Recent studies in Concentrated Photovoltaic System (CPV): A Review

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Abstract

Concentrated Photovoltaic (CPV) is an attractive alternative to fossil fuels due to its ability to reduce the PV cell area and increase the energy outputs using low cost optics. This review paper, details the recent experimental and simulation studies conducted in the field related to CPV in the past few years. The paper details the general expressions used for experimental works, followed by sections detailing the studies conducted on the optics, photovoltaics, heat dissipation and integration application. Different designs proposed by the researchers has also been briefly described. The findings shows the potential for CPV and CPV/T systems is promising with overall efficiencies greater than 60%.

1 Introduction

In the present scenario, 86% of the total energy required by the world is provided by fossil fuel[1]. The energy from fossil fuel has been a direct contributor to global warming which has led to a deterioration of the environment and living things[1]. Solar energy is one of the promising forms of renewable energy to mitigate the use of fossil fuels[2].

For only electrical energy, photovoltaic modules and Concentrated Photovoltaic can be used. For only thermal, solar collectors can be used[3]. And for both electrical and thermal energy, photovoltaic thermal (PVT) and Concentrated Photovoltaic Thermal systems can be used[4][5].

Concentrated photovoltaic (CPV) and Concentrated Photovoltaic Thermal (CPVT) are technologies that may prove to be competitive in the future energy sector. Simulation have shown CPVT with payback period as low as 3.45 years[6]. Similarly, a combined thermal and electrical efficiency of 75.8% was achieved[7]. The main advantage of Concentrated system is the reduction of area of the PV cell area and being replaced by optical and beam splitting elements. The optical elements are more cost effective compared to the PV material[8]. The concentrated system must be enabled with a heat dissipation method to avoid the thermal stress[2] and efficiency deterioration. The thermal energy gathered from the heat dissipation may be utilized for further application like domestic hot water[9], space heating and cooling[5], thermoelectric generators[10].

It is important to understand the underlying concepts of CPV for experimental and analytical studies. Therefore, the paper details out the general expressions used by researcher in the last few years and also an overview of the research attention of the components of the CPV system, namely optics, PV cells, Cooling method and Integration.

NOMENCLATURE	
C	Concentration Ratio
DBC	Direct Bond Copper
FF	Fill factor
G	Solar irradiance
IMS	Insulated Metal Substrate
I	Current
P	Power
PPI	Pores per Inch
T	Temperature
TF	Transmittance Factor
V	Voltage
Subscripts	
c	concentrator
d	Direct irradiance fraction
el	Electrical
MP	Maximum Power point
o	Overall
OC	Open circuit
ref	Reference
SC	Short Circuit
th	Thermal
Greek Letters	

α	Seebeck Coefficient
β	Temperature Coefficient
η	Efficiency

2 Concentrated Photovoltaics: An Overview

2.1 General Expressions

The thermal efficiency is defined as the useful heat to the energy supplied and is expressed as[11]:

$$\eta_{th}=(\text{Useful Energy})*(\text{Input Energy})^{-1}*100 \quad (1)$$

The electrical efficiency is defined as the output power to the energy supplied, which is calculated using[11]:

$$\eta_{el}=(\text{Output Power})*(\text{Input Energy})^{-1}*100 \quad (2)$$

Summing Equation (1) and Equation (2), the overall efficiency can be defined as[11]:

$$\eta_{o}=\eta_{th}+\eta_{el} \quad (3)$$

When the radiation is concentrated, the diffuse radiation is not utilized and only the direct radiation is utilized. The concentrated solar radiation depends on the transmission factor, the fraction of direct radiance and the concentration which can be calculated using [11]:

$$G^{*}=G.C.I_{d}.TF \quad (4)$$

The Fill Factor signifies the maximum actual utilization of the electrical energy under loading to the theoretically maximum possible. Hence, for concentrated light the fill factor is calculated using[12][1]:

$$FF=(V_{MP}.I_{MP}).(V_{OC}.I_{SC})^{-1}=P_{M}.(V_{OC}.I_{SC})^{-1} \quad (5)$$

The concentration factor is defined as the short circuit current under concentration to the short circuit current under 1 sun concentration. Therefore, the concentration ratio is given by[13]:

$$C=I_{SC}(X).I_{SC}^{-1} \quad (6)$$

A module will have cells connected in series and parallel. The total electrical current from a module is calculated using[14]:

$$I_{module}=(\text{Parallel Cells}).(I_{cell}) \quad (7)$$

The total electrical voltage from a module is calculated using[14]:

$$V_{module}=(\text{Series Cells}).(V_{cell}) \quad (8)$$

2.2 Optics

In a CPV system, the concentrating element is the optical element. The arrangement can be reflective[19,20] or refractive[13,18,12]. Han et al.[17] used six different liquids from synthetic oil to mineral oil, to understand the effect of liquid immersion in a triple junction CPV system. The optical transmittance of the liquids was determined and later were subjected to three aging tests namely, UV radiation test, Damp Heat test and Temperature test. The optical transmittance without the accelerated aging showed Therminol-VP had the least transmittance loss for the complete spectral range of the three subcells. But the Therminol-VP showed deterioration of color when subjected to UV radiation. The result after subjecting the rest of the liquids through the accelerated aging test, dimethyl silicon oil showed 0.5% loss in optical transmittance. Renzi et al.[18] designed and developed a secondary refractive optical element. The optical simulation was carried out in ZEMAX software. Two configurations were used for the simulation, one conical and the other hexagonal free form refractive elements. In the simulation, the optimal distance from the primary optical element was determined. The simulation also carried out the radiance distribution due to misalignment for both the configuration. It was determined that the hexagonal free form showed uniform solar radiance better than conical secondary optical element. The experimental study was carried without using the primary optical elements. Two types of triple junction cells were considered. One with IMS construction and the other with DBC construction. The hexagonal free form with DBC was reported to have an electrical efficiency of 39.55% and maximum power output of 0.721W. The homogenizer increased the optical losses but improved the radiation uniformity. The cell configuration with lower number of cells had more radiative losses as it was exposed more to the surroundings and higher number of cells produced more electrical power output[19]. Srivastava et al.[15] modelled four secondary optical elements(SOE) for a HCPV system as shown in Fig.1. The SOEs varied in volume and height. The simulation was carried out in TracePro software. In the simulation the author has considered the effect of spectral properties and the wavelength dependent properties of the material. The spectral matching ratio(SMR) and polychromatic optical efficiency under normal tilt and misalignment were simulated for each SOE.

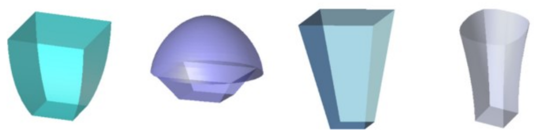

Fig.1. Secondary Optical Elements design for acceptance angle and uniform distribution of illumination [15].

The SOE with the least volume and height showed the largest acceptance angle and the highest optical efficiency. The SMR was better under misalignment for SOE with larger volume and height due to the effect of total internal reflection. Under normal alignment the SMR variation among different subcell were the least with SOE with the least volume and height. Zhou et al.[16] developed a mathematical model to couple the effects of near field optics, electrical characterization and heat transfer of back contact silicon solar cell. Nanostructures having different reflectance index were analyzed under a maximum concentration of 10 for the study.

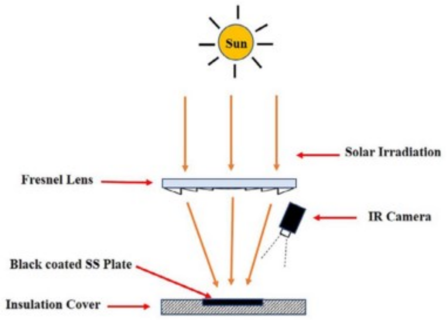

Fig.2. Schematic of the experimental setup Fresnel Lens based Concentrator System.[20]

The results reported that, reflectance of the nanostructure had little effect on the maximum output power density. The annual energy production was also reported for a year with four seasons. Reddy et al.[20] used inverse heat transfer method to determine the flux distribution on the concentrator receiver. The simulated result was compared with the experimental result for direct radiation and maximum deviation of 6% was reported. The schematic of the experimental setup is shown in Fig.2.

2.3 Photovoltaic Cells

Under concentrated light, the power output of the PV cells increase, due to the increase of solar radiation. But this is accompanied with increase in temperature, which leads to a decrease in efficiency of the PV cells as represented in the Eq.9 [21]:

$$\eta_{o}= \eta_{o}(1-\beta_{ref}(T_{cell}-T_{ref})) \quad (9)$$

Renno et al.[2] experimentally setup a plant with three configuration using triple junction cell to understand the difference in performance for a degraded triple junction and a triple junction in pristine conditions. The degraded and pristine TJ cell showed a monotonic increase with concentration for short circuit current and logarithmic open circuit voltage. The degraded solar cell showed greater efficiency at lower concentration due to its increase in series resistance. Aging increases the series resistance of the solar cell. Aging of the cell increases the non-radiative recombination. A reduction of 30% of the mean electric power was noted at a mean radiation of 900W/m^2. The system power efficiency of the aged cell reduced by 50% compared to pristine cell efficiency. The use of kaleidoscope along with a primary optical element can reduce the tracking requirement of a CPV system. Widyolar et al.[3] simulated various combinations of solar cells with different types of spectral beam splitting (ideal filter, interference filter, and semi-transparent/back reflected solar cells) and concentrated solar power. The study also compared the economic analysis in comparison with c-Si flat panel. When using c-Si in the concentrated photovoltaic spectral beam splitting, the efficiency decreased compared to full spectrum utilization of the c-Si solar cell. This was attributed to the wide range of spectrum conversion of c-Si solar cell. When compared with other solar cells like III-IV junction cells, the combined efficiency of the parabolic trough concentrator solar power and photovoltaic was higher than the full spectrum utilization of the individual cells. The economic analysis showed that solar field cost is the major cost involved in the installation of the solar device. The CPV system cost per watt was higher than c-Si flat panel due to lower utilization of the solar radiation, more component requirements and the complexity involved. Renno et al.[13] used an experimental setup to characterize CPV system equipped with triple junction solar cell based on the concentration level. Three configuration were utilized, first, under one sun concentration, second using a kaleidoscope to increase the concentration to 7.3 suns and the third configuration utilizing Fresnel lens and kaleidoscope to increase the concentration up to 310 suns. The focal height can be varied of the Fresnel lens. The electroluminescence spectra were analyzed for each subcell. Different PV parameters were determined with respect to the concentration. The open circuit voltage increases with concentration. The efficiency and fill factor of the cell first increases and then decreases beyond 81 suns. The series and shunt resistance decreases with increase in concentration. The authors also mentioned that using an active cooling is of importance to reduce the rise in temperature in the triple junction cell. Renno et al.[5] experimentally calculated the solar irradiance, concentration ratio and the temperature of the ambient. These inputs were passed into the theoretical model modelled in ANSYS CFX for simulation purpose. Two configuration were considered, the first one involved kaleidoscope as the primary concentrator and the second configuration consisted of a primary concentrator of Fresnel lens and secondary concentrator of kaleidoscope. The concentration ratio was determined by using the short circuit current. The second configuration achieved a concentration ratio of 208.6 while the first a concentration of 6.54. A deviation of 24% from the theoretical and experimental values were determined and this was attributed to the lower real efficiency of the cell and/or non-perfect tracking of the system.

2.4 Different Designs

This section briefly describes the different design used by various researchers. As explained in Section 2.2, the concentrating element can be refractive or reflective. The designs can be classified as Fresnel Lens or parabolic trough collector based on the optical element. Fresnel lens are refractive and parabolic trough concentrators reflective. Fig.2-3, and Fig. 5-7 are designs based on Fresnel Lens and Fig.4 is based on parabolic trough collector. Fig.4 and Fig.7 uses an additional optical element called cold mirror for spectrum splitting. Fig.1 shows the secondary optical elements that can be used in conjunction with Fresnel lens. Based on the integration, designs can be classified as TEG, hydrogen, and domestic hot water production. The TEG is attached directly to the back of the PV cell as shown in Fig.8. The TEG is the heat transfer element for the CPV system. Fig.6. shows the schematic of the experimental setup for hydrogen production through spectrum splitting. In Fig.6. the thermal energy is transferred to water through a heat exchanger.

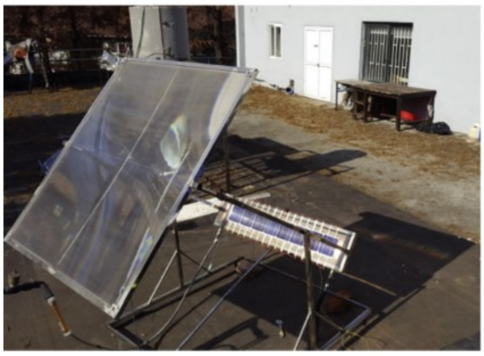

Fig.3 Experimental setup using Fresnel lens concentrator system[11].

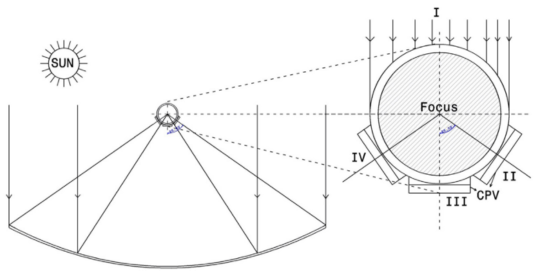

Fig.4. Parabolic trough collector used in CPV application[19].

3 Heat Dissipation/Cooling Methods

Heat dissipation or cooling of a CPV system is of utmost importance as degradation in efficiency occurs due to increase in temperature of the cell as expressed by Equation (9) . So as the temperature of the cell is brought down, then the efficiency of the CPV system will increase. As the study conducted by Flitsanov et al.[22], to test an open cell metal foam arrangement. It was reported that, of the total pressure drop of the fluid flow, 83%-87% of it was due to empty channel. The dependence of the Nusselt number and Reynolds number on the electrical power input was studied. It was determined they were independent of the electrical power input. Three different metal foams were incorporated into the empty channel namely, 20 PPI, 30 PPI and 40 PPI. The best heat transfer was determined for 30PPI, clearly showing an optimum value exists for metal foam. The thermal resistance of the compressed foam is lower than the plain foam under high flow rate and high pressure drop. Lower cell temperature achieved due to the lower flow resistance offered by the metal foam would lead to an increases in 0.5% CPV receiver efficiency[22]. An experimental setup for the performance analysis of CPV with Phase Change Material(PCM) was studied by Su et al. [23]. The experiment was conducted in real world weather conditions. The cooling system was augmented with water cooling, in case PCM was not able to maintain a temperature difference less than 10 ^{0}C between the water storage tank and the water receiver. The water cooling would stop when the temperature difference reduced below 5^{0}C. As PCM requires no additional power for pumping, the electrical efficiency enhancement ratio was greater than water cooling. This resulted in an overall efficiency improvement of 15% compared to water cooling. A simulation study was conducted by Emam et al. [21] to study the effect of various configurations of PCM like single cavity, three and five parallel cavity and three series cavity, on the average temperature and local temperature of the PV cell. The results reported that the five parallel cavity achieved the lowest temperature with 57^{0}C over a time of 150 min. The configuration also had better temperature distribution with the difference in the maximum and minimum temperature being 2.5^{0}C. The study also varied the PCM materials in the parallel three cavity arrangement. It found that, material with the least transition temperature and least latent heat is better to be placed at the bottom of the cavity. The material with the highest transition temperature and highest latent heat to be placed in the top cavity for the best results. Under a concentration ratio of 20, the five parallel cavity reduced the temperature by 200^{o}C relative to uncooled solar cell. The effect of using synthetic oil and nanofluids for different cell configuration was modelled by Srivastava et al. [19]. Also the effect of using a homogenizer, different cell configurations and heat transfer fluids were combined to analyze the temperature of the cell, electrical output and thermal output of the system.. The synthetic fluid with lower heat capacity maintained a uniform temperature over the entire cell length but the nanofluid showed a linear variation across the length of the cell. The electrical output was maximum for nanofluids and the thermal output reached maximum value for synthetic oil.

4 Integration

Concentrated Photovoltaic system has the capability to produce a considerable amount of thermal energy more electrical energy compared to flat panel systems. The increase of electrical and thermal energy opens up different applications. As the energy utilization increases, the combined efficiency of the whole system increases. The thermal output is dependent on the mass flow rate of fluid, specific heat of the fluid and the temperature difference. From the thermal output, the thermal efficiency is calculated using Equation (2). Chen et al.[7] simulated and experimentally determined the thermal and electrical performance of a HCPV/T system. The HCPV/T module was equipped with an aluminum heat sink with cooling water removing the heat from the module. The overall efficiency of the system reported was 75.8%. The maximum error with the simulated and experimental results for electrical and thermal efficiencies were 3% and 1%. The exergy efficiency improved as the inlet water temperature was increased. The electrical efficiency drop in the HCPV/T system was -0.042 %/^{0}C. Yang et al.[9] developed a low cost concentrating system with a quasi-parabolic concentrator with plane mirrors and silicone solar panel. The concentration ratio is around 6-8 with an optical efficiency of 55.5%. The electrical efficiency of the CPVT system reported was 16.6-20% and thermal efficiency of 39%, which when combined bought the overall efficiency to 55.6-59%. The output of the flat panel was better than CPVT under cloudy conditions. Renno et al.[5] Simulated the daily average power output for different seasons. The cell and cooling fluid temperature were also simulated. The study showed that with the fluid temperature calculated, it may be used for air heating and cooling purpose. Karimi et al.[11] designed an experimental setup shown in Fig.6 to conduct two types of studies, one, purely the thermal collection of the concentrated system and the second, to analyse the electrical and thermal energy collected by the CPV/T system. The thermal system was analysed under sunny, cloudy and cloudier days. The average thermal efficiency of the system was 46.6% for 5.85 suns. Low initial water temperature increased the thermal efficiency of the system as the rise in temperature was higher compared to high initial temperature.

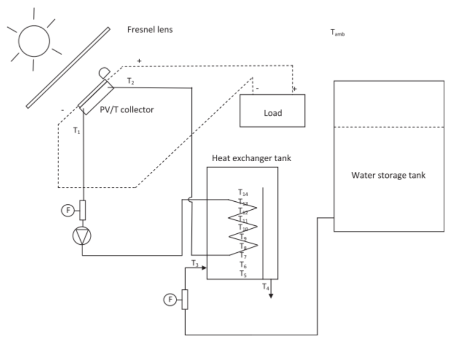

Fig.5. Schematic of the domestic hot water production using CPV/T system[11].

The electrical efficiency of the concentrated system increased from 9.3% without cooling to 16.2% with cooling.

4.1 Hydrogen

This section details the studies that were conducted to produce hydrogen integrated with CPV. The electrical energy is used to produce hydrogen using Photoelectrochemical(PEC) and Proton-Exchange Membrane(PEM) process. Bicer et al.[14] modelled and experimentally setup a concentrated spectrum splitting using cold mirror to generate electrical energy from PV cells and hydrogen from photoelectrochemical(PEC) process as shown in Fig.7. The efficiency of the PV cell decreased with increase in area but the power output increased with PV cell area. Discrepancy with experimental and model values were due to variations in the dark saturation current calculation, cloud cover and defects in the load setup in the experiment.

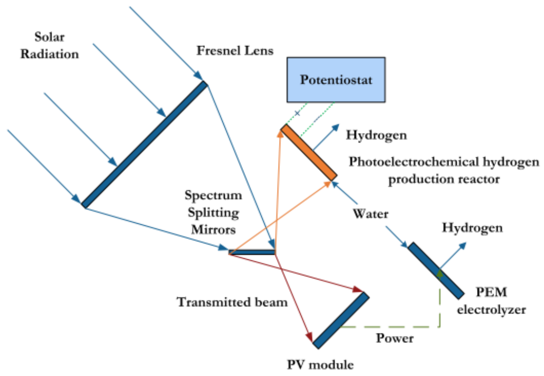

Fig.6. Spectrum Splitting approach for simultaneous generation of electrical energy and hydrogen[14].

In the PEM electrolyser, the exergy destruction for water splitting reduced with temperature. Burhan et al.[24] developed a compact CPV system integrated with a PEM electrolyser to produce hydrogen. The system employed a hybrid tracking system. The maximum CPV efficiency and solar to hydrogen efficiency was reported as 28% and 18%. The test was conducted for a whole day under tropical weather conditions. The electrolyser efficiency dropped with increase in voltage, which was a result of increase in Direct Normal Irradiance(DNI) in the CPV concentrator. The CPV-hydrogen system reported an average production rating of 217 kWh/kg. Bicer et al.[12] developed an experimental setup for simultaneous production of electrical energy and hydrogen through spectrum splitting. The cold mirrors split the light at wavelength of 750 nm and the higher energy spectrum was supplied to the PEC reactor and the rest to the PV panel. A concentration 10x was achieved using Fresnel lens. No effective cooling mechanism was used in the CPV arrangement which led to an increase in the cell temperature with maximum recorded at 70.8 ^{0}C. A comparison of CPV with non-concentrated PV cell showed that a CPV produced higher power output than non-concentrated PV cell. The energy efficiency of all the sub-processes were calculated. The CPV based electrolysis yielded 19 mg/h of hydrogen production with cell area of 0.04085 m^2. Bicer et al.[25] used an experimental setup to produce hydrogen with PEC and electrical energy using photovoltaics. The light was split using a cold mirror, with the visible region transmitted to the PV cells and the near infrared region reflected to the PEC reactor. The hydrogen production increased when PEC was illuminated with concentrated light compared to no light conditions.

4.2 Thermoelectric Generators

Thermoelectric Generators (TEG) are semiconductor materials that use the temperature difference at the junction points to produce electrical energy. This concept is used for further generation of electrical energy in the concentrated system. Thermoelectric generator works on Seebeck Principle and the Seebeck relation for open circuit voltage is given by[26]:

$$V_{OC} = \alpha.\Delta T \quad (10)$$

Tamaki et al.[10] conducted experiments on the hybrid arrangement of Multi-juntion solar cell and thermoelectric generator with four different areas. The system was equipped with Fresnel lens and rod lens used as homogeniser. The open circuit voltage of the multi junction cell and the thermoelectric device increased with area of the TE device. As the area of the TE device increased, the heat disspation from the MJ solar cell increased and its efficiency increased. They concluded by mentioning that, TE device can compensate the efficiency degradation of the MJ solar cell due to high temperature. Kil et al.[26] fabricated a GaAs solar cell on a Si substrate to enhance the heat flow from the CPV to TEG as shown in Fig.8.The open circuit voltage of GaAs with Si substrate was higher than the GaAs at higher concentration due to the Si substrates higher thermal conductivity. The CPV efficiency is dependent on the load resistance of TEG. That is, if the resistance increases then the CPV efficiency decreases. Mohsenzadeh et al.[1] designed a novel system inside the receiver tube of a CPV/T with a triangular crossection as shown in Fig.9. The side exposed to the concentration is fitted with silicon solar cells and the heat generated is converted to electrical energy through thermoelectric generator. Three configuration of the system was tested, first a non-concentrated PV system, second a concentrated PV with glass cover and finally a system with Concentrated PV without glass cover. The result showed that a system with tracking had solar irradiance 15.54% higher than non-tracking system.

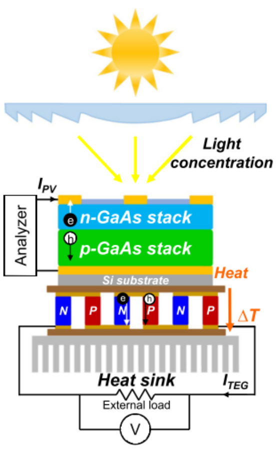

Fig.7. Sketch of CPV integrated with TEG[26].

The open circuit voltage variation with respect to the temperature was determined to be -0.027 V/^{0}C. The total electrical performance, concentrated PV and thermoelectric device, is 303% higher than the non-concentrated PV cells electrical output. The thermal efficiency of the CPV/T+TE with glass cover reported was 46.16% which was higher than the CPV/T+TE without glass cover and the reduction of efficiency attributed to increased loss of heat to the ambient. The overall efficiency achieved by CPV/T+TE with glass cover was the maximum with 50.66%. But the study did not include the energy consumed by the pump. Mahmoudinezhad et al.[27] developed a numerical model of CPV-TEG which was simulated using MATLAB for transient conditions. The concentration of 200suns and heat transfer coefficient of1000W/m^{2}K between the CPV cell and the TEG semiconductor was used. The results showed the variation of the temperature, the power output of CPV and TEG and the efficiency of CPV and TEG on a typical cloudy day. The temperature increased when the sky was clear, which in turn increased the power output of CPV and TEG.

Study	**Design Feature**	**Key Findings**
Mohsenzadeh et al. [1]	CPV+TEG	Output is 303% greater than non-concentrated system
Widyolar et al.[3]	Spectrum Splitting+CSP	Efficiency is greater than CPV
Renno et al.[5]	Fresnel lens+Kaleidoscope	24% deviation in experimental and simulation values
Chen et al.[7]	HCPVT+DHW	75.8% overall efficiency and Temperature Coefficient=-0.042[%/^{0}C]
Yang et al.[9]	Low cost CPVT	Optical Efficiency=55.5% Overall efficiency=55.6-59%
Tamaki et al.[10]	MJPV+TEG	Increase in TEG area increases the efficiency of MJPV
Karimi et al.[11]	CPV+DHW	Thermal efficiecny=46.6% Electrical efficiency=16.2%
Bicer et al.[12]	CPV+Hydrogen	Cell temperature of 70.8^{0}C without cooling
Renno et al.[13]	Variable focal length	Maximum efficiency at 81 suns

Bicer et al.[14]	CPV+Hydrogen	Efficiency of PV cell decreases with increase in area
Ferrer-Rodriguez et al. [15]	HCPV+Refractive Secondary optics	Optical efficiency=83.6% Maximum acceptance angle=1.13^0
Zhou et al.[16]	Nanofluid Cooling	Non-uniform Temperature distribution
Han et al. [17]	Liquid Immersion	Dimethyl silicon oil with optical transmittance loss of 0.5%
Renzi et al.[18]	Refractive Secondary optics	Electrical efficiency=39.55% Maximum power=0.721 W
Reddy et al.[20]	Inverse Heat transfer method	6% deviation in experimental and simulated values
Renno et al.[2]	Triple junction cell without cooling for 500[h]	50% reduction in efficiency compared to pristine cell
Emam et al. [21]	CPV+PCM	Reduced the cell temperature by 200^{0}C compared to without cooling
Flitsanov et al.[22]	Metal foam for heat transfer	30 PPI improved CPV efficiency by 0.5%
Zhang et al.[23]	CPV+PCM	15% improvement in overall efficiency compared to water cooling
Burhan et al.[24]	CPV+Hydrogen	Electrical efficiency=28% Solar to hydrogen=18%
Mahmoudinezhad et al. [27]	CPV+TEG	CPV efficiency increased as TEG efficiency decreased

Table 1. The design features and the findings of the research studies considered in this paper

5 Conclusions

The paper explores the research works conducted in the last few years in the field of Concentrated Photovoltaic. The paper details out the general expressions used for modelling and experimental works in CPV. The summary of all the findings have been tabulated in Table.1. Integrating the CPV with other applications has led to a combined thermal and electrical efficiency of 75.8%[7] might be one of the reasons for the increase in research in this field. Simulation has shown the thermal energy can be used for space heating and cooling purpose[5]. The electrical energy is used for production of hydrogen through PEC[14] [12] [25] and PEM [24] process. The TEG compensates for the degradation of triple junction cell due to increase in temperature[10]. Dimethyl silicon oil was the best fluid for liquid immersion with 0.5% transmission loss[17]. An aged triple junction cell efficiency reduced by 50% compared to pristine cell[2].

6 Future Works/Challenges

CPV systems is showing great potential as a substitute for fossil fuels and an avenue for clean energy harvesting. It has the potential for small scale and large scale production of energy. As it is the sum of individual components like optical element, PV cell, and cooling/heat dissipation device, the improvement of the system can be looked from a broader perspective. From the review article the following future works/challenges are recommended:

1. Experimental studies of CPV with phase change material using different configuration under real weather conditions.
2. Life Cycle assessment of the CPV system. This will provide the effect of CPV on the environment.
3. Economic assessment of the CPV/T to understand the economic feasibility of the system.
4. Improving the combined efficiency of the CPV/T system.
5. Concentrated system utilizes only direct radiations and hence a feasibility study in tropical conditions is required[28].

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