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Exploring Building Roof-Integrated Photovoltaic Energy Potentials: Case Study of Lecture Theatres in MAUTECH Yola, Nigeria

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ABSTRACT

Building Integrated Photovoltaic (BIPV) is a multifunctional building element which performs the dual function as an integral component of a building (such as roof tiles, BIPV skylight, glazed facade) and at the same time generate electrical energy without the need for additional space and emission of carbon. It has served as a tool for designing energy efficient and sustainable buildings with ability to create a conducive micro-climatic environment where visual, thermal and acoustic comforts are attained through reduced energy cost with little or no negative impact on the environment. Among other factors the energy generating potentials of BIPV depends on the available insulation on building site, and its form, orientation and inclination of deployed building component. This research quantifies the energy generating potential of BIPV systems on rooftops of lecture theatres in MAUTECH, Yola, Nigeria. All the lecture theartres of the Univeristy were subjects of the study, based on logical argumentation. A checklist on varialbes of BIPV was generated for the LTs and a mathemathecal model was used in relation to the climatic data of Yola to calculate the energy potentials of rooftops of the lecture theatres. It was found that an average of about 50% of the roof area of the LTs if covered with BIPV system is capable of generating the total energy need of the building. It was also found that LTs with flat roof have more potential of generating solar power than hipped roofs.

Keywords: Energy Efficiency; Sustainable; Multifunctional; Building Envelope; Rooftop.

INTRODUCTION

Building Integrated Photovoltaic (BIPV) is a clean beautiful, effective and safe means of generating electricity by a building for its own utilization without the need for additional space and emission of carbon, thus providing a solar efficient an sustainable building. It is worth to note that energy saving and efficiency associated with BIPV enables cost saving which is one of the themes of sustainable development paradigm (Daramola *et al,* 2012). Thus in this case buildings are designed to incorporate solar architecture with modern technologies such as BIPV and energy efficient building materials in such a way that conducive micro-climatic environment such as visual, thermal and acoustic comfort are attained through reduced energy cost with little or no negative impact on the environment. Mobark and Halil (2015) noted that in BIPV system, PV panels are installed to substitute building fabric; therefore it serves as a climatic barrier for the building occupant, and generates electricity, thereby contributing as a cost effective element in built environment.

In BIPV system the building envelope which comprises of the roof and façades of a building are the ideal parts that act as a platform for integration. A roof of a building envelope is the uppermost part of a building or shelter, its design differs greatly from region to region as a result of some factors which influence the shape of roofs such as climate and the materials available for roof structure, the space it is covering and the outer covering. The roof is also the most exposed part of a building to Sun which makes it to be one of the most suitable parts for BIPV system.

In the hot dry climate solar irradiation is relatively high. Yola, the study area is located on the north eastern part of Nigeria latitude 9^0 12'N and longitude12^0 29'E is endowed with abundant solar irradiation averaging about 5400kwh (Medugu *et al*, 2011). Thus it can be harnessed to be of great advantage to buildings through the application of solar architecture.

It has been estimated by International Energy Agency (IEA) that buildings are responsible for more than 40% of the world's total primary energy consumption (Daramola, 2014). These buildings are of various categories including academic buildings such as lecture theatres, libraries and offices which require energy for lighting, cooling and powering of electronics devices, in order to make these buildings sustainable with conducive micro-climatic environment for learning, architects have a major role to play through the embracement of sustainable architecture in which designing energy efficient buildings through the use of renewable energy such as sunlight becomes imperative. One of the ways to achieve this is through the use of BIPV which serves a dual purpose for generating power to the building and at the same time substituting an integral part of a building envelope such as shading device, roof tiles, and facade by the use of PV module.

Various researches have been conducted on energy efficiency of buildings such as in Odunfa *et al* (2015) focusing on the of effect of building orientation on energy demand in buildings where it was asserted that buildings tend to be more efficient if oriented towards north or south with regards to reducing energy for cooling. Vassiliades, Savvides and Michael (2014) studied the architectural implication of BIPV and solar thermal system which was based on the investigation, assessment and categorization of existing applications on various case studies so as to find out the best practice for different applications. Mobark and Halil (2015) researched on the efficiency of photovoltaic integration in building in hot and cold climates where it was found that thin film PV panel is more appropriate for hot climates and polycrystalline for cold climates. This research work is geared toward enhancing the potentials of roof top BIPV system for sustainable and efficient solar energy harvest in hot dry climate of Nigeria.

CONCEPTUAL FRAME WORK

For one to find out the potentials of BIPV, an analysis of the building stock with respect to suitability of the building skin for photovoltaic deployment is required (Eiffert and Kiss, 2000). This is mainly as a result of technical limitations that might be encountered by some surfaces of a building which may result to inability to generate maximum power for reasons that may include orientation, shading, or inclination, thus the need for proper analysis of building surfaces/ areas before integration of PV.

It has been noted by IEA (2002), and Thomas (2001) that BIPV potential comprises the area in the building stock that is suitable for photovoltaic use under architectural and solar aspect. Therefore an assessment of BIPV Potentials starts with the determination of total roof and façade area which is subsequently corrected for architectural suitability for solar utilisation. It can then be calculated by applying factors for solar yield and architectural suitability to the total roof and facade surfaces. Below is a schematic diagram of the factors for BIPV potentials:

Figure 1: Schematic diagram of factors for BIPV potentials. Source: (Authors, 2017)

An Overview of Building Integrated Photovoltaic System

Solar radiation is the energy that comes from the sun which generate huge amount of energy through the process of nuclear fusion (Medugu and Yakubu 2011). Knowledge of the solar radiation is essential for many applications, including architectural design. Randal (2003) wrote that solar energy is set to play an ever-increasing role in generating the form and affecting the appearance and construction, of buildings. This is largely due to the fact that photovoltaic (PV) systems which produce electricity directly from solar radiation are becoming more common as their merits become clear and as it is becoming more affordable. The knowledge of solar energy helps architects to design buildings that are appealing and environmentally friendly.

Building Integrated Photovoltaic (BIPV)

This infers that photovoltaic elements have been present in the project from the very beginning they are a part of a holistic design. Montoro *et al.*, (2010) define BIPV as photovoltaic cells and modules which can be integrated into the building envelope as part of the building structure. Thus for the BIPV, solar modules have the role of a building element in addition to the function of producing electricity. For example, a BIPV skylight is an integral component of the building envelope as well as a solar electric energy system that generates electricity for the building. The large variety and different characteristics of the available BIPV products makes it possible for them to fully replace many of the building components, mainly in façades and roofs (Montoro *et al,* 2010). The PVs are also used to create a building envelope which guarantees a border between the controlled inner building environment and the outer climate. It helps to provide a stable air-quality, preventing the uncontrolled air mass exchange and enabling the appropriate functioning and efficiency of the air-conditioning systems. Moreover it is bound to be waterproof and fulfil the priority of ensuring the comfortable inner-climate with possibly least energy expense.

Thus, facades and roofs take over a regulation and control functions in relation to the daylight, ventilation, energy, safety, demarcation and privacy protection.. When the photovoltaic modules are to be integrated in the building envelope, all these elements need to be considered during the design phase in order to obtain the most suitable product. Other considerations (from the aesthetics as well as from the pure construction point of view) include colour, appearance, size, weather-tightness, wind and snow load, resistance and maintenance, safety in the construction and utilization phases (fire, electricity and mechanical safety), costs, and weight of materials used.

ENVIRONMENTAL AND STRUCTURAL FACTORS FOR BIPV SYSTEM

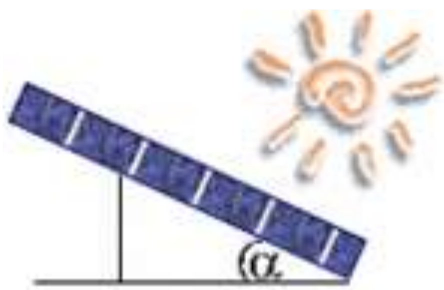
Building Integrated Photovoltaic (BIPV) has some factors to consider while designing; these factors include environmental and structural aspects. The environmental factors to be put into consideration are the nature of solar irradiation in the area, the mean seasonal temperature of the area, shading effects as a result of proximity to other buildings, trees, or the land form such as rocks, global positioning that is the latitude on which the location is. The location determines the system orientation and tilt or inclination (Essah, 2011; Eifert and Kiss, 2001). Thomas (2001) noted that for structural factors considerations are given to energy needed in the building in question which in turn determines the sizing PV system to be used, the type and efficiency of solar cells. All these factors must be taken into consideration in the design stage.

Solar Access

Solar access can be termed as the amount of solar irradiation (insulation) that the surface of PV system receives at a given time. It has strong influence on the amount of power to be generated as noted by Okundamiya and Nzeako (2011) that the solar radiation reaching the earth's surface depends on the climatic condition of the specific site location, and this is essential for accurate prediction and design of a solar energy system; the higher the solar intensity the larger the power output. Thus the environmental factors of a site must be carefully considered. Thomas (2001) wrote that these factors include local conditions such as trees or obstruction, dust, dirt, or local air bone pollutants that might shade the solar arrays. Climate is also a factor that may considerably affect solar irradiation. For example a cloudy weather decreases the concentration of suns radiation and snow may cover solar arrays. Climate varies with time of the day and seasons of the year. Lam *et al* (2004) was cited by Biliyabu (2015) revealing the solar radiation intensities in the tropics varying from 43.6W/m^2 in the north, 74 W/m^2 in the south, 86.1 W/m^2 in the east, and 89.6 W/m^2 in the west. Medugu and Yakubu (2011) wrote that Yola is geographically favourably located to tap unlimited solar energy with maximum monthly solar radiation in March of about 5.4kw/h/m^2/day and with annual mean monthly solar radiation of about 3.5kw/h/ m^2/day (Medugu and Yakubu, 2011; Okundamiya and Nzeako, 2011).

System Orientation and Tilt

The orientation and tilt of a PV system is a determinant in any solar design because it has a direct link with the power output of the system. Waseef (2014) noted that the performance of BIPV systems is highly influenced by the modules' tilt angles and orientations. The PV array has to be tilted at a certain angle in order to gain maximum incident solar rays; this tilt depends on the geographic location of the building. Eiffert and Kiss (2000) wrote that as the main principle governing the BIPV installations located north of the equator, is that it should be oriented to face south and tilted at 15 degrees higher than the latitude of the location so as to perform maximally while for regions south of the equator the BIPV system should be oriented towards north and tilted 15 degrees lower than the latitude of the site. But in a situation where the BIPV system is intended to be used only in a given period of the year, then the guiding principle may not be applicable. Thomas (2001) noted that exact orientation is not critical, as range of orientations and tilts give 95% of the maximum output. Figures 2 and 3 below are illustrations of angle of tilt and orientation respectively.



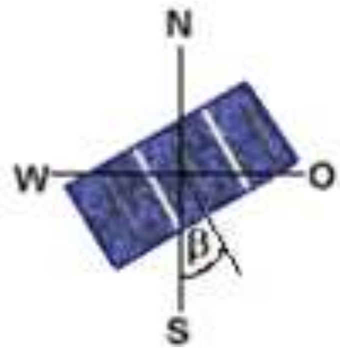


Figure 2: α**= angle of tilt**. **Figure 3: β = orientation.**
Source :(SEAI 2008)

Nature of Load and Efficiency of Cells

The nature and size of electrical power requirement is the main factor that determines the number and area of PV array that is to be integrated on a building. This is as a result of the PV cells efficiency which is also dependent on the type of PV cells used. The efficiency is the amount of solar radiation converted to electrical energy by the solar cells at standard testing condition which is based on the energy provided by 1m^2 of PV cells from an average solar irradiance of 1000w/m^2 (Thomas 2001). There are basically three type of PVs cells namely; the polycrystalline silicon, the mono crystalline and the thin film silicon. The table below shows the type of PVs and their average power generating efficiency.

Table 1: Type of Photovoltaic Cells and their efficiencies (Standard Testing **Conditions:** 25^{o}C, 1,000 W/m^2)

Photovoltaic Type	Average Efficiency
Mono Crystalline Silicon	13-17%
Poly crystalline silicon	12-15%
Thin film silicon	10-11%

Source: Adapted from (European Photovoltaic Association 2008)

BIPV Roof Products

There is a growing interest to integrate PV systems in the roofs due to its advantage as the most exposed part of building to direct solar irradiation (Caroline 2012). Many researchers such as Montoro, Vanbuggenhount &

Ciesielska (2010), Thomas (2001), Wassef (2014) and Caroline (2012) noted that BIPV products that can substitute some types of traditional roof claddings such as tiles, shingles and slates, as shown in figures I-IV below, are becoming commercially available. These BIPV products are developed to match existing building products and are therefore compatible with their mounting systems.
There are various types of BIPV roofing products available; they include prefabricated roofing systems (insulated panels) with integrated thin film laminates. These PV are sandwiched with insulating materials which constitute complete PV systems that comprise PV modules with mounting and interface components. Such products often include imitative elements to facilitate aesthetic integration. Below are examples of roof BIPV types.


(i) Shingle PV, (ii) PV Tiles


(iii) PV slates (Uni-Solar, 2011), (iii) PV laminates (Solar Power Panels, 2011).

Plate 1: Photovoltaic Modular Systems

Energy Output of BIPV Installation

Based on generalised standard, PV modules tested at Standard Temperature Conditions (STCs) of 1000 W/m2 and 25°C. It has been established that a module of 1m2 with an efficiency of 15% is rated at 150 W peak (Wp). (Thomas, 2001; Sustainable Energy Authority of Ireland, 2008; and Eiffert and Kiss, 2007).

It is also worth to note that the maximum annual incident solar radiation (and hence output) is usually at an orientation due south (since Yola is located on the northern hemisphere) and at a tilt from the horizontal equal to the latitude of the site minus 20° (Thomas 2001). But he further noted that exact orientation is not critical, as range of orientations and tilts give 95% of the maximum output.

> Thomas (2001) wrote that for each 1°C increase in cell temperature above 25°C the power output decreases by about 0.4–0.5%. He further noted that it is best to combine such a lost with that of dust and mismatch in a correction factor he called K =0.9 and a further analysis when factors like Conversion loss from AC to DC; mismatch of wires further reduced the constant to 0.8.

For over shading, a table below gives some constant figures as shading will depend on the geography of the site, neighbouring buildings and self shading by the architectural forms. The effects of over shading can be mitigated somewhat through system design. Below is a table indicating some typical over shading factors

Table 2: Typical over shading factors

Over Shading	Percentage of Sky Blocked by an Obstacle	Over shading factor
Heavy	>80%	0.50
Significant	60% -80%	0.65
Modest	20%-60%	0.80
None or very little	< 20%	1.00

Source :(SEAI 2008)

Thus the output of a solar PV array can be approximated by:

Output (kWh) = 0.8 * kWp *S * Zpv..(1)

Where:

0.8 = constant due to dust and temperature effects

KWp = installed peak power = (Efficiency* corrected roof Area)
S = annual solar radiation of Location
Zpv = over shading factor (typically a value of 1 were placed on a roof with no shading)

Eiffert and Kiss (2000) further noted that BIPV potential comprises the area in the building stock that is suitable for photovoltaic use under architectural and solar aspect. An assessment of BIPV Potentials starts with the determination of total roof and facade area which is subsequently corrected for architectural suitability for solar utilisation. It can then be calculated by applying factors for solar yield and architectural suitability to the total roof and facade surfaces.

For one to find out the BIPV potentials of Building roof top, certain factors are to be considered as it has been noted that the output from building-integrated PV installations is the output of the PV array less the losses in the rest of the system (Thomas, 2001; Eifert and Kiss, 2007). Thus the output from the array which is the energy production potential will depend on:

- The daily variation due to the rotation of the earth and the seasonal one (due to the orientation of the earth's axis and the movement of the earth about the sun).
- Location, i.e. the solar radiation available at the site.
- Tilt
- Azimuth, that is orientation with respect to due south
- Shadowing.
- Temperature.

Building Form and Energy Loads

Energy loads of buildings are reported (Catalina *et al,* 2011; Lin *et al,* 2014) to be influenced by the form or shape of the buildings which is often indicated in terms of building shape factor, relative compactness or passive volume ratio. Catalina *et al* (2011) defined building shape factor as the ratio of building volume and the sum of its enclosing surfaces that are in contact with the exterior, ground or adjacent spaces. The relative compactness of a building shape, on the other hand, is a comparism of its volume to surface ratio to that of the most compact shape of the same volume. Passive volume ratio, according to Lin *et al.,* (2014), is the ratio of the space volume within reach of natural lighting and ventilation (passive volume) to the overall built volume. It was recommended that architecture aim at selecting lower building shape coefficient to match higher passive volume ratio for lower energy loads.

Lighting Loads

In order to find out the Number of lighting points required in a given space which in turn determines the size of loading in a building, various methods of calculations are used in which the lumen method of design is one of the most widely used approach to the design of electric lighting (Pabla 2004). And in this method the area of a room plays a significant role in determining the number of lighting points, this method is given as.

$E=F \times N \times U \times M / A$ …………………………………………………………………..(2)

Where

E= Average Illumination in work place in lux

F= Lamp lighting Design in lumen

U= Uterlisation factor

M= maintainance factoe

N= Numner of fitting required

A= Area of work plane in metre squire

Aim and Objectives of the Study

The aim of this research work is to enhance the potentials of roof top BIPV system for sustainable and efficient solar energy harvest. The following research objectives are formulated to achieve the aim of this study:

1. To determine the forms and energy loads of the lecture theatres under study.
2. To determine the extent to which the energy loads can be efficiently harvested from the rooftops of the lecture theatres under study.

Research Questions

1 What are the forms and energy loads of the lecture theatres under study?

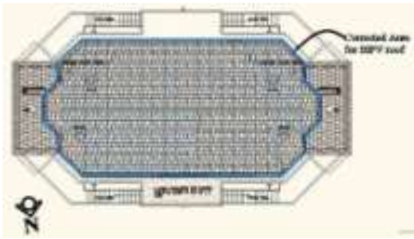
2 To what extent can the energy loads be efficiently harvested from the rooftops of the lecture theatres under study?

METHODOLOGY

This study employs logical argumentation to evaluate the potentials of BIPV on roof top of Lecture theatres buildings at Modibbo Adama University of Technology Yola. While the University was selected based on the convenience of the authors who members of staff, all the lecture theatres were subjects of the study.The lecture theatres were selected due to their relatively high space volume, intensity of use (for lectures in the day and reading at night) and level of energy consumption (for lighting and mechanical cooling-fan). A checklist of variables that affect BIPV such as shading effect, azimuth, roof area, roof type, inclination, as indicated on table 4 were generated. This helps in finding out the corrected suitable roof area for the lecture theatres that include LTs 1 and 2, 3 and 4, 5 and 6, AYR as well as that of SAAT, STSE and new SPAS which are of the same architectural design and configuration thus analysed as an entity. A mathematical model for PV generation by Thomas (2001), and Sustainable Energy Authority of Ireland (2008) was used in relation to the climatic data of Yola to calculate the energy potentials of rooftops of the lecture theatres. Energy consumption loads of the lecture theatres were evaluated based on the form (shape and size) of the lecture theatres, and the number and size of lighting and cooling appliances found in them. The result generated is compared with the size of loading (energy consumption) of the Lecture theatres in which a percentage of corrected roof area needed for energy generation for the theatre is obtained.

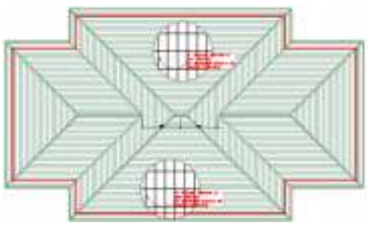
DATA PRESENTATION AND DISCUSSION

Based on the analysis it revealed (Figure 4 and Table 4) that the case studies comprise of various type of roofs with distinct architectural factors such as self shading, angle of inclination and orientation. However LTs 1 and 2, 3 and 4 share common roof type and size of loading; same applies to SAAT, SPAS and STSE LTs which are prototypes with same local environmental and climatic characteristics. Thus it becomes easier to discuss them as a unit as indicated below.

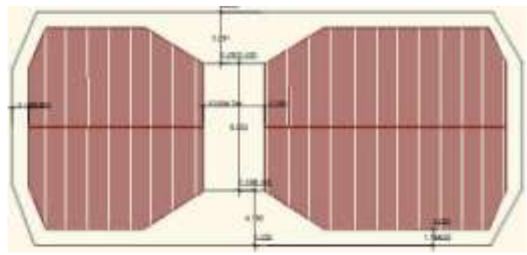


Roof plan of LTs. 5&6

Roof plan of AYR LTs



Roof plan of SAAT, SPAS, STSE LTs



Roof plan of LTs 1 and 2

Figure 4: Corrected roof area suitable for BIPVs
(Source Author 2017)

Table 4: Case Studies BIPV Variables

Lecture Theatre	**Roof Type**	**Shading Effects**	**Orientation**	**Inclination**	**Corrected roof Area**
LT 1&2	Sloped	Modest roof shading by Parapet wall	E/W longer axis	13°	481
LT 3&4	Sloped	Modest roof shading by Parapet wall	E/W longer axis	10°	488
LT 5&6	Gable	No Shading effect	E/W longer axis	18°	664
AYR	Flat	None or very little	E/W longer axis	10°	576
SAAT,SPAS,STSE	Hipped	Significant	E/W longer axis	20°	976

Source: (Authors' field work 2017)

Table 5: PV Power Generation Capacity of Lecture Theatre roof tops

Building	Corrected Roof Area 1	PV Cells type Efficiency % 2	kWp (1*2)	Expected Energy (KWh/day)	Size of Loading (kwh/day	Percentage (%) of roof for BIPV array
LTs 1 and 2	481	15	72	442	205.4	46.5
LTs 3 and 4	488	15	73.2	449	211	47
LTs 5 and 6	664	PV Slates 15	99.6	764	204	26.6
AYR	576	15	86.4	663	478	72
SAAT, STSE LTs	976	15	146	663	458	63

Source: (Authors, fieldwork 2017)

Lecture Theatres (LTs) 1 and 2, 3 and 4: Although the design of these buildings varies significantly, they share same type of roof system, with almost same corrected roof area for BIPV as shown in Table 5. The corrected roof area for PV integration on the roofs is about 481m^2 and 488m^2 respectively for the two buildings with power generation potential of about 442 kWh/day and 449kWh/day which is far more than the energy need of the buildings. Thus if only 47% of each of the roof areas will be integrated with PVs it will serve the energy need of the buildings.

Lecture Theatres 5 and 6: Its roof type slopes in two directions with an inclination of 18^0 which makes it visible to public unlike flat roofs. Thus in the design of BIPV to LT 5 and 6 aesthetic is to be considered therefore the use of PV products such as roof tiles, shingles should be carefully selected to fulfil the aesthetic requirements of the building. Caroline (2012) described it as prominent integration, where the BIPV system is distinguished from the total building design. The roof is also devoid of shading effects and thus has adequate incidence solar irradiation in most hours of the day. As shown in Table 5 above, the roof top of the building is capable of generating about 764kWh/day of electric energy which is far more than the energy need of the building for mechanical cooling and lighting estimated at 204kWh/day. Thus as indicated in Table 5 if 22.6% of the roof area can be integrated with BIPV roof tiles it will be sufficient for its energy need.

AYR Lecture Theatres: The roof of this building can be categorised as flat roof which are defined as roofs with a slope of 10° and below (Barry 1999). The roof of AYR Lecture theatre can be characterized as flat since its angle of inclination is exactly 10°. It is divided in to two, with a central concrete deck as shown in Figure 4. The concrete deck serves as a platform for occasional cleaning of PV arrays mounted on the roof. Waseef (2014) wrote that flat roofs present the least degree of engineering difficulty for BIPVs because it experiences direct incident solar irradiation in most times of the day with little effect of shading caused by a little projection of the parapet wall covering the roof from view as shown in Figure 4. This type of roof system is known as neutral integration of PVs on building as espoused in Caroline (2012) that the system does not contribute to the appearance of the building. Thus the architectural quality of aesthetic has little role to play; however it falls under functional integration since it serves the dual function of electricity generation and roof covering. It can be seen from the summary of energy generation analysis in Table 5 that 72% of the corrected roof area if integrated with BIPV is capable of generating the total energy need of the building estimated at about 478 KWh/day.

SAAT, SPAS, and STSE Lecture Theatres: These are prototype lecture theatres with a common design characteristics of a hipped roof inclined at 20° with its longer side oriented North and South as shown Figure 4. They are significantly shaded based on the fact that only about 50% of the roof surface is having a direct solar irradiation from morning to noon and the other side in the afternoon which results to self shading that greatly minimises the efficiency of the PV arrays. SEAI (2008) mentioned that about 35% reduction of cell efficiency may occur due to significant shading effect. However due to the excessive solar irradiation experienced in Yola, the roof top of these lecture theatres have a potential of generating about 663kWh/day as shown in Table 5. This is more than the energy required by the building which is put at about 458 KWh/day; meaning that if 63% of the roof top integrated with PV roof elements it will be adequate for energy need of the lecture theatres.

CONCLUSION

The provision Healthy and comfortable buildings in hot dry climate requires a lot of design considerations and the provision of adequate electrical energy for lighting and cooling of buildings interior consequently this result to the use of electricity generated through conventional sources such as the national grid and the use of power generating sets which leads to high carbon emission to the environment and high cost of electricity as experienced in Nigeria today. However through proper architectural design and selection of building components and materials such as the use of BIPV roof system, serves as a way of providing sustainable buildings that takes the advantage of the available solar irradiation to generate the required power of a building with little cost and zero carbon emission.

The analysis above shows that BIPV application is possible and on both new building construction and on the existing buildings through replacement of existing roof cover with PV roof elements. Another important finding is that most of the selected case studies have compatible roof system of low pitch angle with covering that can easily be replaced with solar roof products such as tiles or shingles which will act as roof cover and at the same time generate electricity to the building. However hipped roofs—with their varying architecture especially their orientation of faces tend to have more effects of self shading thus rendering a large portion of the roof area to be less effective during a given period of the day. It is important to note that BIPV Systems placed on hipped roof which typically slopes on all the cardinal directions (east, west, north and south) surfaces is found to be less efficient as affirmed by Waseef (2014) that such a type of system orientation tend to be less effective with about 40% as compared to those placed in horizontal surface. But for flat roofs they have little or less tendency of self shading thus have a maximum advantage of solar irradiation in most of the day. Thereby it is more suitable for roof top BIPV installation. Below is an illustration of a shaded and non shaded area of a hipped roof from 8:00-11:00am and vice versa in the afternoon.

Source: (Adapted from Pieter G., *et al.*, 2016)

It has been observed that in lecture theatres and buildings of similar energy needs having only one floor can meet its total energy need for lighting and mechanical (fan) cooling by integrating only about 50% of their roof tops with PV roof system.

However this reveals that roof top BIPV application is suitable for only low rise buildings as it can be clearly seen in the analysis done on AYR Lecture theatres and that of SAAT, SPAS and STSE tend to have a higher percentage of installation of PV system on their corrected roof area: 72% and 68% respectively. This is largely due to its size of loading which is determined by the number of floors a building has, these buildings have two floors each thus needs more energy than a building that has only one floor. Thus it can be asserted that the more the number of floors a building has the less efficient the roof top BIPV system. It is also worth to note that most of the case studies have their roof hidden behind a parapet wall. This affects the BIPV system in two ways; first it serves as a source of shading on the roof top thus reducing its effective area for BIPVs installation and secondly it makes the BIPV to be applied invisibly with the tendency to reduce its aesthetic effects on the building.

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