

Year round Simulation of a BIPV as a shading device through Parameter Variation

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Abstract - In this paper, a modeling process and a brief overview of the overall approach are given as well as the influences of the inclined solar cell panel and the shading from other panels on the power generation which are primarily analysed using the recently developed simulation tool SOLCEL(S.H.Yoo, 2004, 2007 and 2008). For the validation of the theoretical work, experimental results of the SIECT(Samsung Institute of Engineering and Construction Company) building were used. Angle of the BIPV(Building Integrated Photovoltaic) for the maximum power output could be estimated at approximately 75° to the vertical wall, considering all possible factors around the real building. The yearly maximum power generation of the BIPV is gained at exact south in the boundary condition of the building. As reflectance of the façade is increased, power generation becomes higher. The influence of the façade reflectance is approximately 11% much more than the influence of the earth surface reflectance. The influence of the façade reflectance is significantly higher than one of earth reflectance, as the reflectance becomes higher and higher. In this work, the simulation program SOLCEL, used for the calculation of a shading area, surface temperature of a solar cell panel, effective solar radiation on solar cell panel and the power generation of a BIPV as a shading device, has been validated and used for a one year simulation.

Key words : Building azimuth, BIPV, Power generation, Solar irradiance, PV angle

1.Introduction

Many different kinds of solar cells for photovoltaic have been developed, such as crystalline solar cells and thin-film solar cells etc. An important point is not only the efficiency of the solar cell panel itself but also an effective application under real conditions in buildings. Also, we need a precise estimate of the power generation to apply effectively a BIPV(Building Integrated Photovoltaic) system. A BIPV system as a shading device is useful not only for power generation, but also for shading to reduce cooling load. The efficiency variation of a BIPV system as a shading device during a one year period has already been experimentally investigated in an earlier paper (Yoo and Lee, 2002). Details for the SIECT (Samsung Institute of Engineering and Construction Company)building and the BIPV installation are available in Yoo et al(1998). The BIPV is composed of semi-transparent PV units.

The modelling techniques for a PV system simulation has been developed extensively (Menicucci et al., 1984, A.Zahir, 1994, and Walker et al., 2003, etc.). These different simulation tools have their own characteristics and limitations when simulating a newly developed or considered system. A new simulation tool was needed to optimize a special type of BIPV, which is of interest in this study, such as sunshade system with semi-transparent solar cell panel on a vertical facade. In this paper, a modelling process and a brief overview of the overall approach(Inputs, outputs, code/software characteristics, availability etc.) are given and the influences of the inclined solar cell panel and the shading from other panels on the power generation are mainly simulated for 1 year using the recently developed simulation tool SOLCEL(S.H.Yoo, 2004, 2007 and 2008). There are no shadows considered, cast by other buildings, except shadows between any PV panels themselves. The SIECT building for the validation of the simulation program is located in a rural area and oriented to 190 Degree from north. The geographical location is on latitude 37.3 N and longitude 126.6 E. The experimental work had been made from 1997 to 1998 for one year.

2.Theoretical Approach for the simulation of the BIPV

2.1 System of coordinates, calculation process of shading(or sunlit) area and characteristics of SOLCEL

This model calculates the shaded area(ultimately for the sunlit area ratio) depending on the design of BIPV, effective solar irradiance(all the possible components which is possible to meet on the BIPV as shading elements on the façade), solar cell panel over surface temperature, and amount of power generation. The program model uses the following input parameters to calculate the above mentioned elements:

- latitude, orientation of façade which the BIPV is installed;
- Hourly global solar irradiance on a horizontal surface or direct normal and diffuse irradiance on horizontal surface in typical year and hourly air temperatures and wind speeds;
- Ground reflectance, and absorptance, emittance, transmittance, and thermal conductivity of solar cell panel;
- Angle on vertical(or horizontal) surface, length and width of PV panel, number of total Panel, distance between lower and upper panel on the façade, and PV conversion loss(temperature factor, performance ratio(module soiling, inverter efficiency, wire resistance... etc.).
- Module clearness factor

2.2 Solar irradiance incident on surface of a tilted solar cell panel

Quantitative assessment of radiation arriving on an inclined surface is very important to engineers designing solar energy collecting devices, including BIPV. Usually we have a global solar irradiance on a horizontal surface at a site of interest as a measurement data. Therefore we have to begin with measured global solar irradiance received on a horizontal surface and then transpose these quantities onto an inclined plane. The available total solar irradiance incident on the inclined solar cell panel is composed of three components: beam, diffuse and ground - reflected components. There have been developed some kinds of important solar radiation models on tilted surfaces. Because this code SOLCEL has been developed for the BIPV, many reflected

components around the PV modules of solar irradiance should be considered. Therefore the Isotropic sky model has been applied and corrected by an exact calculation of view factors between solar cell panel(sunlit area and shaded area) and sky for the BIPV, for the consideration of a special geometry condition.

The total incident irradiance on a surface can be simply written as the following equation (1)

$$I_t = I_{t,b} + I_{t,d}$$

(1)

In equation (1), total diffuse irradiance $I_{t,d}$ is composed of three components from sky, and radiation reflected from the various surfaces “seen” by the tilted surface, namely $I_{t,d,iso} + I_{t,d,cs} + I_{t,d,hz} + I_{t,d,refl}$, where the subscripts iso, cs, hz, and refl refer to the isotropic, circumsolar, horizon, and reflected radiation streams. The direct part of solar radiation $I_{t,b}$ plays a very important role for a photovoltaic, especially for BIPV, because an amount of a reflected solar radiation from a wall, the ground and other panels and shade area could be mainly influenced by the direct part according to a principle of not view factor, but a specular reflectance like as shown in Figure 1 (D, E and F).

2.3 Calculation of power generation

Various types of solar cells have been developed to get more power generation. It is well known that the efficiency of almost any types of solar cells is also influenced by the surface temperature of the PV cell. This is also the case for the considered cell type in this work. If a solar cell panel is used as BIPV for a shading device, the solar irradiance on the solar cell panel is quite different from a conventional system. The reflected portion from the ground, the re-reflected portion from the wall and the transmitted portion through the upper panel should be considered for the precise calculation.

The simulation process for a power generation can be carried out by the following three principles.

- 1) The most important factor is the precise calculation of irradiation reaching on the panel.
- 2) The upper surface temperature of the solar cell panel should be calculated.
- 3) All the other possible aspects(Assumed reflectance of ground and wall, transmittance of upper panel, etc) that could influence on power generation should be considered.

A more detailed explanation about some important solar radiation processes influencing the power generation is given in Figure 1.

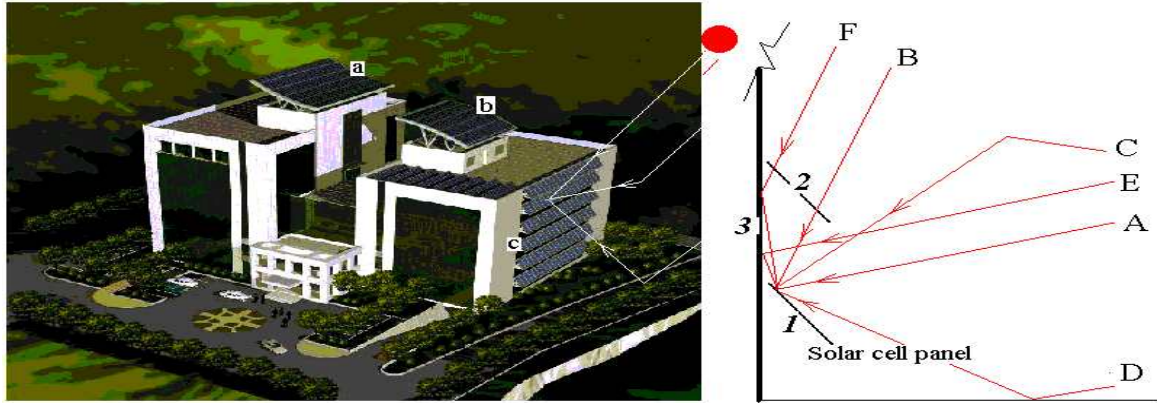


Figure 1 Solar radiation incidence processes reaching on the solar cell panel

In this work, all the most important factors are taken into account for calculating the power generation. The left picture of figure 1 is the SIECT building which is simulated in this work. In the left side of the picture, (c) area is used for the comparison between experiment and simulation. The panels (a) and (b) are not considered in this study.

Total solar irradiance reaching the entire surface of the inclined solar cell panel.

The effective solar irradiance ESR can be written as equation (2). (See Fig.1)

$$ESR = (A+B+C+D+E+F)/TPA$$

(2)

The cell over surface temperature can be calculated according to the heat balance equation between the sky , ground and the cell panel by the using the definition of combination temperature which can consider the long wave radiation from surroundings (G.Nehring, 1962). The power generation of BIPV depends on the cell temperature and now we can calculate the power generation (PG) for the BIPV according to the equation (3).

$$PG = P_n \times (ESR / S_n) \times PR$$

(3)

The PV generator performs best if it is homogeneously illuminated. A partial shading may seriously decrease the available output power, because the cell with the lowest illumination determines the operating current of the whole series string (F.Sick et al, 1996). This partial shading can be usually made only in the case of direct irradiance. We may consider for this influence by giving the partial shading factor Pfactor. In this study, Pfactor is defined by the following equation

(4).

$$P_{\text{factor}} = (1 - C_{\text{INDEX}}) \times (PR1 \times SAR + PR2 \times (1 - SAR))$$

(4)

Therefore we can formulate the amount of real power generation (RPG) to the following equation

(5).

$$RPG = P_n \times (ESR / S_n) \times P_{\text{factor}}$$

(5)

Herein, $PR1 = 1 - 0.01 \times (TLOSS1 + SYS + CONLOSS)$, $PR2 = 1 - 0.01 \times (TLOSS2 + SYS + CONLOSS)$, $P_n = STCW_p \times UNIT$ (in this work, $P_n = 345 \times 114 = 39330$ W (See Table 2), P_n is the nominal power which the module can produce under STC (standard test conditions). This is a definition used to compare different modules. STC represents an irradiation of 1000 W/m² (S_n) at an air mass of AM1.5 and a cell junction temperature of 25°C (T_n).

3. Validation and Simulation

3.1 Validation of the simulation program against experimental data

The measurement had been made from August 1997 to July 1998. The measurement method, device and details are available in the previous paper (Yoo and Lee, 2002). This experimental data is used for the validation of the simulation program SOLCEL. The BIPV cells have been mounted with an inclination of 35° to vertical wall on each floor (South façade) of a building with 6 floors near Suwon city (Latitude: 37.28N, Longitude: 126.58E), South Korea. Characteristic of the solar cell panel is semi-transparent. The cell type is Single crystalline.

The detailed data for PV cells are shown in table 1. These data were used also for simulation.

Table 1 Technical data of PV module unit for the simulation

Building azimuth	190	PV angle to vertical wall	35
Weight	93Kg/unit	No. of cells per unit	230
Standard test condition	345 Wp	1 Unit dimension	2.47m×1.1
Power			7m
Standard efficiency	14.4 %	No. of total units	114
Coverage ratio of cell	85 %	Transmittance of glass in solar cell	0.75

		panel	
Length×Width(PV Panel)	2.47m×22.98m	Absorption coefficient of PV cell	0.9
PV panel abstance	4.2m	Emittance of PV panel	0.9
Thermal conductivity of PV	3.5w/mh ⁰ c	Emittance of wall	0.9
Floor	6	Reflectance of earth	0.3
Reflectance of wall	0.4	System loss	5%

For the relevant validation of SOLCEL, two days were selected. The first day is a typical winter day (February 17); the second one is a typical Summer sunny day (August 12). The global solar irradiance on a horizontal surface, air temperature and surface temperature were measured for validation. From the global solar irradiance data, beam and diffuse components of solar irradiance were derived according to the diffuse ratio as a function of hourly clearness index. (Erbs, D.G. Et al, 1982). For the simulation, the weather data from Suwon, where the building is located, was used for wind speed for convection heat transfer coefficient calculation, because wind speed had not been measured, but the measured global solar irradiance and air temperature were used for simulation. The total area of the solar cell panels is 342 m²(Sum of 6 Floor, TPA).

Fig.2 shows the experimental and simulation results of the cell surface temperature and the power generation for February 17.

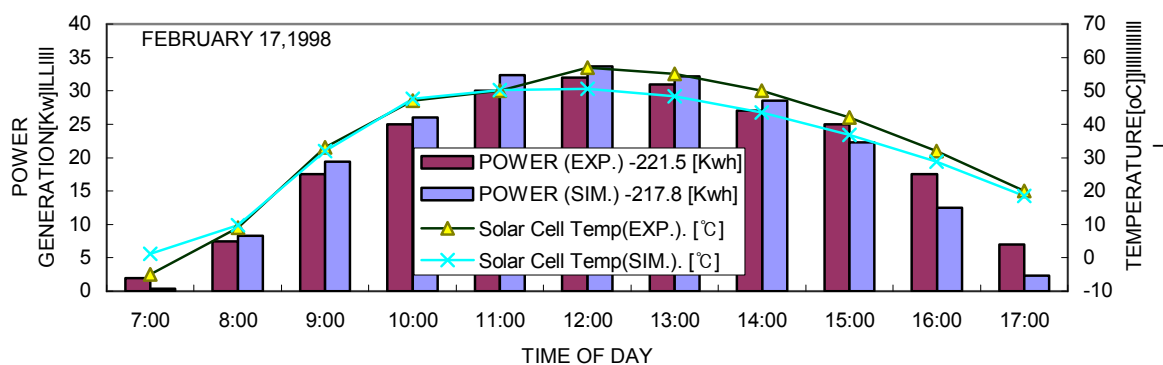


Figure 2 Power generation and surface temperature on a winter day
(February 17, experiment + simulation)

The simulation results for power generation have an excellent agreement of 98% with the experimental results, but the simulation and experimental results for over surface temperature of a solar cell panel is a little bit different, attaining higher solar irradiance. This is derived that the measurement point for the cell surface is directly exposed to the sun, but the simulation was made under the condition which the average value of solar radiation for the whole solar cell panel is used. Figure 3 shows the simulated power generation compared against the measured values for August 12, corresponding to a sunny day

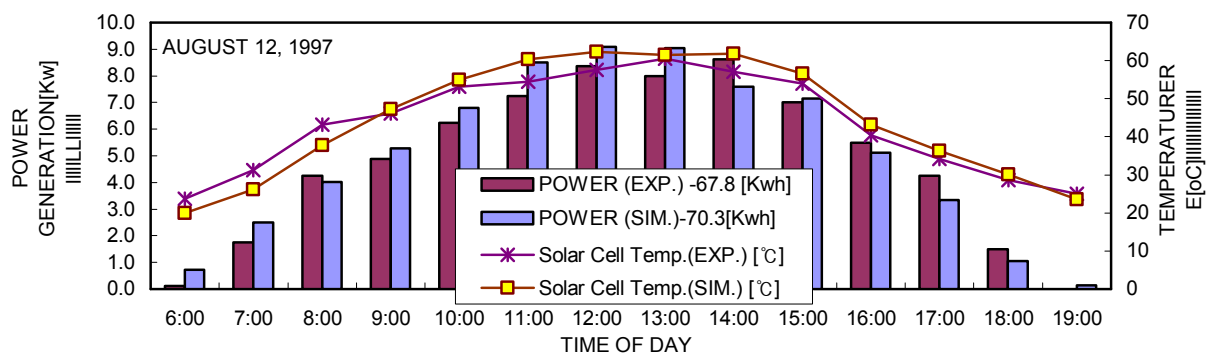


Figure.3 Power generation comparison between experimental data and simulation (August 12 1997)

The simulation results for power generation shows a good agreement of 96% with the experimental results.

The simulation program SOLCEL has been developed for the calculation of power generation of BIPV used as a shading device (S.H.Yoo, 11.2004). The program is validated against experimental data of the SIECT building in Korea. The simulation results show a good agreement with the experimental data. Especially the sum of power generation shows a good agreement of 95%. This accuracy may be fulfilled by the Using of partial shading factor(Pfactor), especially in the case of being any partial shading.

3.3 Parameter Variation

1) Angle of solar cell panel

The angle of solar cell panel is changed from 15° to 85°. Figure 4 shows the power generation dependant upon the angle of solar cell panel.

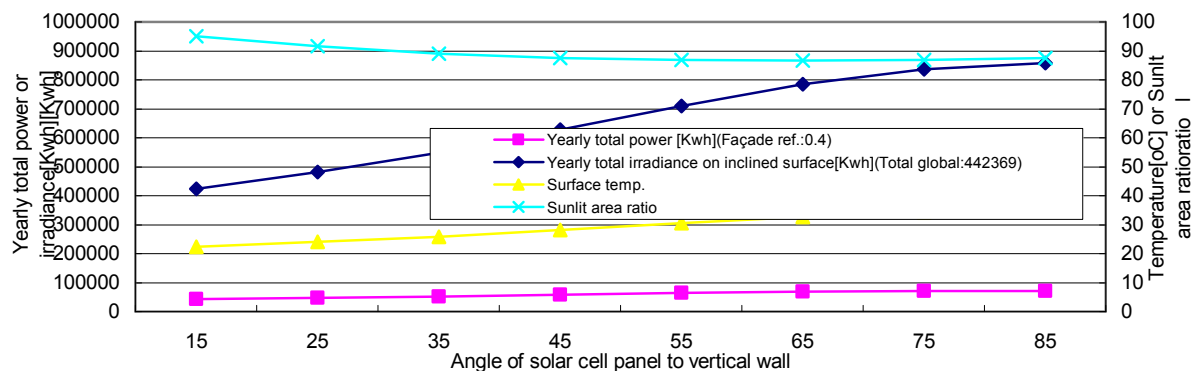


Figure.4 power generation according to change of the angle of the solar cell panel

In figure 4, the angle of the solar cell panel of the real building is 35° to the vertical wall. As it is seen, the maximum power output of the BIPV can be estimated at approximately 75° to the vertical wall, considering all possible factors in the building. Fig.5 shows monthly power generation, when pv angle is respectively at 35° and 75° .

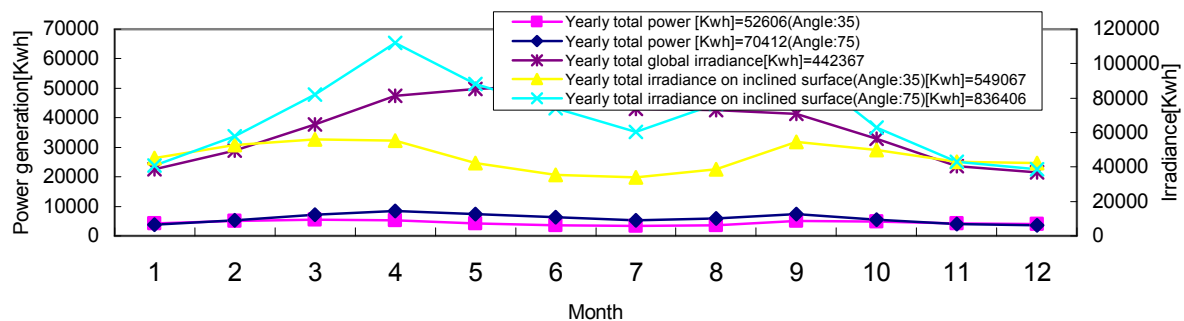


Fig.5 Monthly power generation

In Figure 5, analyzing the amount of monthly power generation as well as the amount of power generated at 35° inclination in Winter(1,2,11,12) is slightly more than one of 75° inclination. This tendency is explained by the yearly total irradiance on inclined surface at PV angle 35° and 75° .

2) Sunlit area ratio on a solar cell panel of the BIPV

The sunlit area ratio(SAR) was calculated by SOLCEL. Fig. 6 shows the monthly ratio of the sunlit area to the total solar cell panel area, depending on the angle of the solar cell panel of the BIPV in SIECT.

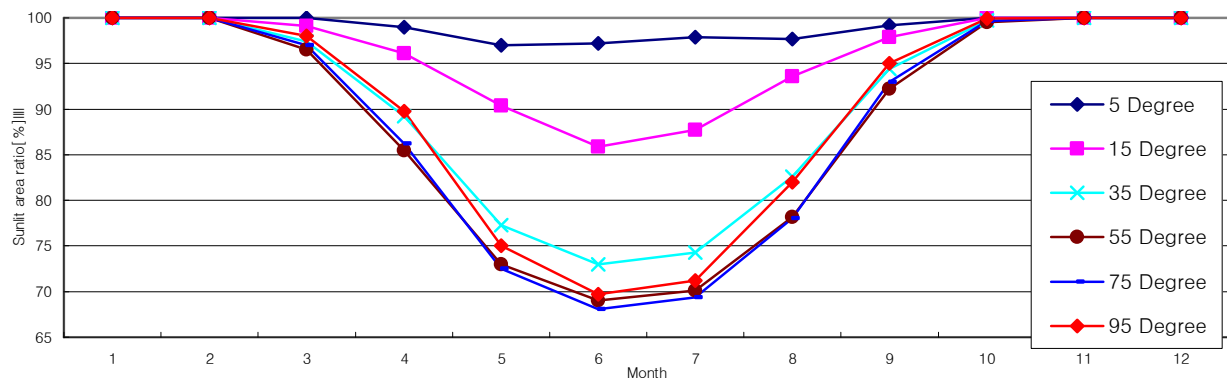


Figure.6 Monthly sunlit area ratio

Analyzing figure 6, the turning point of shading through solar cell panel appears in February and October. Sunlit area ratio is the lowest in June applying any angle of the PV panel.

2) Azimuth angle of building

The angle of building azimuth is changed from 100° to 260° to see the influence of building azimuth on power generation. Figure 7 shows the simulated power generation according to change of the azimuth angle of the building.

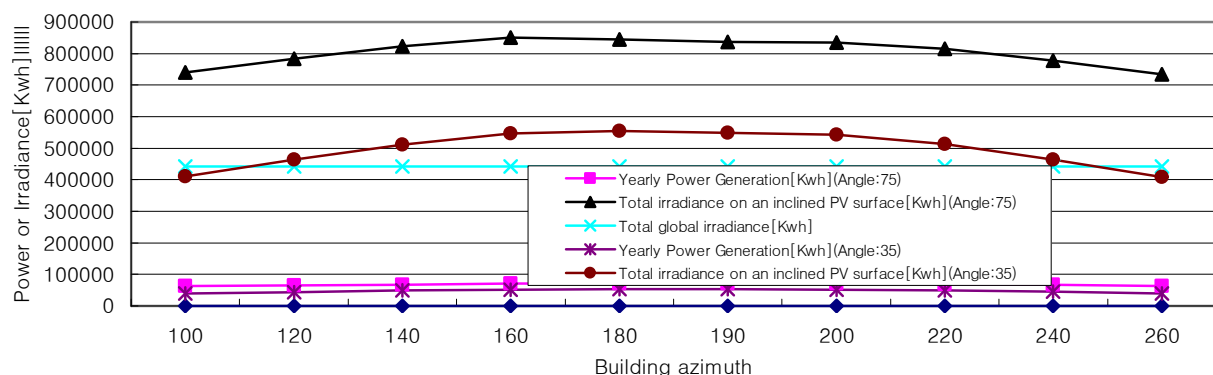


Figure 7 Power generation according to change of the azimuth angle of the building

As it is seen in figure 7, the yearly maximum power generation of the BIPV is gained approximately at south direction in the boundary condition of the SIECT building. But we can see that the differences between azimuth is not so much, if the angle of the solar cell module is fixed year round.

4) Reflectance of façade surface

Reflectance of building facade is changed from 0.2 to 0.6 to see the influence of the reflectance of building around surface on power generation. Figure 8 shows the simulated power generation according to change of the reflectance of façade surface at the PV angle 35° .

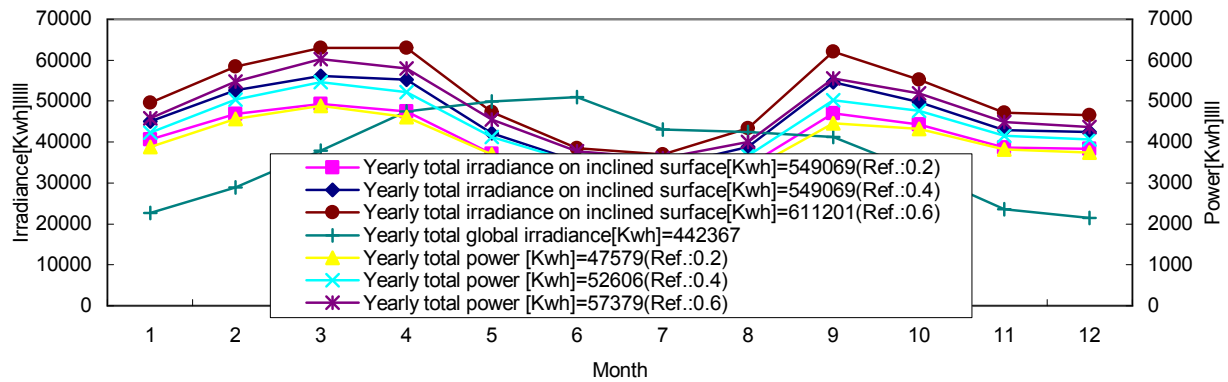


Figure 8 Power generation according to change of reflectance of façade

As seen in figure 8, as reflectance of the façade is increased from 0.2 to 0.6, power generation become approximately 8-10% higher. This tendency is well explained by the total irradiance on the inclined surface.

Figure 9 shows the simulated yearly power generation results at the PV angle 35°.

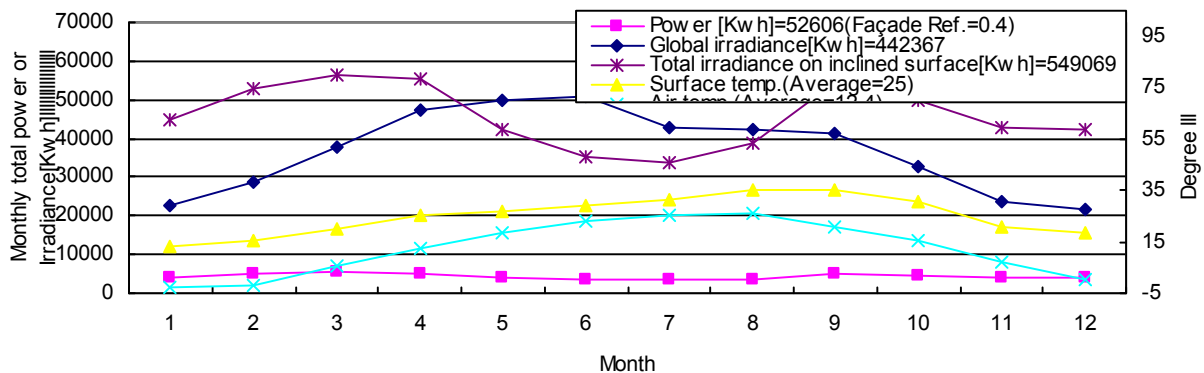


Figure 9 Simulated yearly power generation variation

Comparing with figure 6 and 9, shading through solar cell panel appears from February to October. But reversal of the irradiance between Global irradiance and irradiance on inclined surface appears in April and August. From this point, the power generation declines, even though global irradiance is much more than the total irradiance on an inclined surface. The average solar cell panel over surface temperature is proportioned to the average air temperature and global irradiance.

5) Reflectance variation comparison of façade and earth

Figure 10 shows the simulated yearly power generation change, according to the reflectance variation of façade surface and earth surface at the PV angle 35°.

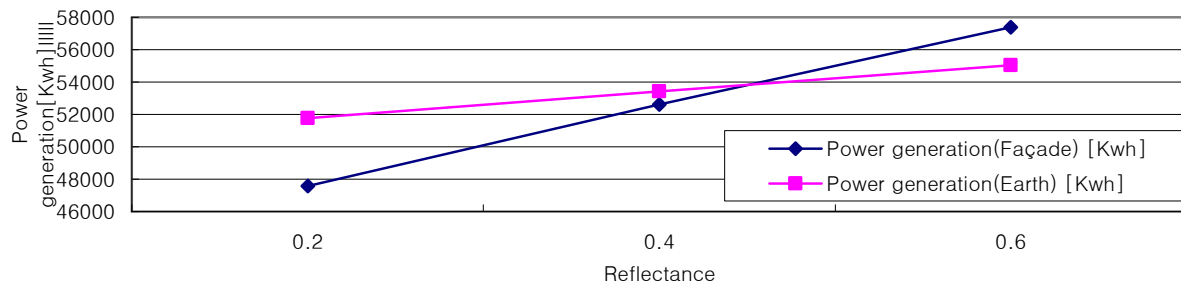


Figure 10 Simulated yearly power generation comparison through variation of reflectance

The yearly power production tendency shows that the influence of façade reflectance is very higher than one of earth reflectance, as the reflectance becomes higher and higher from 0.2 to 0.6.

4. Conclusions

Total irradiance on an inclined surface is mainly influenced by the shaded area of the PV panel, the reflectance factor of wall surface, the transmission factor of the semi-transparent PV panel and the earth surface albedo which depends on the season. The shading on a solar cell panel is a very critical point for the building application of BIPV as a shading device. This critical point can be explained by the partial shading factor (Pfactor). The maximum power output of the BIPV can be estimated at approximately 75° to the vertical wall, considering all possible factors around the building. The amount of power generation of 35° PV panel inclination (Case of real building inclination) to the vertical wall only in is the Winter (1,2,11,12) slightly much more than one of 75° PV panel inclination. The yearly maximum power generation of the BIPV is gained at exactly south in the boundary condition of the building. As the reflectance of the façade is increased from 0.2 to 0.6, power generation becomes approximately 8-10% higher. This tendency is well explained by the total irradiance on inclined surface. The yearly power production tendency shows that the influence of the façade reflectance is approximately 11% more than the influence of earth surface reflectance.

Shading through solar cell panel appears from February to October. But reversal of the irradiance between Global irradiance and irradiance on inclined surface appears in April and August. From this point, the power generation declines, even though global irradiance is much more than total irradiance on inclined surface. The influence of façade reflectance is very higher than one of earth reflectance, as the reflectance increases.

The moderate design of BIPV is also very important factor including PV system itself.

NOMENCLATURE

C_{INDEX} : Clearness index(Global radiation/solar radiation incident on a horizontal plane outside of the atmosphere) [-]

CONLOSS: Conversion loss ($=0.31 \times M^2 - 4.564 \times M + 19.254$ (Nordmann,T., Clavadetscher, L., 5.2003)) [%]

COV: Covering factor of solar cell in panel (0.85, 85% of panel is covered by solar cell and 15% of panel is glass.). [-]

ESR: Effective solar irradiance [W/m^2]

$I_{h,g}$: Global horizontal solar irradiance [W/m^2]

$I_{t,b(c)}, I_{t,b(f)}$: Direct solar irradiance on a tilted surface(respectively (c):cell, (f):façade)[W/m^2]

I_d : Diffuse irradiance [W/m^2]

PR1,PR2 : Performance ratio(Respectively sunlit area and shaded area) [-]

SAR : Sunlit area ratio(Sunlit area on the solar cell panel/Solar cell panel area) (0-1, See also Fig 3)[-]

STCW_p:Power under standard test condition

SYS : System loss (5 (Nordmann, T. and Clavadetscher, L., 5.2003)) [%]

TLOSS1, TLOSS2:Temperature loss for sunlit(1) and shaded area(2))((TLOSS1,2= $0.452 \times T_c - 11.3$, Nordmann,T.and Clavadetscher,L., 5.2003))

Tn: Cell junction temperature under standard test condition[25°C]

TO : Absolute cell module over surface temperature [$^{\circ}K$]

TPA: Total panel area[m^2]

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