Optimum Arrangement of Photovoltaic Panels for BIPV Application

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Abstract:- Building integrated photovoltaics (BIPV) has the potential to become a major source of renewable energy in the urban area. This paper presents monitoring and calculated results of the ratio of beam radiation on the surfaces of the collectors for BIPV applications. The solar collectors were installed as shading devices around a building from each face, south, west, north, and east. The slope angles in this case study are $\beta = 90^\circ$ and $\beta = 10^\circ$, with the hour angle of $\omega = -60^\circ$ at 8:00 am. The system is installed on an educational building at the center of Kuala Lumpur. Spreadsheet is used in the simulation of the data. The results presented that the optimum value of the ratio of beam radiation is in December and the solar collector toward east. The ratio of the beam radiation when the collector constructed vertical $\beta = 90^\circ$, the ratio is small, $R_b = 0.1518$ to 1.81922. The study also found that in some of the direction resulted show no ratio due to negative value. In most direction when $\beta = 10^\circ$ the value of ratio is within acceptable range of $R_b = 0.81922$ to 1.31121.

*Key-Words***:-** BIPV, shading, PV and solar collector.

Nomenclature

δ	Declination angle
ϕ	Latitude
β	Slope or tilt angle
γ	Surface azimuth angle
ω	Hour angle
θ_z	Zenith angle
θ	Angle of incident
R_b	Ratio of beam radiation on collector surface

1 Introduction

Kuala Lumpur is the capital city of Malaysia and the city where the total energy use will increase for every year because of increase the number of building and consumer. Because of that, solar energy systems become more important in order to reducing building energy consumption. Building integrated photovoltaics (BIPV) is one of the best solution because it can replaces conventional building elements such as roof tiles, asphalt shingles, facade elements, and shading devices with photovoltaic modules that perform the same function but also provides electrical power [1-3].

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system in the BIPV is the solar collector. This is a device which absorbs the incoming solar radiation and converts it into electrical power [4]. The collector usually consists of a cover system, absorber, and heat exchange system. In addition, insulation must be provided to prevent heat loss; also, a structure which supports the various elements and parts is also required.

Usually, in Kuala Lumpur the solar collectors are installing on the roof of a building and slope being the same as the slope of the roof. However, because of incorrectly installed and lack of awareness among the designer consider about vary the slope angle considerable from different building, the optimum receiving radiation is less compared with a properly installed the conductor or on the other word because of mistake during the install the conductor the electrical power produced by the BIPV is low. In Malaysia, the most collectors are installing and received the radiation (solar energy) 65-90% and some of them only received 50% [5&6].

The other parameter needed to be considered is shading where it can reduce the amount of solar radiation on a surface when not needed, or it may be a characteristic of the site on which solar collectors are to be located. There are three types of shading problem needed to be handle; the first is shading of a collector and window or other receiver by near by trees, buildings or other obstructions, the second type includes shading of collectors in other than first row of multirow arrays by the collectors by the joining row and lastly, includes shading of windows by overhangs and wingwalls [7].

It was, therefore, decided to study about the effects of variable like slope or tilt angle by using the solar collectors (thermal and photovoltaic) as a shading devices on the walls of building and to determine the ratio of beam radiation for collectors on vertical surface and inclined surface also try to get the maximum value for the tilt angle in order to find the best solution for designer to install the solar collector.

2 Mathematical Model

The slope angle (β) of any collector is defined as the angle between the planes of the collector and the horizontal as shown in Fig. 1 and 2, where the solar collector as a shading devices. The azimuth angle (γ) is defined as the displacement angle between the projection on a horizontal plane of normal to the collector surface and due north. The incidence angle (θ) is the angle between the direct radiation on surface and the normal to the surface. For maximum direct radiation, the incidence angle should be a minimum [8].

The purpose of solar process design and performance calculations, it is often necessary to calculate the hourly radiation on tilted surface of a collector from measurements or estimates of solar radiation on a vertical surface. The most commonly available data are total radiation for hours or days on the horizontal surface, whereas the need is for beam and diffuse radiation on the plane of a collector.

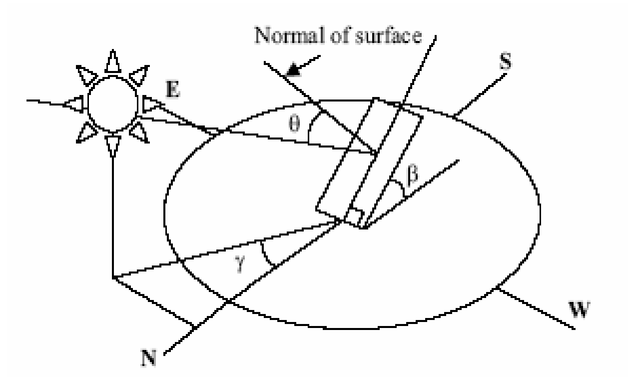

Fig. 1: Major angle in solar application [5].

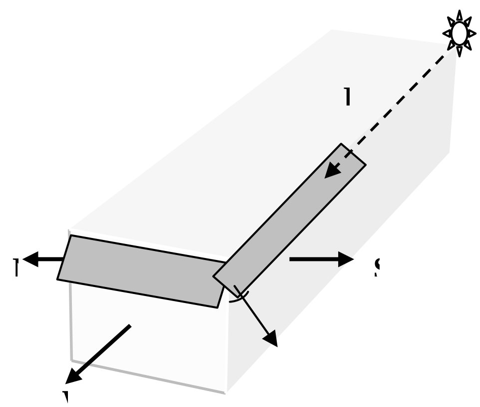

Fig. 2: Diagram for solar collector as shading device

The geometric factor R_b, the ratio of beam radiation on the tilted or vertical surface to that on a vertical surface at any time, can be exactly by appropriate use of the equation (1) as follow [9]:

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega \quad (1)$$

There are several commonly occurring cases for which equation (1) is simplified.

For fixed surfaces sloped toward the south or north, that is, with azimuth angle γ of 0° or 180° (a very common situation for fixed flat plate collectors), the last term drops out.

For vertical surfaces, $\beta = 90^\circ$ and equation becomes:

$$\cos\theta = -\sin\delta\cos\phi\cos\gamma + \cos\delta\sin\phi\cos\gamma\cos\omega + \cos\delta\sin\gamma\sin\omega \quad (2)$$

The angle of incidence is zenith angle of the sun θ_z .its value must be between 0° and 90° when the sun is above the horizon. For this situation the equation becomes:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (3)$$

After finding the angle between the beam radiation on a surface and the normal to that surface, the incidence angle θ, and obtained on the angle between the vertical and the line to the sun. We can calculate the ratio of beam radiation on the vertical surface and tilted surface by using the equation as follow:

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (4)$$

3 Result and Observation

Solar shading device is used now very widely, this paper presented the ratio of beam radiation on the surface of collector. When the solar collector installed on the wall, the optimum orientation of a collector for the several slope angle (β = 90° and 10°) and different side (toward south, west, north, and east) have been examined. The latitude angle has been used is $\phi = 3.1^\circ$ for Kuala Lumpur where the location of the research has been done. The data taken for the declination is at 15^{th} in every month for a year and the hour angle for this study is ($\omega = -60^\circ$) at 8:00 am.

3.1 The beam radiation on solar collector β=90°

The value of the ratio of beam radiation on collector surface on vertical surface β=90° for different sides, the value of zenith angle and angle of incident are given in Table 1 and Fig. 3 below. Toward south, the ratio of beam radiation is a maximum on the surface in December ($R_b = 0.95881$), while in June $R_b =$ -0.77453 which mean there is no ratio, because of the value is negative and during that time there is no beam radiation falls on the surface, which mean the sun, not reach the south side yet.

In the west side as we can see in Figure (3), the beam radiation on the collector surface in negative value between R_b = -1.81922 and R_b = -1.65971, meaning that the sun location not reach the west, which the collector toward west side. In this case there is no ratio of beam radiation.

In the north side the ratio of beam radiation some value in positive side in the middle of year in between $R_b = 0.249501$ and $R_b = 0.77453$, and in start of year or in end of year the value in negative, because there is no beam radiation fall on the surface during that time. In this case the ratio of beam radiation has small value, which mean just half of the year has some ratio and the other half does not half ratio of beam radiation on surface of the collector. As we see in Figure (3) the curve of ratio of beam radiation during a year and the maximum value in June where $R_b = 0.77453$ and decrease till reach to the minimum value in end of the year in December and the value is $R_b =$ -0.95881.

When the collector installed toward east, the ratio of beam radiation has a value in range of R_b = 1.819222 and R_b = 1.659708, that value is maximum in December and decrease gradual till June then going to increase again. From Fig. (3) we can indicate that the ratio of beam radiation which falls on the collector surface that has minimum value in middle of year and maximum value in end of year.

Table 1 The Ratio Of Beam Radiation On Vertical Surface B=90°

$\cos\theta$ South	$\cos\theta$ West	$\cos\theta$ north	$\cos\theta$ east	$\cos\theta_z$	R_b south	R_b west	R_b north	R_b east
0.387	-0.81	-0.387	0.807	0.446	0.867713	-1.81614	-0.86771	1.809417
0.252	-0.843	-0.225	0.842	0.474	0.531646	-1.77848	-0.47468	1.776371
0.0753	-0.865	-0.075	0.865	0.496	0.151815	-1.74395	-0.15181	1.743952
-0.1375	-0.854	0.137	0.854	0.501	-0.27445	-1.70459	0.273453	1.704591
-0.297	-0.819	0.297	0.819	0.489	-0.60736	-1.67485	0.607362	1.674847
-0.371	-0.795	0.371	0.795	0.479	-0.77453	-1.65971	0.77453	1.659708
-0.342	-0.806	0.341	0.806	0.484	-0.70661	-1.66529	0.704545	1.665289
-0.212	-0.841	0.212	0.841	0.497	-0.42656	-1.69215	0.426559	1.692153
-0.0125	-0.865	0.125	0.865	0.501	-0.02495	-1.72655	0.249501	1.726547
0.192	-0.854	-0.192	0.854	0.484	0.396694	-1.76446	-0.39669	1.764463
0.352	-0.818	-0.352	0.818	0.454	0.77533	-1.80176	-0.77533	1.801762
0.419	-0.795	-0.419	0.795	0.437	0.95881	-1.81922	-0.95881	1.819222

The results show that the ratio of beam radiation is between $R_b = 0.1518$ and $R_b = 1.81922$ and some direction show no ratio of beam radiation when the value is negative. The maximum value of obtainable is $R_b = 1.81922$ and toward east side.

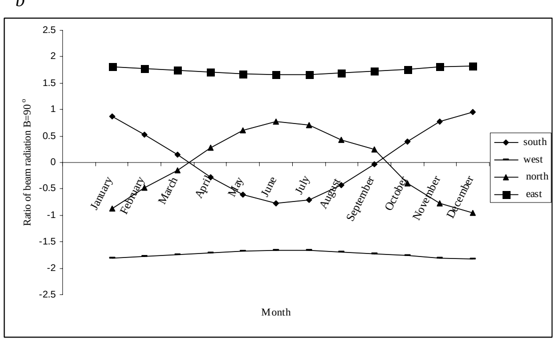

Fig. 3: The ratio of beam radiation on the surface toward side β=90°

3.2 The beam radiation on solar collector β=10°

The other case that we discussed in this paper is installation the collector on the wall by the slope of $\beta = 10^\circ$. After analyze and calculated the ratio of beam radiation on each side, as we see in figures below, each side produced different value. Fig. 4 shows the ratio when the collector installed toward south. The results show the ratio value is in between R_b = 0.849687 and R_b = 1.196796. The value is higher in early and the end of the year but decrease in the middle of the year. The maximum value is $R_b = 1.196796$ in December. Toward install to the west, the value of beam radiation less than when collector in the south sides. The results show in the graph produced contra patent with the south value, where the value is maximum in June and lower in the early and the end of the year. The maximum value is $R_b = 0.7473$.

When the collector installed in north side on the wall, the ratio of beam radiation is higher than toward west value. The value is in range of $R_b = 0.81922$ and $R_b = 1.11899$. The final ratio beam radiation discussed in this reported is toward to the east side. The result shows that the ratio of beam radiation is satisfied. This is due to the range of the data is highest compare to the other. The value is in between $R_b = 1.31121$ and $R_b = 1.27272$ as we can observe from Fig. (4) below. The value of the ratio of the beam radiation maximum is in December where the value is $R_b = 1.31121$ and minimum in July 15th.

The value ratio of the beam radiation for $\beta = 10^\circ$ is in range of $R_b = 0.72421$ and $R_b = 1.31121$, where all the value is positive. The suitable collector is laid to the east side compare to the other side. This is due to the higher value for R_b.

Table 2 The Ratio Of Beam Radiation On Vertical Surface B=10°

$\cos\theta$ **South**	$\cos\theta$ **West**	$\cos\theta$ **north**	$\cos\theta$ **east**	$\cos\theta_z$	R_b **south**	R_b **west**	R_b **north**	R_b **east**
0.526	0.323	0.372	0.579	0.446	1.179372	0.72421	0.83408	1.29820
0.532	0.345	0.422	0.613	0.474	1.122363	0.72784	0.89029	1.29324
0.523	0.364	0.476	0.638	0.496	1.054435	0.73387	0.95967	1.2862
0.464	0.371	0.517	0.642	0.501	0.926148	0.74051	1.03193	1.28143
0.431	0.364	0.534	0.624	0.489	0.881391	0.74437	1.09202	1.27607
0.407	0.358	0.536	0.611	0.479	0.849687	0.7473	1.11899	1.27557
0.436	0.361	0.536	0.616	0.484	0.900826	0.74586	1.10743	1.27272
0.473	0.369	0.526	0.636	0.497	0.95171	0.74245	1.0583	1.27967
0.512	0.369	0.496	0.644	0.501	1.021956	0.73652	0.9900	1.28542
0.531	0.353	0.443	0.625	0.484	1.097107	0.72933	0.91528	1.29132
0.529	0.329	0.386	0.589	0.454	1.165198	0.7246	0.8502	1.29735
0.523	0.317	0.358	0.573	0.437	1.196796	0.7254	0.81922	1.31121

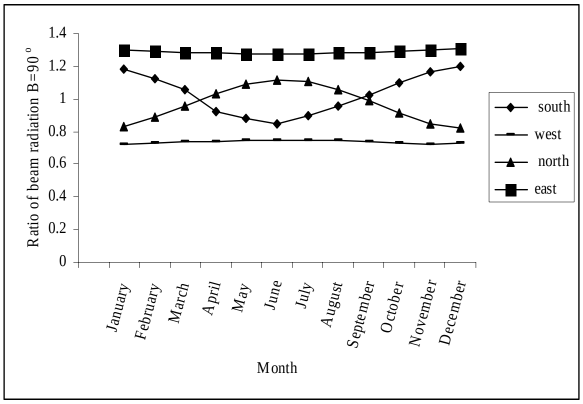

Fig. 4: The ratio of beam radiation on the surface toward side β=10°

4 Conclusion

As a conclusion, the collectors used as shading devices discussed in this paper presented the ratio of beam radiation that fall on vertical surface and inclined surface. The solar units can be used as shading device on all sides, in vertical or inclined, but when the collector inclined is better than in vertical, it has some value at each side. The suitable angle for Kuala Lumpur location is ($\beta = 10^{\circ}$) where the maximum value of the ratio of beam radiation in December when the collector toward east, and the minimum value in January when the solar collector toward west.

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