Economic Performance of Solar Panel Installations with Heat Gain Reduction Benefit

Sappinandana Akamphon*

Faculty of Engineering, Thammasat University, Pathumthani 12120, Thailand
*Email: sup@engr.tu.ac.th, Phone: +662-564-3001-9 ext 3258, Fax +662-986-9545

Abstract

The feasibility of solar panel wall and roof installations in building is investigated. Without considering reduced heat gain benefit, it has been widely shown that solar panels remain prohibitively expensive. With the benefit, however, certain building configurations become attractive candidates. This research explores the combinations of building shapes and panel locations leading to economically viable installations using a building energy simulation program called eQuest. Employing Bangkok weather data, the results show that roof installations have the highest rate of return for tall and slim buildings, while west and south wall installations gives the highest return for short and wide buildings.

Keywords: Building-integrated photovoltaics, economic performance, heat gain reduction

1 Introduction

Photovoltaic (PV) has become an important renewable energy source. In Thailand, however, its cost effectiveness remains doubtful due to solar panel's high manufacturing cost compared to inexpensive—albeit environmentally unfriendly—grid electricity. Furthermore, government tax incentive and subsidy programs do not yet offset the high investment costs of panels and inverters. These contribute to the limited use of solar panels in Thailand despite the abundance of available solar power.

The partial reason for the currently assumed infeasibility of solar panel is that economic performance evaluation of solar panel installations consists only of two parts: the investment and the profit from generated electricity [1-3]. In fact, there is an additional benefit to solar panel installation on a building—the installation would shield the building from solar irradiance, reducing the building heat gain and, consequently, the required space cooling energy [4, 5]. The reduced heat gain and resultant cooling load of PV-integrated walls have been studied extensively, in which the heat gain through the wall is reduced by 30%-50% depending on the solar irradiance in the area [6, 7]. However, this benefit has not been incorporated into current solar panel feasibility analyses, which would likely improve the economic performance of solar panel significantly.

By considering profit both from the generated electricity and reduced cooling load, a more thorough and justified feasibility analysis of any installation is possible. The proposed analysis method will subsequently be conducted to determine building characteristics leading to economically viable installations.

2 Assumptions and Methodology

The objective of this work is to show the significance of reduced heat gain to the economic performance of solar panel installation and also to determine building characteristics that lead to the most viable solar panel installation. In order to do so, baseline assumptions regarding the buildings, solar panel installations, and economic performance evaluation must be addressed.

2.1 Building assumption

Three building base sizes and three heights are considered. Small *"S"*, medium *"M"*, and large *"L"* bases are 15 m x 15 m, 30 m x 30 m, and 60 m x 60 m, respectively. The three heights are 2-floor, 5-floor, and 8-floor respectively. Each floor is 4 m high (floor-to-floor). The buildings from this point on will be referred to by their floor numbers and base sizes such as 8M or 5S.

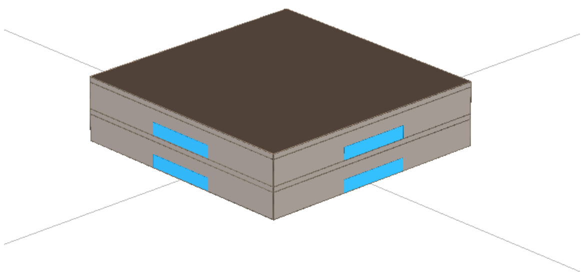

Figure 1: Modeled medium 2-floor building (2M)

The building walls and roof are modeled as 15 cm-thick concrete. The window-to-wall ratio is 15%. Each floor is 0.6 m thick.

2.2 Solar panel installation assumption

The modeled characteristics and costs of solar panels and inverters are listed in Table Table 1 and Table 2. The parameters are used to model the amount of electricity generated from solar panel installations.

Table 1: Modeled solar panel characteristics and cost based on Samsung LPC250S panel

Maximum Power	250	W
Maximum Power Voltage	50.5	V
Maximum Power Current	5.65	A
Open Circuit Voltage (V_{oc})	62	V
Short Circuit Current (I_{sc})	6.2	A
Temperature Coefficient of V_{oc}	-0.1267	V/°C
Temperature Coefficient of I_{sc}	3.44	mA/°C
Dimension (LxWxH)	1.9x1.3x0.05	m
Unit Cost	15000	baht

Table 2: Modeled inverter characteristics and cost based on Fronius IG Plus-5.0

Capacity	5	kW
Operating DC Voltage	100 - 500	V
Unit Cost	100000	baht

The solar panels modeled here are fixed and face outward normal to the building surface on which they are installed, and they completely cover the surface, leaving only window area exposed to the sun. The panels are assumed to be directly connected to a power grid, eliminating the need for batteries. The buildings are assumed to have no shades from other buildings or surrounding trees. The solar panels and inverters are assumed to have lifetime of 20 years.

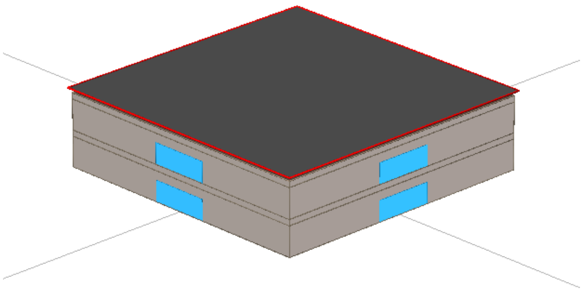

Figure 2: Illustration of roof PV installation on 2M building

The number of solar panels needed (n_p) is simply calculated from

$$n_p = \frac{A_{bs} - A_w}{A_p}$$

where A_{bs} is the building surface area, A_w is the window area, and A_p is the panel area. The number of panels connected in series (n_{series}) is calculated by

$$n_{series} = \frac{W_i}{W_{panel}}$$

where W_i is the power capacity of the inverter and W_p is the peak wattage of the panel. Finally, the number of panels connected in parallel ($n_{parallel}$) is simply

$$n_{parallel} = \frac{n_p}{n_{series}}.$$

2.3 Economic performance evaluation

In this work, economic performance of a panel installation is measured by its the internal rate of return (IRR), which is the interest rate at which the net present value of the investment is equal to that of the benefits. In this work, the investment consists of panel cost and inverter cost, while the benefit is the sale of electricity generated from the panels. As previously mentioned, however, a frequently overlooked benefit is the reduced heat gain through wall or roof of the building on which it is installed. The reduced heat gain translates into smaller space cooling load and, consequently, electricity cost saving. The IRR in each case is evaluated based on the same building but without the PV installation. For example, the IRR of 2S East is calculated based on the electricity cost of 2S building without PV.

To evaluate the electricity cost saving and income from solar electricity, the cooling load reduction and electricity generated must be determined, a task which will be calculated by an energy simulation program called eQuest. The program, developed by

US Department of Energy, has been used in many reviewed literature to determine energy requirement in a building [8-11], taking into account solar irradiance, solar angle, weather data, and heat transfer coefficients of building materials. Furthermore, it can determine the electricity generated from PV installation using solar panel characteristics, azimuth, and tilt angles.

The reduced electricity required for cooling is translated into saving using an electrical tariff equation. The tariff is made up of two parts, the required peak power W_p and the total electrical energy consumption E, as shown in Equation

$$ElecCost = k_1 \times W_p + k_2 \times E$$

where k_1 = 210 baht per kW per month and k_2 = 2.8408 baht per kWh.

The income from electricity generated is calculated from the power and electrical energy generated (E_G).

$$ElecSale = k_3 \times E_G$$

where k_3 = 3 baht per kWh.

The tariff and income equations are based on actual Metropolitan Electricity Authority rate for office buildings.

Once the annual cash flow is calculated, the IRR of each case is determined. The combination of building characteristic leading to the maximum IRR is the most viable solar panel installation.

3 Results and Discussions

Using the methodology detailed earlier, IRRs of solar panel installations with and without heat gain reduction will be compared. Then the IRR of various installations with the heat reduction will be compared to determine the characteristics of building and panel orientation leading to the most viable installation.

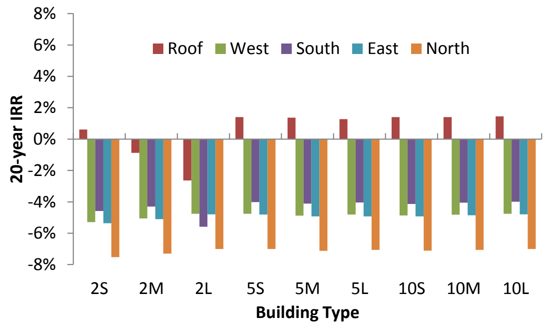

Fig. 1: 20-year IRR of various solar panel installations without heat gain reduction benefit

Fig. 1 shows that for most installations except roof, the 20-year IRRs are negative due to high solar panel and inverter costs and relatively low income from electricity sale. Without heat gain reduction consideration, most installations are not economically viable or provide too small a return to be attractive. The maximum IRR is 2.1% for 10L roof installation

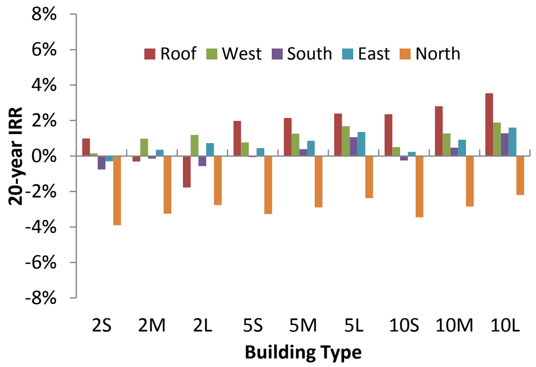

Fig. 2: 20-year IRR of various solar panel installations with heat gain reduction benefit

However, once heat gain reduction is considered, all solar panel installations see increase in their IRRs, as shown in Fig. 2. The maximum IRR is 3.5% for 10L roof installation, and the minimum IRR is -3.8% for 2S north installation. Although it is important to note that the IRRs of many other installations have now become positive.

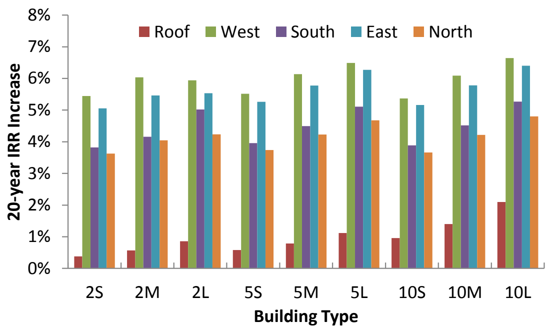

Fig. 3: IRR improvements due to heat gain reduction benefit

Fig. 3 shows the magnitudes of IRR improvements for various buildings. The largest increases are from west installations (10L at 6.6%), followed by east, and south. The increased IRRs in the west wall installations are the highest due both to the reduced monthly peak load and reduced energy consumption, while that in the east and south installations are mostly due to reduced energy consumption. Since the peak load tends to occur in late afternoons, the west installation is able to prevent a majority of heat gain from solar irradiance.

Fig. 3 also shows the effect of building shape on economic performance of solar panel installations. For 2-floor buildings, the roof IRR decreases with the increasing base area. For 5- and 10-floor buildings, the roof IRR increases with the base area. This is because the benefit of heat gain reduction is minimal in short buildings to small air volume. For wall installations, IRRs always increase with the base area regardless of building height.

4 Conclusion

This work proves that the effect of heat gain reduction should not be ignored when evaluating economic performance of a solar panel installation, especially in regions with high solar radiation like Thailand, as it can add up to 6.6% of IRR. Furthermore, the results show that roof solar panel installations can be economically viable in buildings especially when it is tall and wide, in which roof installations are particular suitable because it can generate more salable electricity. In shorter buildings, west installations are the optimal selection due to large heat gain reduction benefit.

This work also shows great promises for the future use of solar panels in Bangkok area where tall and large office buildings are the norm. In these buildings, the heat gain reduction benefit would be even larger. Coupled with increasing electricity tariff and decreasing panel costs, the economic viability of building-integrated solar panels would be even greater.

5 References

1. Oliver, M. and T. Jackson, Energy and economic evaluation of building-integrated photovoltaics. Energy, 2001. 26(4): p. 431-439.

2. Fanney, A.H., B.P. Dougherty, and M.W. Davis, Measured performance of building integrated photovoltaic panels. Journal of solar energy engineering, 2001. 123: p. 187.

3. Davis, M.W., A.H. Fanney, and B.P. Dougherty, Measured versus predicted performance of building integrated photovoltaics. Journal of solar energy engineering, 2003. 125: p. 21.

4. Yang, H., et al., Grid-connected building-integrated photovoltaics: a Hong Kong case study. Solar energy, 2004. 76(1-3): p. 55-59.

5. Henson, J.W.C., CLIMATE AND LATITUDE EFFECTS FOR BIPV SHADE ELEMENTS.

6. Yang, H., J. Burnett, and J. Ji, Simple approach to cooling load component calculation through PV walls. Energy and buildings, 2000. 31(3): p. 285-290.

7. Wang, Y., et al., Influence of a building's integrated-photovoltaics on heating and cooling loads. Applied energy, 2006. 83(9): p. 989-1003.

8. Crawley, D.B., et al., Contrasting the capabilities of building energy performance simulation programs. Building and Environment, 2008. 43(4): p. 661-673.

9. Scheuer, C., G.A. Keoleian, and P. Reppe, Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. Energy and buildings, 2003. 35(10): p. 1049-1064.

10. Yezioro, A., B. Dong, and F. Leite, An applied artificial intelligence approach towards assessing building performance simulation tools. Energy and buildings, 2008. 40(4): p. 612-620.

11. Erickson, V.L., et al. Energy efficient building environment control strategies using real-time occupancy measurements. 2009. ACM.