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Photovoltaic Thermal (PV/T) and Its Recent Developments

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Abstract**—**Due to the climate change at global level, various steps have been taken in the development of renewable energy especially solar energy which have a great potential in future. Current technology produce electricity and heat from solar energy but photovoltaic/thermal (PV/T) are used to generate both at the same time. Developments are done on PV/T's since 30 years. Depending on the type of cells, photovoltaic (PV) convert 5-15% of solar radiations into electricity and rest is lost in the form of heat to the atmosphere. So many developments have been done for efficient use of solar energy. Efficiency of the solar PV drops when it works on high temperature especially at high insolation. Electrical efficiency can be increased by reducing the temperature of photovoltaic plate. Temperature can be reduced by removing that thermal energy in the form of heat by using some mode of heat transfer. The forced or natural convection mode of heat transfer is used for cooling up PV/T which keeps the temperature at satisfactory level so that it can work efficiently. This review presents the different types of PV/T's and the advancement done so far.

Keywords**—** Solar energy; photovoltaic/thermal collector; types of PV/T; energy efficiency; energy conversion; application of PV/T system.

I. INTRODUCTION

Energy is the prime source of generation of wealth and it plays a significant role in the economic development of any country and living standard of people. Being cheaper and more convenient to use, the fossil fuels have provided most of the energy in the past until it became an issue for environment pollution. The climate changes which leads to global warming problem due to increase in the consumption of conventional resources lead the world to shift to non-conventional sources, the main sources are wind, air, solar, water etc. There is a strong relation between the energy available, economic activity and importance of energy in development. 85 million barrels of crude oil is consumed daily Worldwide [1]. Knowing the consequences done by fossil fuels combustion, they are expected to increase to 123 million barrels per day by 2025 which is the main cause of pollution [2]

The most promising energy source among all renewable energy available is solar energy that is due to variety of applications, solar energy is considered as the largest renewable energy source which is freely available everywhere in large amount making it pollution free, clean and most promising to use. It holds a great potential in many countries with effective methods of utilisation, there are many solar energy devices such as solar pumps, solar heater, solar PV lighting, solar thermal devices etc. which are commercialised widely and at the same time these applications protects our environment from degrading and balancing the ecosystem. Solar energy devices help to fulfil the demand of the people to a great extent. Because of the great efficiency and performance stability devices, solar hybrid system for renewable energy is considered over individual solar devices. Solar energy devices fall on two categories depending on conversion method: electricity e.g. Photovoltaic module and heat e.g. Thermal collectors.

In Solar PV/T, radiations are converted into thermal energy through moving fluids or/and transport medium by solar thermal energy collectors. All Solar system requires collectors that can absorb solar radiation and convert them into heat energy which can be transferred with the help of fluids such as water, air or oil for useful applications that are solar dryers, air dryers, solar air heaters and cooling/heating with auxiliary heaters that are used for air conditioning of building. Different solar collectors are given in fig 1.

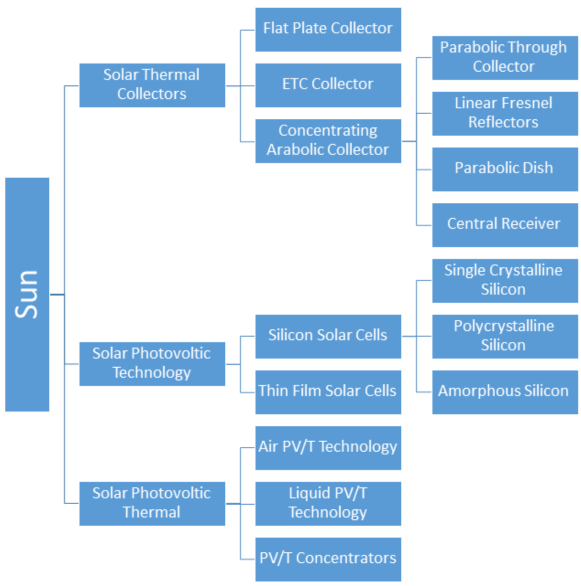

Fig. 1. Different types of solar collectors.

PV module is an energy device which converts sunlight into electricity by photoelectric effect. They are made up of Solar cells which convert Sun radiation directly into electricity. The first demonstration and the first practical conversion of radiations of the sun using p-n junction type solar cell was examined in 1954 at bell telephone laboratory

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with 6% efficiency [3]. Power conversion efficiencies lie between 15 to 20% [4].

There is a loss in the efficiency of the PV module because solar being the low grade energy. Efficiency decreases due to increase in the temperature of the plate of photovoltaic module. Many researchers have seen that today within the single device both the conversion takes place called photo thermo-conversion where heat and electricity is converted from solar radiations [5]. Hence simultaneously both the heat and power are produced.

II. Solar Photovoltaic/ Thermal Technology

A module where electricity is not only produced by PV but it acts as a thermal absorber is a PV-thermal collector. As there is a demand of both heat and electricity, therefore a single device which compliments both the demand is a great idea. A fraction of the solar radiations is converted into electricity but the major part of that radiation is turned into heat with cells which in turn leads to temperature rise of PV and hence reducing the efficiency. Now that heat is recovered and is used for many applications by photovoltaic/thermal technology of the system. Electrical efficiency is increased and maintained by cooling PV module and keeping the temperature at satisfactory level for better use of solar energy.
The ratio of solar energy collected that is used (electrical and heat) to the total amount of solar radiations falling on the panel is combined efficiency of the PV/T system. With the increase in the temperature, there is a delay in the electrical efficiency which can be represented by temperature coefficient that varies with different PV cell material used. -0.3 to -0.45%/k in case of crystalline silicon[6] and -0.2 to -0.35%/k when thin film type technologies are used. The schematic diagram of the various solar technologies is given below in fig 2.

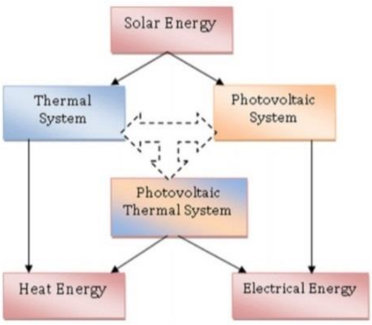

Fig. 2. Various solar system.

Many development have been done to improve PV/T efficiency. Some important features of PV/T are [7]:

- It is dual in nature that single device can produce heat and electricity simultaneously.
- It is flexible and has better efficiency. It can be understood from the fact the efficiency of the two independent systems is less than single system performing both the work.
- Heat produced by PV/T can be used both for cooling and heating applications depending on season and as domestic application as well.
- It is cheap and practical to use. It doesn't need much modification and can easily be integrated to building and PV/T can replace the roof material and pay back period is reduced.

There are different types of PV/T used these days e.g. PV/T /Air, PV/T/water and PV/T concentrated collectors [8].

III. Types of PV/T

Depending upon the various applications PV/T can vary in design e.g. PV/T hot water system is used for domestic application, PV/T used for heating air for building actively cooled PV concentrators. The wide range of applications are seen in solar PV/T and can be used for domestic and commercial applications. Hence can be classified as

- PV/T water collector
- PV/T air collector
- PV/T concentrators

A. *PV/T Water Collectors*

To heat up the water we use thermal collectors. The various applications of photovoltaic thermal collectors is producing electricity in various industrial and domestic places. It is very much close and similar to flat plate collector where the electricity is produced and water is also heated for domestic purposes. Heater is generally used in parallel flat plate collector where as in industries they are connected in series and to maintain the flow of water in a collector it uses photovoltaic driven water pumps. Water based photovoltaic thermal collectors is shown in figure 3.

Generally, we use flat plate collectors for domestic water heater in parallel connection and with the action of thermo-siphon they run automatically on the other side of flat plate collector which are in series and is useful in industries for water heating and to maintain the water flow in collector we use water pumps which is photovoltaic driven.

An experimental study was done by Chow *et al.*, [9] on photovoltaic thermal water heating system and found 38.93% thermal efficiency and 8.56% as electrical efficiency in Hong Kong during summer. The forced water circulation was compared with natural water circulation and he got that the natural water circulation is more preferable and suggested that direct water circulation arrangement can serve in a improved way.

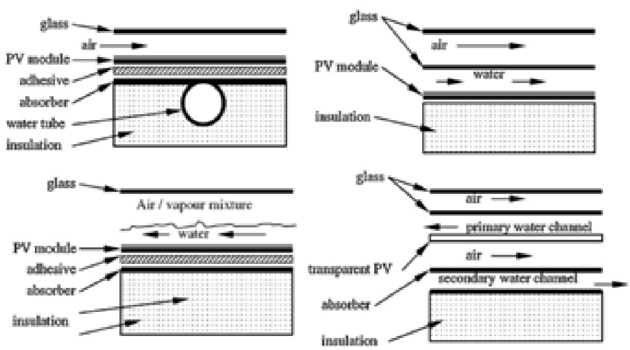

Fig. 3. PV/T water collector (source:[10])

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Liquid based PV/T are more desirable practically and effective than air based PV/T.Temperature fluctuations in liquid based is less than air based PV/T collecters with content to variations in radiations of the sun.

Bibao and Sproul [11] have done an experiment on a unglazed box channel PV/T water collector in which they took a polymer plate and bounded with a PV module as shown in fig 4. The whole experiment was conducted in Sydney (temperate climate condition) and found that a thermal effiency was nearly about 20% and electrical effeciency of 7%. The outlet water temperature was found to be 44˚C during summer.

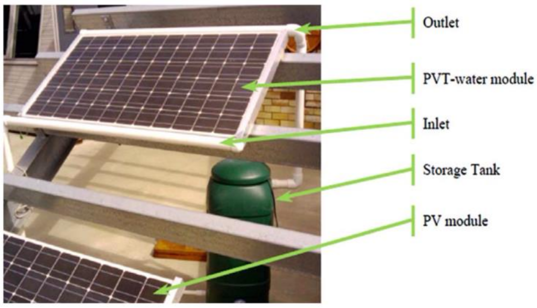

Fig. 4. A low cost polymer flat plate pv/t water heating prototype.

B. PV/T Air Collectors

A single pass air channel is placed behind the PV panel in an unglazed PV/T air collector. Electricity is produced by the PV panel when solar radiation lands on its surface and rest of the radiation that are not converted into electricity results in rising the temperature of the PV by heating it up. Air gets heated up when it passes through the channel resulting in the removal of heat from the panel and producing warm air. Since all the heat from the sun is not utilized because of the heat that is lost from the top of the panel.

Heat can be extracted from solar collectors by using various fluids like air, water etc. PV/T water system is more efficient compared to PV/T air system because air as compared to water is having low thermo-physical properties [12]. Moreover due to the low operating cost and minimum use of materials it can be used in many practical applications.
Thermal efficiency of (10-26%) is observed in an output temperature of 28-58°C in typical unglazed air PV/T type collector [13] as shown in fig 6. there is a increase in the temperature efficiency of (20-35) % with the increase in the output fluid temperature repeated glass cover is added to the unglazed PV/T but there is decrease in the electrical efficiency of (1-2) % [14], [16].

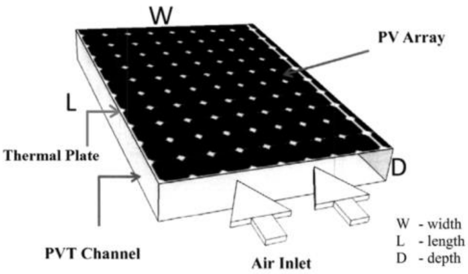

Fig. 6. An example of a PV/T air collector (source: [15]).

Tonui and Tripanagnostopoulos [16] has worked on air cooled PV/T in which they improved the cost of solar collector. They worked on two heat extraction system which is having low cost and they modified the channel of the system so that we get higher thermal output.

A thin metallic sheet was added in the middle of the channel referred as thin metallic sheet (TMS) PV/T collector [14]. When this was compared with the air PV/T collector, it showed the thermal efficiency of (10-25) % and electrical efficiency is reduced from 12% to 10% [14], [16].
PV/T collector with fins was investigated to increase the area of heat exchange at the back of channel wall [17]. The thermal efficiency up to 30% with temperature varying from 25-58℃ was achieved in this arrangement and electrical efficiency in the range of 10-12% [14], [16], [17]. When a glass cover is added, the thermal efficiency of 20-50% was achieved and 8-11% electrical efficiency was reduced in the temperature range of 35-37℃.

C. PV/T Concentrators

PV/T concentrators can operate easily at higher temperatures as compared to those of flat plate collectors and they collect the rejected heat from CPV system which leads to CPV/T system, and which provide both heat and electricity at medium temperature.

PV/T collectors with reflectors were designed by Kostic [18]. Flat reflector has been placed on PV/T collector for solar radiations to get maximum thermal and electrical energy. They design reflectors to obtain high radiations on movable PV/T collector system. Electrical and thermal efficiency of PV/T collectors in this work can be calculated in optimal positions. Energy saving efficiency is 60.1% higher than solar thermal collector and using reflectors, the thermal efficiency of a conventional solar thermal collector is almost same which is 46.7% in optimal position for PV/T collector. The schematic diagram of concentrated photovoltaic shown in the fig 7:

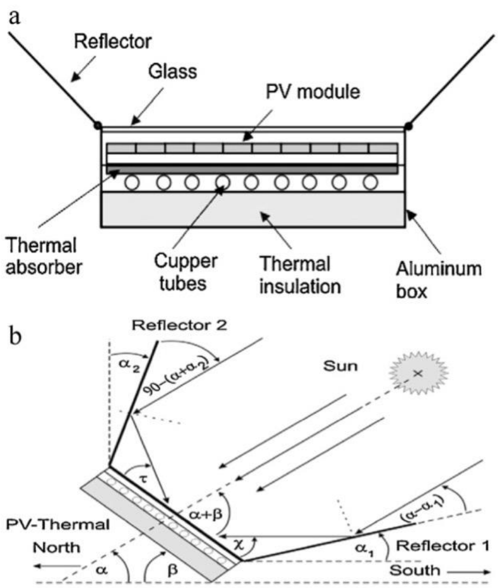

Fig. 7. a) Schematic diagram of the cross section of PV/T.
b) Schematic diagram of the PV/T collector with solar radiation reflectors. (source:[10]).

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The combination of CPV with the concentrated reflectors has a great potential of production of power from a solar cell area. Active cooling is also taken into account of photovoltaic module. The shape and size also decreases due to decrease in the value. Solar cells that work on high current though expensive in comparative to flat plate collectors can be used for higher efficiency. Efficiency decreases with non-uniform temperature across the cell.

With the geometric concentration ratio of 37 X at ANU Australia, Coventry [19] designed a parabolic through PV/T collectors as shown in fig. 8. Under ideal conditions, the thermal and electrical efficiencies of ANU CHAPS were taken . At ambient, lower efficiencies were seen low by CHAPS as compared with flat pate collectors due to optical losses. Thermal efficiency of 58% and electrical efficiency of 11% were shown under operating conditions and combined efficiency is 69%.

Fig. 8. Prototype CHAPS collector at the ANU.

Presently the research work is going on CPV/T collectors so that they provide more electricity and generate more heat. Many authors have worked in multipurpose hybrid system but they enable to fulfil the demand of increasing thermal and electrical energy, for protecting the environment.

IV. PV/Thermal Recent Advancements

Photovoltaic thermal collectors can be useful for various applications such as water desalination, solar cooling, solar photovoltaic air conditioning, thermal heat pump. Various developments are described below.

Mittelman *et al.*, [20] designed solar cooling having concentrated photovoltaic system. They present power and heat that gives high performance to CPV/T technology so that they produce thermal energy and electricity at medium or low temperature. The range of the temperature will found is wide enough so that they satisfy the recruitment of thermal application for both industrial and domestic use. The CPV/T collectors operate at the temperature above 100 degree Celsius and thermal energy can do some useful process like desalination, steam production and refrigeration.

Davidson *et al.*, [21] developed a building which is integrated with multifunctional PV/T solar window and construct the PV cells laminated on window which is solar absorbers. Tilt able reflectors are used so that cost will be reduced of solar electricity. In building the radiation get transmitted by controlling the possibility of reflectors. Through the window the insulated reflectors reduce the thermal losses. A model was developed for simulation of hot water and electric production which perform energy simulation for distinct factor like shading of cells /effect of glazing can be excluded or included.

Jian Fan et *al.*, [22] conducted an experiment on solar PV/T collector in which they compare the performance of three different PV/T collectors as shown in fig 9.

Fig. 9. a. An unglazed PV/T collector.

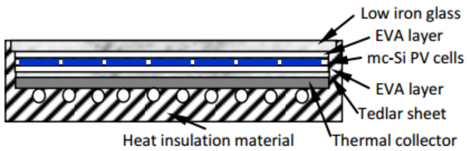

Fig. 9. b. A glazed PV/T collector (source: [22]).

which include (1). 1.536 kWp unglazed, forced circulation a Si PV/T system, (2). 1.8kWp glazed, forced circulation mc-Si PV/T system and (3). 1.2 kWp grid-tied forced-circulation CIGS PV/T system.

PV/T systems was having the same configuration as shown in fig 10.

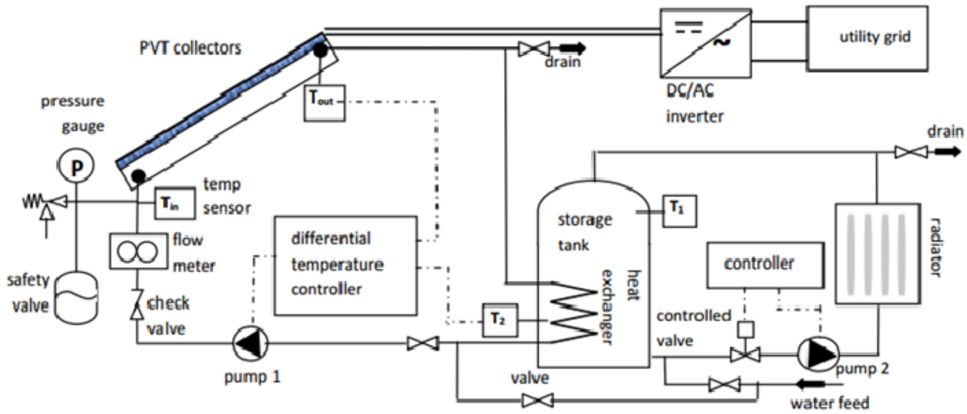

Fig. 10. The common configuration of PV/T systems(source:[22]).

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A new mc-si PV/T collector was designed with max efficiency as shown in fig 11. From the experimental data it has been found that three conversion system has three different efficiencies, ranging from 34.87% for unglazed CIGS PV/T system, 40.05% for unglazed a-Si PV/T system , 41.08% for glazed mc-Si PV/T system[23][24][25][26]

New mc-si pv/t collector has been designed by them which consist of a glass cover, ethyl-vinyl-acetate (EVA) layer, 48 mc-Si PV cells, EVA encapsulation layer, tedlar sheet, thermal collector and heat insulation material.

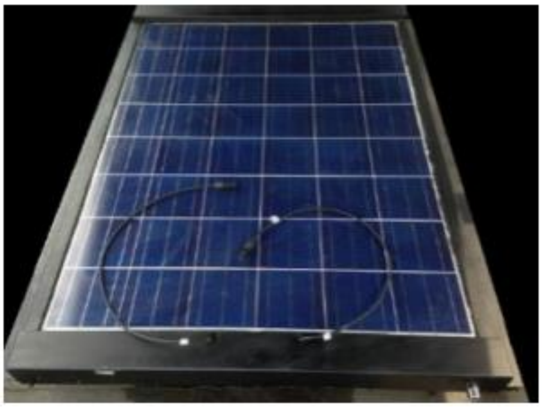

Fig. 11. Structures of flat type liquid PV/T collector. (source:[22])

Technical parameters are shown in the table 1

TABLE I: Technical data of PV/T collector.

Electrical specification	
P_{max} (W)	200
$V_{max(V)}$	24.5
$I_{max(A)}$	8.2
$V_{oc(V)}$	29.8
$I_{sc(A)}$	8.9
Solar cells	48 multi-crystalline
Certifications	IEC61215,61730
Thermal specification	
Volume of water(litre)	7.5
Collector area (m^2)	1.5
Predicted efficiency	> 48%
Heating medium	water
Length(m)	1.4
Width(m)	1.1
Thickness(m)	0.04
Weight/kg with/without water	43/35
Water temperature(˚c)	>45

Its efficiency was estimated to be higher than 48 %. It has been concluded that testing results fit the manufacturer's data closely.

V. Conclusion

Hybrid Photovoltaic thermal technology is a great advancement and is made on the detail research and reviews on its present and historical trends, which has a photovoltaic module and unit that extracts heat are moulted together. This single device converts energy into electricity and heat for future energy demand. Energy conversion rate is higher as the system provides electrical and thermal at the same time from the absorbed solar radiations than simple photovoltaic system. Different developments have been done for efficient utilisation of energy by using different types of thermal collectors and new materials for photovoltaic cells. Building integrated photovoltaic thermal system, liquid photovoltaic thermal concentrators, solar air heating photovoltaic thermal system, heat pipe based photovoltaic thermal are some of the applications of this system.

The efficiency is low of the photovoltaic thermal system because the ambient temperature is high in hot countries and there is non-availability for cooling the system. Photovoltaic cells can be cooled and heat that is produced within system can be extracted with the help of a solar thermal collector by placing it at the back of the solar PV. Water and air fluids are circulated for cooling, that helps in recovering and can be used for useful applications. The contact with the photovoltaic panel is direct in case of air and in case of water through heat exchanger. Heat generated by photovoltaic collector can be utilised within a range which is controlled by controlling the rate of flow of fluid.

It is concluded from the literature review that PV/T's are demanding devices and therefore substantial steps are needed to be taken for its development. Hence a large amount of research is required in this field especially in thermal absorbing design to increase its efficiency, reduce its cost and for better performance.

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Refrences

[1] http://www.nationmaster.com/graph/ene oil con-energy-oil-consumption.
[2] www.worldwatch.org.
[3] H. Zondag, M. Bakker, W.V. Helden, "PVT Roadmap/An European Guide for the Development and Market Production of PV–Thermal Technology," *Energy Research Centre of the Netherlands ECN*, Netherland, PV Catapult– Contract No. 502775 (SES6), 2006.
[4] DM. Chapin, CS. Fuller, GL. Pearson, "A New Silicon *p-n* Junction Photocell for Converting Solar Radiation into Electrical Power, " *Journal of Applied Physics*, vol. 25, pp. 676, 1954.
[5] CD. Grant, AM. Schwartzberg, GP. Smestad, J. Kowalik, LM. Tolbert, JZ. Zhang, *Journal of Electroanalytical Chemistry*, vol. 40, pp. 522, 2002.
[6] C. Guo, J. Ji, W. Sun, J. Ma, He W, Wang Y, "Numerical simulation and experimental validation of tri-functional photovoltaic/thermal solar collector," *Energy*, vol. 87, pp. 470-480, 2015.
[7] M.A. Hasan, K. Sumathy, "Photovoltaic thermal module concepts and their performance analysis," Renewable and Sustainable Energy Reviews, vol. 14, pp. 1845-1869, 2010.
[8] TT. Chow, "A review on photovoltaic/thermal hybrid solar technology," Applied Energy, vol. 87, pp. 365-379, 2010.

[9] TT. Chow, W. He, J. Ji, “An experimental study of facade-integrated photovoltaic/ water-heating system,” Applied Thermal Engineering, vol. 27, pp. 37-45, 2007.
[10] V. V. Tyagi, “Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology, Renewable and Sustainable energy reviews, 2011.
[11] JI. Bilbao, AB. Sproul, “Experimental results of a PVT-water module design for developing countries, in Proceedings of the 50th annual conference, Australia Solar Energy Society, 2012.
[12] J. Prakash, “Transient analysis of a photovoltaic/thermal solar collector for co-generation of electricity and hot air/water,” Energy Conversion and Management, vol. 35, pp. 967-972, 1994.
[13] F. Calise, L. Vanoli, “Design and dynamic simulation of a novel solar trigeneration system based on hybrid photovoltaic/thermal collectors (PVT),” Energy Convers Manag, vol. 60, pp. 214-225, 2012.
[14] JK.Tonuj,Y.Tripanagnostopoulos,“Performance improvement of PV/T solar collectors with natural air flow operation, Solar Energy, vol. 82, pp. 1-12, 2008
[15] M. Farshchimonfared, JI. Bilbao, AB. Sproul, “Channel depth, air mass flow rate and air distribution duct diameter optimization of photovoltaic thermal (PV/ T) air collectors linked to residential buildings,” *Renewable*, vol. 76, pp. 27-35, 2015.
[16] JK Tonuj, Y. Tripanagnostopoulos, “Air-cooled PV/T solar collectors with low cost performance improvements,” *Solar Energy*, vol. 81, pp. 498-511, 2007.
[17] JK Tonuj, Y. Tripanagnostopoulos, “Improved PV/T solar collectors with heat extraction by forced or natural air circulation,” *Renew Energy*, vol. 32, pp. 623–37, 2007.
[18] T.Lj. Kostic, TM. Pavlovic, ZT. Pavlovic, “Optimal design of orientation of PV/T collector with reflectors,” *Applied Energy*, vol. 87, pp. 3023-3029, 2010.
[19] JS. Coventry,”Performance of a concentrating photovoltaic/thermal solar collector,” *Solar Energy*, vol. 78, pp. 211-222, 2010.
[20] G. Mittelman, A. kribus, A. Dayan, “Solar cooling with concentrating photovoltaic/thermal (CPV/T) systems,” *Energy Conversion and Management*, vol. 48, pp. 2481-2490, 2007.
[21] H. Davidsson, B. Perers, B. Karlson, “Performance of a multifunctional PV/T hybrid solar window,” Solar Energy, vol. 84, pp. 365-372, 2010.
[22] T. Lj. Kostic, TM. Pavlovic, ZT. Pavlovic, “Optimal design of orientation of PV/T collector with reflectors,” *Applied Energy*, vol. 87, pp. 3023-3029, 2010.
[23] T. P. Seng, J. Fan, and G. L. Hua, “Solar photovoltaic/thermal (PVT) test-bed,” in *Proceedings International Congress on Informatics, Environment, Energy and Applications*, Singapore, 2012.
[24] J. Fan, T. P. Seng, and G. L. Hua, “Development of an unglazed solar photovoltaic/thermal (PV/T) collector, in *Proc. International conference on Clean Energy*, Quebec, Canada, 2012.
[25] J. Fan, T. P. Seng, L. K. On, and G. L. Hua, “Experimental study on glazed mc-Si solar photovoltaic/thermal (PVT) system,” in *Proceedings the 6th International Conference on Applied Energy*, Taipei, Taiwan, 2014.
[26] J. Fan, T. P. Seng, G. L. Hua. L. K. On, and K. Loh, “Design and Thermal Performance Test of a Solar Photovoltaic/Thermal (PV/T) Collector,” Journal of Clean Energy Technologies, Vol. 4, Y. Tripanagnostopoulos, “Air-cooled PV/T solar collectors with low cost performance improvements,” *Solar Energy*, vol. 81, pp. 498-511, 2007.