

STUDY OF SHADING DEVICE BUILDING-INTEGRATED PHOTOVOLTAIC PERFORMANCE ON ENERGY SAVING

Aris Budhiyanto*, Jatmika Adi Suryabrata and Soeleman Saragih
Department of Architecture and Planning, Gadjah Mada University, Indonesia

Received 3 August 2017; received in revised form 017 January 2017; accepted 19 January 2017

Abstract:

This paper presents the study of the performance of building-integrated photovoltaic (BIPV) applied on vertical building envelope as overhang shading devices on energy saving. In Indonesia, where solar energy is abundant, the utilization of PV system as renewable energy is very potential, especially in remote area. However, in the urban core of Indonesia, the utilization of PV system is not yet economically viable. In this study, six BIPV models with different design of PV panel shading devices were simulated using weather file of Jakarta, an urban core of Indonesia. The results show that installing fewer PV panel shading devices on building façade with greater distance is more effective than installing more PV panel shading device with less distance. The LCOE (levelized cost of electricity) of all models that is lower than the national grid electricity cost indicates that BIPV could be economically profitable if it is designed properly.

Keywords: BIPV, shading device, energy efficient, building envelope, building simulation

© 2017 Journal of Urban and Environmental Engineering (JUEE). All rights reserved.

INTRODUCTION

Since modern buildings are built taller and consume more energy, it leads energy conservation emerges as an important and urgent issue due to the soaring price of energy and the gradual depletion of fossil fuels (Hwang et al., 2012; Ismail et al., 2015). Harnessing the sun's energy, photovoltaic (PV) is one of the most promising renewable energy technologies. Based on its average insolation levels of 4.8 kWh/m² per day and approximately 1752 kWh/m² per year, Indonesia shows potential for solar energy (Ismail et al., 2015). In remote islands of Indonesia, grid-connected PV can help to increase electrification ratios and to decrease the dependency on fossil fuels (Veldhuis & Reinders, 2015). However, previous study in Surabaya, an urban core in Indonesia, indicated that PV system electrification was not economically viable in Indonesia because its unit cost of electricity of 0.34–0.61 USD/kWh, while the price of electricity from national grid was 0.08 USD/kWh (Tarigan et al., 2014).

In order to improve the performance of PV system, the photovoltaic materials are used to replace conventional building materials in parts of the building envelopes, such as the roofs or facades, and cladding elements of the building envelope or as shading device for sun protection system. It is known as building-integrated photovoltaic (BIPV) (Basnet 2012; Jelle et al. 2012) and provided integrated electricity generation while serve as part of the weather protective building envelopes. Apart from the electricity generation, the cooling energy consumption reduction due to cooling load reduction of building envelopes should also be regarded as parts of the total electricity saving when the energy performance of BIPV systems was evaluated (Ng et al., 2013; Sun et al., 2012).

To increase BIPV efficiency, PV modules direction and inclination angle need to be considered, as well as the distance between PV modules energy efficiency; because PV modules would be affected by the longitude-latitude of the building, the local weather condition, and the distance to module length (D/L) ratio that is recommended between 1 and 3 in consideration of the required amount of power supply (Atmaja, 2013; Hwang et al., 2012; Strong, 1987). In Indonesia, the installed PV panels on West vertical façade as folding surface that facing North-South with 17,71% coverage of PV to total surface area, can fulfill 40,8% electrical energy needed by office building (Susan & Antaryama, 2015). In Singapore, that has the same weather as Indonesia, East façade and panel slope of 30–40° are the most suitable location and inclination (Saber et al., 2014).

In tropics, shading devices are utilized to reduce the solar radiation entering into the building so that the cooling load can be reduced. In the hot-humid climate of Malaysia, it indicated that egg-crate shading devices had significant impact on decreasing indoor temperature,

followed by horizontal shading and vertical shading (Al-Tamimi & Fadzil, 2011; Arifin & Denan, 2015). However, if PV panels are arranged as egg-crate shading devices, the amount of solar radiation received by PV panels could be decreased. Therefore in this study, the PV panels were applied on building envelope as horizontal shading device. Furthermore, the energy performance of the BIPV was evaluated. Since the economic barrier is the most significant barrier of the PV systems implementation in South Asian countries, including Indonesia (Karakaya & Sriwannawit, 2015), the cost-effectiveness of PV systems was analyzed. As an indicator of the competitiveness of the PV technology, the levelized cost of electricity (LCOE) was applied and calculated (Orioli & Di Gangi, 2015; Veldhuis & Reinders, 2015).

METHOD

This study used simulation method. A model of a ten stories typical office building, with a square floor plan and glass facades, was set up within EnergyPlus simulation software (version 8.4). EnergyPlus is building energy simulation software developed by the United States Department of Energy (Crawley et al., 2001). It has capability to simulate cooling/heating loads, daylighting and photovoltaic systems with repeated accurate results which had been validated through analytical, comparative and empirical tests (Pereira et al., 2014; Wittkopf et al., 2009).

A standard floor (L-40 m × B-40 m × H floor to floor-4.2 m and 3 m from floor to ceiling) was modeled. The space was divided into five zones, consisting of four perimeter zones, facing east, west, north and south, and a core zone. The occupancy of the building was 0.1 person/m², the lighting load was 12 W/m², and the equipment load was 10 W/m², and the cooling set point of air-conditioning was 25°C and COP of 3.7 to comply with the building legislation requirements in Jakarta (SNI 6197:2011, SNI 6390:2011). A daylight control also used to measure the lighting load reduction as a result of the shading device BIPV.

c-Si Trina Solar TSM 310 PD-14 PV panels with 310 Wp peak power, 16% efficiency and 1.956 m length and 0.992 m width were applied on the model. Based on Saber's research (Saber et al., 2014), six models of BIPV with different PV panel array plans were presented (**Table 1** and **Fig. 1**). The models were simulated using weather file of Jakarta, that is located in 6°204' South and 106°821' East.

Comparative analysis was done to explore the performance of shading device BIPV claddings of different configurations in terms of total electricity consumption and LCOE. In order to reduce the investment cost, an on-grid PV system was applied. Therefore the battery and charger were not installed.

Table 1. Details of BIPV models

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|-----------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| East Wall | 30° inclined D/L = 4.2 | 30° inclined D/L = 1.5 | - | - | 30° inclined D/L = 4.2 | 30° inclined D/L = 1.5 |
| West Wall | - | - | 30° inclined D/L = 4.2 | 30° inclined D/L = 1.5 | 30° inclined D/L = 4.2 | 30° inclined D/L = 1.5 |

D/L: distance to module length

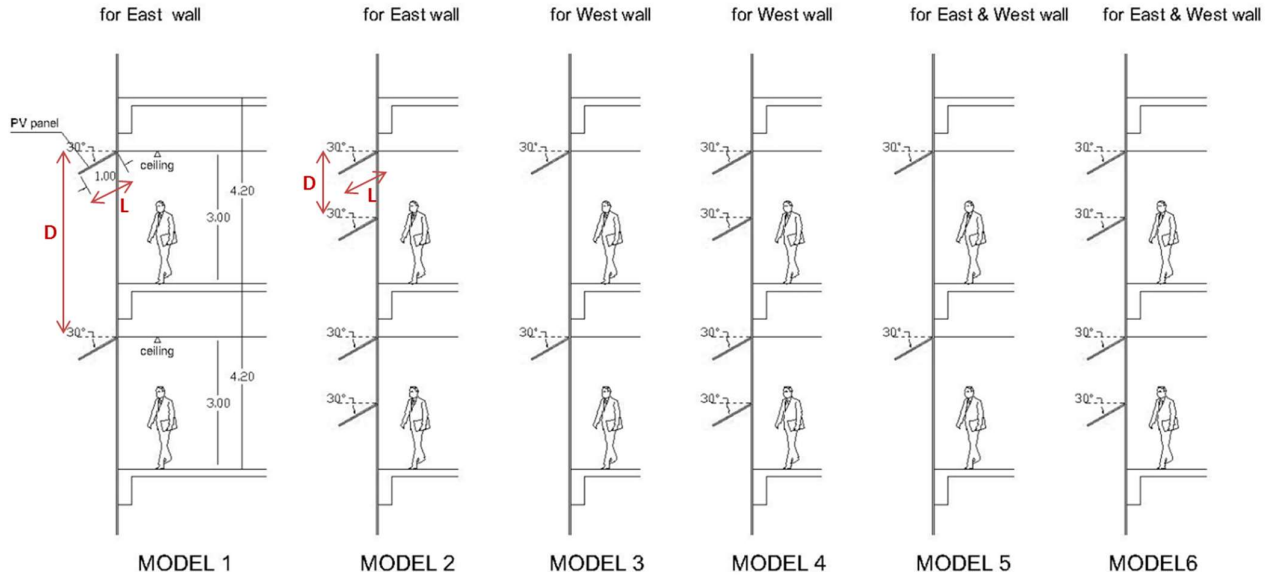


Fig. 1. The PV panel shading device design of six BIPV models.

The life cycle cost (LCC) is the investment cost of BIPV. It consists of the total costs of owning and operating an item over its lifetime, expressed in today’s money. The LCC of the PV system includes the sum of all the present worths (PWs) of the costs of the PV modules (C_{PV}), inverter (C_{Inv}), the cost of the installation (C_{Ints}), and the maintenance and operation (M&O) cost (C_{MWP}) of the system (Nafeh, 2009). The details of the used cost data for all items are shown in **Erro! Fonte de referência não encontrada.** As the PV module in Indonesia is imported from abroad, the import tax (C_{Tax}) has to be calculated. Import tax includes the sum of the import duty (ID), value added tax (VAT), and income tax (IT) (Ghofur, 2014).

$$LCC = C_{PV} + C_{Inv} + C_{Ints} + C_{MWP} + C_{Tax} \quad (1)$$

$$C_{Tax} = ID + VAT + IT \quad (2)$$

$$ID = ((C_{PV} + C_{Inv} + C_{Ints}) - \$50) \times 10\% \quad (3)$$

$$VAT = ((C_{PV} + C_{Inv} + C_{Ints}) - \$50 + ID) \times 10\% \quad (4)$$

$$IT = ((C_{PV} + C_{Inv} + C_{Ints}) - \$50 + ID) \times 7.5\% \quad (5)$$

The maintenance cost C_{MPW} can be calculated using the maintenance cost per year (M/yr) and the lifetime of the system ($N = 25$ years), assuming an inflation rate i of 3% and a discount or interest rate d of 10%.

$$C_{MPW} = M\&O/year \times \left(\frac{1+i}{1+d}\right) \times \left[\frac{1 - \left(\frac{1+i}{1+d}\right)^N}{1 - \left(\frac{1+i}{1+d}\right)}\right] \quad (6)$$

Table 2. The used cost data of all items

| Item | PV | Inverter | Installation | M&O/ year |
|------|---------------|----------|----------------|---------------|
| Cost | \$210.8/ unit | \$1/W | 10% of PV cost | 2% of PV cost |

To be cost-effective, the levelized cost of energy (LCOE) of grid-connected PV must be lower or equal to the generation cost of electricity with existing technology. The LCOE is calculated by dividing the total lifecycle cost of BIPV (LCC) by the total lifetime energy production (E_{PV} total) considering the system degeneration rate (SDR) is 1% per year. (Campbell et al., 2009; Veldhuis & Reinders, 2015)

$$LCOE = \frac{LCC}{E_{PV} \text{ total}} \quad (7)$$

$$E_{PV} \text{ total} = \sum_{n=1}^N \frac{E_{PV}/year \times (1-SDR)^n}{(1+d)^n} \quad (8)$$

RESULT AND DISCUSSION

Energy Performance Intensity (EPI)

Fig. 2 shows that the more PV panel shading devices installed, the less EPI of the models. As the PV panel shading devices installed on Model 6 is the largest, its

EPI is the lowest, which is 94.48 kWh/m².yr that is 14.06 % lower than the EPI of the baseline model (the model without BIPV shading devices) (Fig. 3).

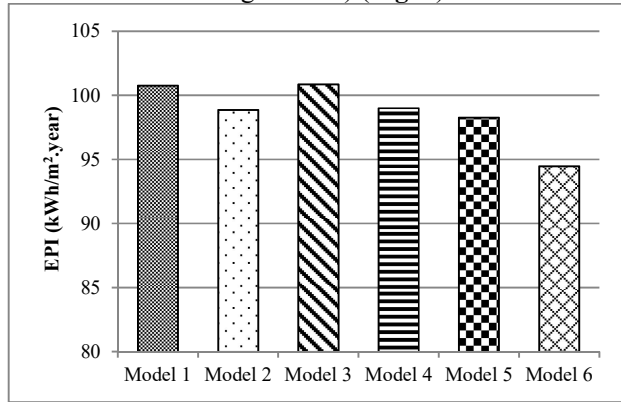


Fig. 2. The EPI of six BIPV models

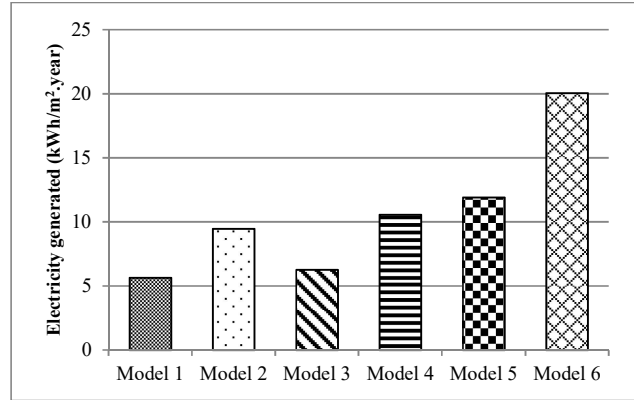


Fig. 3. The percentage of EPI saving of six BIPV models

Table 3. Details of BIPV models.

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|-------------------------------|------------------|-------------------|------------------|-------------------|-------------------|-------------------|
| <i>C_{PV}</i> (USD) | 42,160.00 | 84,320.00 | 42,160.00 | 84,320.00 | 84,320.00 | 168,640.00 |
| <i>C_{Inv}</i> (USD) | 8,875.50 | 14,888.00 | 9,850.30 | 16,608.50 | 18,725.70 | 31,496.50 |
| <i>C_{Ints}</i> (USD) | 4,216.00 | 8,432.00 | 4,216.00 | 8,432.00 | 8,432.00 | 16,864.00 |
| <i>C_{MWP}</i> (USD) | 13,117.58 | 25,555.44 | 13,349.01 | 25,963.91 | 26,466.57 | 51,519.34 |
| <i>C_{Tax}</i> (USD) | 16,146.44 | 31,470.08 | 16,431.57 | 31,973.32 | 32,592.60 | 63,458.02 |
| LCC (USD) | 84,515.52 | 164,665.51 | 86,006.88 | 167,297.73 | 170,536.87 | 331,977.87 |

The percentage of EPI saving affected by PV panel shading devices of 8.25-14.06 %. Although the number of PV panel shading devices of Model 2 is twice more than the ones of Model 1, however the EPI saving of Model 2 is only 1.74 % higher than the one of Model 1.

It is same to the difference of EPI saving between Model 3 and Model 4 and the one between Model 5 and Model 6. The EPI saving of Model 4 is only 1.68 % higher than Model 3, while the EPI saving of Model 6 is only 3.45 % higher than Model 5. Among Model 1, Model 3 and Model 6, the number of PV panel shading devices of Model 6 is four times more than the one of Model 1 and Model 3, yet the EPI saving of Model 6 is only 5.73 % higher than Model 1 and it is only 3.99 % higher than Model 3. The EPI saving that is less than 6 % indicates that installing more shading devices is less effective in energy saving.

Different to the EPI, the more PV panel shading devices intalled, the more electricity generated. Model 6 has the highest electricity generated, which is 20.07 kWh/m².year, while Model 1 has the lowest one, which is 5.65 kWh/m².year, followed by Model 3 that has 6.28 kWh/m².year electricity generated (Fig. 4). The electricity generated of Model 3 that is higher than the one of Model 1 shows that PV panel shading devices oriented to the west receiving solar radiation higher than oriented to the east.

Although Model 2 has PV panels twice more than Model 1, the electricity generated of Model 2 is not twice more than the one of Model 1. The comparison of the electricity generated between Model 1 and Model 2 is 5.65 kWh/m².year: 9.48 kWh/m².year, which the scale of 1: 1.68. It is the same to the comparison of the electricity generated between Model 3 and Model 4, and between Model 5 and Model 6. The electricity generated between two models that is not twice more, while its PV panels is twice more than the other's is caused of the D/L of PV panels. PV panels with small D/L is potentially shading other PV panels, as Hwang et al. (2012) pointed out that greater PV panels distance yields greater amount of sunlight that generate greater electricity. Therefore, it is more effective installing a few number of PV panels with great distance than installing a large number of PV panels with small distance.

Table 3. Details of BIPV models.

), while the comparison of electricity generated between Model 1 and Model 2 is 5.65 kWh/m².year: 9.48 kWh/m².year, which the scale of 1: 1.68 (Fig. 4). Since the comparison of the electricity generated is lower than the comparison of LCC, the LCOE of Model 2 is higher than Model 1. For the same reason, the LCOE of Model 4 is higher than the one of Model 3, as well as the LCOE of Model 6 is higher than the one of Model 5. The difference of LCOE indicates the fewer PV panel

Levelized of Electricity Cost (LCOE)

Of six models, the LCOE of Model 2, which is 0.108 USD, is the highest while the LCOE of the Model 3, which is 0.085 USD, is the lowest (Fig. 5). Different to Tarigan's research (Tarigan et al., 2014), LCOE of all models is lower than the national grid electricity price,

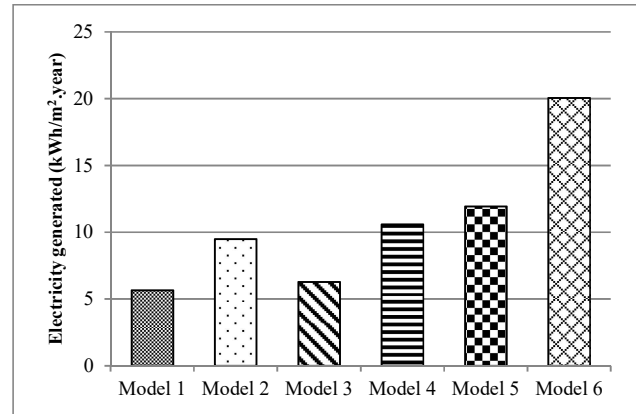


Fig. 4. The electricity generated of six BIPV models.

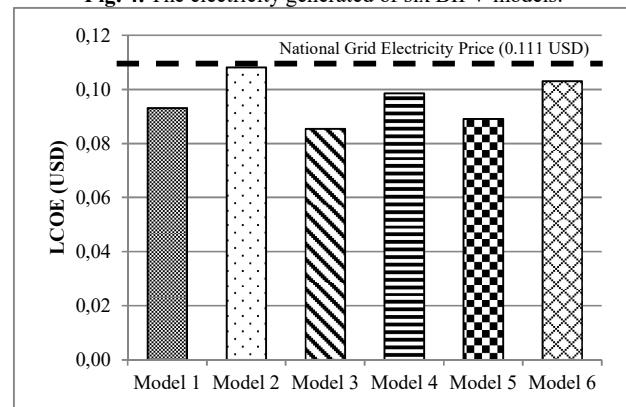


Fig. 5. The LCOE of BIPV models.

which is 0.111 USD. It indicates that the BIPV is possible to be profitable if it is designed properly.

The comparison of LCC between Model 1 and Model 2 is 84,515.52 USD: 164,665.51 USD, which the scale of 1: 1.95 (

shading devices installed in greater D/L, the lower LCOE obtained.

Based on the orientation of PV panels, the PV panels installed on East façade is less effective than West façade. It is showed by the LCOE of Model 1 that is higher than the one of Model 3 as well as the LCOE of Model 2 that is higher than the one of Model 4.

Payback analysis

The payback period is the minimum time it takes to recover investment costs. The payback period for an

energy system is calculated as the total investment cost divided by the first year's revenues from energy saved, displaced, or produced (Eiffert, 2003). In this case, the total investment cost divided by the energy saving obtained by installing PV panel shading devices and the electricity produced by the PV panels.

Table 4. The payback period of six BIPV models

| | LCC (USD) | Energy saving (USD) | Energy produced (USD) | Payback period (years) |
|---------|--------------|---------------------------|-----------------------------|------------------------------|
| Model 1 | 84,515.52 | 8,408.65 | 14,040.29 | 3.76 |
| Model 2 | 164,665.51 | 14,104.84 | 16,968.44 | 5.30 |
| Model 3 | 86,006.88 | 9,332.12 | 13,917.64 | 3.70 |
| Model 4 | 167,297.73 | 15,734.89 | 16,753.81 | 5.15 |
| Model 5 | 170,536.87 | 17,740.77 | 17,888.27 | 4.79 |

The payback period calculation shows that Model 3 gets payback faster than other models, that is 3.70 years, while Model 6 gets payback longer than other models, that is 6.20 years. The payback period of Model 6 that is longer than the one of other models is caused by the high investment cost, the low energy saving and the low energy produced. As the investment cost of Model 6 is 3.86 times more than the one of Model 3, the energy saving difference is only 1.7 times more and the electricity generated is 3.41 times more. As the investment cost of BIPV system is expensive and the energy produced is small, installing smaller PV panel shading devices on building façade is more effective.

CONCLUSION

In this paper, the effectivity of BIPV shading devices on energy performance is discussed in terms of power output of PV panels, EPI saving, and economic assessment. The study reveals that:

- More PV panel shading devices installed on the building with less distance between shading devices is less effective because the amount of energy saving and energy produced is not equal to the number of PV panel shading devices installed. Therefore it is more effective to instal fewer PV panel shading devices with greater distance.
- The LCOE of the models that is lower than the national grid electricity price and the payback period of 3.7-6.2 years indicate that BIPV that designed properly can be economically benefit. In this case, the PV panels are oriented to the west or the east with 30° inclined, as both of the orientations received great amount of sunlight, combined with an on-grid system that doesn't need to use battery, in order to reduce the investment cost.

REFERENCES

Al-Tamimi, N. A., & Fadzil, S. F. S. (2011). The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics. *Procedia Engn.*, **21**, 273–282. <http://doi.org/10.1016/j.proeng.2011.11.2015>

Arifin, N. A., & Denan, Z. (2015). An Analysis of Indoor Air Temperature and Relative Humidity in Office Room with Various External Shading Devices in Malaysia. *Procedia - Social Behav. Sci.*, **179**, 290–296. <http://doi.org/10.1016/j.sbspro.2015.02.432>

Atmaja, T. D. (2013). Façade and rooftop PV installation strategy for building integrated photo voltaic application. *Physics Procedia*, **32**, 105–114. <http://doi.org/10.1016/j.egypro.2013.05.014>

Badan Standardisasi Nasional (BSN) - National Standardization Agency of Indonesia. SNI 6197:2011 Konservasi energi pada sistem pencahayaan - Energy conservation on lighting systems (2011). Jakarta, Indonesia.

Badan Standardisasi Nasional (BSN) - National Standardization Agency of Indonesia. SNI 6390:2011 Konservasi energi sistem tata udara bangunan gedung - Energy conservation of the building's air-conditioning system (2011). Jakarta, Indonesia.

Basnet, A. (2012). *Architectural Integration of Photovoltaic and Solar Thermal Collector Systems into buildings*. Norwegian University of Science and Technology.

Campbell, M., Blunden, J., & Smeloff, E. (2009). Minimizing utility-scale PV power plant LCOE through the use of high capacity factor configuration. *Proceedings of the 34th IEEE Photovoltaic Specialists Conference (PVSC)*, 421–426.

Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., & Pedersen, C. O. (2001). EnergyPlus: New Capabilities in a Whole-Building Energy Simulation Program. *Build. Sim.*, **201**, 51–58. Retrieved from http://www.ibpsa.org/proceedings/BS2001/BS01_0051_58.pdf http://www.ibpsa.org/?page_id=122

Eiffert, P. (2003). Guidelines for the Economic Evaluation of Building- Integrated Photovoltaic Power Systems. *International Energy Agency PVPS Task 7: Photovoltaic Power Systems in the Built Environment Nation*, (January).

Ghofur, A. (2014). Rancangan Sistem Fotovoltaik untuk Pemenuhan Sebagian Kebutuhan Listrik Gedung Asrama Mahasiswa Kinanti 1. Gadjah Mada University.

Hwang, T., Kang, S., & Kim, J. T. (2012). Optimization of the building integrated photovoltaic system in office buildings - Focus on the orientation, inclined angle and installed area. *Energy Build.*, **46**, 92–104. <http://doi.org/10.1016/j.enbuild.2011.10.041>

Ismail, A. M., Ramirez-Iniguez, R., Asif, M., Munir, A. B., & Muhammad-Sukki, F. (2015). Progress of solar photovoltaic in ASEAN countries: A review. *Renew. Sust. Energy Rev.*, **48**, 399–412. <http://doi.org/10.1016/j.rser.2015.04.010>

Jelle, B. P., Breivik, C., & Drolsum Røkenes, H. (2012). Building integrated photovoltaic products: A state-of-the-art review and future research opportunities. *Solar Energy Mat. Solar Cells*, **100**, 69–96. <http://doi.org/10.1016/j.solmat.2011.12.016>

Karakaya, E., & Sriwannahit, P. (2015). Barriers to the adoption of photovoltaic systems: The state of the art. *Renew. Sust. Energy Rev.*, **49**, 60–66. <http://doi.org/10.1016/j.rser.2015.04.058>

Nafeh, A. E. A. (2009). Design and Economic Analysis of a Stand-Alone PV System to Electrify a Remote Area Household in Egypt. *The Open Renew. Energy J.*, **2**, 33–37.

Ng, P. K., Mithraratne, N., & Wei Kua, H. (2013). Energy analysis of semi-transparent BIPV in Singapore buildings. *Energy & Build.*, **66**, 274–281. <http://doi.org/10.1016/j.enbuild.2013.07.029>

Orioli, A., & Di Gangi, A. (2015). The recent change in the Italian policies for photovoltaics: Effects on the payback period and levelized cost of electricity of grid-connected photovoltaic systems installed in urban contexts. *Energy*, **93**, 1989–2005. <http://doi.org/10.1016/j.energy.2015.10.089>

Pereira, W., Bögl, A., & Natschläger, T. (2014). Sensitivity analysis and validation of an EnergyPlus model of a house in Upper Austria. *Energy Procedia*, **62**, 472–481. <http://doi.org/10.1016/j.egypro.2014.12.409>

Saber, E. M., Lee, S. E., Manthapuri, S., Yi, W., & Deb, C. (2014). PV (photovoltaics) performance evaluation and simulation-based energy yield prediction for tropical buildings. *Energy*, **71**, 588–595. <http://doi.org/10.1016/j.energy.2014.04.115>

Strong, S. J. (1987). *The Solar Electric House, A Design Manual for*

- Home-Scale Photovoltaic Power Systems*. Pennsylvania: Rodale Press.
- Sun, L., Lu, L., & Yang, H. (2012). Optimum design of shading-type building-integrated photovoltaic claddings with different surface azimuth angles. *Appl. Energy*, **90**(1), 233–240. <http://doi.org/10.1016/j.apenergy.2011.01.062>
- Susan, & Antaryama, I. G. N. (2015). Optimization of Energy Efficiency by Integrated Design of Folding Wall-BIPV and Users Behaviour in Office Building at Surabaya. *GSTF J. Eng. Techn.*, **3**(2), 39–48. http://doi.org/10.5176/2251-3701_3.2.124
- Tarigan, E., Djuwari, & Purba, L. (2014). Assessment of PV power generation for household in surabaya using solarGIS-pvplanner simulation. *Energy Procedia*, **47**, 85–93. <http://doi.org/10.1016/j.egypro.2014.01.200>
- Veldhuis, A. J., & Reinders, A. H. M. E. (2015). Reviewing the potential and cost-effectiveness of off-grid PV systems in Indonesia on a provincial level. *Renew. Sust. Energy Rev.*, **52**, 757–769. <http://doi.org/10.1016/j.rser.2015.07.126>
- Wittkopf, S. K., Kambadkone, A., Quanhui, H., & Khai, N. P. (2009). Development Of A Solar Radiation And Bipv Design Tool As Energyplus Plugin For Google Sketchup. *Eleventh International IBPSA Conference*, 1989–1996.