Tropical X-Y transformation design for building courtyard integrated photovoltaic

FX Teddy Badai Samodra
Department of Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
*Email: fxteddybs@arch.its.ac.id

Abstract. The tropical region has a richness of solar radiation with its consequences on building thermal comfort. For that exception, the photovoltaic hold a role in generating eco-friendly energy also. Two-dimensional geographical location, recognized as X-Y for translating latitude (X) and altitude (Y) are analyzed for determining the optimum integrated thermal comfort of building and energy generating. This research utilizes open space, courtyard, which not only provides a slimming body of the tropical building to reduce deepness of cross ventilation work but also develops potential green energy by a simultaneous method in making opening area. All were done by Ansys Fluent and Ecotect simulation method in order to give a recommendation for each location. The result highlighted that higher width and length different ratio for East-West orientation courtyard, more energy can be generated. It has a capability in reducing more than 10% of energy consumption with maintaining indoor temperature by providing air. Comparing latitude (X), altitude location (Y) shows the higher effect on providing thermal comfort and energy efficiency because the different tropical location has less difference on solar distribution.

1. Introduction
The abundant solar radiation in the tropical region has consequences on building thermal comfort. For that exception, the photovoltaic hold a role in generating eco-friendly energy. Building surfaces can then be varied towards these sensitive orientations to generate optimized alternatives. Surfaces of optimized alternatives can have different photovoltaic (PV) integration options [1].

The well-designed courtyards may represent a valid option for building. The definition for optimum courtyard ratio should which allows the form to receive minimum solar radiation for the tropical regions [2]. The solar radiation is directly proportional to the atmospheric temperature while it is inversely proportional to the relative humidity. Moreover, wind speed has little influence on solar radiation [3].

Integrated PV increases the building’s indoor air temperature by about 4°C, when compared to a building of the same size without PV integrated [4]. Therefore, the embedded closed ventilated courtyards achieve indoor thermal comfort and avoid excessive humidity in hot-humid climates and it needs a staggered form courtyard with V-shaped roofs [5]. This roof model could be integrated for PV. In this research, two-dimensional geographical location, recognized as X-Y for translating latitude (X) and altitude (Y) are analyzed for determining the optimum integrated thermal comfort of building and energy generating.
2. Method

This research utilizes open space, courtyard, which not only provides a slimming body of the tropical building to reduce the deepness of cross ventilation work but also develops potential green energy by a simultaneous method in making opening area. All were done by Ansys Fluent and Ecotect simulation method in order to give a recommendation for each location.

The lowland locations of the research are Singapore, Bangkok (Thailand), and Hanoi (Vietnam) as representative of 0-8°, 8-16°, 16-23.5°, respectively. For the highland tropical area, Bogota (Colombia), Santa Rosa de Copan (Honduras), and Mexico City (Mexico) are selected. Three difference tropical latitude locations are analyzed by <100 m above mean sea level (MSL) and more than 1000 m MLS for altitude (see figure 1). The X-Y locations indicate solar radiation distribution as consequences for X latitude difference (figure 2). The Y, altitude, determines tropical climate elements changes, with temperature as the most influence indicator. However, in this study, solar radiation will be the focus of discussion related to the photovoltaic potency.

Figure 1. Research locations

Figure 2. Global irradiance distribution
(source: www.solargis.com)
3. Results and Discussions

3.1. Courtyard Ratio
Tropical climate, both in north and south hemispheres receives solar penetration in various conditions. In general, the lower latitude position gets a higher impact on its environment, hotter condition—higher Mean Radiant Temperature (MRT) even it is very depended on the micro or site condition of the courtyards.

For providing physiological cooling, wind acceleration should be designed for thermal comfort. Figure 3 evaluates air movement simulation using Ansys Fluent Program for critical courtyard (1:1 ratio for building width to height/length). Meanwhile, as shown in figure 4, the Ecotect analysis compares the various MRT resulted by the various ratios. It illustrates that the lowest ratio, 1:1, has potential in reducing heat accumulation into the building and increasing solar radiation for generating eco-friendly energy all at once. Therefore, this model is selected for PV integrated placement.

![Figure 3. Air velocity for critical courtyard patio](image)

![Figure 4. Mean Radiant Temperature of courtyard by different ratios](image)

3.2. Total Radiation on X-Y Transformations
This section discusses the contribution of the surface (indicating for PV tilts) in various X and Y locations. As described by Figure 5, the results show that the 30° and 45° are the worst PV tilts where 90° reaches as the best. 90° means the perpendicular angle of PV surface from the incoming solar radiation or 0° for elevation. However, this angle should be avoided because it reduces the courtyard space. Thus, 0° and 60° could be decided as the most effective PV tilt based on technical and architectural reasons.

Discussing the difference between lowland and highland of total radiation, because of the closer distance to the main source of solar energy, highland should be the potential place in receiving solar radiation. However, in actual condition, for low, mid, high tropical location, it could not indicate the significant trend for both X and Y locations. It could be affected by site condition or local climate. In general, the X-Y transformation does not work for differing the recommendation of building courtyard
integrated PV (BCIPv). As research finding by Burg et al [6], the photovoltaic performance is more determined by global albedo impact, regional atmospheric heat islands, and locally heated surfaces. It also applied for the orientation variable. With the similar distribution, East (90°) and West (270°) have the same performance. Northern or Southern hemispheres do not affect on solar radiation distribution difference. North (0°) and South (180°) orientations could not imply the solar power source variation. For a while, it concludes that divergence on latitude for the tropical region, significant climate element dissimilarity, altitude, and building or courtyard orientation have no relationships for tropical regenerating energy.

![Figure 5. Total radiation on X and Y locations for various surface tilts](image1)

The optimum BCIPv produces potential solar energy by receiving in any location criteria but it could be deceiving trend that lowland more fluctuated result than highland (Figure 6. and 7.). In mid tropical latitude, it receives the highest when 16-23° is the most potential highland area. The problem of the courtyard as PV location is that inner shading occurs but it has disadvantages on utilizing the integrated inner wall or roof for beneficial limiting space for accelerating the wind. The demerits of the potential shading for thermal comfort could be anticipated by its average of total radiation for PV. With more 1000 kWh annual received solar radiation, the BCIPv ensures the eco-friendly power equipment and the problem of shading means nothing.

![Figure 6. Total radiation for 60° of surface tilt](image2)
3.3. Generating Solar Energy

The stereographic diagram in Figure 8. would be the next assurance for optimism of producing energy. In fact, the shadow happens in limited time in the morning or evening when solar energy has less effective than in the noon. As a result, Equation 1. proves the potential producing energy by BCIPv. In the case of 24 m² of panel area, 15% of solar panel yield, 0.75 PR and variation of 1750 kWh, 1810 kWh, and 1501 kWh of annual average irradiation on 60 tilted panels result in 4722 kWh, 4884 kWh, and 4050 kWh for 0°-8°, 8°-16°, and 16°-23.5° location, respectively. Comparing to 8845 kWh annual Electric power consumption (kWh per capita) for Singapore [6], it has a capability in substituting more than 50%. When the declination angle is decreased, the result of energy rating difference increases [7]. In general, shading effects have an influence on the seasonal variation of produced power as much as ambient temperature, building orientation, and PV module’s inclination angle. However, the tropical locations result in constant potential in generating energy for all orientations.

\[
E = A \cdot r \cdot H \cdot PR
\]

where:
- \(E\) = Energy (kWh)
- \(A\) = Total solar panel Area (m²)
- \(r\) = solar panel yield (%) 
- \(H\) = Annual average irradiation on tilted panels (shadings not included)
- \(PR\) = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)
4. Conclusions
Regarding providing better thermal comfort, the result highlighted that higher width and length different ratio for East-West orientation courtyard, more energy can be generated. In addition to Eicker et al [7] that the solar electric has a capability in reducing primary energy consumption by 21–70%, depending on the location, this study found more than 50% efficiency of energy consumption with maintaining indoor temperature by providing air movement. Comparing latitude (X), altitude location (Y) shows the higher effect on providing thermal comfort and energy efficiency because the different tropical location has less difference on solar distribution. In line with Karthick et al [8], the integrated modules should reduce the cooling load by minimizing the heat gain by the room around the courtyard.

5. Acknowledgments
This research is part of Penelitian Doktor Baru No. 881/PKS/ITS/2017 funded by Dana Non PNBP ITS 2017. The authors gratefully acknowledge this financial and technical supports.

6. References
[1] Youssef AMA, Zhai Z, Reffat RM 2015 Building Simulation 8 353–366.
[2] Muhaisen AS 2006 Building and Environment 41 1731-1741.
[3] Yazdani MG, Salam MA, Rahman QM 2014 International Journal of Sustainable Energy 1-14.
[4] Akata MAE, Njomo D, Mempouo B 2015 Future Cities and Environment 1(1) 1-10.
[5] Kubota T, Zakaria MA, Abe S, Toe DHC 2017 Building and Environment 112 115-131
[6] Burg BR, Ruch P, Paredes S, Michel B 2017 Solar Energy 147 399-405.
[7] Eke R, Demircan C 2015 Solar Energy 122 48-57.
[8] The World Bank Data, 1964-2014, Electric power consumption.
[9] Eicker U, Pietruschka D, Schmitt A, Haag M 2015 Solar Energy 118 243–255.
[10] Karthick A, Murugavel KK, Kalaivani L, Babu US 2017 Advances in Building Energy Research 1-17.

Figure 8. Stereographic diagram of 60° of PV tilt