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# Review of hybrid photovoltaic thermal(PV/T) water based system

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**ABSTRACT**

*Photovoltaic thermal collectors (PV/T) have proven to be an effective and viable method of producing electricity and thermal energy for low grade heating application with reduction in carbon emission. With the growing awareness of benefits in PV/Thermal application, a review of PV/T water heater with PV cells mounted on the absorber is carried to be able to retrofit on rooftops.The combined system proves to be much energy efficient with improved electrical efficiency due to cooling of PV cells and higher thermal efficiency gained due to heat absorbed by the fluid from the heated PV Cells. The utilization of the system is more effective compared to employing the PV alone, however economic competitiveness depends on the technology used.The paper carries out a critical review on the PV and thermal absorbers with various integration methods for the purpose of designing a combined PV/T modules. An overview of different PV/T applications is initially summarized and subsequently various combinations of designs for PV/T water heating application is discussed and summarized in terms of their advantages/disadvantages. Compared to traditional PV module the PV/T water heating module with BIPV panel and roll-bond heat exchanger with ethylene-vinyl acetate based lamination seems to be the best option when compared with conventional method of PV with sheet-and-tube structure, the former combination is promising due to the significant enhancement in terms of efficiency, leakproofness, light weight and cost. Lastly suggestions for further research works are proposed. The overall review will provide useful information for further development of solar PV/T modules with high efficiency and low cost for widespread application at all levels.*

***Keywords- Photovoltaic Thermal Collectors (PV/T),PV/T Water Heater.***

## I INTRODUCTION

The energy of the sun is inexhaustible and conversion of solar energy to electrical energy using PV cell system is an effective method of using solar energy with an average efficiency ranging between ten to twenty percent for all types of PV cells. The photovoltaic modules for power generation are a combination of photovoltaic cells in series and parallel with auxiliary systems which are dependent on the availability of effective solar irradiation, module temperature and other weather parameters including shading factor. The advantage of PV system are most significant due to various environmental considerations as well as clean energy production. It is a low noise device as there are no moving parts as well as do not pollute the environment while producing electricity, which means that the carbon dioxide produced are very less per unit energy produced with respect to the energy from fossil fuel. A photovoltaic cell with efficiency fifteen percent means it is capable of converting one sixth of solar irradiation energy into electricity. Photovoltaic energy has great potential as it has the ability to efficiently work as standalone on rooftops as well as larger solar farms with reducing the transmission complexities when combined with a microgrid. Today the society is facing the most effects of industrial revolution in the history of mankind and there is a need to reduce the effect of global warming to acceptable levels and therefore there is a dire need to bring new technologies capable of providing clean energy solutions.

Most of the solar energy is used either with photovoltaic or thermal systems to produce electricity or heating application. If both the systems are used together and if the combined system provides us an efficient system with greater overall efficiency then it stands a great importance considering available restricted rooftops on the buildings. Here on combining photovoltaic and thermal system into one module the photovoltaic thermal (PV/T) module, the per square meter overall efficiency(electrical and thermal) can be increased along with reduced manufacturing cost.

Previously various researchers have carried out the study of PV/T in different combination which will be discussed in the section “Researches about PV/T technology”.The purpose of the PV/T water system is to provide efficient conversion of PV cell with cogeneration of hot water. The efficiency enhancement of PV conversion from solar to electricity is by cooling the cell with water at ambient temperature using a thermal absorber. This paper carries out a critical review of various PV, thermal absorbers and various integration methods for the purpose of designing a combined PV/T modules. Finally the paper compares a PV module,traditional PV/T using Polycrystalline PV module and copper sheet-and-tube structure thermal absorber with that to PV/T module using BIPV panel and roll-bond heat exchanger.

## II WHAT IS PVT TECHNOLOGY

PV modules are well known solar electricity generating components and the solar efficiency of the PVs is a parameter associated with the cells’ materials and temperature. In general,the PVs ’electrical efficiency is in the range 6–18%, which is a value measured at the Nominal Operating Cell Temperature (NOCT). The solar electrical efficiency of the PV cells falls with the rise of its operating temperature. To increase electrical efficiency of the PVs and make good use of the incident solar radiation, it is most desired to remove the accumulated heat from the concealed PV module surface and use this part of heat appropriately. The PV/T is a technology developed for this purpose which combines the PV cells/modules and heat extraction components into a single module. This allows cooling of the PV cells leading to increased PV module electrical efficiency and in the meantime, simultaneously utilizing the extracted heat for heating purpose. By doing so, the PV/T solar collector can obtain the enhanced overall solar efficiency and thus provide a better way utilizing solar energy. The PV/T, merging PVs into the solar thermal module, represents a new direction for renewable heating and power generation. A typical PV/T module is a sandwiched structure comprising several layers, namely a layer of photovoltaic cells or a commercial PV lamination with beneath the cover with a small air gap/tubes or flowing channels through the absorber which closely adhered to the PV cell layer and a thermally insulated layer located right below the flow channels. All the layers are fixed into a framed module using the adequate clamps or various joining methods and connections. For a PV/T module, the solar irradiation with the wavelength from 0.6 to 0.7 m is absorbed by the PV cells and converted into electricity, while the remaining irradiation is mostly transformed in form of thermal energy. The PV/T module can collect solar energy at different grades (wavelengths) and consequently lead to an enhanced energy and exergy efficiency . According to Zang and Zhao et al. [1], the PV/T module could collect and convert higher percentage of solar energy than either an individual PV panel or thermal collector do at the same absorbing area and therefore, offers a potential creating a low cost and highly effective solution for heat and power generation.A schematic of a typical PV/T module structure is as below in fig. 1

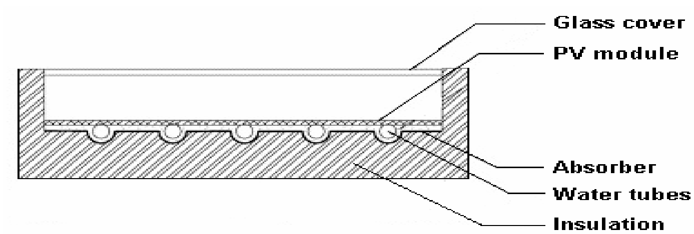


**Fig. 1 schematic of a typical PV/T module structure**

## 2.1 Classification of PV/T

The PV/T modules could be structurally and functionally very different. The PV/T can be classified in many ways,however broad classification is based on the type of coolant as air, water, refrigerant and heat-pipe fluid based types further it can be divided into flat-plate, flexible and concentrated, depending on the type of PV module as referred by Jinshun Wu and Xingxing Zhang[2].

(a) Air-based PV/T : An air-based PV/T module is a solar air heater with an additional PV layer laminated on the top or bottom of the naturally or mechanically ventilated air channels. This PV/T type could be formulated by incorporating an air gap between the PV modules’ back surface and the building fabric (facade or tilted roof). Usually, this type of PV/T module is designed for the end-users who have demand in hot air, space heating or increased ventilation, as well as the electricity generation. For this type of module, air could be delivered from above, below or on both side of the PV absorber, as shown in Fig 2 below.

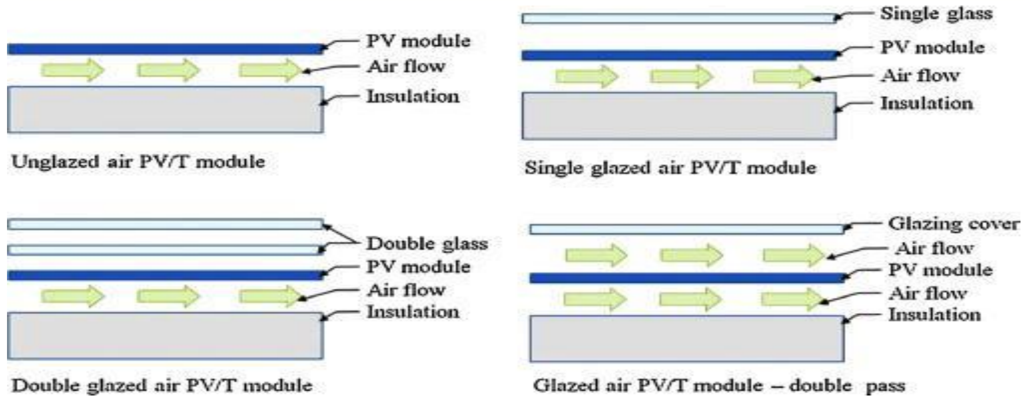


**Fig.2 schematic representation of air-based pv/t**

(b) Water-based PV/T : A water-based PV/T module, as shown in Fig.3, has a similar structure as the conventional flat-plate solar collectors. The absorber is a serpentine or a series of parallel tubes underneath. Water is forced to flow across the tubes and if the water temperature remains lower, the PV cells will be cooled, thus leading to the increased electrical efficiency. In the meantime, the passing water will be heated by absorbing the PV heat and will be delivered to certain heat devices to provide heating. This part of water may be consumed; or alternatively cooled in the heating services and flows back the module to regain heat. Compared to the air-based system, the water-based PV/T systems could achieve the enhanced cooling effectiveness due to higher thermal mass of water over the air and therefore both the thermal and electrical efficiencies of the systems would be higher.

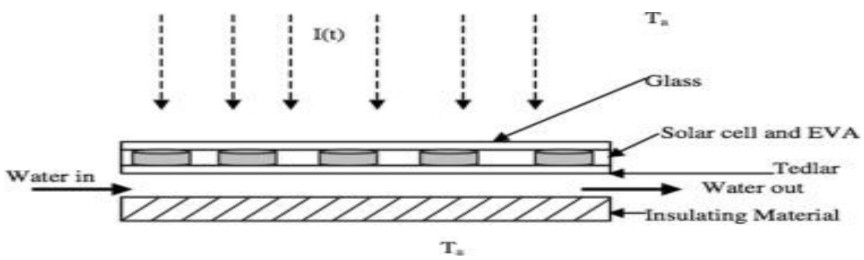


**Fig.3 schematic representation of water-based pv/t**

(c) Refrigerant based PV/T : The refrigerant-based hybrid PV/T heat pump systems have been studied by researchers. Initially researchers had proposed a simple PV/T hybrid collector connected with heat pump systems. Recent studies suggest a novel concept of hybrid PV/T module for heat pump application. The module design the direct expansion evaporator coils lays underneath the PV module which allow a refrigerant to be evaporated when passing through the module. Thus coils would act as the evaporation sector of the heat pump, which will allow the refrigerant to evaporate at a very low temperature approx in the range 0–20◦C. The PV cells would in turn would be cooled to a similar low temperature, which will result in significant increase in the module thermal and electrical efficiency. The compressor in the heat pump will increase the pressure of the vapour generated from the module and deliver it to the condenser to provide heating. The compressor would be driven by the PV generated electricity, creating a solar powered heat pump independent of fossil energy.

The PV/T hybrid technologies can further be divided into flat-plate, flexible and concentrated, depending on the type of PV module as shown in fig 4 below

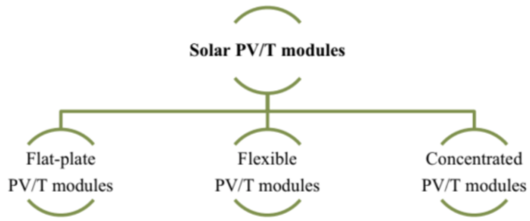


Fig.4 Types of pv module based on shape

(a) Flat-plate hybrid PV/T modules. The hybrid flat-plate PV/T modules usually combine a flat-plate PV panel in the front converting sunlight into electricity, with a solar thermal absorber at the back, which captures the remaining energy and removes excessive heat from the PV module. The capture of electricity and heat simultaneously allow these devices to have higher exergy [4] and therefore have greater overall energy efficient than solar PV or solar thermal alone [5]. A significant amount of research has gone into developing the hybrid flat-plate PV/T technology since the 1970s [6]. Flat-plate PV/T modules are produced in regular flat shapes that could be applied in rooftops, wall mounted etc and for building energy supply. Each module is fitted with a tubular inlet and outlet at the back or the side that allow for connection between module to module in either a serial pattern to allow the working fluid to pass through from one to another, or a parallel pattern. It is feasible to make further use of the absorbed heat through a heat pump for one or more of the following purposes like hot water supply [7–9], space heating [10,11], solar cooling [12,13], thermal storage [14], desalination [15], drying [16,17] and pool heating [18,19] etc.

(b) Flexible hybrid PV/T modules. Flexible hybrid PV/T panels have an almost identical structure as compared to hybrid flat-plate panels aside from the PV layers. They are often made of amorphous silicon (a-Si). The flexible hybrid PV/T modules include thermal pipes or air space beneath the metal sheet supporting the PV, which may be installed above on the current rooftop structure in the case of building retrofits.

(c ) Concentrated PV/T modules. The concentrated PV/T module, consists of upper glazing, mirror compound parabolic concentrator (CPC), high-temperature PV layer, thermal pipe and thermal insulation. The PV cell is pasted on the under surface of solid CPC. The higher concentration ratio are expected in the concentrated PV/T modules in order to generate higher temperature thermal energy,mostly in case of roof or ground-mounted installation, allowing for a wide range of applications, such as solar air or water heater and solar air conditioner etc.

## III EVOLUTION OF PVT TECHNOLOGY

The evolution of hybrid PV/T water heater system started with the need for cooling the PV cell to improve its conversion efficiency. In practice only fifteen to twenty percent of the solar irradiation can be transformed into electricity, the rest being wasted as heat. PV module efficiency decreases at a rate of approximately 0.40–0.65% with a one-degree increment of module temperature. PV module temperature can reach as high as 80 degree Centigrade particularly in hot regions. So, efforts are being given to improving the efficiency of the photovoltaic cells by controlling the cell temperature. The reason for requirement of cooling in solar PV module is due to the reduced conversion efficiency by solar PV module due to impact of temperature on PV module.

### 3.1 Temperature impact on PV module

The temperature drops the performance of PV cell. PV modules require solar irradiation for electricity generation, but the heat from the sun deteriorates their conversionability.The most affected parameter due to temperature rise in a solar photovoltaic cell or PV module is its open-circuit voltage. The properties of solar cell materials is also affected by the temperature. The temperature coefficient , drop in voltage per unit rise in temperature of a particular material characterizes the temperature dependence of the PV module performance. For polycrystalline PV modules, the voltage drop is 0.12 V for each degree rise in cell temperature. So the temperature coefficient is 0.12 V/C for polycrystalline cells. The effects of irradiance and temperature rise on the power output of a PV cell is as shown in Fig. 5 below.

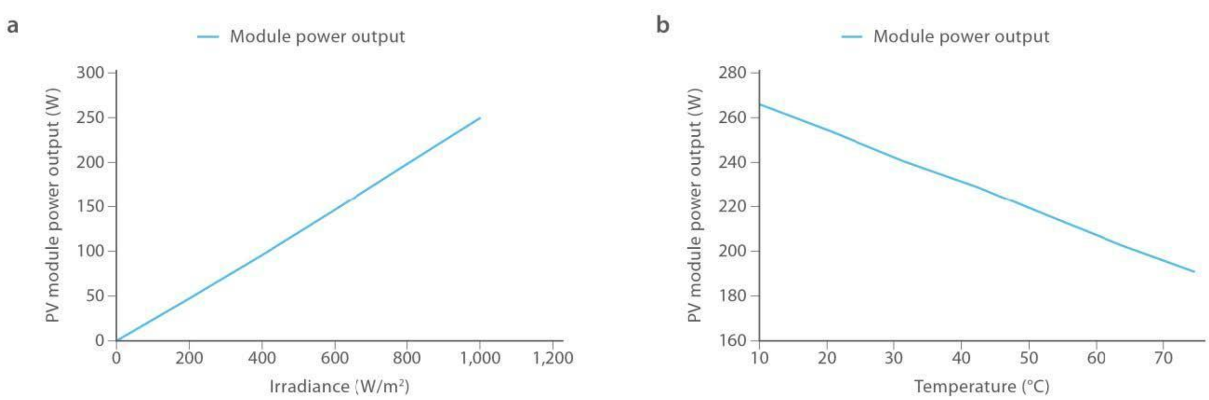


**Fig.5 The effects of irradiance and temperature rise on the power output of a PV cell**

### 3.2 Construct of solar PV module

The PV module is a combination of many material sandwiched as shown in fig. 7 to produced desires effect,of which solar cell is the primary solar to electricity conversion material. The module components include the following:-

(a) Glass. The front glass is the heaviest part of the photovoltaic module and it has the function of protecting and ensuring robustness to the entire photovoltaic module, maintaining a high transparency.

(b) EVA. One of the most important materials is the encapsulation,which acts as a binder between the various layers of the PV panel. The most common material used as an encapsulation is ethylene vinyl acetate(EVA) as shown in fig 6. it is a translucent polymer sold in a roll. it must be cut in sheets and deposited before and after the photovoltaic cells. When subjected to a thermal process of vacuum cooking, this particular polymer becomes to a transparent gel and incorporates the photovoltaic cell.

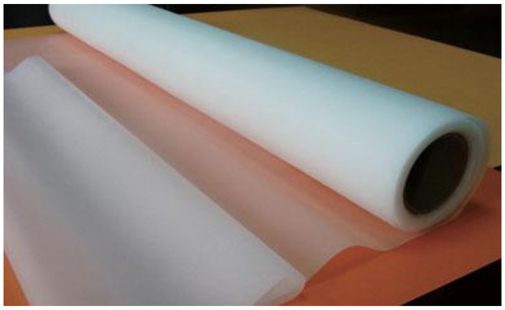

**Fig.6 Ethylene vinyl acetate sheet**

(c) Backsheet. This is made from plastic material which can electrically isolate,protect as well as shield the PV cell material from weather and moisture. This sheet is usually white in colour. Tedlar Polyester Tedlar(TPT) is used.The tedlar refers to Polyvinyl fluoride , a thermoplastic fluoropolymer material. The tedlar features high weather resistance and strength which has low permeability of moisture and vapor and used in a wide temperature range between -70°C to +110°C.The tedlar if transparent allows for a high degree of light spectrum permeability. The alternatives is Polyethylene terephthalate (PET) based backsheets.

(d) Ribbon. It is a hot dip tinned copper conductor installed in photovoltaic panels which is interconnected in series and parallel. The interconnected ribbon is soldered directly into silicon crystal.The ribbon carries the current generated in solar cells to bus bar.

(e) Junction box. The function of junction box is to bringing the electricity of the PV module outside the module. It consist of protection diodes for shadows as well as the cables for the connection of the panels. In choosing junction box attention is to be payed to the quality of plastic, goodness of sealing, type of connection of the ribbon as well as the quality of bypass diodes.

(f) Module Frame. One of the last parts to be assembled is the frame. It is normally made of aluminium and has the function to ensure robustness and safe coupling to the photovoltaic module.Together with the frame a layer of silicon solvent is deposited around the walls of the panel as a moisture barrier.

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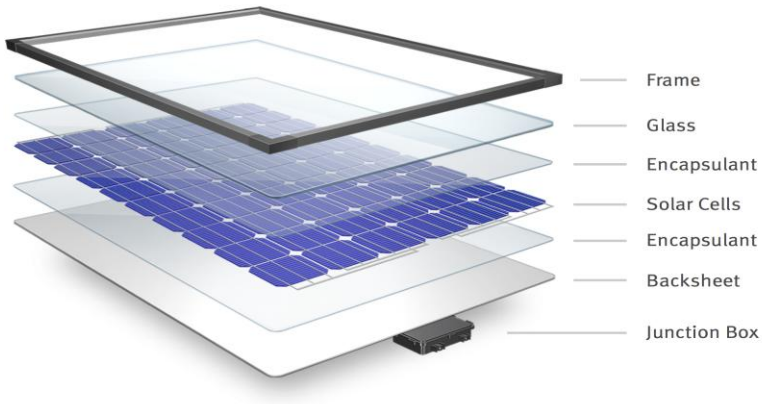
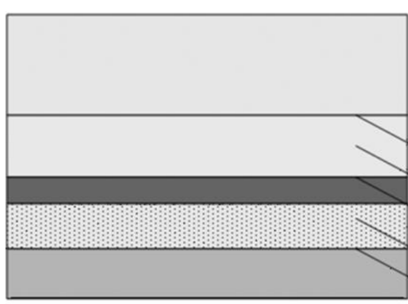



**Fig.7 Representation of pv module laye**

## 3.3 Thermal properties of major PV module components

Glass, EVA encapsulation on PV cell is used to is used to encapsulate PV cells and prevent environmental degradation, however these materials have low thermal conductivity. The multiple layers found in a typical PV laminate are shown in Fig 8 .Using the values in Fig 8, the calculated conductivity of the composite is approximately 0.82W/(m·K). If the conductivity of the EVA layer on the backside of the PV cell is increased from 0.23W/(m·K) to 2.85W/(m·K),the overall composite conductivity increases by nearly 25% to 1.02W/(m·K). Hence the EVA layer below and the tedlar layer is a challenge in PV cooling. Hence there is a need to identify PV modules with better thermal conductivity to increase the overall electrical and thermal efficiency. The table in the fig 8 represents various thermal conductivity of layers based on its thickness



| Layer | Layer Thickness (m) | Thermal Conductivity (W/m•K) |
|---|---|---|
| Glass | 0.003 | 0.98 |
| EVA | 0.0004 | 0.23 |
| Solar Cell | 0.00018 | 148 |
| EVA | 0.0004 | 0.23 |
| Tedlar | 0.0005 | 0.36 |

**Fig 8. Representation of various layers of PV with there thermal conductivity**

## 3.4 Classification of PV Cells

Most of photovoltaic solar panels used commonly are silicon based or a variations of it. There are different types of PV modules like tiles or film which are lightweight. The main difference in solar panels is the purity or alignment of the silicon. The more perfect the alignment of molecules of silicon the better it as at converting solar irradiation into electric power.

(a) Monocrystalline PV panel. The most effective of the solar PV modules with 15% efficiency, monocrystalline silicon cells are expensive compared to others. It requires less space than other cells simply because they produce more energy and generates up to four times more power than thin-film solar cell as of know. They have a longer life than other PV panels and perform better at low light. The main disadvantage is the cost per unit area . It is also affected by dirt and shade which can break the circuit. The production process is often seen as wasteful because the cells have to be cut into wafers.

(b) Polycrystalline or multicrystalline PV panel. It has an efficiency of 13%, polycrystalline PV panel are often a better economic choice. They are made from a number of smaller silicon crystals that are melted together and there after recrystallized. The production process is often simpler and less wasteful than with monocrystalline panels, however they do get affected more at high heats that can reduce their lifespan. The main disadvantage for polycrystalline PV panels is the lower energy conversion efficiency.

(c) Amorphous/thin -film PV panels. It has an efficiency of 7%, thin film PV panels are among the least efficient, however they are cheapest option. It works well in low light and are made from non-crystalline silicone that can be transferred in a thin film onto another material such as glass. The main advantage is that it can be mass produced at a much cheaper cost but is more suitable for situations where space is not a big issue.The main disadvantage for thin film solar panels are not generally used for residential purposes and will degrade quicker than crystalline cells.

(d) Hybrid silicon PV panels. It has an efficiency of 18%, hybrid PV panels are made from a mix of amorphous and monocrystalline cells to generate maximum efficiency. Various researches have been carried out with different combinations. They are still very much at the research and development stage.

A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers, or thin film of photovoltaic material on a substrate, such as glass, plastic or metal and were as a wafer is a thin layer or a substrate.

## 3.5 Thermal Absorber

Thermal absorbers for PV/T hybrid modules are complementary to PV cells as another way of getting solar energy. The overall conversion efficiency of hybrid PV/T module increases with the efficiency of its thermal absorber. Different types of thermal absorber design are namely sheet-and-tube structure, rectangular tunnel with or without fins or grooves, flat-plate tube, microchannel heat pipe array, extruded heat exchanger, roll-bond heat exchanger and cotton wick structure .Jinshun Wu and Xingxing Zhang[2].

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(a) Sheet-and-tube structure. The sheet-and-tube structure dominates the absorbers types in solar thermal application. Fig.9 shows four sheet-and-tube structures types that are commonly employed as the thermal absorbers for different PV/T modules [19–23]. In the flat-plate absorber, metal sheet is enwrapped or bonded to a metal tube [24].

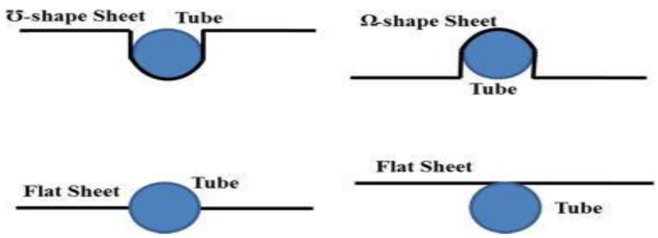


**Fig. 9. Four sheet-and-tube structures as thermal absorber for PV/T modules**

The metal sheet offers a contact between the PV layer and the tube as well as works in conjunction as the fin function to enhance the overall heat transfer efficiency from the PV layer to the working fluid inside the tube. The sheet-and-tube structure is the most common thermal absorber, having a high pressure bearing capacity [25] as well as good heat-transfer efficiency which is estimated to be approx 2% less efficient [19] as compared to other designs. It requires precise welding technology, sheet-and-tube structures can be manufactured by well-established industry at an attractive cost. However, the groupings of metal tube arrangements often add a lot of weight to PV/T modules which limits their application on buildings in large-scale projects.

(b) Rectangular tunnel with or without fins or grooves. Rectangular tunnels is as shown in Fig. 10 are the most basic but a promising structures as thermal absorbers for PV/T modules. It is constructed from metal sheets or a polymer materials in separate channels. It is easy to be integrated with PV module. This type of thermal absorber is characterized by their simple structure, low weight, low cost and relatively low heat transfer efficiency. They are normally applied in large-scale PV/T projects where an equilibrium between the investment and the amount of energy harvested is attainable.

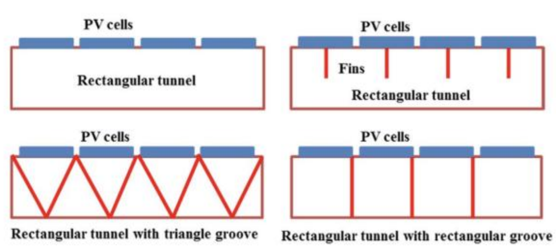


**Fig.10 Representation of rectangular tunnel with or without fins/grooves**

(c) Flat-plate tube. The flat-plate tube absorber has flattened tubes in a round tube configuration, making it easier for integration with a PV module. There are various types of designs of which spiral and coil are mostly used. The flat plate tube absorber can be made of rectangular hollow tubes of metal using a welding method for tube connection. This type of absorber has a single unilateral channel for the fluid flow as shown in Fig. 11.

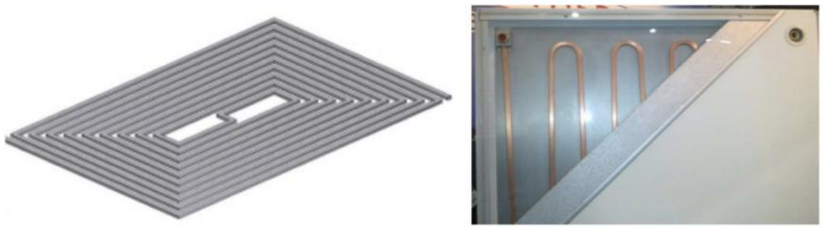

**Fig.11 spiral or coil configuration of flat plate absorber.**

The flat-plate tube absorber has at one inlet and outlet to allow the working fluid to enter exit. This kind of thermal absorbers has an improved contact between PV layer and absorber plate from line to surface , but they still have problems in increasing fluid temperature along flow direction as well as high flow resistance. There is a risk of leakage and choking. Most of flat-plate tube absorbers are only applied in water cooled flat plate PV/T modules, which therefore is a limitation.

(d) Micro-channel heat pipe array. Micro-channel heat pipe array (MHPA) , is a flat-plate heat pipe based thermal absorber suitable for flat-plate and flexible PV/T modules.

(e) Extruded heat exchange. In this type a single layer of steel sheet is extruded into corrugations and then attached beneath the back sheet of the PV layer as shown in fig 12. This thermal absorber is made up of two parallel thin flat-plate metal sheets, one of which is extruded by machinery mould to form arrays of pin-fin banks, while another sheet remains smooth in order to fit beneath the PV layer. A laser-welding technology is applied to join them together, forming up the built-in turbulent flow channels. The heat exchanger is extruded into a particular flow pattern that allows the working fluid to pass through. These types of thermal absorbers could be produced at low cost . There can be different arrangement and combination of the extruded corrugations and can form up various flow channels by eliminating complex tubing system.,hence the channel structures can feature a high complexity without any additional costs. These thermal absorbers usually require a high volume of fluid flow due to the relatively low heat transfer coefficient.

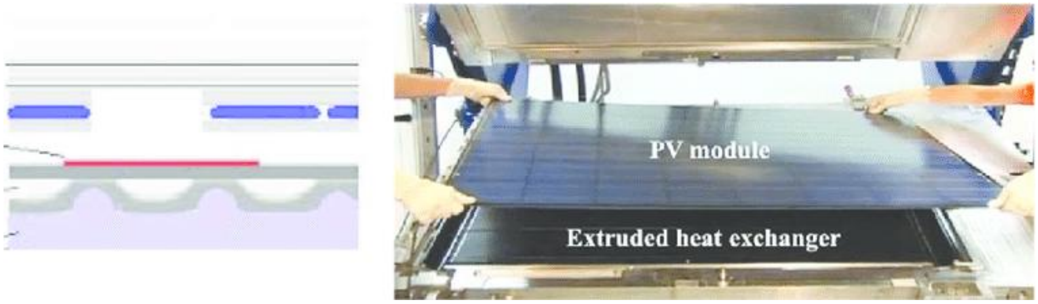


**Fig.12 Representation of extruded heat exchange**

(f) Roll-bond heat exchanger. Roll-bond technology is widely employed for the manufacturing of heat exchangers, such as evaporators for refrigeration and radiant panels It is now also popular in cooling the flat-plate and flexible PV modules [26–33]. Roll-Bond heat exchangers are manufactured using a well-established production process that foresees the construction of panels with various channel configurations by a sandwich bonding technique, using two 99.5% pure aluminium sheets, based on a rolling process and a consequent inflation process . Fig. 13 displays a roll-bond heat exchanger for PV/T modules with two aluminium sheets.

**Fig 13. Representation of roll-bond heat exchanger**

Before bonding the inner surface of one aluminium sheet will have desired pattern of flow channels printed onto it with serigraphic process. A special graphite ink is used to prevents welding of the inner surfaces. The unbonded pattern of channels is elevated by inflating the sheet with air at high pressure. The thermal absorbers with roll-bond technology enables the customization and optimization of the fluid channels to achieve higher efficiency in a cost-effective way. This features allows for a more uniform temperature distribution across the absorber with respect to the standard sheet-and-tube structure. However further research has to address the long-term reliability and corrosion risk of pure aluminium sheets within these roll-bond heat exchangers.

(g) Cotton wick structure. It is a passive thermal absorber. It is used in conjunction with cotton wicks. The absorber have recently been developed for controlling the temperature during operation of flat-plate PV module.

### 3.6 Integration methods for PV/T modules

A PV/T module is assembled by attaching a commercially available PV panel to a thermal absorber using various techniques such as mechanical or chemical bonding. The integration is a critical aspect that directly influences a PV/T module efficiency.

(a) Direct contact type. Some air or water based flat-plate or flexible PV/T modules have direct contact between the PV layer and the working fluid .

(b) Thermal adhesive. Thermally conductive adhesives are the most widely used method in integration of PV layer with the thermal absorber for all kinds of PV/T modules, which include epoxies, silicones and elastomeric solutions with the thermal conductivity ranging from 0.8 to 11.4 W/m-K, depending on the geometry. Thermal characteristics include high thermal conductivity, low electrical conductivity, extreme operating temperature range, good elongation properties, which improves the overall efficiency of the PV/T module greatly . This thermal adhesive integration method is a simple and cost effective. The disadvantage is the uncertainty as to its long-term performance in cases of high solar intensity as well as the risk of mini air gaps/bubbles forming. The imprecise thickness between the PV layer and thermal absorber can also cause poor performance.

(c) EVA based lamination. A ethylene vinyl acetate (EVA) based lamination method can eliminate risks, such as imprecise thickness of adhesive, formation of air-gaps or bubbles etc between the PV layer and the thermal absorber. It is possible to replace the TPT back sheet of the PV layer with an EVA attached thermal absorber, with conductivity ranging from 0.31 to 5.56 W/m-K depending on the vinyl acetate content and the way the material are used. Presently the researches demonstrate that the transparent EVA sealant can be applied to combine the PV layer and thermal absorbers through the PV vacuum lamination chamber in most flat-plate PV/T modules.To further reduce the thermal resistance between the PV cells and the fluid, researchers replaced the TPT back sheet of PV cells with the metal sheet [34,35].

(d) Mechanical fixing type. The integration of the PV layer with thermal absorber through mechanical fixing is also very common in most of the flat-plate and concentrated PV/T modules by several specially designed mounting brackets.

## IV RESEARCHES ON HYBRID PV/T WATER BASED TECHNOLOGY

B. J. Huang et.al[36] studied the performance of an integrated photovoltaic and thermal PV system as compared to a conventional solar water heater.A polycrystalline PV module was used for making a PV/T collector.The results of the experiment showed that the solar PV/T collector made from a corrugated polycarbonate panel obtained a better thermal efficiency. The primary energy saving efficiency of the system exceeded 0.60 which was higher than that for a pure solar hot water heater or standalone PV system. Niccolo Aste, Fabrizio Leonforte and Claudio Del Pero [37] had designed a glazed PV/T system made with thin film PV technology and a roll-bond flat plate absorber with water as heat transfer fluid. The study showed that the PV/T technology presents an higher overall efficiency than the simple PV module in terms of primary energy. Arvind Tiwari , Swapnil Dubey, G.S. Sandhu, M.S. Sodha and S.I. Anwar [38] studied an analytical expression for the water temperature of an integrated photovoltaic thermal solar water heater system under constant flow rate for which numerical computations was carried out for the design with climatic parameters of the system used by B.J. Huang et al[36].It was observed that the daily overall thermal efficiency of the system increases with increase in constant flow rate and decrease with increase of constant collection temperature. The exergy analysis of the system was also carried out and was further noted that the overall exergy and thermal efficiency of an the system was maximum at the hot water withdrawal flow rate of 0.006 kg/s. Ahmad Fudholi, Kamaruzzaman Sopian, Mohammad H. Yazdi , Mohd Hafidz Ruslan, Adnan Ibrahim and Hussein A. Kazem [39] A simulation of water-based hybrid PV/T solar collector system with energy models was developed and the electrical as well as thermal performances of PV/T water collector were determined under 500–800 W/m2 solar radiation levels with mass flow rates ranging from 0.011 kg/s to 0.041 kg/s were introduced on different absorber designs. The results showed that the spiral flow absorber exhibited the highest performance at a solar radiation level of 800 W/m2 and mass flow rate of 0.041 kg/s. This absorber produced a PV/T efficiency of 68.4%, and a PV efficiency of 13.8%, with thermal efficiency of 54.6%. Dilsad and Metin [40] studied the hybrid PV/T system’s electrical and thermal efficiency bysimulating a mathematical model and developing a prototype of the system. A PV/T system was modeled and constructed using a thermal collector placed beneath the photovoltaic panel where the excess heat and solar irradiation through the transparent PV module was the input of the thermal collector. A transparent solar PV module was used in order to improve the total efficiency of the hybrid PV/T system by means of increasing the radiant solar energy reaching the absorber plate of the collector. The absorber plate was coated with titanium dioxide which increases the thermal output by 10%. The researcher observed that using TINOX coating had the advantage of increasing the thermal yield of the hybrid system. It was also observed that wind speed had a minor effect on the performance and that forced circulation improved the thermal efficiency. Ilaria Guarracino, Christos N. Markides, Alexander Mellor, Nicholas J. Ekins-Daukes [41] studied a dynamic model of a hybrid PVT collector with a sheet-and-tube thermal absorber. The results showed that while the thermal efficiency increases with the additional glazing, the electrical efficiency deteriorates due to the higher temperature of the fluid and increased optical losses. The study also reviewed the use of solar cell with modified optical properties in the infrared spectrum which would reduce the thermal losses of the PV/T collector at the cost of only a small loss in electrical output. Jee Joe Michael, Iniyan Selvarasan, Ranko Goic[42] studied that the high thermal resistance in a PV/T collector due to the thermal conductive adhesive, sheet and tube metal absorber reduces the heat transfer from the PV cells to the fluid and increases the overall cost of the system as well as causes non-uniform and inefficient cooling of the PV cells. Therefore in his study, a solar PV/T module was developed by laminating a thin, flat copper sheet instead of Tedlar as the bottom layer. This modification is there after integrated to a single water channel to make a collector. Primary energy saving efficiency of 35.32% was obtained at 0.01 kg/s mass flow rate, whereas the reference PV module attained 20.87%. Tomas matuska et.al.[43] studied the influence of BIPV modules on their performance and potential for use of active liquid cooling by use of building integrated photovoltaic thermal collectors by simulation analysis. Thermal output of unglazed collectors was up to 10 times higher than electricity. Electricity up to 25% higher than BIPV without cooling for warm climate and up to 15% in moderate climate. M. Piratheepan and T.N. Anderson[44] studied a combined optical and thermal model to describe the performance of a faç ade integrated BIPV/T solar concentrator PV/T system and subsequently validated with a physical prototype. It was seen that key parameters such as tube spacing, and thermal conductivity between the solar cell and the absorber have a significant effect on the overall efficiency. The system was proposed to complement to roof mounted photovoltaic systems to achieve net zero energy buildings.

## V NEED FOR PV/T TECHNOLOGY

The reasons why we need PV/T technology is to maximise the rooftop space used to generate both electricity and heat simultaneously which intern can increase PV module efficiency and replace traditional heating fuel in building inorder to reduce the emission of greenhouse gases and maximise solar utilization per unit roof area in terms of electricity and hot water application. The depletion of fossil fuels, bad impact of greenhouse gases and climate change needs to be taken care. In recent years, almost every conventional solar thermal technology has been integrated with photovoltaic (PV) technology. is combination known as photovoltaic thermal (PV/T) is a self-sustainable renewable energy technology which enhances the overall efficiency and performance of the system. A PVT technology includes PVT water collectors, PVT air collectors, Building integrates PVT systems, etc using photovoltaic modules. The technology can be a boon for the underdeveloped and developing countries as for as the energy security and environmental challenges are concerned and can significantly reduce the greenhouse gas emissions.

## VI HOW TO IMPROVE PERFORMANCE OF HYBRID PV/T WATER BASED TECHNOLOGY

The improvement in the performance can be achieved by having a suitable combination of PV, thermal absorber, suitable integration method and most appropriate mass flow rate of the fluid which can be experimentally descerend. Two different combinations are analysed here.Firstly with Polycrystalline BIPV panel and copper tube over sheet thermal absorber mechanically integrated and secondly Polycrystalline PV panel with aluminium roll bond thermal absorber laminated together.The Summary of different thermal absorbers with advantages and disadvantages is shown in the Table 2 below.

| Thermal absorbers | Advantages | Disadvantages |
|---|---|---|
| Sheet-and-tube | a. Attractive cost due to established industry<br>b. Good heat-transfer efficiency | b. Require precise welding technologies<br>c. Heavy weight<br>d. Limited application on buildings<br>e. Leakage risks |

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| | | |
|---|---|---|
| Roll-bond heat exchanger | a. Uniform temperature distribution<br>b. Cost-effective<br>c. High efficiency<br>d. Low weight | a. Problem of long-term reliability<br>b. Corrosion risk |

**Table 2 Summary of two types of thermal absorbers with advantages and disadvantages,**

Apart from the advantages shown the roll bond heat exchanger has three major advantage compared to tube and sheet thermal absorber which are mass inertia, Fin efficiency,Transmission efficiency.The thermograph image of the heat transfer spread is as shown in the fig 14

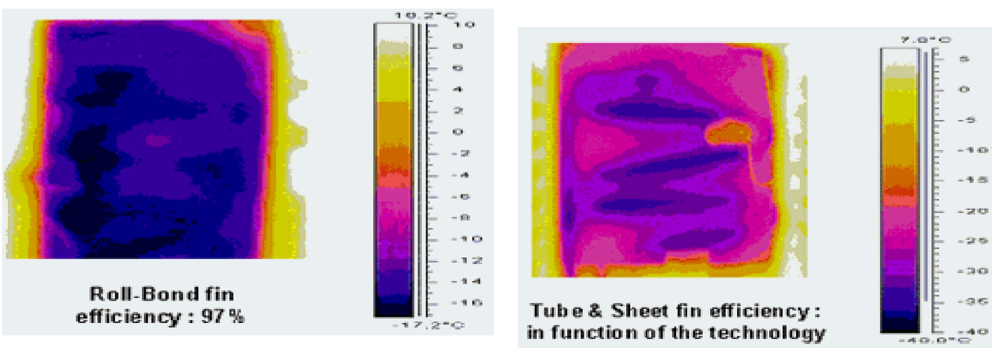


**Fig.14 Thermograph image of the heat transfer spread of roll bond and tube and sheet.**

The comparison of different integration methods with their advantages and disadvantages for their application in PV/T modules are shown in the Table 3 below.

| **Integration method** | **Advantages** | **Disadvantages** |
|---|---|---|
| Mechanical fixing | a. Mature technology<br>b. Secured firm combination | a. Increase overall cost<br>b. Increase overall weight<br>c. Small air gap exists between PV layer and thermal absorber<br>d. Weak the overall performance |
| EVA based lamination | a. Secured firm combination<br>b. Possible to eliminate TPT back | a. Careful attention needs to be paid to the cooling of lamination piece |

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| | | |
|---|---|---|
| | sheet for reduction in the overall thermal resistance<br>c. Cost-effective due to established PV manufacturing industry lines | b. Slightly low thermal conductivity |

**Table 3.Summary of different integration methods with advantages and disadvantages.**

The above comparison and the simulation on both the combination in MATLAB shows that the PV/T with Polycrystalline PV module and aluminium roll bond absorber is more efficient in terms of electrical and thermal efficiency. Hence to improve the performance of the PV/T water system various combinations depending on the efficiency and cost of PV module and the thermal conductivity of each layer of PV module,thermal adhesives, thermal absorber and the packing has to be considered based on the requirement. The integration method also governs to enhance overall efficiency, however presently it has been seen from various research papers that ethylene vinyl acetate (EVA) based lamination of the PV and thermal absorber is more superior. Further the quantity ie Liters per day ( LPD) also governs the selection and design of thermal absorber for the use in rooftops. The most important above all is to consider the dimensions of the channel in the absorber as well as the shape of the flow pattern in the thermal absorber. The decision to have a natural circulation or forced circulation is also important to achieve optimum overall efficiency. The decision of a glazed PV/T or an unglazed PV/T is also critical in achieving overall increased efficiency.

## VII CONCLUSION

A systematic review work of PV/T is carried out to understand the various combination of PV/T water system.After a critical review of the various enlisted papers it is summarized that polycrystalline PV module or BIPV polycrystalline module in combination with single sided roll bond aluminium absorber together laminated with ethylene vinyl acetate layer is a better design which can be subsequently adopted by various researchers during their PG/Doctoral program. Further a replacement of tedlar layer due to its reduced thermal conductivity by a suitable material is suggested to enhance the thermal performance. It is obvious that such type of technology has ample potential in Indian Army for the use in the shelter in high altitude areas and colder regions. This PV/T water system can be a replacement to the existing GI roofing of the prefabricated shelters there by making the shelters self sustainable in terms of electricity and hot water.

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