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Comparison of Different Topologies of Building Integrated Photovoltaic Thermal Systems (BIPVT)

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Abstract: Building-Integrated Photovoltaic (BIPV) is a smart energy production system that incorporates solar PV panels as part of the roof, windows, facades and shading devices. When active heat recovery is combined with BIPV systems either in closed loop (like PV-T with liquid loop) or in an open loop with forced air they are known as building-integrated photovoltaic-thermal (BIPVT systems).The BIPVT modules are designed for both solar electricity and thermal air collector that offer heat and power consumption of heat pump for space/water heating applications. This makes air stream effectively extract the recovered heat as thermal reuse and PV efficiency consequently enhanced with waste heat removal. The result of BIPVT air collector performance evaluation reveals that the efficiency can achieves up to 56%.

***Index Terms*– Solar thermal, bipvt, solar photovoltaic.**

1. INTRODUCTION

Building integrated photovoltaic thermal (BIPVT) systems have been growing under rapid development over past decades and several buildings with BIPVT systems exist across the world [1, 2]. Different ways of installing the photovoltaic (PV) modules into a building have been illustrated by Kimura [3], Taleb and Pitts [4], and Zhai et al. [5].

These systems serve dual purpose namely:

1. Production of electrical energy and,
2. A heat source for the residence by circulation of the air behind the PV, which not only cools them, but also increase the overall electrical performance.

A building integrated multifunctional roofing system has been designed to harvest solar energy through photovoltaics (PVs) and heat utilization while minimizing PV efficiency loss and eliminating the material and labour redundancies of conventional PV systems. Silicon PV modules are embedded between a transparent protective layer and a functionally graded material (FGM) layer that is fabricated from a mixture of heat conducting aluminum and insulating high-density polyethylene with water tubes cast within the FGM. Solar energy is

Collected by the PV modules in the form of PV electricity and heat energy. Due to high thermal conductivity of the upper part of the FGM, the heat in the PV modules gets transferred into the FGM and captured by the water flowing through the embedded tubes, so the modules' temperature can be controlled and, thus, the PV efficiency can be optimized. The warm water can be used as it is gathered for heat supply in a radiant floor system or it is heat can be extracted into a phase change material (PCM) storage unit, for use during night, heating or more efficient ejection during cooler evening hours. Due to the high thermal insulation of the lower part of the FGM and heat collection by water flow, excellent indoor thermal comfort can be achieved and building cooling needs minimized thermal resistive structural substrate is integrated into the composite system to provide structural support for FGM and PV elements.

This holistic design will fulfill the basic functions of the building envelope: waterproofing, insulation, and structural strength and durability, while simultaneously producing energy and reducing energy consumption to achieve a high degree of energy efficiency and sustainability.

A prototype study has proven the concept. The performance analysis indicates that the proposed solar roofing system provides significant advantages over the traditional asphalt shingle roof and PV systems without cooling.

2. NEED OF THE STUDY

One of the promising applications of photovoltaic (PV) technologies is building integrated photovoltaic thermal (BIPVT) system. The overall efficiency of BIPVT system is better than a PVT system as the formal gives useful thermal energy in addition to the electricity. Further, a BIPVT system is better than a PVT system as it maintains a better electrical efficiency by withdrawing heat from the back surface of PV module. It provides space heating and day lighting by the use of semi-transparent PV modules. In such systems, no additional land area is required. It avoids the cost of batteries remarkably, when grid connected, Norton et al. (2011) and reduces costs and losses associated with transmission and distribution, Paatero and Lund (2006). The above properties and applications provide the scope of research and study in the field of BIPVT system.

3. Description of BIPVT system

Following two types of BIPVT systems are considered in the study:

1. BISPVT system – In this system a number of semi-transparent (glass-to-glass) PV modules are integrated to a room of building.
2. BIOPVT system – In this system a number of opaque (glass to tedlar) PV modules are integrated to a room of building. Combinations of these systems with and without air duct are described below. The classification of such integrated PV modules to a room is given in Figure 1.1.

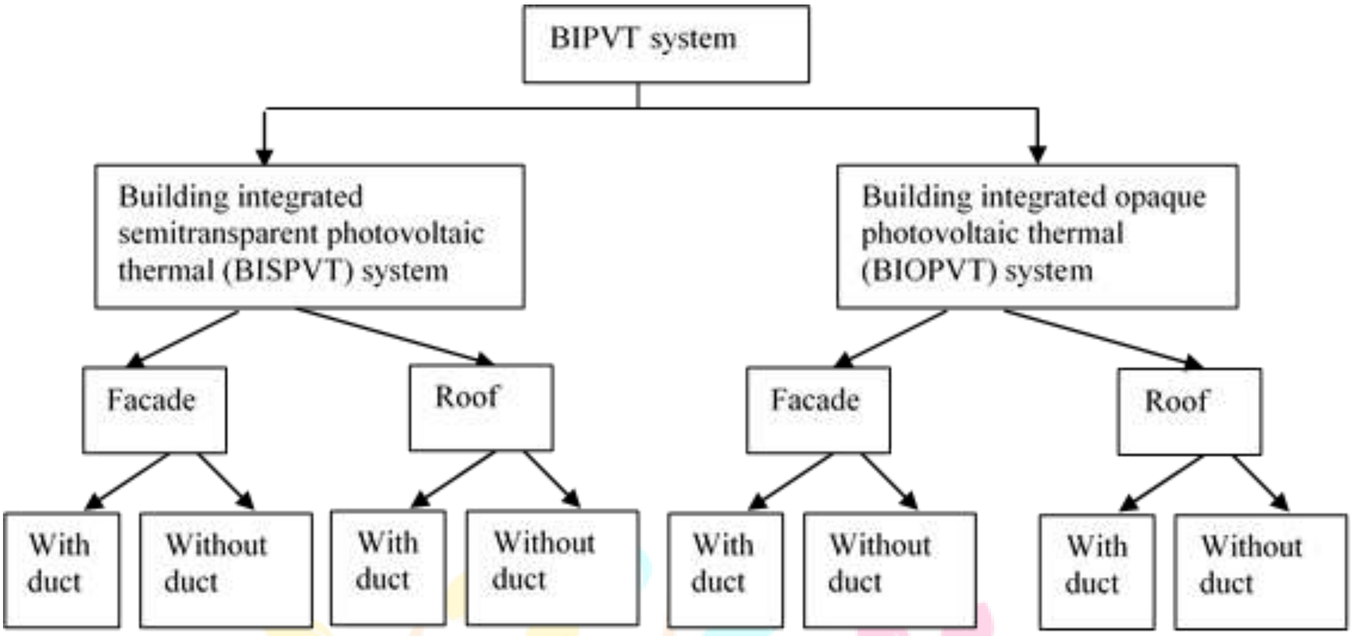

Figure 1.1: Classification of BIPVT system.

3.1. With air duct (BISPVT and BIOPVT)

The cross-section view of SPVT facade and SPVT roof integrated to a room with air duct are shown in Fig. 2(a) and (b), respectively. Fig. 2(a) shows that a SPVT facade is mounted at a distance (airgap) to the wall of a room whereas in case of SPVT roof as shown in Fig. 2(b), the PV modules are installed at angle of 34◦ to the horizontal which corresponds to latitude of the Srinagar, India. The PV modules are located outside the room and sealed from all the sides. Inlet and outlet vents are provided at the top and bottom of wall and also on the roof for the air flow. When solar radiation falls on the PV module, it gets heated. The cooler room air enters through inlet vent from bottom, takes the heat of PV module and escapes through outlet vent. Due to the density difference between cooler air (at inlet) and hot air (at outlet), the hot air at outlet enters into the room and replaces the cooler room air. For smooth circulation of air fan is provided at the outlet but not shown in figures. In this way thermal energy of PV modules is utilized for space heating. Further this reduces the temperature of PV module and increases the electrical efficiency. The cross-section view of OPVT facade and OPVT roof integrated to a room with air duct are shown in Fig. 2(c) and(d), respectively. Description of OPVT system is same as that of SPVT system except for the difference in heat generation. In SPVT the heat gain is through packing area (glass–PV–glass) and non-packing area(glass–glass), whereas in OPVT system the gain is through packing area (glass–PV–tedlar) and non-packing area (glass–tedlar).

3.2. Without air duct (BISPVT and BIOPVT)

Fig. 3(a)–(d) shows SPVT facade, SPVT roof, OPVT facade and OPVT roof integrated to a room without air duct. Inlet and outlet vents have not been provided at the top and bottom. Therefore, heat gain in the room is by natural convection. Apart from generating electrical power, the module heat is also utilized for warming up the cold weather room by BIPVT system. This study has been carried out for a room, which consists of brick and insulation material (sand, cement and polystyrene and straw fiber). Volume of room, PV modules area (consists of 9 PV modules), roof area, facade area and other parameters are taken same for both systems. Design parameters of a room of a building, semi-transparent and opaque PV module are given in Table 1.

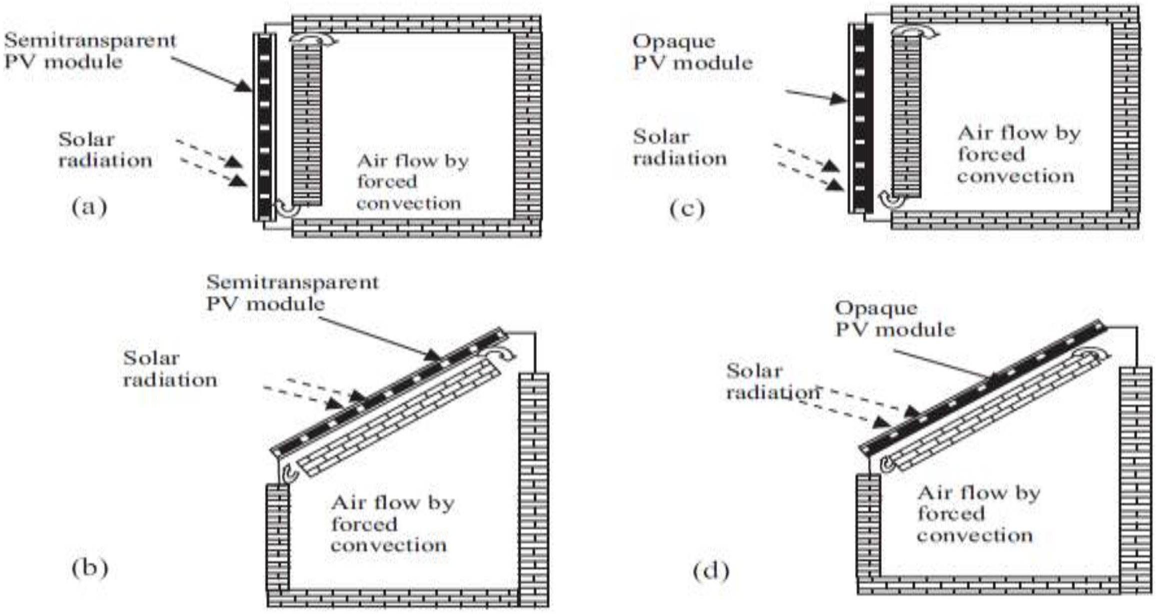

Figure 1.2

a) Cross-section view of a building integrated semi-transparent photovoltaic thermal (BISPVT) system integrated to façade of a room with air duct.
b) Cross-section view of a building integrated semi-transparent photovoltaic thermal (BISPVT) system integrated to roof a room with air duct.
c) Cross-section view of building integrated opaque photovoltaic thermal (BIOPVT) system integrated to façade of a room with air duct.
d) Cross-section view of building integrated opaque photovoltaic thermal (BIOPVT) system integrated to roof a room with air duct.

Table 1
Design parameters of a room of a building, semitransparent and opaque PV module.

Parameters	Values	Parameters	Values
b	0.605 m	η_c	0.12
L_1	1.0 m	τ_g	0.95
PV roof area	5.44 m^2	K_g	1.1 W m^{-1} K^{-1}
L_r X B_r X H_r	3 m × 1.81 m × 4 m	L_g	0.003 m
V	21.78 m^3	L_b	0.12 m
Roof inclination	34°	K_b	0.69 W m^{-1} K^{-1}
M_a	25.64 kg	L_{cm}	0.04 m
$\dot{m}_f$	0.8548 kg s^{-1}	K_{cm}	0.6 W m^{-1} K^{-1}
C_a	1005 J kg^{-1} K^{-1}	L_s	0.04 m
ρ_a	1.77 kg m^{-3}	K_s	0.049 W m^{-1} K^{-1}
ν_a	1.568 × 10^{-5} m^2 s^{-1}	L_{td}	0.003 m
α_c	0.9	K_{td}	0.033 W m^{-1} K^{-1}
β_c	0.83	N	2 m

4. History of BIPVT system

Building integrated photovoltaic thermal (BIPVT) systems have been growing under rapid development over past decades and several buildings with BIPVT systems exist across the world, Bazilian and Prasad (2002) and Tonui and Tripanag nosto poulos (2008). Loferski et al. (1988) have reported results for a hybrid PVT system with air circulation on a residential building. Hayakashi et al. (1989) have presented a system in which a roof has covered by 48 m2 of PV modules, which were connected to transparent tubes and filled with a black fluid. The electrical and thermal energy has stored in batteries and two water tanks of 1 m3 each respectively.

Different PV systems in terms of architectural application as classified by Kimura (1994) are:
(a) standalone system,
(b) one-way grid connection system,
(c) grid connection system, and
(d) small power system.

He has also presented the PV system combined with passive solar house. A passive solar house is the house with primarily a thermal system in which heat flows by natural means, i.e., conduction, radiation and natural convection within house so that space heating or cooling can be fulfilled without conventional energy. However, a small fan is also required to circulate warm air in the sun space to the rooms which provide thermal comfort within the house. Besides space heating, these PV modules also act as a shading device for a solar house. A parametric study of a PV cladding for building roof and façade has been reported by Brinkworth et al. (1997). Infield et al. (2004) have observed that the ventilated facades lead to enhancement of the electrical efficiency of a PV module on account of corresponding low temperature.

A BIPVT façade can act as unglazed thermosyphon photovoltaic thermal air heating collector to provide natural ventilation in summer Wang et al. (2006), pre heated air in winter and electrical output throughout the year, [Humm and Togg weiler, 1993; Sick and Erge, 1996; Bazilian and Prasad, 2002; Shaw et al. 1995]. Chow et al. (2007) have developed a PV ventilated window system, which saves energy by the use of solar cell transmittance of range 0.45-0.55. Drif et al. (2007) have mentioned that the grid connected PV systems are very popular in industrialized countries.

PV(s) in building have potential to become a major source of renewable energy in the urban environment, Tian et al. (2007). Zondag (2008) has described the electrical and thermal performance of various BIPVT facades and roofs for both natural and forced circulation of air. In his review, he also suggested that the type of PV influences the thermal performance of the PVT system.

Park et al. (2010) have suggested that the light transmission characteristics and temperature variation of the semi-transparent PV modules influence its electrical and building's cooling and heating loads. Hybrid PVT System with air heat extraction are not only effective for space heating of buildings, but they are also cost-effective solution for crop drying.

Hybrid PVT System provides optimum inside temperature in a solar house, which gives good food values. [Fohr and Figueiredo, 1980; Diamante and Munro, 1993; Palaniappan and Subramanian,1998; Ekechukwu and Norton, 1999; Enibe, 2002] used the thermal energy of PVT system for many industrial and agricultural applications, including the drying of crops and medicinal/aromatic plants, timber, natural rubber, tea and coffee products, and fodder for animals.

5. Literature review

S.no	Title of the paper	Authors, Publisher and year of publication	Objective/ work done	Literature gaps	Suggestions / scope of work
1	Performance evaluation of a building integrated semi-transparent photovoltaic thermal system for roof and facade	Kanchan Vats*, G.N. Tiwari, Energy and buildings, science direct nov 2011	Expressions for room air temperature in BISPVT and BIOPVT systems each integrated to the roof of a room with and without air duct.	The present study is limited to analytical analysis of performance of BIPVT system for fixed insolation and PV chemistry	The study can be extended to experimental verification with site-specific conditions for validation of analytical data.
2	Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions	Basant Agrawal, G.N. Tiwari, Applied energy, July 2009	1. Generation of higher electrical energy per unit area to produce necessary thermal energy required for space heating. 2. One-dimensional transient model suitable for the cold climatic conditions of India developed	It is found that for a constant mass flow rate of air, the series combination is more suitable and for constant velocity of airflow, parallel combination is suitable for the buildings fitted with BIPVT systems as rooftop.	The result for constant velocity helps in a better understanding of functioning strategies.
3	The impact of building-integrated photovoltaics on the energy demand of multi-family dwellings in Brazil	Martin Ordenesa, Deivis Luis Marinoskia, Priscila Brauna, Ricardo Ruther, Energy and buildings, Science direct, august 2006	1. This work analyses the potential of seven BIPV technologies implemented in a residential prototype simulated in three different cities in Brazil (Natal, Brasılia and Florianopolis). 2. Simulations were performed using the software tool Energy Plus to integrate PV power supply with building energy demand (domestic equipment and HVAC systems).	It was demonstrated that the integration of PV elements to vertical facades in Brazil, even at low-latitude sites, is not negligible and should always be considered. local climatic conditions lead to considerable deviations in the expected solar energy distribution,	The integration of PV elements to vertical facades in Brazil, even at low-latitude sites, is not negligible and should always be considered.
4	Influence of a buildings integrated photo-voltaic on heating and cooling loads	Yiping Wang, Wei Tian, Jianbo Ren, Li Zhu, Qingzhao Wang, Applied energy October 2005	1. Four different roofs are used to assess the impacts of BIPV on the buildings heating-and-cooling loads; namely ventilated air-gap BIPV, non-ventilated (closed) air-gap BIPV, close roof mounted BIPV, and the conventional roof with no PV and no air gap. 2. One-dimensional transient models of four cases are derived to evaluate the PV performances and building cooling and-heating loads across the different roofs in order to select the appropriate PV building integration method in Tianjin, China.	The performance comparisons for the three different BIPV roofs and the conventional roof are made based on the one-dimensional transient model for Tianjin, China	It should be noted that the PV performance and the change of heating and cooling loads through the different roofs depend also on many other factors, such as initial roof insulation level, roof solar absorptivity, local climate, etc.
5	Energy and exergy analysis of a building integrated semi-transparent photovoltaic	Kanchan Vats, G.N. Tiwari, Applied Energy, science Direct march 2012	In this paper, evaluation of the energy and exergy performance of a BISPVT system integrated to the roof of a room is done. Comparisons have been carried out on the basis of energy and	1. One dimensional heat conduction in quasi-steady state is considered. 2. There is no temperature	Cell efficiency decreases with increase in cell temperature. Si produces maximum

	thermal (BISPVT) system		exergy by considering six different photovoltaic (PV) modules.	stratification in the air of a room and semi-transparent PV module.	annual thermal energy (464 kW h)and therefore, suitable for space heating applications.
6	An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector	F. Sarhaddi, S. Farahat, H. Ajam, A. Behzadmehr, M. Mahdavi Adeli, Applied Energy, January 2010	In this paper, A detailed thermal and electrical model is developed to calculate the thermal and electrical parameters (solar cell temperature, back surface temperature, outlet air temperature, open-circuit voltage, short-circuit current, maximum power point voltage, maximum power point current) of a typical PV/T air collector. Some corrections are done on heat loss coefficients in order to improve the thermal model of a PV/T air collector.	1. According to the electrical model used in present work the real behavior of the electrical efficiency with respect to solar radiation intensity is not linear. 2.At low solar radiation intensity, the electrical efficiency must be reach to small value. But electrical efficiency of PV module does not show this fact	When inlet air temperature or wind speed or duct length increase, the overall energy efficiency and thermal efficiency of a PV/T air collector decrease.
7	Design and Performance Evaluation of Building Integrated Photovoltaic/ Thermal (BIPVT) Air Collector	Huan-Liang Tsai, Chieh-Yen Hsu, Fu-Sheng Hsieh, and Yu-Hsuan Chiang, IEEE, 2013	This paper addresses the design and performance evaluation of a novel building integrated photo-voltaic/thermal (BIPVT) air collector that is augmented with a fin-type heat sink. The system performance is evaluated through an experimental measurement for space/water heating applications.	At the irradiance of 1 kW/m2, ambient temperature of 25°C, and wind speed 1m/s, the blower is controlled to keep the outlet air temperature of 35-40°C as possible. The PV efficiency is about 14%, and the thermal efficiency is about42%.	Form the experimental evaluation, the total efficiency achieved is 56%. The hardware implementatio n of the BIPVT air collector with air source heat pump water heater (AS/HPWH) can be done
8	Building-Integrated Photovoltaics for Maximum Power Generation	Yang Hongxing, Lou Chengzhi and Sun Liang liang, IEEE 2008	The optimum tilt angle of BIPV claddings, the ventilation effect on BIPV's energy performance, the application of semi-transparent BIPV modules were obtained for 1MWp of PV modules that have been integrated in The Hong Kong Polytechnic University buildings.	The results of these studies provide valuable reference to local engineers, designers and professionals for efficient BIPV design and operation. More studies are necessary in this area.	A simple and efficient method has been proposed for avoiding partial shading of PV modules.
9	Effect of packing factor on the performance of a building integrated semi-transparent photo-voltaic thermal (BISPVT) system with air duct	Kanchan Vats∗, Vivek Tomar, G.N. Tiwari, Energy and Buildings, july2012	1. The effect of packing factor of semi-transparent PV module integrated to the roof of a building, on the module and room air temperature and electrical efficiency of PV module is studied. 2.Energy and exergy analysis have been carried out by considering different packing factors (0.42, 0.62, and 0.83) of PV module namely mono crystalline silicon (m-Si), poly crystalline silicon (p-Si), amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium	1. One dimensional heat conduction in quasi-steady state is considered. 2. There is no temperature stratification in the air of a room due to force mode of operation. 3. The room is thermally insulated and physical properties of air are constant.	1. Decrease in packing factor from 0.83 to 0.42, decreases the module temperature by 10◦Cwhich increases its efficiency by 0.2–0.6%. 2. Decrease in packing factor increases the non-packing area and results in

			diselenide (CIGS), and a hetero-junction with thin layer (HIT).		increase in room temperature by 3◦C.
10	Power output analysis of transparent thin-film module in building integrated photovoltaic system (BIPV)	Jong-Hwa Song, Young-Sub An, Soek-Ge Kim, Sung-Jin Lee, Jong-Ho Yoon, Youn-Kyoo Choung, Energy and Buildings, may 2008	1. Evaluation of performance of the thin-film solar cell through long-term monitoring of the power output according to the inclined slope (the incidence angle). 2. This is conducted by using a full-scale mock-up model of the thin-film solar cell applied to a double-glazed system. 3. The aim of the application data of the thin-film solar cell is to analyze the effect of both the inclined slope and the azimuth angle on the power output performance by comparing this data with the simulation data for PV modules.	The direction in which the PV module faces can also be a very important factor that can affect the power performance efficiency by 11% on average and by a maximum of 22%, depending on the azimuth angle.	This study evaluated a transparent PV module in terms of lighting and power performance depending on installation circumstances such as the inclined slope, incidence angle and the azimuth angle.

6. Conclusion

The complete comparison of different types of BIPVT system is discussed with operation of the system with and without air duct. It has been concluded that the BIPVT system becomes an ultimate solution as it contributes to the overall energy saving in a building. In order fulfil both thermal and electrical load demand of a building both residential and commercial. BIPVT can be an optimum option. Thereby in future economic analysis of the system can be studied.

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