The Sustainable Façade and Roof Design Approach Based on Local Climate Character

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***Abstract* - Two approaches which important in sustainable building envelope design process are the orientation of the building openings and the use of Photovoltaic panel as renewable energy source. They are discussed in this paper. The first approach is the use of a simple sun path simulation sketches in building plan and façade design.**

This approach is important to control the heat gain from outside caused by the sun radiation and to define the building opening for natural daylighting. For this approach three country locations are chosen, the United Arab Emirates (UAE), Indonesia and Malaysia.

The second approach is the use of PV panels as renewable electricity resource. The panels can either replace roof material, form a transparent skylight or use as building glass window or facade material forming a vertical surface.

Based on a research result done in Universiti Teknologi Malaysia (UTM) Johor Bahru its implementation and the suggestion for PV electricity yield rule of thumb were discussed. It showed an example to determine the approximate daily, monthly or yearly PV electricity yield in terms of kWh.

Keywords - Sun path diagram, PV electricity yield, rule of thumb

A. Introduction

The two approaches which important in sustainable building envelope design process; the orientation of the building openings and the use of Photovoltaic panel as renewable energy source are important aspects in green building rating tools such as LEED US, Greenmark Singapore, Greenstar Australia, Green Building Index Malaysia, Estidama UAE or Greenship Indonesia. The discussions are as reminder to young architects to implement these local climate potential for passive design approach. At an early stage, a sustainable building design including its energy supply system should already be able to be evaluated and rated.

Controlled building design opening and PV panel integration into the building design will earn significant points in the rating calculation because it shows the intention to control the heat gain, to reduce the dependency to the conventional energy resource and to support the world sustainable development to save our built environment.

B. Sun path diagram

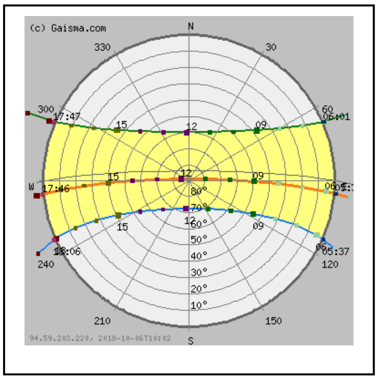

Figure 1: Sun path diagram for Jakarta in hot tropical climate region near Equator [11]

One building case study, the sun path diagram for the UAE and one diagram implementation example are introduced in this section. A building design of an office had been used for a sun path simulation. By using the simple sun path diagram all the necessary angle of the coming sun light during the day were determined. The building site is in Jakarta.

The sun path diagram was used to determine the sun's position in an exercise to implement the green building assessment tool in an existed building design in Jakarta. The aim of the simulation is to determine the incoming direct sunlight to its façade. Using the diagram all the needed angle could be found and used to define the design correction of the building façade which face exactly north, south, west and east orientation. The sun path simulation results are shown in figure 1 and figure 2.

The building has long east and west oriented and short north and south façades. The east and west façade get direct sun radiation during day time. The east façade receives daily direct sun radiation from sunrise until noon time and the west façade in noon time until sunset.

Based on the site surrounding situation, only the south façade faces the main street. The other façade are surrounded by buildings. In this case main focus to reduce heat gain is on the south building side.

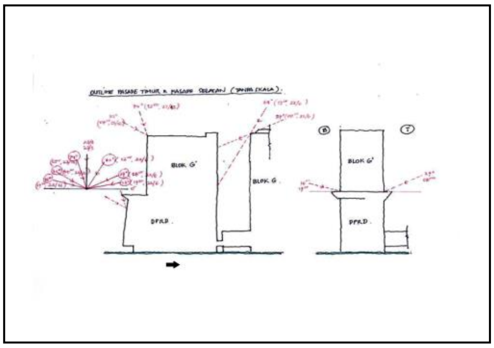

Figure 2: The angles of direct sun light on east, east and south building façades (elevation) [4]

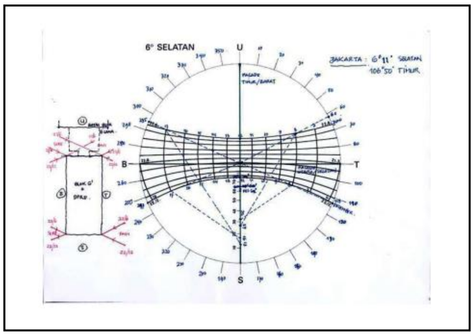

Figure 3: The angle of direct sun light on north, south, east and west façades of the building in Jakarta (plan)[4]

Furthermore the north and south building façades receive direct sun radiation only in few month of the year. The north façade receives direct sun radiation in May, June, July, and August. In September the sun position at noon is directly above Equator. The south façade gets it in month October, November, December, January and February. In March the sun's position at noon is back above the Equator. The incoming angles in certain time of the day can be read directly from the sketches on the diagram (figure 1 and figure 2).

By knowing these incoming angles the façade design solution can be defined. Also the need of horizontal or vertical sun screen outside the building or balcony addition to protect the façade opening on particular building façade as well as the dimension can be decided. Based on the simulation result in figure 1 and figure 2 the lowest inclination angle in June is 72 degree on the north façade and its lowest in December is at 69 degree on the south façade [4]. This simulation result showed also that the sun's position is sometime at the north and sometimes at the south part of the building.

The simulation effect to building design is that the direct sunlight comes into the rooms only in certain time of the year. Outside the period the façade is almost free from direct sunlight. This means a lower heat gain and lower daylight intensity situation which should be fitted to the façade design especially to the indoor cooling, indoor ventilation and indoor lighting.

Another example is a sun path of the UAE which location is in the middle-east (figure 4). The path showed that the sun movement is more to the southern part of the earth and southern part of a building. This means most direct sun radiation comes from the south and significantly less from the north. In the summer months June, July and August the sun positions there are mostly at the northern part of the earth, but in UAE case even in June the sun position at noon time is almost perpendicular to the ground and still on the south side of a building. This means the north façade of buildings in UAE receives low direct sun radiation compare to the other façade orientation.

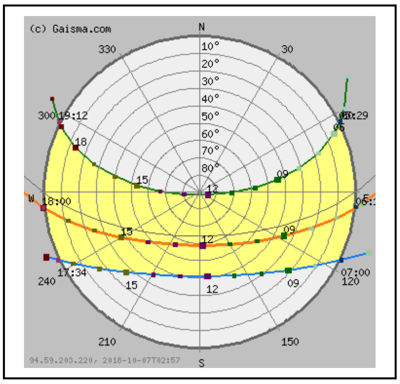

Figure 4: Example Dubai UAE, the sun path diagram for Dubai [11]

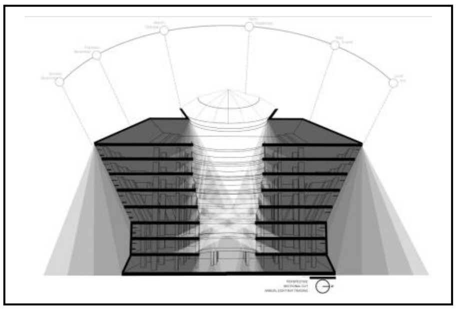

Figure 5: The Self-Shading Facades. The Diamond Building, Putrajaya Malaysia. (The north and south façade are self shaded. [1]

Figure 5 is the last example of the sun path simulation result implementation to determine building form based on the local sun path character. The north and south façades inclination of the example building in Malaysia above followed the sun inclination in summer and winter season at noon time. These two building facades are called self-shading facades because of their position, they almost never get direct sun radiation in the year especially during noon time.

C. *PV yield "rule of thumb"*

Peter Gevorkian [6] mentioned that photovoltaic (PV) or solar cell is an electronic device essentially can convert directly the solar radiation or solar energy into electric energy or electricity. PV production reduces in the evening or during cloudy weather; it will totally stop during dusk and will resume again in the early morning.

Because of the high sun radiation energy the tropical and subtropical countries near Equator have potential to implement the building integrated photovoltaic (BIPV) systems in every building as a renewable energy resource. BIPV can produce energy from an unlimited resource and can be used for a long-term usage. In an urban area, BIPV technology with the grid connected system is already available. This system can support the local electric company to produce electricity and reduce dependency on conventional energy production [2].

A good building-integrated photovoltaic (BIPV) design starts at the beginning of the building design concept. In order to do that, the architect should know how much PV panel they need to supply enough to support the design of building energy needs

Some tools for estimating the PV yield were already available on the market. They include the "PV-Calculator" (http://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_cal.html) from Hong Kong, the "PV-Watt v.1" (http://rredc.nrel.gov/solar/calculators/vwatts/version 1) from USA and the "PV Sol/SMA Sunnyboy" from USA / Germany [3]. They are "ready-to-use" calculators which were developed and made available for moderate and subtropical climate region.

Three estimating tool were discussed in the research but only one was discussed in this paper. The equation was proposed and developed by Weik [9] in 1986 and was used by Sediadi to calculate the PV yield for several buildings. The equation is simple and easy to understand. Most importantly, this equation has been used in Jakarta, Indonesia and Johor Bahru, Malaysia which they are part of the tropical hot humid climate region. The equation is stated below:

$$E = G_d \times A_{pv} \times \eta$$

E = PV electricity Product (kWh/d)
G_d = Sum of solar radiation (kWh/m²d)
A_{pv} = The PV surface area
η = Efficiency of PV system (0.1-0.2, based on type & material PV cell)

In terms of data collection, several data will be collected based on the equation need [5]. The data are [9]:

C.1. Solar Radiation

A research done in Malaysia was introduced as example [3]. It was done in Universiti Teknologi Malaysia, Skudai Johor Bahru. The solar radiation data usually can be collected from the Climate and Meteorological offices. For Malaysia, the targeted solar radiation area is around Skudai, Johor Bahru. The nearest weather station is at its Senai international airport. The average 2011 solar radiation reading in Skudai was taken and was considered as the average mean value of the solar radiation. The average mean value of solar radiation was used in the equation to generate the rule of thumb for the PV calculation.

C.2. Roof Area

Some buildings are chosen as a sample in this research. The selected buildings are in UTM Campus Skudai in Johor Bahru. All building's roof areas are the main data for the simulation calculation. Each roof surface area are considered as flat and represent the PV surface area in the equation for simulation calculation.

C.3. PV system efficiency factor

The PV efficiency determines the effectiveness of PV operation. The system efficiency factor used in this research is 0.1 (= 10%). It means that 10% of incoming solar radiation will be converted by PV cells to electricity. The rest (= 90%) is converted to heat that will increase the PV panel surface temperature. The high PV panel temperature will reduce the PV system electricity product by a certain percentage as was mentioned by Laukamp [8]. The current PV system efficiency might be higher than 0.1 but for this simulation calculation, η = 0.1 will be used in the calculation as a constant factor to represent the average PV yield value.

The calculation result also was analysed to determine the effectiveness of PV roof used in building design. These can be seen by looking at the percentages of how much the PV yield can support the electricity consumption for each selected building. A research result example about the monthly capability of PV roof electricity to cover the building energy need showed in the figure 6 below. It shows the comparison between the electricity consumption and the PV yield simulated in building B04 in UTM campus Johor Bahru. In certain months of the year the simulated PV yield are significantly above the electricity consumption.

Furthermore, the calculation should include the 20% PV effectiveness reduction factor caused by the PV panel surface temperature [8]. The calculation will be more accurate by considering the reduction factor.

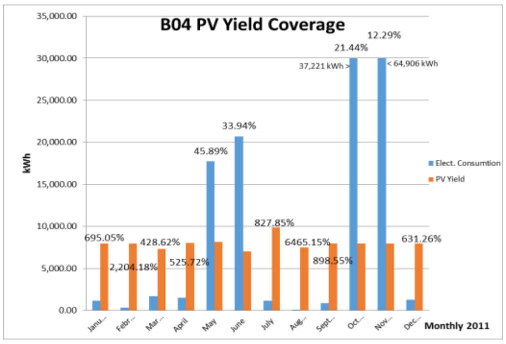

Figure 6: Building Block B04 (Johor Bahru) PV yield coverage for building electrical consumption [3]

D. The Mathematical Approach

Weik equation has three variables. They are the daily, monthly or annual local solar global radiation (G_d, G_m or G_a), the PV surface area (A) and the PV system efficiency (η). The approach to the rule of thumb is to fix the two variables, the local solar global radiation and the system efficiency. The PV surface area (A) will be left as an open variable which will be determined by the building design.

Another variable is the yield decreasing factor due to the hot PV surface in tropical climate which reduce the total PV energy yield [8]. The actual PV yield can be determined by multiplying the solar radiation data, the system efficiency, the reducing factor and the roof area, which is based on the architect's building roof design. As mentioned in the introduction, the Weik PV yield equation is as follows:

$$Ed = Gd \ x \ Apv \ x \ \eta \quad (1)$$

Where,

E_d = daily PV-Yield in kWh/d

G_d = daily solar radiation in the area in kWh/m^2.d

A_{pv} = PV surface in m^2

η = efficiency of the installed PV system (assumption, η = 0,1)

$$E_{dt} = E_d - (E_d \ x \ P_t) \quad (2)$$

Where,

E_{dt} = PV-Yield at t° C surface temperature (for Johor Bahru is 77°C)

E_d = PV-Yield at the local area

P_t = the reduction factor = 0.2

It may also be formatted as:

$$E_{dt} = E_d \ x \ 0.8 \qquad (3)$$

Where,

E_{dt} = PV-Yield at t° C surface temperature

E_d = PV-Yield at the local area

Using global solar radiation data available, the E_{dt} for every area can be calculated. Finally, to get the PV yield, architects should multiply the local E_{dt} with the designed roof surface of their building design. Thus, the actual PV yield is as follows:

$$PV \ yield = A \ x \ E_{dt} \qquad (4)$$

Where,

PV yield = electricity produced by the designed PV panel horizontal surface, in kWh/d or Wh/d.

A = designed PV surface area, in m^2

E_{dt} = the daily mean/average value of local PV yield, in kWh/d or Wh/d.

The beginning of mathematical approach of the suggested rule of thumb for Jakarta and Johor Bahru PV yield was calculated using the same equation and variables mentioned above:

PV yield $= E_{dt} = G_d \ x \ A_{pv} \ x \ 0.1 \ x \ 0.8$
$= G_d \ x \ A_{pv} \ x \ 0.08$

For average value (avg) the equation became like this:

PV yield$_{(avg)}$ $= G_{d(avg)} \ x \ A_{pv} \ x \ 0.1 \ x \ 0.8$
$= G_{d(avg)} \ x \ A_{pv} \ x \ 0.08$

Then the respective daily global solar radiation data in Jakarta and Johor Bahru below are used for further calculation example:

Daily global solar radiation in Jakarta $G_{d(avg)}$ = 4.36 kWh/m^2.d.
Daily global solar radiation in Johor Bahru $G_{d(avg)}$ = 4.00 kWh/m^2.d.

The cloudy sky condition in both areas were not considered because the global solar radiation data contains both the direct and diffuse solar radiation.

$G_{d(avg)}$ $= (G_{d(avg)}$ JKT+ $G_{d(avg)}$ JB) / 2
= 4.36 + 4.00
= 4.18 kWh/m^2.d

PV yield$_{(avg)}$ $= 4.18 \ A_{pv} \ x \ 0.08 = 0.334 \ A_{pv}$

The final calculation result of average PV yield is PV_{avg} = $0.334A_{pv}$ (rounded = $1/3A_{pv}$). This means equal to 1/3 the PV roof area. Thus the suggested rule of thumb of PV yield in Jakarta and Johor Bahru cases is:

"1/3 times designed PV roof area, in term of kWh/day".

Implementation example:
If a building in Jakarta and Johor Bahru is designed to have a 150 m² PV flat roof, then the daily average of PV electricity yield is 1/3 times 150 m² equal to 50 kWh/day [3].

If more detailed calculation result is needed a separate PV simulation for Jakarta and Johor Bahru can be made using their own respective daily global solar radiation data.

E. Conclusion

The sun path simulation in roof and façade design under local condition can support the building design process. In this case a simulation can guide the roof and façade detail design which at the end will be an effort to reduce heat gain caused by the direct sun radiation.

In some building design cases architects are unable to decide easily the final design of the roof and façade because of their best building opening orientation faces directly the sun position on its path. The solution options are to attach sun screen outside or inside the building façade or use PV panel sunscreen on the façade and roof.

In the latter situation the PV rule of thumb approach can be implemented to estimate the approximate PV yield. Based on the estimated result architect, building designer and other building expert can then decide the design of the building energy system.

The discussion in this paper showed that a rule of thumb for the PV yield in Jakarta and / or Johor Bahru is 1/3 the total PV roof area designed. Architect In Jakarta and / or Johor Bahru may easily calculate the PV yield in their building design just by knowing the total PV roof area times the PV rule of thumb factor. Of course using similar approach similar rule of thumb can be developed also for the UAE and other countries in the middle-east climate region.

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