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The Electric Power Generation Efficiency of a Louver-type BIPV on an Urban Building as Determined by Annual Field Measurements

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Abstract

Louver-type BIPV (building integrated photovoltaic) systems can be applied to façade of urban buildings. This study aimed to evaluate the electric power generation efficiency the louver-type BIPV system in Seoul, South Korea as determined by the annual field measurement. In addition, the performance parameters that affect the efficiency were determined. The results of the field measurement show an annual average power generation efficiency of approximately 6.8% for an installed photovoltaic (PV) system, which is generally low for monocrystalline solar cells. This low efficiency in our study resulted from a decrease in the incident solar radiation to the PV system due to seasonal changes and shading from adjacent buildings. The effect of the adjacent buildings on the electric power generation efficiency was evaluated by analyzing the electric power generation efficiency of the PV system after the adjacent buildings were erected.

Keywords - louver-type building integrated photovoltaics (BIPV), electric power generation efficiency, field measurement, urban building

1. Introduction

Due to increasing concerns about global warming problem, many researchers have focused on the application of renewable energy in building a net zero-energy building (ZEB). The energy requirements for residential and commercial building must be reduced by improving the energy efficiency within the building itself and also by balancing its energy supply needs with renewable energy technologies. To reduce greenhouse gas emission, the photovoltaic (PV) system has, in particular, become widely used for buildings despite certain geographical requirements due to adjacent natural and man-made features. There are many ways to install PV systems on a building. For existing buildings, the PV modules are mounted above and parallel to the roof surface with a standing frame. With a new building, in addition to mounting the system on the rooftop, the PV system could be installed in a creative, aesthetically pleasing manner via integration into the building façade. This type of PV system is commonly known as a building integrated photovoltaic (BIPV) system. This system could be placed on any part of the roof or on external wall claddings, windows, and external shading devices.

Louver-type BIPV systems can be used not only for electric power generation but also for daylight control. To successfully apply the louver-type BIPV system, it is necessary to anticipate performance parameters to increase the electric power generation efficiency without a loss in daylighting performance. Generally, the PV modules should be installed in locations that are not shaded by adjacent objects. Shading may drastically reduce the electric power output of the entire module. Therefore, shadows cast by adjacent tall trees and neighboring buildings (including those planned for future construction) should first be evaluated.

This study aimed to evaluate the electric power generation efficiency of louver-type BIPV systems applied to urban buildings and to determine the performance parameters that affect the power generation efficiency. For this purpose, we installed a louver-type BIPV system on the south façade of an urban building in Seoul and measured the electric power generation rate and incident solar radiation from June 1, 2013 to May 31, 2014. By analyzing annual field measurement results, electric power generation efficiencies were calculated and the relationship between the generated power and the local weather conditions, as well as the location of adjacent buildings, was analyzed.

2. Overview of Field Measurements

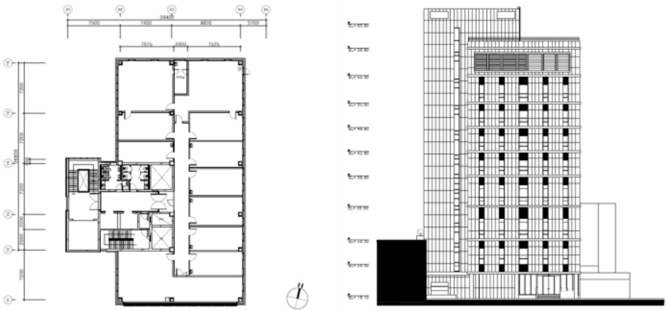
The louver-type BIPV was installed on the south elevation of the educational and research building in Seoul. The plan and elevation are illustrated in Figure 1. The solar cells were incorporated on the upper surface of the louver, which can act as a shade to block excessive direct incident irradiation and generate electricity that can be used directly in the building or connected to the national power grid.

As shown in Figure 2, the louver-type BIPV consisted of five sets, each of which had nine slats. The left three sets were movable to adjust the angle of the slats, while the right two sets were fixed. Two PV modules were installed on the slats except for the topmost slats. Five or six monocrystalline solar cells with dimensions of 6 x 6 inches were connected in series for each module. The specifications of the PV module are shown in Table 1.

A direct current (DC) output generated in the PV module converted an alternating current (AC), which can be used as electricity in the building. The inverter, with a rated capacity of 3.1 kW, was installed on the same floor of the building (shown in Figure 1).

The inverter allowed the PV module to remain at the maximum power point through the maximum power point tracking (MPPT) method.

Measurements were taken for one year, from July 1, 2013 to June 30, 2014. The angle of the slats was set at 30 degrees during the measurement period for both the movable and fixed louvers in order to exclude tilted-angle-dependence parameters. The outdoor air temperature, humidity, global horizontal radiation, output current, voltage, and power were measured in one minute intervals. The measurement equipment is listed in Table 2.



(a) Plan (b) Elevation

Fig. 1 Plan and elevation of the building

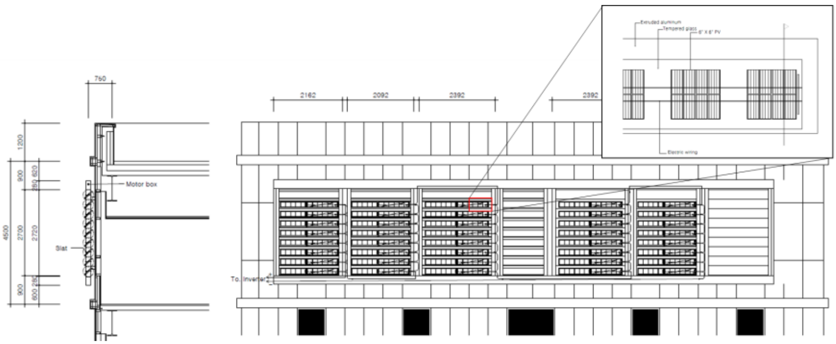


Fig. 2 Section and enlarged elevation of the louver-type BIPV

Table 1. Specifications of the PV module

Cell type	6-inch monocrystalline solar cell	Rated power	21 W
V_{oc}	3.10 V	I_{sc}	8.3 A
V_{mp}	2.65 V	I_{mp}	7.8 A

Table 2. Measurement equipment

Measured data	Sensor	Specification
Global horizontal radiation	LP PYRA 03AC	Measured range: 0~2,000 W/m^2 Accuracy: ISO 9060 level 2
Temperature	HD9817T	Measured range: -40~60℃ Accuracy: ±0.2℃±0.15%
Relative humidity		Measured range: 0~100%RH Accuracy: ±2%RH (10~90%RH), ±2.5%RH (other)

3. Results and Discussion

3.1. Daily generated power and efficiency

To simply obtain the generation efficiency (ε) of the louver-type PV, the efficiency was defined as the ratio of the incident solar radiation (G) by the total surface of the louver (A) to the PV total generated power (P) before reaching the inverter, as follows:

$$\varepsilon = 100 \times P / (G \times A) \tag{1}$$

where the incident solar radiation was calculated using the measured global horizontal solar radiation at the site and the equations provided by ASHRAE [1] were used in consideration of the orientation, tilt angle, and solar incident angle.

Table 3 outlines the monthly average generated power and efficiency and Figure 3 illustrates the daily generated power and corresponding efficiency. The monthly average generated power was 4.78 kWh in October, which was highest, while the lowest monthly average was in July at 1.18 kWh. The seasonal average can be ranked as follows: autumn > spring > winter > summer. The averages for autumn and spring were higher than the annual average while the averages for summer and winter were lower.

The generated power was mainly influenced by the comprehensive weather conditions such as solar radiation, cloud cover, and duration of sunshine, and was influenced as well by shading from adjacent objects, module and surrounding temperatures, and soiling of equipment.

In order to investigate general weather conditions, the work of W.C. Cha [2], who analyzed the 1981-2010 monthly average weather data in South Korea was reviewed and it was found that the solar radiation of spring is largest followed by summer, autumn, and winter. The solar radiation of winter is half that of spring. However, the cloud cover in summer is larger than in all other seasons. In addition, the duration of sunshine is shortest in July followed by January and December, and is dependent on the number of rainy or snowy days.

The measurement results were mostly affected by the overall weather characteristics of South Korea. The highest monthly efficiency was 11.6% in October when the power generation was largest. The seasonal efficiency can be ranked as follows: autumn > winter > spring > summer. In the autumn, the monthly average generated power was largest and the efficiency was highest. The solar radiation during autumn was generally high, and the cloud cover and number of rainy days were low. Conversely, during summer, both the monthly average generated power and efficiency were lowest. These results related to larger cloud cover and number of rainy days, although the solar radiation in summer is higher.

Fig. 3 Daily generated power and corresponding efficiency

During winter, the generated power was 1.99 kWh, which was lower than in the spring, but the efficiency was 7.6%, which was higher than that of spring. Even though the absolute generated power was lowest, the actual generation was more efficient in winter. As shown in Figure 4, it was generally found that the higher the generated power, the higher the generation efficiency. However, it can be shown that the overall corresponding efficiency was higher at the same generated power in winter than in other seasons. This was due to clearer sky conditions than in other seasons, and even solar radiation was the smallest at this time.

Table 3. Monthly average generated power and efficiency

Month	PV generated power (kWh)	Efficiency (%)	Month	PV generated power (kWh)	Efficiency (%)
6	1.49	4.8	12	1.26	6.4
7	1.18	5.1	1	1.58	6.8
8	2.25	4.9	2	3.13	9.5
Summer average	1.64	4.9	Winter average	1.99	7.6
9	3.29	7.4	3	3.41	8.1
10	4.78	11.6	4	2.46	5.0
11	2.24	8.2	5	2.21	3.5
Autumn average	3.44	9.1	Spring average	2.69	5.5
			Annual average	2.44	6.8

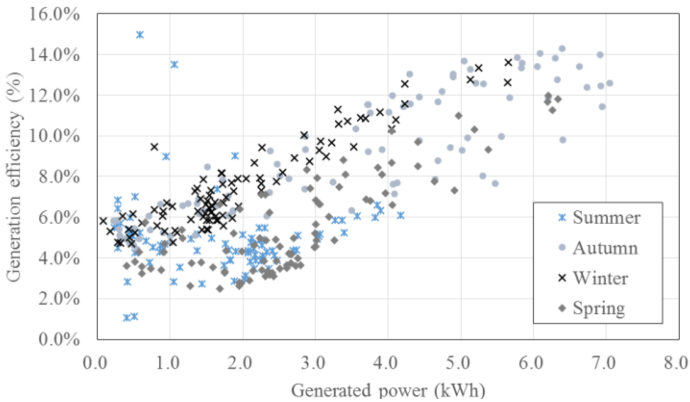


Fig. 4 Relationship between generated power and efficiency

3.2. Effect of local weather conditions on power generation

Figures 5-7 show the relationships between generated power and incident solar radiation, ambient temperature, and relative humidity, respectively. Ambient temperatures and relative humidity were measured onsite. Incident solar radiation was calculated from the global horizontal solar radiation also measured onsite, with a consideration of tilt angle and louver area.

As shown in Figure 5, the incident solar radiation had the greatest effect on the generated power. The effect was more obvious in the winter and autumn than in summer and spring. In the summer and spring, incident solar radiation was higher than in winter but the amount of generated power was smaller. As evident in Figure 6, the ambient temperature did not have a specific relationship with the generated power, but seasonal differences were found, which did affect the generation efficiency. For example, in the summer, higher ambient temperatures was one of the factors that lowered the generation efficiency of the solar cell. The relative humidity was not directly related to the generated power, as shown in Figure 7.

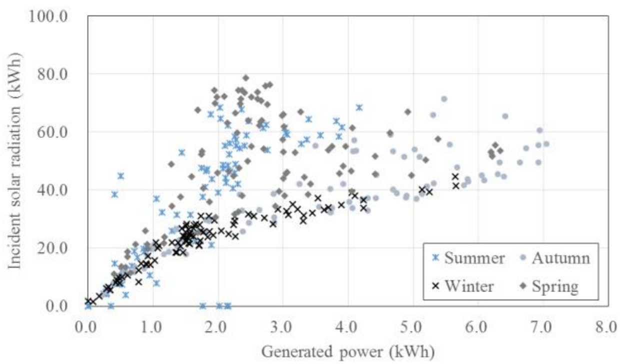


Fig. 5 Relationship between generated power and incident solar radiation

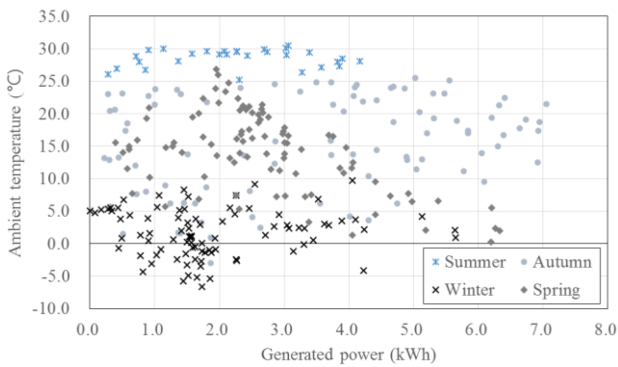


Fig. 6. Relationship between generated power and ambient temperature

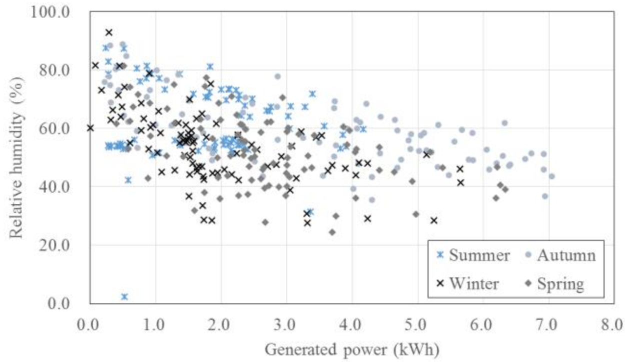


Fig. 7 Relationship between generated power and relative humidity

3.3. Effect of the adjacent buildings on power generation

Four 25-story buildings were constructed in front of the building where the louver-type BIPV was installed. Construction was completed in December 2013. This development was not predicted in the design stage of the BIPV system. However, when a PV system is designed for use in an urban area, the design is likely to encounter such a situation.

In this study, the generated power on a clear day in December, January, April, and May were investigated, as it was anticipated that the PV modules on the louver would be shaded by these adjacent buildings. As shown in Figure 8(a) and (b), with the low solar altitude in winter, the generated power was temporarily reduced from 9:00 to 11:00 a.m. and after 12:30 p.m. n the other hand, as shown in Figure 8(c) and (d), the reduction in generated power was not observed during spring.

To ascertain the temporary shading on a winter day, shading analysis was conducted using a shading visualization tool of DesignBuilder [3]. The results are shown in Figure 9. The louver-type BIPV is demarcated by the red circle. As shown in Figure 9(a) and (b), the PV modules were partially shaded by adjacent buildings from 07:30 to 9:30 a.m. and from 11:30 a.m. to 12:30 p.m. on December 21, thereby resulting in a temporary reduction in generated power. The PV modules were not shaded from 9:30 to 11:15 a.m., only about 2 hours during the day. After 12:30 p.m., the PV modules were fully shaded until sunset, as shown in Figure 9(c). However, as the intensity of the shading was not severe, a slight amount of power was still generated. During spring, there was no shading from adjacent buildings because the solar altitude was sufficiently high to avoid the phenomenon.

As mentioned above, the erection of unanticipated buildings can occur adjacent to a building outfitted with PV modules in a highly dense urban area. The subsequent construction of buildings is likely to lead to issues in the generation performance of a PV system, especially a BIPV system installed on a building façade. In addition, it is difficult to foresee the exact locations, shapes, and heights of future adjacent buildings in the design stage of a PV system. Therefore, it is necessary to analyze generation performance under various possible scenarios. Alternatively, shading patterns can be defined by certain standard locations of buildings. The length of shading and the shading intensity also need to be analyzed, thereby accurately and efficiently evaluating the possible reductions in the generation performance of a PV system.

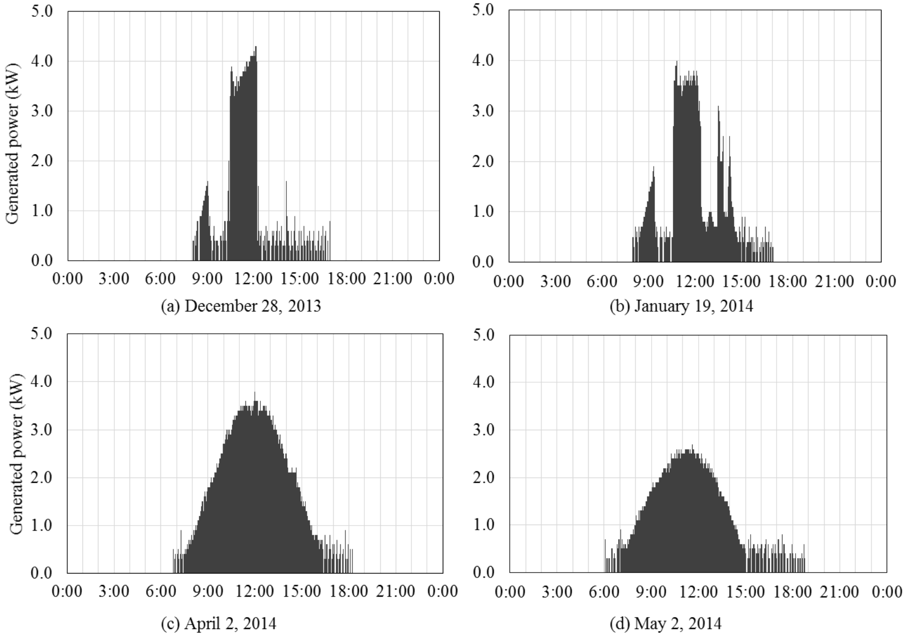
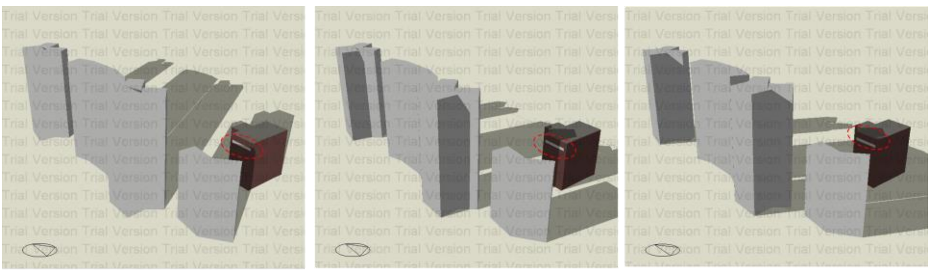


Fig. 8 Generated power after construction of adjacent buildings



(a) 9:00 a.m. December 21 (b) 12:00 p.m. December 21 (c) 15:00 p.m. December 21

Fig. 9 Results of shading analysis

4. Conclusions

In this paper, the generated power and efficiency of the louver-type BIPV in an urban area were analyzed through annual measurements. The effect of local weather conditions and the shading from adjacent buildings on power generation were also investigated.

According to analysis results, the annual average daily generated power was 2.44 kWh and the generation efficiency was 6.8%. The season with the highest average daily generated power and efficiency was autumn, and the lowest average daily generated power and efficiency occurred in winter and summer, respectively. The generated power was mainly affected by incident solar radiation. The generation efficiency was affected by ambient temperatures as well. The shading from adjacent buildings affected the louver-type BIPV only during winter when the solar altitude was low.

The BIPV system, which is installed on a building façade, can be shaded by unanticipated adjacent buildings or objects such as a newly constructed cooling tower or water tank atop a roof, especially in a dense urban area. Therefore, design and operating strategies considering these potential limitations should be further developed.

Acknowledgment

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