A Novel Review on Nano-fluid and Phase Change Material based Photovoltaic Thermal (PV/T) Systems

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Abstract. In this paper, advanced researches on photovoltaic thermal systems are reviewed. First, the PV/T concept and its advantageous and disadvantageous are mentioned. Then the latest innovations for improving the performance of PV/T systems such as applying Nano-fluid and Phase Change Material (PCM) and also hybrid-Nano-fluid are discussed. The results of numerical, energy, exergy and experimental studies in this issue have been considered. Investigations show that the utilization of Nano-fluid and PCM improve the thermal efficiency of the PV/T systems and reduce the consumption of fossil fuels.

1. Introduction
The increase in Carbon Dioxide (CO₂) emission due to human activities and the burning of fossil fuels has led to global warming and environmental pollution for the last few decades, on the other side the global demand of energy has been greatly increased after industrial reformation [1-2].

All types of energies are fundamental and crucial for the life of human and its utilization is extended as shown in figure 1 [3]. Based on the record of international energy outlook (IEO) the Energy Information Administration (EIA) projects that the energy demand globally will mount by 44% from 2006 to 2030 [4].

The reduced availability of non-renewable resources and the damaging effects of CO₂ emission in the environment are causing exploration for renewable energy. Consequently, harvesting renewable energies generally and especially solar energy is a tempting option and gives one of the best choices for meeting the energy demand in a clean way. [1-2].
Iraq is predicted to be one of the richest countries in renewable energy resources, especially in solar energy as shown in figure 2. However, as shown in figure 3, it is suffering from shortage of electrical power because of the growing demand. Therefore, it becomes necessary to rely on solar energy to generate electrical power by using photovoltaic cell (PV) to meet this need [5].

Figure 1. World energy consumption [3].

Figure 2. Iraq solar irradiation [6].
Figure 3. Comparison between electricity production and demand in Iraq [7].

Thermal systems have been investigated by numerous scientists experimentally and numerically because of the great importance of these systems in many mechanical and electrical engineering applications. Previous works in this paper are classified into three groups:
- Review on PV/T system cooled by Nano-fluids,
- Review on PV/T system cooled by PCM material,
- Review on PV/T system cooled by Hybrid Nano-fluids.

2. Photovoltaic Thermal (PV/T) system

2.1. Concept of Photovoltaic Thermal (PV/T) system

Photovoltaic Thermal system is an interesting solar technology. By utilizing different methods, heat is extracted from this system and the heat is used as thermal energy as shown in figure 4 [8].

![Concept of PV/T system](image)

Figure 4. Concept of PV/T system [8].

The idea of photovoltaic system, first time was introduced in twentieth century by Martin Wolf [9]. To extract the heat from the PV modules, water and air were used extensively in the beginning. The concept of PV/T systems is almost five decades old, but still, the technology is not much commercialized.

The performance evaluation of PV/T system depends on the efficiency. The total efficiency of PV/T is the algebraic sum of the electrical efficiency ($\eta_{el}$) and thermal efficiency ($\eta_{th}$) [2]:

$$\eta_T = \eta_{th} + \eta_{el}$$  \hspace{1cm} (1)

Thermal efficiency is assessed by:

$$\eta_{th} = \frac{Q_u}{(G_r A_e)}$$  \hspace{1cm} (2)

Relation for usable heat collected, $Q_u$ is:

$$Q_u = m \cdot c_p \cdot (T_{out} - T_{in})$$  \hspace{1cm} (3)

The power generation from PV/T depends on the specification of the cell. Output power can be determined by the equation [10]:

$$P = \frac{V_r I_r}{n}$$
\[ P_{PM} (W) = V_{mp} \times I_{mp} \]  

(4)

Where \( P_{PM} \) is maximum power and \( V_{mp} \) and \( I_{mp} \) are voltage and current at peak power point, respectively.

The \( \eta_{ele} \) of PV/T collector is calculated by:

\[ \eta_{ele} = \frac{P_{PM}}{(A \times G_T)} \]  

(5)

Where \( A \) is Area of the solar panel and \( G_T \) is irradiation collected by it.

2.2. The components of Photovoltaic Thermal (PV/T) collector

The components of a photovoltaic thermal collector are [11-12]:

I. PV module: different type of PV panels.
II. Absorber: joined to the PV module, usually made of a metal with great thermal conductivity like aluminum, copper, etc.
III. Connections: pipes or hoses are attached to the inlet and outlet connections which show the two ends of the flow tubes in which fluid is transferred.
IV. Insulator: the very important part, that is used to minimize heat losses and maximize performance of collector.
V. Framework: mostly is used to protect the various parts of PV/T and to keep them steadier.

The schematic of flat plate PV/T collector that used in present work is shown below:

![Figure 5. Components of the flat plate PV/T collector that used in present work [11].](image)

2.3. Classification of Photovoltaic Thermal (PV/T) systems

PV/T systems can be extensively categorized on different basis such as upcoming technology, system configuration, type of solar input, type of heat extraction and medium of heat extraction as shown in figure 6 [8].
2.4. Advantages and disadvantages of Photovoltaic Thermal (PV/T) systems

The main benefits of a PV/T system can be summarized as [9]:

- use of wider range of solar spectrum
- installation of hybrid system can reduce the price comparing to separate systems and also need lesser space
- construction is isolated more by using PV/T systems so thermal load reduces.
- Easy installation
- Simple maintenance requirements
- Lower operational cost and maintenance

The main disadvantages of a PV/T system can be summarized as [6]:

- Always there is a competition between increment of electrical efficiency and decrement of optical and thermal efficiency, as increasing thermal performance in most cases causes the decrease in electrical performance.
- The system incurs relatively high cost because yet it has not been adopted by consumers properly even though economic analysis doesn't remark this.
- PV systems have no noise and emissions and they are steady mechanically; that is not the case for PV/T systems [6].

3. Cooling techniques of Photovoltaic Thermal (PV/T)

Incident radiation and operating temperature of PV panel have the direct impact on the energy output of system. The operating temperature of panel should be kept at minimum temperature, which is Standard Test Condition, to maintain the efficiency. [3].

Diverse methods are employed for reducing the inappropriate temperature to attain the best performance. The cooling techniques can be classified base on various types of heat transfer (radiation, conduction, and convection)

In present paper, we will review different ways of improving the performance of PV/T such as using Nano-fluids and Phase Change Materials (PCM).

3.1. Cooling of Photovoltaic Thermal (PV/T) systems by Nano-fluids

Nano-fluids have caught the attention of scientists due to their high thermal capabilities to utilize in solar systems. The common types of Nano-fluids are SiO₂, Al₂O₃ and CuO as shown in figure 7 [14].
Figure 7. (a) Nano-fluid samples from PV/T system [13].

Hussien et al. [15] designed and implemented hybrid PV/T to study experimentally the improvement of the thermal and electrical efficiency by utilizing Al₂O₃-Water Nano-fluid with different concentration ratios in Iraq. Based on results, using Nano-fluid at various concentration ratios decreases the PV module temperature significantly (from 79.1 °C when using base fluid to 42.2 °C with 0.3% concentration ratio) and increases the solar panel efficiency. Although when concentration ratio increases more than 0.3%; panel temperature increases to (52.2 °C) and efficiency decreases.

Nano-particles of Fe₃O₄ in water as a base fluid has been experimented by Ghadiri et al. [16] in the sheet and tube PV/T system as shown in figure 8. The fluids considered in the experiment are distilled water and a Ferro fluid (Fe₃O₄-water) with 1% and 3% concentrations by weight (wt. %). The experiments were performed in indoor conditions under two constant solar radiations (1100 W/m² and 600 W/m²) using a solar simulator. The Ferro fluids in this paper have been studied in 3 cases, when magnetic field is constant and periodic and when there is not magnetic field. It is concluded that utilizing ferrofluid with periodic magnetic field gives the maximum efficiency comparing to other cases.

Figure 8. A schematic diagram of the experimental setup [16].
Copper Nano-particles in water, flowing in a PV/T collector, with glass and without glass, is studied experimentally by Michael and Iniyan [17] in India as shown in figure 9. The PV/T performance was tested using 0.05% volume fraction CuO/water Nano-fluid. Based on results, they concluded that the Nano-fluid has been proved to increase the thermal efficiency up to 45.76%, and they observed that the electrical and thermal efficiencies of the discussed solar photovoltaic/thermal collector can be further improved if the heat exchanger is re-designed for the new Nano-fluid.

Figure 9. The PV/T collector connected to the storage tank and the schematic diagram of the experimental setup [17].

Effects of utilizing different Nano-fluids in a PV/T collector, for Monastir, Mashhad and Lyon Cities respectively located in Tunisia, Iran and France, was studied experimentally and numerically by Rejeb et al. [18]. They utilized water and ethylene glycol as base fluid and aluminium oxide and copper as Nanoparticles and investigated their effects on thermal and electrical performance of the system. Based on their study; Cu-water is the best choice comparing to other combinations and electrical and thermal efficiency for Monastir is more than Lyon and Mashhad.

Likewise, Experimental and numerical investigation on using various Nano-fluids in PV/T sheet and tubes was carried out by Sardarabadi and Passandideh-Fard [19]. The considered Nano particles include Aluminium-oxide, Titanium-oxide and Zinc-oxide all dispersed in deionized water as base fluid, with 0.2% by weight (wt. %). They concluded that electrical performance of TiO$_2$-water and ZnO- water, and thermal performance of ZnO-water is better. As well, Al-Shamani et al. [20] investigated the effect of adding oxide and non-oxide Nano-particles to the pure water as working fluid of PV/T system under the Malaysia tropical climate conditions. They found that between all of the experimented Nano-fluids the SiC Nano-particles has the best result on overall system performance.

A novel method for cooling LCPV/T (low concentrated photovoltaic-thermal) system was presented by Radwan et al. [21]. The influence of Al$_2$O$_3$ and SiC on performance was studied and compared. Result shows that utilizing Nano-fluids at high concentration ratio in comparison to utilizing water causes a great decrease in the temperature of solar cell. SiC-water inures comparatively more decrease in solar cell temperature than Al$_2$O$_3$. By varying concentration ratio of Nano-fluids, effects of Nano-fluids on efficiency will change.

Nano-fluids also use in optical filter, Cu$_9$S$_5$-Oleylamine and Polypyrrole was used as such an application in a Fresnel lens CPV/T by An et al. [22] as shown in figure 10. Furthermore, they worked on water channels for decreasing the plates temperature and indicated that by using Nano-fluid in the optical filter, efficiency of system increases to 34.2%, that is 17.9% more than absence of filter. If Nano-fluid concentration increases, overall and electrical efficiency will be improved, but thermal efficiency will be decreased. presence of glass cover improves thermal efficiency and decreases electrical efficiency.
Soltani et al. [23] studied five different cooling methods of the PV/TE system, namely natural air cooling, forced air cooling, pure water cooling, water based SiO$_2$ Nano-fluid cooling, and water-based Fe$_3$O$_4$ Nano-fluid cooling experimentally in Iran. They proposed hybrid photovoltaic/ thermoelectric system in this work and compared with the conventional cooling method. The results showed the promise of SiO$_2$/water Nano-fluid cooling, which yielded the highest power and efficiency, showing 54.29% and 3.35% improvement, while Fe$_3$O$_4$/water Nano-fluid cooling showed 52.40% and 3.13% improvement in power production and efficiency respectively, comparing with the natural cooling method.

Lari et al. [24] designed in their study a PV/T system cooling by Nano-fluid to fulfil the electrical needs of a building for the weather of Dhahran, Saudi Arabia as shown in figure 11. They analysed daily and yearly performance by using EES software, then optimized collector design. They studied economic analysis to show the financial gains of the suggested system. They concluded thermal output increases 13% when Nano-fluid is used for cooling of PV/T system and the energy cost of this system is saved 82% compared to domestic price. Also, the system can obliterate a large amount of CO$_2$ (16,974.57 tonnes) emission to the atmosphere.
Al-Waeli et al. [25] added three Nanomaterials (Al₂O₃, CuO, and SiC) to water as a base fluid with several volume fractions in Malaysia. Comparatively, SiC has the maximum thermal conductivity and stability. thermal conductivity of CuO is higher than Al₂O₃ but it is less stable.

Yazdanifard et al. [26] vastly studied the effects of Nano-fluids parameters including volume fraction, size, type of base fluid and Nano-particle in photovoltaic-thermal collector. Based on the results the augmentation of Nano-particles improves the performance in both laminar and turbulent flow but the increment is higher in turbulent flow. It has been stated that the bigger the diameter of the Nano-particles, the higher the energy and exergy of flow for the turbulent flow, but an inverse behaviour is occurred in the laminar flow. additionally, when performance considered, aluminium oxide is more efficient than titanium and also Nano-fluids with water as a base fluid have better energy and exergy than other base fluid.

Al-Waeli [27] investigated the thermophysical properties of Nano-fluid composed of water and SiC Nano-particles without the use of a surfactant as a coolant for a PV/T system experimentally in Malaysia as shown in figure 12. An increase in the density, viscosity and thermal conductivity is observed by addition of these Nano-particles, for the specified temperature range. They tested stability and confirmed this Nano-fluid is stable for long time use. Also, the results showed that the use of 3 wt. % SiC Nano-fluid increased the electrical efficiency by up to 24.1% compared to the PV system alone, while the thermal efficiency increased by up to 100.19% compared to the use of water for cooling.
Figure 12. A schematic diagram of the experimental rig [27].

In Iran, the two-phase flow of aluminium oxide with methanol experimented in an array of thermosiphon in the PV/T system named TPCTs by Moradgholi et al. [28]. The researchers studied the effect of filling ratio and also Al₂O₃ Nano-particles concentration in the working fluid on electrical and thermal efficiency of the PV/T system. The optimum value of filling ratio and Nano-particles concentration respectively is 50% and 1.5 wt. % and at these conditions the temperature of panel is reduced by 14.52 °C and made 1.42W more electrical power output in comparison to equivalent ordinary PV panel. Some other optimum values also reported in the mentioned paper.

A numerical analysis on utilizing Al₂O₃-water in photovoltaic/thermal collector has been done through COMSOL software by Bianco et al. [29]. Two-dimensional Nano-fluids laminar convection flows was simulated for Reynolds number between 250 and 1000, concentration in the range of 0% and 6%, inlet temperatures of 293.15 K and 323 K and particles dimension of 20 and 40 nm in a nonsymmetric heated channel. The result shows that the wall temperature is reduced 3 to 5 degree when using 0–6% concentration of Al₂O₃ Nano-particles and leads to improvement of system performance.

An experimental research, on the TiO₂ and MWCNT effect on the photovoltaic-thermal system performance, was performed by Rukman et al. [31] as shown in figure 13. The study carried out under the condition of Malaysia. The researchers studied the effect of different concentration, mass flow rate (0.012 kg/s to 0.0255 kg/s) and solar radiation (500 W/m² to 900 W/m²). The lowest recorded temperature, when using TiO₂ in concentration of 1%, was 1.80 °C and 2.01 °C.
Figure 13. Setup of the Nano-fluids-based PV/T system under solar simulator: (a) top view of system, (b) top view of spiral absorber [30].

Comparison of Performance of Nanofluids [48]

| Author                  | Type of Nanofluids | Particle size, nm | Mass fraction, %wt | Results                                                                 |
|-------------------------|--------------------|-------------------|-------------------|-------------------------------------------------------------------------|
| Sardarabadi et al. [49] | SiO$_2$/water      | 11-14             | 1, 3              | For 1 %wt and 3 %wt energy efficiency increase up to 3.6% and 7.9%       |
|                         |                    |                   |                   | Total exergy increased by adding nanofluid                              |
| Ghadiri et al. [16]     | Fe$_3$O$_4$/water  | -                 | 1, 3              | For 3 %wt, the overall efficiency improved by 45%                       |
|                         |                    |                   |                   | When alternating magnetic field (50 Hz) is applied, overall efficiency   |
|                         |                    |                   |                   | increases up to 50%                                                    |
| Yun CHUI and Qunzhi ZHU | MgO/water          | 10                | 0.02, 0.06, 0.1   | Transmittance of nanofluids decreases when mass fraction and film      |
|                         |                    |                   |                   | thickness increase.                                                     |
|                         |                    |                   |                   | The overall efficiency of the PV/T system with a 2mm thick liquid layer |
|                         |                    |                   |                   | is beyond 60%                                                           |
| Jing et al. [51]        | SiO$_2$/water      | 5, 10, 25, 50     | 2 v% for 5 nm     | Transmittance of nanofluid with particle size of 5 nm and 2 v% ca be    |
|                         |                    |                   |                   | as high as 97% very close to pure water.                                |
|                         |                    |                   |                   | Thermal conductivity of nanofluid with smaller nanoparticles is greater  |
|                         |                    |                   |                   | than larger nanoparticles.                                              |
| Taylor et al. [52]      | Au, SiO$_2$, Al, Ag| 20-50             | 0.01 v%           | Volume fraction of 0.0011% is required to achieve optimum filters.      |

3.2. Cooling of Photovoltaic Thermal (PV/T) systems by hybrid-Nano-fluid

Gorji and Ranjbar [31] studied Nano-fluids containing different Nano-particles at the same volume fractions numerically and experimentally in Iran. They studied graphite, magnetite, and silver Nano-particles in deionized water as the absorbing medium in the flat-plate collector. They modified the surface of Nano-particles via the two-step method in order to increase the dispersion stability of the Nano-particles. They developed a 2-D CFD simulation model for solving equations of heat transfer and the radiative transfer in particulate media as shown in figure 14. Influence of solar flux intensity, Nano-particle concentration and flow rate on the thermal system performance was investigated. The results demonstrated that the outlet temperature of collector is improved when Nano-fluids is used and the higher value of the Nano-fluid volume fraction causes greater outlet temperatures at constant flow rate and solar flux. By increasing Nano-particle concentration and Nano-fluid flow rate, the thermal efficiency of collector increases, referring to their experiment.
Figure 14. Schematic model of formulation of Nano-fluid DASC (Direct Absorption Solar Collector) [31].

Gangadevi and Vinayagam [32] prepared three different volume concentrations (0.05, 0.1 and 0.2%) of Al₂O₃-water, CuO-water and Al₂O₃ CuO-water (50:50) Nano-fluids adopting a two-step Nano-fluid preparation method as shown in figure 15. They studied the influence of the average diameter, temperature and viscosity of Nano-fluids on the thermal, electrical and overall efficiency of PV/T system under India weather condition. Based on the experiment results, viscosity and thermal conductivity increases as the volume fraction increases, viscosity reduces as the temperature increases. At highest solar radiation for 0.2% volume concentration of the Hybrid-Nano-fluid the maximum thermal efficiency obtained is 82%, maximum electrical efficiency is 15% and the greatest overall efficiency is 97%.

Figure 15. Photograph of prepared CuO-water, Al₂O₃-water and CuO–Al₂O₃-water Nano-fluid [32].

Verma et al. [33] studied the effect of Hybrid-Nano-fluids on the performance of FPC experimentally in India. Hybrid of CuO and MgO with MWCNTs with water base was selected. They used concentration range of (0.25%-2.0%) and flow rate range of (0.5 lpm to 2.0 lpm) for Nano-fluids. The energy and exergy responses of FPC were observed quantitatively and qualitatively. According to their
results, the concentration of particles in range of 0.75–1.0% at mass flow rate 0.025–0.03 kg/s are the optimum operating conditions for FPC. Also, exergy and energy efficiency are 71.54% and 70.55% for MgO Hybrid-Nano-fluid and they found that the Hybrid-Nano-fluid Magnesium Oxide works better than other suggested fluids.

An experimental and computational study, to investigate the influence of hybrid-Nano-fluid on thermal, electrical and exergy efficiencies in Qatar, was conducted by Younis et al. [34]. Water, and Al₂O₃-ZnO-H₂O Nano-fluid mixed with Ethylene Glycol as surfactant were the experimented fluids. Mass fraction of Nanoparticles was 0.05 wt. % Aluminium oxide with particle size of 5nm and 0.05 wt. % Zinc oxide with particles size of 10-30 nm. The COMSOL Multiphysics was used for obtaining average temperature of PV surface. The comparison between water and the above-mentioned Nano-fluid as absorption medium, shows an increase in thermal and overall efficiency of the system for the Nano-fluid, despite taking concentrations of the Nanoparticles relatively low.

![Figure 1](image_url)

**Figure 16.** (a) Al₂O₃-ZnO distilled water with Ethylene Glycol Nano-fluid and (b) Photograph of solar PV/T collector set connected in series within a closed hydronic circuit at the Techno Hub facility, Gulf organization for research and development, Qatar [34].

### 3.3. Cooling of Photovoltaic Thermal (PV/T) systems by Phase Change Materials (PCMs)

PCM (Phase Change Material) has a high heat of fusion which boosts the substance to melt and solidify at melting point. These materials have the capacity to store and release energy. In integrated PV modules with high latent heat PCMs; when the charging process occurs, the panel temperature reduces and heat is also stored for other thermal usage. PCMs can sustain the needed temperature of photovoltaic module for a specified time.

In solid state of PCM, when it is heated the sensible heat is absorbed and after that its temperature increases from ambient temperature to attain its melting temperature. At a constant temperature during melting, PCM absorbs the latent heat. Then it melts completely and the temperature begins to mount as the sensible heat is absorbed by PCM in its liquid state in the final stage. There are many types of PCM like organics, inorganics and eutectics. A PV/T water collector with PCM is illustrated in figure 17.
The solar radiation conversion into thermal energy and energy storage into PCM in the PV/T collector was examined by Al-Imam et al. [35] as shown in figure 18. They used compound parabolic concentrator (CPC) mounted on PV/T collector in order to get better solar radiation satisfactory. The outdoor test was done in Bangladesh for comparing performance of system between a clear day and a semi-cloudy day in winter. They studied different parameters such as total heat loss, total useful energy, thermal efficiency and overall efficiency of the system. The researchers concluded that for a clear day all the mentioned parameters are higher than a semi-cloudy day.

Paraffin wax was use as PCM in PV/T collector to store thermal energy accompanied by electricity production by Ceylan et al. [36]. They compared the thermal and electrical energy attainment in the concentrated and non-concentrated collectors and analysed the overall efficiency. The concentrator solar cells were combined with a greenhouse and utilized to dry product like an air drier as shown figure 19. At average solar radiation of 2000 W/m², the maximum temperature gained at the back of the panel was scored as 37 °C and the efficiency of panel was 11%.
A comparative study on a PV/T in three modes of ‘‘upper PCM’’, ‘‘lower PCM’’, and ‘‘no PCM’’ was conducted by Su et al. [37]. They studied many factors such as solar cell temperature, outlet temperature of air, electrical power, thermal power, electrical efficiency, thermal efficiency and overall efficiency. They concluded that overall efficiency of system is 10.7% higher when the PCM was mounted in the upper side of the air flow namely ‘‘Upper PCM’’ mode compared to the absence of PCM. Likewise, a comparative study on photovoltaic-thermal system with PCM in Ireland was done by the Browne et al. [38]. In this study, a eutectic mixture of capric and palmitic fatty acids (CP) was used as PCM. The results show that using PCM is an effective way of storing thermal energy for later application.

A numerical study on PV/T collector with and without PCM was carried out by Gaur et al. [39] in France. OM37 that is an organic material is utilized as PCM. They used thermal model for calculating components temperatures. According to this research, the obtained electrical efficiency in summer was 16.3% and 16.40% with and without PCM respectively and in winter climatic conditions it has been found to be 16.87% and 16.5% respectively. Also, they found that the maximum reduction of module temperature was observed up to ~16.04 °C and ~5 °C for summer and winter respectively.

Radziemska and Kucharek [40] discussed a PV/T system with three kinds of PCMs (Paraffin 42–44, Rubitherm RT 22, Ceresin) experimentally in Poland as shown in figure 20. Based on the promising results of this experiment; for constant solar irradiance, the modified solar PV module (PV/PCM) heats up to a lower temperature than the unmodified PV module and applying 42–44 paraffin to the panel without cooling is the cheapest choice, which may decrease the temperature of the panel by 7 K. An experimental investigation on performance of water and PCM based PV/T systems was carried out by Preet et al. [41]. The study was done in India and Paraffin wax RT-30 was utilized. Electrical efficiency of water and PCM based PV/T systems improved considerably. They confirmed that PCM based PV/T system is better as compare to PV/T system without PCM.
Shukla et al. [42] studied the increment in the potential of hybrid solar photovoltaic-thermal (PV/T) system incorporating with composite phase change materials experimentally in India as shown in figure 21. As the heat transfer efficiency of paraffin wax is not desirable and is low, they used paraffin wax mixture with others organics materials like the mixture of fatty acid. The effect of various parameters: solar panel type and quality, shading effect, electricity consumption, withdrawal rate, and heat source temperature on the system performance were studied. They concluded that the temperature of the heat source is the most important factor that influences the performance of the system, as this increases the system output affects strongly. Also, they found that PV/T is characterized by 50% higher efficiency than comparable conventional module.

Figure 20. PV/PCM schematic [43].

The effect of using PV/T-PCM and PV/T systems was investigated by Yang et.al. [43] and they compared both systems on the basis of the PV module back temperature, cooling water temperature, and power output. They used capric acid used as PCM as shown in figure 22. The experimental study was carried out in china. They found that the in the case of integrating PV/T system with PCM, the performance of the suggested system clearly enhanced.

Figure 21. Over view of solar PV-Thermal hybrid system [45].
H. Fayaz et.al [44] improved theoretically and experimentally the performance of PV/T by adding Paraffin with commercial code A44-PCM. COMSOL Multiphysics software was employed for three-dimensional numerical analysis. The test is done indoor under controlled operating parameters and conditions with passive module cooling. They conducted numerical and experimental calculation on electrical efficiency for both PV/T-PCM and PVT. The results show enhancement of electrical performance for PV/T-PCM system. An energy, exergy and economic study on performance of the system was provided in Malaysia by Hossain et al. [45], while the design of a (PV/T-PCM) system modified as shown in figure 23. The utilized phase change material was the uric acid and it is placed inside the aluminium foil envelopes, the foils were embedded around the flow channel. Maximum thermal and exergy efficiency was 87.72% and 12.19% respectively.

The energy efficiency of a novel Solar PV/T-LHP (PhotoVoltaic-Thermal Heat Pipe) System utilizing operator micro channels and a new organic PCM as the thermal storage converter was investigated by Diallo et al. [46] as shown in figure 24. They assessed the different environmental influence on the performance of PV/T system. It was found that the increase in solar radiation, ambient temperature, coating number, number of micro channel pipes and packing factor were desirable parameters for the COP (performance factor) of the system, but the increase in wind velocity and cold-water mass flow rate are unfavourable parameters on the performance factor.
Figure 24. PCM-PV/T heat pipe system [49].

The numerical FVM (Finite Volume Method) was used by Kazemian et al. [47] to examine the behaviour of PV/T_PCM system. They considered multiple parameters like the PCM properties, solar radiation and mass flow rate. 3-D models of PV/T and PV/T-PCM systems were simulated using ANSYS Fluent software. It was concluded that the PV/T-PCM system has lower surface temperature and coolant outlet temperature compared to the solo PV/T system. The results also showed that if the PCM thermal conductivity improves, thermal and electrical energy efficiency of PV/T-PCM system will also enhance.

4. Conclusions
Following outcomes can be drawn from all reviewed paper:

- Nano-fluid hybrid PV/T systems work better than their base fluids due to improved thermal conductivity of Nano-fluid.
- Overall efficiency can improve as much as 140% through Nano-fluid utilization. Maximum improvement is found to be attained by SiC-water and Cu-ethylene glycol.
- Many types of Nano-fluid used to enhance the PV/T performance such as TiO$_2$-water, Al$_2$O$_3$-water, ZnO-water, SiC-water, SiO$_2$-water, Fe$_3$O$_4$, and MWCNT.
- Many researchers studied multiple parameters such as different concentration, mass flow rate, base liquid, types of flow, volume of Nano-particles, and enhancement of its surface.
- Some authors presented new technic of PV/T cooling to increase the thermal and electrical energy, this technique is based on mixing two or more types of Nano-fluids as hybrid Nano-fluids such as Al$_2$O$_3$-ZnO-H$_2$O and CuO, MgO with MWCNTs with water, Al$_2$O$_3$ CuO/water and (graphite, magnetite, silver). As a base fluid they used (water and mixture of ethylene glycol-water. This method proved more efficiency than using single types of Nano-fluid.
- Combination of Nano &PCM is more effective in PV cooling than solo use of Nano or PCM. Heat is extracted from PV module first by PCM and then by Nano-fluid i.e. by two highly heat absorbing media.
Some of the incident solar energy on photovoltaic, converted to electrical energy and other part can be stored by PCMs in form of latent heat. The improvement of PV efficiency can be reached by as much as 32% when integrated with PCM while electrical energy improvement can be reached to 17%. Observed reduction in temperature of water-based PV/T-PCM is less than that of convectional PV panel. Using composite phase change like paraffin wax mixture with others organics materials, leads to improve the efficiency by 50% compared with conventional PV/T. Various parameters affecting performance of PV/T-PCM system such as layers, types, mode, melting temperature and thickness of PCM. Used PCM-PV/T heat pipe system is very important for increasing the thermal and electrical energy.

The simulations and general experimental works were carried out in many countries such as Malaysia, Egypt, Iran, Qatar, Iraq, Greece, Poland, Italy and India. Using all above cooling methods reduces the dependence on fossil fuels for electricity demand and decreases carbon dioxide and other greenhouse gases emissions, yet as the novel working fluids are more complex, expensive and etc., they confront more issues than conventional fluids. Long-term stability investigation, environmental impact and economic analysis of nano-fluids and PCMs should be done in future. Further research could be done on advanced nano-fluid like magnetic nanofluids, Boehmite nanofluid, etc to improve heat transfer process of the PV/T collector.

Both the PCM and the nano-fluid based PV/T system technology is in start-up stage. Future work may be done on the effect of different types, sizes, and shapes of nanoparticles and development of novel combination of nanomaterials and nanofluids, improving thermal conductivity of PCM, development of new PCM and PCM containers.

List of symbols

- \( \eta_{el} \): Electrical efficiency
- \( \eta_T \): Overall efficiency
- \( \eta_{th} \): Thermal efficiency
- \( A_c \): Area of collector (m\(^2\))
- \( C_p \): Fluid-Specific heat (J/kgK)
- \( G_T \): Irradiation (W/m\(^2\))
- \( I_{mp} \): Current at maximum power point (A)
- \( \dot{m} \): Mass flow rate (kg/s)
- \( P_{PM} \): Maximum power
- \( Q_u \): Usable heat (W)
- \( T_{in} \): Inlet temperature of channel (K)
- \( T_{out} \): Outlet temperature of channel (K)
- \( V_{mp} \): Voltage at maximum power point (V)

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