

Building Integrated Photovoltaic Systems in Bangladesh: Prospects and Challenges

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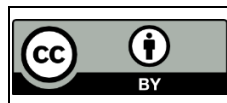
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ABSTRACT

Around the world, one-third of all fossil fuels and CO₂ gas are produced and consumed by the building sector. Energy efficiency and the utilization of renewable energy are regarded as the two main approaches to tackling the issues of increasing emissions and energy consumption. Solar energy is an admirable solution for addressing this problem because it is a plentiful renewable energy source. While the use of solar energy through building-integrated photovoltaic (BIPV) systems is becoming more popular worldwide due to its ability to generate clean energy and reduce building energy usage. However, in Bangladesh, the use of BIPV systems is minimal. Nonetheless, there is no government legislation addressing this prospective construction technology, nor is there extensive research on the BIPV system. Considering this research shortfall, the purpose of this study is to provide a general overview of BIPV systems and technologies. Furthermore, provide an overview of the published literature on BIPV systems that considers Bangladesh and finds out its future prospects. Besides, list the major obstacles and difficulties in adopting the BIPV system in Bangladesh. The implementation of feed-in tariffs, public acceptance, government financial support in the form of subsidies, and appropriate policy for spreading this promising technology are the main obstacles to BIPV systems. On the other hand, a few recent studies demonstrate that in Bangladesh, BIPV window systems have a lot of potential for power generation, building energy conservation, and CO₂ reduction. It was found that a 12.5 kWp BIPV facade system put in a Dhaka city commercial building could generate 22,600 kWh of power yearly, which could lower the release of about 15 tons/yr. of CO₂.

Keywords: BIPV, Photovoltaic system, Building energy efficiency, Renewable energy, Energy policy



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1. Introduction

In order to ensure sustainable growth, the Government of Bangladesh (GOB) has made energy security one of its top priorities. Energy is one of the most important infrastructure inputs in socio-economic development and a key determinant of a nation's economic advancement. Natural gas currently makes up 54% of Bangladesh's total electricity production, making it the country's main domestic energy source [1]. Several analyses indicate that the current reserve of natural gas in Bangladesh is about 12 trillion cubic feet (TCF), which will meet the country's rising demand for 10–12 years [2]. Domestic natural gas output will be depleted shortly. Given the unpredictability of the long-term primary energy supply, it is critical to diversify the country's primary energy sources. In that circumstance, coal could serve as a significant alternative energy source for the country [3]. However, coal production is insufficient to meet the current demand, and excessive coal burning is not environmentally friendly.

In Bangladesh, the building sector is the dominant sector in terms of primary and electricity consumption. As shown in Fig. 1 (a), the building archive consumes the most primary energy in Bangladesh, accounting for approximately 46% of total primary energy consumption. While this sector consumed more than 50% of electricity in 2019, as shown in Fig. 1 (b). On the other hand, most electricity in Bangladesh is generated using fossil fuels. The total installed generation capacity of Bangladesh is 25.95 GW as of February 2024 [4].

Table 1 illustrates how fossil fuels, namely coal, natural gas, and HFO, have been increasingly crucial in Bangladesh's

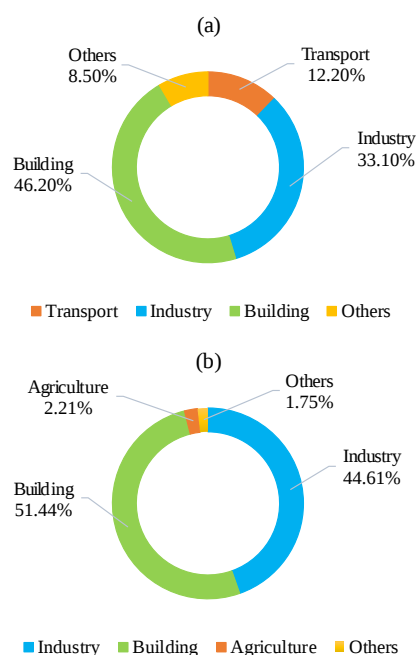


Fig.1 (a) Primary energy and (b) electricity consumption scenario of different sectors in

recent mix of electricity generation. Bangladesh's Power Sector Master Plan (PSMP) 2016 estimates that the country will need to bring 60,000 megawatts (MW) of new capacity

online by 2041 to meet this demand [5]. Moreover, energy demand increases yearly due to rapid economic development, urbanization, industrialization, and an increasing population. Bangladesh may diversify its power mix, lower its exposure to the risk of fluctuating fossil fuel costs, and lessen the damaging environmental effects of thermal power generation by switching to clean energy. Considering the climate change issue, the country could meet its rising energy demand by setting energy conservation targets and utilizing the available renewable energy resources.

Table 1 Power generation energy mix of Bangladesh since October 2024 [6].

Fuel Type	Capacity (MW)	Total (%)
Gas	12384.00	44.56
Coal	7179.00	25.83
HFO	5885.00	21.18
HSD	290.00	1.04
Imported	1160.00	4.17
Solar	603.00	2.17
Hydro	230.00	0.83
Wind	60.00	0.22
Total	27791.00	100

Bangladesh has a very good daily solar radiation on the horizontal surface range of 4 to 6.5 kWh/m², making it a great place to use solar energy [7]. Several different solar photovoltaic applications are currently being used in this area. Building integrated photovoltaic, or BIPV, is another significant application of PV technology. Although BIPV systems are rarely applied in Bangladesh [7], they are widely regarded as an essential component of zero-energy buildings since they generate power and reduce energy usage [8]. However, Bangladesh lacks both a government policy about this new building technology and a comprehensive study on the BIPV system. This paper initially gives a broad overview of BIPV systems and their technology in light of this circumstance. Then, by examining numerous scholarly research articles on BIPV systems that take Bangladesh into account as a geographical location, look into the opportunities and difficulties for implementing BIPV systems in Bangladesh.

2. Research materials and methods

This research explores the prospects and challenges of BIPV systems in Bangladesh. Relevant material for this research is obtained from various secondary sources, like published journal papers, conference proceedings, and books. Besides, various information and data are collected and reviewed from online pages and published articles by different national and international organizations like the Bangladesh Power Development Board (BPDB), the United States Agency for International Development (USAID), the Sustainable and Renewable Energy Development Authority (SREDA), the International Energy Agency (IEA), etc. In analyzing the collected data, various statistical tools like averages, percentages, tables, and diagrams will be applied to make the study more worthwhile, informative, and valuable for its purposes. The scope of the present work is to provide a detailed idea of the BIPV product and BIPV systems. Then, we reviewed various published articles on the BIPV system in Bangladesh and explored its potential in terms of environmental, energy production, and conservation. Finally,

multiple challenges and barriers are deliberated upon, considering the current scenario in Bangladesh.

3. Building Integrated Photovoltaic System

BIPV systems, or building-integrated photovoltaic systems, are installations of photovoltaic (PV) products on the exterior of buildings that simultaneously act as a building material and an electrical power generator. Building exteriors like facades, roofs, or skylights are used by BIPV devices to convert buildings from energy consumers to energy producers [9]. BIPV products can be integrated with materials widely used in buildings, such as glass or metal, and they are flexible in size, form, color, and appearance, allowing for versatility in architectural design [10]. They also offer structural strength, weather and noise resistance, thermal insulation, a beautiful aesthetic look, and protection from the elements. Additionally, some BIPV items may let in the sunshine, offer a view of the outside, and, most crucially, in specific configurations, supply electrical and heating energy [11]. Due to the multifunctional benefits of the BIPV system, an increasing number of countries have set goals for using BIPV products in the building sector, as PV integration in buildings offers a substantial advancement in urban PV applications [9], [12]. In various regions of the world, solar photovoltaic technology installation is widespread on building surfaces like roofs and facades. As seen in Fig. 2, numerous BIPV systems are in use in actual building scenarios throughout the world [13].

3.1 Building integrated photovoltaic

The essential elements of a BIPV system are building-integrated photovoltaic (BIPV) or BIPV modules. BIPVs, however, are defined differently by researchers, in several standards, and by financial institutions at different times and in various ways. To develop a shared working understanding of the subject, the International Energy Agency's (IEA) photovoltaic power system program (PVPS) defined the BIPV based on the existing standards [14]. PVPS defines the BIPV module as: "A BIPV module is a combination of a PV module and a construction product intended to be used as a building component. A BIPV product is the smallest



Fig.2 BIPV systems in actual construction scenarios [13].

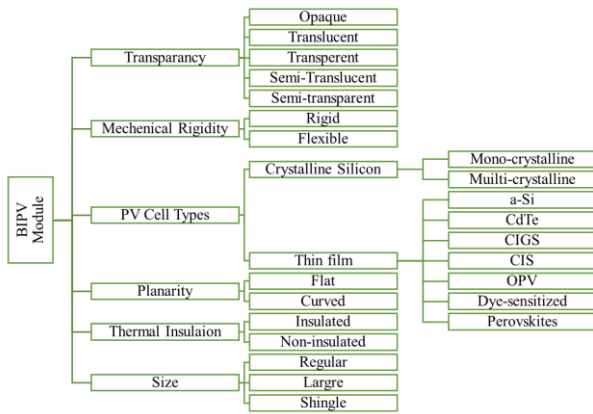


Fig.3 Classification of BIPV module.

(electrically and mechanically) non-divisible photovoltaic device in a BIPV system that maintains building functionality. If the BIPV product is removed, it must be replaced with a suitable construction material” [14], [15]. BIPV modules can be classified in many ways. Fig. 3 presents a comprehensive categorization of the BIPV module.

3.2 Application categories of BIPVs

The standard IEC-63092-1:2020 addresses the electro-technical requirements of BIPV modules by way of mounting as a building product [16]. This standard category is the mounted BIPV system according to the combination of some criteria like its accessibility within the building, slop of mounting, and the integration or attachment of it with the building [15], [17]. Based on these criteria, BIPV applications in building skins are categorized into five alphabets from A to E [15], [17], [18]. The pictograph of each category of BIPV application is shown in Fig. 4. The following section presents a brief discussion of each category.

- A. Sloping, roof-integrated, and inaccessible from within the building are all classified as Category A. A BIPV is considered inaccessible when another construction product is behind it. The BIPV modules are tilted between 0° and 75° from the horizontal plane, with another construction product fitted beneath.
- B. A sloping, roof-integrated, and accessible from within the building is classified as Category B. The BIPV modules are tilted between 0° and 75° from the horizontal plane when mounted.

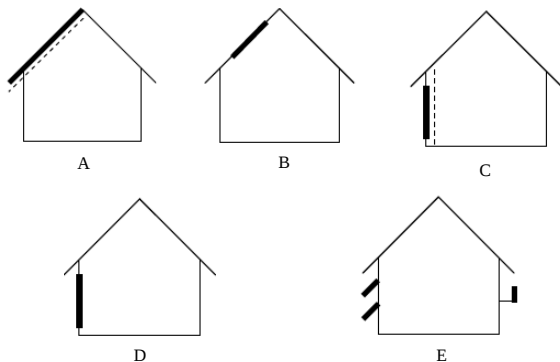


Fig.4 Different application categories of BIPVs in building [15].

- C. A non-sloping (vertically) envelope-integrated structure that is not accessible from within the building is classified as Category C. The BIPV modules are mounted at a 75° to 90° tilt angle from the horizontal plane, with another construction product erected behind them.
- D. Category D is defined as non-sloping (vertically), envelope-integrated, and accessible from within the building. The BIPV modules are installed at a tilt angle of between 75° and 90° from the horizontal plane.
- E. Externally integrated, accessible, or not accessible from within the building is designated as Category E. The BIPV modules are fitted to provide an extra functional layer that meets a building's needs, such as balcony balustrades, shutters, awnings, louvers, shade, and so on.

3.3 Classification of BIPV systems

BIPV modules are used in a building as a functional element of the building envelopes. PVPS also defines BIPV systems. According to their definition, A BIPV system is also a photovoltaic system in which the PV modules must satisfy the aforementioned definition of BIPV, as well as include the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building [14], [15]. BIPV is usually a building envelope construction component. In addition to construction components, there are other balances of the system (BOS) components that complete the PV electrical system. BOS components include a DC-to-DC converter, a DC-to-AC converter (Inverter), and batteries for electrical energy storage. According to the main building skin construction system, the BIPV system can be categorized into the following groups: Roof system, facade system, and externally integrated devices [17]. Fig. 5 illustrates the classification of different BIPV systems under various BIPV application categories.

The facade system represents the BIPV application categories C or D. Rainscreen facade, double-skin-faced (DSF), window, curtain wall, and masonry wall are the subdivisions of facade BIPV systems. Skylight/atrium, continuous roofing, and discontinuous roofing belong to roof

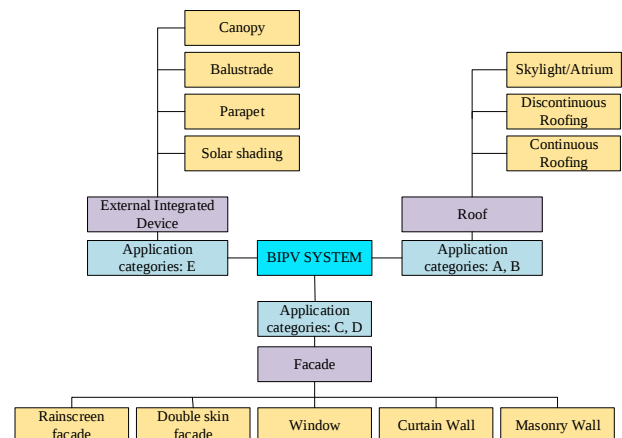


Fig.5 Classification of BIPV system [17].

BIPV systems. Roof BIPV systems are either A or B in BIPV application categories. Finally, balcony, parapet, balustrade,

and solar shading are examples of externally integrated BIPV systems that indicate the BIPV application category E.

4. Prospects of the BIPV system in Bangladesh

Depending on the goal of electrification in the grid and off-grid areas, photovoltaic technology is applied in Bangladesh in a variety of ways. Solar home systems, solar irrigation pumps, building-added photovoltaic systems (BAPV) or rooftop solar systems, solar street lights, solar mini-grids, etc., are a few popular means of PV application in this region[7]. In addition, land is a major concern when constructing solar systems for the production of power in a highly populated country like Bangladesh. Furthermore, compared to building facades, high-rise buildings have less roof area. When it comes to generating electricity and conserving building energy, BIPV systems, like the BIPV façade system, may be a viable option for a high-rise structure. Simultaneously, BIPV systems eliminate the need for extra installation space. However, there is no significant study on building energy conservation and electricity generation using BIPV systems concerning Bangladesh's climate conditions. Thus, there is a scope of research to investigate the potentiality of different BIPV systems in Bangladesh's climate conditions.

A study on the affordability of BIPV systems in the context of Bangladesh was carried out by Haque et al. [19]. According to their analysis, the BIPV system's electricity cost is comparable to the local tariff. Additionally, they contrasted the price of a BIPV system with the cost of producing electricity using various fossil fuels. The results show that the BIPV system in Bangladesh has a bright future. The effects of temperature, azimuth angle, and tilt angle change on the output of the BIPV system were investigated by Chowdhury et al. [20]. They found that if the tilt angle is changed from 90° to 21° while the azimuth angle is left at 0°, the power might be increased by about 5.07% at a temperature of 30°C in the setting of Bangladesh's environment. The performance of semi-transparent c-Si photovoltaic glazing was examined by Refat et al. [21] in a variety of climates, including the tropical climate of Bangladesh. According to the findings, Low-E glass photovoltaic insulated glazing and single photovoltaic glazing can reduce energy costs in Dhaka, Bangladesh, by 50% and 90%, respectively.

A few studies investigate the performance of BIPV façade system in high-rise residential [22], academic [23], and commercial [7] building in Bangladesh. Ali et al. [22] assesses the energy outcome of BIPV façade system integrated on the vertical surface of a pre build residential building in Dhaka city. Their finding reveals that the BIPV façade system could generate around 45.8 MWh of electricity when cloud effect is not considered. That make the building grid independent for more than half year. Barman et al shows that the BIPV façade system mounted on the various surfaces of a 20 storied academic building could generate around 386 MWh electricity at first year of its operation. Furthermore, in the both cases, the economic analysis of BIPV façade system shows that the payback period is around 4 years [22], [23].

Taking into account three distinct climate zones in Bangladesh—the southeast (Chittagong), the center (Dhaka), and the north (Rangpur)—the author examined three different kinds of BIPV window systems [7]. The south-facing wall is analyzed for three different CdTe-based BIPV window configurations: PV-VDS (photovoltaic ventilated

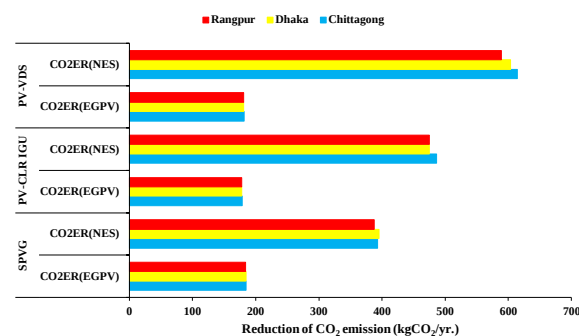


Fig.6 The greenhouse gas emissions reduction prospect of various BIPV window system in Bangladesh climate condition [7].

double skin), PV-CLR IGU (photovoltaic-clear insulated glazing unit), and SPVG (single photovoltaic glazing). These window systems are evaluated in comparison to the other three widely used window glazing types, such as single-glazed, tinted-glazed, and clear double-glazed, in terms of their capacity to produce electricity, save building energy, and reduce CO₂ emissions. This performance analysis was performed with a numerical simulation model based on EnergyPlus, validated by data from an outdoor experiment. The annual energy simulation findings show that, as compared to traditional window systems, CdTe-coupled BIPV windows can save anywhere from 30 to 61% of power consumption under all climate conditions. In addition, this small BIPV window system (installed capacity 381 Wp only) produces about 270 kWh of power and maintains 300 lux of daylight illumination indoors.

Furthermore, to calculate the greenhouse gas emissions reduction (GHGER) potential, the generated electricity (EGPV) and net electricity-saving (NES) performance of these BIPV window systems in comparison to a single clear window system are multiplied by Bangladesh's grid emission factor (GEF). Fig. 6 illustrates that, with regard to EGPV alone, the GHGER ability of every type of BIPV window system is nearly identical (around 181 KgCO₂/yr.) across all climate areas. In contrast to the SPVG and PV-CLR IGU window systems, the PV-VDS window system exhibits a more considerable GHGER potential regarding NES. For the PV-VDS window system, the greatest GHGER was recorded at Chittagong, at about 615 KgCO₂/yr. [7].

In the case of the BIPV initiative, only a few private organizations have installed BIPV systems in their building. For example, the new corporate headquarters of Eastern Bank Limited in Dhaka, Bangladesh, has an a-silicon photovoltaic glass façade that makes it more environmentally and energy-friendly. A-silicon glass modules with a high degree of transparency cover approximately 500 m² of the façade space. The overall installed power capacity of the BIPV facade system is 12.5 kWp. According to projections, this façade will produce 22,600 kWh annually, which is enough to power 1,300 lights while preventing the release of 15 tons of CO₂ [24].

The above discussion led to the conclusion that BIPV systems can create clean energy to fulfill the building sector's increasing energy demand. Furthermore, it may help to reduce grid dependency and carbon emissions. Overall, widespread adoption of BIPV systems in Bangladesh could contribute to the country's future renewable energy ambitions and sustainable development goals.

5. Challenges of BIPV system in Bangladesh

We may conclude that the BIPV system has a lot of promise for a region like Bangladesh dominated by cooling from the prior literature review on the topic. However, neither a comprehensive study on BIPV systems nor a government strategy about this promising building technology exists. As a result, it is presently difficult to penetrate this promising technology on a large scale. The following is a list of the BIPV system's most frequent difficulties for implementing it in Bangladesh.

- a. The major obstacles to implementing this promising PV application in Bangladesh are the significant initial capital expenditures of the BIPV system and the lack of public awareness. Most people believed that capital expenses in Bangladesh and many other nations were the most significant risk or barrier to installing solar power systems in buildings. Although individuals are aware of the high upfront costs of BIPV systems, they are unaware of their long-term advantages and payback period.
- b. Another main challenge of the BIPV system is that most of the BIPV systems are customized in nature. The reason that the integrated nature of BIPV systems involves greater complexity in the design process of both BIPV and buildings to incorporate the BIPV modules into building envelopes architecturally [25]. Besides, there is a shortage of design professionals with BIPV experience. As a result, the design process is more expensive due to the customized nature of the BIPV product in production and integration into the building.
- c. Low energy conversion efficiency (ECE) of BIPV systems compared to other electrical power generating systems is another foremost challenge to adopting it. The ECE of the BIPV module in BIPV systems is low and dependent on weather conditions and its installation location on the building. Table 2 shows the ECE of currently available regular type BIPV. Moreover, in the case of BIPV glazing, the ECE is even lower as its cell coverage ratio (CCR) is lower than the regular type BIPV module, and it is mostly attached to the vertical surface of the building. Thus, the ECE of the BIPV system greatly depends on the PV technology used in the BIPV module and CCR [26].

Table 2 List of various regular type BIPV module energy conversion efficiency measured under STC conditions (IEC 60904-3: 2008 or ASTM G-173-03 global) [27].

Classification	Efficiency (%)
Si (crystalline)	24.4 ± 0.5
Si (poly-crystalline)	20.4 ± 0.3
CIGS (Cd-free)	19.0 ± 0.9
a-Si/nc-Si (tandem)	12.3 ± 0.3
CdTe (thin-film)	19.2 ± 0.5
Perovskite	17.9 ± 0.5
Organic (OPV)	8.7 ± 0.3

- d. Another challenge to scaling up the BIPV system in Bangladesh is the lack of government policy and support. In Bangladesh, traditional BIPV modules are manufactured using crystalline silicon PV technology. Still, specialized BIPV modules like PV glazing or PV tile are not manufactured locally.

However, there is no government policy that helps the primary BIPV supply chain stakeholders, offers end users incentives and subsidies, or offers any other solutions for reducing risks and eliminating all the obstacles mentioned above.

- e. The adoption of feed-in tariffs (FiT) is one of the main obstacles to penetrating BIPV systems on a mass scale. By selling additional power generated by the BIPV system at a price that is typically higher than the selling price from the power grid, FiT is a course of action intended to encourage investment in the BIPV system. Whereas the GOB supports net energy metering guidelines for industrial photovoltaic systems that are connected to the grid, there are still certain obstacles that need to be overcome [28].
- f. BIPV acts as a building envelope; however, the Bangladesh National Building Code (BNBC) does not indicate or policy on implementing this advanced building technology in Bangladeshi buildings. As a result, in terms of health and safety considerations, there is still a lack of standards in the building codes.

6. Conclusion

The building sector dominates in Bangladesh in terms of electricity and primary energy consumption. By applying the BIPV system in buildings, it could turn energy consumers into energy producers. Based on Bangladesh's climate, BIPV facade and window systems show excellent prospects for electricity generation, CO₂ emission reduction, and economic benefits. For instance, the BIPV facade system of a 20 storied academic building generates around 386 MWh/yr. Furthermore, for Dhaka's high-rise urban buildings, the payback period for a BIPV facade system took around 4 years. On the other hand, a tiny BIPV window system has the ability to reduce CO₂ emissions by around 615 kgCO₂/yr. Conversely, implementing the BIPV system in buildings is in its very initial phase in our country. However, to increase the BIPV application in Bangladesh, we must mitigate many challenges, like executing an effective FiT method, increasing government incentives, applying suitable policies, raising public awareness, increasing research and development, increasing skilled manpower in this sector, etc.

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