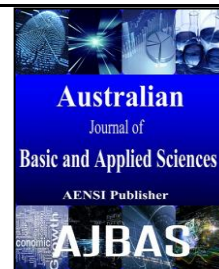




ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com



Performance Analysis of Photovoltaic Panel Shading on Energy Demand in Tropics

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ARTICLE INFO

Article history:

Received 6 June 2015

Accepted 19 July 2015

Available online 1 August 2015

Keywords:

Photovoltaic panel, Shading, Energy saving, Tropics

ABSTRACT

Energy saving in buildings is gaining more attention nowadays while the energy crisis is highlighted. Different strategies are being conducted around the world to reduce the energy demand in buildings. Using sun power and solar radiation which is highly available in the tropics is a very promising resource. This paper investigates the photovoltaic panels as shading devices in terms of energy saving in the tropics. Integrating inclined PV shades on an office room is simulated by the Designbuilder program and different lengths of shadings based on length to distance between shadings (L/D) are compared. '0.2, 0.4, 0.6' ratios are compared and the results demonstrate that the highest energy savings in cooling load and highest energy production can be achieved by the 0.6 ratio. Overall, the results revealed that the PV shades can save up to 40% of the energy demand in the modeled office by reducing energy demand because of decreasing heat gain and cooling load and production of electricity.

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To Cite This Article: Narciss Karimi, Eka Sediadi and Lim Yaik-Wah., Performance Analysis of Photovoltaic Panel Shading on Energy Demand in Tropics. *Aust. J. Basic & Appl. Sci.*, 9(24): 30-34, 2015

INTRODUCTION

Energy consumption and energy savings in buildings are two topics that gain high attention in different fields these days. High amount of energy consumption in the building sector is rising by increasing the height of buildings and this issue has provoked architects to create energy efficient designs and take action to reach higher amounts of energy savings in buildings. The energy demand in the building sector in Europe and the USA is around 40% (Pérez-Lombard *et al.*, 2008, A.Khezri, 2012, Olympia Zogou, 2011) and this value is 33 % in Malaysia (MECM, 2012). Malaysia is a fast growing country and there has been a drastic increase in high rise buildings growth. However, Malaysia is highly dependent on coal and fossil fuels which is very concerning. (Hwang *et al.*, 2012). From 2011, this issue has been greatly addressed by the government and renewable energies are encouraged (Shahril Irwan Sulaiman, 20--). Passive and active design strategies have been applied in the design of some government office buildings to practice energy saving in office buildings. This paper practices a combination of two strategies a) shading and b) photovoltaic panel (PV) to reduce energy demands in office buildings. Photovoltaic panels (PV) can be similar to materials in the building industry and the

PV panels are proposed as shading devices which can affect the indoor heat gain and cooling demand while producing electricity.

Shading devices, which can be external or internal, are a crucial element for preventing the sun light in a building. There are different kinds of external shadings: overhang, fin and egg-crate (Olgay, 1957) which can help to eliminate the unwanted heat, (Lim, 2011), excessive glare, (Lim *et al.*, 2012) and make better daylight quality. A study examined the external shading devices and their effect on energy demand for office buildings in Italy. Two types of shadings in three different locations in Italy (Palermo, Rome and Milan) were examined. Louvers for east-west and overhang for south façade were used and the results showed that with shadings, energy savings could reach up to 20% in Palermo, 15% in Rome and 8% in Milan. The differences in the results were because of differences in the climate. Furthermore, the authors proposed that the optimum overhang depth for a window with a height of 1.5 m is a 1.00 m projection (Bellia *et al.*, 2013). Researchers studied external shadings in terms of blocking solar heat gain and energy savings in the sub-tropical region of Taiwan. Shading performance was evaluated by correlation between shading ratio and shading coefficient. The results showed that these correlations could be used to analyze the

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effectiveness of shading factors like depth, width and azimuth angle (Cheng *et al.*, 2013).

High amounts of radiation in the tropics has led to some recommendations about using the best effective shading which will not block the benefits of daylight, but reduce the heat gain. Assoc Prof Dr Ku Azhar Ku Hassan from USM described that the horizontal shading devices are highly effective at the west and east façade against the high sun, Vertical shadings are more beneficial for the south façade and egg-crate works for all orientations (Aun, 2009). Another study of a region with tropical climates studied optimization of window shadings due to thermal comfort in the country of Singapore. The results showed that having shading devices on the east and the west was necessary to optimize thermal comfort in buildings (Wang *et al.*, 2007). Wong, Istiadji and Djoko (2004) studied seven different types of shadings in terms of indoor illuminance. The study defined that the Singapore sky model is categorized as partly cloudy (intermediate) and shading devices with shading coefficient 0.55 and above will lead to higher amounts of illuminance than the recommended amount (Wong and Istiadji, 2004).

The high solar radiation in the tropics is abundant and different strategies are used to block it before reaching the building envelope, however it can be used by PV panels before it falls on other building elements. Technology has helped to change the old picture of integrated photovoltaic panel (BIPV) that was photovoltaic installed on pitched roof. Nowadays the PV panels are available in different colors and transparency and can be even used as a vertical façade or even in curved surfaces. These developments let the architects to use PV panels by considering the aesthetics and effectiveness of them as an integral part of the building. Choosing an optimum angle and orientation for the photovoltaic panel is very crucial however, there are simple steps which PV installers advise to follow for best results. But the optimum angle and orientation for PV stand alone is not same as best angle and orientation for PV shades because of the shadow cast by other shadings on upper level (Yoo and Manz, 2011).

PV performance is affected by many different environmental elements such as weather conditions, dust, humidity, snow, cell temperature and air velocity which should be considered for any location. Tejwani and Solanki (2010) studied the effects of dust and dirt on the PV panel's efficiency in Mumbai. It showed that if the panels were not cleaned in 30 days, the PV production drops 50 percent. In Malaysia because of heavy rain, this matter is negligible especially during rainy season, but a slope between 5 to 30 degree is recommended that will help to avoid the accumulation of dust and dirt on PV surface (Amin *et al.*, 2009, Mekhilef *et al.*, 2012) The energy efficiency of the PV panels,

the type of PV module which is used and the shadow on PV panels also has a great impact on PV performance (Yoo and Lee, 2002).

Using photovoltaic panels as shading devices goes back to 1996 in the USA (Mandalaki *et al.*, 2012) and then it got popular in Europe. The PV shades are not common in the tropics and the effectiveness of them continues to be debated. A research on ZEB (zero energy building) in Singapore reviews the effectiveness of PV shades in that building and found that they reach 70% of their optimum power generation. However the results revealed that the proper angle and orientation for PV shading in the tropics are between 30° and 45° on East (Saber *et al.*, 2014). Another study revealed that in the high-rise office buildings the 30° inclined PV shades on East capture the highest amount of radiation. Based on these findings the east façade and the 30° tilted shade is chosen to study the impact of PV shades.

This study investigates the PV panel shades effect on energy consumption in an office room with a single window on the east façade. An inclined PV shade with different widths is simulated to illustrate the effects of PV shades on energy demand and the amount of power output.

Methodology:

The energy evaluation is a very complicated procedure and different methods are used by researchers. The mathematical calculation, field measurements and computer simulation each can be used separately or combined. Computer simulation has the advantage over the other methods because it considers the weather condition and also takes a shorter time compared to the other methods. The focus of this study is on energy demand and energy production thus the software which is chosen should be capable to fulfil these demands.

Designbuilder is a user-friendly simulation software with Energyplus simulation engine. Designbuilder software Ltd. (DBS) Company started from 1999 and in 2005 the first version of Designbuilder was produced and since then the newest version which is v4.2.0.054 has advanced greatly. The adaptability of the software with other architectural programs like AutoCAD and the accuracy of it because of Energyplus engine makes this software more popular between architects and engineers. From the whole neighborhood to building specifications (from material to HVAC) can all be simulated in Designbuilder. Furthermore, the software is widely validated through different studies in cases of energy evaluation and generation of PV output (Tronchin and Fabbri, 2008, Rahman *et al.*, 2010, Andarini, 2014, Rallapalli, 2010).

The model's specification:

An office room (7m*6m*2.7m) is modelled in Designbuilder software. The different length for

shading is examined through W/D ratio (Width of shading /Distance between shadings). This ratio is chosen based on the importance of the shadow effects on PV panels and reviews the width impact on the energy saving and energy production. The

different ratios based on a constant distance between shadings are applied to the base model. The distance between shadings is chosen 4.5 m and W/D ratio is calculated based on as figure 1 shows.

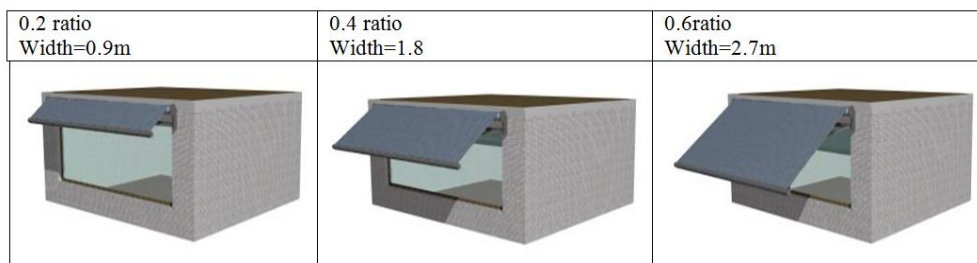


Fig. 1: different ratios.

There are two choices to calculate PV production in Designbuilder: 1) simple model 2) equivalent one diode model. Since the second

method produces more accurate calculations, this method was chosen. The table below presents the specifications of the model.

Table 1:

Characteristics /components	Description of Model
Location	Johor, Malaysia
Weather file	Senai station (TMY)
Floor dimensions (m)	6m*7m
Height (m)	2.7m
Gross floor area (m ²)	42 m ² from 1250 m ²
External wall (U value)	0.5 W/m ² k
Internal wall (U value)	2.8 W/m ² k
Ceiling (U value)	2.0 W/m ² k
Floor (U value)	0.5 W/m ² k
Glazing	3 mm single clear
Shading	Single inclined shading
Occupation	Open office
HVAC	Split with no fresh air
Cooling set point (C)	24° C

RESULT AND DISCUSSION

The results indicate high changes in energy demand by applying shading which clearly emphasizes the effects of shading on energy savings. Figure 2 shows the effect of PV shades on the energy demand. Interestingly, it reveals that as the PV shade ratio was increased, one did not see the same incremental decrease in electricity consumption that one would have assumed to see. At the first increment, which is at a ratio of 0.2, the amount of electricity demand reduced around 14% and by adding to PV shade's width, the demand reduced 21%. It should be noticed that from the base model without any shade to base model with 0.2 ratio shading the reduction is 14% but from 0.2 ratio shading model to 0.4 ratio shading the reduction is 7%. In the model with 0.6 ratio, the electricity demand reduced around 5% compared to the 0.4 ratio. This revealed that by adding to the width the energy demand reduced, but its reduction slows down and in this case after the 0.6 ratio, the energy demand actually increased and that was the last point of reduction. The reason for this result is that from

this point the need for artificial lighting is highly increased and not enough daylight penetrates in, thus the electricity demand for lighting adds to the total electricity consumption.

Besides this reduction, the PV shadings produce electricity which adds to energy saving percentages. The results are presented in figure 3 and the results emphasize on the high effect of area in PV shade's output. The amount of production increased as the PV shade increment increased.. The amount of production from 0.2 ratio to 0.4 almost doubled while from the 0.4 ratio to 0.6 ratio the production in electricity increased around 30%.

The results revealed that the amount of energy consumption and energy production is reverse and energy usage is reduced by increment PV shades ratio while the electricity production is increased. Figure 4 shows the amount of cumulative percentage of energy saving from reduction in usage and PV shade electricity production. The results revealed that the electricity consumption is saved from 19% with 0.2 ratio to 32% and 41% for 0.4 and 0.6 ratio respectively.

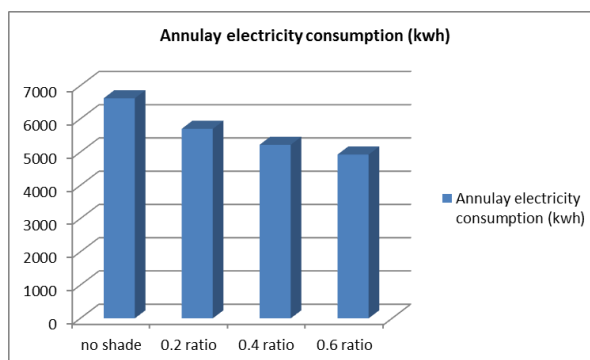


Fig. 2: Annual electricity consumption without PV shade and with PV shade.

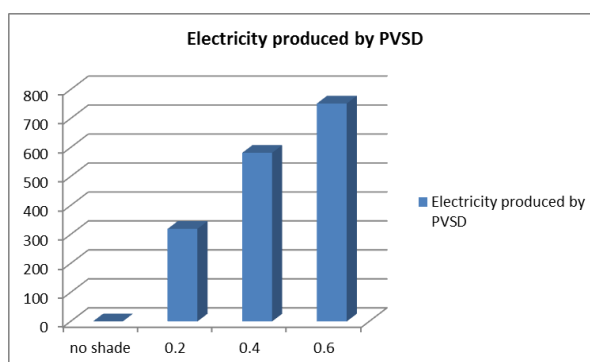


Fig. 3: Annual electricity production without PV shade and with PV shade.

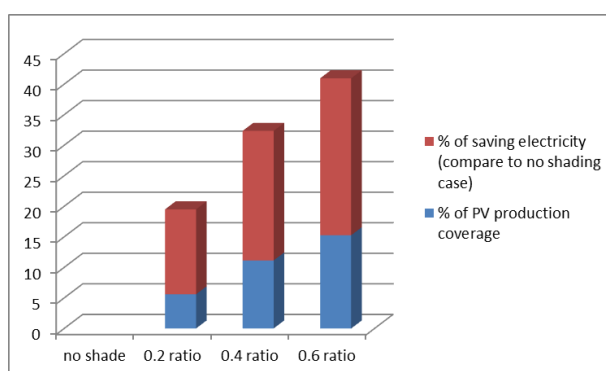


Fig. 4: Percentage of energy saving for different shadings ratio.

Conclusion:

The aim of this study was to analyze the PV shade performance as an energy efficient design strategy. It is concluded that the simulation model with reliable software provides very accurate results. However, software PV library limits to monocrystalline and polycrystalline thus thin film and other types cannot be modeled. It also revealed that despite the debates that exist about PV shade effectiveness in the tropics, the PV shade on proper orientation and angle (East, 30° inclined) produces a great amount of energy and can save 5%, 11% and 15% for different widths. The results further revealed that PV shade width has direct effect on energy demand and therefore, energy savings of a building. Since the PV shades are not common in the tropics,

this paper attempted to study the best option in case of solar radiation gain throughout the year, however the other orientations still can be used for PV shade placement and would produce less electricity in some months and more electricity in other months.

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