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Low Carbon Emission through the Use of BIPV Windows in Algerian Mid-Rise Buildings

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Sustainable developments in the field of architecture are turning out to be increasingly vital which requires the utilization of renewable energy and the reduction of energy consumption in Algerian mid-rise buildings. However, Algeria energy utilization which is not sustainable has contributed to excess amount of CO_2 emission. This study investigated the potential of using PV system in vertical façade (azimuth 90 °) and identifies the yield of photovoltaic in each orientation and tilt angle (horizontal, 30 °, 90 °). Through a series of simulations were perform in eight azimuth (and tilt angle from 0 ° to 90 °) throughout four season by using Polysun software in order to evaluate the optimum power output of 1.54 m^2 of Mono-crystalline windows. This was carried out on a 7th floor office building of Tebessa University which contain, the area of the roof 242 m^2, the area of whole facades
1,904 m^2, whereas the surface of the opening (windows) 580 m^2. The difference of energy output in mid-rise building (7 levels) between the Roof area and whole façade area was up to 3.6 times. Consequently, after calculation the total amount of energy output. It revealed that the energy output of BIPV windows is higher than BIPV on the roof; however the performance of the BIPV in the roof is much better than façade. In overall, the application the BIPV windows in mid-rise buildings under semi-arid climate is favorable and convenient, increased the CO_2 saving to 173.4 kWh/y, and reduce more than 200 kWh/y energy to supply the energy of buildings.

1. Introduction

According to the Renewable Energy Policy Network for the 21st Century (REN21), there has been a noticeable growth by 55 % in the utilization of photovoltaic (PV) as it is considered to be the most substantial energy resources available. In addition, study by Zahedi (2006) found that it is expected that solar PV electric's capacity worldwide shown to incline tremendously by 2030 from 1,000 MW in 2000 to 140,000 MW. By 2040, the renewable electric energy may possibly become adequate to support the base load and half of the global electricity energy demand claimed by the European Renewable Energy Council (Teske et al., 2007). Further study by Stambouli et al. (2012) shows that the amount of solar electricity produced surpasses the global need as projected by the solar pyramid in the case of the Algerian Sahara with 50 % of the space, 10 % of the system energy efficiency and 14 % PV module coverage.

In this decade, the ability to fully utilize renewable energy innovation in building as well as environmental sustainability is the main topic for human societies around the planet. Many researchers, such as Huijts et al., (2012), stated that quality is taken into account of all countries in short and long term of natural resources, sustainable development and in addition to the technology used to designate economic, social, and environmental dimensions of our upcoming survival. According to Intissar Fakir (2016), low oil prices affects immensely on Algeria's finances and energy use leaving the economy at struggle in 2016. Alternatively, Algeria is interested to supplant fossil fuels and natural Gas with renewable energy resources. However, according to (Stambouli et al., 2012), it is a challenge for the government to promote renewable energy to minimize the utilization of energy in buildings as it is a new sector in the country. Across all nations, the sector of energy consumption in buildings alone consumes around 20 % to 60 % of the overall account that is used by all sectors, and an average of about 31 % worldwide.

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Algeria, a standout amongst the most nations on the planet's energy utilization assessed more than 41 % than the average by more than 10 %, subsequently by 37 % in transport sector and 22 % in industrial sector The utilization creates 25 % of the national CO2 outflow as these measurements are liable to ascend over the later because of the developing interest for convenience in building sector (Sotehi et al., 2015). This major consumption level warrants a point by point comprehension of the building sector's consumption elements to formulate and guide the sector's energy consumption in the attainment to stimulate efficiency, conservation, technology implementation and energy source substituting such as to on-site renewable energy.

2. Aim of this Study

The aim of this study is to investigate the potential of using PV system in vertical façade (azimuth 90 °) of Algerian mid-rise buildings under semi-arid climate, afterword, to identify the yield of photovoltaic in each orientation and tilt angle (horizontal, 30 °, 90 °).

3. Literature Review

Photovoltaic (PV) is derived from the Greece tongue. Researchers, such as, Mahato et al. (2015) agreed that the word photo indicates "light" and voltaic indicates "producing electricity". In 1839, the photovoltaic effect was discovered by Alexander Becquerel and the trend began developing at the following years (Sfaelou and Lianos, 2016). According to Heinstein et al. (2013), PV is defined as an integral building component called "BIPV": electricity producing modules are both functional unit of the finished building; and construction elements of the building skin since the conventional material are replaced. The energy production of BIPV can be merged with other functional unit features of a building such as solar shading (cooling energy decrease), building envelope protection, preheating air or water (Friling et al., 2009). The PV module is the standard element of a BIPV which individual solar cells are unified and enfolded on various materials to form a module. To form a PV array, modules are linked together in an electrical series with cable and wires. Unregulated DC electric power is generated by the production of photovoltaic effect of direct or diffuse light (mainly sunlight) on the solar cells. The DC power can be used, deposited in a battery framework, or to provide into an inverter that converts and synchronizes the power into AC electricity. The electricity can be utilized in the building as well as to export to a utility company through a grid interconnection. The locations of photovoltaic elements can be incorporated into a new building usually involve three different aspects; Façade such as: (curtain wall window or glazed, wall), on slope or flat roofs, as well as curved pavilion surfaces.

Algeria is the tenth-largest country in the world, and the largest in Africa located in the North of Africa on the Mediterranean coast with a total area of 2,381,741 km^2 bordered in the northeast by Tunisia, Libya in the east, Morocco in the west, Western Sahara in southwest, Mauritania, and Mali, Niger in southeast, and the Mediterranean Sea in the north. This country is separated topographically into three main regions that run east-west. Region of Tell is the first which is the Mediterranean coastal area. High Plateaus is the second with semi-arid climate, which are more inland and are equally consistent, until the third region, the Sahara, which covers almost 80 % of Algeria's territory (Abdelhakeem, 2015). Exploitation of this renewable energy BIPV system is insufficient, however most countries in the semi-arid region benefit from a large amount of solar radiation. Satellites assessment conducted by the German Aerospace Center (DLR) concluded that Algeria holds one of the highest solar potential in the Mediterranean basin exactly to its geographical location with 169,440 TWh/y. The daily energy received on a horizontal surface is roughly at 5 kWh in most territories; 1,700 kWh/m²/y for the North and 2,263 kWh/m²/y for the South as shown in Table 1. All countries receive over 200 h of sunshine duration per year and can reach up to 3,900 h in the Highlands and the Sahara. Thus, solar energy's development is convenient due to the climatic conditions in Algeria throughout the year.

The performance of PV arrays at different orientations and tilt angles for Guangzhou city (latitude 27°N) was investigated by Wei et al. (2008). According to their report the monthly average power output of the PV arrays at different angle-settings has a nearly same trend in the spectrum with the monthly average solar radiation incidence on them. This finding approved that the amount of solar radiation on a PV array is the major factor that determines its system efficiency. From the graphs of 2D power output plots of PV arrays), it was also concluded that the optimum yearly power output value can be achieved from PV array facing south with a tilt angle of 19°. Yang et al 2002 investigated the optimal tilt angle and azimuth angle for a wider range of locations in China by means of a specifically developed mathematical equation based on the anisotropic model.

In this context, BIPV windows façade are being investigated in order to reduce CO_2 emission and energy consumption. Recently, Susan and Antaryama (2015) increase power output by using folding concept through collaborate both BIPV and orientation principle to decrease the CO_2 emission. in japan office building by using different transmittance of the semi-transparent solar cell, and the consideration of both cooling and the heating loads, power output and daylighting. The total reduction of energy was 55 % (Miyazaki et al., 2005).

Tebessa city (Algeria) also has a very important amount of solar irradiance that requires a rational and sustainable exploitation in architecture field such as: Building Integration Photovoltaic system. The graph below consists of global horizontal radiance along with direct and diffuse element. The graph indicates that monthly solar radiation in Tebessa (Algeria) under semi-arid climate is Different and irregular according to the seasons throughout the year. The global horizontal irradiance accounted 245 kWh/m^2 as maximum value at summer season while the lowest value 82 kWh/m^2 at winter season with variability of 3.5 %/y, in the other hand, the diffuse element value is between 30-51 % of the global solar (Abdeladim et al., 2013). The findings were further buttress by Gairaa and Bakelli (2013). The global horizontal irradiance accounted 245 kWh/m^2 as maximum value at summer season while the lowest value 82 kWh/m^2 at winter season with variability of 3.5 %/y, in the other hand, the diffuse element value is between 30-51% the global solar radiation (Meteonorms, 2010).

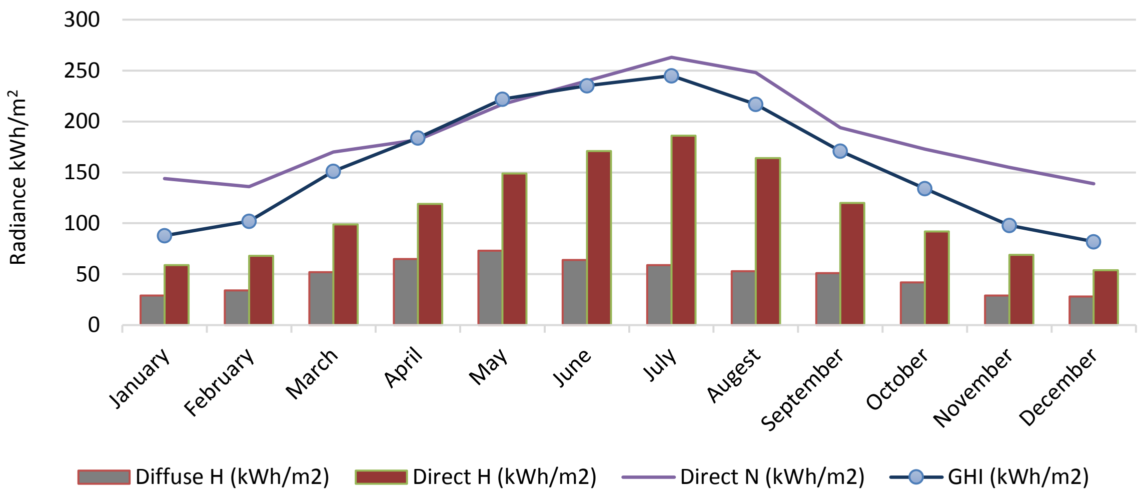


Figure 1: Distribution of Direct and diffuse radiance in Tebessa (Algeria) (Meteonorms, 2010)

4. Method

To adequately capture the characteristics of current BIPV windows (Mono-crystalline, PV-mono 200) design practice in mid-rise buildings, a series of simulations were performed under Algerian climate in eight azimuth and tilt angle from 0 ° to 90 °. The simulation was conducted throughout the four seasons by using Polysun software. This process was carried out to evaluate the optimum power output of 1.54 m^2 of BIPV windows. Then transfer the results to 3D model expressed by percentage in each façade as guideline for the future designer and Architects in Algeria.

5. Result

During the first stage of investigation, the energy production data was based upon the following parameters Figure 5 depicts the relationship between the annual power output and CO_2 saving taken from using 1.54 m^2 Mono-crystalline PV module under semi-arid climate depending on the inclined angle and azimuth of the module.

These analyses carry out on vertical BIPV windows power performance depending on different orientations of the PV module, as shown in Figure 2. From the annual data in it can be seen that the most effective power output during the year obtained 207.5 kWh/m^2 by facing the module to the south-east orientation. While the lowest power output attained by facing the PV to the North is 3 times more. Nevertheless, both east and west orientations were within accepted level of power production. This indicates the significant role of the sun path in each season throughout the year in the design of PV windows.

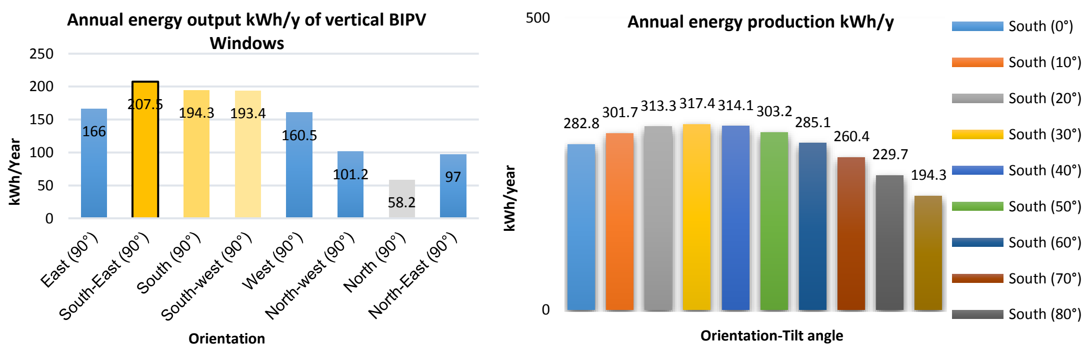
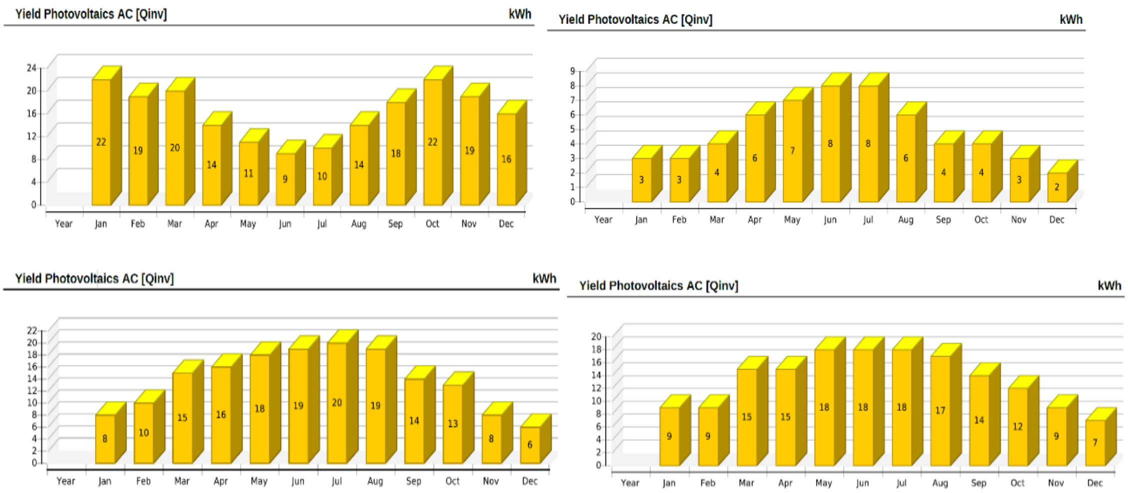


Figure 2: Annual energy output affected by different tilt angle and orientation

In the other hand, repeated covering different tilt angles of the panels' plane were implemented for a range of 0 ° to 90 ° with increments of 10 °. The power output increased dramatically from 90 ° to 30 ° slope, and then decreased again up to the horizontal 0-slope. The highest power output was obtained at SLOPE_30. However the vertical BIPV windows only produce 61.24 % of energy comparing the one installed in SLOPE-30. This particular result are consistent with previous research have been done at Beirut (Salem and Kinab, 2015)
The figures below show the monthly power performance depending on the amount of solar irradiation and the orientations (S, N, E, and W) respectively of vertical installed PV module. The result show a direct correlation between the solar irradiation and the yield of PV in both (North, East, West) orientations, since the power output increased with increase of solar radiance unless the south orientation due to the sun path in Algeria. The sun passes quite close to the zenith at summer season (height 81 °) since it was in low latitudes at winter season, the highest power output recorded in June and October 22 kWh, while approximately similar result achieved in west and east orientation because there is symmetry of the incident solar energy, the maximum loss of energy output from East to west façade doesn't exceed 14 %.



Figures 3: power output by using Mono-200PV at (S, N, E, W) orientation throughout the year

According previous results, we can identify the potentiality of utilization the BIPV windows in Mid-rise buildings under semi-arid climate by means of using Eq(1) at PV module temperature standard condition 25 ºC (Hendarti and Sediadi, 2008). The amount of energy generated in the whole façade is based on Eq(1).

$$E = G_d \times A_m \times n \quad (1)$$

Where
E = The PV-electrical energy at 25ºC in kWh
G_m = The monthly global solar radiation per area on horizontal surfaces in Tebessa-Algeria in kWh/m^2.m
A_m = The total PV surface area in m^2
n = The PV system efficiency = 0.1 (includes inverter efficiency, wiring losses etc.)

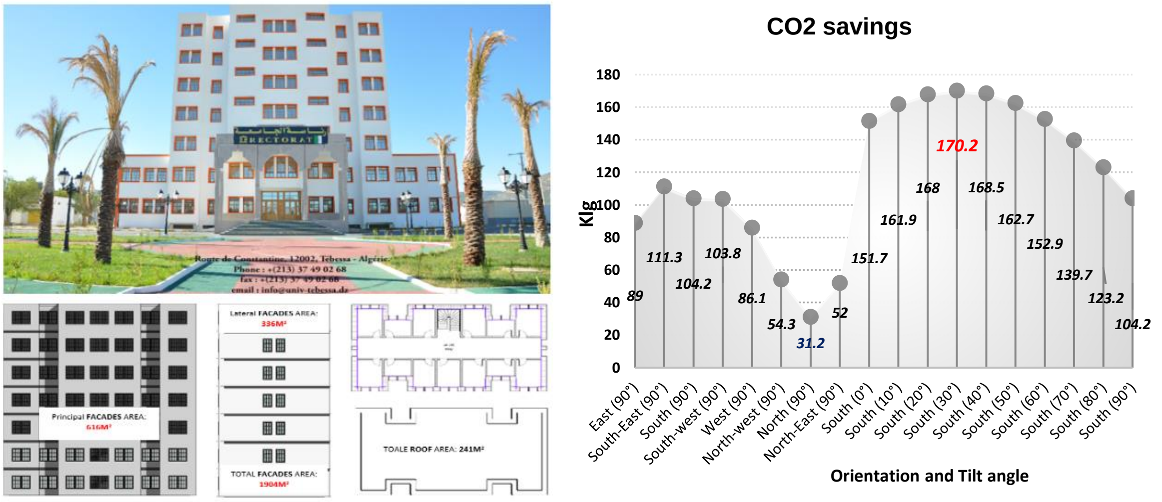


Figure 5: the area of potential BIPV used (Roof, opaque, windows) and CO2 savings against the orientation and tilt angle of BIPV window façade.

The Case study selected to prove this matter is an office building of Tebessa University which contain 7 floors, the area of the roof 242 m^2, the area of whole facades 1904 m^2, whereas the surface of the opening (windows) 580 m^2, as seen the figure above. Consequently, after applying this simple equation it revealed that the total amount of energy output of BIPV vertical windows is higher than BIPV on the roof, however the performance of the BIPV in the roof is much better in the façade.

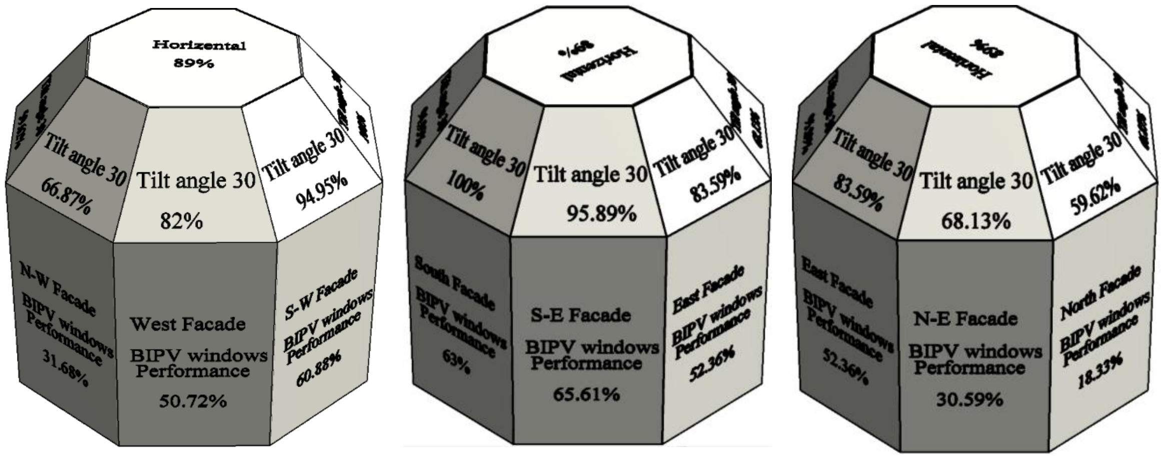


Figure 6: the percentage of the yield photovoltaic in 3D model under semi-arid climate

The difference of energy output in mid-rise building (7 levels) between the minimum production of Roof area and the maximum of whole façade area was up to 3.6 times. Finally, through the ratio between the highest power output facing south slope-30 that consider 100 % with 317.4 kWh/y and the power output of other facades and the roof. The final result is 3D model can used by architects and designers in Algeria

6. Summary

This study assessed the power output performance of PV module in mid-rise buildings depending on the inclined slope and the azimuth angle. Furthermore, brief about the current state of the use BIPV in Algeria. (1) In overall, the use of BIPV in Algerian building's sector compared to its potentiality, favourable climate and environment is almost completely non-existent, only presented in some scattered projects in the desert that consider small part of today's global energy picture in Algeria. (2) The application the BIPV windows in Mid-rise buildings under semi-arid climate is favorable and convenient, increased the CO_2 saving and produce enough energy to supply the energy of buildings. (3) The use of these 3D models is very beneficial for future architects and designers in Algeria to apply the BIPV windows.

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