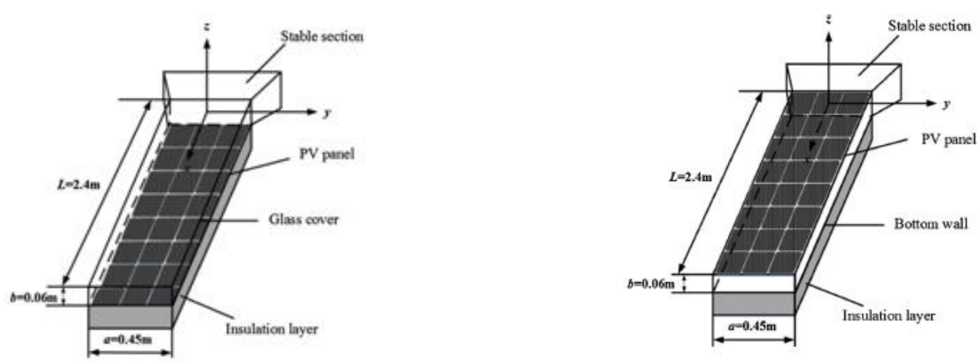
Popovici et al [13] presented a numerical approach for study the effect of air cooling heat sinks on the reduction of the PV panel's temperature. The heat sink designed as a copper ribbed wall with high thermal conductivity. It has circular holes of 0.003 m radius and 0.03 m of successive spacing. They studied the impact of different heights (from 0.01 to 0.05 m) and three angles (45°, 90°, 135°) of the ribs on the cooling efficiency of the heat sink. RNG k-ε model was used to simulate turbulent flow under ANSYS Fluent. The results show that the average temperature of the PV panel is decreasing with using a heat sink, even for small heights of the ribs and temperature is reduced with at least 10 °C below the value obtained in the basic case. The heat transfer and air flow were affected by the angle of the ribs. The raise of maximum power produced by photovoltaic panel is from 6.97% to 7.55% comparing to the base case, for ribs angles from 90° to 45° respectively. The maximum temperature achieves 61°C for the 135° angle while its is limited to 57°C for the other two angles. The angle of 45° gave a more important heat transfer.



(a) (b)

FIGURE 4. (a) Geometry of the studied model, (b) Variation of average temperature of PV panel depending on the ribs angle and heights [13].

Wu et al [14] conducted a 3D numerical method to study the effect of cooling channel position on thermoelectric performance and heat transfer characteristics above and below PV panel. A finite volume method (FVM) was used to solve the 3-D governing equations by means of Fluent software. Two case systems were studied under the same conditions: ambient temperature T_{amb}= 293.15 K, inlet air temperature (293.15 K–305.65 K), ambient wind velocity (0.5 m/s–3 m/s), inlet air velocity (0.93 m/s–3.33 m/s) and solar radiation intensity (300 W/m²–800 W/m²). The effect of those conditions on the PV average temperature $T_{pv,ave}$ and on the efficiencies (thermal efficiency η_{th}, average electrical efficiency $\eta_{e,ave}$, total energy efficiency η_{total}, and total exergy efficiency η_{ex}) of two case systems were presented (Table1). The results show that maximum total energy efficiency was obtained when the air inlet temperature was 298.15 K for case1 system and 295.65 K for case2 system. In terms of the amount of supplied energy, the case1 system is preferred.



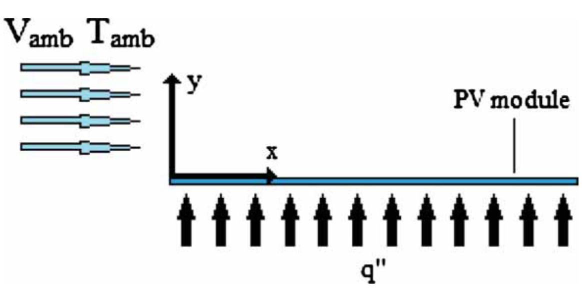
Case1: cooling channel above PV panel case2: cooling channel below PV panel

FIGURE 5. Physical models of air-cooled PV/T systems [14].

Cuce et al [15] realized a numerical and experimental studies to analyze the cooling effect on performance parameters of silicon solar cells. 12 tungsten-halogen bulbs with 12 KW of illumination system capacity were used as a light source as solar simulator. The experiments were carried out for four photovoltaic cell temperatures T_C from 15 to 45°C. They were conducted in a control room by air conditioning system. The results were validated by comparing with the standard test conditions (STCs) (G=1000 W/m^2 and T_C = 25 °C). The numerical study was conducted by varying velocities (from 1 m/s to 5 m/s) and air temperature (15 °C, 20 °C and 25 °C) using FLUENT 6.3. Experimental results indicated that the maximum power output, energy, exergy and power conversion efficiencies of the PV module decrease linearly with increasing PV cell temperature. The power output can be expressed by a linear function (P_m= 11.01 – 0.0387*TC). Numerical results showed that the case (T_{air}=15 °C, U_{air} = 5m/s) provides the best results in terms of performance. It achieved 3.22% comparing with the standard case (without cooling, Figure 6(b)).

Table 1. Effects of different parameters on the efficiencies of case1 and case2 systems [14].

Parameter	System	First law efficiency	Second law efficiency
Inlet temperature of air 290.65 K→303.15 K	case1	$\eta_{e,ave}$ (13.58%→13.04%) η_{th} (52.40%→33.07%) η_{total} (65.98%→46.11%)	η_{ex} attains a maximum value at Tin=298.15 K
	case2	$\eta_{e,ave}$ (14.77%→14.49%) η_{th} (23.90%→5.80%) η_{total} (38.67%→20.26%)	η_{ex} attains a maximum value at Tin=295.65 K
Inlet velocity of air 0.93 m/s→2.93 m/s	case1	$\eta_{e,ave}$ (13.26%→13.97%) η_{th} (40.80%→50.30%) η_{total} (54.05%→64.27%)	η_{ex} (15.80%→16.30%)
	case2	$\eta_{e,ave}$ (14.60%→14.71%) η_{th} (13.04%→19.60%) η_{total} (27.64%→34.31%)	η_{ex} (16.00%→16.20%)
Solar radiation intensity 300 W/m2→700 W/m2	case1	$\eta_{e,ave}$ (13.73%→11.90%) η_{th} (36.12%→46.15%) η_{total} (49.85%→58.04%)	η_{ex} (15.88%→15.45%)
	case2	$\eta_{e,ave}$ (14.81%→13.97%) η_{th} (8.10%→19.35%) η_{total} (22.92%→33.32%)	η_{ex} (16.06%→15.66%)
Ambient wind velocity 0.5 m/s→3 m/s	case1	$\eta_{e,ave}$ (13.24%→13.30%) η_{th} (41.98%→37.55%) η_{total} (55.21%→50.85%)	η_{ex} (15.85%→15.66%)
	case2	ηe,ave (14.53%→14.78%) ηth (15.20%→7.05%) ηtotal (29.74%→21.83%)	ηex (15.98%→16.01%)



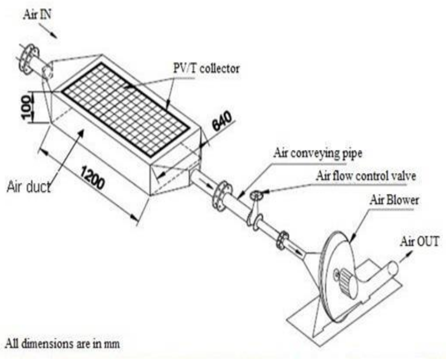
(a)

	U_{air} (m/s)	η_e	η_{pc}	η_{ex}	P_m
T_{air} = 15 (°C)	1	18.34	14.94	11.62	9.34
	2	18.46	15.21	12.01	9.65
	3	18.52	15.34	12.18	9.79
	4	18.55	15.41	12.29	9.87
	5	18.57	15.46	12.36	9.93
T_{air} = 20 (°C)	1	18.26	14.77	11.38	9.15
	2	18.38	15.04	11.77	9.46
	3	18.44	15.16	11.94	9.59
	4	18.47	15.24	12.05	9.68
	5	18.49	15.29	12.12	9.73
T_{air} = 25 (°C)	1	18.18	14.60	11.14	8.95
	2	18.30	14.87	11.52	9.26
	3	18.36	14.99	11.70	9.40
	4	18.39	15.07	11.80	9.48
	5	18.41	15.12	11.87	9.54
Without cooling		17.99	14.02	10.32	8.30

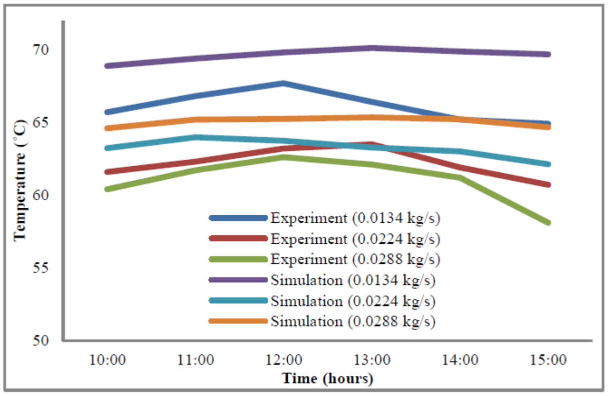
(b)

FIGURE 6. (a) Problem specification. (b) Variation of the maximum power output P_m, the energy η_e, power conversion η_{pc} and exergy η_{ex} efficiencies of the photovoltaic module with cooling conditions [15].

Michael et al [16] realized experimental and numerical studies of a solar PV/T air collector installed under PV system. The solar radiation was measured using a solar power meter (Tenmars TM207). They tested three different flow rate (0.134kg/s, 0.224kg/s and 0.288 kg/s) in turbulent region (Re>2300) on the roof-top. The flow velocity of air was created by a ventilator powered by the photovoltaic module itself. Numerical study was carried out by using ANSYS Fluent for flow analysis and using CATIA for CAD modeling. Experimental and numerical results show the same temperature profiles regarding to flow rate evolution. When the flow rate increases, the temperature decreases. (Figure7b). The average temperature gaps were found between 5°C and 9°C for tested flow rates, whereas the temperature experimental results were less compared to the obtained numerical results.



(a)



(b)

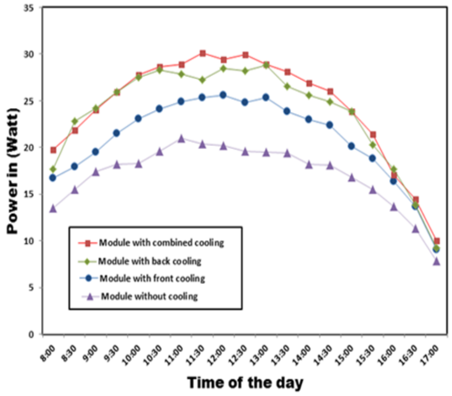
FIGURE 7. (a) Schematic diagram, (b) Top glass surface temperature of the PV/T collector [16].

Amanlou et al [17] realized numerical and experimental studies for eight different geometries of diffuser. The numerical study was conducted by using computational fluid dynamics (CFD). The effect of air flow rate (0.008 Kg/s, 0.012 Kg/s, and 0.016 Kg/s) on the thermal, electrical, and overall performances of PV systems (with and without concentrator) were experimentally measured. Thus, the results showed that by increasing air flow rate from 0.008 Kg/S to 0.016 Kg/s; the electrical, thermal and overall efficiencies were improved by 13.5%, 22.75% and 22.41% respectively. Also, the electrical efficiency of the PV/T collector was improved by 20% when the new diffuser (three deflectors and concave side walls) was used. Also, using the concentrator, electrical, thermal and overall efficiency were improved by 36%, 42.2% and 40.5% respectively.

REVIEW OF WATER COOLING SYSTEMS

Abdellatif et al [18] realized an experimental study to investigate three cooling techniques for photovoltaic. The first is cooling with film water over the front surface where they found the PV surface temperature decreased to 16°C. The second is cooling with direct contact back water. They found the PV surface temperature decreased to 18°C. The third is combining between film and back cooling, they found the PV surface temperature decreased to 25°C. The experimental results were taken by infrared camera. It was shown that the daily output power of the PV cooling module increased up to 22 %, 29.8% and 35% for film cooling, back cooling and combined film – back cooling module, respectively compared to non-cooling module.

(a)



(b)

FIGURE 8. (a) View of PV module with water film cooling system, (b) Comparison of output power of the PV-module for three cooling models [18].

Jailany et al [19] conducted an experimental study to analyze a forced-water spraying method and cooling technique with a variable flow rate of water on the front surface of the PV panels. Four modules of photovoltaic were used, two modules with air cooling and the other two models with water cooling. The impact of the difference flow rate of water on performance ratio and the net power saving was studied and displayed. The maximum flow rate of 0.022 l/min was obtained by using a DC pump (12 volts and 3 Amp). By comparing air cooling with water cooling of the PV panel, the results showed that solar cell temperature decreased by 9.07°C when water cooling was used. Also, the power gain and efficiency increased to 9.27% and 0.71% respectively for one day.

Table 2. Summary of average output power and temperature [19].

Average	**Modules**				**Results**
	Cooling with air		**Cooling with water**		
	1	2	3	4	
Power, volt	17.59	17.39	19.27	19.16	% increasing in voltage = 9.89%
	Average = 17.49 volt		Average = 19.22 volt		
Temperature °C	38.20	41.46	31.18	30.33	% decreasing in Temperature = 22.77%
	Average =39.83 °C		Average =30.76°C		

Han et al [20] used a 3D method to simulate the direct liquid immersion for linear trough CPV (concentrating photovoltaic) and hybrid CPV-T (concentrating photovoltaic thermal) systems by using FLUENT software. The authors studied numerically the effect of fluid flow characteristics, the optical concentration ratio (CR=57 suns, 47 suns, 37 suns), the fluid inlet velocity (flow rate are 0.22 kg/s, 0.28 Kg/s and 0.33 Kg/s) and the fluid inlet temperature (293 K, 298 K and 303 K) on cell temperature, in order to achieve low and uniform cell temperature. De-ionized water (DI) and four organic liquids such as Dimethyl silicon oil, glycerin, isopropyl alcohol (IPA) and ethyl acetate were selected and tested. The DI water was chosen due to its higher thermal conductivity and good optical properties. They found as preliminary results that the short circuit current (Isc) of the bare cell decreased by 3.2% after 112 days of the DI water immersion at room temperature, caused by corrosion deposition on the cell surface. Also, the results showed that the solar cell temperature increased directly linear and the inlet fluid temperature should be maintained as low as possible in order to maximise electrical conversion efficiencies of CPV.

Syafigah et al [21] conducted two numerical studies to examine and discuss the PV panel with both air and water cooling system. The air cooling system was installed at the rear side of the PV panel used 2 units of DC fan to create a wind speed of 3.07 m/s. And, the water cooling system was installed at the front surface of the PV panel. The water mass flow rate utilized was of 0.0556 Kg/s. The geometry model was designed by SOLIDWORK and thermal and electrical performances was analyzed using ANSYS CFX and PSPICE respectively. The results showed that the highest temperature and the output power generated of the PV panel are 66.3 °C and 66.9 W respectively. When the air cooling was installed the temperature decreased to 53.6 °C and the output power increased to 71.13 W. By using the water cooling system, the temperature and the output power achieved to 31.5 °C and 78.5 W. After the take into account the power consumption by the cooling system the percentage of net output power saving is 3% and 14% for the air and water cooling respectively.

Nahar et al [22] used COMSOL Multiphysics software for numerical study of heat transfer on absorber-plate system under the photovoltaic thermal (PV/T). The effect of irradiation level (from 200 to 1000 W/m^2), depth of the flow channel (0.02, 0.015, 0.01 m) and different flow parameters such as Reynolds number (from 200 to 1600) and Prandtl number (from 4 to 6.5) on heat transfer and electrical performance were studied and developed. The results displayed that PV/T electrical and thermal efficiency increased with both of Re and Pr number. By increasing Re number and channel depth respectively, the heat transfer rate increased to 25.5% and cell temperature reduce to10.2°C.

Baloch el al [23] used an experimental and numerical investigation in a converging channel cooling planned to achieve low and uniform temperature on the surface of the PV panel. The experimental study for an uncooled PV system and converging channel cooled PV system was realized under the hot climate of Saudi Arabia for the month of June and December. The numerical study was used to analyze the effect of changing the converging angle ϕ (0, 1, 2, 3, 4, 5, and 10°) on the thermal characteristics of the PV system. By comparing with a standard deviation, the best performance in terms of temperature distribution and average cell temperature attained to 0.91 °C when the two degrees angle was used. The results showed that maximum percentage of improvement in output power was 35.5% whereas the maximum percentage increase in the conversion efficiency was 36.1% when compared to the performance of an uncooled PV system. Also, they showed that by employing converging cooling, cell temperature was reduced significantly from 71.2 to 45.1 °C for June and from 48.3 to 36.4 °C for December.

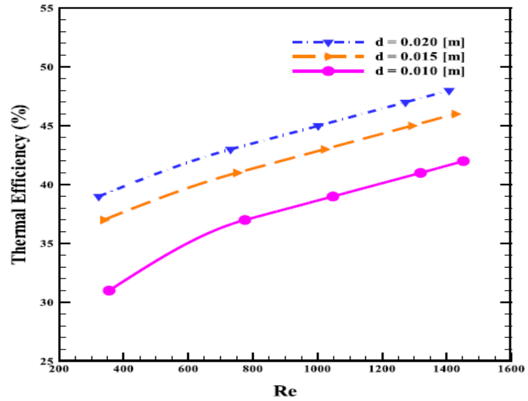


FIGURE 9. Effect of Reynolds number on PVT thermal efficiency (R= 1KW/m^2, T_{in} = 25 °C, T_{amb} =25 °C) [22].

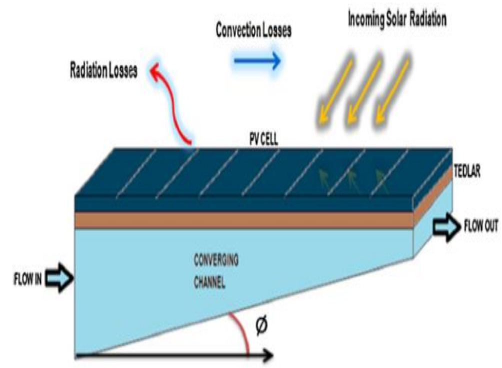
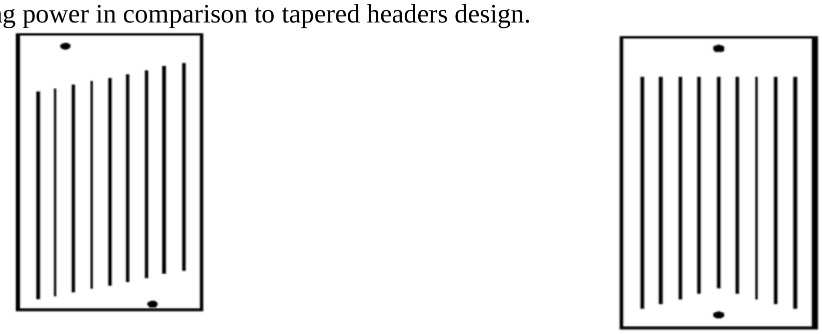


FIGURE 10. Schematic of converging channel heat exchanger with heat transfer modes [23].

Ben cheikh et al [24] used the COMSOL environment to realize a 3D model of PV collector with FEM approach to analyze electrical and thermal behaviors for an absorber integrated at PV back. The influence of the mass flow rate (from 0.0001 to 0.4 Kg/s) on the cell temperature and the electrical energy was studied and analyzed numerically and experimentally. The results show that when the mass flow rate increased the PVT collector temperature decreased and led to an increase in electrical energy. It was found that the PV temperature and electrical power achieved to 23.845°C and 59.434 W respectively when the mass flow rate reached 0.0256 Kg/s.

Siddiqui et al [25] created a novel heat exchanger to decrease cell temperature and uniform cooling of photovoltaic. The impact of the heat exchanger design on PV performance for each of the fourteen cooling models was presented. They used an analytical model validation, CFD model and experimental validations to select the best channel layout and the optimized designs. The impact of different heat exchanger parameters such as channel numbers (10, 18 and 20), manifold width, the location of inlet/outlet ports (corner, center and offset toward center) and tapered channels on the PV panel performance was studied and analyzed in the fourteen designs. The non-uniformity temperature for PV module, cooling quality, top surface average temperature and the heat transfer per unit pumping power measured the performance of the photovoltaic model. The authors found as results that the V-shaped heat exchanger has a lower average temperature, smaller hotspots and lower pumping power. The V-shaped design had 5.5% better heat transfer per unit of pumping power in comparison to tapered headers design.



(a) (b)

FIGURE 11. Two optimized heat exchanger channel layout designs, (a) with tapered headers and (b) with centered inlet and outlet and V-shaped outlet header [25].

REVIEW OF PCM COOLING SYSTEMS

Tan et al [26] used an experimental study to assess the electrical and thermal performance of the photovoltaic system by comparing the latent heat-cooled PV panel with a naturally-cooled panel by the surrounding air. In this work, the non-corrosive paraffin wax RT27 PCM was used as latent heat thermal energy storage (LHTES) installed at back side of the PV panel. The PCMTS (phase change material thermal storage) consisted of a simple rectangular container of aluminum filled with PCM. The impact of different numbers of metallic fins (0, 3, 6 and 12 fins) on heat transfer performance was compared and analyzed. The results indicate that the maximum temperature difference achieved to 15 °C when comparing the 12-fin PV-PCM panel with that of the natural-cooled panel. The temperature gaps were 13 °C, 10 °C and 5 °C according to 6-fin, 3-fin and finless PV-PCM panels respectively. Similar results were obtained, for the output power, it was achieved to 19.14 W with the PCM container of 12-fin while it was 18.16W in the naturally cooled panel. Also, the maximum electrical efficiency of 5.39 %, 4.44 %, 2.92 % and 1 % was achieved by using the PCM-cooled of 12-fin, 6-fin, 3-fin and finless PV-PCM panels respectively.

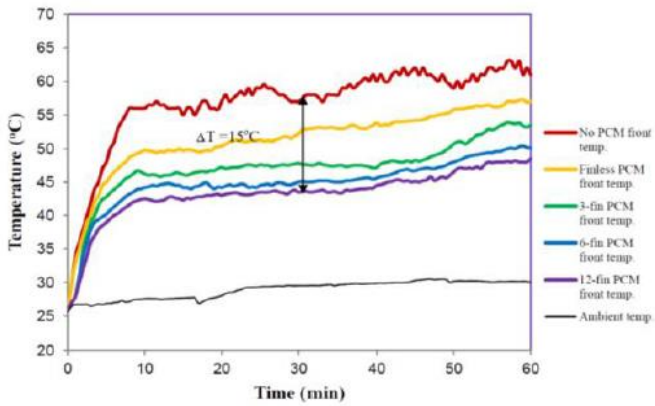


FIGURE 12. PV frontal panel temperature of respective PCMTS configuration [26].

Choubineh et al [27] realized an experimental study to evaluate the effect of using PCM on the performance of an air cooling system installed on the back side of the PV panel. They placed several sensors and K-type thermocouples to measure the temperature of different components at different locations including air inlet and outlet, PV panel, ambient air and surfaces of absorber plate and PCM pack. Four cases were experimentally tested, the first case concerned by natural convection and the other three cases regard three different forced air convection (high velocity=1.25m/s, medium velocity = 0.95 m/s and low velocity = 0.75 m/s). The results showed that the panel temperature was reduced to 4.3 °C in average natural flow mode, 3.4 °C for forced high velocity, 3.6 °C for medium velocity and 3.7 °C for low velocity. The authors concluded that PCM's using leads to an important increase in natural and forced convection situations with 9% increase, at least, in the electrical efficiency of PV panel.

Nehari et al [28] used RT25 PCM attached at the rear side of the PV system to control the temperature of the PV cell. They used a 2D numerical study for simulation by using the FLUENT 6.3 software. An extended fins surface was used to enhance conductive heat transfer and boost the thermal homogeneity (Figure13). The results showed that the fins reduce the temperature, and the configuration of L=25mm, 30mm, and 35mm let better cooling of the panel.

Benlekkam et al [29] realized numerical study to assess the thermal control of the PV panel by using PCM with the inner fins. They used a 2D model of heat transfer to solve Navier-stokes equation by the finite volume method (FVM) by using the FLUENT software. The Effect of the fins tilt (0°, 5°, 10°, 15°, 20°, 25°, 30°, 35° and 45°) on heat transfer was analyzed during 200 minutes. The results showed that the change of the fins tilt was able to improve the thermal performance of the PV system compared with straight fins. The temperature difference achieved to 1.5 °C and 3°C when comparing the system of 25° with the systems of 0 ° after 100 minutes and 175 minutes respectively.

Khanna et al [30] studied the optimization of finned-PV-PCM system by using ANSYS FLUENT 17.1. They conducted the numerical study for three types of systems, the first consists of PV panel with RT25HC PCM container attached at the rear side of the panel, the second consists of PV with PCM and inner fins of the aluminum and the last consists of PV without inner fins and without PCM. For different total solar irradiance level (2, 3, 4, 5, 6 KWh/m^2/day), the most appropriate depth δ (2, 2.2, 2.4, 2.6, 2.8, 3, 3.2 cm) of PCM container, fin thickness (0, 1, 2, 3, 4 mm) and fin length (0, δ/3, 2δ/3, δ) has been studied to keep PV temperature low during the operation. Also, they calculated the best fin dimensions. The results show that the most appropriate depth of PCM container is 2.8 cm and 4.6 cm for total irradiance $\sum I_T$=3 KWh/m^2/day and $\sum I_T$=5 KWh/m^2/day respectively. As well and the best spacing between successive fins is 25 cm, the best fin thickness is 2 mm, and the best fin length is the one when it touches the bottom of the container. For PV-PCM without fins the most appropriate depth of PCM container is 2.3 cm and 3.9 cm for $\sum I_T$=3 KWh/m^2/day and $\sum I_T$=5 KWh/m^2/day respectively.

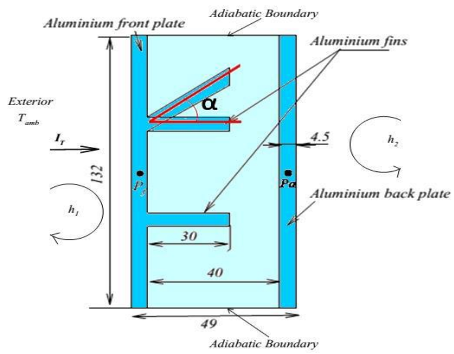


FIGURE 13. Presentation of the PV/ PCM system (dimension to mm) [29].

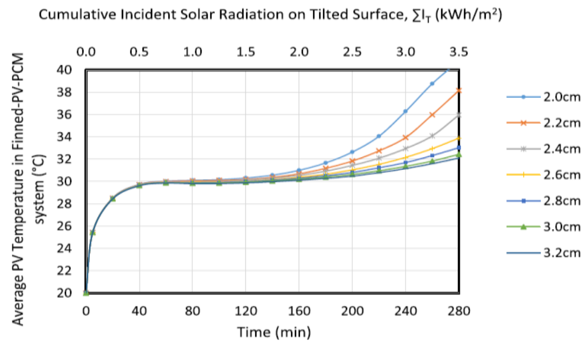


FIGURE 14. PV temperature in Finned-PV-PCM system for various spacings between successive fins [30].

Nasef et al [31] integrated an active and passive cooling by using PCM and nanofluid of concentrated photovoltaic solar cells. This study combine between a heat storage battery of phase change material and a closed-loop water cooling system to analyze PV panel efficiency. Two models were developed, modeled and solved numerically by using ANSYS FLUENT 17.2 software. The first model is the integration between the CPV layers and closed loop water with PCM plates. The second model is the direct contact between the CPV layers and PCM. Results were compared with experimental data noted in another literature. The effects of different arrangements of the PCM plates in the water tank on the system performance have been studied. The results showed that the system performance was enhanced when the nanofluid was used as heat transfer fluid (HTF). By comparing with the conventional direct PCM-PV and water-cooling individual system, the new system achieved 60% reduction in the CPV average temperature. At 10 concentration ratio (CR) and 0.01m/s HTF velocity, the cell temperature did not exceed 78°C. The impact of the arrangement of the PCM plates on the system was negligible. Also, using the nanofluid increases the CPV efficiency by 27% and reduces the PV maximum temperature by 4 °C and the PCM melting time by 12%.

Stroponik et al [32] realized a numerical and experimental study to increase electrical efficiency and output power of the photovoltaic panel. The numerical setup was studied to simulate the heat extraction from the PV panel by using TRNSYS software with type 601. Measurements used three thermocouples to take the temperature of two points on the front of the panels (with and without PCM) and the surrounding air temperature behind the panels. They used 35 mm of Phase change material RT28HC at the rear side of PV panel temperature. The experimental and numerical results of the conventional PV panel temperature with and without PCM were given and compared. The experimental results showed that the maximum temperature's difference on the surface of the PV panel achieved to 35.6 °C when comparing to the PV system with and without PCM for one day. Comparing to the reference PV panel in one year for Ljubljana city, the simulation shows that the electrical production was improved by 7.3% for PCM cooling panel.

Kawtharani et al [33] used a numerical and experimental study to evaluate a PCM model and to study its properties and capacity of absorption waste heat. The organic fatty acid PCM used on back side of the PV panel is Decanoic acid. The numerical temperature variations of the PCM and PV panel with and without PCM were obtained by using MATLAB. The results showed that around 13 % of the PV panel output power energy could be saved when the organic PCM was used. Another results can obtained from Figure 16, the temperature gradient was almost 10°C after 400 seconds and was almost 20°C after 1200 seconds between with and without PCM cases.

Hassan et al [34] utilized a numerical and experimental study to identify an optimum PCM melting point in extremely hot environmental of United Arab Emirates (UAE) with the help of the historical weather data. To assess the PCM energy saving performance throughout the year, the paraffin wax RT42 was used. A 2D heat transfer model was employed to simulate numerically the cooling of the PV panel. A Conjugate heat transfer model using enthalpy based formulation is developed and validated with the experimental data. The model was used to predict solidification fractions and melting in each month of the year. It is observed that the PCM shows variant performance in different months of the year. The higher average temperature drop of 6 °C in April compared to that of 2.3°C in June. Also, the PV annual electrical energy was increased by 5.9 % in the hot climatic conditions.

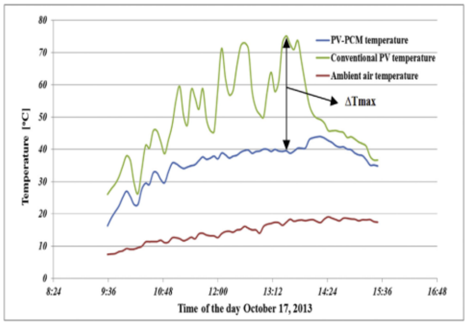


FIGURE 15. Temperature of the conventional PV panel, PV-PCM panel and ambient air temperature [32].

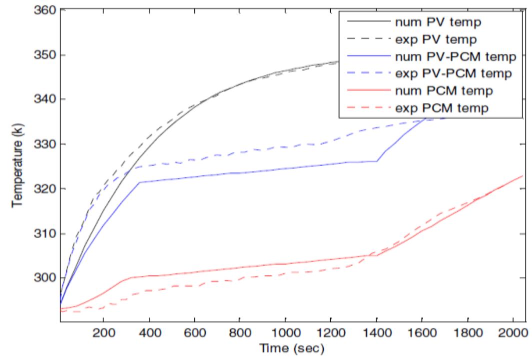


FIGURE 16. Numerical and experimental temperature variations for PCM and PV panel with and without PCM [33].

Rabie et al [35] realized an experimental and numerical studies to investigate the influence of the over height ratio (0, 20, 40 and 60%) between the height length of the RT35HC-PCM heat sink to the solar cell length, allthought the inclination angle effect of the PCM heat sink (-45°, 0° and 45°) on the temperature distribution along the solar cell under solar radiation concentrated ratio (CR=5 and 10). The numerical study was conducted in 2D model using ANSYS FLUENT 17.2 software. Results are validated with experimental measurements. Also, the evolution of the solid-liquid interface and PCM melting were experimentally carried out at different times and for different inclinations above at a heat flux of 3000W/m^2 and T_{amb}=25°C. The results showed that the increasing the over height ratio reduces the solar cell maximum temperature and improves temperature uniformity due to the remarkable enhancement of natural convection current in the PCM enclosure. They found that the peak cell temperature reduces from 92 °C to 74 °C, and the temperature uniformity varies from 13.7 °C to 5.3 °C when the over height ratio rises from 0 % to 60 % at a solar concentration ratio of 5 and PCM heat sink inclination angle of −45°.

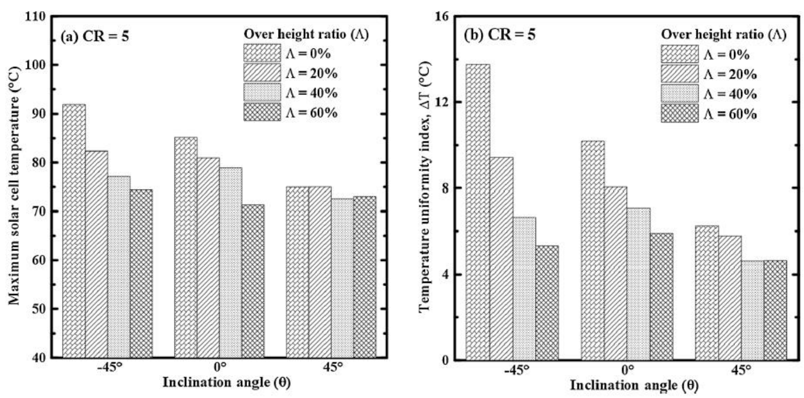


FIGURE 17. Variation of the maximum temperature and temperature uniformity index versus the inclination angle of CPV-PCM system at CR=5 suns [35].

CONCLUSION

This paper summaries several works of cooling techniques which has been carried out experimentally and numerically. It was noted that the photovoltaic performance improved in terms electrical output by decreasing the surface temperature which led to reduce the rate of cell degradation and maximize the life span of the photovoltaic panel. Many Devices were used to conduct measurements such as fans, pumps, infrared camera, solar power meter and thermocouples. Also, many analysis tools were used for numerical studies such as ANSYS FLUENT, TRNSYS, CATIA, SOLIDWORK, COMSOL Multiphysics, MATLAB and PSPICE.

The highlighted main results were:

- For the air cooling system, the maximum power output, energy, exergy and power conversion efficiencies of the PV module decrease linearly with increasing PV cell temperature. When the airflow rate increases, the temperature of the PV panel decreases. Nevertheless, as the performance doesn't increase automatically with increasing airflow rate, it is important to determine an optimum for the air flow rate in order to insure a good performances enhancement.
- For the water cooling system, the impact of the difference flow rate of water on performance ratio and the net power show a better result comparing to the air cooling system. Also, it was remarked that the cell temperature was reduced significantly by combining film water on front surface with direct contact back water cooling module.
- The photovoltaic thermal electrical and thermal efficiency increased with both of Reynolds and Prandtl numbers. By increasing Re number and channel depth, the heat transfer rate increased and cell temperature reduced.
- Under the hot climate, a converging channel cooled PV system leads to the best improvement of temperature distribution, output power and conversion efficiency when compared to the performance of an uncooled PV system.
- For the PCM cooling system, the PV panel temperature was reduced thanks to the latent heat thermal energy storage. PCM's using leads to an important increase of electrical efficiency of PV panel in natural and forced convection situations.
- The maximum electrical efficiency was achieved by using finned PCM-cooling system. The change of the fins tilt improves the thermal performance of the PV system compared to straight fins.

This review allows us to suggest other fields of research to be developed. In the majority of the cited works, the analysis of the flow topology and its influence on heat transfer have not been studied. The knowledge of coexisting physical phenomena and the combination of hydrodynamic and thermal effects during cooling processes will lead to a good understanding of the mechanisms influencing the improvement of the PV solar panels performances [36]. And this, for all the studied configurations and fluids.

The exploitation of the thermoelectric method to generate electricity and its integration in the different cooling processes could be an interesting approach to develop innovative solutions [37].

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