Façade Optimization of Building Integrated Photovoltaics (BIPV) For Sustainable Energy in High Rise Residential Buildings

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Abstract - Buildings are accountable for one-third of the world's energy utilization and residential buildings account for 27% of this. One of the most significant inventions that is sustainable and reduces buildings energy consumption is Building Integrated Photovoltaics (BIPV). Among the major areas of BIPV application is building facades. This paper discusses the conflict between PV façade design and energy performance. The study conducted an experiment testing the parameters affecting energy generation of PV façade identified from literature. The results show that cylindrical building form has the highest % of self-shading and did not perform best in terms of heat loss, but it generated more sustainable energy due to having the highest array yield and has the highest ratio of direct normal irradiance (DNI), which is of relevance to photovoltaics system performance, the higher the DNI the higher the energy output. Therefore, a curved PV façade is recommended to be used for high-rise residential buildings.

Index Terms - BIPV, façade, residential building

1 INTRODUCTION

Buildings are accountable for one third of the world energy consumption, accounting for 40% of all carbon emissions and residential buildings account for 27% of global energy consumption and 17% of global carbon emissions (International energy agency 2017). The world generates 78.7% of energy from non-renewable sources (World Energy Council 2019). The most well-known impact of utilization of non-renewable sources of energy is emission of greenhouses gases, causing climate change, and negatively impacting our environment and wellbeing.

In order to address the world energy emergencies, one of the noteworthy developments that mean to be feasible, sustainable and economically competitive with today's fossil fuel is solar energy. Solar energy is the most plentiful, unlimited and clean of all the accessible energy resources. Buildings have the potential to create adequate sustainable energy on site in form of Photovoltaics (PV) (Ahmad 2017). This gave birth to a new vernacular of solar electric architecture, where the PV elements become an essential part of the building envelop called Building Integrated Photovoltaics (BIPV) (Strong, 2016).

In countries such as Nigeria, that are located in the tropical region, where incident solar radiation is very high, the improvement possibilities of solar energy appear very obvious. Nigeria gets a colossal measure of solar radiation the aggregate of 5.5kw/hr/m2 every day (Ajayi, Oluseyi, Ajanaku & Kolawole 2009).

Achenza & Desogus (2019) stated that one of the major field of BIPV application is on facades, where solar panels of all technologies can be integrated as a conventional cladding system for curtain walls and single layer facades. However, various studies on BIPV found out that among its greatest challenges is architectural design objectives conflict with energy performance, studies have shown that facade of high rise buildings are suitable for integrating PV, in order to address the challenge of space scarcity. Other studies that integrated PV found out that among the major problem is optimizing facade for sustainable energy generation and maintain adequate view and daylight. These are conflicting, as larger facade surface for integrating PV results to less glazing.

Another major challenge of integrating PV on façade is partial shading due to complex geometry, studies have shown that this is a design challenge that results to performance losses.

Therefore, this study sets to explore façade design of PV systems into buildings to find the best performing design, to serve the dual purpose as building component and a source of sustainable energy.

2 LITERATURE REVIEW

Architecture Solar Association (2018) defined BIPV as a smart energy production system that incorporates photovoltaic components into the building fabric, thus, replaces conventional material in addition to generating energy, these components power generation performance are considered to be secondary to its role as building component. Odersun (2011) stated BIPV is the concept of integrating photovoltaics components into the building fabric, forming a symbiotic relation between cost saving, functionality and aesthetics of design. thus the PV modules replaces conventional building elements and serving the function they would otherwise perform. some major significant advantages of BIPV are generation of on-site clean energy, no additional land is required, replacement of other conventional building elements such as windows, skylights and roof (Bambara, 2012).

Conventionally the façade comprise of building elements like wall, cladding, glazing and fenestrations; also other components like balconies and shading devices. Every one of these structures give chances to incorporating Photovoltaic to the building. (Attoye, Aoul & Hassan 2015). Sharma and Kothari (2017) described façade as what separates the interior and exterior of building, it is a public face and characterizes the appearance of the building, additionally it also protects from solar radiation, aids in daylight distribution and also helps in saving energy by reducing heating and cooling load. Sharma and Kothari (2017) asserts that BIPV aims at saving energy and providing environmental protection, the element give designers new potential to utilize glass in facade which replaces costly cladding.

Peter (2019) stated that the main façade parameters affecting energy performance of PV are:

i. Placement and orientation

The placement of the PV panel on façade is the most important aspect to put into consideration so as to ensure the system will be functional and efficient. Also, the amount of solar radiation at the location, the weather must also be considered.

The positioning of the building in relation to seasonal variations in the sun's path orientation have an impact on the energy performance of PV. The amount of incident solar radiation on a surface of a PV module depends on its orientation and angle of inclination.

In the case of BIPV systems that are arranged according to architectural criteria, however, optimal positioning of the modules is rarely possible.

ii. Building geometry

Self-shading due to complex building geometry, can significantly affect the yield of a PV system or layers of dirt on overhanging parts of the mounting system. shade can be minimized by careful planning in order to maximize the incident solar radiation. Simulations of the daily and yearly path of the shadows can be carried out to enable the position of the solar modules and the orientation and structure of the building to be optimized accordingly. If shading cannot be completely avoided, the effects can be mitigated by using the appropriate module technology, the module design and the electrical connection of the modules best suited to the environment.

iii. Site features

When designing a building with BIPV system, a compromise must be reached between the requirements of energy yield optimization and those of the architectural environment.

The right type of technology for the environment in question is important. Often, the usually less efficient thin-film technologies (conversion of sunlight to electricity) represent the best choice here, particularly in situations with suboptimal environmental variable.

TABLE 1
SUMMARY OF DESIGN PARAMETERS FOR BIPV INTEGRATION

Element	Parameters	Requirements
Facade	Placementand orientation	Positioning of building in relation to seasonal variations on the sun's path.
	Building Geometry	Self-shading due to complex geometry, can be minimized by careful planning.
	Site features	Compromise must be reached between requirements of energy yield optimization and those of architectural environment.

3 METHODOLOGY

The research adopted an experimental approach; From the literature review, the dependent variables for façade optimization are orientation, building form, micro climate, and shading. The data analysis techniques used was BimSolar software to determine areas of self-shading, also to determine electricity production by PV systems at various orientations. After which a comparative analysis was carried out on the results of the various parameters tested to determine the best performing design. The graphical user interface that was used for the BimSolar is Revit Architecture. BimSolar was used for the simulation of base case. BimSolar is an integrated software that provides easy visualisation of BIPV benefits at a building level. The 3D modelling and instant simulations of solar power help predict the performance of BIPV, and their overall impact on a building's energy performance.

3.1 Base Case Modelling

The proposed base cases were modelled in Autodesk Revit architecture and were exported to Bimsolar for analysis. the parameters used are summarized in table 2. Façade type was tested against the variables which are building form, orientation, micro climate. Four building forms were chosen for the analysis which are Cuboid, Cubic, Triangular and Cylindrical forms. and were tested against all four orientations, the micro climate of Abuja was used. The modules were arranged in rows of five by six with one extra at the end with spacing horizontally on all four sides of each form as shown in figure 1.

TABLE 2
PARAMETERS AND SPECIFICATIONS OF PANEL USED FOR FAÇADE WHILE CARRYING OUT THE EXPERIMENT

Building size	300m2
Building height	30m
Estimated energy demand/apartment	12kWh
Estimated energy demand of building	240kWh/daily
Estimated energy demand of building/year	87120kWh/year
40% energy demand	34848 kWh/year
Expected energy generated	36009.6 kwh/year
No. of BIPV module on building	124
Module area on building	812.6m2
Average module power output	200 watts
Module power peak	433 kwp
Size of module	2.56 x 2.56m
Supplier	ONYX Solar
Model	PVSITES_X5_cSi glass_156*156pseudo_V2
Technology	mono_Si
Size	2560by2560mm
Cells	10by10 (100)

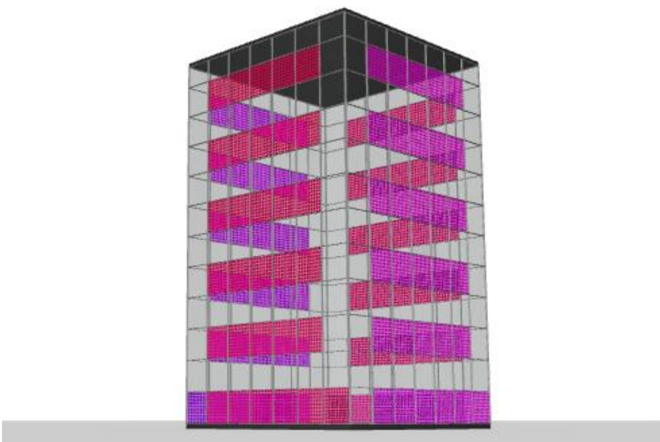

Fig. 1. Arrangement of integrated PV panels on cubic form

4 RESULTS AND DISCUSSION

The comparison of tested building forms is listed in Table 3. The results have shown that cylindrical form performs better in terms of energy production estimated at 36836.8 kWh from January to December. The next in terms of energy production is cuboid estimated at 36674.8 kWh/year. Followed by cubic with energy production of 36584.1 kWh/year and the least is pyramid with energy production of 36000.8 kWh/year as shown in Figure 2. in terms of shadow losses cuboid has the least with 0.0%, followed by cubic with 0.3%, and cylinder and pyramid has 0.4% each as shown in Figure 3. for heat losses cylinder, cuboid and cubic has 11.9% each, pyramid has highest with 12.0% as shown in Figure 4.

Cylinder performs best due to the form having the highest array yield. Array yield is the ratio of Irradiance is a measurement of solar power, defined as the rate at which solar energy falls onto a surface. Direct, diffuse and indirect. The larger the % of diffuse radiation the less the total insolation and the higher the DNI the higher the energy output.

TABLE 3
SIMULATION RESULTS

Building form	Energy production (kWh/year)	Array yield (kWh/kWh)	Shadow losses (%)	Heat losses (%)
Cuboid	36674.8	683.1	0.0	11.9
Cubic	36584.1	681.4	0.3	11.9
Cylinder	36863.9	686.6	0.4	11.9
Triangular	36000.8	670.5	0.4	12.0

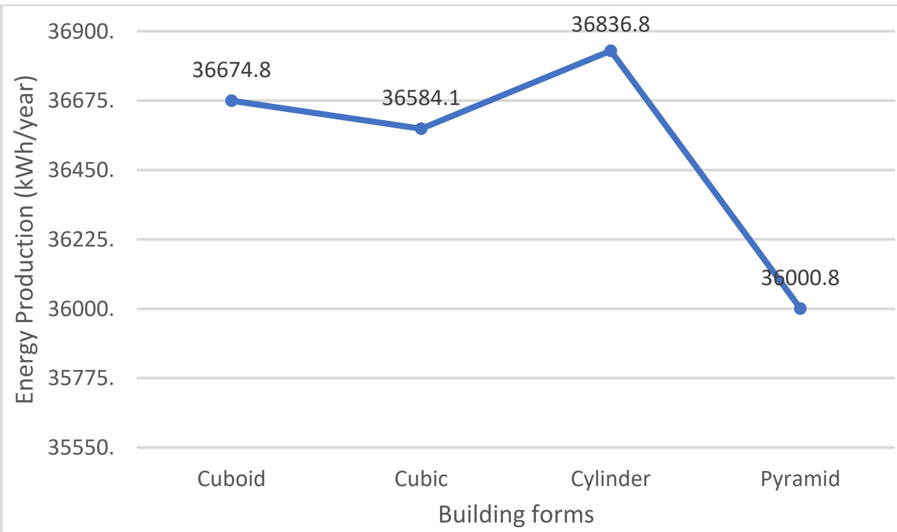

Fig. 2. Energy generation of all building forms.

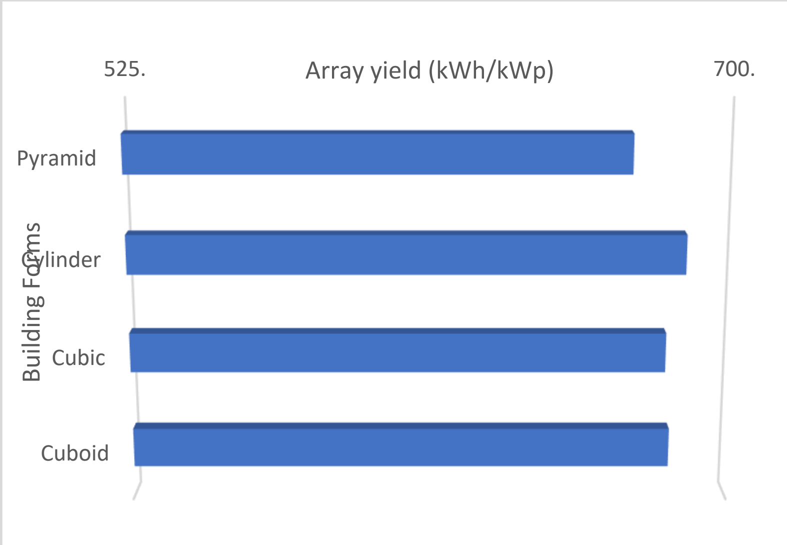

Fig. 3. Array yield of all building forms.

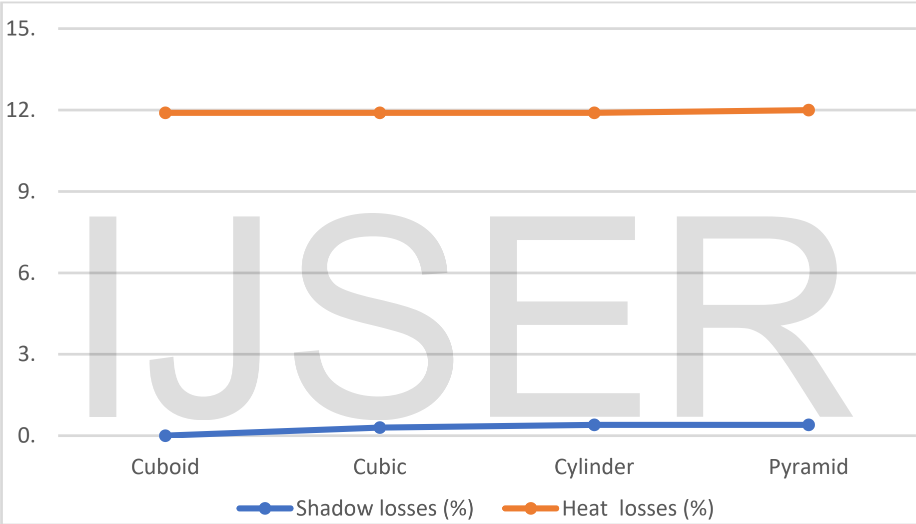

Fig. 4. Heat and shadow losses of all building forms.

TABLE 4
IRRADIANCE

Building form	Direct Irradiance(DNI)	Diffuse Irradiance	Indirect Irradiance
Cuboid	253750	245331	130703
Cubic	252685	245514	130080
Cylinder	255380	245056	132613
Pyramid	246251	244290	128851

5 CONCLUSION

In this study, BIPV façade were explored in terms of self-shading, heat loss and sustainable energy generation. Standard high-rise residential building parameters were used to conduct the experiment. It is concluded that cylindrical BIPV façade is more effective because it has the highest ratio of irradiance. Therefore, it is recommended to be used in high rise residential buildings.

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