PERGAMON

Building and Environment 37 (2002) 615–623

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Efficiency characteristic of building integrated photovoltaics as a shading device

Seung-Ho Yoo[a,*], Eun-Tack Lee[b]

[a] *Department of Architectural Engineering, Daebul University, 72-1 Sanho-Ri, Samho-Myeon, Youngam-Gun, Chon-Nam, South Korea*
[b] *Samsung Corp., SIECT, 25, Gongse-Ri, Giheung-Eup, Yongin-Si, Kyunggi-Do, South Korea*

Received 9 April 2001; received in revised form 30 May 2001; accepted 21 August 2001

Abstract

A building-integrated photovoltaic system (BIPV) has been operated over 1 year in the Samsung Institute of Engineering & Construction Technology (SIECT) in Korea. The PV cells are mounted on the south facade and on the roof of the SIECT in the Giheung area. Special care was taken in the building design to have the PV modules shade the building in the summer, so as to reduce cooling loads, while at the same time allowing solar energy to enter the building during the heating season, and providing daylight. This paper gives a 1 year analysis of the system performance, evaluation of the system efficiency and the power output, taking into account the weather conditions. As a part of certain design compromises, that took into account, aesthetic, safety, and cost considerations, non-optimal tilt angles and occasional shading of the PV modules made the efficiency of PV system lower than the peak rating of the cells. The yearly average efficiency of the sunshade solar panel is 9.2% (average over 28.6°C surface temperature), with a minimum of 3.6% (average over 27.9°C surface temperature) in June and a maximum of 20.2% (average over 19.5°C surface temperature) in December.

Keywords: BIPV; Shading; Efficiency; Power generation

1. Introduction

A Building Integrated Photovoltaic (BIPV) system was developed to generate electrical power on the south facade and roof of the Samsung Institute of Engineering & Construction Technology (SIECT) in Korea, and the design concept , construction and the system were described in the earlier paper [1]. The efficiency of the BIPV and the variation of electrical power generation from the PV system during 1 year are investigated in this paper. The influence of the inclined BIPV panels, surface temperature, and of the shaded area caused by the other panel, on the efficiency are also analyzed for 1 year.

In the past, architects have tended to use glazed facades mainly for aesthetic reasons, but in fully glazed facades, the heat losses tend to be excessive, and the energy consumption for cooling in summer becomes critical. Consequently, double-building skin is being developed, then if a building skin is properly designed, these can be made to convert not only solar energy but electricity as well. A case in point is the BIPV system as a part of the building's exterior [2,3].

It is installed on the south facade of the SIECT in the Giheung area, the southern part of Seoul, Korea. Certain data in this paper are based on the data of Yoo et al. [1], and these sources may be consulted for further details.

2. Description of the building-integrated PV system

2.1. Design concepts

SIECT building has two buildings at the site, of differing heights. Fig. 1 shows the overview of the SIECT building.

As the figure shows, the design includes mainly both sunshade PV modules (marked "C" in Fig. 1) and roof-mounted PV modules ("A" and "B" in Fig. 1). The sunshade modules are fixed in a position above the windows.

* Corresponding author. Tel.: +82-2-842-4235; fax: 00-82-0693-71-0165.

E-mail addresses: energy@unitel.co.kr (S.-H. Yoo), leeet@samsung.co.kr (E.-T. Lee).

0360-1323/02/$ - see front matter
PII: S0360-1323(01)00071-3

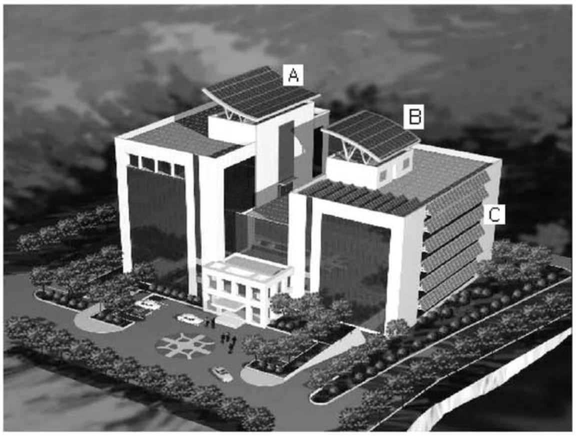

Fig. 1. An overview of the SIECT building.

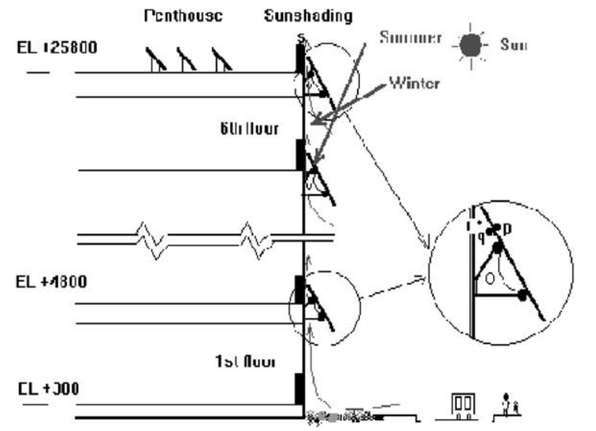

Fig. 2. Concepts of the sun shading solar cell panel and measurement points.

Table 1
Solar cell modules used in SIECT

	Roof a	Roof b	Penthouse	*Sunshading©*
Peak power (kWp)	28	20	12	*40*
Number of unit (-)	440	308	120	*114*
Module area (m^2)	259	183	118	*342*
Standard efficiency (%)	12	12	12	14
Cell material		Polycrystalline		*Single crystal*

Table 2
Technical data of inverter

Max. no-load voltage	480 V DC
MPP voltage at 25°C/1000 W/m^2	340 V DC
DC ripple	$< 5\%$
Grid voltage	380 V 3-phase $\pm$ 10%
Grid frequency	60 $\pm$ 1 Hz
$\cos\varphi$	> 0.9 at nominal power
DC-power	40 kW
Maximal rated DC-current	120 A
Grid fuse minimal	100 A gl

2.2. The system

Two types of PV modules were used for the system. Table 1 summarizes their material data. Depending on the kind of cell material, about 12% or 14% of the total incident solar radiation is converted into electricity under standard conditions. The actual efficiency also depends on the cell temperature. The sunshading module in point is rated at 40 kWp, which is installed on the south façade of the building.

Table 2 shows the technical data of the inverters.

3. Measurement and analysis of performance

3.1. Measurement details

The system output is monitored at the PV inverters by a data acquisition system controlled by a measurement-and-analysis program (PV-WR 1800/1500 PV-DATA), mounted on a PC. The program loads up and stores these output data, and later converts it to a daily data summary, which is stored at midnight (or whenever the device is switched on or off). Also measured and recorded, every 10 min, are several temperatures and the global solar irradiance on a horizontal surface. Fig. 2 shows the principles of the sun shades for solar cell panel in summer and measurement points.

The temperature measurement points include the outdoor air temperature, the solar cell top-surface temperature (measured at “p” in Fig. 2), and the solar cell under-surface temperature (measured at “q” in Fig. 2). Also, the air temperatures behind certain modules were measured; in particular, those behind the modules near the 6th floor (measured at “r” in Fig. 2), the 1st floor, and Roof B. All these measurements were made by using a Fluke data logger connected to thermocouples at the measurement sites, and also to an Eko solar pyranometer (marked “s” in Fig. 2).

3.2. Operation results for 1 year

To simplify the analysis of the results of the 1 year operation, we first analyze only the results for the sunshade module (40 kW) for every month (12 months): From August 1997 to July 1998.

3.2.1. Summer season results (June, July, August and September)

Among the summer months, selected as June, July, August and September, Figs. 3, 4, 5 and 6 show plots of the

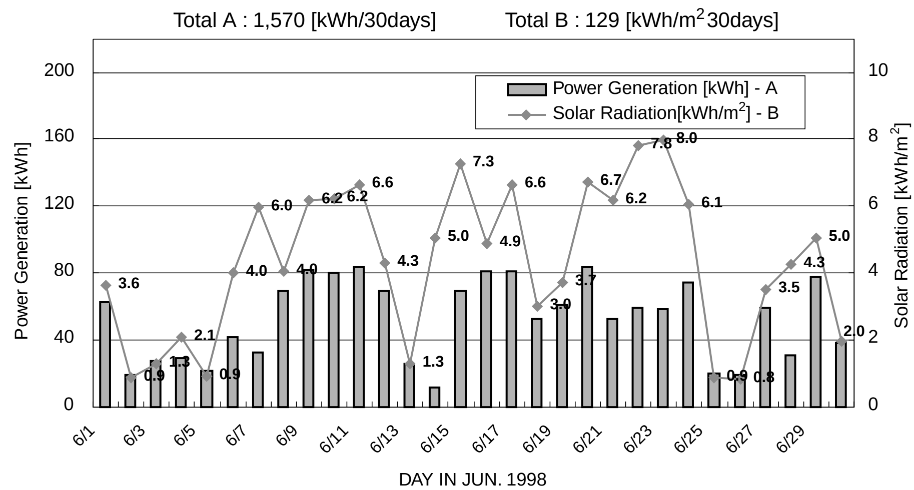

Fig. 3. PV power generation results for the summer month (June 1998).

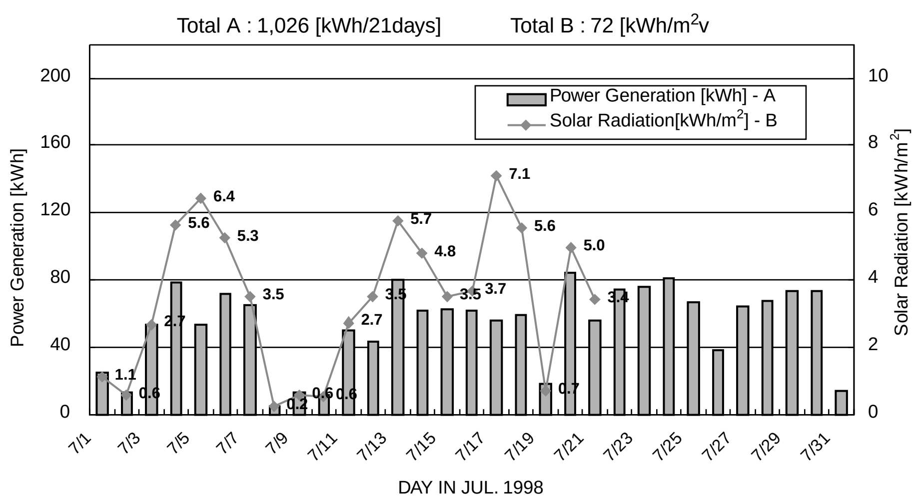

Fig. 4. PV power generation results for the summer month (July 1998).

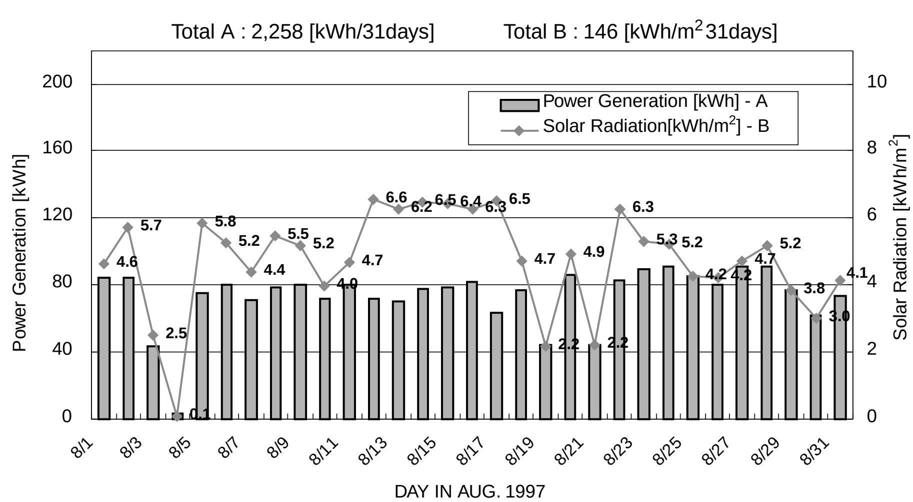

Fig. 5. PV Power generation results for the summer month (August 1997).

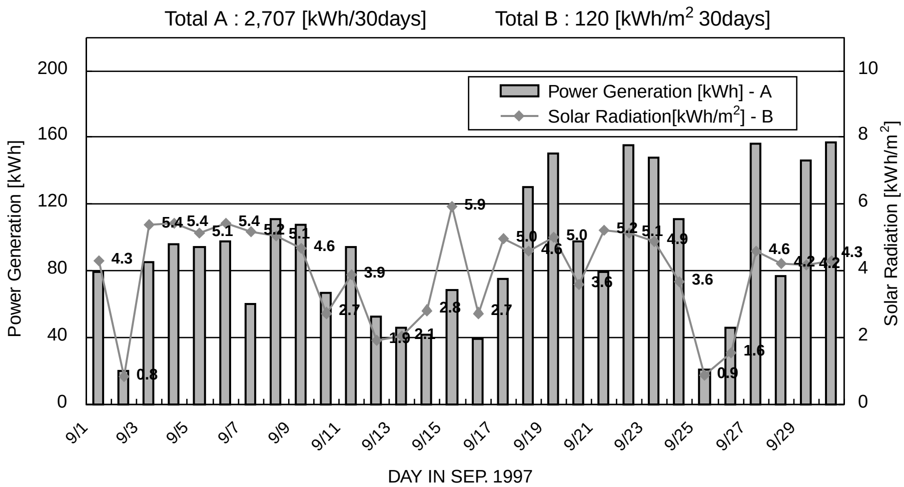

Fig. 6. PV power generation results for the summer month (September 1997).

PV power generation results, respectively, for June 1998, July 1998, August 1997 and September 1997, along with the solar irradiance, as a function of day.

Table 3. shows the total power generation, total solar radiation and the efficiency (total power generation/total solar radiation) for summer months.

The average efficiency for summer season is approximately 4.7%, while the average surface temperature and outdoor air temperature during this season is, respectively, 32.3°C (2F) and 24.2°C.

Even though the over surface temperature of the solar cell panel is relatively lower than one of the other months among summer months, the efficiency of the PV system shows the lowest value in the month (June) which has a highest solar altitude, because of the influence of shades cast by the other solar cell panel. This means that the available shaded area of the solar cell panel should be considered most significant in the design phase. When the electrical power of 80 kWh was generated for 1 day of these summer months, the solar radiation intensity corresponded to 6.2 kWh/m^2 on June 10,

Table 3
Total power generation, total solar radiation and the efficiency (total power generation/total solar radiation) for summer months

		June 1998	July 1998	August 1997	September 1997
Total power generation (kWh)		1569.7	1025.5	2258.2	2707.0
Total solar radiation (kWh/m^2)		129.1	72.3	146.0	120.0
Efficiency (%)		3.6	4.1	4.5	6.6
Average solar cell	(2F)	27.9	29.8	35.5	35.9
temperature	(6F)	30.7	31.7	38.9	35.2
Average air temperature		22.5	25	27.5	21.8
No. of day (days)		30	21	31	30

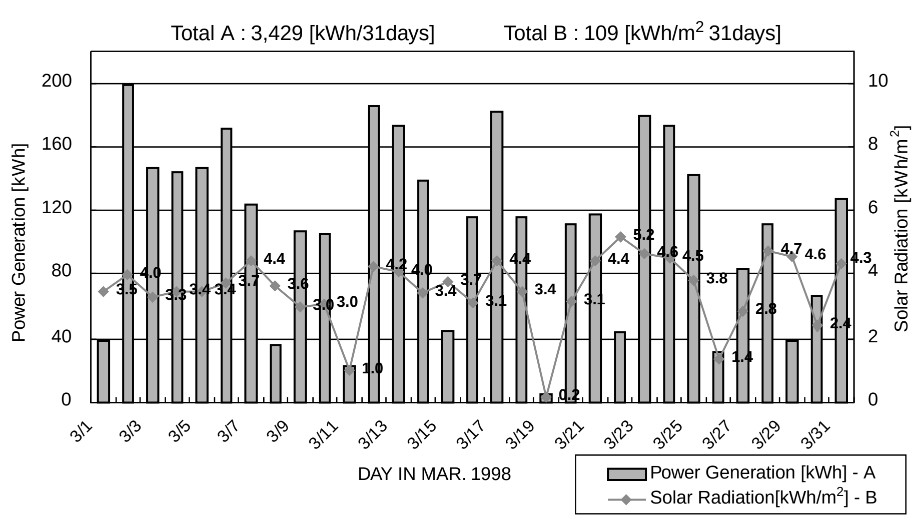

Fig. 7. PV power generation results for the mid-term month (March 1998).

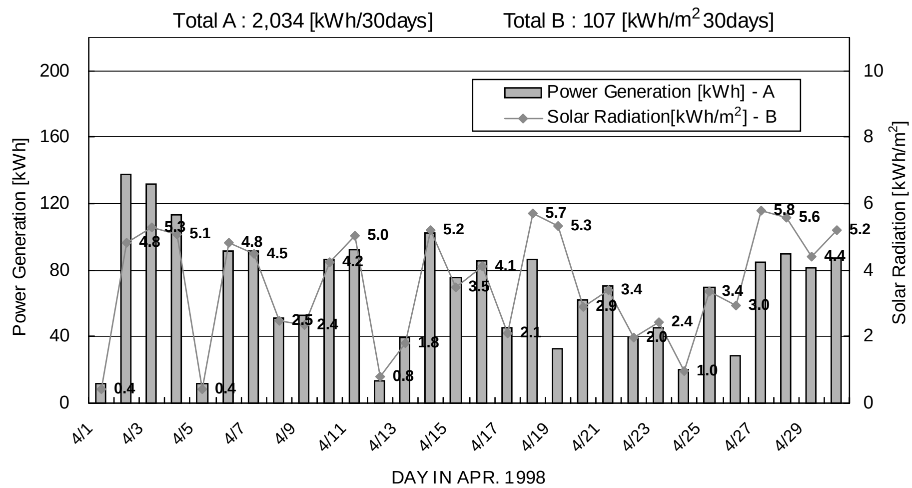

Fig. 8. PV power generation results for the mid-term month (April 1998).

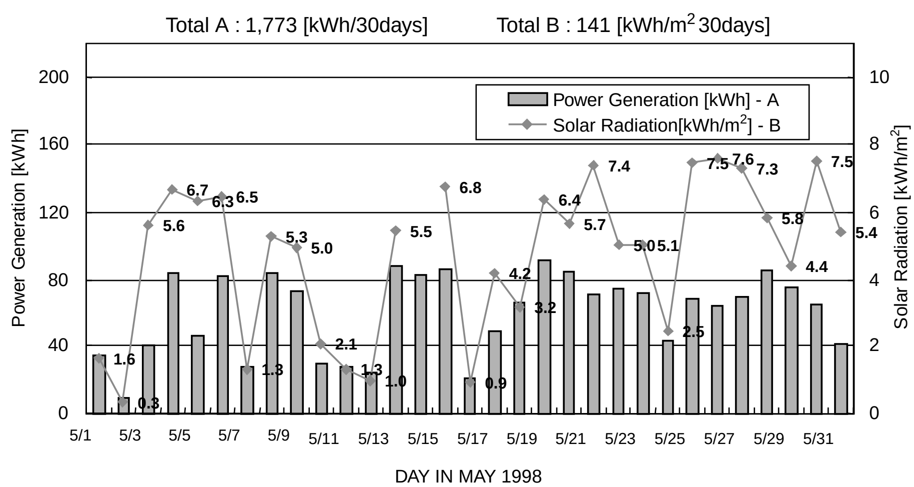

Fig. 9. PV power generation results for the mid-term month (May 1998).

5.7 kWh/m^2 on July 14, 5.5 kWh/m^2 on August 10 and 5.2 kWh/m^2 on September 22.

3.2.2. Mid-term results (*March, April, May and October*)

Among mid-term months (i.e. a month neither cold nor hot), selected as *March*, *April*, *May* and *October*, Figs. 7, 8, 9 and 10 show plots of the PV power generation results, respectively, for March 1998, April 1998, May 1998 and October 1997, along with the solar irradiance, as a function of day.

Table 4 shows the efficiency (total power generation/total solar radiation) for the mid-term months.

The average efficiency for the mid-term season is approximately 7.5%, while the average surface temperature and outdoor air temperature during this season is, respectively, 29.9°C (2F) and 15.6°C. When the electrical power of 80 kWh is generated for 1 day of this mid-term months, the corresponding solar radiation intensity was 2.8 kWh/m^2 on March 28, 4.4 kWh/m^2 on April 30, 5.8 kWh/m^2 on May 29 and 4.4 kWh/m^2 on October 6.

3.2.3. Winter season results (*November, December, January and February*)

Among winter months, selected as *November*, *December*, *January* and *February*, Figs. 11, 12, 13 and 14 show plots of the PV power generation results, respectively, for November 1997, December 1997, January 1998 and February 1998 along with the solar radiation, as a function of day.

Table 5 shows the total power generation, total solar radiation and the efficiency (total power generation/total solar radiation) for winter months.

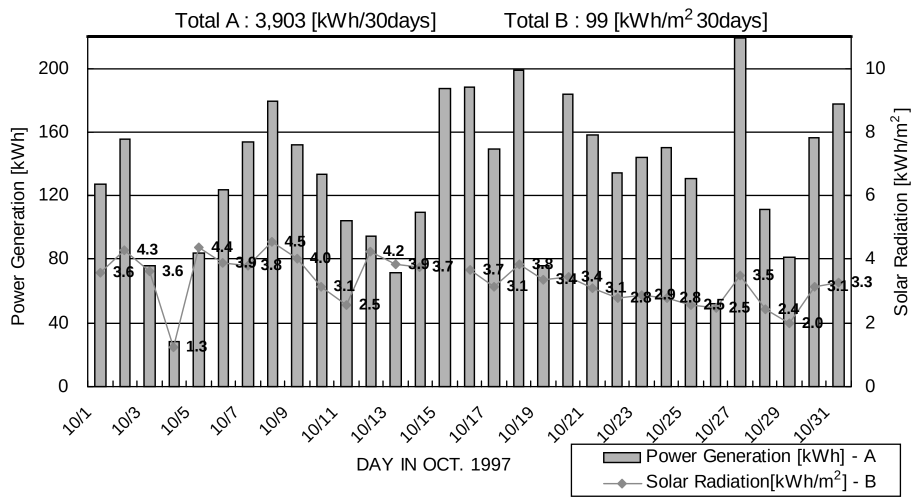

Fig. 10. PV power generation results for the mid-term month (October 1998).

Table 4
Total power generation and efficiency

		March 1998	April 1998	May 1998	October 1997
Total power generation (kWh)		3428.7	2033.8	1773.2	3903.8
Total solar radiation (kWh/m^2)		108.8	107.0	140.9	99.1
Efficiency (%)		9.2	5.6	3.7	11.5
Average solar cell	(2F)	29.1	25.8	25.7	38.9
temperature	(6F)	23.3	26.9	29.6	32.5
Average air temperature		9.3	17.1	20.2	15.8
No. of day (days)		31	30	30	30

The average efficiency for winter season is approximately 15.5%, while the average surface temperature and outdoor air temperature during this season is, respectively, 23.8°C (2F), and 5.3°C. When the electrical power of 160 kWh is generated for 1 day of these winter months, the solar radiation intensity was corresponding to 2.6 kWh/m^2 on November 21, 2.1 kWh/m^2 on December 11, 3.2 kWh/m^2 on January 31 and 3.4 kWh/m^2 on February 27.

The efficiency of the PV system shows the highest value in the month (December), which has a lowest solar altitude, because the shaded area is less than that of the other months.

Fig. 15 shows the temperature distribution around the PV modules on February 17, 1998. The difference between the top surface cell temperatures (p in Fig. 2) on the 2nd floor and 6th floor is quite large. Namely, the air temperature, and solar cell surface temperature of the 6th floor are lower than that of the 2nd floor. This tendency is shown from October to March. This is because the 6th floor (being the top most floor) is more influenced by the long wave radiation from a colder sky, while that on the 2nd floor is not so

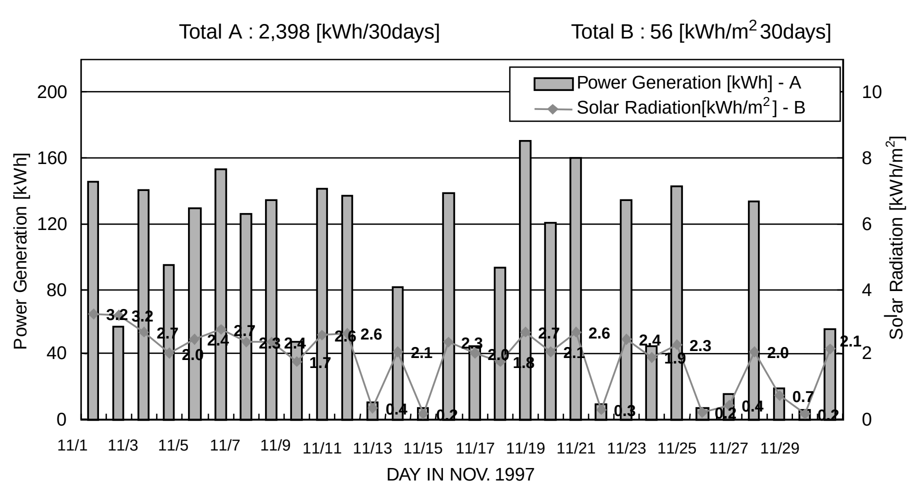

Fig. 11. PV power generation results for the winter month (November 1997).

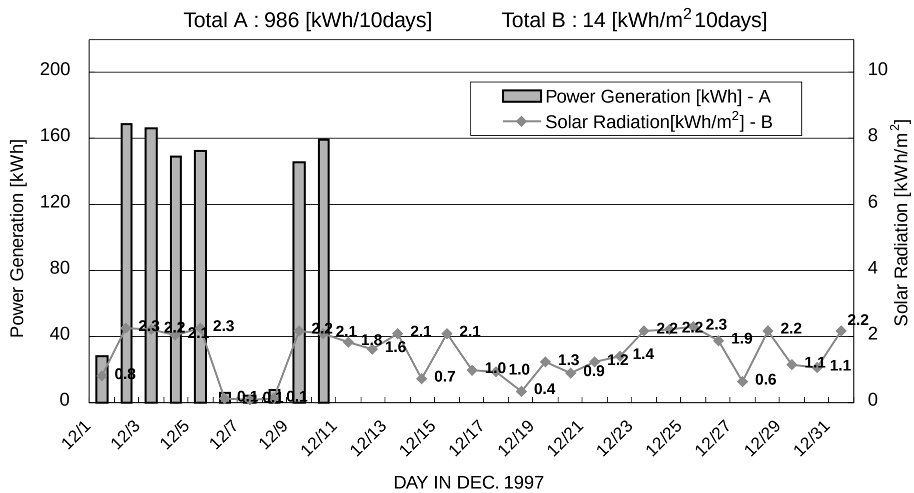

Fig. 12. PV power generation results for the winter month (December 1997).

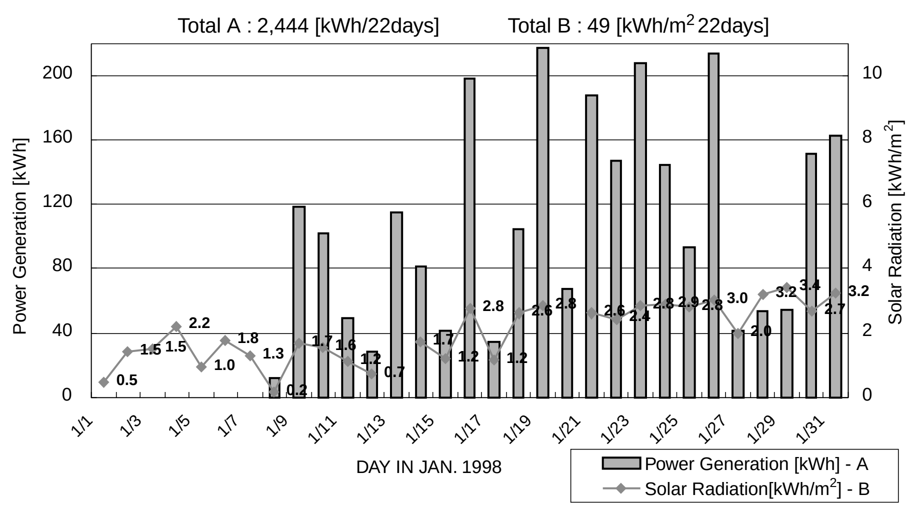

Fig. 13. PV power generation results for the winter month (January 1998).

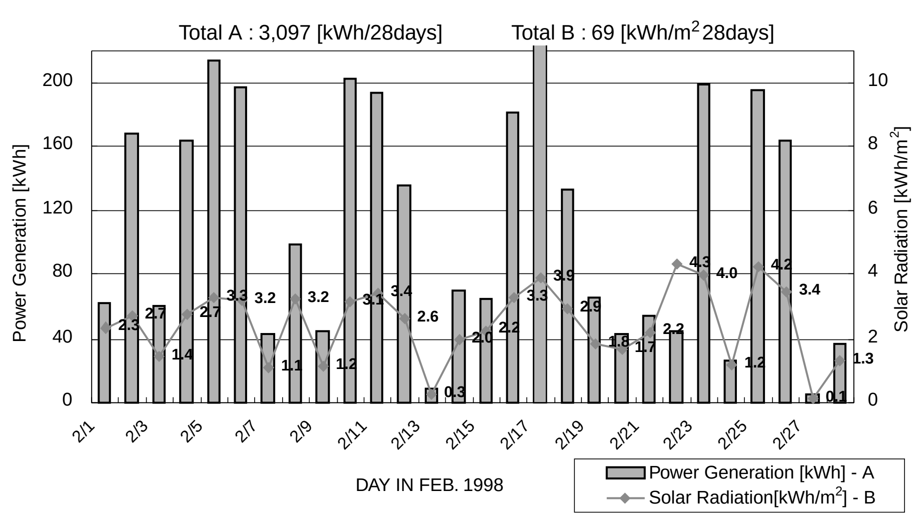

Fig. 14. PV power generation results for the winter month (February 1998).

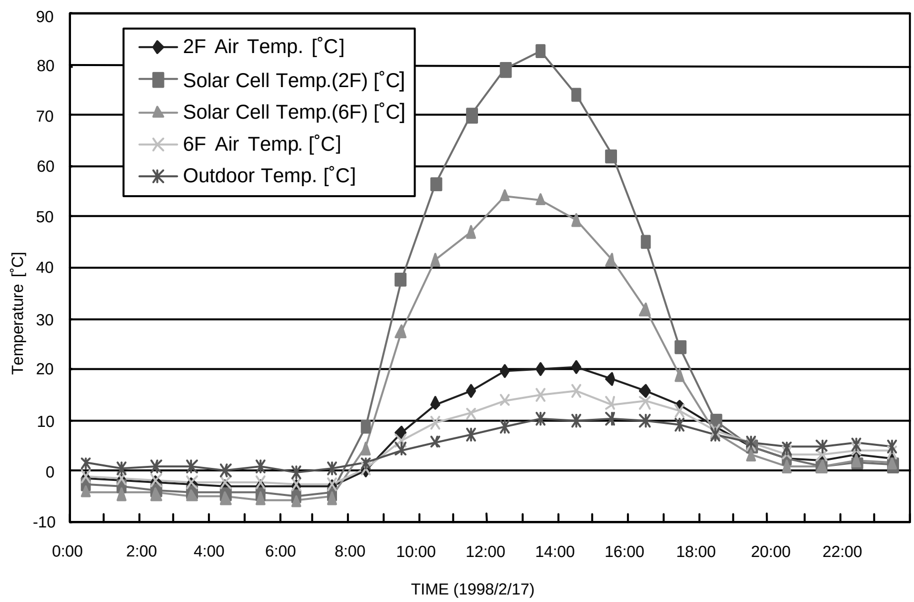

Fig. 15. Temperature distribution around the solar cell (February 17, 1998).

much influenced, because of the shades cast by the above PV panels. Air temperature and solar cell surface temperature of the 6th floor is higher than that of the 2nd floor from April to September (see also [1]), because the 6th floor is influenced by the long wave radiation from the warmer sky, while the 2nd floor is not so much influenced, because of the shade cast by the above PV panels.

Fig. 16 shows plots of the PV power generation and solar cell temperature, along with the solar irradiance, as a function of time on February 17, 1998 (relatively sunny day).

The total energy generation is 221 kWh (68 kWh on August 12, 1997, relatively a sunny day, see also Yoo et al. [1], and the global solar irradiation on a horizontal surface is 3882 Wh/m^2 (6554 Wh/m^2 on August 12, 1997). Even though the outdoor temperature is about 10°C, the average cell surface temperature on the 2nd floor is 33.2°C (43.5°C on August 12, 1997, the outdoor temperature was about 31°C). The temperature difference between air temperature and solar cell surface temperature is about 23.2°C in the same day, and about 12.3°C in summer (August 12). This means that there was no shade cast by the above solar cell panel in the winter. Therefore, the efficiency of the winter season is higher than that of the summer season.

4. Summary and conclusions

Considering the efficiency of a BIPV system, the findings and observations during the 1-year operation in Korea can be summarized as follows:

The efficiency of the sunshade module on the south façade varies considerably depending on the month and the season, due to the shadows cast by other PV panels and the tilt, the orientation and the surface temperature variation of the PV panel. Therefore, the influence of the shadow cast by other PV panels should be carefully considered during the design phase. Precisely, the maximum and minimum values of the efficiency in June and December are, respectively, 3.6% and 20.2%.

The yearly average efficiency of the sunshades is 9.2%, while the average over surface temperature is 28.6°C. The average efficiency of the sunshades according to the season is shown below.

Season	Average efficiency (%)	Average over surface temperature
Summer	4.7	32.3°C, 2nd F
Mid-term	7.5	29.9°C, 2nd F
Winter	15.5	23.8°C, 2nd F

Table 5
Total power generation and the efficiency for winter months

		November 1997	December 1997	January 1998	February 1998
Total power generation (kWh)		2697.7	985.8	2443.8	3097.3
Total solar radiation (kWh/m^2)		56.4	14.3	48.6	69.1
Efficiency (%)		14.0	20.2	14.7	13.1
Average solar cell	(2F)	28.1	19.5	21.1	26.4
temperature	(6F)	25.1	18.3	16.3	20.1
Average air temperature		11.2	4.1	0.8	5.1
No. of day (days)		30	10	22	28

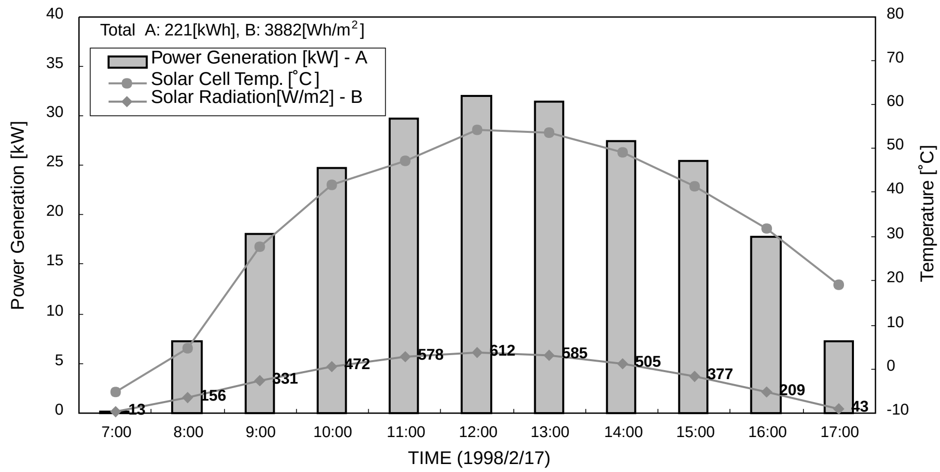

Fig. 16. Power generation on a winter day (February 17, 1998).

From October to March, the solar cell surface temperature of the 6th floor (top floor) was relatively lower than that of the 2nd floor. The temperature was reversed from April to September because of the influence of the long wave radiation from the sky.

It is recommended that a solar cell panel as a shading device on a south façade should be applied in such a way that it is not shaded by the above panel. For example, the angle of the sun-shading panel should be planned to be flexible, changing at least according to the season. Alternatively, a more economical option would be the installation of solar cell panels on every second story.

Some distance from the panel to the façade should be kept in order to promote natural ventilation around the panel surface for reducing its surface temperature.

Based on this investigation, the key point we suggest is that a photovoltaic system should be applied, not just for generating electricity, but also for improving general aspects including the use of thermal energy behind the panel during the winter, daylight provision inside the room, shade provision for the interior of the building during the summer, and aesthetical contribution to the interior view and exterior of the building.

Acknowledgements

This work was supported by the Korea Research Foundation Grant “(KRF-2001-013-E00124)”. We would like to express our gratitude to the KRF for offering the possibility to concentrate on the academic and technical issues presented in this paper.

References

[1] Yoo SH, Lee ET, Lee JK. Building integrated photovoltaics: a Korean case study. In: Solar Energy, vol. 64. Amsterdam: Elsevier Science, 1998. p. 151–61.

[2] Kiss G, Kinkead J. Building-integrated photovoltaics: a case study. First World Conference on Photovoltaic Energy Conversion, Hawaii, 1994.

[3] Yoo SH, Lee JK. Building envelope system constructed by solar cell. Korean patent 0201540, Korea patent office, 1999.