Review

Status of BIPV and BAPV System for Less Energy-Hungry Building in India—A Review

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Abstract: The photovoltaic (PV) system is one of the most promising technologies that generate benevolent electricity. Therefore, fossil fuel-generated electric power plants, that emit an enormous amount of greenhouse gases, can be replaced by the PV power plant. However, due to its lower efficiency than a traditional power plant, and to generate equal amount of power, a large land area is required for the PV power plant. Also, transmission and distribution losses are intricate issues for PV power plants. Therefore, the inclusion of PV into a building is one of the holistic approaches which reduce the necessity for such large land areas. Building-integrated and building attached/applied are the two types where PV can be included in the building. Building applied/attached PV(BAPV) indicates that the PV system is added/attached or applied to a building, whereas, building integrated PV (BIPV) illustrates the concept of replacing the traditional building envelop, such as window, wall, roof by PV. In India, applying PV on a building is growing due to India's solar mission target for 2022. In 2015, through Jawaharlal Nehru National Solar Mission, India targeted to achieve 100 GW PV power of which 40 GW will be acquired from roof-integrated PV by 2022. By the end of December 2019, India achieved 33.7 GW total installed PV power. Also, green/zero energy/and sustainable buildings are gaining significance in India due to rapid urbanization. However, BIPV system is rarely used in India which is likely due to a lack of government support and public awareness. This work reviewed the status of BIPV/BAPV system in India. The BIPV window system can probably be the suitable BIPV product for Indian context to reduce the building's HVAC load.

Keywords: India; BIPV/BAPV; BIPV-Glazing; JNNSM; MNRE; Zero energy-building

1. Introduction

India's energy consumption has increased to 931 billion kWh which is double than of the level marked in the year 1990 making it one of the largest energy consumers in the world along with China, the USA and, Russia. In 2014, India's per capita electricity consumption was 900 kWh which was 1/3 of the average worldwide consumption [1,2]. Also, compared to 1971, Indian per capita energy use has increased from 3116.84 to 7408.31 kWh in 2014. India's energy sources primarily depend on non-renewable coal-based sources which contribute to a massive amount of greenhouse gases [3–5].

Currently, India is facing urbanization due to the migration of people into larger cities from smaller towns and villages. This transition enhances the necessity of developing new buildings. During 2014–2015, India consumed almost 840 million m² floor space for commercial use. Buildings in India, consume 29% of the total energy, of which residential contributes to 20% and commercial to 9% [6]. In residential buildings, lighting and space cooling accounts to one-third of the energy consumption (1–3 kWh/m²/month), whereas commercial buildings consume two-third of the total energy (5–25 kWh/m²/month) [7]. The phenomenal growth in the building sector will be witnessed by the year 2030 with an annual building rate of 700–900 million sq. m. These buildings consume a considerable amount of energy for heating, ventilation and air conditioning (HVAC) load demand. Further, the indoor air condition rate is growing at a rate of 30% every year. Projected energy usage for 2050, with the current scenario, shows an 85% increment compared to the energy level in 2005 [8].

The present energy consumption scenario, along with future projections, has forced India to take some necessary actions. In 2015, the international energy association (IEA) has set a target to limit the ambient temperature increment to below 2 °C than the pre-industrial levels. Hence, India should focus on finding out the energy-efficient ways to generate power and also reduce building energy consumption rates. Fortunately, India is blessed with high solar radiation, which receives 6 billion GWh equivalent energy potential per year. The average incident solar radiation in India is 5.1 kWh/m²/day (with large regional differences). This makes India deploy solar photovoltaic (PV) technology to meet the IEA target. The PV device is one of the most promising renewable energy technologies, which converts solar energy into environment-friendly electrical energy by using abundant incident solar radiation. Replacing fossil fuel-generated power by secure, clean and suitable PV generated power can mitigate issues like climatic changes [9,10].

The Ministry of Power, which controls the power sector in India, created an impressive mission through Jawaharlal Nehru National Solar Mission (JNNSM). Previously, JNNSM has set a target to install a PV capacity of 22 GW by the year 2022 which later increased to a more ambitious target of 100 GW [11]. Subsequently, to reduce building energy consumption and generate power from renewable sources in the buildings; zero energy buildings (ZEB) or net-zero energy buildings are also getting a promotion. Hence, addition of the PV system into the building is one of the most holistic approaches, where, PV will generate a benevolent amount of energy, sufficient for the building-energy requirements. The inclusion of PV technologies into buildings include building-integrated photovoltaics (BIPV) and building-applied photovoltaics (BAPV). For the BIPV system, the PV system replaces the traditional building envelopes, such as windows, roofs, walls and itself acts as a building envelope, whereas for the BAPV system, PVs are applied or attached to the building walls or roofs. Both BAPV and BIPV works as an onsite green power generation, reducing the transmission losses, and improving the building's overall performance.

In this paper, various technologies involving BIPV and BAPV approaches have been discussed and their potential application for Indian context has been critically analyzed in detail. Moreover, solar potential and PV power electricity market in India are also discussed.

2. PV Technologies for BIPV/BAPV

Presently PV technologies include first-generation opaque silicon type, second-generation transparent or semitransparent thin film and third or emerging types [12]. Until now, the first generations are employed for BIPV and BAPV applications, whereas second and third generations are primarily considered for BIPV application.

Crystalline silicon (c-Si) PV cells are the most widely used and predominant technology in the market due to their mature and long-term durability. Monocrystalline PV cells are made from a single crystal, developed using the Czochralski process with the best-reported efficiency of nearly 22%. Polycrystalline solar cells are developed by melting several fragments of silicon together to form a wafer. Typical efficiency is in the range of 14–18% for polycrystalline PV cells, which is less efficient than the monocrystalline counterparts, since electrons have less freedom of movement due

to grain boundaries of many crystals in each cell. However various anti-reflective coatings can be applied onto the surface to change the color of the PV cells. Presently colored silicon PV is also under investigation [13,14]. The major constraints of crystalline silicon PV cells are power losses due to the shading and at elevated temperature [15–22].

Thin films include (i) amorphous silicon (a-Si) (ii) Copper – Indium Selenide (CIS) or Copper-Indium-Gallium- Selenide (CIGS), (iii) Cadmium-Telluride (CdTe). The thickness of the film could be a few nanometers to micrometers. These technologies have meager efficiencies in comparison to c-Si, typically 11–12%. However, they have several advantages such as (a) less loss in performance under overcast cloudy climatic conditions and partial shading from obstacles [23,24] (b) employ lower semiconductor material and hence lower production cost (c) manufacture of transparent or translucent modules using laser scribing [25–27]. Amorphous silicon is the non-crystalline form of silicon, with atoms disoriented in a random network structure. The major advantage of it is being able to be deposited as thin films on to a moldable substrate like plastic at less than 300 °C of manufacturing temperature. Moreover, its absorptivity is higher (~40 times) and needs only 1% (about 1 µm) of material of crystalline silicon, which results in lower making cost/unit-area. Due to its flexible nature, it can be molded into any suitable complex shape for building integration. Although it has high efficiency in comparison to other thin-film technologies, it suffers from degradation due to hydrogenation (Staebler-Wronski effect) [28–33]. Cadmium telluride (CdTe) is a single-junction solar cell having 1.45 eV bandgap energy. It is a direct bandgap semiconductor nearly ideal for optimal conversion of solar radiation into electricity. An efficiency exceeding 20% has been reported CdTe PV. The major limitations of CdTe cells are its instability and toxicity of cadmium which makes it less suitable for PV application. Copper Indium Gallium Diselenide (CIS) is a polycrystalline compound consisting of copper, indium, gallium, sulphur and selenide elements, with the highest reported conversion efficiency of about 25% in combination with perovskites [34] CIS has high light absorptivity and 0.5 µm of CIS can absorb 90% of the solar spectrum [35]. Similar to other thin-film technology, CIGSs are semi-transparent and flexible.

Emerging third generations are gaining importance due to their low fabrication cost, and transparent and semitransparent makes them a potential candidate for aesthetic building integration. Organic photovoltaics uses organic polymer as the light-absorbing layer. Organic PVs are lightweight, and flexible which allows them to be applied in building as a BIPV system [36–38]. O'Regan and Gratzel carried out seminal work on dye-sensitized solar cells (DSSC) [39]. Since its inception, extensive research was carried out to improve the efficiency and stability of DSSC. DSSCs are considered for BIPV application due to its simpler and low-cost fabrication process, flexible, have potential to operate at diffuse solar radiation [40,41]. Colored and semi-transparent windows are popular for BIPV application [42,43]. However, factors inhibiting to its commercialization are long term- stability and durability. Table 1 listed the advantage and disadvantages of various PV technologies. Recently, Perovskite PV gained attention due to its efficiency improvement in 10 years. However, they are mostly operated and fabricated at inert atmospheric condition. Tunable transparency [44], and low temperature fabrication [45] makes it fascinating to researcher for BIPV application [46,47].

Table 1. Advantages of disadvantages of various solar cells.

Solar cell	Advantages	Disadvantages
Monocrystalline silicon solar cells [17,48,49]	<ul style="list-style-type: none"> • Matured PV technologies. • Highly durable. • Suitable for BAPV application. 	<ul style="list-style-type: none"> • There is a lot of waste material when silicon is removed during processing. • At high temperature, performance degrades. • Opaque in nature, hence less suitable for artistic BIPV application.

Table 1. Cont.

Solar cell	Advantages	Disadvantages
Polycrystalline silicon solar cells [50–52]	<ul style="list-style-type: none"> The production process is simpler than the monocrystalline cells. Highly durable. 	<ul style="list-style-type: none"> Due to low level of silicon purity, performance is only around 13–16%.
Amorphous silicon solar cells [53–55]	<ul style="list-style-type: none"> Low manufacturing costs. The cell can be produced in various shapes. At high temperature, performance degradation is lower than crystalline silicon. 	<ul style="list-style-type: none"> The efficiency is typically 6–8%. They have shorter lifetime compared to other solar cells. Required twice, the space to get same PV power than that of crystalline silicon.
CdTe solar cells [56–61]	<ul style="list-style-type: none"> Cadmium is abundant. The manufacturing process is simple. It can absorb light of shorter wavelength. 	<ul style="list-style-type: none"> The efficiency operates in the range 9–11%. Tellurium is not abundant. Cadmium telluride is toxic and not environmentally benign.
CIGS solar cells [35,52,62–67]	<ul style="list-style-type: none"> CIGS solar cells use lower levels of cadmium, in the form of cadmium sulphide. CIGS solar cell substrates are more versatile in comparison with c-Si. CIGS solar panels show better resistance to heat compared to silicon solar cells. 	<ul style="list-style-type: none"> The efficiency ranges in between 12–14%. High fabrication and production costs.
Organic solar cells [36–38]	<ul style="list-style-type: none"> The PV modules are low weight and flexible. Lower production costs than traditional inorganic technologies, such as silicon solar cells. 	<ul style="list-style-type: none"> Lifetime is short. Very low efficiency around 4–5%.
DSSC [68–70]	<ul style="list-style-type: none"> It consists of low-cost materials easy fabrication. It works even in low light conditions such as the cloudy weather. Tunable transparency is possible by tuning the thickness and dye. Use of flexible substrate makes it flexible and suitable for BIPV. 	<ul style="list-style-type: none"> Low efficiency around 12%. The liquid electrolyte has temperature stability problems. The liquid will quickly dry up. Long term stability is questionable.

Table 1. Cont.

Solar cell	Advantages	Disadvantages
Perovskite solar cells [71–73]	<ul style="list-style-type: none"> • Perovskite uses smaller quantity of material to absorb the equivalent amount of light in comparison to c-Si. • Perovskite materials, like methylammonium lead halides are cheap and easy to produce. • Semi-transparent/transparent cells are possible, which makes it suitable for aesthetic building application. 	<ul style="list-style-type: none"> • Not stable at ambient condition. • Not fully matured technology. • Thermal performance of this technology is not well.

3. Building Integrated and Applied Photovoltaic (BIPV/BAPV) Technologies

BAPVs are an addition to the traditional or new PV system, on an existing or new building whereas BIPVs replace the existing traditional building envelope, such as window, roof, and wall [74]. Hence, BIPV has a greater impact on the building's indoor environment. BIPVs are often transparent or semi-transparent by nature, which allows incident daylight and solar heat to pass through, thereby directly modifying the indoor ambiances. Additionally, it also has a variety of capabilities like control solar heat gain or loss, daylight glare and offset the window, roof or wall material cost [75]. On the other hand, BAPVs have no such contribution to the building environment other than the production of green power. Currently, available BIPV products include BIPV tile, foil and glazing [76,77]. BIPV foils and tiles are primarily applied on the roof while BIPV glazings are mostly employed for vertical semi-transparent and transparent windows, façade and wall applications. Presently, 80% of the BIPV market contributes to rooftop-mounted and only 20% of it is in accord for façade-mounted [2,78–82]. Generally, rooftops, standing without any hindrance from nearby tall buildings or trees, are the ideal solutions to harvest the best energy when pitched at certain elevation angles. BIPV foil products are best suited for building applications due to their flexibility and light-weight properties. PV cells for BIPV products are mostly thin films, which possess low power generation due to the high electrical resistance of the thin film. However, due to a low temperature coefficient of thin-film BIPV foil, power degradation is comparatively less at high temperatures to silicon types. Alwitra GmbH and Co, which uses amorphous silicon cells and Uni-Solar cells are the present manufacturers of BIPV foil. Next, BIPV tiles are most prominently used as roof integration, which includes covering the entire roof or selected part of the roof with BIPV tiles. Some of these tiles also appear to be similar to that of a ceramic curved tile, which might be aesthetically pleasing but are not effective in terms of power generation, due to its curved surface area [76,77]. SRS Energy, Solar Century, Luma solar, Suntegra and, Sunflare Tesla are few of the present BIPV tile manufacturers.

Figure 1 shows the presently available BIPV and BAPV products. BIPV windows are one of the most fascinating applications, responsible for maintaining visual comfort between the external world and building interior, modulating available daylight and heat. Crystalline silicon [83,84], amorphous silicon [85–88], CdTe [89,90], DSSC [91,92] and perovskite [44] are the few materials, which when intensely investigated for BIPV window applications (shown in Figure 2), have found impressive possibilities towards building integration.

Figure 1. Major BIPV and BAPV products [79].

Figure 2. Window integrated with different types of PV cell materials [93].

Concentrator-based BIPV windows are also very attractive for less energy-hungry building integration. Low concentrating compound parabolic concentrator (CPC) [94] and luminescent solar concentrators (LSC) [95] are now dominating the major building-integrated concentrating photovoltaic research activity. Low concentrators are static which reduces the cost of the expensive solar tracker. The thermal effect is lower than a high concentrator, due to a low concentrator on PV cells, which reduces the necessity of a cooling system and makes a low concentrator a suitable candidate for building's window and façade application [96–98]. For northern latitude location, diffuse solar radiations are higher, CPC and LSC both work efficiently. Concentrating PV came into a scenario to reduce the usage of the costly silicon material by replacing low-cost material, which concentrates a

higher amount of incident solar light on a lesser PV material [99]. For crystalline silicon-CPC-based BIPV window, regular distribution of spacing between PV cells offer semi-transparency (silicon solar cells are opaque), as shown in Figure 3. Different geometries of CPCs were investigated for BIPV window and façade application [100–103]. Recently, the performance of DSSC and perovskite solar cells was also investigated, using low concentrating CPC, which enhanced the PV performance than non-concentrating counterpart [104,105].

Figure 3. (a) CPC based BIPV, (b) Semi-transparent building blocks using CPC-silicon PV (image courtesy Build Solar).

A typical LSC consists of a glass or plastic-based square/rectangular-shaped waveguide luminophores, which absorbs a short-wavelength photon and convert them into long-wavelength. Further, due to total internal reflection, these photons finally reach the PV cells attached at the edge of the waveguide [106–110], as shown in Figure 4. The advantage of LSC-BIPV system is that the PV cells are placed at the edge, which does not create an obstacle for viewing. Also, this waveguide plate can be made semi-transparent to fully-transparent or different colors, which is aesthetic for building application and suitable for building window integration [111–114]. Promising results, using LSC-thin film integration, was also reported by [115]. LSC does not possess any thermal effect on PV cells, which is an added advantage over low concentrating CPC.

Figure 4. Working principle of inkjet-printed luminescent solar concentrator and photograph of a printed A4 sized luminescent solar concentrator [109].

The performance degradation of both BIPV and BAPV is possible at higher ambient temperature and exposure to higher incident radiation, which increases the PV cell's temperature. Crystalline silicon and thin-film both work, with poor efficiency, at higher PV cell temperature. Thermal regulation BAPV

system is possible by employing forced water flow, forced airflow or phase change material (PCM) at the back of the system [116,117]. At the back of the BPAV system, copper pipes are integrated to flow the air [118–120] or water [121,122]. This typical BAPV is also known as BAPV-thermal (BAPV/T) water or air collector, where water or air will extract the additional heat energy from the PV system and allow PV system to operate efficiently. Hot air or water can be used by building purposes [123]. Notably, researchers often misuse the BIPV term [121,122,124–130]. As BIPV is attached as a building envelope, natural airflow and PCM are the only two available and investigated options to diminish the elevated PV cell temperature [131–133]. The inclusion of collector to BIPV was forced to compromise with buildings aesthetic. For a system which is BAPV/T system is most often referred to as BIPV/T in the articles. Hence, care should be taken when referring to a PV/T system as BAPV/T or BIPV/T. A typical BAPV/T with a water flow system is shown in Figure 5. Details of BIPV and BAPV are listed in Table 2.

Figure 5. BAPV/T system installed at Sodha BERS complex, Varanasi (25.33° N, 82.99° E) [134].

Table 2. Details of different BIPV and BAPV products.

Product	Type of Cell	Particular Purpose
BIPV window	1st generation 2nd generation 3rd generation	Control daylight, solar heat Aesthetic application Power generation gets lower priority
BIPV foil/tiles	2nd generation (mostly available) 3rd generation (suitable but stability should be improved)	Works as building shading from the harsh external environment Power generation gets lower priority
Spaced type concentrating BIPV	1st generation (experimentally validated/commercial product is available) 2nd generation (no report) 3rd generation (experimentally explored in the lab)	Improve the power generation Reduce the cost of the system Spaced type allow daylight suitable for passive house application/zero energy application
BAPV/T	1st generation 2nd generation	Suitable for rooftop application

4. Potential of BIPV/BAPV in India

India lies between 68°7' to 97°25' east longitude and 8°4' to 37°6' north latitude, has 2.9 million Km² of landmass, and is the seventh largest country in the world. It is in the tropical region and receives maximum solar radiation in summer, and experiences about 300 sunny clear days in a year. Ambient

conditions vary from 45 °C in summer while 4 °C in winter and has a hot-dry, warm-humid, composite, temperate, and cold climatic zones [135]. India's rich solar radiation profile shows 4.5–5.0 KWh/m²/Day of annual average direct normal irradiance in most of the Indian states and around 5.0–5.5 KWh/m²/Day average global horizontal irradiance [136,137]. This makes India one of the most potential candidates to contribute to PV power generation. Figure 6 shows the solar radiation intensity throughout India. India's projected electricity demand in 2047 is expected to be 5518 TWh. India's present energy demand is supplied by 70% of imported crude oil and coal. Indian thermal power plants, that are run by coal, are the most inefficient ones. Hence, in order to become an energy-secured country and dependent from oil-import, India should use its solar PV power potential. Although, India has a higher solar radiation, being a developing country, PV power generation faces issues, including high initial installation cost of PV power generation, the lack of suitable storage devices or unavailable during an instant power supply demand. Backup power supply from fossil fuel-generated kerosene oil lamps, diesel generators, etc. are still low cost in India [138]. However, this fossil fuel generated power emits considerable amount of green house gas (GHG). India is committed to lowering its GHG to 30–33% by 2030, compared to 2005 level.

Figure 6. Physical map Indian solar radiation [139].

Interestingly, energy generation from PV devices was in discussion in India since 1960. However, progress was limited until 2010 [140,141]. The first significant move was taken in 2010 to priorities the PV power generation through the National Action Plan on Climate Change, by launching the JNNSM scheme [142]. In 2010, the total installed capacity from PV was only 39.6 MW. After Prime Minister Narendra Modi came into power, India's 2022 target changed from 20 GW to 100 GW, which included grid-connected projects, off-grid projects, and solar parks. It was also fixed that out of 100 GW, rooftop PV should produce 40 GW by 2022 [143]. Under the JNNSM mission, grid-connected rooftops and small solar power plant programs have been launched to obtain the 40 GW rooftop power generation. The minimum and maximum limit of installing PV power capacity are to 1 kWp, and 500 kWp, respectively [139,144]. India has 29 states and 7 union territory out of which Madhya Pradesh, Gujarat Ladakh, Andhra Pradesh, Maharashtra, and Rajasthan receive the maximum amount of average annual solar radiation, as compared to other states of India. Gujarat is the first Indian state which implemented a solar policy in the year 2009, well before the initiation of JNNSM. Rajasthan started its solar mission in 2011 to meet the national target. Karnataka started its solar mission for the

period of 2014 to 2021. Madhya-Pradesh started its solar policy in 2012 and provided the incentives and benefits to the Private Sector to encourage the PV installation [145]. To initiate the government target, several commercial investors came in front. Cleanmax solar had invested Rs 600 crores to set up a 150 MW solar farm in Sirsa District, Haryana (near to New Delhi, 29.05° N, 76.08° E) on a stretch of 600 acres of land. Bharathi Cement had commissioned a 10 MW solar power plant in the manufacturing facility, located at Kadapa in Andhra Pradesh (14.46° N, 78.82° E). The plant is expected to generate 1.6 crore units of electric power annually, and help to reduce Bharathi's overall energy costs by reducing its dependence on thermal power. Maruti Suzuki India had planned to invest Rs 24 crore (\$3366k) to set up a 5 MW solar power plant at its Gurugram (28.45° N, 77.02° E) facility. The plant would help to lower CO₂ emissions by 5,390 tonnes annually in 25 years. ReNew Power had commissioned 300 MW solar plant at Pavagada Solar Park in Tumkur district in Karnataka (13.37° N, 76.64° E). The solar power plant could reduce 0.6 million tonnes of CO₂ emission per year. The plant uses high efficiency Mono PERC solar modules and is based on seasonal tilt technology with string invertors. However, solar power plants are practically is not feasible for urban areas where large amount of space is required. India's population growth and rapid urbanization land availability for solar plants will be a complicated issue. Hence, solar rooftops should be given higher priority. Some of the major PV installations include Braboune stadium, Mumbai, which is the world's largest solar rooftop with capacity of 820.8 kWp, as shown in Figure 7a. Another major installation is carport at Cochin International Airport, which is India's largest carport solarized by Tata Power Solar. The plant is 2.67 MW, and is spread across an area of 20289.9 m², which offsets 1868 tons of CO₂ as shown in Figure 7b.

Figure 7. (a) World's largest solar rooftop with a capacity of 820.8 kWp installed on Braboune stadium, at Cricket Club of India, in Mumbai (18.93° N, 72.82° E) (b) India's largest solar carport 2.67 Mw at Cochin International Airport (Cial) (10.15° N, 76.39° E).

Although, in India, 83.3 crore reside in a rural area out of 121 crores, urbanization is occurring at a rapid pace. Every minute, 30 Indians move from a rural area to a city, seeking better-paying jobs. Population and economic growth have fostered urbanization in the country and the number of urban towns and cities has drastically increased [146,147]. By the end of 2030, 590 million Indians will be in city for which new buildings are required. It is expected that five-fold built space will be in 2030 than 2005 level in India, of which 60% will be air-conditioned space. Maintaining similar conditions, Indian's building can consume energy and emits GHG with a 700% increment by 2050, compared to 2005 levels [135]. Presently building consumes 30% of electricity in India [148]. The reduction of building energy enhances the demand for sustainable building, which will perform as low energy or less energy-hungry building by trim down the HVAC load demand. To attain such a building, envelopes need to be energy efficient and responsive to an outdoor conundrum. To assess the performance of the buildings, The Energy and Resource Institute of India (TERI) and MNRE has created Green Rating for Integrated Habitat Assessment (GRIHA), and the Leadership in Energy and Environmental Design (LEED) rating tools to help curtail the substantial resources consumed by the building industry, and

to reduce the overall environmental impact within tolerable limits. GRIHA evaluates the ecological performance of the building comprehensively by controlling energy consumption, reducing carbon dioxide gas emissions and reinforce the use of inexhaustible and processable sources to the best possible extent [149,150]. MNRE also encourages now passive building which will use solar energy by the suitable orientation of building for daylighting, heating and cooling load demand [151].

BIPV and BAPV both can contribute a considerable amount of energy and improve the building's indoor environment in India [152,153]. However, the dearth of BIPV experts and BIPV marketing professionals, limited in-house consumption data, dearth of ability in planning, commissioning, operation, and maintenance of solar PV/BIPV projects, inadequate training and capacity building, not enough available information about BIPV for policy-making and mobilizing civil society are the barrier for Indian BIPV/BAPV market [81,82]. Another major barrier for widespread PV in India is the lack of resources of raw materials for PV manufacturing. BIPV technology, which is mainly thin-film-based, did not have much uptake in India due to the same reason. For crystalline silicon, India depends on import of the silicon wafer. Currently, in India, the thin-film PV industries are run by US-based First Solar (22% share), Canadian Solar (6% share) and 6% share of Trina Solar Chinese manufacture (6%). India also cannot support CdTe production as India's copper refining industry size is not big enough and upgradation is required to enhance tellurium recovery rates from the copper refining process [154]. The Indian developer, Vikram Solar, has a 3.5% share followed by Moser Baer, Tata Power Solar and Lanco [155]. China controls over 97% of rare earth material which makes them capable to control the price of thin-film [155]. Poor performance of thin-film PV system compared to silicon PV system creates a negative impact on thin-film BIPV system. Thin film degradation occurs in higher rate than crystalline PV over 25 years. Also, thin-film PV cells possess micro-cracks after few years of operation, due to the temperature gradient differences between bottom and top, which cause additional cost of replacement. In India, utilization of BIPV and BAPV is still not fully well established and primarily most of the major integration types are BAPV. Solar rooftop PV application which is BAPV technologies are predominant in India. According to census 2011, in India, there are 331 million households, with urban settlement area of 77,370 km², which can be a huge potential of 124 GW for rooftop BAPV to satisfy 40 GW rooftop PV power generation target by 2022. Rooftop PV installations grew at robust pace adding 1,836 MW in the financial year 2018–2019, with a total becoming 10 GW. Figure 8a shows the spaced type semitransparent crystalline solar BIPV module integrated on the rooftop having installed capacity of 1.68 kWp. Each module had dimensions of 1963 mm × 0.987 mm × 40 mm covered with 36 c-Si panels with a transparent area of 49% and rated power of 150 W. Figure 8b shows the India's first zero energy building, which was constructed in 2014. PV panels occupy 4600 m² area and annual energy generation cost is 14 lakh (\$19k) Unit kWh, while the cost of installation was Rs 18 crore (\$2533k). Coal India Limited's Corporate Headquarters at Rajarhat in Kolkata (22.57° N, 88.37° E) installed 632 PV panels with total capacity of 140 kW. The solar energy powers the uninterrupted power supply for desktops, emergency lighting systems and the landscape lighting of CIL's corporate office. Tata BP Solar has implemented 30 kWp (\$250,000) BAPV system in Samudra Institute of Maritime Studies in Pune (18.52° N, 73.85° E). Moser Baer has installed a 1.8 kWp BIPV exterior façade of Jubilee shopping complex in Hyderabad (17.38° N, 78.48° E) to meet power requirements in shopping complexes. The government buildings in India are also encouraged to use solar energy in an aesthetic approach by using BIPV/BAPV technology. The government is also focused on increasing the roof top systems and streamlining policy implementation processes. In 2015, Novus green installed a 1MW BAPV system (4000 PV system each had 250 Wp) at the rooftop of IIT Delhi. Energy Efficiency Services (EESL) had planned to invest INR 800 crore for rooftop solar in Maharashtra across 5000 state-owned buildings to install 200 MW grid-connected systems. EESL estimates that about 100 million units would be saved per year by replacing energy-inefficient ceiling fans (6 lakh), LED bulbs (11 lakh) and air-conditioners (7000) along with streetlights (14,000) and retrofitting 3000 buildings.

Figure 8. (a) Spaced type crystalline silicon solar-based BIPV roof for daylighting application (Source: HHV solar, Bangalore, India), (b) BAPV system in Indira Paryavaran Bhawan India (Image source: BT).

Another barrier in India for poor BIPV/BAPV - standalone system is the unorganized Indian electricity market. The PV power generation sector includes three different customers. The first customer state distribution companies (DISCOMs) who have renewable purchase obligations (RPO) to buy PV power and meet 10.5% PV electricity generated, second is the rooftop PV consumers (RPVCs) and third is large buyers of power who are also known as open access consumers (OACs) [156]. Under open access (OA), consumers are capable of buying electricity from producers who generate electricity independently. Indian rail started exploring PV power from OA. Developers feel that RPO is not same for all state as State Electricity Regulatory Commissions (SERCs) has different benchmark for each state. PV power electricity price varies from INR 7.5 to INR18.5/kWh. In 2010, Central Electricity Regulatory Commission (CERC) has implemented the PV/BIPV feed-in tariff of INR 17.9/kWh [157]. In India, the coal power electricity price is about INR 5.5/kWh, while the PV power price is about INR6.5/kWh. Hence, project developers are compelled to offer discounts [158]. Thus, DISCOMs are failing to comply with RPO requirements, due to their poor financial health and lower solar tariff support. Hence, they prefer to wait for buying low price PV electricity. DISCOMs also argued that BIPV/BAPV based standalone systems increase their financial burden as RPV customers prefer to buy grid electricity over BIPV/BAPV power due to intermittency. Intermittent PV power generation is also an issue for the promotion of OA [159]. To rectify this issue, energy banking can be created where DISCOM will facilitate OA transactions through electricity banking, between an independent power producer and OAC. DISCOM can generate less power whenever an independent power producer generates a higher amount of power than the OAC's demand, in order to use surplus PV power and generate when PV generation is reduced and shortfalls arise [159,160]. The presence of multiple electricity regulatory boards like MNRE (Ministry of New and Renewable Energy), CERC (Central Electricity Regulatory Commission), SERC (Ministry of Power and State Electricity Regulatory Commission) also make the legal process a cumbersome task [161].

By the end of Sep 2019, India's cumulative installed solar capacity stood at 33.8 GW, of which 88% are PV plants and 12% rooftop installations. Ambiguity in incentive implementation, non-availability of storage systems incentives, lack of consumer awareness and research studies are the reason behind this sluggish movement for rooftop PV application in India [162]. Dust accumulation, which reduces PV power generation, should also be taken care of as air quality in India can pose a negative impact [163–165].

5. Perspective and Discussion

It is evident that in India, solar PV power generation got heads up after the year of 2015. Rooftop installation got priority however it included rooftop of any large construction whether it is a building

(residential/commercial) or other area, such as a stadium or car park. Hence, it is difficult to differentiate or estimate the installed percentage for only rooftop building. Until now, power generation from PV has only just become a higher priority than aesthetic application. In India, BAPV system is prevalent and they are wrongly termed as BIPV systems. Actual, BIPV technology is not particularly popular in India, which could be the reason for lack of government plan and policy, and awareness to the public. BIPV window tiles or foil technology is not popular in India. Thermal regulation of BAPVT in the name of BIPVT is available in India [129]. The primary goal of this work to enhance PV power generation, rather than reducing the building cooling load demand. Improvements in the building environment, using BIPV, should be in government policy. Concentrating PV in India is mainly higher in concentrators [166]. To the best of our knowledge, no work has been reported on a low concentrator using LSC- or CPC-based BIPV/BAPV in India. To meet the GRIHA rating, large commercial buildings are now growing, however, they do not use BIPV to improve the built environment. Most green buildings, which meet the GRIHA rating, use rooftop BAPV system, while external shading devices control the admitted daylight and heat for those large glazed façades [167]. Table 3 listed the availability of BIPV and BAPV products in India.

Table 3. Availability of BIPV/BAPV products in India.

Product	Availability in Research Paper	Reference
BIPV window	×	
BIPV foil	×	
BIPV tile	×	
BAPVT (water/air)	✓	[168,169]
BIPV/BAPV-(PCM)	✓	[170,171]
BIPV/BAPV-LSC	×	
BIPV/BAPV-CPC	×	

Future Pathway of BIPV/BAPV in India

Weak BIPV implementation and national planning, lack of energy policy and details of BIPV products, fewer BIPV experts and market professionals are the key responsible factors for slow or no progress of BIPV, for less-energy hungry building in India. The Indian Central government should motivate and support deployment of BIPV research and development by removing non-economic issues to BIPV uses, creating building codes for BIPV integration in building assembly. New training programs related to BIPV can educate the builders, developers, and engineers. Support from central or state-level government organizations, such as NISE, SECI, NIWE, MNRE, IIT, NITs and the state nodal agencies should work together.

Windows are one of the weakest components in a building. It allows external heat to come inside (enhance the air condition load), internal heat to outside (enhance heating load) and offer visual connection to building interior to exterior [172–185]. Building window systems are affected by an overall heat transfer coefficient (U -value) and solar energy transmittance (g -value) [186–189]. For warmer place, high U -value and low g -value are required, while for colder area, low U -value and high g -value are suitable. Generally, single pane glass possesses higher U -value (U -value 3–5 W/m²K) and higher g -value followed by double (U -value-2-3 W/m²K g -value lower than single glass) and triple (U -value < 2W/m²K; g -value lower than single and double) glass window [190–193]. This clear and highly transparent window is not able to limit the heat entering from exterior ambient of buildings. Thus, building interior temperature often crosses over occupants' comfort limit (thermal comfort temperature 18–20 °C). Hence, in order to maintain thermal comfort level, an excessive amount of grid power is consumed to run air-condition (AC). Integration of PV system into the single or double glass can create a single glass BIPV window or double glass BIPV window, which will, not only generate benevolent electricity, but also contro heat and restrict its flow into the exterior, where required, as shown in Figure 9. Semitransparent c-Si PV based BIPV windows can reduce 5.3% heating and cooling load compared to standard BIPV [194] and has ability to limit up to 65% in total heat gains compared

to traditional clear glass [195]. Previous investigation of BIPV window in cooling load dominated climate such as Singapore, Hongkong showed a positive impact on load reduction [196–198].

Figure 9. Schematic of a semitransparent BIPV window (left) and Sankey diagram while BIPV window is integrated into a building (right).

In India, buildings' AC load is excessively high, due to the high g-value of window. In summer, buildings' windows are closed, in order to abate hot air and sunlight [199,200]. This also creates a dearth of light in an indoor setting, which encourages occupants to employ artificial light. Small-to-medium office buildings use air conditioners during the day and peak summer, and are not in use at night or off-peak season. Hence, advanced single or double glass-based semitransparent BIPV window systems, which possess lower g-value compared to clear glass, are favorable in India as they can be particularly be influential in limiting excess usage of AC and lighting load for a less-energy hungry building. The inclusion of this semi-transparent BIPV window, not only lowers the g-value, but allows sufficient daylight and generates benign electricity concomitantly. India has primarily cooling load (AC load) demand climate, but can trim down this excessive grid power consumption by employing BIPV window to obtain less energy-hungry building. Also, replacing the traditional window system by BIPV window is easier than replacing other building components, such as roof or wall [201,202].

6. Conclusions

The following conclusion can be drawn from this review article:

- Building integrated photovoltaic (BIPV) replaces traditional building envelop, such as window, wall, roof and most often they are thin film, or third-generation based transparent or semi-transparent in nature.
- Building attached/applied photovoltaic (BAPV) indicates when PV systems are attached to a building without replacing its traditional envelops.
- India's solar mission which geared up from 2015, accelerated the rooftop PV integration. For building, the rooftop application's majority are BAPV types and capacity higher than kW level. India's total installed solar capacity reached only 33.8 GW by the end of September 2019, which is way behind to achieve India's 40 GW rooftop PV power generation by 2022.
- New technologies, such as PV tiles, foil and windows, as part of BIPV or BPAV, are not popular in India.

- Indian electricity market needs a complete reform to allow smooth penetration of BIPV/BAPV in building. Also, due to rapid urbanization and development of zero and sustainable building industry, BIPV will keep pace in India soon.
- Single and double glass BIPV window systems have been identified as one of the most potential candidates for India.

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