

A review of building integrated photovoltaic: case study of tropical climatic regions

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ABSTRACT

The building integrated photovoltaic (BIPV) system have recently drawn interest and have demonstrated high potential to assist building owners supply both thermal and electrical loads. In this paper, the BIPV technology has been reviewed, in terms of its performance, efficiency and power generation capacity. Specifically, the applications of the BIPV in tropical climate regions have been discussed, together with its prospects and challenges. For these schemes to be implemented in a tropical climatic region, the following issues must be considered: 1) Certain studies must be done relating to electrical load demand, predicted PV output, location of the buildings and its integration and constraints associated with roof design; 2) For the highest energy production from solar PV, the solar collectors need to be with the right tilt depending on the location; 3) Design criteria such as safety, efficiency, durability, flexibility and constructive issues need to be considered; 4) The government of such countries must train electricians and carpenters on PV installations; 5) The BIPV roofing must perform same function as normal roofing materials, such as noise protection, water tightness, insulation and climate protection, and 6) As practiced around the world, these countries must establish design standards for the BIPV.

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1. INTRODUCTION

In the contemporary world, the global community apprehended that the non-sustainable energy sources (e.g. fossil fuel) will be available only for a limited period. Consequently, the urgency to avail sufficient renewable energy sources has already become an issue of discussion. One such source, commonly

regarded as a complete clean energy is the solar energy [1]–[3]. Recently, due to the development of new regulatory frameworks coupled with rising densification of cities, there is a need to acknowledge the significance of applying solar technology for buildings [4]–[6]. In most European countries, buildings account for 40% of the total energy use [7], but still the situation has not improved despite improved technologies and building codes that make such buildings more comfortable. Due to the global world population growth, energy demand in buildings has raised up to rise up to 50% by 2020, with the global building region anticipated to double by 2050 [8].

It is vital to understand that solar energy can play a vital role in modern buildings such as solar heating and cooling and photovoltaic (PV) powered [9], [10]. Already, architectural firms are opting for this trend, joining hands with energy experts to design and construct totally solar buildings [7]. The main characteristics of solar PV technology and building integration technology involve a wide range of disciplines. Systemization and deliberate efforts from solar manufacturers, construction companies, designing institutions, property developers and component construction department are necessary in order to achieve the utilization of solar energy and building integration technology. The role of regulations department and national policies cannot be omitted either. For years, many problems have arisen in developing renewable energy, including the issues of energy security and the threat of climate change which eventually also serve as the prime factors for development of such energy sources. The sun is the greatest substantial sustainable power source [11]. The concentration of greenhouse gas due to the abuse of fossil fuel usage has resulted in global temperatures and environmental degradation. The declining oil and gas supplies, coupled with the increasing concerns for the global effect of CO₂, gave rise to green buildings (i.e. buildings designed and constructed so as to reduce their environmental impact) [12].

A tremendous effort has to be made to reduce energy demand of civil structures by applying effective measures that maximize energy usage produced by PV [13]. From time to time, the technical developments of optical, electronic, thermal, and architectural and fluid mechanics also served the purpose to make the solar energy and integration technology more lucrative. Over the years, solar panels have produced green energy on the rooftops of buildings i.e. by integrating the PV elements into the building structure, thereby transforming it into a generating set [14]. By 2020, the industry of building integrated PV is predicted to reach 11.1GW [15]. In particular, Europe will have the highest utilization of this technology. In another perspective, James et.al [16] recommend several ways to help increase the relevance and growth of solar PV in buildings. These include the reduction in the PV prices and the increased interest in policies on solar energy. There is also little commercialization with full functionality of building materials. Generally, the fundamental reason for the limited BIPV deployment is that the average market price of installed systems is presently higher than for rack-mounted PV.

Nonetheless, it cannot be denied that an advanced construction process of integration technology is required to develop the solar energy. The complex construction of the waterway and circuits are another method, other than the conventional one, in order to install and debug tasks of solar equipment. Nevertheless, solar energy remains the single extensive alternative energy resource as it offers more economic benefits, safety and secure process of energy production and environment friendliness. Therefore, the acceptance of solar energy is more apparent than any other alternative energy resources [9]. Over the years researchers have investigated the application of BIPV in tropical areas [17]–[19]. Recent study [20] shows that for tropical climate, the BIPV can increase the quantity of heat transfer through the building structure, thereby influencing the inner temperature and discomforting the residents. Another study [21] investigated the heat comfort and adaptive actions for occupants in naturally ventilated areas and proposed certain adjustments to the acceptance of the heat burden on the occupants; one is the improvement of the velocity of the air and adopting cross-ventilation, and the other is reducing the insulations related to the building. Aaditya and Mani [22] proposed the development of a climatic responsive BIPV scheme. For tropical climates, the design of the building should be done in such way to reduce heat gain while enhancing heat loss within buildings. The best option is to design a BIPV with controlled ventilation, higher heat mass and shading. In another study, Gut and Ackerknecht [23] discussed the optimum building scenarios in tropical and subtropical regions. The wind orientation plays a big role in the building's thermal insulation. It was suggested that proper coatings in roofings and reflections in ceilings could reduce overheating. Ghazali and Abdul Rahman [24] investigated the application of solar tracking in tropical climates. For BIPV, the solar tracking not only enhances the PV output power but it also helps to reduce direct sun radiation on building envelopes. Recently, Lawal [25] investigated the energy conservation in buildings located at the southern part of Nigeria and concluded that for tropical climates, special consideration should be made in such a way that building are constructed with materials possessing high heating storage capacity and avoiding sustained lagging. The lag can create unwanted re-radiation of heat that may cause discomfort to the residents. Despite all the developments, little work has been made on the implementation of BIPV for tropical areas due to several factors such as high cost of installation and lack of awareness in the building industry.

One example of a tropical climatic region is Nigeria. It is a country that has abundant unutilized solar radiation. The average daily solar radiation in the northern region is 7 kWh/m² while in the southern part of the country is about 4 kWh/m² [26], [27]. Though, Nigeria has improved local manufacturing of PV [28], a lot need to be done to support this market. Solar energy is frequently utilized in Nigeria for street lighting and domestic energy consumption, however no visible solar technology integration within buildings can be remarked for both solar heating and solar power. Therefore, this paper attempts to review and discuss BIPV integrations advancements in many countries, using Nigeria as a case study, in order to suggest and recommend the further development of such technology in tropical climates. In such process of reviewing, this paper also evaluates the challenges associated to BIPV technology, and analyses future improvement options to accommodate it in the national energy mix.

2. BUILDING INTEGRATED PV

There are two main types of solar PV integration in buildings. These are the building integrated PV system (BIPV) and the building attached PVs (BAPV) [29]. However, there is misperception concerning the actual definition of BIPV within the building industry and such confusion extends to the PV industry. BIPV are delineated as PV modules feasible to assimilate within the building envelope by reinstating the normally used materials of the building, [30] while BPAV are PVs attached to the building with no direct influence on any structural function [31]. As stated in the literature [32], there are certainly many parameters that need to be carefully inspected in solar PV building integration such as: (1) buildability; (2) design; (3) durability; (4) environmental factors; (5) maintenance; (6) performance safety, and (7) standard regulations.

The classification of BIPV is done based on the type solar cell, their application and market availability [29]. BIPV products are categorized into four; i.e. solar cell glazing, tiles, foils, and modules [33]. A complete schematic diagram is illustrated in Figure 1.

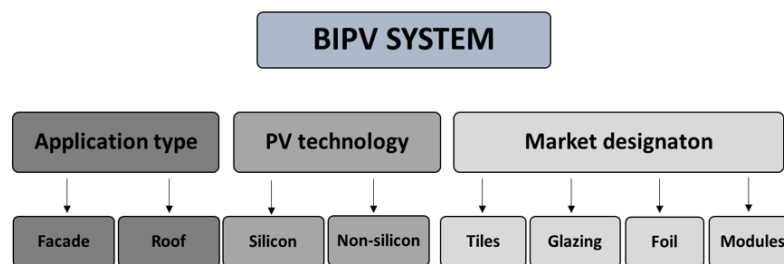


Figure 1. BIPV classification. Adapted from [33].

BIPV refers to PV components substituting the normal building components through its incorporation to the usual building envelope [34], thus decreasing heat spread over the building [35]. It is quite established that the productivity of PV modules declines with the rise in temperature, and many studies have been conducted to solve this problem. One solution, as suggested in literature [29], is that the PV modules efficiency might be improved through heat absorption at the rear of the PV module, using fluid or air to generate a convection mechanism, thereby opening new inputs for hot or cold area around the PV. Another method to enhance the performance of the PV modules is through shadowing effect or changing the direction or slope of the PV.

Chow *et al.* [36] modeled a 260 m² BIPV system that was analyzed using multi-platform building performance software (ESP-r). The simulation was done by creating an air gap of 250 mm between the building and the PV. The air-gap permits the air to be heated so that it can be utilized for water pre-heating. Three scenarios were implemented; i.e. BIPV with cooling of cells, BIPV with air heating, and BIPV without any integration. The year-long energy outputs from those three situations were reported being 83,680, 83,584 and 83,205 MJ, correspondingly.

Jiménez *et al.* [37] developed a BIPV component for heat transfer via stochastic differential equation. A sequence of experiments made up of 121 polycrystalline PV modules covering 1.44 m² areas was implemented in the model. The authors found that this technique is beneficial in modeling nonlinear stochastic heat occurrence in BIPV.

Pantic *et al.* [38] examined 3 configurations of the BIPV/thermal (BIPVT) system. Configuration one was the base case of unglazed BIPV with air consistently run underneath it. Configuration two involves

1.5 m vertical glazed solar collected and incorporated into the system. And, the third configuration is the addition of a complete glazing on top of the PV. It was observed, from these configurations, that heating, ventilation, air conditioning (HVAC), and water pre-heating can be achieved using the first configuration. Heat energy efficiency can be achieved through the second and third configuration. In the third configuration, electric power creation was considerably reduced due to the overheating of PVs.

Corbin and Zhai [39] examined a novel BIPVT consisting of absorbers, heat storage and pump. The authors developed two computational fluid dynamics (CFD) models. The first model is a standard model adjacent to the top surface, while the second comprises liquid-cooled-tube absorber for recovery effects. At the end of the research, it was shown that the later BIPVT has up to 5.3% better electrical efficiency. The whole productivity of the system was found to be within 19-34.9% respectively.

Peng *et al.* [40] studied the architectural design features of BIPV systems as follows: (i) design procedure, (ii) life-span of the system and (iii) suitability of the BIPV. They also designed a new arrangement to solve matters related to the proper care of the PV components. The authors concluded that technology, aesthetics, function and cost are key features. Urbanetz *et al.* [41], examined the annual electricity generation of two systems. One is the 10 kWp BIPV system and the other is a curved 12 kWp PV system. The first is a thin film a-Si technology made up of 24 elastic modules, while the second consisted of 88 flexible panels made of thin-film a-Si layers. Specific findings indicated that the 10 kWp BIPV system holds more yearly energy revenue than the second one.

Zogou and Stapountzis [42] conducted the experimental investigation of the transient heat analysis for the BIPV system, using the PV module and the Plexiglas module. The authors carried out the experiment in 3 main stages. No natural convection (i.e. fan) in the first stage, while fans were operated at 110 m³/h, and 190 m³/h flow for the second and third approaches respectively. Findings show that the temperature variation of air for various approaches was between 4.5°C and 8.9°C with the power ranged between 74.7 W–85.5 W. Observation on the least panel temperature in mode 3 suggested that total cooling and transfer of heat rises as more air flows.

Yoon *et al.* [43] developed the pioneer BIPV application, with thin-film a-Si cells mounted on the windows. The authors observed the system for about 2 years and noted the monthly power generation sum to be 48.4kWh/kWp. Additionally, the annual generation amount is 580.5kWh/kWp. The simulation effects confirm that particular electrical energy generation for the system can reach up to 47% if the azimuth and shading effects are adjusted.

There are two BIPV/BAPV systems examined by Santos and Rüter [10] on the possibility of implementation of both systems for a current domestic building. One is the 2.25 kWp c-Si system and the other is the 10 kWp a-Si system. The findings revealed that 87% of the PV sets can create 95% of the peak hypothetical potential. In addition, only 3% of the systems were able to create 85% of the peak theoretical output value. Their results show that the PV kits are able to produce separate yearly energy demand for the whole buildings.

Ban-Weiss *et al.* [44], examined the cooling system and electricity production saving effects of PV modules, made up of thin-film a-Si triple junction solar cells. After installation of BIPV, the solar absorptance of roof reduces from 0.75 to 0.38. The outcomes show that the daily energy output range of the system appears to be 0.4kWh/m² in the summer and 0.15kWh/m² in the winter. They further concluded that the BIPV system mounted in an office building in Phoenix, Arizona, USA would cause 9.6kWh/m² yearly cooling and 2.9 MJ/m² heating power savings.

Han *et al.* [45] compared the performance of 2 different types of PVs, i.e. conventional clear façade and ventilated double-sided. The conventional clear façade is a PV layer made up of a-Si PV cell, while the second one is a transparent glass and screen on the façade. The authors show that the interior air temperature for the ventilated double-sided PV scheme was lower than the conventional clear façade. Moreover, their results show that the module temperature on the efficiency of PV was small for all these modules. Apart from power generation, the ventilated double-sided PV can contribute to power savings via decreasing the load on the air-conditioning.

Drif *et al.* [46] shows a technique for power evaluation losses as a result of the partial covering of BIPV systems. In this scenario, 9 sub-arrays of PV modules were split to 2.5 kWp each. For a 1 sub-generator, measurements were 10.6 2 kWh/day, against theoretical measurements of 12.41 kWh. The authors concluded that the daily power losses caused by covering were 1.79 kWh. That is equivalent to 14.4% of the overall BIPV system power generation.

The 22 PV arrays performance under different tilt and orientations were investigated by Wittkopf *et al.* [47]. These systems comprise an on-grid BIPV system of 142.5 kWp. The monthly average performance ratio was recorded to be 0.81 and the monthly mean power generation was 12.1 MWh. The authors also studied the influence of different criterion on the BIPV performance such as irradiance changes, partial covering, PV temperature changes.

Defaix *et al.* [48] evaluated the BIPV's technical potential within the EU-27 using the available statistical fingerprints. The BIPV is assumed to be a mixture of crystalline wafer. The performance ratio for the thin film of PV panels was 0.8, while the mean of efficiency was 17.9%. The obtained for the BIPV's potential within the EU was 951 GWp and the annual potential power production was 840 TWh. This power can meet approximately 22% of the expected electricity needed by the European continent.

The cost-effectiveness of BIPV was investigated by Wei *et al.* [49] and it was compared with domestic solar water heater (DSWH). The lifespan of the BIPV system is approximately 25 years with power generation capacity of 140kWh/m². The authors were able to show that the BIPV system was more favorable with 6 m² roof area and the domestic solar water heater (DSWH) of the BIPV is more beneficial as it can be better installed if the cost of the BIPV is RMB 0.9/kWh.

López, and Sangiorgi [50] examined the influence of BIPV modules on human comfort using identically two 10 m² rooms. Their first trial shows that the thin-film related PV modules have better performance compared to hygro-thermal comfort. Amorphous silicon (a-Si) PV modules have higher energy generation capacity. In terms of heating and lightning, CIS PV modules appear to have higher energy consumption. They conducted another test using the m-Si PV modules and found that it has higher lightning demand than the CIS modules. The m-Si PV modules have higher energy generation within 0.09-1.31 kWh/day as compared to the CIS PV modules.

In another study, Yang and Athienitis [51] examined BIPVTs thermal efficiency using two inlets. Results show two inlet panels having 5% higher thermal effectiveness in comparison to a single input semi-transparent panel. Apart from this, they concluded it is preferable to design a simple and cheap two inlet panel. The authors also carried out the performance assessment of BIPVT having different inlets. They developed a correlation regarding some inlet solar simulators and BIPVT prototype. Findings show that a four inlet type has 7% higher efficiency when compared to one inlet type.

Bigaila *et al.* [52] investigated a BIPVT system made up of 1030 x 548 mm m-Si panel, 5 x 10 cm insulation, and 7 cm air gap. The experiment was conducted with 8 lamps; each has a maximum power of 4.6 kW. The lamps can be attuned within 0°-90°. Their results show that the solar heat collectors possess similar efficiency to the unglazed thermal collector (UTC), with up to 15% higher efficiency.

Eke and Demircan [53] studied the shadowing effect of BIPV on a structure comprising five floors, and each floor was installed with a three a-Si (triple junction amorphous PV) modules. The results show that the yearly energy rating for the first array is 1072 kWh/kWp while for the second array is 885kWh/kWp. Low electricity output was measured towards the end of the year due to the lowest radiation at that time. It was concluded that the shading effect has substantial effect due to the building direction, PV tilt angle and the ambient temperature.

Timchenko *et al.* [54] applied certain system specifications (i.e. 1.5m x 0.7m x 0.1m size) to evaluate open channel PV. Three different two-wall configurations were used, (i) uniform, (ii) staggered, and (iii) non-uniform. Their results show that there must be alternative inputs between hot and cold zones in order to improve the heat transfer.

Ritzen *et al.* [55] mentioned four vital aspects of PV market such as BIPV, PV efficiency, electrical storage and PV market. Some tests were carried out under different conditions of condensation, coloring and backstring ventilation. Test 1 showed that the output of PV varies between 10-40% on autumn and spring period respectively. Due to 100% relative humidity, the PV output was reduced by 0.5%. Test 2 comparing between black module and color module, there is a difference of 10% for the PV output. Vertical and zig-zag type lineup showed a difference of 62%. There were better advantages of zigzag type module lineup during the autumn-spring period.

Chen and Yin [56], designed a BIPVT system for heating liquid with water through cooling the PV. The PV module was developed by aluminum high density polyethylene that contained aluminum water tubes. In this situation, there is reduction of temperature through heat transfer from PV to the water tubes. Laboratory results indicated enhanced energy conversion efficiency. There is almost 5% reduction in the module temperature. There is also a flow rate increase by 500%. At particular flow measure of 150 ml/min, the electricity production was of 32.94 W and 44.91 W correspondingly for 800 W/m² and 1000 W/m².

Lu *et al.* [57] experimentally developed a new PV parabolic reflector with a concentration ratio of 2, suitable for building façade applications. In this paper, a broad enclosed test was conducted to assess the thermal and electrical categorization of the developed scheme. The factors affecting the output power of the system were also discussed. In comparison to the non-concentrating PV, the results indicate that Building Façade Integrated Asymmetric Compound Parabolic Photovoltaic concentrator (BFI-ACPPV) scheme has the capacity to raise the output power per unit area of the solar cell by 2. The results further indicate that the BFI-ACPPV coupled with phase change material have higher efficiency in comparison with a non-phase change system. The results were obtained at solar radiation intensity of 280 W/m² and 69 W/m². At 280 W/m², the measured power output is 3.51 W.

Table 1 shows a summary of literature review regarding the BIPV systems. In summary, the BIPV is expected to be highly beneficial in the future design of buildings. According to literature, and in many countries, BIPV is capable of satisfying building energy requirements of 70% [58]. In most BIPV researches and applications, monocrystalline solar PV has been widely used due to its higher efficiency and heat tolerance. The façade application is mostly to take advantage of shading and heat insulation on walls. In tropical climates, the thermal shielding effect of BIPV can reduce space cooling by around 30% [11]. Either as a rooftop or façade application, the BIPV can, in the long term, have good investment returns. BIPV can also give buildings better visual appearance and ensure reduced electricity tariff. One major issue is the likelihood of the BIPV experiencing higher temperatures, because of their attachment to the building structure, thereby reducing the conversion efficiency of the PV module. Some highlighted barriers that may hinder the development of BIPV [59], include: i) lack of awareness of the BIPV especially in developing countries as a means of energy saving and reduction of greenhouse gas emission, and ii) lack of economic and technical solutions about BIPV technology.

Generally, incorporating BIPV to the building structure give rise to net-zero energy buildings. This depends on many factors such as building topology, availability of surfaces for polarization, total energy needs and techno-economic feasibility analysis.

Table 1. Summary of the BIPV systems

Reference	Energy Generation	Nominal Power	Electrical conversion Efficiency (%)	PV type	Application
Chow <i>et al.</i> [36]	-	-	-	Monocrystalline	Façade and roof
Jiménez <i>et al.</i> [37]	-	-	-	Monocrystalline/ polycrystalline	Façade
Pantic <i>et al.</i> [38]	19-40kWh	7000	10.5-15	Monocrystalline	Roof
Corbin and Zhai [39]	-	-	14.5-17.2	-	Roof
Peng <i>et al.</i> [40]	-	-	-	Amorphous	-
Urbanetz <i>et al.</i> [41]	1265-1110kWh/kWp	10-12kWp	-	polycrystalline	-
Zogou and Stapountzis [42]	-	<9	-	-	Façade
Yoon <i>et al.</i> [43]	1277kWh/year	-	7	Amorphous	Façade
Santos and Rütther [10]	5.8-12.3GWh/year	5.11MWp	-	Amorphous	Roof
Ban-Weiss <i>et al.</i> [44]	0.15-0.40kWh/m ²	-	5	Amorphous	Roof
Han <i>et al.</i> [45]	4.43-4.72kWh/year	-	-	Amorphous	Façade
Drif <i>et al.</i> [46]	10.62kWh/day	-	-	Monocrystalline	Façade
Wittkopf <i>et al.</i> [47]	12.1MWh	142500	13.15	polycrystalline	Façade
Defaix <i>et al.</i> [48]	850TWh/year	951GWp	17.9	Monocrystalline/ polycrystalline	Roof
Wei <i>et al.</i> [49]	140kWh/m ²	-	-	-	Roof
López and Sangiorgi [50]	0-1.32kWh/day	31-85Wp	6-17	Monocrystalline/ Amorphous	Façade
Yang and Athienitis [51]	-	-	5-7.6	Monocrystalline	Façade
Bigaila <i>et al.</i> [52]	-	-	10-15	Monocrystalline	Façade
Eke and Demircan [53]	46-125kWh/m ² . month	40.3kWp	0.92	Amorphous	Façade
Timchenko <i>et al.</i> [54]	--	-	-	-	Façade
Ritzen <i>et al.</i> [55]	-	90-246Wp	-	Monocrystalline	Façade
Chen and Yin [56]	-	-	10.48-15.82	Monocrystalline	Roof
Lu <i>et al.</i> [57]	-	-	15.8	Monocrystalline	Façade

3. PV PANELS BUILDING INTEGRATION CONFIGURATIONS

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

3.1. Slope glazing

Sloped glazing includes atriums, titled walls, sunspace or green house on top overhead of the walls. Such glazing also incorporates framed aluminum, coated with tinted frames, glasses with lamination, or plastic glazing in case of semi-transparent glazing systems. One of the examples of Atrium with integrated amorphous silicon PV panels has been shown in Figure 2, which is taken from the Doxford International Park, situated in Sunderland. PV panels majorly work for the transmission of the ample amounts of diffused light, therefore, day lighting is essential solution of buildings.

It is always desirable to have a diffused day lighting condition in office buildings in order to produce sufficient energy, however, excessive sunlight can cause generates overheating which eventually ends up excessive glare [60]. Regular glass provides more transparent basis than the PV glazing glass (5-10%

transparency). Regarding such transparency, excessive daylight substantially impacts in the building. Therefore, a balanced design should be the prime concern in order to advance PV glazing and the daylight in the building.

For BIPV, and in order to achieve the maximum supply of daylight, window is always advised to be 20% of the facade area on the south orientation in the northern hemisphere. According to [61], that number varies when the systems are built with crystalline silicon (increase to 24%) and thin-film PV panels (increase to 32%).

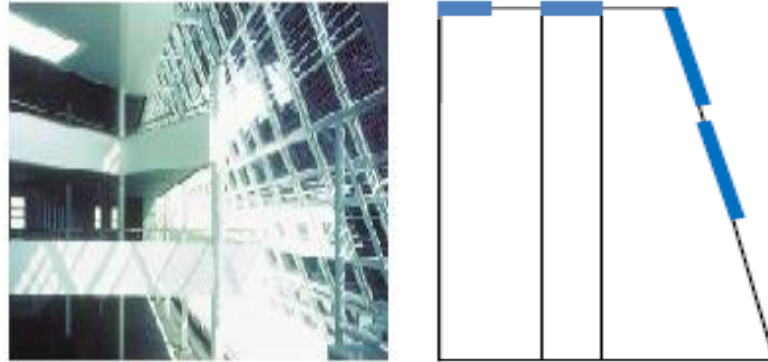


Figure 2. Atrium with integrated amorphous silicon PV panels in the solar office of Doxford International Park, in Sunderland, UK [62].

3.2. Vertical panel

Vertical orientation of the PV panel reduces the results of PV output, because they possess the same construction characteristics as atria/sloped-glazing. Curtain walls are appropriate for a wide range of PV products; they contain opaque surfaces (spandrel areas) in multi-story buildings, whereas, materials of non-transparent products can also be used. To adopt such configuration, compromises should be made between overheating, density, and the glare of PV panels that are employed in the façade. Example of such configuration at APS office building situated in California is shown in Figure 3.



Figure 3. APS office facility in California [60]

Amorphous PV modules shown in Figure 3 at the APS Facility in California with integrated PV panels, are generally combined with the panels that are constructed with vision glasses and framed with standard curtain wall [60]. Just like the spandrel panels in a multi-story curtain wall, PV modules are also sealed at the back with an opaque insulating panel. If the PV glazing can be formed in a way where the clear glass can be adjusted between the upper and lower part of the entire construction, then the glare can be prevented, as shown in Figure 4. In addition, such structure provides the necessary daylight with the view

sight as the clear glass is situated in the middle part of it. As seen in Figure 4, PV panels do not take the whole space of the window and provide enough room for the clear glass.

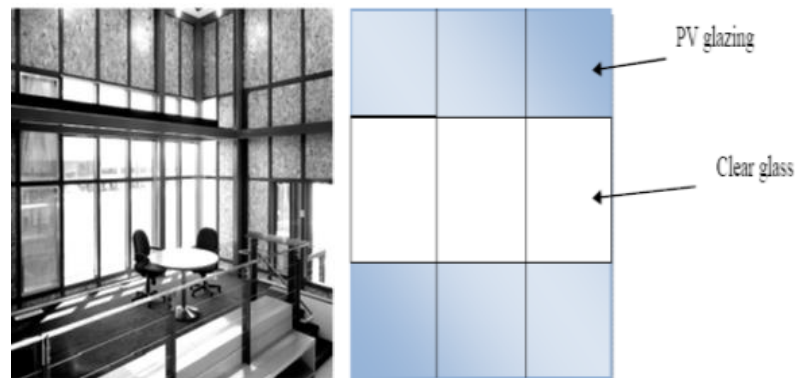


Figure 4. APS Facility in California, interior space.

3.3. Inclined walls with PV panels

In this particular type of arrangement, the efficiency of PV panels is enhanced as they are tilted, that includes complexity in the design of the building. Figure 5 provides a detailed picture of the inclined PV panels at the University of Northumbria, UK [62]. The most amazing thing of this configuration is that such design can be utilized with any kind of commercial PV panels, which means, its use is not limited to window-based technology, because such design creates a degree of self-shading.

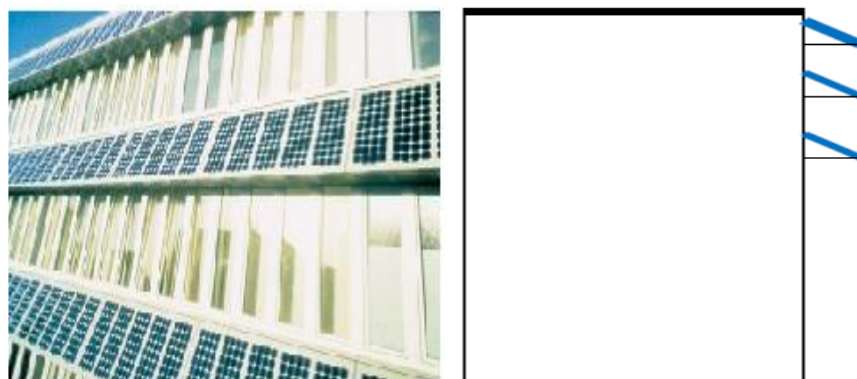


Figure 5. Inclined PV panels at the University of Northumbria, UK [62].

3.4. Fixed Sunshade

Configurations such as shown in Figure 6 can enhance the shading benefits in order to reduce glare. However, such structures can avoid the proper access of daylight. In this kind of configuration, mostly standard PV modules are attached using a metal frame to the envelope of the building. The construction of such configuration is also easy as it takes the same procedure as installing regular sunshades on the building.

Nonetheless, the main advantage of this configuration is that it can be constructed even with shading from adjacent buildings and, in such case, all kinds of PV panels are functional. The nature of this configuration is more convenient as it provides different alternative choices to the designers and maintenance [62]. In Figure 7, the example is taken from a commercial office building in Switzerland, built in 1993 which shows how a fixed sunshade can be operated in an efficient way.

The tilting of the panels increases the efficiency of the PV panels. Moreover, in such configuration, PV laminates are accommodated in a way that can provide a flat surface for shading elements and also rear ventilation that dissipates the generated heat.

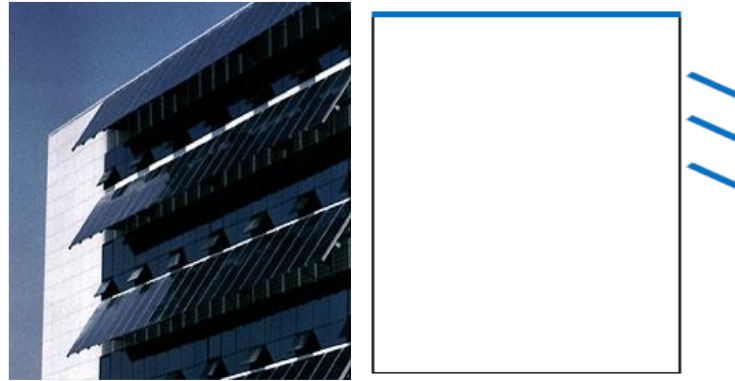


Figure 6. Samsung commercial office building in Seoul, Korea, integrated in fixed sunshades and the roof of the system [63]



Figure 7. Fixed sunshades in the SUVA building. A commercial office building in Switzerland, built in 1993 [64]

3.5. Moveable sunshades

Moveable sunshades are the most efficient configuration in regards to solar panel, as it can achieve the greatest efficiency with all the advantages of fixed sunshades. Such configuration works with the change of tilting according to solar radiation level. Such adjustments can be made either manually or electrical and mechanical means.

Example of moveable sunshades applied in a commercial office building is shown in Figure 8 which is situated in Switzerland. It is true that due to the added feature of moving sunshades, such configuration may be a little expensive; nevertheless, the efficiency of producing energy is greater than other solar configurations.

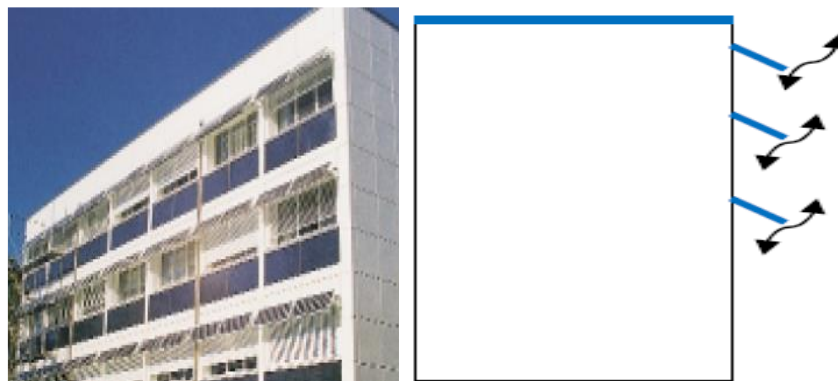


Figure 8. Moveable sunshades in a commercial office building, in Switzerland [62]

4. POSSIBILITY OF BIPV IN TROPICAL CLIMATES: CASE STUDY OF NIGERIA

Nigeria is known for its tropical weather. Nigeria is situated approximately between latitude 4° - 14° N and longitude 2° - 15° E with a landmass of 9.24×10^5 km² and receives 6.25 hours of average daily sunshine, which ranges between 3.5 hours at the coastal areas and, in case of northern border, it turns out to be 9.0 hours [65]. The country is also known for its huge energy consumption, estimated as 15×10^6 kWh per year, according to 2001 index [65]. In addition, only 3.7% of Nigeria's land area is required to produce energy through solar means in comparison with conventional energy reserves of fossil fuel that has been in process now [66].

The climate depends on the tropical to subtropical regions. Nigerian territory has two seasons: dry season, which lasts from October to March, and rainy season, from April to October. Northern region generally has hot and dry climate where the rainy season lasts from April to September. Whereas, in the southern region, the climate is generally hot and wet, and the rainy season extends from March to December. Therefore, in general, Nigeria enjoys a long dry season from December to March [67]. In the coastal area, the temperature may rise above 32°C in this time. Meanwhile, the north enjoys drier temperatures, ranged between 32°C and 42°C . Generally, the humidity remains approximately 95% during this period of time [66].

Furthermore, in Nigeria, solar PV installations have steeply declined over the years and are forecasted to continue declining due to the struggles in the optimal harnessing of the solar electricity as a sustainable resource. The challenge remains to be the development of solar energy which solves technological installation problems, unclear governmental policy and politics, economic inefficiency in purchasing such power, lack of public awareness and cultural integration. It is already a fact that solar energy is the most abundant renewable resource in Nigeria because of the broad daylight which on average provides sunshine of 6.5 hour/day.

According to the literature [68], the best PV energy production results in Nigeria are achieved when using a 6° tilting angle. In addition, it was suggested that between January and March, the best tilting angle will be 6° , 24° and 30° respectively, and 0° between April and September, and 18° , 30° and 36° between October and December respectively. An energy amount of 192.70 W/m² can be produced with the adjustment of the tilting angle to its optimum angle, according to the month. It increases significantly about 3 % in comparison to applying fixed angle, which produces 186.86 W/m².

To obtain maximum power output from solar PV, and since Nigeria is close to the equator, the solar collectors must be with a slight tilt of 6° near the north or south, as shown in Figure 9. The maximum amount of energy year-round can be absorbed by inclining the solar panel at an angle closer to the latitude of the area as possible. These requirements are necessary for maximum power from BIPV.

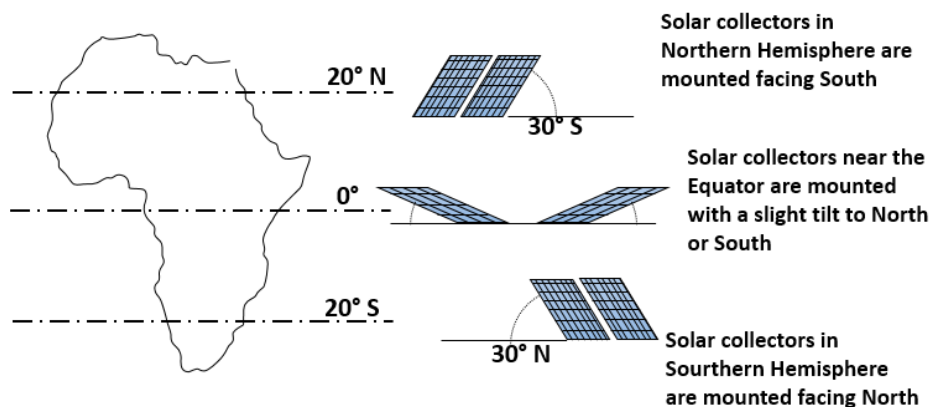


Figure 9. Mounting angles for fixed solar collectors in Africa [70]

Although BIPV has not been yet implemented in Nigeria, it is possible to introduce it in Nigerian buildings, if some issues are addressed. Such considerations include market failure and distortions, financial and economic constraints, lack of government and institutional policies and incentives, lack of awareness and public information. A large number of abandoned PV initiatives in Nigeria are should also be addressed, including all the already installed renewable energy infrastructures that are inefficient [69]. For BIPV to be fully implemented in a tropical region, like Nigeria, buildings must be constructed with materials having high

thermal storage capability. There is also need for proper coating in roofing and ceilings. Solar tracking can also be an option to minimize direct sun radiation on buildings and increase the power output. Since these technologies are serving two functions (i.e. electricity and heating in buildings), they must conform to the codes and standards of both solar and building industry. To encourage builders and private investors to use BIPV, the governments should establish appropriate environmental policies and subsidies, with well-structured feed-in tariffs. Also, for successful implementation of the BIPV technologies, the building engineers must have a good understanding of building design that includes solar technology because the solar elements must replace other building components and may reduce the overall building cost. This is vital, because, nowadays most solar works on building are done solely by solar engineers without any input from other building professionals.

5. CONCLUSION

This paper provides an overview of BIPV technologies. Specifically, the paper analyses the possible implementation of this scheme in tropical climatic conditions. First, the BIPV technology has been reviewed and several author contributions have been tabulated. Most BIPV concentrates on new designs to improve the efficiency, such as novel cooling techniques and system arrangements. Literature extensively reports the electric power generating capacity of BIPV, with efficiency reaching between 5-18%, as well as many applications relating to roof top and façade BIPV.

In order to get higher power output from the BIPV, certain factors need to be considered, for example, slope of the PV, shadowing effect, temperature and the direction of the building. A lot of research on BIPV shows simulation and computational analysis because it is easier and cheaper for evaluation and encouraging results have been reported. In general, silicon-based PV modules have been applied to BIPV applications. Recently, there have been rising interests in BIPV systems with low cost and investment feasibility. Recent researches proposed the application of dye-sensitive solar cell technology as a solution for BIPV technology.

The BIPV-thermal is another system that made tremendous progress due to its high cost of implementation. It has the advantage of providing both power and heating systems for buildings. Several researches proposed that it is a promising technology for the future.

After reviewing the literature, some of the lessons that tropical climate regions can learn from the BIPV include: (1) In order to fully implement BIPV with high efficiency, certain studies must be done relating to electrical load demand, predicted PV output, location of the buildings and its integration and constraints associated with roof design, (2) To obtain maximum power output from solar PV the solar collectors must be tilted to the correct position, (3) To implement BIPV, design criteria such as safety, efficiency, durability, flexibility and construction issues need to be considered, (4) To be able to implement BIPV, the government must train electricians and carpenters on PV installations, (5) To implement a good system, the BIPV roofing must perform same function as normal roofing, that is, noise protection, water tightness, insulation and climate protection, (6) As practiced around the world, each country should establish design standards for the BIPV. These standards shall provide protection from wind, precipitation, temperature and solar irradiation for greater comfort, (7) For a tropical region like Nigeria, thermal comfort for residents must be considered when designing BIPV technology. If possible, techniques to reduce thermal heating on buildings surfaces must be implemented.

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