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DESIGN AND EVALUATION OF SOLAR ELECTRICITY IN A PUBLIC SCHOOL BUILDING

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ABSTRACT: *In 2011, a Building Integrated Photovoltaic (BIPV) system was implemented in the building of Maahad Tahfiz Negeri School Taman Nong Chik Johor Bahru. PV panels were used as transparent skylight. At the early stage of the design sunpath diagram and shadow casting simulation were done to find shadow free roof area. It was followed by calculation simulation using Weik equation to know its average PV yield of the system. Weik equation was used because it is a simple and easy to use calculation tool. The registration of the above BIPV grid that connected the system to the Sustainable Energy Development Authority (SEDA) Malaysia and the Tenaga Nasional Berhad (TNB) in Johor was approved early 2015.*

From June to July 2015 a PV yield evaluation was made at the building to compare the global solar radiation (G_d), the daily PV yield (E_d) and the PV system efficiency (η) used in the calculation simulation and in real situation. Again the Weik equation was used to get their real amount during the evaluation period. The data collected showed that during certain monitoring days the daily PV yield was lower than the simulation result. Some conditions can cause this situation. First is the external factor like the low solar radiation in rainy and cloudy days or the installation factor where the PV panel are still affected by building shadow. The other condition is the maintenance factor where the PV panel surface was not regularly cleaned. Dirty PV panel surface can reduce total yield. The evaluation calculation using Weik equation during the evaluation period showed that the average real G_d, real E_d and real η were slightly below the simulation result. These were because of the cloudy rainy days, heavy haze problem and dirty PV surface.

Key Words: shadow casting simulation, PV skylight, PV calculation simulation, PV yield

INTRODUCTION

Sustainable energy supply remains the main requirement of modern society to responding to the increased demand caused by larger consumption and population growth. For a long time, energy boom was based on fossil fuels. Not only is the supply of oil, coal, and natural gas limited, but there is also major pollution and environmental concerns associated with such traditional energy sources [4]. Renewable energy technologies including Photovoltaic (PV) are seen as some of the most important solutions for the future and they need to be developed in this century to take over most of the energy production [5][7][8].

In 2011, a Building Integrated Photovoltaic (BIPV) system was designed and implemented in the Maahad Tahfiz Negeri building; a school at Taman Nong Chik, Johor Bahru (Figure 1L, 1R). To integrate the PV roof system at the design stage, shadow casting and calculation simulations were made as basic requirements for the system to get its maximum electricity yield [1]. At the building design stage, a complete calculation simulation for the PV system was made using Weik equation. Rough PV yield calculation simulation was done to know how much electrical energy can be generated. This exercise was important for the arcitects to know and to decide the kind of energy

At the beginning of the design stage, the available roof area to be integrated to the PV system was approximately 300 m^2. The PV panels were used as transparent skylights (Figures 2L, 2R). The area was divided into eight PV arrays (a group of PV panels) because of the amount of the skylight openings available for it. The simulations were needed to decide shadow free roof area, and the calculation simulations were done to define the size and the cost of the PV system as well as its PV yield.

system the building should have. It was also to decide the amount of alternative electrical energy that can be supplied directly by the TNB network in the neighbourhood. Therefore, this project may be financially supported by the Malaysian Sustainable Energy Development Agency (SEDA) through the Malaysian government *Fit-in-Tariff (FiT)* program [3].

After registering the PV system with Sustainable Energy Development Authority (SEDA) Malaysia and the Tenaga Nasional Berhad (TNB) in Johor, the system received TNB approval early 2015 after which it was connected to the local electricity network. Some tests were done by SEDA and TNB to ensure the capability of the PV system. Now, it runs and continually distributes PV solar electricity to the TNB grid in Johor.

Figure 1 : Maahad Tahfiz Negeri Johor, Nong Chik (L) and the location of the PV panel on the roof (R)

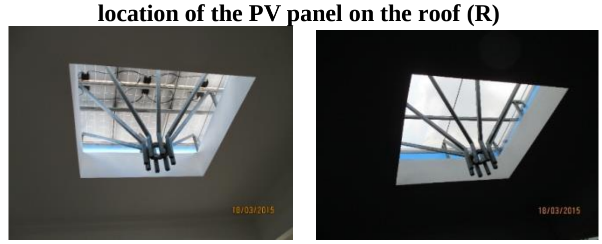

Figure 2: bottom view of PV array (L) and the sky light (R) without PV panels

Figure 3: TNB solar electricity meter (L) to read the total PV yield distributed to the grid and the PV Inverter which converts the PV DC electricity current to AC current (R)

After completing the construction of the building and the TNB approval, a post PV-installation research was done to develop the architectural and engineering report on the implementation of PV electricity system integration into the building to show its effectiveness [9]. Field observation and monitoring were done for one month to compare the predicted simulation result and the real result. The observation was also to evaluate the effectiveness of the Weik simple equation; which could be implemented by architects to get the first calculated PV yield of a building integrated PV system design.

LITERATURE REVIEW

Nowadays, green technology development is gaining a lot of attention not only on a personal level; but also on a collective level as lots of parties have been attracted to adopting green technology as part of their daily lives [4]. One part of green technology is photovoltaic (PV) technology. Photovoltaic (PV) or solar cell is an electronic device that can essentially convert solar radiation or solar energy directly into electricity without any moving part [5]. Furthermore, the photovoltaic cell can produce electricity as long as sunlight is available. PV production will however, be low in the evening or during cloudy season. It will totally stop during dusk and will resume again in the early morning [5]. Malaysia as one of the countries in the tropics has the potential to use and implement photovoltaic technology as one of its renewable energy resource [6]. It has a strategic geographical location where the availability of sunlight/solar radiation is almost constant during the year [9]. Malaysia also has almost constant hours of day in a year and almost constant yearly, monthly and daily solar radiation value.

Architects, as designers should consider the entire building components as parts of the design of a building, including the energy sources available for the building [12]. Therefore, the need for architects to know the PV system yield is important in the design stage. Thus, the selected calculation for architects should be simple and easy to understand and use [11]. Several studies have therefore been done to select the right equation and finally concluded on selecting three equations. The first equation is proposed by Sediadi [9] and it was developed by Weik in Germany in 1986. The equation is as follows [11]:

$$\mathbf{E_d = G_d \times A_{pv} \times \eta} \qquad (1)$$

E_d = Daily PV electricity Product (kWh/d)
G_d = Sum of daily solar radiation (kWh/m².d)
A_{pv} = Total PV surface area
η = Efficiency of PV system (0.1-0.2, based on type & PV cell material)

The second calculation was introduced by Prasad [8] and it is almost the same as the first equation. The only difference is that this equation has been developed and used in Australia and Prasad developed it based on his understanding. However, the input variables remain the same as Weik's equation as shown below:

$$\mathbf{Q_{PV} = \eta \times I_{tot,rad} \times A_{PV}} \quad (2)$$

Q_{pv} = Yearly electricity output of the PV system (kWh)
η = Average efficiency of the system
$I_{tot,rad}$ = Yearly total solar radiation on the PV surface (kWh/m².yr)
A_{pv} = Surface area of PV system (m²)

This equation was introduced to four season climate regions like mid and South Australia. The approach of the equation tends more towards Australian climate.

Another research using equation to determine PV yield was developed by Wittkopf [11]. This equation calculated the PV yield in Singapore's Zero Energy Building. The equation was quite complicated and needed deeper studying to understanding it. The research was in the tropical context, but more sub-equations were needed to get to the final result. It was indeed accurate though complicated. Moreover, Wittkopf's equation was used basically to measure the performance of existing PV panel in buildings, to calculate PV yield more accurate and to know the current PV yield base on real situations. In conclusion, Weik equation is preferable because it can be used in PV system design stage, simple to understand and is applicable also to Malaysian climate condition.

RESEARCH METHODOLOGY

A descriptive field observation research was done to evaluate the performance of the installed PV system equipment and its effectiveness in contributing solar electricity to the TNB grid. It was a quantitative research consisting of two stage research activities. The first stage was to compile field data of the daily PV system performance during the observation period. The second stage was the quantitative comparison analysis of the compiled field data and the simulation result in the early design stage. The observation consisted of scheduled daily visit, data collection from the installed PV equipments, and documentation of construction details, discussion and interview with the management of the building. The amount of daily PV yields observed from TNB PV meter were manually tabulated within one month observation period which started early in June 2015 until early July 2015. Besides the PV yield, the local weather conditions during the observation days were also recorded. Their conditions varied from hot dry to rainy cloudy and hazy days. Some of the days during the observation period were affected by the heavy haze problem that happened between June and July of 2015 in Johor Bahru and other western parts of Malaysian peninsular.

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DISCUSSION AND FINDINGS

Shadow casting simulation

At the building design stage, a shadow casting simulation was made using Ecotect software. The simulation was intended to find part of the building roof affected by building shadow in certain times of the day, month and certain times of the year. The periods chosen were the 21st of March and 23rd of September; when the sun position was directly above the Equator, the 22nd of June when the sun was at the utmost position from Equator on the northern part of the earth, and the 22nd of December when the sun was at the utmost position from Equator on the southern part of the earth. The daytime simulation was from morning 10.00 am until 03.00 pm in the afternoon. Figure 4 below shows the result of shadow casting simulation done at the design stage. It shows that some western part of the roof area was under building shadow starting from 03.00 pm until sunset (Figures 5, 6).

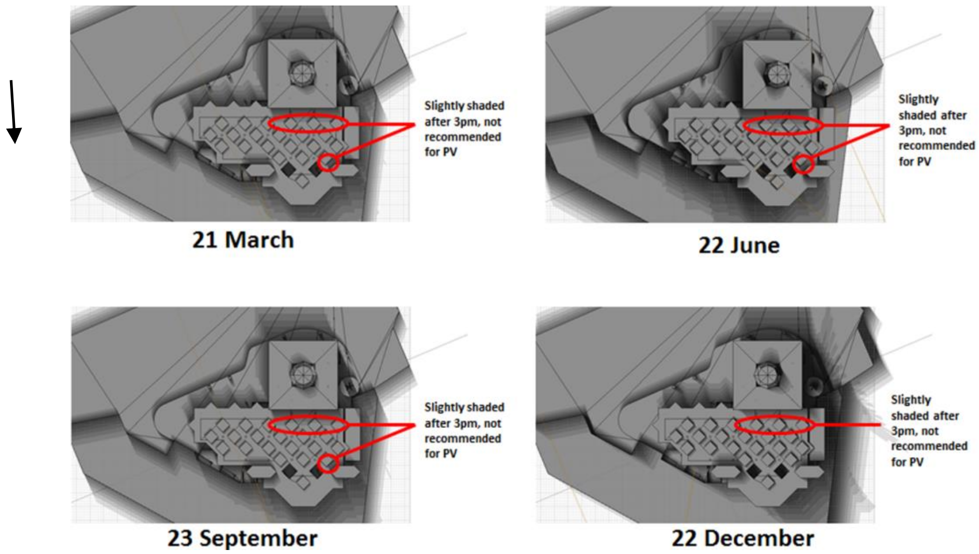

Figure 4: shadow casting simulation result

Calculation analysis

The field data calculation analysis focused on the three variables given in Weik equation:

a. Daily PV electricity yield (G_d)
b. PV System perfomance/ system efficiency (η)
c. PV surface area (A_{pv}),
d. It also included the daily local weather condition.

Two calculations to define the global solar radiation (G_d) and the efficiency of the installed PV system (η) were made. The first calculation fixed the real PV yield (E_d), the PV surface area (A_{pv}) and the PV system efficiency (η) to get the real global solar radiation (G_d). The second calculation fixed the daily real PV yield (E_d), global solar radiation (G_d) and the PV surface area (A_{pv}) to get the real PV system efficiency (η). Then both results were compared with the simulation result to find the effectiveness of Weik equation in the first PV system calculation stage and also to determine that the installed PV system works. The daily global radiation (G_d) in the calculation simulation in 2011 was a secondary data from Johor Bahru Senai weather station data of 2008 for the month of June.

Calculation simulation at the PV system design stage in 2011

Below is the daily PV yield calculation done in design stage [8][10]:

G_d = 3.8 kWh/m^2.d (Senai Weather station data)

PV system efficiency = η = 0.1

PV array dimension = a skylight opening area

= 3.340 x 3.340 m^2 = 11.15 m^2

PV surface for eight (8) skylight openings = A_{pv}

= 8 x 11.15 m^2 = 89.20 m^2

E_d = G_d x A_{pv} x η

= 3.8 kWh/m^2.d x 89.20 m^2 x 0.1

= 338.96 kWh/d x 0.1

= 33.89 kWh/d.

Based on the first calculation simulation using Weik equation, the average daily PV yield from the integrated PV system was estimated to be 33.89 kWh/d.

Field observation and monitoring result

The observation and monitoring were done during visits, and the daily PV yield was compiled every day for 30 days from 5th June to 5th July 2015. The twelve (12) hours solar electricity product data was recorded every day at 07.00 pm. For real condition calculation purpose, only the average of daily PV yield for five (5) hours was used (from 10.00 am to 03.00 pm.) The observation result showed building shadow on some PV surfaces during the afternoon period after 03.00 pm. (figure 5, figure 6).

Table 1 shows the compilation of some daily PV yield during the observation period and the results of the calculation analysis. It shows the date of the day (Date), the daily PV yield in calculation simulation (E_d sim), the daily PV yield recorded from the TNB meter (E_d real) , the G_d in simulation, the G_d real, the E_d difference, the PV system efficiency in

Table 1: Comparison of real data with simulation result

date	Weather	E_d sim (KWh/d)	E_d real (KWh/d)	Difference (kWh/d)	G_d sim.	G_d real	Ƞ sim.	Ƞ real
26/6	Hot dry	33.89	65.00	31.11	3.80	7.28	0.1	0.19
10/6	Hot overcast	33.89	33.00	(-) 0.89	3.80	3.69	0.1	0.09
14/6	Cloudy raining	33.89	10.40	(-) 23.49	3.80	1.16	0.1	0.03
6/6	Hot, spot raining	33.89	30.00	(-) 3.89	3.80	3.36	0.1	0.08
23/6	Hot cloudy	33.89	27.00	(-) 6.89	3.80	3.03	0.1	0.079
Avg	---	**33.89**	**33.08**	---	**3.80**	**3.70**	**0.1**	**0.09**

Figure 5: Building shadow covering part of the PV array

Figure 6: Some PV arrays too close to the building

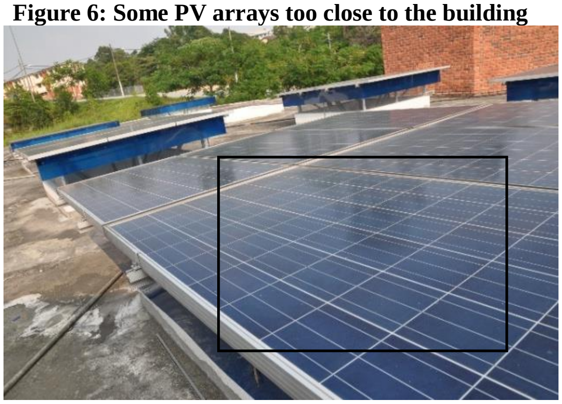

Figure 7: The PV surface needs regular cleaning

calculation simulation (Ƞ sim) and the real PV system efficiency (Ƞ real). It was also found that some PV panel surfaces needed cleaning because of dirty spots (figure 7).

Findings

The calculation of the real condition using the real PV yield shows that the real average of daily solar radiation ($G_{d)}$ and the real average of the PV system efficiency (Ƞ) are slightly below the average amount of the same variables in the simulation calculation result in 2011. It means there was no significant difference between the PV system simulation result and the PV system real situation. Aspects that should also be considered in this discussion which can limit the observation and monitoring research findings are:

a. At the monitoring period June-July 2015 Johor Bahru and western part of Malaysian peninsular were affected by heavy haze which significantly reduced the global solar radiation (G_d). Since solar electricity depends totally on the amount of solar radiation then the PV yield during these days were lower than normal situation.
b. The compiled data were valid because the PV system installation was checked and tested by SEDA and TNB before its approval, so the low PV yield was not caused by equipment or system failure.
c. The monitoring process was simple and the data recording was done manually without sophisticated digital equipment.
d. The observation and monitoring research mainly intended to get the real average amount of daily PV yield (E_d) to allow the use of Weik equation as calculation tool.

CONCLUSION

The monitored PV yield data from June 2015 till July 2015 shows that the real daily PV yield (E_d) varies from 23 kWh/m^2.d to 156 kWh/m^2.d. These data represent the real minimum and maximum PV yields (E_d) under Johor Bahru weather condition during the monitoring period while the real average system efficiency (Ƞ) was 0.09 and the real daily solar radiation average (G_d) was 3.70 kWh/m2.d. This shows that the real PV yield (E_d), the daily solar radiation average (G_d) and the PV system efficiency (Ƞ) differ; but the differences between the simulation calculation result of 2011 and the field monitoring study result of 2015 are relatively small. In this project, the Weik equation role was very important for the design team. It helps architects and engineers figure promptly the first estimated amount of the PV system electricity product with proper accuracy before the involvement of PV system experts or contractors who can figure the PV yield (E_d) more accurate. The Maahad Tahfiz Negeri building project was a trial to the use of this equation.

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