Resource-Efficient Technologies 3 (2017) 263–271

Contents lists available at ScienceDirect

Resource-Efficient Technologies

journal homepage: www.elsevier.com/locate/reffit

Review article

Comparison of BIPV and BIPVT: A review ☆

Mary Debbarma, K. Sudhakar*, Prashant Baredar

Energy Centre, Maulana Azad National Institute of Technology, Bhopal, M.P., India

ARTICLE INFO

Article history:
Received 6 November 2016
Revised 19 November 2016
Accepted 21 November 2016
Available online 20 December 2016

Keywords:
Photovoltaic
Thermal insulation
Thermal performance
Design
Comparison
Applications

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). This paper reviews the BIPV and BIPVT technology. The paper shows various technologies involved in BIPV and BIPVT as well as their function, cost and aesthetics. In addition a review of the application of BIPV and BIPVT installations is described. In comparison to BIPV systems, BIPVT system has significant benefits and potential for wide use in buildings. The building integrated photovoltaic-thermal system design (BIPVT) is also becoming popular among architects and design engineers.

1. Introduction

The most abundant energy source among all the renewable sources available is solar energy which is abundant in both direct and indirect forms. The solar energy can be converted into electricity through PV cells at different efficiency varying between 7 and 40%. Basically the PV cells are semiconductor devices that can convert the energy in both dispersed and concentrated solar radiation into direct current (DC) electricity. 80% of the incident solar radiation available in the solar spectrum can be absorbed by these photovoltaic (PV) cells; however, only a certain percentage of these absorbed incident energy is converted into electricity depending on the conversion efficiency of the PV cell technology [1]. Solar energy utilization can be divided into two fields: solar thermal and photovoltaic. Solar thermal is mainly concerned with the utilization of solar radiation to provide useful heating. Some of the best examples include passive solar heating of houses and solar water heating. Photovoltaic, on the other hand, are meant for the conversion of solar energy to electricity, mainly using the silicon based solar cells [2]. Solar PV performance is dependent on the local climatic conditions and availability of solar radiation (Table 1).

The detailed classification of the solar technologies is presented in Fig. 1. Table 2 shows the values of temperature coefficient and module efficiency at standard test condition for the various types of PV modules.

A brief description of the study has been presented in an integrated flowchart as shown in Fig. 2. The present paper aims to review and compare the design, thermal performance and application of BIPV and BIPVT systems.

2. BIPV and BIPVT

A new and promising way to integrate renewable energies in the constructed environment is to integrate photovoltaic technologies in buildings. Building-integrated photovoltaic (BIPV) will become one of the fastest growing segments of the solar industry worldwide with an assumed capacity growth of 50% or more from 2011 to 2017 in the next few years. The advantages of integrated photovoltaics over common non integrated systems is that the initial cost can be offset by reducing normal construction costs of building materials and labor for parts of the building replaced by the BIPV modules. The growing interest in BIPV is mainly due to the fact that many countries are nowadays establishing specific targets related to net-zero energy buildings (NZEBs). For BIPV systems to achieve multifunctional roles, various factors must be taken into account, such as the photovoltaic module temperature, shading, installation angle and orientation. Among these factors, the irradiance and photovoltaic module temperature

☆ Peer review under responsibility of Tomsk Polytechnic University.
* Corresponding author at: Energy Centre, Maulana Azad National Institute of Technology, Bhopal, M.P., India. Fax: +91-755 2670562.
E-mail address: sudhakar.i@manit.ac.in (K. Sudhakar).

http://dx.doi.org/10.1016/j.reffit.2016.11.013

Nomenclature

a-Si	amorphous silicon
BIPV	building-integrated photovoltaic
BAPV	building applied photovoltaic
BIPVT	building-integrated photovoltaic with thermal
BOPVT	building integrated opaque photovoltaic thermal systems
BISPVT	building-integrated semitransparent photovoltaic thermal system
c-Si	crystalline silicon
DC	direct current
ETFE	ethylene tetrafluoroethylene
HIT	heterojunction intrinsic thin layer
NZEB	net-zero energy buildings
m-Si	multicrystalline silicon
p-Si	polycrystalline silicon
PCM	phase change material
PV	photo-voltaic
STC	standard testing condition

should be regarded as the most important factors because they affect both the electrical efficiency of the BIPV system and the energy performance of buildings where BIPV systems are installed [7].

Integrating the PV panels improves the cost effectiveness since they provide additional functions like active solar heating and day lighting.

The following are some recognized methods of integration:

1. Integration of the PV Panels into the Building Envelope (BIPV) – This method involves the replacement of roof shingles or wall cladding with PV panels. It has significant advantages over the more usual "add on" strategy. It not only eliminates an extra component (e.g., shingles), but also removes penetrations of a pre-existing envelope that is required to attach the panel to the building. In this type of BIPV system architectural and aesthetic integration is a major requirement. These strategies lead to much higher levels of overall performance, at the same time it can also provide enhanced durability.
2. Integrating Heat Collection Functions into the PV Panels (BIPV-T) generally converts 6–18% of the incident solar energy to electrical energy, and the remaining solar energy is captured to be used as useful heat. This is normally lost as heat to the outdoor environment. A coolant fluid, such as water or air, is circulated behind the panel, extracting useful heat to cool the panel. The coolant also serves to decrease the temperature of the panel which is very necessary, because the panel efficiency decreases with an increase in panel temperature. This can be obtained either in an open-loop or a closed-loop configuration. In one open loop configuration, outdoor air is passed under PV panels and the recovered heat can be used for space heating, preheating of ventilation air, or heating domestic hot water – either by direct means or through a heat pump.
3. BAPV as the name suggests building applied photovoltaic – In this method modules are used only for generating energy, even as part of the architectonical composition of the building, but do not replace or used as a construction component. They may

Table 1
Solar radiation and climatic condition data [3].

Type of days	Ratio of daily diffuse to daily global radiation	Sunshine hours
Clear days (blue sky)	≤0.25	≥9 hrs
Hazy days (fully)	0.25–0.50	7–9 hrs
Hazy and cloudy days (partially)	0.50–0.75	5–7 hrs
Cloudy days	≥0.75	≤5 hrs

Table 2
Values of module efficiency and temperature coefficient for different PV modules [4–6].

Type of PV module	Module efficiency at STC (%)	Temperature coefficient (%)
a-Si	6.30	−0.26
m-Si	13.50	−0.40
p-Si	11.60	−0.40
CdTe	6.90	−0.20
CIS	8.20	−0.45
HIT	17.00	−0.33

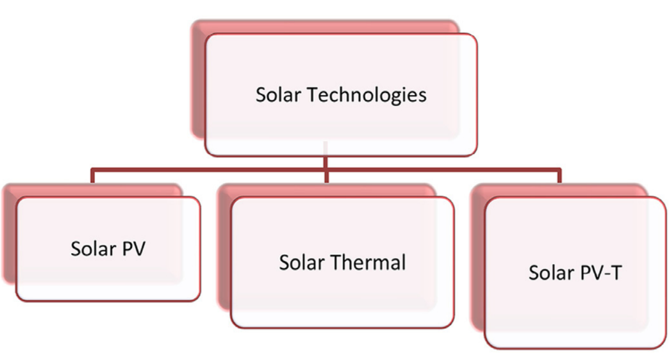

Fig. 1. Brief classification of solar technologies.

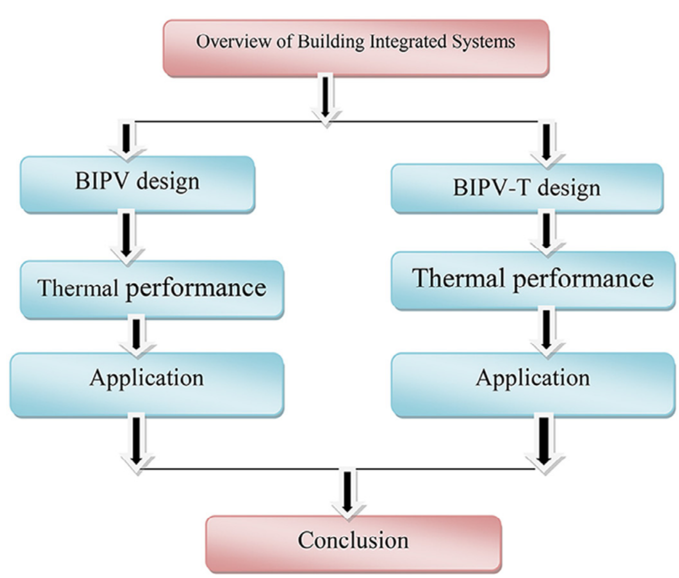

Fig. 2. Flowchart showing the framework of the study.

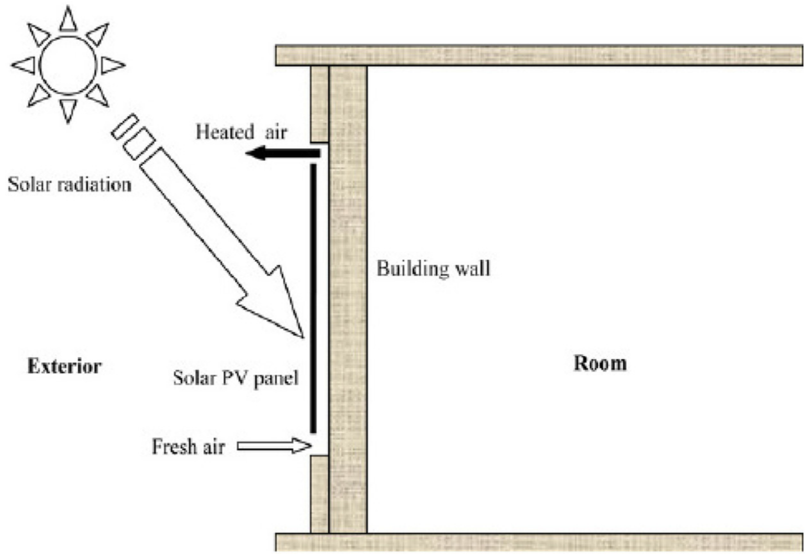

Fig. 3. Schematic diagram of building integrated photovoltaic system [12].

be assembled coplanar but not to the building envelope on roofs, facades, atria or shading devices [8].

BIPV solutions have many advantages:

i) Innovative design
ii) Sunscreen and power generation
iii) Reduce the carbon footprint of a building
iv) Thermal insulation
v) Acoustic insulation, comfort increase
vi) Increase the value of a building
vii) Environment friendly
viii) Sustainability.

BIPV systems are highly reliable in the long term. The average guarantee for this type of building product is 20–25 years [2].

Building-integrated photovoltaic with thermal energy recovery (BIPV-T) shows great potential for integration into net-zero energy buildings.

PV can be integrated in the building envelope to provide:

> Sun protection
> Weather protection
> Modulation of daylight
> Heat insulation
> Noise protection
> Security

Before designing the BIPV the detailed study of types of solar module is required and also type of photovoltaic cell material used in the solar module should be studied to examine which module is more suitable, reliable and beneficial for the system according to design, cost and environment. Also solar radiation and climatic condition data should be analyzed to integrate in a proper manner [9–11].

2.1. BIPV system

Building integrated photovoltaics (BIPV) is the integration of photovoltaic into the building parts. The PV modules serve the dual function of building skin that is it is replacing conventional building materials and power generator. The incremental cost of photovoltaic is reduced by avoiding the cost of conventional materials, and likewise its life cycle cost can also be improved. BIPV system often has lower cost than PV system.

2.2. BIPVT system

A photovoltaic-thermal hybrid system (referred to as a PV-T system) is a device capable of the simultaneous conversion of radiant solar energy into both electricity and thermal energy. These systems consist of a photovoltaic (PV) panel responsible for the conversion of energy into electricity due to the Becquerel/photovoltaic effect, and thermal energy via an absorption process. This PV-T system when integrated to a building is known as Building Integrated Photo-voltaic System (Figs. 3 and 4).

Building Integrated Photovoltaic-Thermal (BIPVT) can be used on both new and existing buildings [13]. Their use in the building envelope is very varied and opens many opportunities for creative designers (Fig. 5).

3. BIPV and BIPVT as thermal insulation

BIPV systems applied as thermal insulation to building envelope in hot and humid climates showed the significant influence of insulation on the energy use in residential buildings [14]. Due to the temperature control on the roof, the room temperature can be significantly reduced and thermal comfort in the building can be much improved. The energy performance of the building envelope dictates the use of thermal insulation. There is a significant effect on the yearly cooling load and peak cooling demand by covering the envelope and partitions with thermal insulations. The thermal capacity of the building fabric can be varied according to the local climatic conditions. Moreover various range of design options for energy efficient buildings can be assessed. However these options are more costly to build if the envelope and partitions would become much thicker. Further, detailed economic analysis and life cycle cost analysis are required to study the construction cost of the building integrated with PV [15].

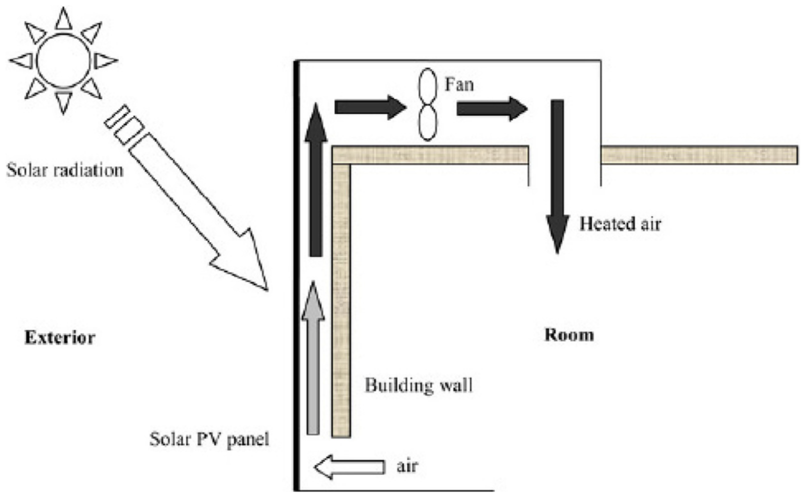

Fig. 4. Schematic diagram of building-integrated solar thermal system [12].

4. Comparative performance study of BIPV and BIPVT (Table 3)

5. Application of BIPV and BIPVT system (Table 4)

6. Future scope and research

BIPV is structural, architectural and aesthetic integration of photovoltaics into the building structure. They can be integrated into the roof and façade. Various products are available in the market for façade and roof integration. Due to the free surfaces available on roofs and façade there is a huge untapped potential for generating electricity at the source of consumption. The electricity generated from BIPV can satisfy approximately 20–75% of the buildings electricity requirements depending on the country and its location. BIPVs can help reduce the GHG emissions and the emissions due to losses of electricity in transmission and distribution. BIPV and BIPVT system inclusion in building envelopes opens the way for net zero energy constructions, whose potential in terms of energy consumption and reduction of global warming is more and more recognized. In a near future, with constant developments and improvements, BIPV and BIPVT will be extensively used in building applications. More research is necessary to develop simulation program to predict the energetic behavior of BIPV and BIPVT systems and optimization of their performances. Linking the PV and construction sectors, guidelines for ventilation strategies, preparing BIPV-standards is needed for large scale application. Also several building physical challenges have to be solved for extensive use of BIPV systems in various climates.

7. Conclusion

The various designs of BIPV and BIPVT have been reviewed in this paper. The application of the BIPV system has also been discussed. Based on the past studies done on these systems the following recommendations are made:

- ► The literature review reveals that there is a gap in the field of BIPVT system for building sector and very few studies and investigation about the use of BIPVT are carried out.

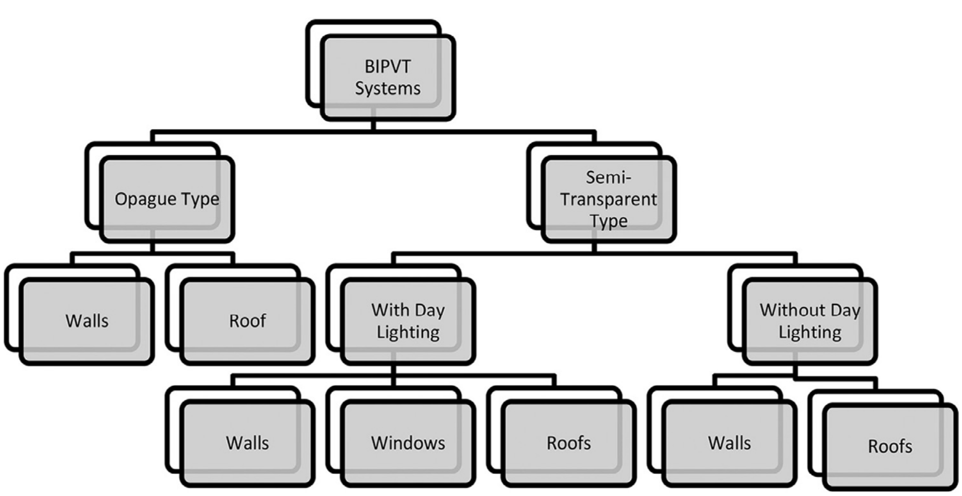

Fig. 5. Classification of BIPVT system.

Table 3
Comparative studies of BIPV and BIPVT at different locations.

System	Location	Results obtained	Special features
BIPV system [16–21]	Turkey	Daily average electrical efficiency is 4.52% and thermal efficiency is 27.2%.	a-Si semitransparent PV module is integrated on Trombe wall façade.
	Lisbon	Maximum electrical efficiency reach up to 10% and the thermal one is 12%.	Modeling of hybrid BIPV-PCM is done.
	Korea	Energy generation. Efficiency can be improved up to 47% by changing the building location in terms of azimuth and reducing the shading.	Using transparent thin-film amorphous silicon solar cells installation of building integrated. Photovoltaic (BIPV) modules are done on the windows covering the front side of a building.
	India	The detailed analysis of the model indicates that performance and life enhancement of BIPV module could be achieved with 10 °C cooling without loss of power.	The dynamic model of BIPV-Thermoelectric system considering the PV panel temperature has been developed.
	Hong Kong	Annual thermal efficiency is found to be 37.5% and electrical efficiency is 9.39%.	Building Integrated photovoltaic/water heating system is developed at a vertical wall of a fully air conditioned building and with collectors equipped with flat-box-type thermal absorber and polycrystalline silicon cells.
BIPVT [7,19,22–29]	South Korea	Average thermal and electrical efficiency is 30% and electrical efficiency is 17%.	Heating system combined with a water-type PVT collector integrated into the roof of an experimental unit is analyzed.
	India	HIT produces maximum annual electrical energy (810 kW h) and Si produces maximum annual thermal energy (464 kW h). Annual overall thermal energy (2497 kW h) and exergy (834 kW h) is maximum for HIT PV module.	Building Integrated semitransparent photovoltaic thermal (BISPVT) system integrated to the roof of a room.
	Malaysia	Primary energy saving efficiency produced from a BIPVT system is about 73% to 81%. PVT energy efficiency of 55–62% is higher than the PVT exergy efficiency of 12–14% in an hourly variation of a BIPVT system.	A high efficiency multicrystal photovoltaic (PV) module and spiral flow absorber has been designed, performed and investigated.
	Canada	Application of two inlets on a BIPVT collector increases thermal efficiency by about 5% and electrical efficiency increases marginally. Addition of vertical glazed solar air collector improves thermal efficiency by about 8% which becomes more significant with wire mesh packing in the collector by an increase of about 10%. The developed model is applied to a BIPVT roof of an existing solar house with four simulated inlets and the thermal efficiency is improved by 7%.	A BIPVT system with glazed air collector and multiple inlets is analyzed.
	China	Technical feasibility of ETFE cushion structure integrated photovoltaic provides a way to expand the application of BIPVT to cushion structure.	An experimental mockup composed of a three layer ETFE cushion and amorphous silicon photovoltaic panel has been developed and a series of experiments have been conducted in summer, especially under sunny and sunny to cloudy conditions.
	India	Annual electrical exergy is 16,209 kW h and thermal exergy is 1531 kW h with overall thermal efficiency is 53.7%.	BIPVT is used as the rooftop of a building with an effective area of 65 m^2. Analysis is done to select an appropriate BIPVT system suitable for the cold climatic conditions of India.
	New Zealand	The net electric yield of the PV/T system was increased by approximately 9.4%.	Effect flow distribution on the photovoltaic yield of a BIPV/T collector of various sizes is studied.
	India	Daily average electrical efficiency of the module of a-Si solar modules without air duct is found to be 7.25% and room temperature is about 18.7 °C respectively, whereas with air duct it is found to be 7.57% and 15.2 °C respectively.	Building integrated opaque photovoltaic thermal (BIOPVT) systems based on thin film photovoltaic (PV) modules are developed.

- ► The performance of BIPV and BIPVT systems varies according to the design and the local climatic conditions.
- ► The thermal gain obtained from building integrated system can be used for space heating or drying application.
- ► North South facing BIPV system generates more energy than East West system.
- ► Tall obstructions near the building increase the shading effect and reduce the energy production and consequently the economic viability.
- ► Application of PV module as thermal insulation can contribute to the future development of building integrated photovoltaic and thermal systems.
- ► There is a substantial benefit of integrating PV systems in facades and roofs for electricity generation.
- ► The maximum thermal efficiency of building integrated PV-T system reported is around 55%.
- ► The research done across various countries indicate the massive prospects of integrating BIPV and BIPVT systems into the green building architecture.

Table 4
Various applications of BIPV and BIPVT systems are described.

Types	Applications	Figures
BIPV [8,18,19,28–31]		
Skylight	**Skylight** structures are usually one of the most interesting places to apply BIPV. In this type of application, PV elements provide both electricity and light to the building. The PV modules and support structures used for this type of application are similar to those used in semi-transparent glass facades. The structures, which may be unspectacular from the outside, produces fascinating light hallway walks and floors and allow a stimulating architectural design of light and shadow.	
Shading Systems	**Shading Systems**. PV modules of different shapes can be used as shading elements above windows or as part of an overhead glazing structure. Since many buildings already provide some sort of structure to shade windows, the use of PV shades should not involve any additional load for the building structure. PV shading systems may also use one-way trackers to tilt the PV array for maximum power while providing a variable degree of shading.	
BIPV Solar Facade	**BIPV Solar Facade**. The facade forms the external weatherproof envelope of a building. In modern buildings, the facade is often attached to the building frame and provides no contribution to structural stability. This type of facade can be referred to as a non-load bearing vertical building enclosure. Many different types of construction can be used. These include profiled metal sheets, cladding panels or glass and aluminum curtain walling. Each type of facade has advantages and disadvantages. These need to be understood if the facade is to be maintained and risks properly managed. The building facade provides the separation between the inside and the outside environments but is also required to provide acceptable light levels and a visual connection with the outside in the form of views out of the building. The facade may also be required to provide the building user with open able windows for ventilation. Facade systems are of different types, some of the façade systems are Brickwork and stonework, curtain walling, precast concrete panels with various types of finishes, insulated render, metallic cladding, tiles and stone veneer panels, large boards consisting of an aesthetic and weather tight veneer, glass and steel facade systems.	
BIPV In-Roof Systems	**BIPV In-Roof Systems**. Roofs are ideally suited for BIPV integration usually there is less shadowing at roof height than at ground level. Roofs often provide a large, unused surface for integration. So nowadays BIPV or PV system is widely used on a roof because of a lot of advantage of roofing integration, when we integrate BIPV on roof system we achieve more power than the ground level and no shadowing effect and hence efficiency of the BIPV is increased.	
Semi Transparent Facades	**Semi Transparent Facades**. The transparent and semitransparent solar facades not only absorb and reflect the incident solar radiation but also can transfer direct solar heat gain into the building. If such solar facades transform part of the incident sunlight into electricity directly or indirectly or by transmitting the thermal energy into the building using electrical or mechanical equipment then they are called transparent and semi transparent facades.	
Installation of BIPV system using transparent amorphous silicon thin-film PV	BIPV installed using transparent thin-film BIPV modules	

(continued on next page)

Table 4 (*continued*)

Types	Applications	Figures
Curved clay solar tiles	The BIPV tile products can cover the entire roof or just parts of the roof. They are normally arranged in modules with the appearance and properties of standard roof tiles and substitute a certain number of tiles. This is a good option for retrofitting of roofs. The cell type and tile shape vary. Some tile products resemble curved ceramic tiles and will not be area effective due to the curved surface area, but may be more aesthetically pleasing.	
Glass ceiling with transparent BIPV modules	BIPV modules are used as glass ceiling which add to the aesthetics of the building	
External Building Walls	PV modules can be added to existing walls to improve the aesthetic appearance of the facade. They are simply added on to the structure. There is no need to provide a weather-tight barrier as this role is already performed by the structure underneath the modules.	
BIPVT [6,19,22,27,28,32]		
Duct design of BIPVT	Under the panel a duct has been made for the flow of air as thermal cooling medium.	
PVT Water collector integrate into the roof	A building heating system is combined with a water type PVT collector integrated into the roof of an experimental unit.	

(*continued on next page*)

Table 4 (*continued*)

Types	Applications	Figures
BIPVT system fitted on the rooftop of a building	BIPVT system integrated on the rooftop of a building in order to generate higher electrical energy and necessary thermal energy required for space heating.	
Phase Change Materials (PCM) integrates the BIPVT	A thermal storage element, Phase Change Materials (PCM) integrates the BIPVT.	
BIPVT Ethylene tetrafluoroethylene (ETFE)cushion structure system	An ethylene tetrafluoroethylene (ETFE) cushion structure integrated photovoltaic panels is proposed for solar energy utilization of cushion structures. It can maintain cushion operation by photovoltaic electricity and provide a way of collecting thermal energy due to enclosed cushions.	

References

[1] A. Makki, S. Omer, H. Sabir, Advancements in hybrid photovoltaic systems for enhanced solar cells performance, Renew. Sustain. Energy Rev 41 (2015) 658–684.

[2] T.N. Anderson, M. Duke, G.L. Morrison, J.K. Carson, Performance of a building integrated photovoltaic/thermal (BIPVT) solar collector, Sol. Energy 83 (4) (2009) 445–455.

[3] L. Maturia, G. Belluardo, D. Moser, M. Del Buono, BiPV system performance and efficiency drops: overview on PV module temperature conditions of different module types, Energy Procedia 48 (2014) 1311–1319.

[4] T. Yamawaki, S. Mizukami, T. Masui, H. Takahashi, Experimental investigation on generated power of amorphous PV module for roof azimuth, Sol. Energy Mater. Sol. Cells 67 (2001) 369–377.

[5] S. Nann, K. Emery, Spectral effects on PV-device rating, Sol. Energy Mater. Sol. Cells 27 (1992) 189–216.

[6] K. Vats, G.N. Tiwari, Energy and exergy analysis of a building integrated semi-transparent photovoltaic thermal (BISPVT) system, Appl. Energy 96 (2012) 409–416.

[7] C. Penga, Y. Huang, Z. Wu, Building-integrated photovoltaics (BIPV) in architectural design in China, Energy Build 43 (2011) 3592–3598.

[8] J. Cronemberger, M. Almagro Corpas, I. Cerónb, E. Caamano-Martín, S. Vega Sánchez, BIPV technology application: highlighting advances, tendencies and solutions through Solar Decathlon Europe houses, Energy Build 83 (2014) 44–56.

[9] J.P. Kalejs, Silicon ribbons and foils F state of the art, Sol. Energy Mater. Sol. Cells 72 (2002) 139–153.

[10] G.N. Tiwari, R.K. Mishra, S.C. Solanki, Photovoltaic modules and their applications: a review on thermal modeling, Appl. Energy 88 (2011) 2287–2304.

[11] T.T. Chow, A review on photovoltaic/thermal hybrid solar technology, Appl. Energy 87 (2010) 365–379.

[12] G. Quesada, D. Rousse, Y. Dutil, M. Badache, S. Hallé, A comprehensive review of solar facades. Opaque solar facades, Renew. Sustain. Energy Rev 16 (2012) 2820–2832.

[13] C. Lamnatou, G. Notton, D. Chemisana, C. Cristofari, Life cycle analysis of a building-integrated solar thermal collector, based on embodied energy and embodied carbon methodologies, Energy Build 84 (2014) 378–387.

[14] M. Bojic, F. Yika, Cooling energy evaluation for high-rise residential buildings in Hong Kong, Energy Build 37 (2005) 345–351.

[15] M. Bojic, F. Yik, P. Sat, Influence of thermal insulation position in building envelope on the space cooling of high rise residential buildings in Hong Kong, Energy Build 33 (2001) 569–581.

[16] B. Kundakci Koyunbaba, Z. Yilmazb, K. Ulgen, An approach for energy modeling of a building integrated photovoltaic (BIPV) Trombe wall system, Energy Build 67 (2013) 680–688.

[17] T.T. Chow, A.L.S. Chan, K.F. Fong, Z. Lin, W. He, J. Ji, Annual performance of building-integrated photovoltaic/water-heating system for warm climate application, Appl. Energy 86 (2009) 689–696.

[18] J.-H. Yoon, J. Song, S.-J. Lee, Practical application of building integrated photovoltaic (BIPV) system using transparent amorphous silicon thin-film PV module, Sol. Energy 85 (2011) 723–733.

[19] J.-H. Kim, S.-H. Park, J.-G. Kang, J.-T. Kim, Experimental performance of heating system with building integrated PVT (BIPVT) collector, Energy Procedia 48 (2014) 1374–1384.

[20] A. Ibrahim, A. Fudholi, K. Sopian, M. Yusof Othman, M. Hafidz Ruslan, Efficiencies and improvement potential of building integrated photovoltaic thermal (BIPVT) system, Energy Convers. Manag 77 (2014) 527–534.

[21] T. Yang, A.K. Athienitis, A study of design options for a building integrated photovoltaic/thermal (BIPV/T) system with glazed air collector and multiple inlets, Sol. Energy 104 (2014) 82–92.

[22] J. Hu, W. Chen, B. Zhao, H. Song, Experimental studies on summer performance and feasibility of a BIPV-T ethylene tetrafluoroethylene (ETFE) cushion structure system, Energy Build 69 (2014) 394–406.

[23] F. Ghani, M. Duke, J.K. Carson, Estimation of photovoltaic conversion efficiency of a building integrated photovoltaic/thermal (BIPV/T) collector array using an artificial neural network, Sol. Energy 86 (2012) 3378–3387.

[24] A. Gaur, G.N. Tiwari, Analytical expressions for temperature dependent electrical efficiencies of thin film BIOPVT systems, Appl. Energy 146 (2015) 442–452.

[25] A. Kane, V. Verma, Performance enhancement of building integrated photo-voltaic module using thermoelectric cooling, Int. J. Renew. Energy Res 3 (2013) 2.

[26] ertex-solar, Building integrated photovoltaics: a new design opportunity for architectsenergie Ag, 2014. Linz, Austria www.Ertex-Solar.At.

[27] G.N. Tiwari. Centre for Energy Studies Indian Institute of Technology (IIT) Delhi & BAG Energy Research Society (BERS). Performance evaluation of BIPVT systems (2014).

[28] L. Aelenei, R. Pereira, Innovative solutions for net zero-energy building: BIPV-PCM system – modeling, design and thermal performance, in: Proceedings of the IYCE conference, 2013 Siofok, Hungary, 6–8 June.
[29] A.K. Shukla, K. Sudhakar, P. Baredar, Exergetic analysis of building integrated semitransparent photovoltaic module in clear sky condition at Bhopal India, Case Studies Thermal Eng 8 (2016) 142–151.
[30] A.K. Shukla, K. Sudhakar, P. Baredar, Exergetic assessment of BIPV module using parametric and photonic energy methods: a review, Energy Build 119 (2016) 62–73.
[31] A.K. Shukla, K. Sudhakar, P. Baredar, A comprehensive review on design of building integrated photovoltaic system, Energy Build 128 (2016) 99–110.
[32] V. Delisle, M. Kummert, A novel approach to compare building-integrated photovoltaic/thermal air collectors to side-by-side PV modules and solar thermal collectors, Sol. Energy 100 (2014) 50–65.