LITERATURE REVIEW
2.1 Hybrid PVT air/water collector system

During the starting decade of 1970’s, Wolf [11], Florschuet [12, 13], Kern and Russell [14], Hendrie [15] presented the concept that either water or air can be used as coolant. The work done during 1980’s by various scientists like Raghuraman [16], Braunstein and Kornfeld [17] and Lalovicn [18] is mainly having concentration on flat plate collectors. A system having covered area of 48 m$^2$ by PV module on the roof was proposed by O’leary and Clements [19], Mbewe et al.[20], Al-Baali [21] and Hayakashi et al. [22]. Here transparent tubes are connected to the system and these tubes are filled with black fluid which acts as absorbing medium. The electrical as well as thermal energy received from PV panel get stored in the battery in the form of electrical energy while in the two water tank of 1m$^3$ in the form of electrical energy. The outcome of variation in air mass flow, depth and length of air channel was investigated by Bhargava et al. [23].

Unglazed PVT system performance under obligatory mode of procedure for Cyprus climatic condition was investigated by Kalogirou [24] and found that there will be rise in mean annual efficiency of PV solar system from 2.8% to 7.7% with 49% of thermal efficiency. Zondag et al. [25] has done experimental studies for a model of PVT air collector for various sizes. Tripanagnostopoulos et al. [26] describes the hybrid PV/T experimental models based on commercial PV modules and test outcome shows that cooling increases the electrical efficiency of PV and as a consequence, the total efficiency of the system increases. In addition to it, the thermal output can be increased by additional glazing.

Elham and Nather [27] compares the effectiveness and cost of water unit pumped by PV systems as well as using diesel units and concludes that proved PV-battery systems can be used efficiently as well as rate of the water unit pumped by PV systems is much lesser in comparison to diesel systems. The comparison between conventional gas turbine plants & hybrid PV gas turbine plant was done by Jaber et al.[28] and findings proves that the hybrid
system is the best. By studying the performance of concentrating PVT system, Coventry [29] concluded that an overall thermal as well as electrical efficiency comes out be 58% and 11% which give 69% overall efficiency. A variety of results regarding the effect of design and operation parameter on the performance of air type PVT systems was presented by Tiwari and Sodha [30]. Tonui [31] uses the free air convective cooling for heat removal from PV module back and compares it with the forced one and concluded that free air cooling is low cost and simple but desirable cooling rate is achieved by forced scheme.

By evaluating and comparing the thermal performances of hybrid PVT air collector for glass-tedlar and glass-glass system under the composite climate of Delhi, Joshi et al.[32] concludes that glass-to-glass PV/T air collector is better than glass-tedlar PV/T air collector in numerous perspective. For thermal and electrical testing of PV/T collectors connected in series, Solanki et al. [33] developed an indoor standard test procedure and concluded that thermal and electrical efficiency of the solar heater is 42% and 8.4% respectively. Park et al. [34] investigated the effect of glazing component and showed that the power decreases about 0.48% (in STC with the exception of the temperature condition) and 0.52% (in outdoor conditions, less than 500 W/m²) per one degree raise of the temperature of PV module. A diverse approach to examine thermal and optical properties linked together PV and solar thermal functions in order to identify an optimum combination leading to a maximum overall efficiency was introduced by Dupeyrat et al. [35]. Agrawal and Tiwari [36] used the concept of series and parallel connections of micro-channel solar cell thermal tiles in analyzing overall energy and exergy of PVT module.

Agrawal and Tiwari [37] evaluated the theoretical performance of a glazed hybrid micro-channel solar cell thermal (MCSCST) tile. Consequences of design parameters on different combinations (series and parallel) of glazed hybrid MCSCST tile for Srinagar climatic condition, India, has also been
evaluated. Experimental PVT air system by Bambrook and Sproul [38] demonstrated that by increasing air mass flow rate, thermal efficiencies increases in the range of 28–55% and electrical PV efficiencies between 10.6% and 12.2% at midday. The performance evaluation of a two-way hybrid photovoltaic/thermal (PV/T) solar collector was analysed by Mortezapour et al. [39] and conclude that the glass to glass PV/T solar collector is superior in many aspect than the glass to tedlar PV/T solar collector. Rajoria et al. [40] developed a one dimensional transient model for hybrid PVT and by using basic heat transfer equations, overall thermal energy and exergy analysis for different configurations of hybrid photovoltaic thermal (PVT) array has been carried out. The performance evaluation of a solar photovoltaic (PV) array system was investigated by Sharma and Tiwari [41] which was based on electrical energy yield and power conversion efficiency.

Agrawal and Tiwari [42] did the relative examination of distinctive sort of photovoltaic warm (PVT) air collector to be specific: (i) unglazed hybrid PVT tiles (ii) glazed hybrid PVT tiles and (iii) conventional hybrid PVT air collector for the composite atmosphere of Srinagar (India). It has been watched that general yearly warm energy and exergy addition of unglazed hybrid PVT tiles air collector is higher by 27% and 29.3% separately when contrasted with coated mixture PVT tiles air collector and by 61% and 59.8% individually, when contrasted with ordinary crossover PVT air collector.

2.2 BIPVT collector system

Due to easier construction and operation, hybrid PVT systems with air heat extraction has more extensively been studied as an alternative and cost effective solution to building integrated photovoltaic systems (BIPV). By studying photovoltaic–thermal solar collectors, their technology and recent advancement, a scientific expression for room air temperature of building incorporated semitransparent photovoltaic warm (BISPVT) and misty photovoltaic warm (BIOPVT) frameworks with and without air channel has
been dissected by Vats and Tiwari [43]. A parametric study of a PV cladding for building roof and façade has been presented by Brinkworth et al. [44]. Moshfegh and Sandberg [45] and Schröer [46] have carried out design and performance studies regarding air type PVT systems. Loferski et al. [47] have given the results for a hybrid system with air circulation installed on a residential building, by using two separate one-dimensional analysis compared with test measurements. In addition, Eicker et al. [48] have reported monitoring results from a building integrated photovoltaic thermal (BIPVT) system operated during winter for space heating and during the summer for active cooling. Most of these investigations focused on simple and cheap heat extraction improvements and commercial PV modules have been used, Tripanagnostopoulos et al.[49]. Bazilian et al. [50] have evaluated the practical use of several PVT systems with air heat extraction in the built environment.

Murata et al. [51] have developed a new type of PV module integrated with roofing material (a highly fire-resistant PV tile). Yang et al. [52] have mentioned that the PV systems can easily be installed on the roof of residential as well as on the wall of commercial buildings as grid-connected PV application. They have investigated the effect of natural ventilation on power output and heat transfer across the air gap between the PV wall and PV roof. They have also studied the energy performance of BIPV systems for Hong Kong weather conditions and found that the system can provide about 41% of electric power for indoor lighting.

The applications of roof mounted, multi-operational ventilated photovoltaic and solar air collector has been studied by Cartmell et al. [53]. They have concluded that the solar cell efficiency is marginally improved. The electrical and thermal performance of PV systems (glass to glass) integrated as a cladding component in the building envelope has been evaluated by Bloem [54]. Norton et al. [55] have given the solution to enhance the performance of building integrated photovoltaic. Lu and Law [56] have developed an overall
methodology for investigating the thermal and power behavior of semitransparent single-glazed photovoltaic windows for office buildings in Hong Kong.

2.3 Energy and exergy analysis

Energy analysis, based on the first law of thermodynamics, is a traditional method which does not provide the information on the degradation of energy or resources during a process and does not quantify the usefulness or the quality of the various energy and material stream flowing through a system and exiting as a product or waste.

Exergy is the maximum work potential that can be obtained from a form of energy, Kotas [57]. Exergy analysis can clearly indicates the locations of energy degradation in a process and can therefore lead to improved operation or technology.

The exergy concept based on the second law of thermodynamics provides an analytic framework for system performance evaluation Bejan, [58]. Exergy analysis yields useful results because it deals with irreversibility minimization or maximum exergy delivery. Performance of a PVT system has been carried out by many researchers either in terms of energy or exergy. Prakash [59] has developed a mathematical model for transient analysis of PVT solar collector for cogeneration of electricity and hot air/water. They have conceded the various flow rates and duct depths for summer conditions of New Delhi. The overall PVT performance can be evaluated by the energetic (first law) efficiency. This is in fact the major evaluation approach of PVT systems in the previous studies, like the works of Garg and Agrawal [60] and Sopian et al. [61] have been on energy based. The relations between energy and exergy, energy and sustainable development and exergy and the environment in detail are reported by Dincer [62]. Exergy losses due to irreversibility in collector acts as the driving force for the system while exergy losses due to irreversibility in storage barrel are of little
contribution, Xiaowu and Bena [63]. It has been proved that exergy analysis of flat plate collector, PVT and a refrigerator is a powerful tool in the thermodynamic analysis of energy systems Lior et al., [64]. Tiwari et al. [65] have analyzed the performance of PVT air collector for the composite climate of Delhi, India and concluded that an overall efficiency of hybrid PVT thermal system increases by 18% due to gain of thermal energy.

Exergy analysis is conducted with the aim of providing some methods to save cost and keep the efficiency of the PVT system to the desired extent. Exergetic performances of solar water heater based on exergy efficiency correlation have been studied by Gunerhan and Hepbasli [66]. Exergy and its applications to various energy systems and applications as a potential tool for design, analysis and optimization, and its role in minimizing and/or eliminating environmental impacts and providing sustainable development have been discussed by Dincer and Rosen [67].

Joshi and Tiwari [68] have studied the PVT parallel plate air collector and observed that energy and exergy efficiency varies between 55-65% and 12-15%, respectively for climatic condition of Delhi, India. The popularity of the exergy analysis has grown consequently and is still growing (Rosen and Dincer, [69]; Kanoglu, [70]; Lior and Zhang [64]; Nayak and Tiwari, [71]. Performance analysis of a hybrid PVT integrated system has also been done by Radziemska [72]. He presented the concept of exergy analysis for evaluation of the PVT systems as useful tools for the improvement and cost-effectiveness of the system. Chow et al. [73] have carried out the thermodynamic analysis of a thermosyphon flat-plate PVT collector system with and without glass cover in Hong-Kong. They concluded that the energetic efficiency of the glazed collector is found always better than the unglazed collector.

However, the exergetic efficiency of the unglazed condition has been found better than the glazed condition. Dubey and Tiwari [74] have carried out the detailed analysis (energy, exergy and carbon credit) of PVT flat plate
water collectors partially and fully covered by PV module connected in series. It has been observed that the collectors partially covered by PV module are beneficial for hot water production under forced mode and collectors fully covered by PV module is better for electricity generation.

Overall energy and exergy analysis of integrated photovoltaic thermal (IPVT) water heater under constant flow rate [75], building integrated photovoltaic thermal system [76] and hybrid PVT double pass façade for space heating, Kamthania et al.[77] have also been carried out.

An evaluation of flat-plate solar water heating collector, a PV module and a single–glazed PVT collector with mono-crystalline silicon solar cell and an unglazed one was done by Fujisawa & Tani [78]. It was found that in terms of energy gain, the single glazed PVT collector is the best while in terms of exergy gain, the best performance is done by unglazed one.

2.4 Energy matrices, Energy payback time, Life cycle conversion efficiency

Recently, PVT technology is an advancement of work of researchers which was previously done. PVT technology has an added advantage of producing thermal energy along with electrical energy and that too with enhanced module efficiency. The EPBT significantly reduces and the EPF, LCCE of the PVT system increases due to the higher overall output from a PVT system.

Evaluation and comparison of the energy matrices of a PVT water collector under stable collection temperature mode with five different types of PV have been evaluated by Mishra and Tiwari [79] and they observed that the highest and least EPBT of 1.01 and 0.66 years is obtained for C-Si on energy basis and EPF, LCCE enhances with increasing the life time of the system. Under the composite climate of Delhi, energy matrices analysis has been done by Tiwari et al. [80] and concludes that by taking into consideration thermal energy in adding together to the electrical energy, the value of EPBT get
considerably reduced. In addition to it, value of EPF and LCCE become higher as expected. The similar expense investigation of the single slant passive and PV/T dynamic sun oriented stills in light of the yearly execution at 0.05 m water profundity, was investigated by Kumar & Tiwari [81]. Slesser and Houman [82] firstly, did the energy analysis by concluding that energy payback time (EPBT) which is defined as the proportion of energy consumed in PV system production to the annual generated energy by PV system comes out to be 40 years. A value of 12 years of energy payback time was obtained by study of Hunt [83]. The work of Hunt also proves the work done by Kato et al. [84] for crystalline silicon (c-Si) solar cell module. For a crystalline silicon module, the value of EPBT is 8 years as evaluated by Aulich et al. [85]. Prakash and Bansal [86] have found out the EPBT under Indian climatic condition for a crystalline silicon solar cell module for yearly crest load duration to be 4 years. Alsema and Nieuwlaar [87] have attempted to predict the EPBT for a mono-crystalline solar cell for the year 2020 taking into account the enhanced skill and the effectiveness of the solar cell. It has been concluded that the present EPBT which is 5-6 years gets reduced to 1.5 -2 years. With the efficiency of 5% under the climatic condition of Detroit, USA, Keolein and Lewis [88] have predicted the EPBT of 7.4 years for amorphous silicon while with the increment of efficiency to 9% , the value get reduced to 4.1 years. Having taken into concern gross energy requirement (GER) and concealed energy, Srinivas et al. [89] has reported that the EPBT for an amorphous silicon gets reduced to 2.6 years.

Considering the annual power production rate of .01 GW/year, the value of EPBT evaluated by Yamada et al. [90] for polycrystalline and an amorphous silicon solar cell comes out to be 5.7 and 6.3 years. Battisti and Corrado [91] have investigated that value of EPBT gets reduced from 3.3 years to 2.8 years. Agrawal and Tiwari [92] have carried out the evaluation of energy matrices of PVT air collector on the basis of annual overall thermal
energy and exergy for New Delhi and they concluded that by counting the expense of energy in the assembling of parts of the PVT module air gatherer, the payback/proficiency was expanded/diminished individually by about an element of four.

Gaiddon and Jedliczka [93] have presented the relative evaluation of selected environmental indicators of photovoltaic electricity in OECD cities on the worldwide survey. They found that the EPBT of a complete PV system was in the range of 1.6 to 3.3, a long time for a rooftop mounted framework and from 2.7 to 4.7 years for a PV-façade. The impact of PV technology on EPBT estimation in UAE commercial building has been studied by Radhi [94] and result shows that the embodied energy pay-back time for photovoltaic system is within the range of 12–13 years.

2.5 Envireoeconomic analysis

Chauray and Kandpal [95] have made an attempt to guesstimate the CO$_2$ mitigation quite a while for a housetop mounted structure and from 2.7 to 4.7 years for a PV-façade and essentialness return component (ERF) is some place around 8 and 18 for housetop mounted systems and some place around 5.4 and 10 for PV façades, considering 30 years long business life cycle. They have similarly found that the one single kWp of PV sheets can keep up a vital separation up to 40 tons of carbon dioxide in the midst of its whole business life and 23.5 tons of CO$_2$ for each kWp for PV façade. The theoretical potential number of solar home systems has been expected to be 97 million. A managerial approach of carbon credit trading was used to organize the pollution by providing extra enticement for achieving reductions in the discharge of pollutants.

At solar Energy park at IIT, Delhi, Prabhakant and Tiwari [96] presents a study of carbon credit earning based on annual experimental and theoretical performance. Prabhakant and Tiwari [97] have done an investigation of carbon credit earned by each district for supplying least
amount continuation electricity to each family and thereby maintaining energy security in India.

2.6 Exergoeconomic analysis

In the present scenario, a large portion of the frameworks are broke down and planned under thought of the mix of thermodynamics and expense bookkeeping (monetary) disciplines. The analysis which is based on exergy is known as exergoeconomic analysis or exergetic cost analysis. The exergoeconomic analysis of glazed hybrid photovoltaic thermal module air collector was done by Agrawal and Tiwari [98] and it has been concluded that the coated cross breed PVT module air system offers a more noteworthy potential contrasted with PV module as far as energy sparing investigation. The yearly general warm energy and exergy addition are 1252.0 kWh and 289.5 kWh, separately.

Exergoeconomic analysis of power plants operating on various fuels has been studied by Rosen and Dincer [99] and they concluded that the results may (i) provide useful insight into the relations between thermodynamics and economics, both in general for electrical generating stations, (ii) help demonstrate the merits of second-law analysis, and (iii) extend throughout the electrical utility factor. Exergoeconomic analysis of a solar assisted ground-source heat pump greenhouse heating system has been presented by Ozgener and Hepbasli [100] and they explained the simple thermoeconomic optimization methodologies to determine a correct design of new equipment.

Ozgener et al. [101] have presented an exergoeconomic study of geothermal district heating systems through mass, energy, exergy and cost accounting and a case study for the Salihli geothermal district heating system (SGDHS) in Turkey to illustrate the present method. Oktay and Dincer [102] presented an application of an exergoeconomic model through exergy and cost accounting analyses to the Gonengeothermal district heating system (GDHS) in Balikesir, Turkey for the entire system and its components and they found
that an increase of the load condition leads to a decrease in the overall thermal costs which will result in more cost-effective energy systems for buildings.

2.7 Performance analysis of hybrid PVT solar dryer

In the past years, villagers generally used traditional sun-drying technique for which a lot of land is required. In order to conserve the conventional energy sources, a lot of research and development work has been started. For forced convection drying, PV module powered air circulation has been used by very few researchers. The fan or blower which is used to extract the heat and fed it to the dryer is operated either by grid electricity or by the electricity which is produced by PV module itself. Forced circulation of heated air is done with the help of fan or blower. Later on development of a solar grain incorporating photovoltaic powered air circulation was done by Mumbe Ji [103] and he concluded that drying by incorporating PV driven DC fan reduces the drying time by 70% in comparison to open sun drying. A comparison of hybrid PVT air heating collector coupled with CPC & without CPC was carried out by Garg and Adhikari [104].

The transient performance of conventional PVT air collector with different configuration i.e single pass & double pass has also been analysed by Garg and Adhikari [105]. In regards to this Farkas et al. [106] developed a solar dryer PV module which can run a fan for artificial circulation of air. An innovative approach in the field of double pass photovoltaic thermal (PVT) solar collector for solar drying purpose was done by Sopian et al. [107]. A mathematical model of indirect sun drying of banana was developed by Phougchandag and woods [108] and his results found to be in good agreement with the experimental result. A new model of solar dryer was developed by Saleh and Sarkar [109] in which a separate PV panel of 20W was installed to operate a 12 V DC fan which can be further used for forced convection. Hossian et al. [110] optimized a solar tunnel dryer for chilli drying in Bangladesh and conclude that design geometry is more sensitive to costs
occurred in construction of collector, solar radiation & air velocity in the dryer in comparison to material costs, fixed costs and operating costs.

Dubey et al. [111] has done the analysis by performing their experimental work for fixed mode under no load condition during April 2008 and their experimental result validate the theoretical result for New Delhi climatic condition. Hybrid PVT green house dryer was developed by Barnwal and Tiwari [112] for grape drying in order to evaluate heat and mass transfer of the proposed model. Various experimental data regarding amount of moisture content evaporated, surface temperature of the grape, ambient air temperature and humidity, green house air temperature and humidity were also recorded. Four different type of weather conditions have been classified as Type a-d, Singh and Tiwari [113].

Sajith and Muraleedharan [114] found that the better drying performance was obtained for drying process of Amla with hybrid system in comparison to sun drying. Parikh and Agrawal [115] have designed a double shelf cabinet dryer connected to flat plate collector and studied various combinations of glass and polycarbonate sheet as glazing & thermocol as insulator. Maia C.B et al. [116] present a numerical simulation of air flow inside a hybrid solar –electrical dryer using a commercial CED package and found that the velocity and temperature of air flow are homogenous in drying chamber which is desirable and suitable for drying purpose. Mortezapour [117] has study the performance of hybrid PV/T solar dryer equipped with heat pump for Saffron drying and concluded that adding a heat pump to dryer led to the reduction in drying time & energy consumption and also increases electrical efficiency of solar collector. Sahdev [118] give his reviews regarding various greenhouse structures, constructional and working principle and concluded that greenhouse technology improves the quality of products and reduces drying time.

Mortezapour et al. [119] done the quality evaluation of Saffron drying using a heat pump-assissted hybrid PV/T solar dryer and result showed that
colouring characteristics of Saffron improves with drying temperature and heat pump system. Aromatic strength of Saffron also increased with increasing air temperature. Sajiith et al. [120] have done the economic analysis for drying of Amla fruit and found payback period to be 5.66 years which was very low compared to the life span (20 years) of the system. Aravidh et al. [121] research reviews includes different type of dryers, different aspect of solar drying, parameters involved in drying process and economic analysis and their conclusion proves that this technology should be given wider publicity.