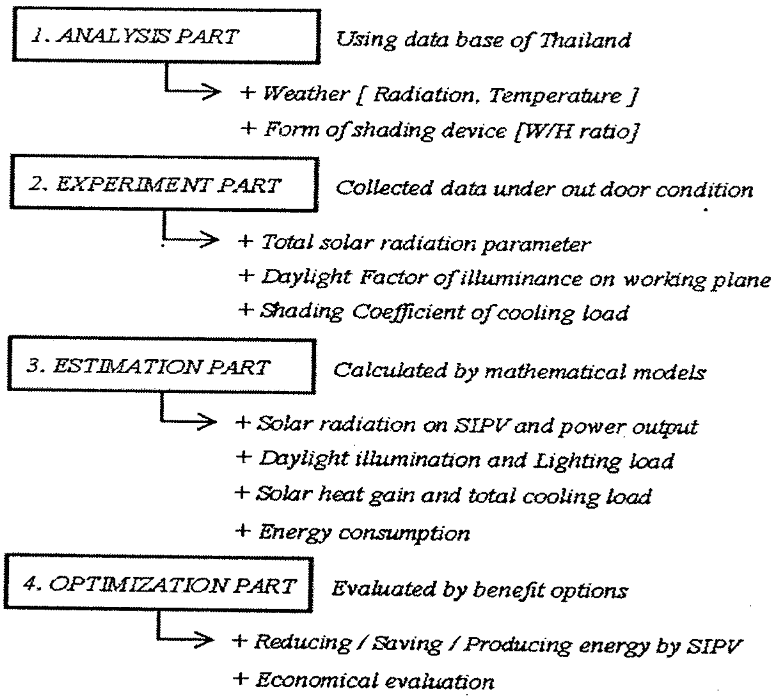
CHAPTER IV

RESULTS AND DISCUSSION

Study process

There are 2 objectives in this research as follows: first is to optimize heat reduction and light usage in buildings. Second is to optimize in economics due to the usability of Shading Device Integrated Photovoltaic system, study process as shown in Figure 113.



Part 1; Analysis is to study data on solar irradiance and weather including the forms of shading devices proper for direct solar irradiance prevention.

Part 2; Experiment is to study parameters used in equation of calculating total radiation, daylight factor and shading coefficient.

Part 3; Estimation is to study estimation of developed equation to predict benefit concerning energy gained from SIPV installation.

Part 4; Optimization is to study benefit and expenses in SIPV investment to evaluate worthiness and study objectives response.

Figure 113 The study process diagram

Analysis part

1. Solar radiation and weather data in Thailand

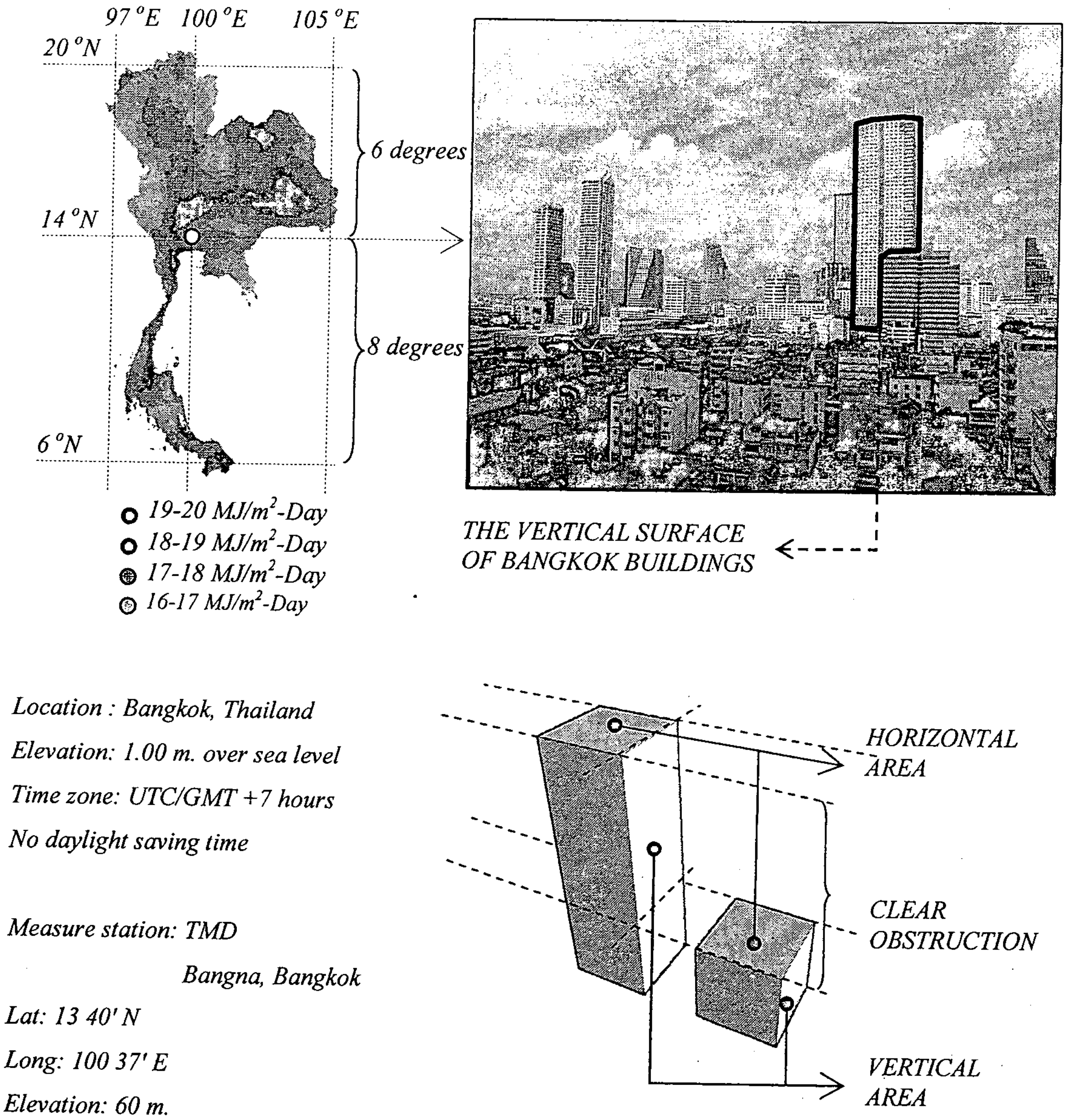


Figure 114 The represented city of Thailand location

Source: Department of Alternative Energy Development and Efficiency [65]

Bangkok as a hub representing Thailand appears to have a large amount of building envelopes receiving more of solar radiation than buildings in other cities. Buildings in Bangkok consist of high-rise buildings with vertical surface rather than horizontal surface. Shading devices and high-performance glass are needed for solar heat gain prevention as presented in Figure 114 showing Bangkok location with image of the city on geographical territories gaining solar radiation averagely 18-19 MJ/m^2-Day.

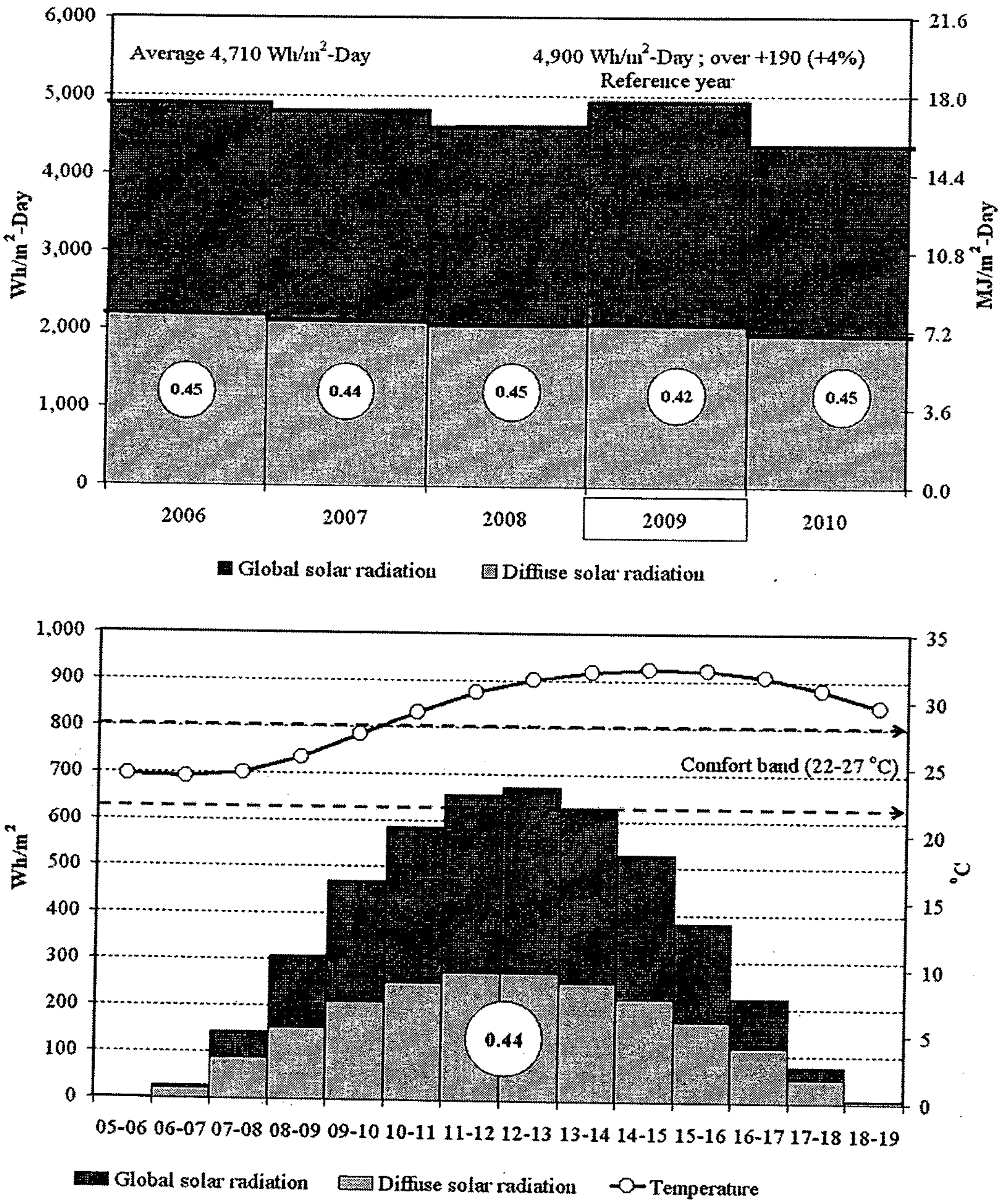


Figure 115 Average solar radiation and air temperature of Bangkok

During 2006-2010, solar radiation data of Bangkok shown in Figure 115 (Top) showed ratio of solar diffuse radiation at 42%-45%. In 2009, ratio of solar diffuse radiation was about 42% and total solar radiation was about 4,900 Wh/m^2-Day which was higher than the average of the total data 4% or about 190 Wh/m^2-Day. Figure 115 (below) shows the comparison between the hourly average of solar radiation and air temperature concerning comfort zone of between 22-27 °C. It is found that the temperature was higher than comfort zone after 10.00 A.M. and remained for the whole day.

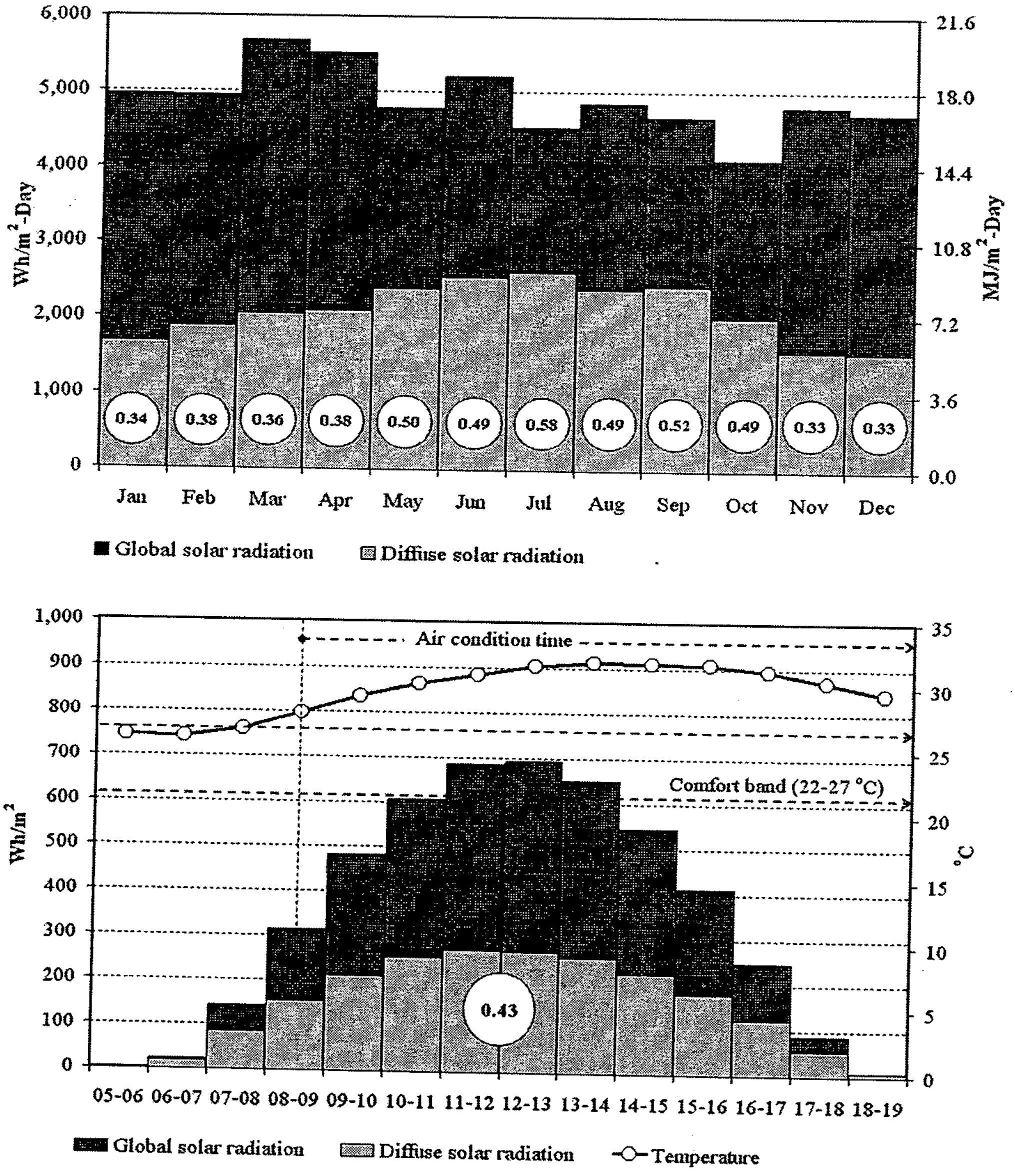


Figure 116 Average radiation and air temperature of Thailand in 2009

Data collected in 2009 was used as database being referred for calculation as shown in Figure 116 (top). It presented ratio of solar diffuse radiation in each month. It is found that in rainy season; May-September, contained high ratio of solar diffuse radiation, which is sometime higher than direct solar radiation, due to the declination moving towards north of equator line resulting in low energy from direct solar radiation with module installation turning towards south. In contrast with other months with declination encircling towards south, it was corresponded with data from other years during 2006-2010. In Figure 116 (below), the conclusion was to have suitable period of air conditioning systems start working from 8.00 A.M. to create comfort zone consistent to general working hour.

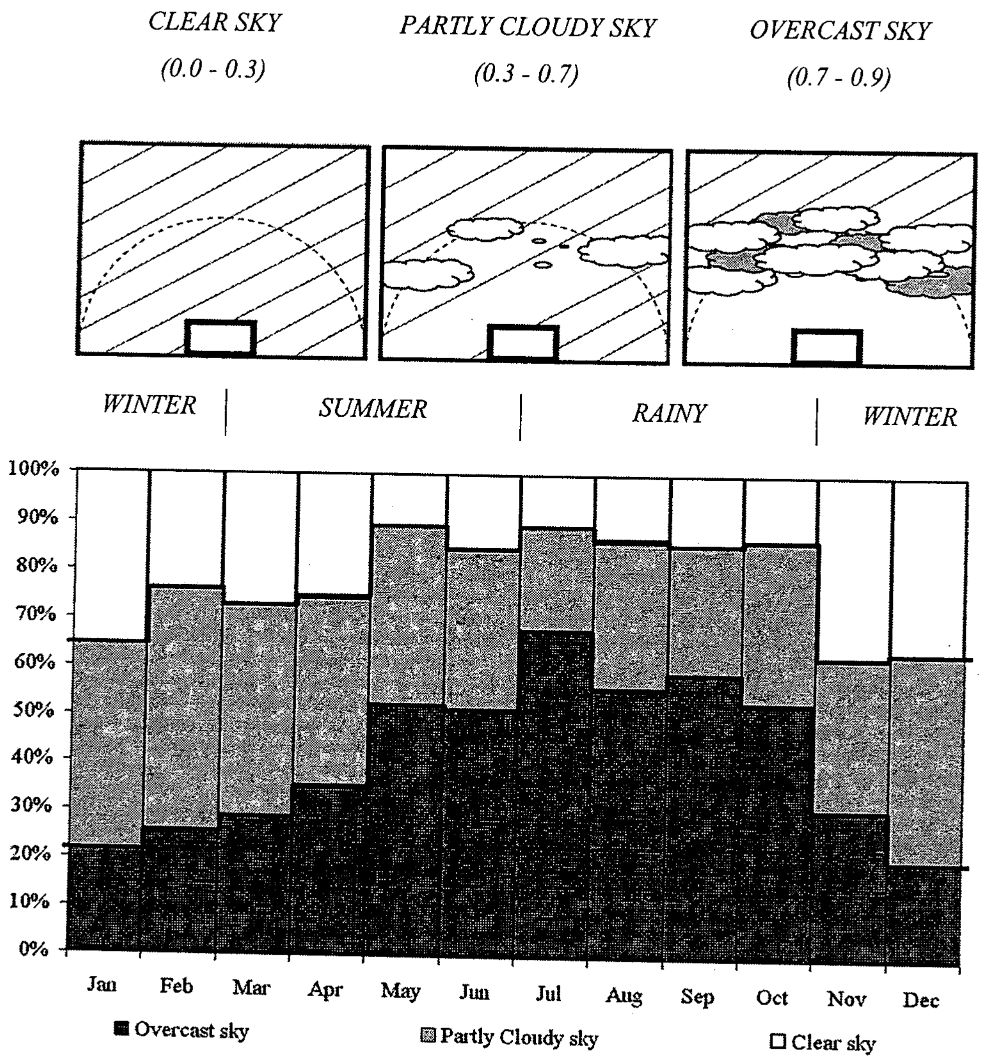


Figure 117 Average ratio of diffuse solar irradiance to total solar irradiance

In Figure 117, shows ratios of solar radiation according to sky conditions in 2009 divided into 3 seasons as follows:

1. Summer season between February and May
2. Rainy season between May and October
3. Winter season between October and February

Most of solar radiation ratio shows appearances of sky component with partly cloudy sky and overcast sky in rainy season affecting total solar radiation on solar module

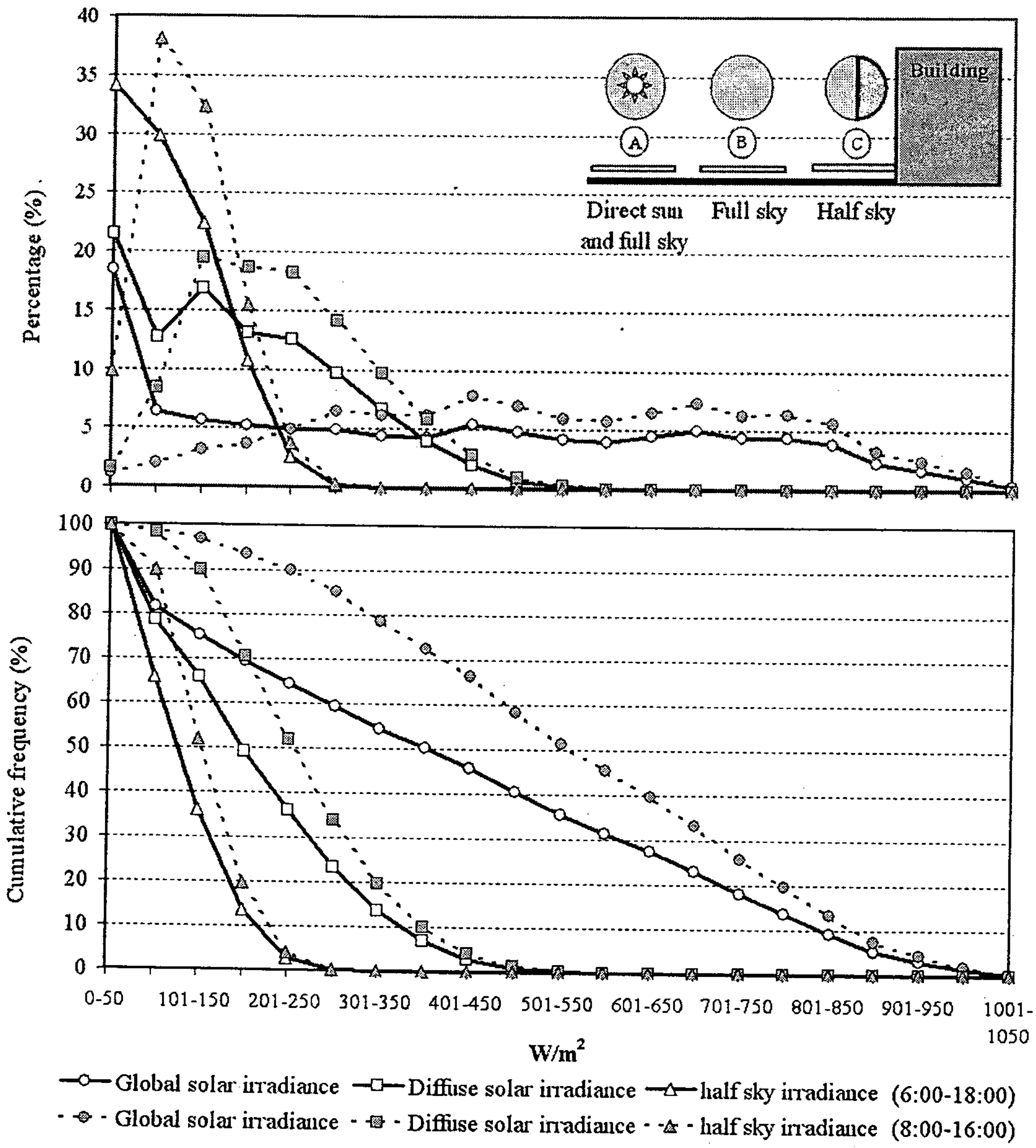


Figure 118 The frequency and cumulative frequency of solar irradiance in 2009

As Figure 118 shows frequency of solar irradiance reception on the condition of sky component, it is found that 8.00-16.00 mostly provides low solar diffuse radiation. It is said the same way that 80% of the mentioned time provides solar irradiance not less than 300 W/m^2 in the case of diffuse radiation under full sky and 150 W/m^2 in the case of diffuse radiation under half sky. Figure 118 (below) shows influence of diffuse radiation is mostly quite low.

Therefore, total solar irradiance in case of SIPV under half sky was probably reduced about 25% due to the fact that 50% was direct solar radiation and 50% more of diffuse radiation was reduced by building shade.

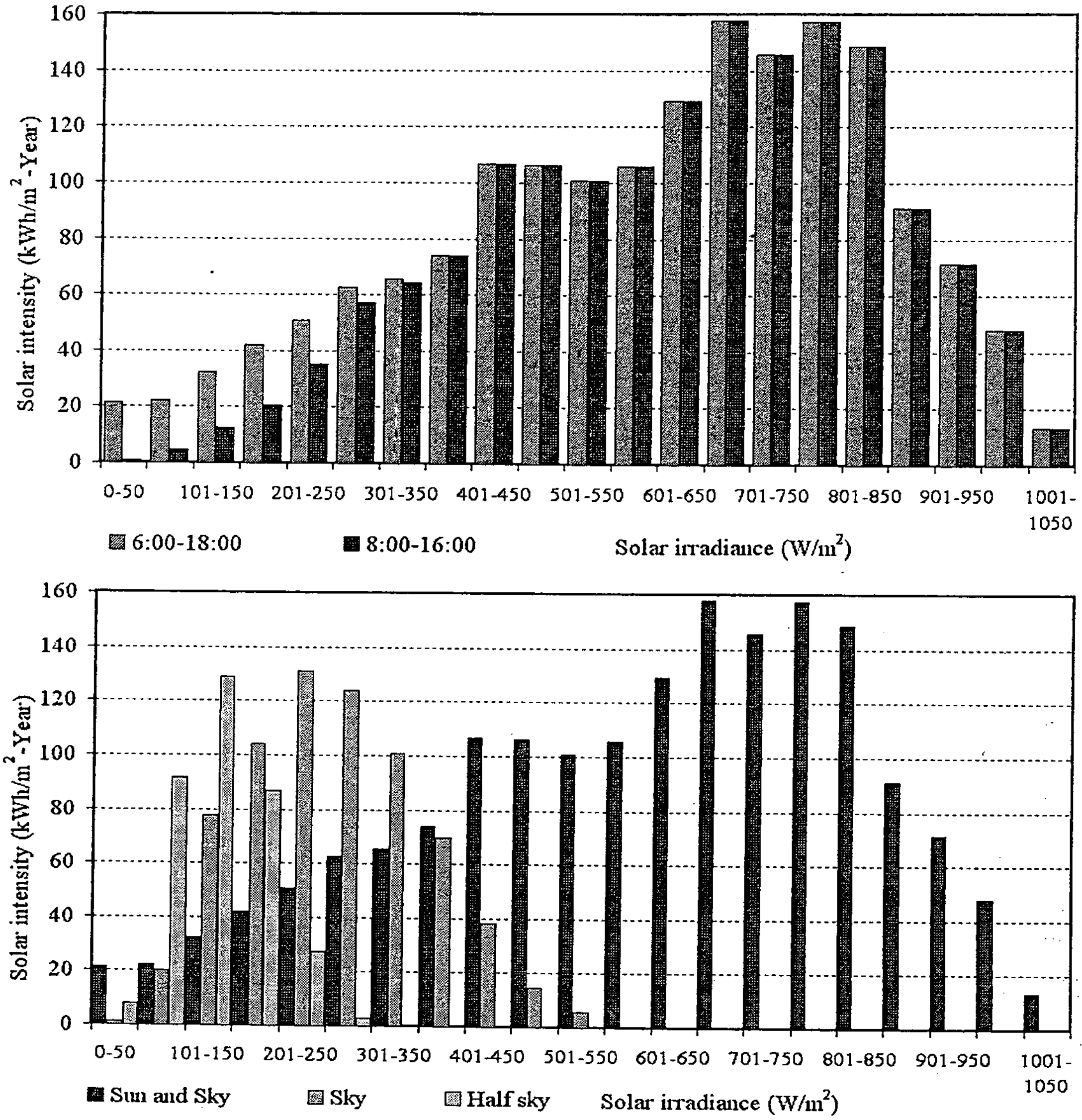


Figure 119 The solar intensity of Bangkok in 2009

The highest level of solar intensity was about 150 kWh/m^2-Year in the case of global solar irradiance in the period of total solar irradiance between 700 and 800 W/m^2. The highest level of solar intensity was about 130 kWh/m^2-Year in the case of half sky in the period of diffuse solar irradiance between 100 and 150 W/m^2 as shown in Figure 119 and Figure 120 presenting that more than 65% of midday at 8.00 A.M. provides temperature of more than 27°C.

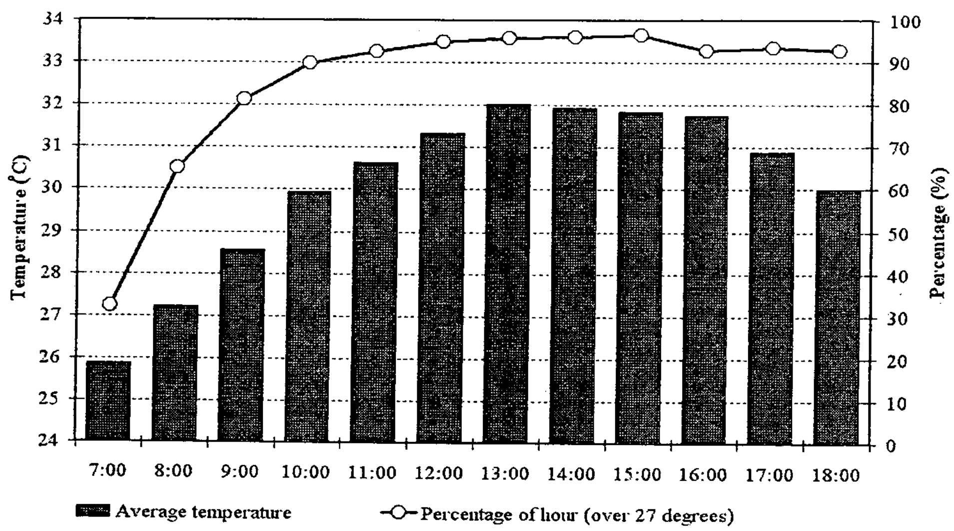


Figure 120 Average and percentage of air temperature

In conclusion, appearances of data of 2009 used in calculation in the period of SIPV operation are as follows:

1. In the case of half sky, most diffuse irradiance was at about 150W/m^2 resulting in sum total per year of about 130 kWh/m^2

2. To design shading to prevent direct solar radiation in basic step, the suitable time to start should be at 8.00 A.M. according to the use of air conditioning system. It is because of temperature higher than comfort zone

2. Ratio of outstretched part of shading devices at latitude 14° north

In designing horizontal shading devices with outstretched part to prevent direct solar radiation, it is changed according to profile angle which is uprisen angle perpendicular to wall where considered. In this study, 8.00-16.00 was considered in direct solar radiation prevention as it is working hours with thermal uncomfortable condition. In Figure 121 shows total solar irradiation falling down on vertical surface like window provides value as low as diffuse radiation in the period containing the highest level of the day as it is considered non-severe. However, sunlight prevention until 17.00 P.M. can reduce more heat with the design of more outstretched part of shading devices due to the low value of the sun's uprisen angle.

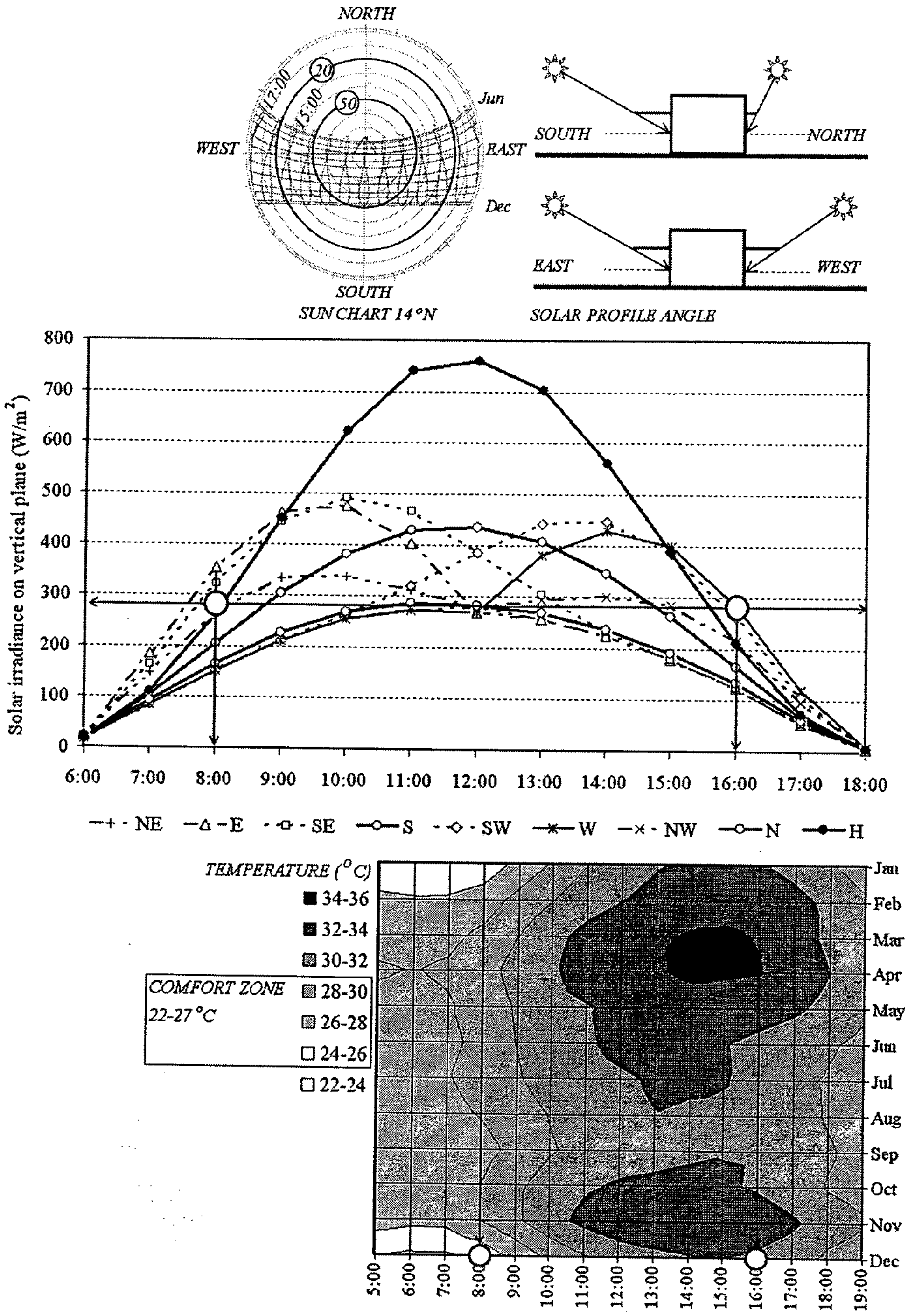


Figure 121 The analysis of shading time for thermal comfort

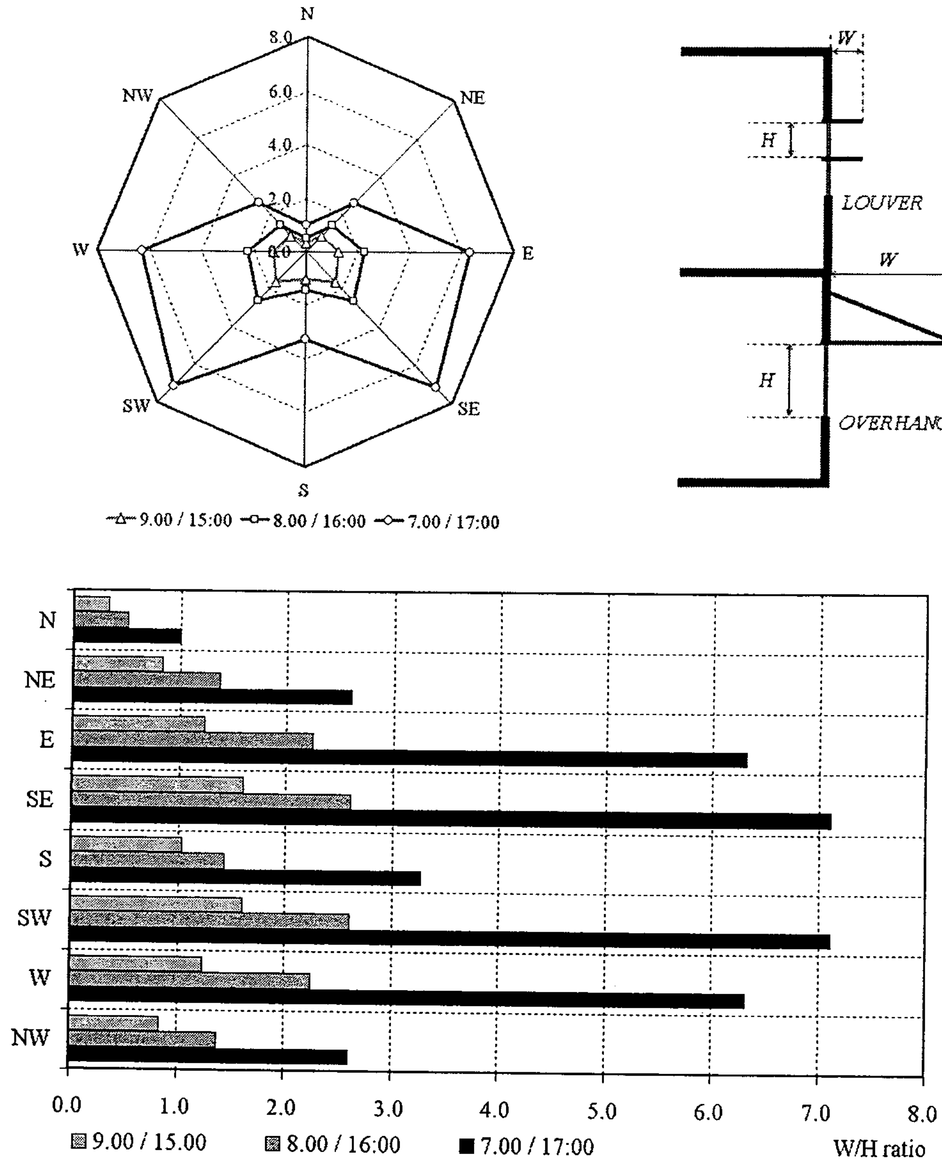


Figure 122 The shading extension ratio

Shading in both cases of over hang and louver can specify their forms from W/H ratio as shown in Figure 122 which is dimension indicating the ability in sunlight prevention resulting in SC_b equivalent to 0.0. In cooling time, outstretched part W should be corresponded according to position or solar attitude. Outstretched part design during 9.00-15.00 is a little bit shorter that during 8.00-16.00 unlike during 7.00-17.00 with outstretched part of shading devices is increasing more than needed affecting structure, budget and depletion of area around building. Therefore, the suitability in shading devices design is limited only during 8.00-16.00.

3. Solar tracking of shading devices

Solar tracking depending on solar altitude indicates that the angle of system being installed in some directions is adjusted at not more than 20 degrees which is considered a few when compared to the need of maintenance. The installations are such as N, NE and NW as shown in Figure 123 (top).

When considering the area of angle throughout the windows due to the shading devices according to W/H ratio, it is found that in the case of fixed installation, there is open angle area more than 60% unlike the case of installation turning towards N, NE, NW and S and the case of tracking installation which there are more angle area than fixed installation. The comparison is shown in Figure 123.

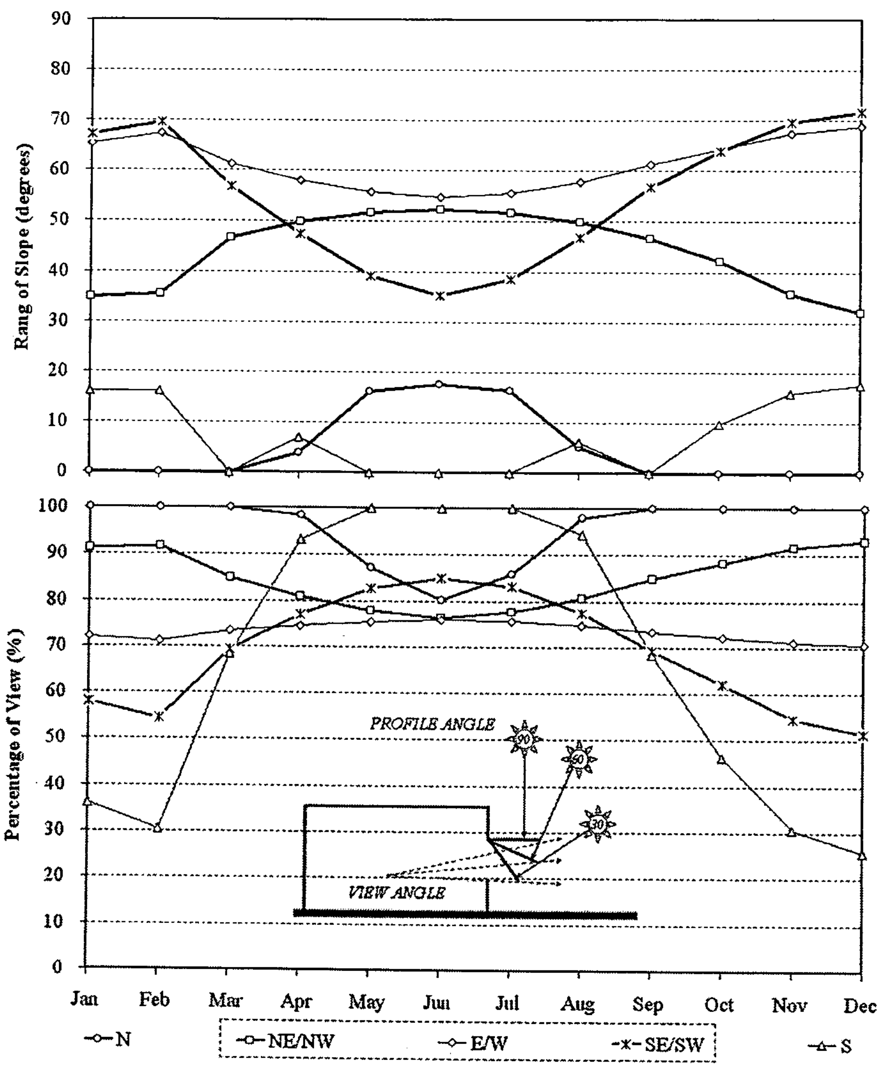


Figure 123 The clear view height of tracking effect

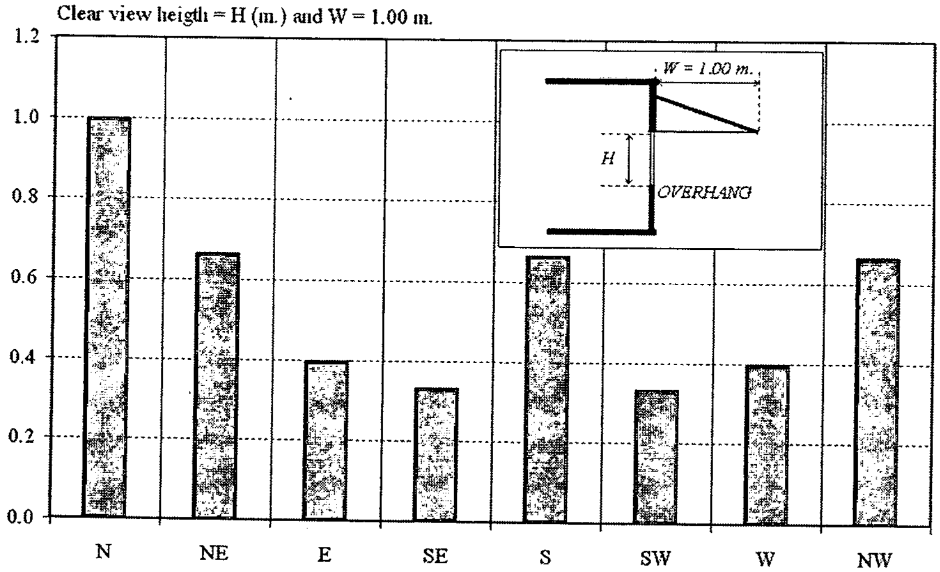


Figure 124 The clear view height of fixed effect

4. Summary of the analysis part

The summary of analyzing the forms of shading devices design

4.1 Weather and solar irradiance data of 2009 are used in analysis and estimation

4.2 Shading devices is designed to have outstretched part during 8.00-16.00. It is for suitability to avoid having unnecessary outstretched part and correspond to working hours

4.3 The design is determined to have outstretched part of shading devices according to ratio W/H in each direction as follows: N=0.5, NE/NW=1.5, E/W= 2.5 and S=1.5 for fixed installation as shown 4-12

4.4 For tracking design, outstretched part should be short due to structure. It should also be installed in E/W, SE/SW and S

Experiment part

1. **Total solar irradiance on slope surface [Chapter III; page 100-103]**

   1.1 Diffuse solar irradiance factor under half sky condition

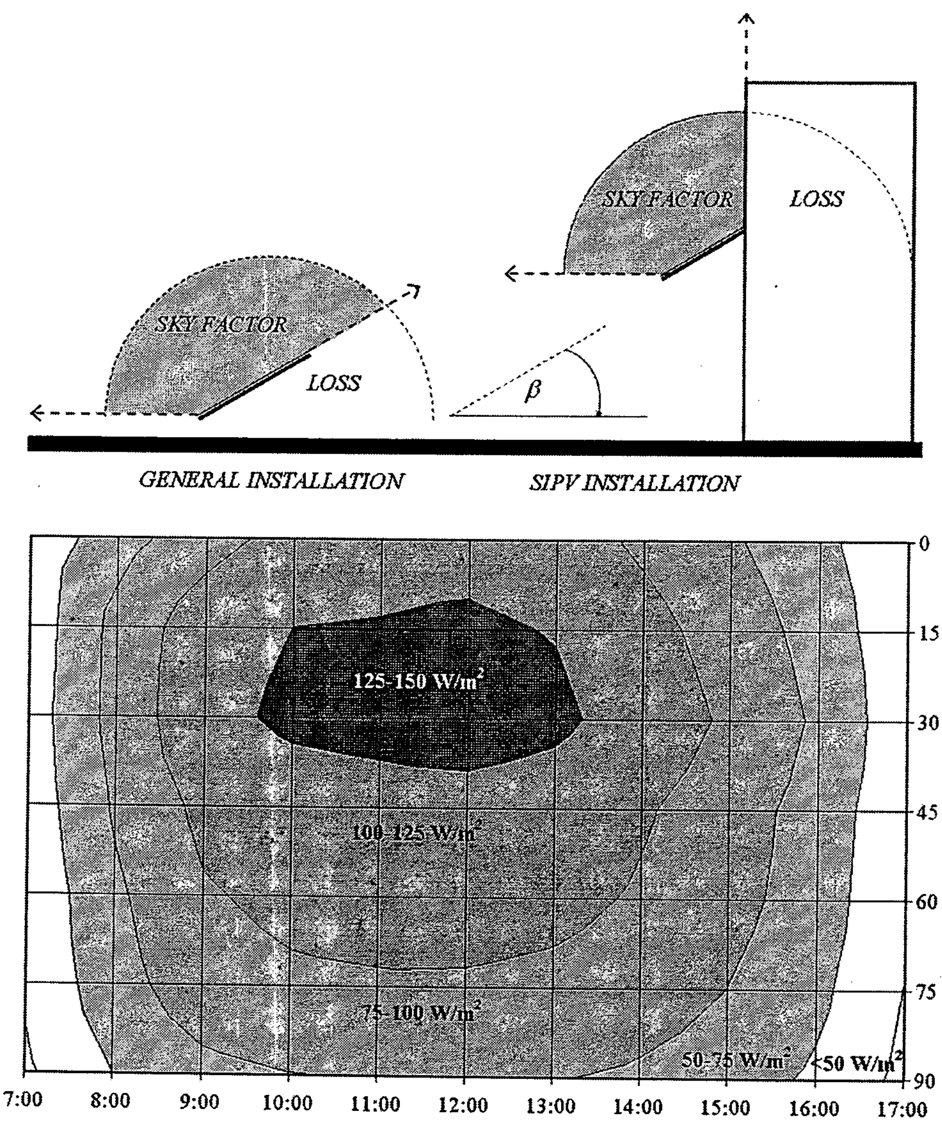


Figure 125 The collected data of the diffuse solar irradiance from the half sky

Half sky condition only diffuse solar radiation as shown in Figure 125. The result of experiment found that SIPV's tilt angle at about 15-45 degrees is the angle receiving the most of solar irradiance. It is also a hilltop sloping down towards the ground at more or less angle in every period of different solar altitude. The most value of angle is at noon where the position of the sun is at the highest.

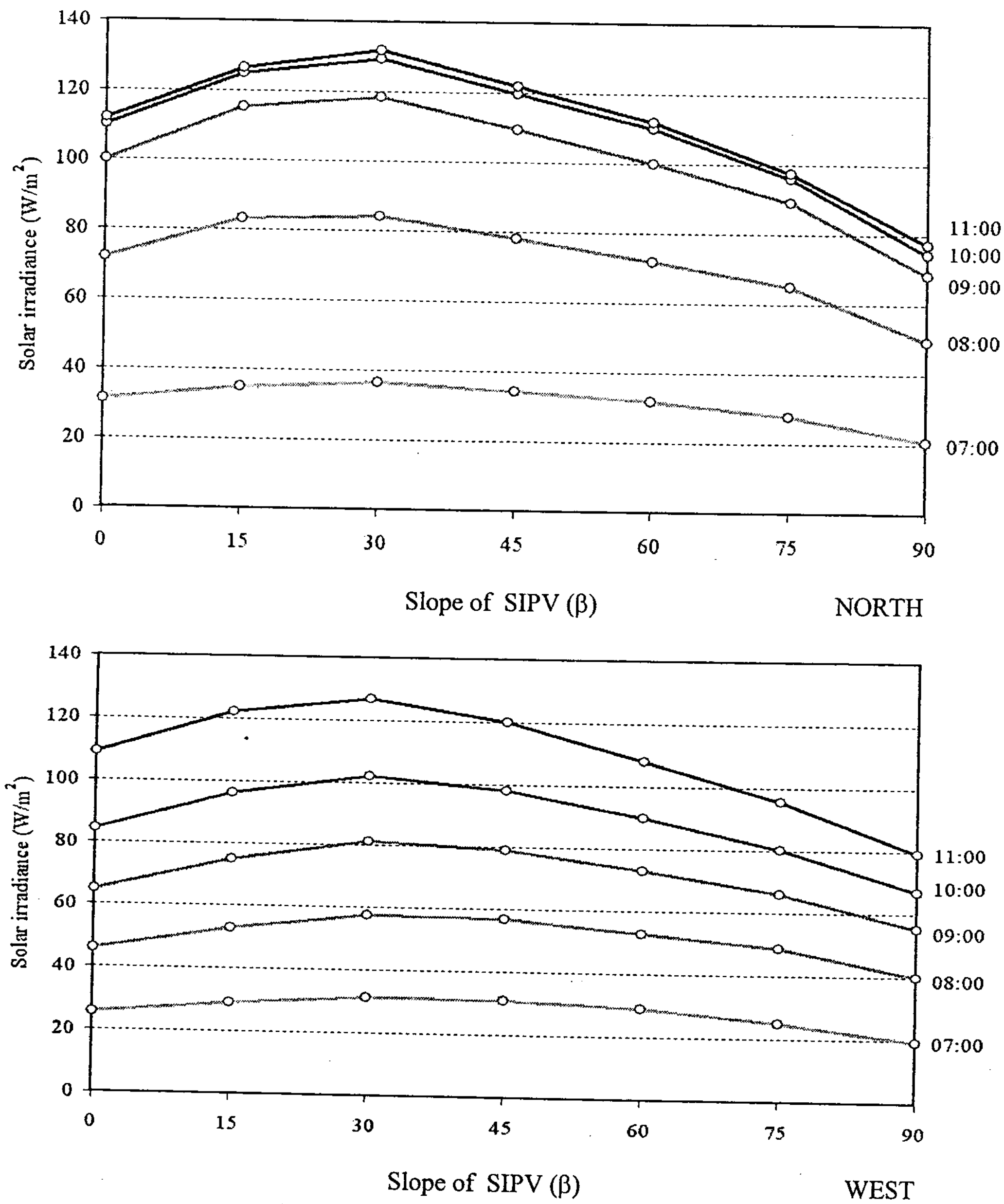
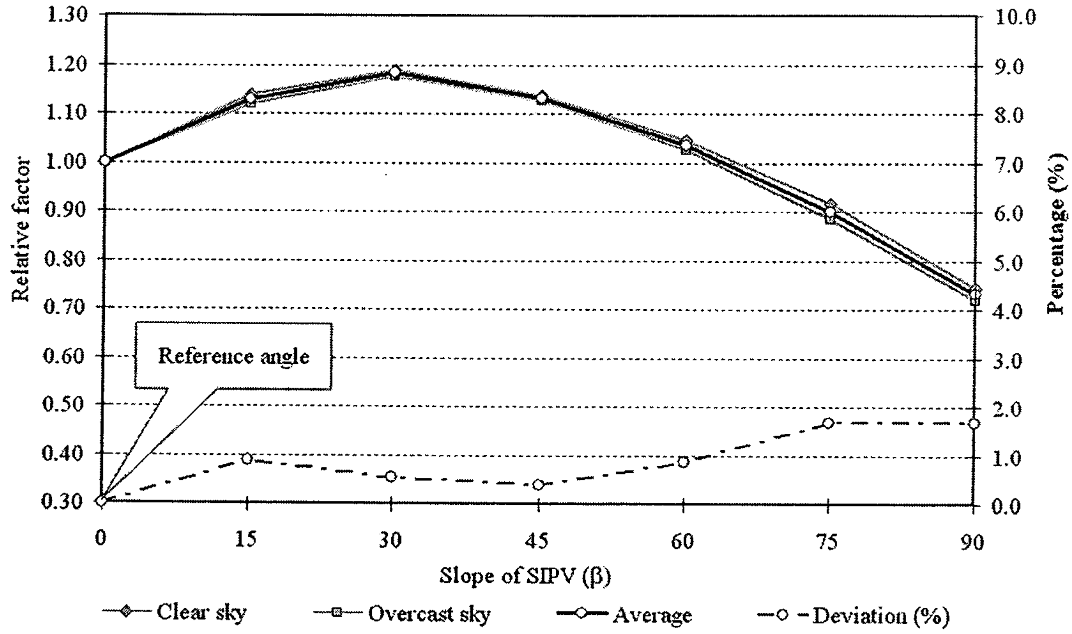


Figure 126 The diffuse solar irradiance comparison of every SIPV slope

Figure 126 shows solar irradiance in each period during 7.00 to 11.00. In the case of half sky turning towards north and west, it is found that tilt angle at 30 degrees is at the highest level in every case and decreases when there is other more or less angles. The difference is clear when the solar altitude is high.



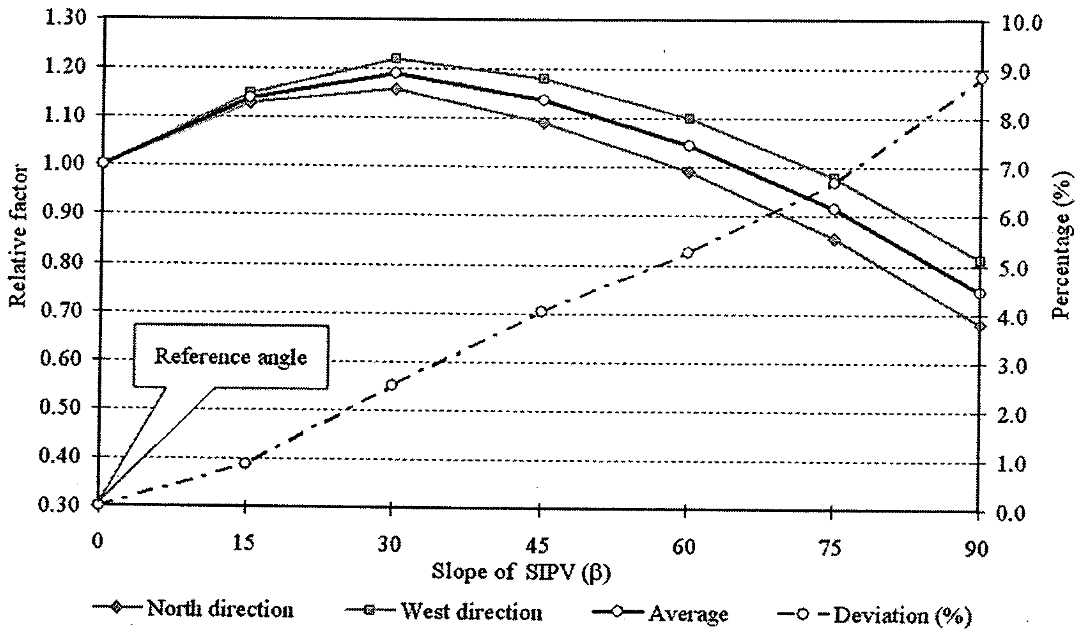
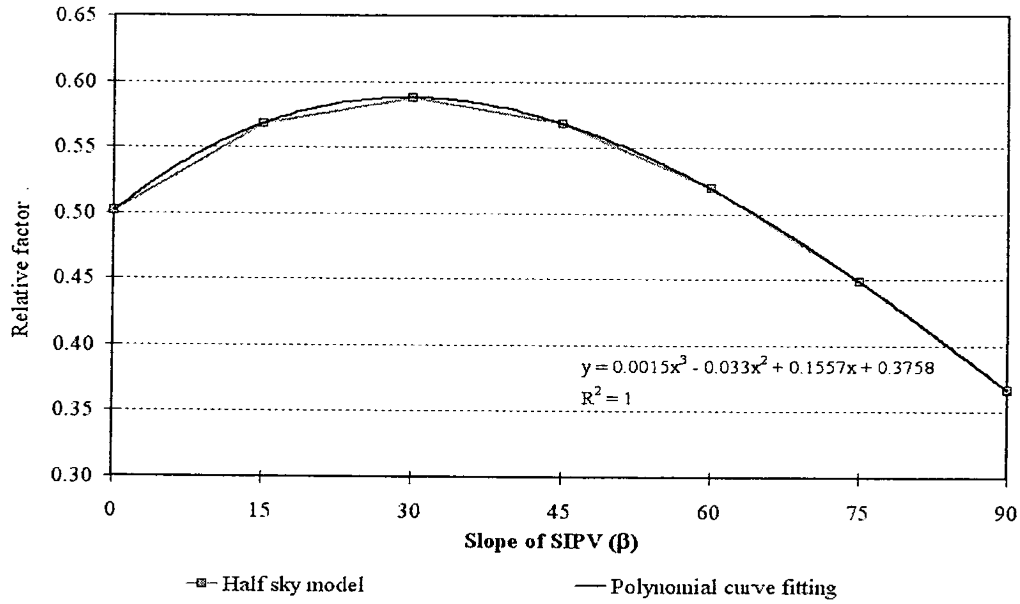


Figure 127 The diffuse solar irradiance comparison of sky condition

Figure 127 shows the relation of the ratio of diffuse radiation of every tilt under half sky compare with the tilt angle of 0 degrees or horizontal surface in case of clear sky and overcast sky. In the top Figure shows the difference not more than 2% unlike the below Figure which is the comparison between sky direction showing the more difference but not exceed 9%. In every case, the differences will increase at the high tilt angle.



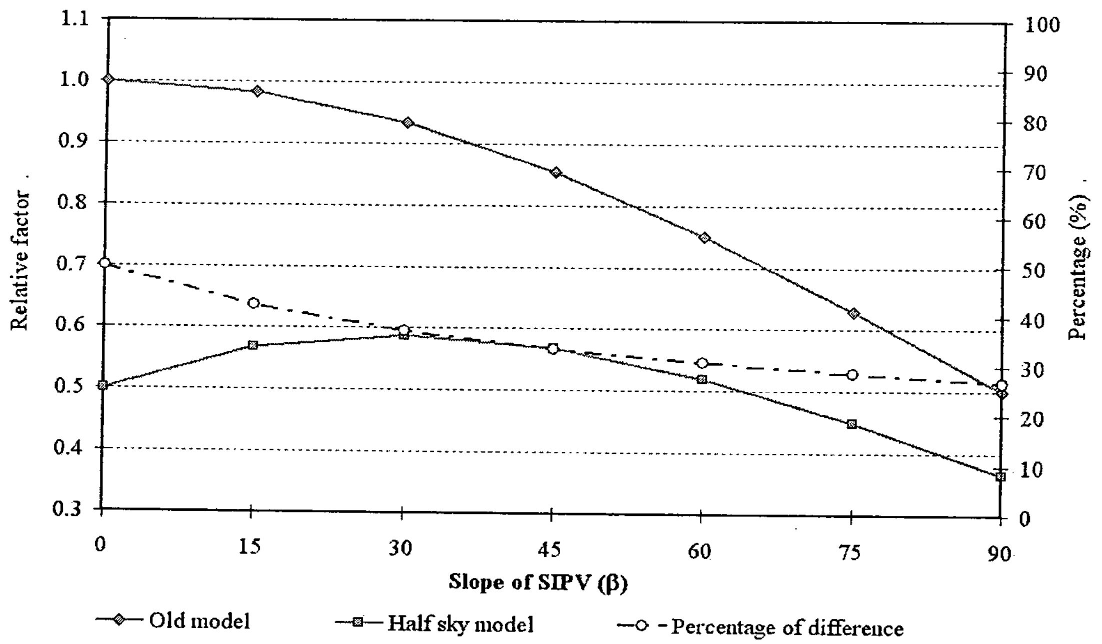


Figure 128 Math models of half sky condition and full sky condition

Figure 128 on top shows the averaging of data gained from analysis under conditions of all sky types. Below Figure shows the comparison with full sky condition at tilt angle of 0 degrees or flat surface with the value of 1.0 in the case of full sky and the value of 0.5 in the case of half sky. It indicates that in the case of half sky have clear differences in the matter of amount and the position of the highest value. The mentioned relation will be created as equation to predict.

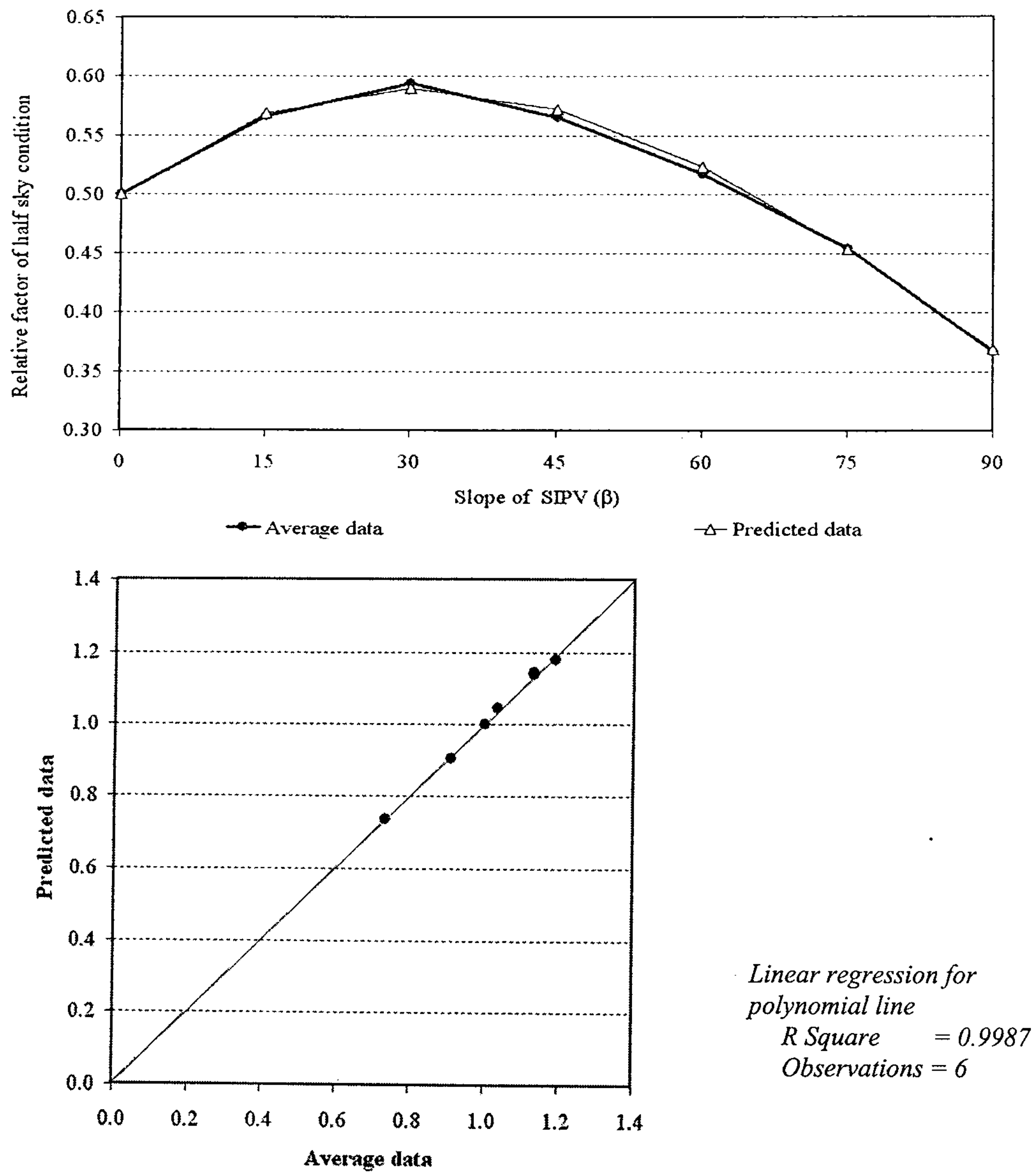


Figure 129 The evaluation of half sky model

$$R_d = 0.5(1+\cos B)\ ;\ \textit{for full sky} \qquad Eq.109$$

$$R_d = -0.0015A^3 + 0.0330A^2 + 0.1557A + 0.3758;\ \textit{for half sky} \qquad Eq.109$$

$$A = (15+\beta)/15$$

The diffuse solar irradiance of half sky model shown in Figure 129 indicates that the highest value is about 0.59 at tilt angle of 30 degrees appeared in a form of polynomial line multiply by 3. The coefficient of determination, R^2, of this model is at 0.9987 as Eq. 109.

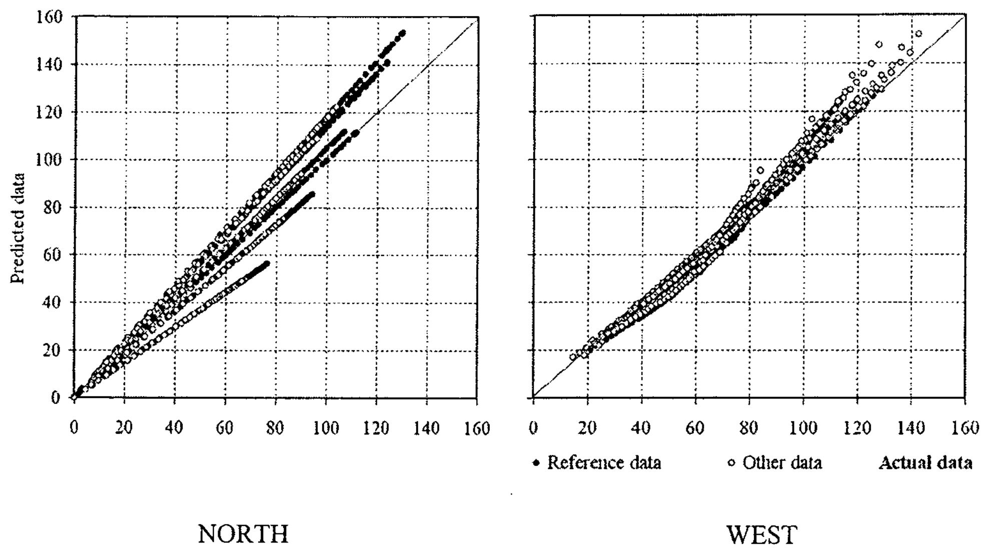


Figure 130 The comparison between predicted data and actual data

Table 21 The evaluation of the solar diffuse irradiance under half sky model

	North		West	
	Reference data	Other data	Reference data	Other data
	Feb 6th 2010	Feb 7th 2010	Feb 3rd 2010	Feb 2nd 2010
Observation	11,550.00	12,600.00	10,320.00	10,080.00
RMSE	10.75	10.10	3.92	4.55
NRMSE	15.29%	17.00%	5.72%	6.40%
MBE	2.91	2.62	-1.54	0.18
NMBE	4.14%	4.41%	-2.25%	0.26%
R square	0.9360	0.9407	0.9849	0.9857

Comparing with data from other days not data used in analysis with root mean square error (RMSE) and the mean bias error (MBE) as shown in Table 21, it can be explained that sky condition in the west can be used to predict the value much closer than in the north. However, there are reasons according to the site of installation to collect data with the different environment

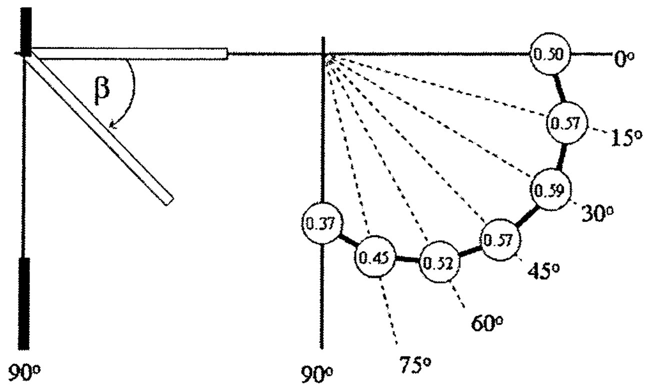


Figure 131 The diffuse solar irradiance explanation of half sky condition

1.2 Reflected solar irradiance factor from the buildings surface

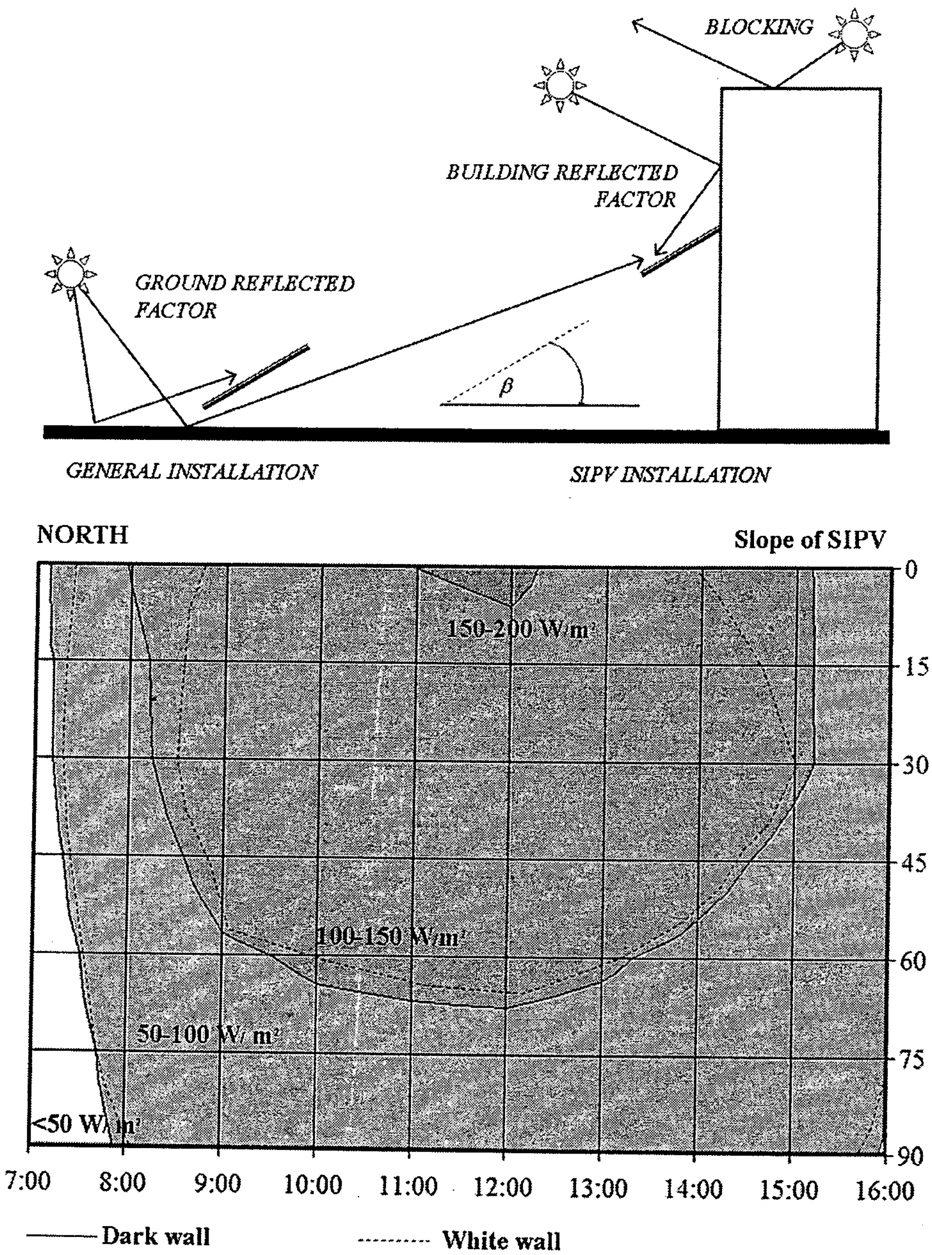


Figure 132 The collected data of the reflected solar irradiance from the North sky

Building envelope on top of SIPV shown in Figure 132 and Figure 133 found that SIPV with tilt angle at 0 degrees or horizontal plane can receive most of solar irradiance in every cases of sky turning towards every direction and lesser when SIPV slopes to make angle wider. This factor is only a few.

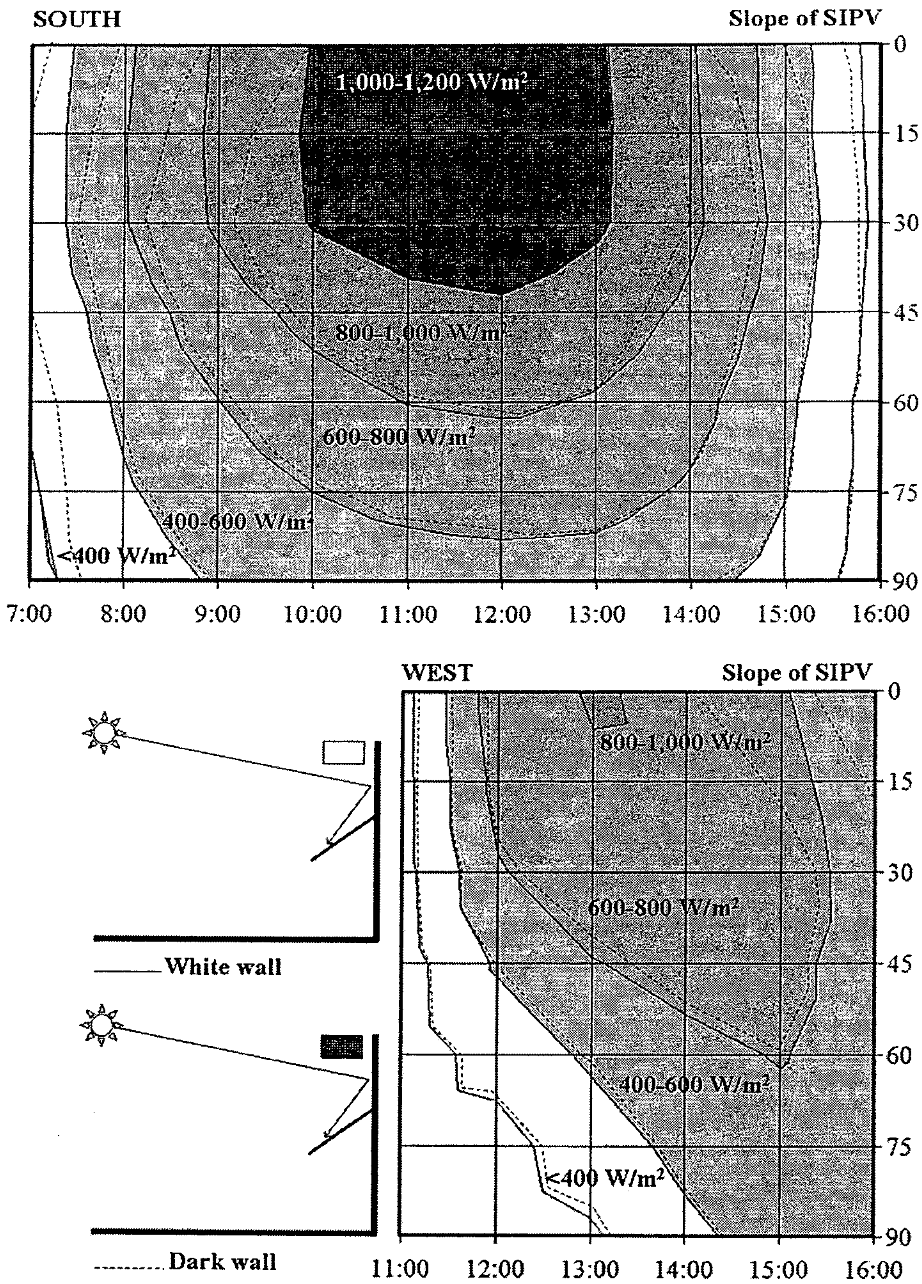


Figure 133 The collected data of the reflected solar irradiance from the South and West sky

Although building envelope can affect the increase of solar irradiance on SIPV module, it affects a little in the case of experiment showing solar radiation reflectance at 38% and lesser when consideration is accordance with law containing the suitability of solar radiation reflectance at 30% in order to make buildings a non-heat source and non-light pollution to nearby buildings.

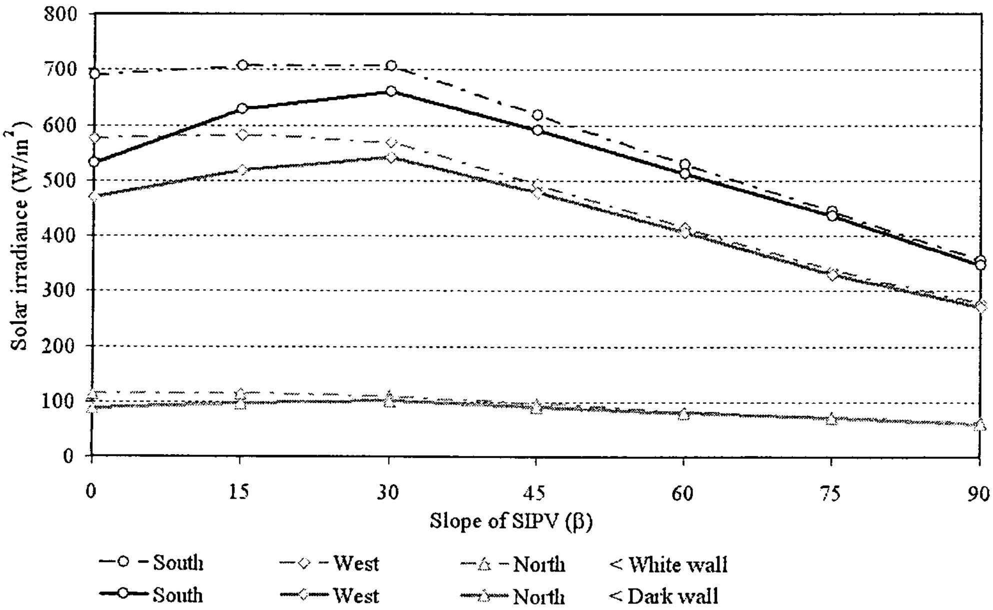


Figure 134 The solar reflected irradiance of the white and the dark panel

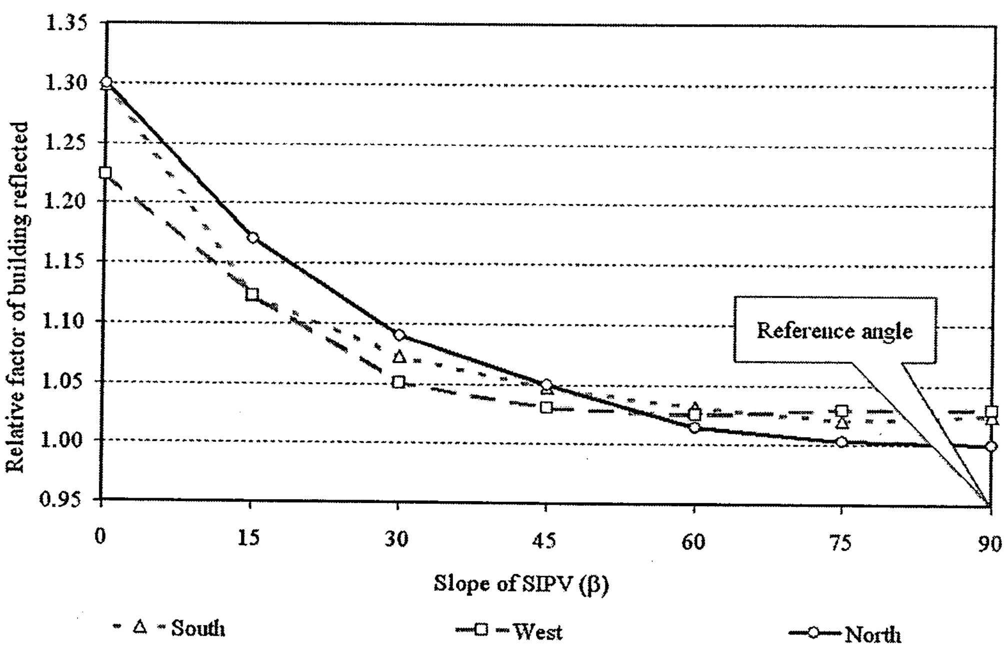


Figure 135 The reflected solar irradiance comparison of the sky conditions

Figure 134 shows the experimental result of solar radiation falling down on SIPV both white and black wall. Figure 135 shows the result in a form of ratio of reflectance compared to directions of sky such as South and West and in a form of average value by considering solar radiation reflectance at 38%.

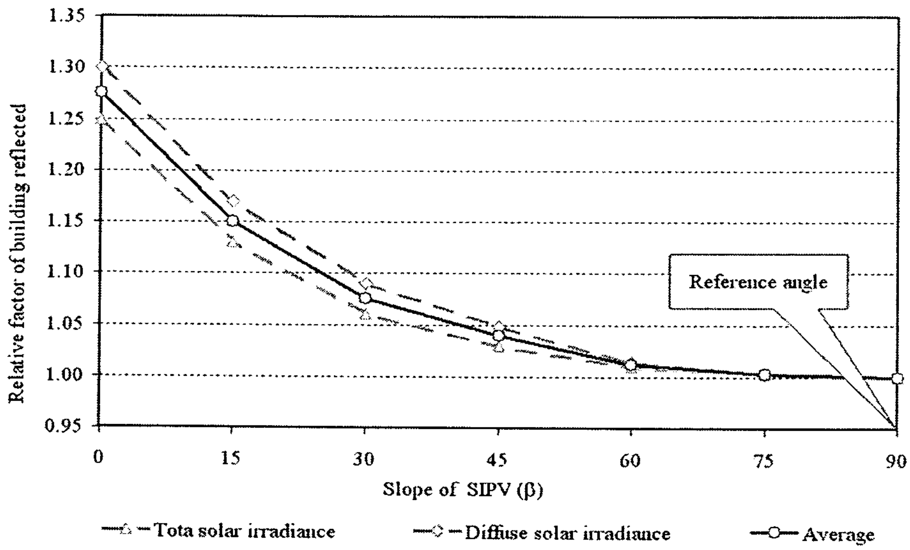


Figure 136 The building reflected trend of the solar irradiance conditions

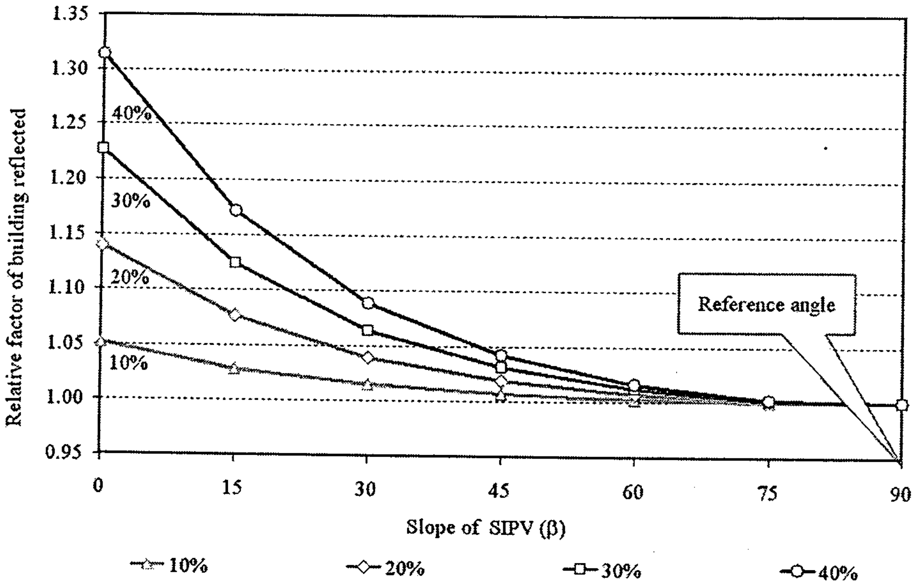


Figure 137 The building reflected trend of every the solar reflectance

The comparison of total solar irradiance reflectance in the case of sky on the West and diffuse solar irradiance reflectance in the case of sky on the North shown in Figure 136 result in the same type of characteristics. Figure 137 shows the comparison of the ratio to estimate in the case of solar radiation reflectance qualifications of building envelope materials between 10%-40% according to qualification of color and building material generally sold in market.

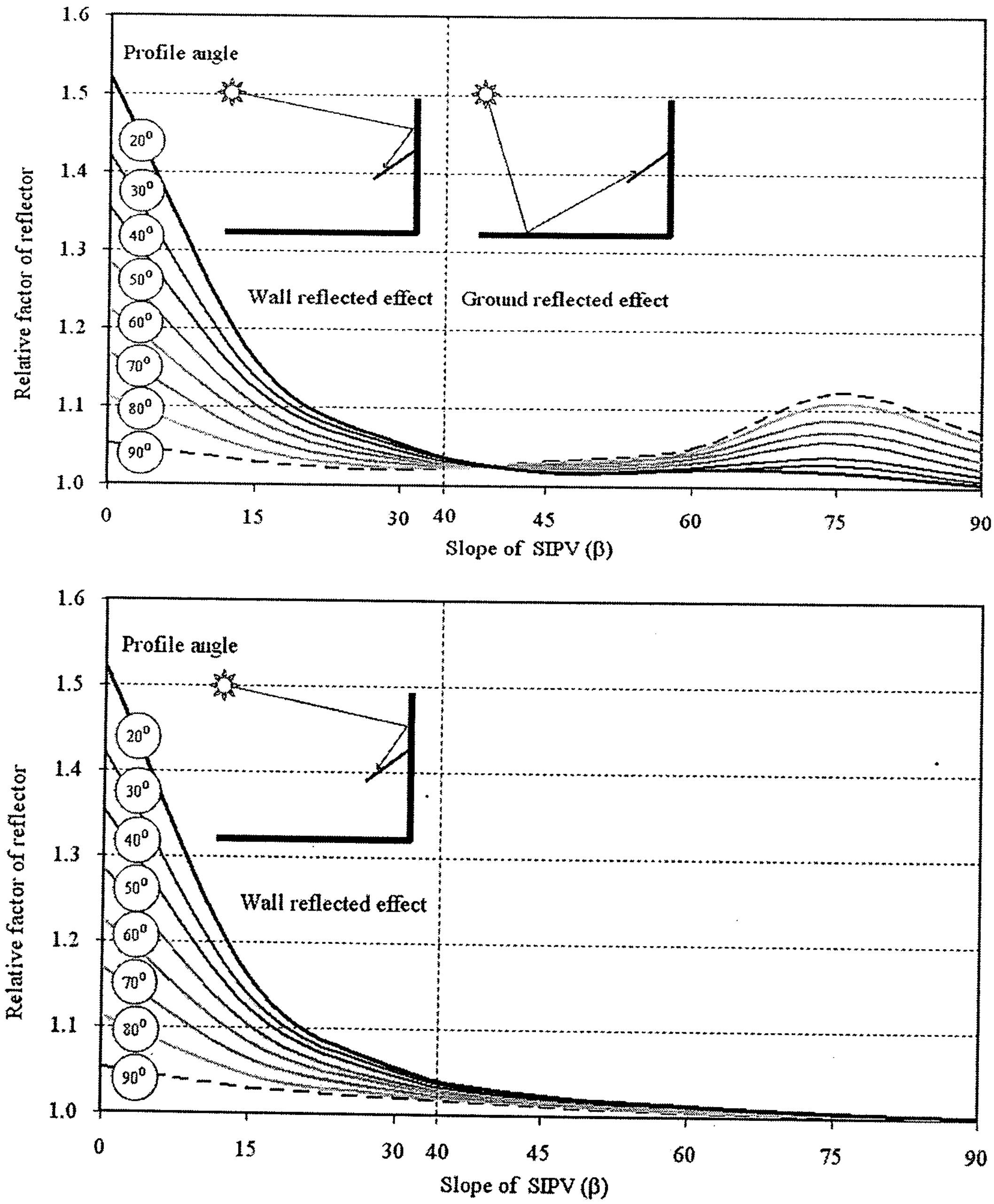


Figure 138 The relative factor of every profile angle and every SIPV slope

Figure 138 (top) shows solar irradiance reflectance factor in each period of time according to solar altitude. Besides, Figure 138 (below) shows the consideration to improve data of angle from 45 degrees to 90 degrees in order not to have factor of solar irradiance reflecting from ground surface to create suitability according to trend line.

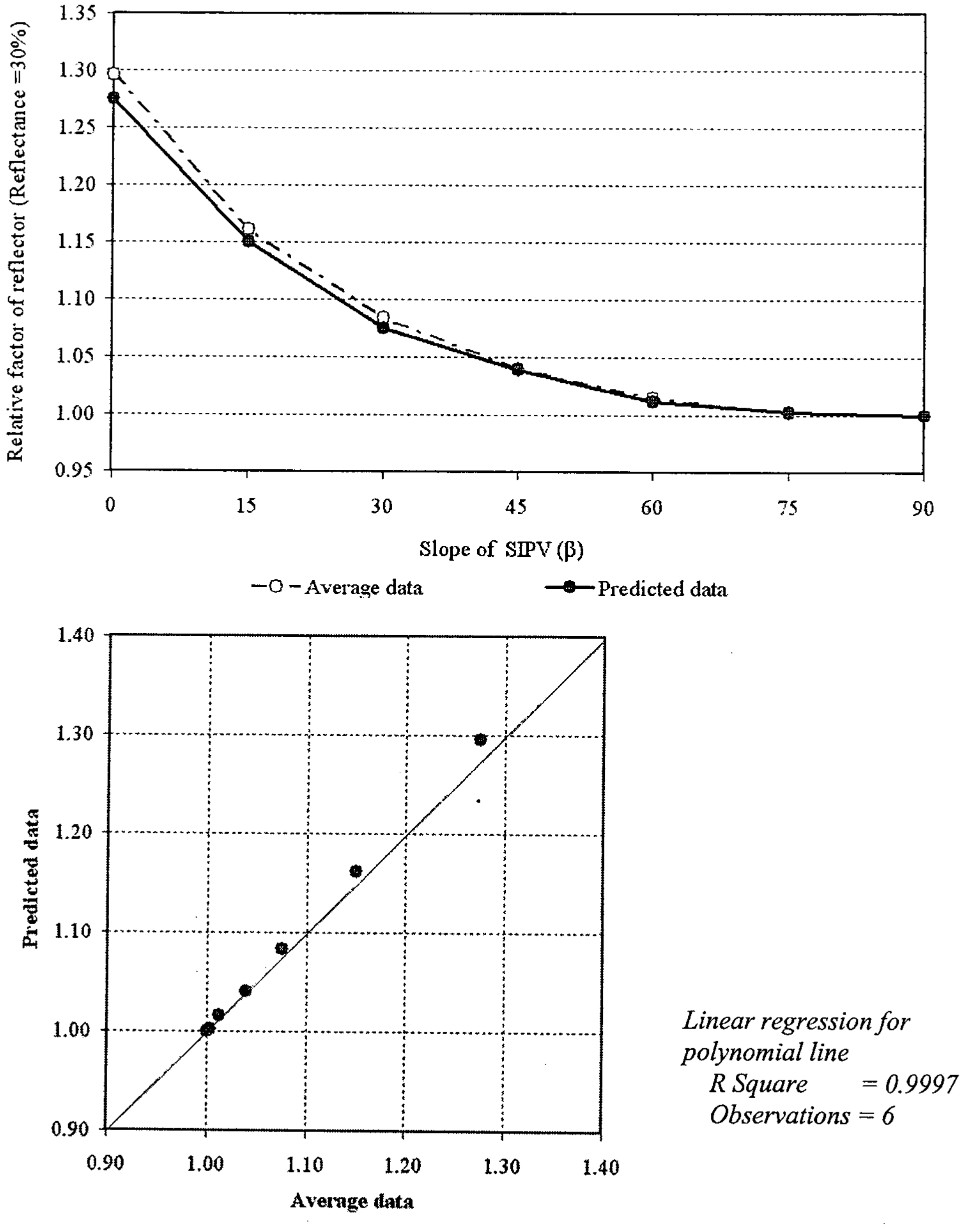


Figure 139 The evaluation of building reflected model

$$R_{rB} = 0.0003A^4 - 0.0029A^3 + 0.0153A^2 - 0.0278A + 1.0154 \qquad Eq.110$$

$$A = (105-\beta)/15$$

The building reflective model as shown in Figure 139 shows the highest value is at tilt angle of 0 degrees and value is decreasing rapidly in a curve of polynomial line as well as shows the reliability in a form of the coefficient of determination, R^2, at 0.9997.

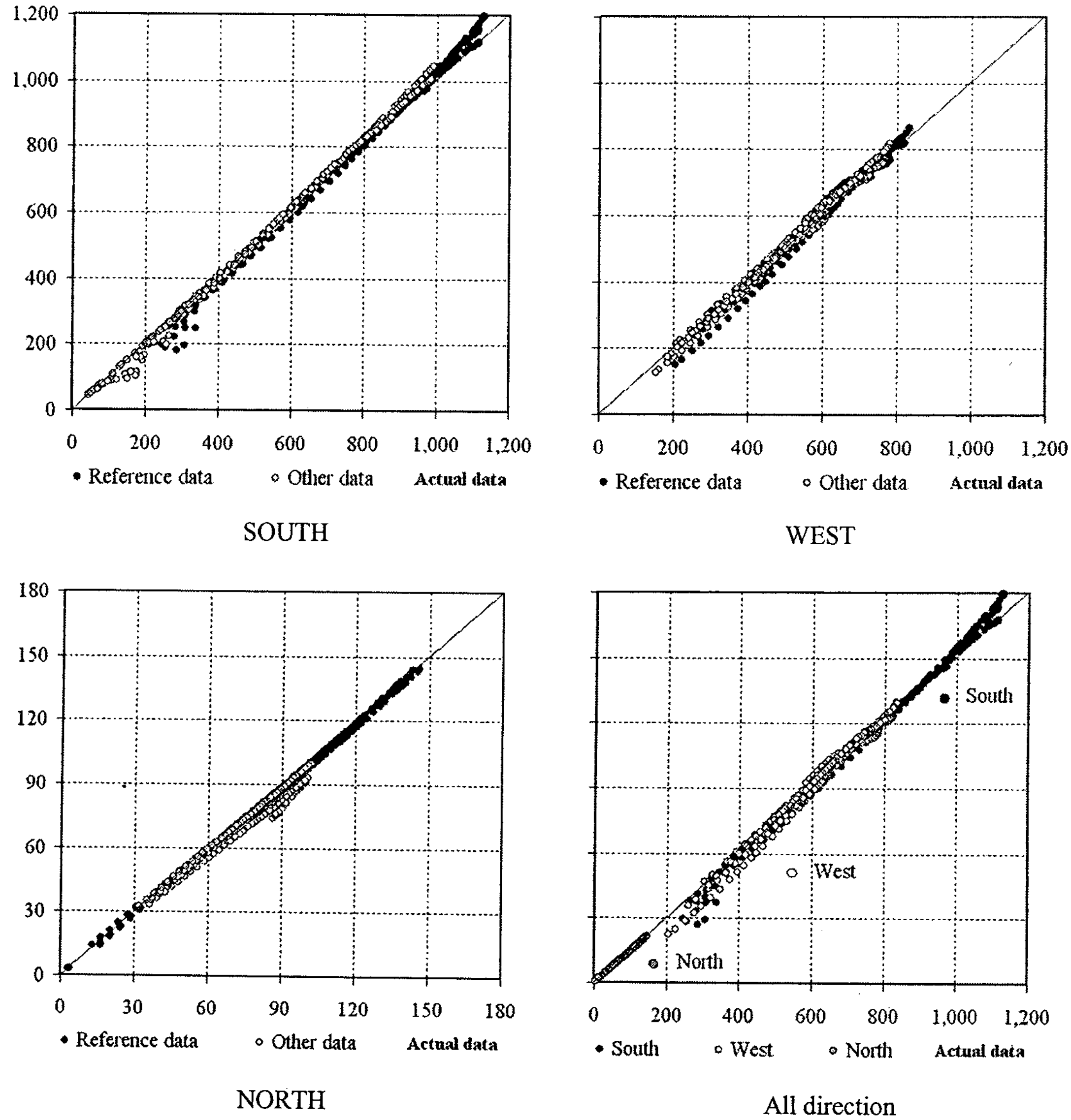


Figure 140 The comparison between predicted data and actual data

Table 22 The evaluation of the building reflected model

	Reference data	Other data	Reference data	Other data
	West		South	
	Feb 3rd 2010	Feb 2nd 2010	Feb 8th 2010	Feb 5th 2010
Observation	5940	6420	7200	7200
RMSE	23.27	16.11	21.96	30.26
NRMSE	3.84%	3.09%	4.13%	3.74%
MBE	5.6071	4.7228	7.7054	12.4975
NMBE	0.9254%	0.9047%	1.4484%	1.5440%
R square	0.9875	0.9938	0.9961	0.9981
	North		All direction	
	Feb 6th 2010	Feb 7th 2010	Feb 6th 2010	Feb 7th 2010
Observation	6600	6600	19740	19740
RMSE	1.91	4.63	22.32	16.35
NRMSE	2.16%	5.86%	4.40%	4.33%
MBE	-1.5186	-3.5981	5.7379	3.1435
NMBE	-1.7140%	-4.5560%	1.1313%	0.8327%
R square	0.9991	0.9739	0.9977	0.9984

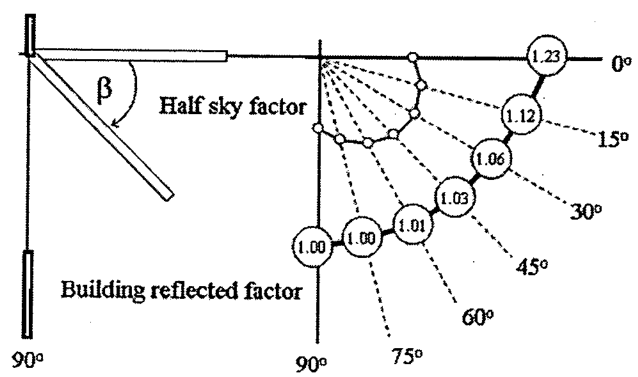


Figure 141 The reflected solar irradiance explanation of half sky condition

Comparing to data from other days which is not data used in analysis with root mean square error (RMSE) and the mean bias error (MBE) as shown in Table 22 explains that values of all sky conditions can be predicted similarly.

The comparison of diffuse solar irradiance factor and the building solar reflectance in each installation with all kind of tilt angles of SIPV as shown in Figure 142 presents that both have the different highest values. However, if the calculation result in a form of annual solar radiation on SIPV is being compared, it is found that at the tilt angle of 30 degrees provides the highest value due to a few factor of solar irradiance reflectance as shown in Figure 143.

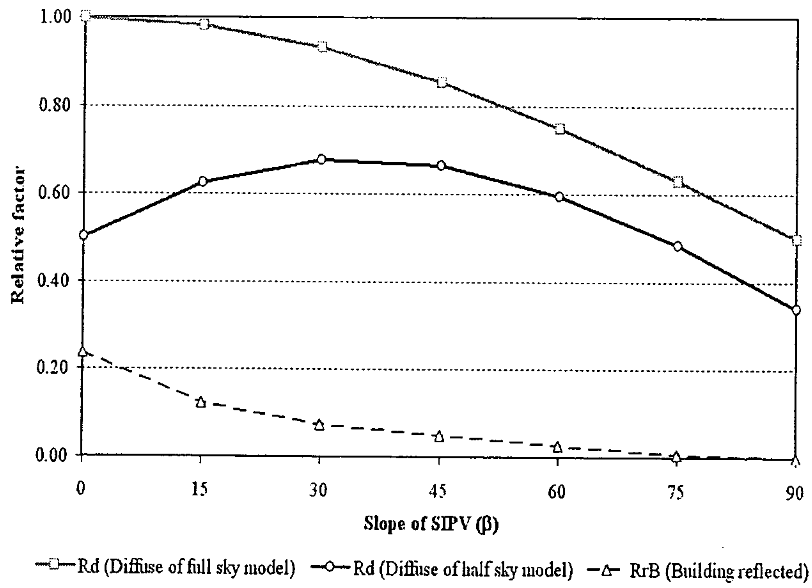


Figure 142 The comparison of experimental models

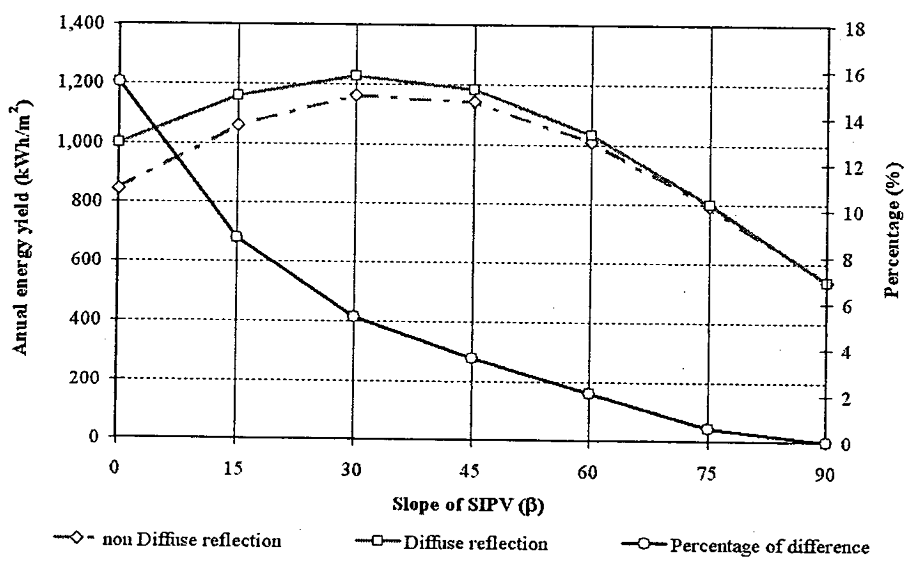


Figure 143 The effect of building reflected and diffuse solar irradiance

1.3 Factors of overlapped SIPV installation

SIPV is solar module installed on vertical plane of building. It has one disadvantage indicating that when another PV array is installed down below being covered by the array on the top, it results in the below one receives less solar irradiance both direct and diffuse irradiance. Figure 144 and Table 23 shows the relation of the decrease due to installation with outstretched part and distance according to all kind of vertical planes in both cases of clear sky and overcast sky. The values are changed because of opened angle allowing to see the sky and trends of both sky conditions are similar.

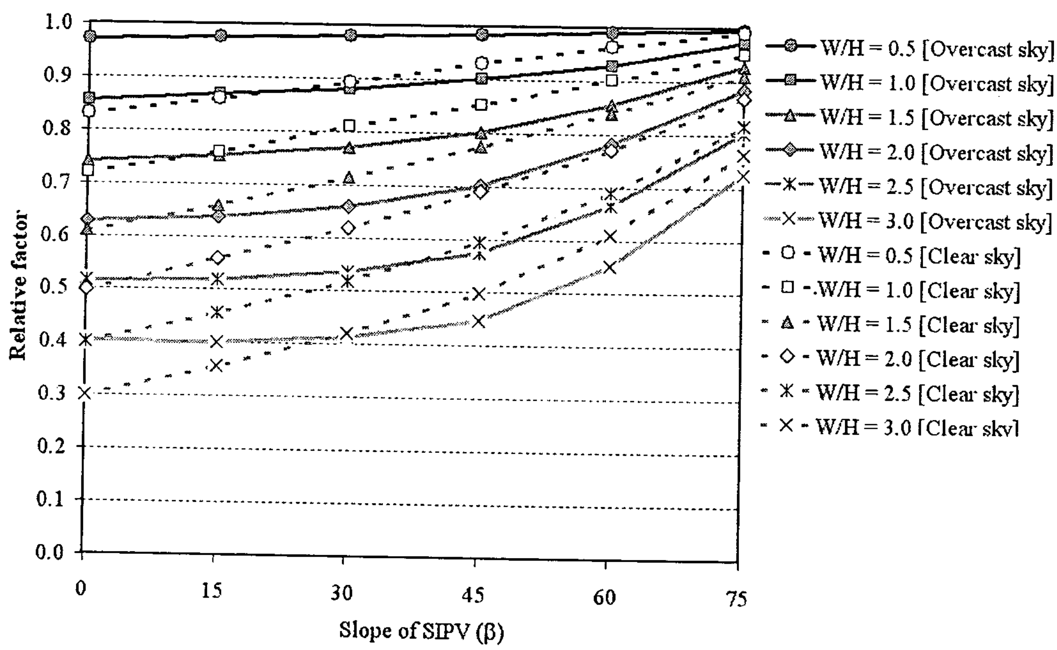


Figure 144 The relative factor of stack effect

Table 23 The relative factor of stack effect

	Slope					
W/H	**90**	**75**	**60**	**45**	**30**	**15**
Clear sky						
0.5	0.83	0.86	0.89	0.93	0.96	0.99
1.0	0.72	0.76	0.81	0.85	0.90	0.95
1.5	0.61	0.66	0.72	0.78	0.84	0.91
2.0	0.50	0.56	0.62	0.69	0.77	0.87
2.5	0.40	0.46	0.52	0.60	0.69	0.82
3.0	0.30	0.36	0.42	0.50	0.61	0.76
Overcast sky						
0.5	0.97	0.98	0.98	0.99	0.99	1.00
1.0	0.86	0.87	0.88	0.90	0.93	0.97
1.5	0.74	0.75	0.77	0.80	0.85	0.93
2.0	0.63	0.64	0.66	0.70	0.78	0.88
2.5	0.52	0.52	0.54	0.58	0.67	0.81
3.0	0.40	0.40	0.41	0.45	0.55	0.73

2. Efficiency of PV module [Chapter III; page 100-103]

2.1 Module temperature effect of solar irradiance in the case of full sky condition

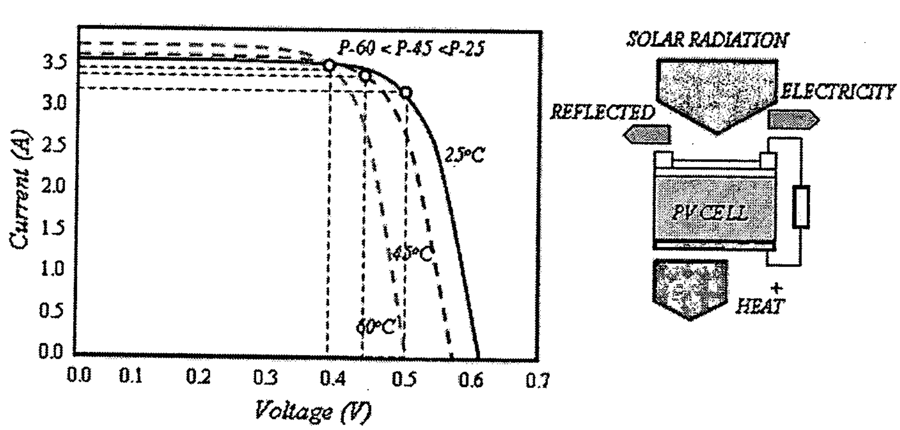


Figure 145 The effect of module temperature

In this part is to find efficiency of PV which is changed by PV module temperature. However, PV module temperature is altered according to solar irradiance and whether as shown in Figure 145. This is because the installation in outdoor condition according to quality of thermos, heat reflecting and heat transferring materials. As a result, there is a difference between both mentioned cases of installations as shown in Figure 146.

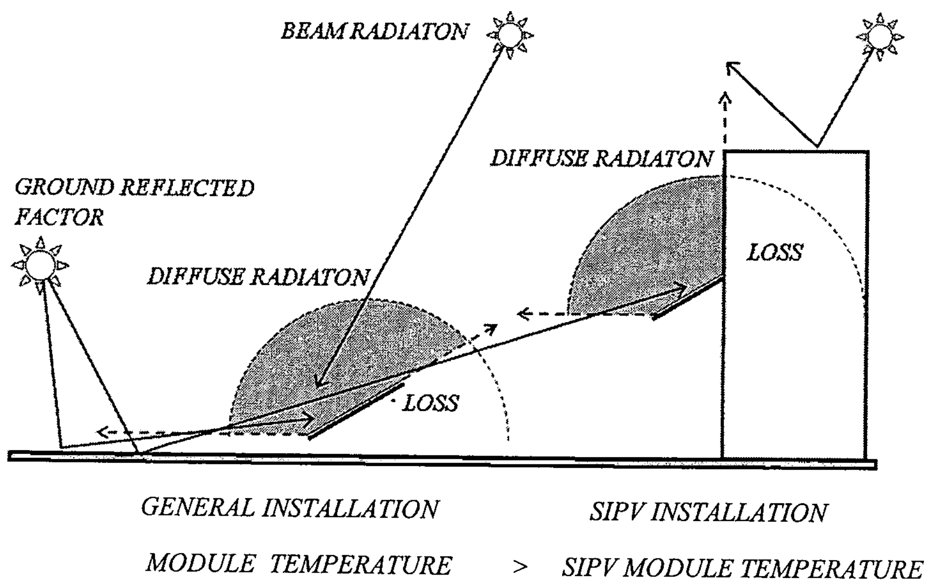
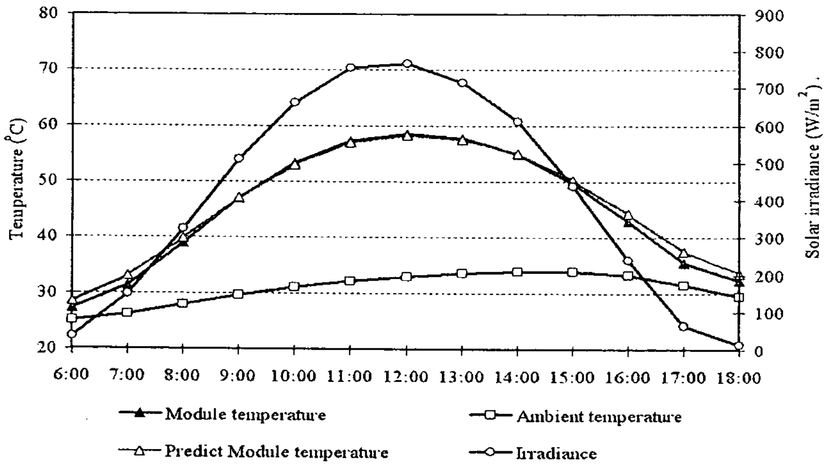
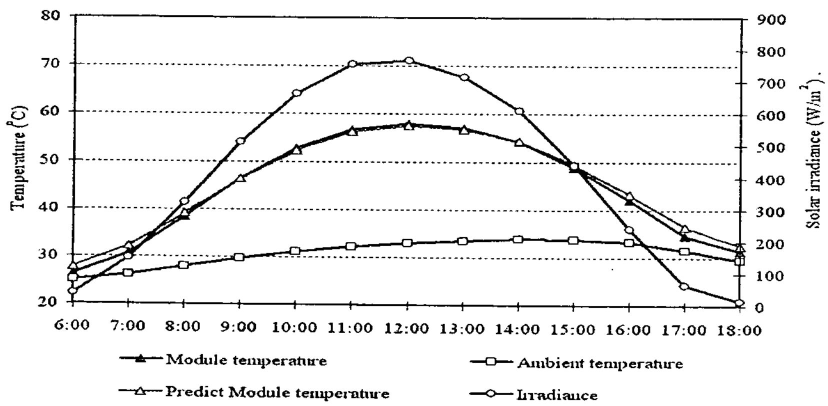


Figure 146 The comparison of the PV installation

PV is material with low heat radiation reflectance capable of collecting only a few amount of solar irradiance because of its thinness and non-insulator. This results in heat on skin of module causing lower efficiency. In the case of half sky, the effect of solar irradiance is lesser while effect of whether is being equally received.



Amorphous silicon



Polycrystalline silicon

Figure 147 The comparison of the module temperature, solar irradiance and ambient temperature

$$Tm_{a\text{-}Si} = -2.9564 + (1.2249\ T_{amb}) + (0.0271\ I_{tT}) \quad Eq.104$$

R Square = *0.9456*

Observations = *29,483 ; during 2007*

$$Tm_{p\text{-}Si} = -3.3869 + (1.2055\ T_{amb}) + (0.0276\ I_{tT}) \quad Eq.104$$

R Square = *0.9460*

Observations = *29,482 ; during 2007*

Figure 147 shows that both technologies have similar module temperature in the case of experiment under full sky condition. It is found that the temperature is changed by solar irradiance and because of effect of weather causing the low decrease of module temperature as the solar irradiance is supposed to decrease more in the evening. From using the equation gained from regression analysis, the values of both technologies can be predicted similar to the actual data.

2.2 PV module efficiency under full sky condition

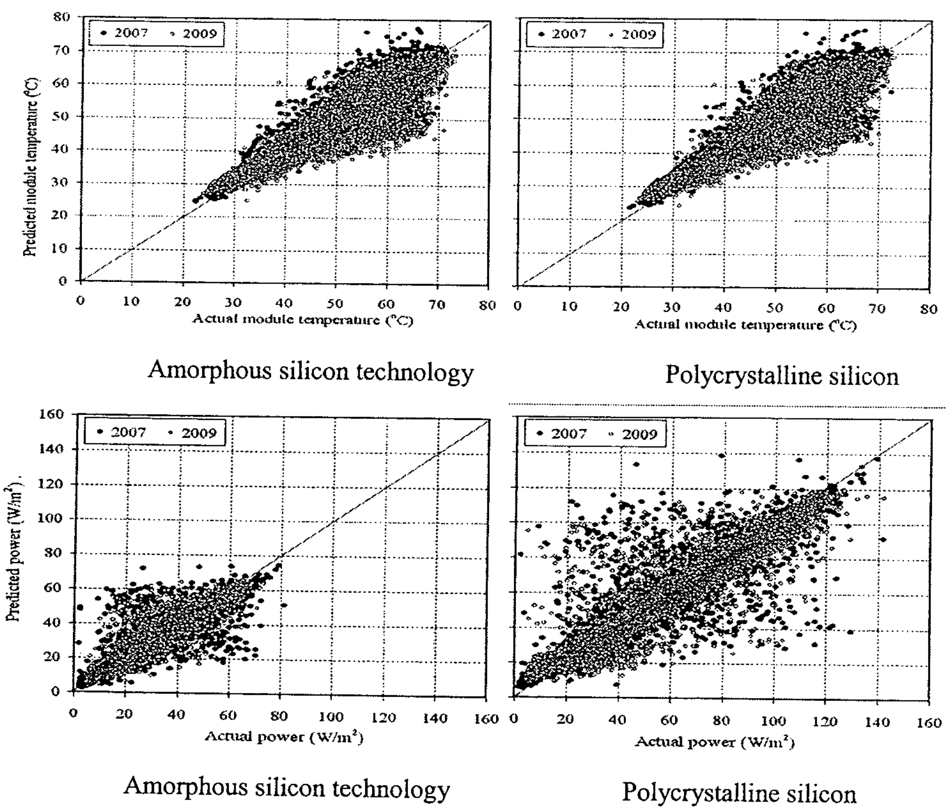
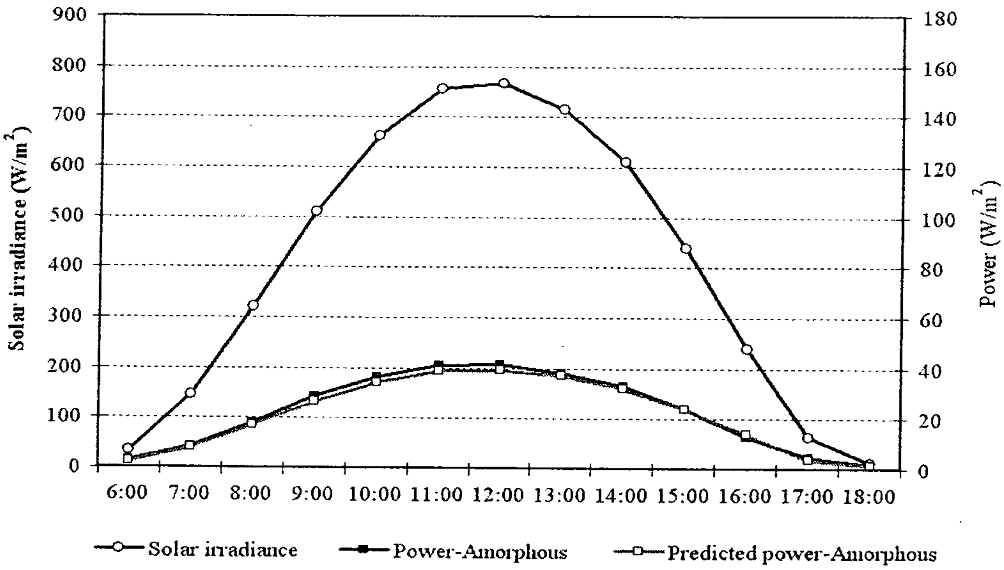


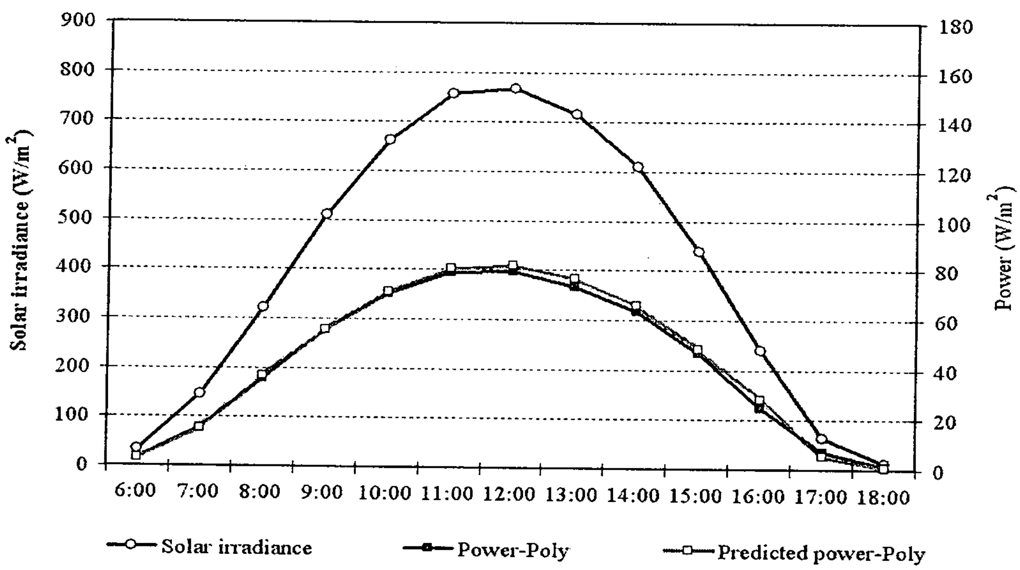
Figure 148 The comparison between predicted data and actual data

Table 24 The evaluation of the module temperature models

	Module temperature				**Power**			
	Amorphous silicon		Polycrystalline silicon		Amorphous silicon		Polycrystalline silicon	
	2007	2009	2007	2009	2007	2009	2007	2009
Observations	17,487	21,020	17,487	21,020	17,487	21,020	17,487	21,020
RMSE	2.9833	3.8660	3.1114	3.8053	4.2269	3.2557	7.1870	6.2038
NRMSE	5.7580	7.6252	6.0899	7.6333	12.7638	10.6719	11.9829	10.8979
MBE	-0.0635	-1.9004	-0.1128	-1.8130	0.1080	0.1322	-0.0341	-1.2394
NMBE	-0.1226	-3.7483	-0.2208	-3.6367	0.3262	0.4333	0.0568	-2.1773
Rsquare	0.9115	0.8764	0.9061	0.8787	0.9266	0.9478	0.9323	0.9486



Amorphous silicon technology



Polycrystalline silicon

Figure 149 The power prediction by the mathematical models

Comparing to data from other years which is not data used in analysis with root mean square error (RMSE) and the mean bias error (MBE) as shown in Table 24 explains that the equation can be used in prediction and with database from different other years. From the data disperse shown in Figure 148 of both technologies, it is found that the disperse rather provides a clear linear trend in both cases of module temperature and produced power.

Figure 149 shows result of comparison due to the use of equation to predict the values of both solar cells technologies as shown in Eq. 105 and database of 2009.

$$\eta_{a\text{-}Si} = [-5.8527 + (0.2659\, T_m) + (0.0446\, E_{tT})] / E_{tT} \qquad \text{Eq.105}$$

R Square = *0.8978*

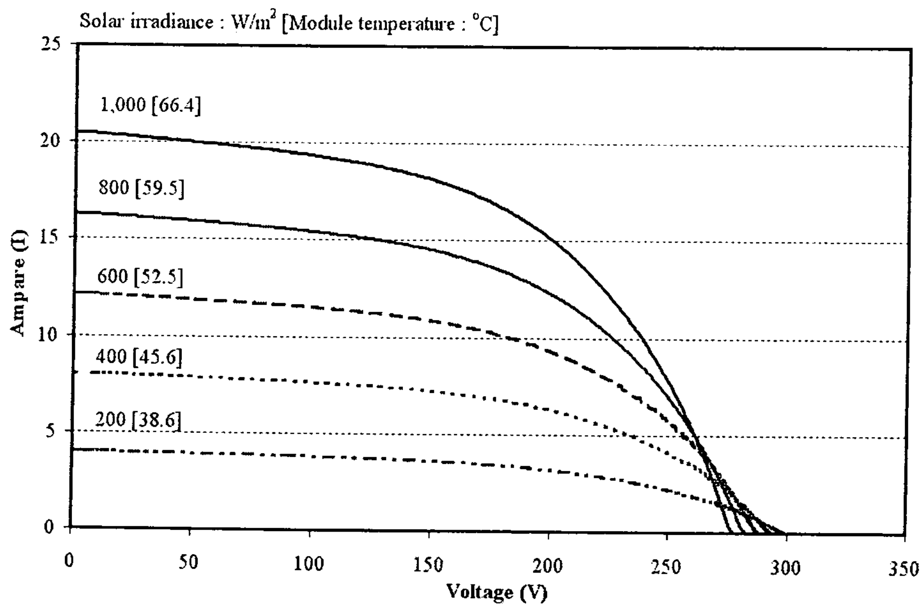
Observations = *19,445 ; during 2007*

$$\eta_{p\text{-}Si} = [-1.9995 + (0.2207\, T_m)+(0.0893\, E_{tT})] / E_{tT} \qquad \text{Eq.105}$$

R Square = *0.9043*

Observations = *21,209 ; during 2007*

2.3 Module efficiency under half sky



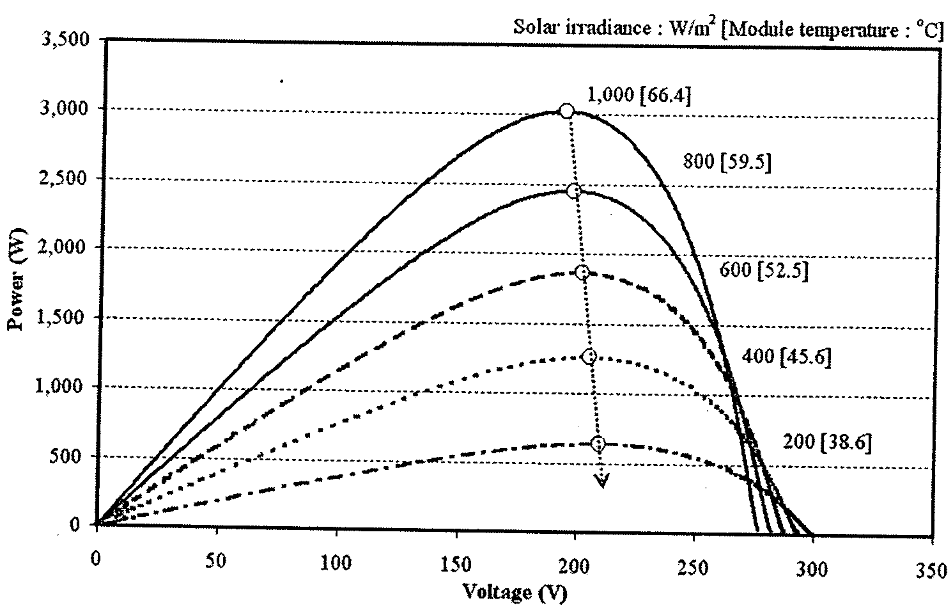


Figure 150 The characteristic curves of amorphous silicon technology

Figure 150 shows the comparison of solar irradiance change and module temperature change in the forms of I-V curve and P-V curve of amorphous silicon technology. It is found that the highest value of electric power at curve of each condition tends to decrease as a linear.

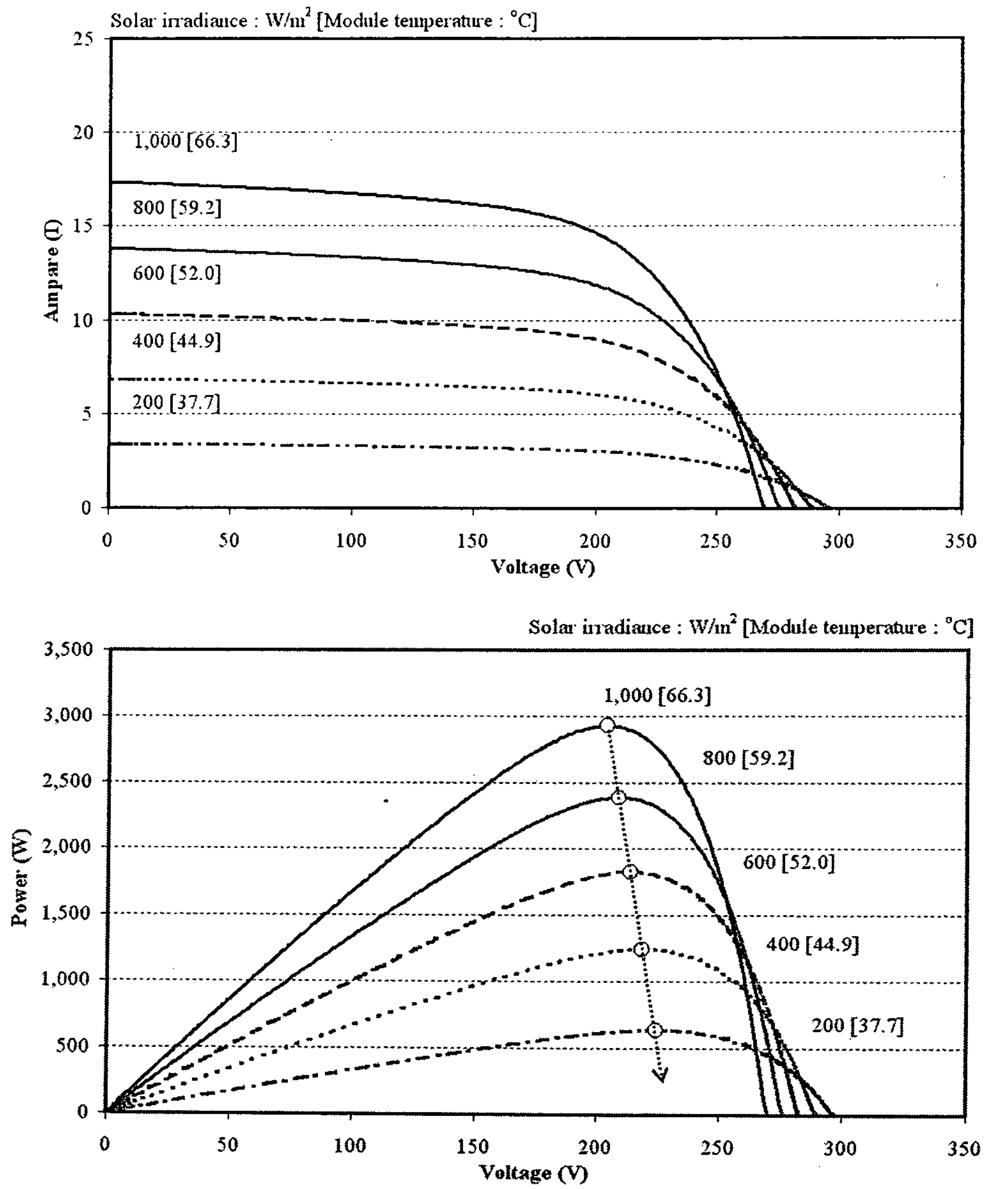


Figure 151 The characteristic curves polycrystalline silicon technology

Figure 151 shows the comparison of solar irradiance change and module temperature change in the forms of I-V curve and P-V curve of polycrystalline silicon technology. It is found that highest value of electric power at curve of each condition tends to decrease as linear with a little difference of line slope.

When the period of Solar irradiance at 50-300 W/m^2 and air temperature between 20°C to 36°C as shown in Figure 152, it is found that the period of the change in polycrystalline silicon module efficiency is more than Amorphous silicon technology.

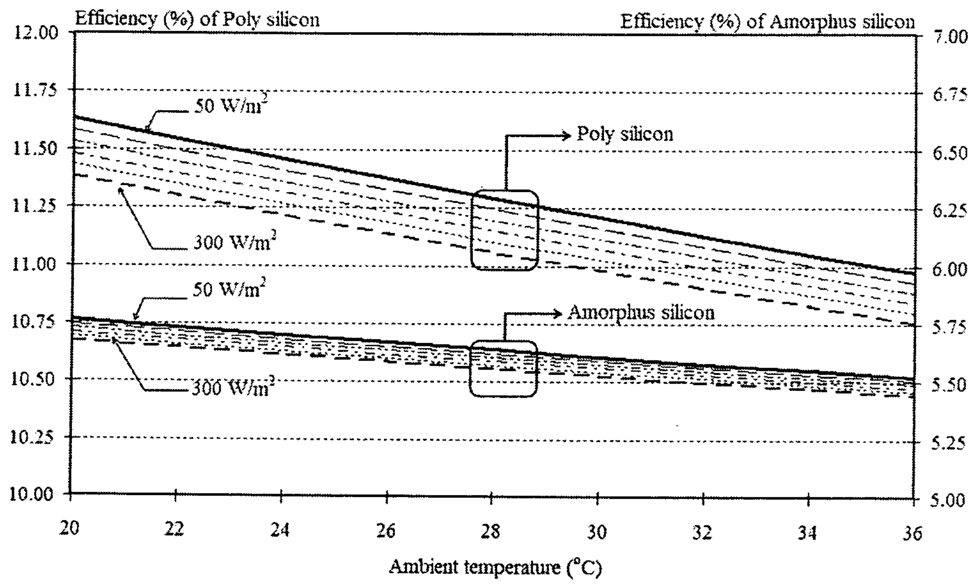


Figure 152 The module temperature effect under half sky condition

$$Eff_{a\text{-}Si} = 6.0709 - 0.0003\, I_{tT} - 0.0148\, T_{amb} \qquad Eq.106$$

$$R^2 = 0.9995$$

Observations = *54 ; during 2008*

$$Eff_{p\text{-}Si} = 12.4671 - 0.0009\, I_{tT} - 0.0402 T_{amb} \qquad Eq.106$$

$$R^2 = 0.9993$$

Observations = *54 ; during 2008*

Figure 153 shows the prediction of PV efficiency compared to solar irradiance. Figure 154 shows the comparison of ambient temperature; the Eq. 105 is used in the case of full sky and Eq. 106 is used in the case of half sky. It is found that in Polycrystalline silicon, p-Si, efficiency is clearly changed according to solar irradiance and in Amorphous silicon, effect of temperature is shown. From the increase by the trend of ambient temperature, it is found that efficiency of both technologies under half sky is more stable than full sky condition.

Therefore, the power change of solar cells technology contains two following factors in prediction: solar irradiance and ambient temperature. The gained math models will be separately used in prediction according to solar irradiance receiving and solar cells technologies.

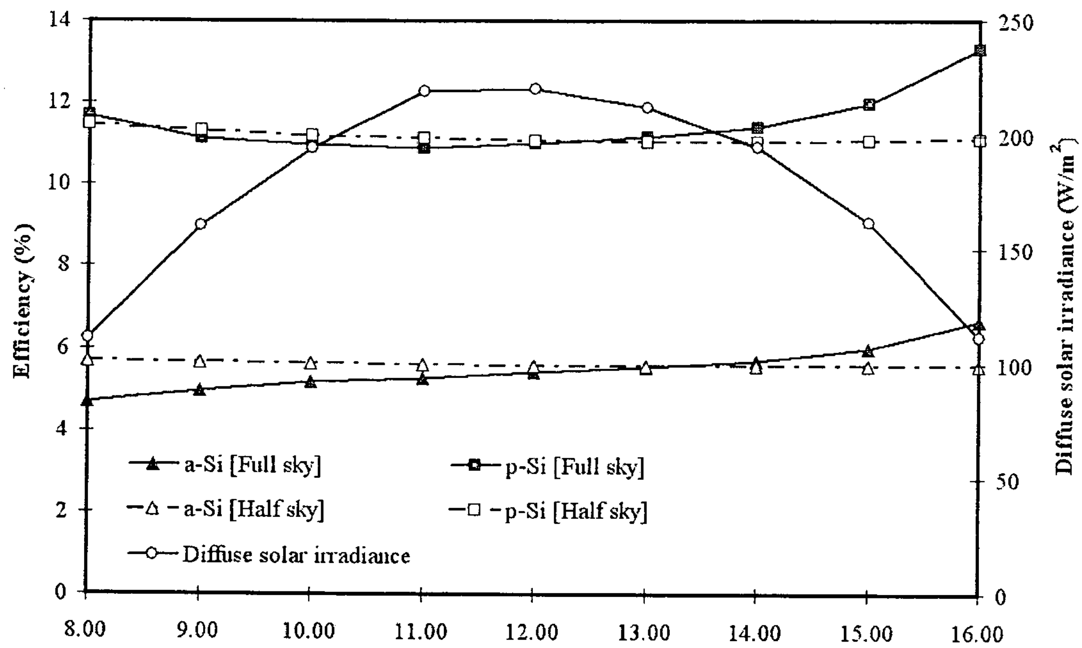


Figure 153 The comparison between the PV efficiency and the solar irradiance

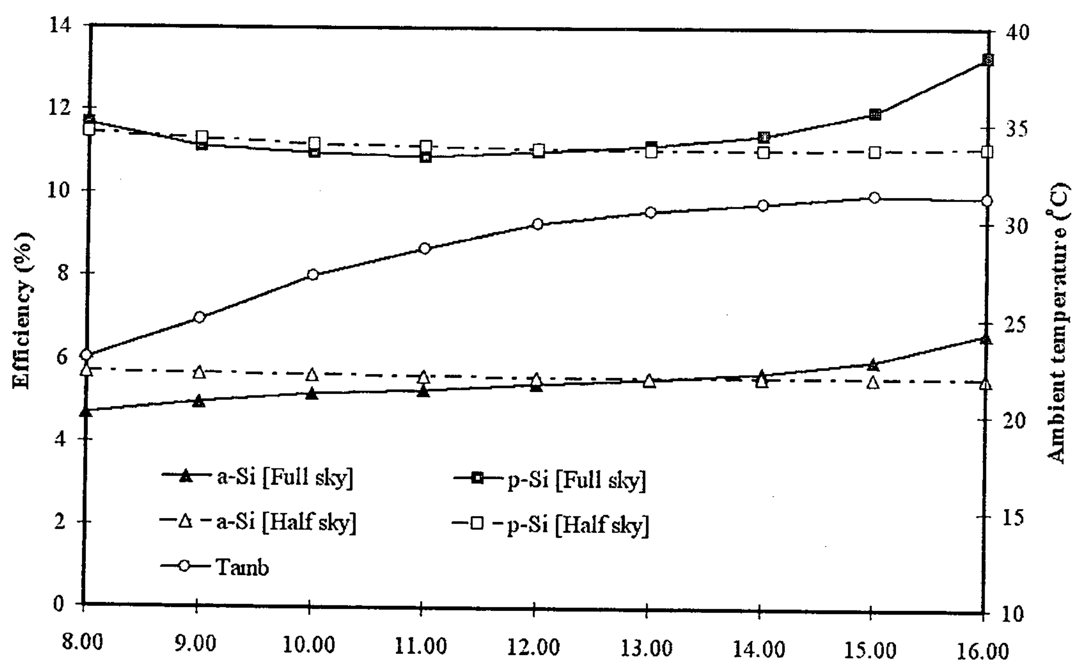


Figure 154 The comparison between the PV efficiency
and the ambient temperature

3. The efficiency of inverter under out door condition

The experiment using B. Tarika's [53] research data analysis as shown in Figure 155 and the improvement of equation used in prediction by using regression analysis technique as shown in Figure 156, it is found that inverters can work well or have high efficiency when receiving total solar irradiance more than 600 W/m^2 which is not half sky case.

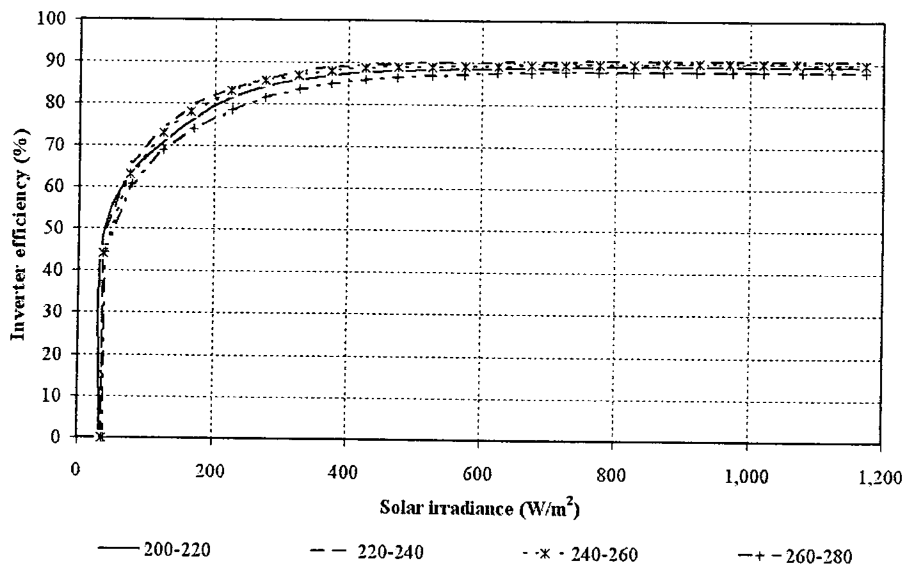


Figure 155 The efficiency of inverter operation between 200 V and 280 V

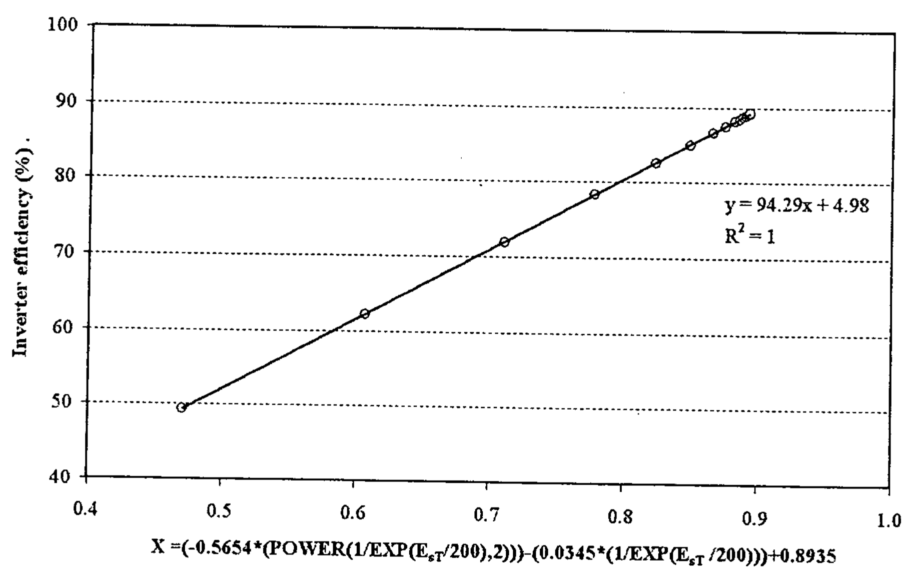


Figure 156 The relation between efficiency and modified solar irradiance

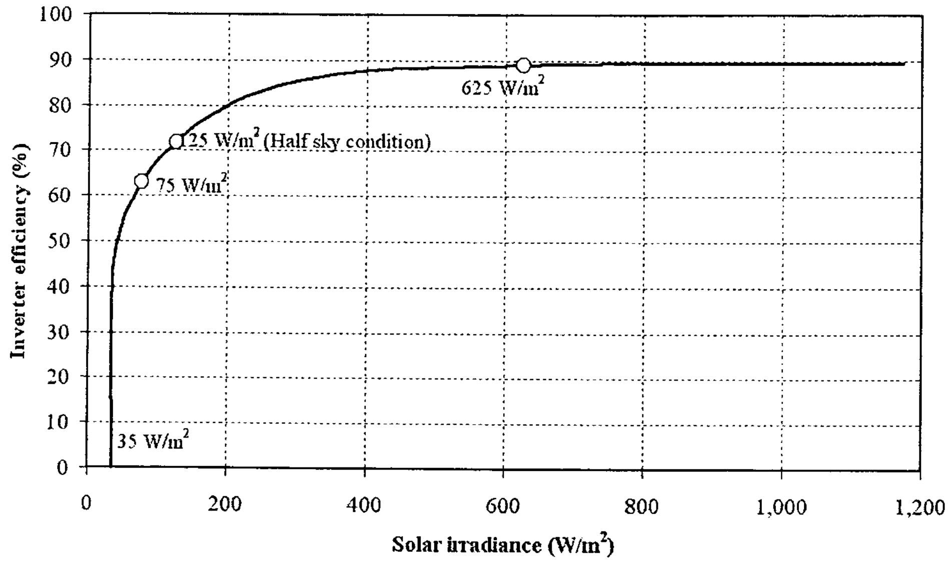


Figure 157 The predicted line of inverter efficiency

$$\eta_{inv} = 0.0498 + 0.9429(X) \qquad Eq.107$$

$$X = (-0.5654x((1/exp(E_{t}S/200))^{2}))-(0.0345x(1/exp(E_{t}S/200)))+0.8935$$

Figure 157 shows efficiency of inverters operation. It is found that the highest efficiency is at about 90%, at 625 W/m^2. While half sky condition at 125 W/m^2 has about 72% of efficiency and cannot work well at 35 W/m^2. It can be said that the operation under full sky condition will have efficiency from 85% to 90% corresponding to the operation of shading devices during 8.00-16.00. In addition, inverters' operations have low efficiency when there is low solar irradiance before 8.00 or after 16.00.

4. Daylight Factor (DF) [Chapter III; page 104-105]

4.1 The Sky Component (SC)

Figure 158 shows the data comparison between the case of with shading devices at W/H=0.3 and without shading devices at W/H=0 in various period of time. It is found that the collected data tends to be similar in every period of time including the case of clear sky as shown in Figure 158. In Figure 159, trend of the overcast sky is more different.

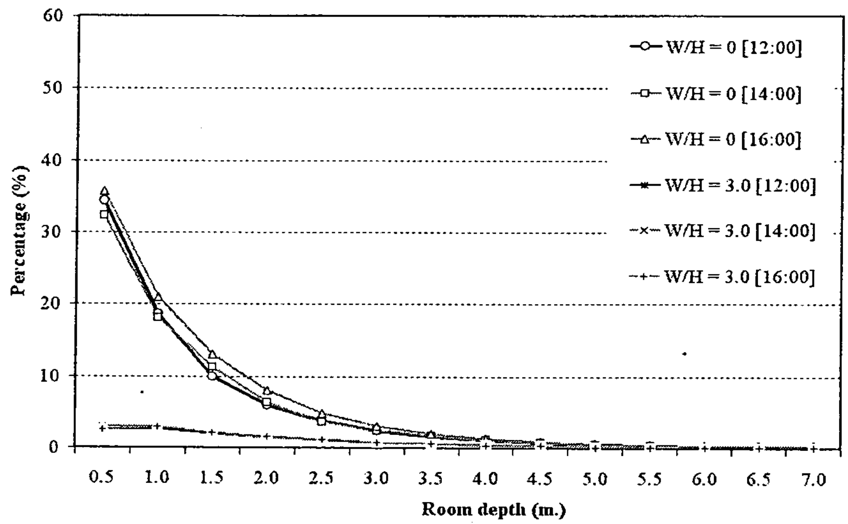


Figure 158 The SC comparisons of clear sky condition

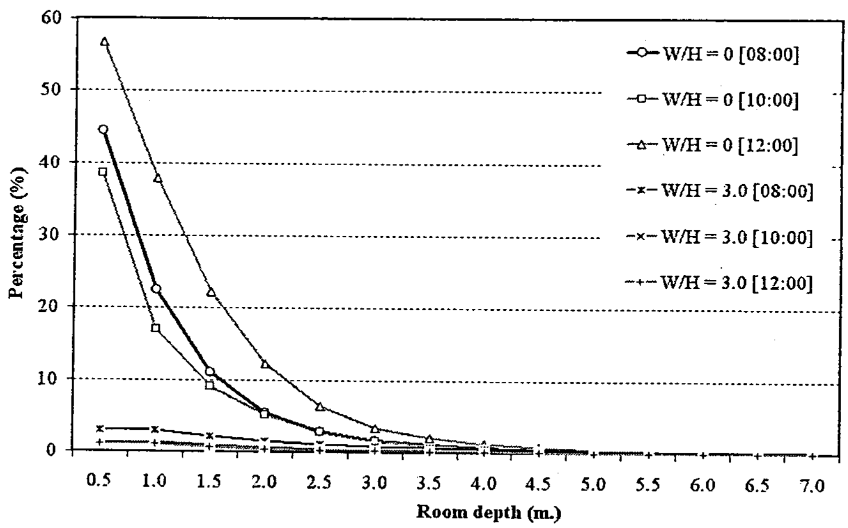


Figure 159 The SC comparisons of overcast sky condition

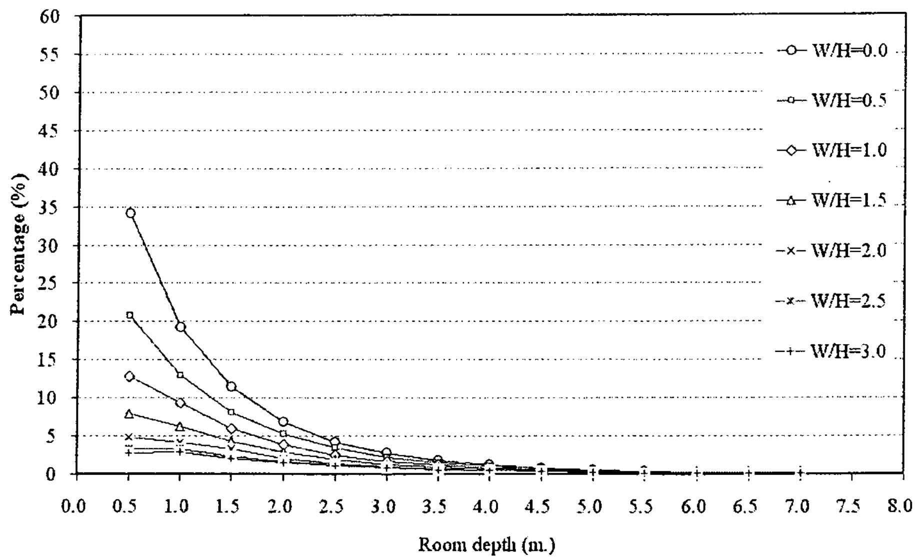


Figure 160 The SC comparison every W/H ratio of clear sky condition

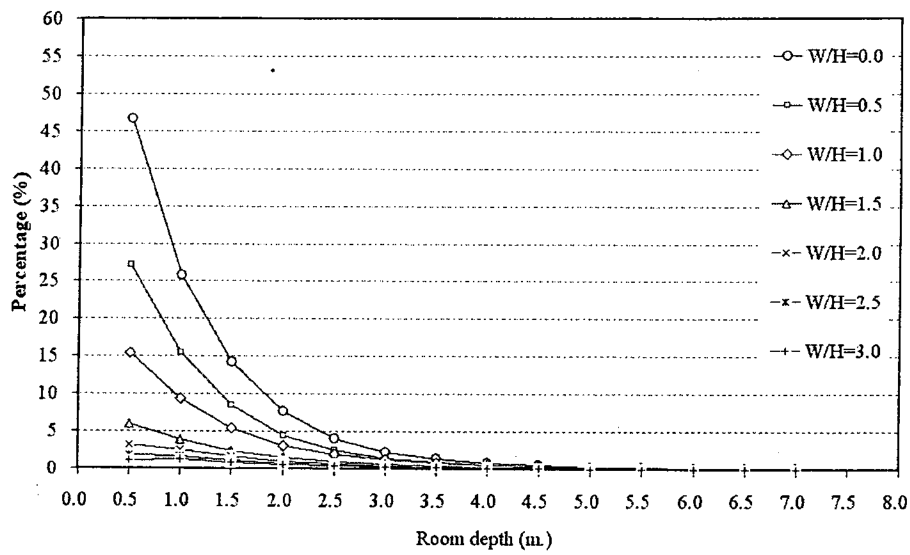


Figure 161 The SC comparison every W/H ratio of overcast sky condition

Both sky conditions have similar trends by receiving daylight which is decreased according to W/H ratio of shading devices and rapidly decreased where there is a long distance from window causing the similar values at the distance about 4 times of window height.

4.2 The Internal Reflected Component (IRC)

The Mirror box was used in this experiment to reproduce overcast sky in order to find effect of reflectance of room surface within the buildings. The comparison is between normal surface model and dark surface model with qualification of low reflectance as shown in Figure 162. When the gained IRC ratio being confuted, it is found that the trend of high value is the area close to window but it will not rapidly decrease and have different effect through the depth of the room.

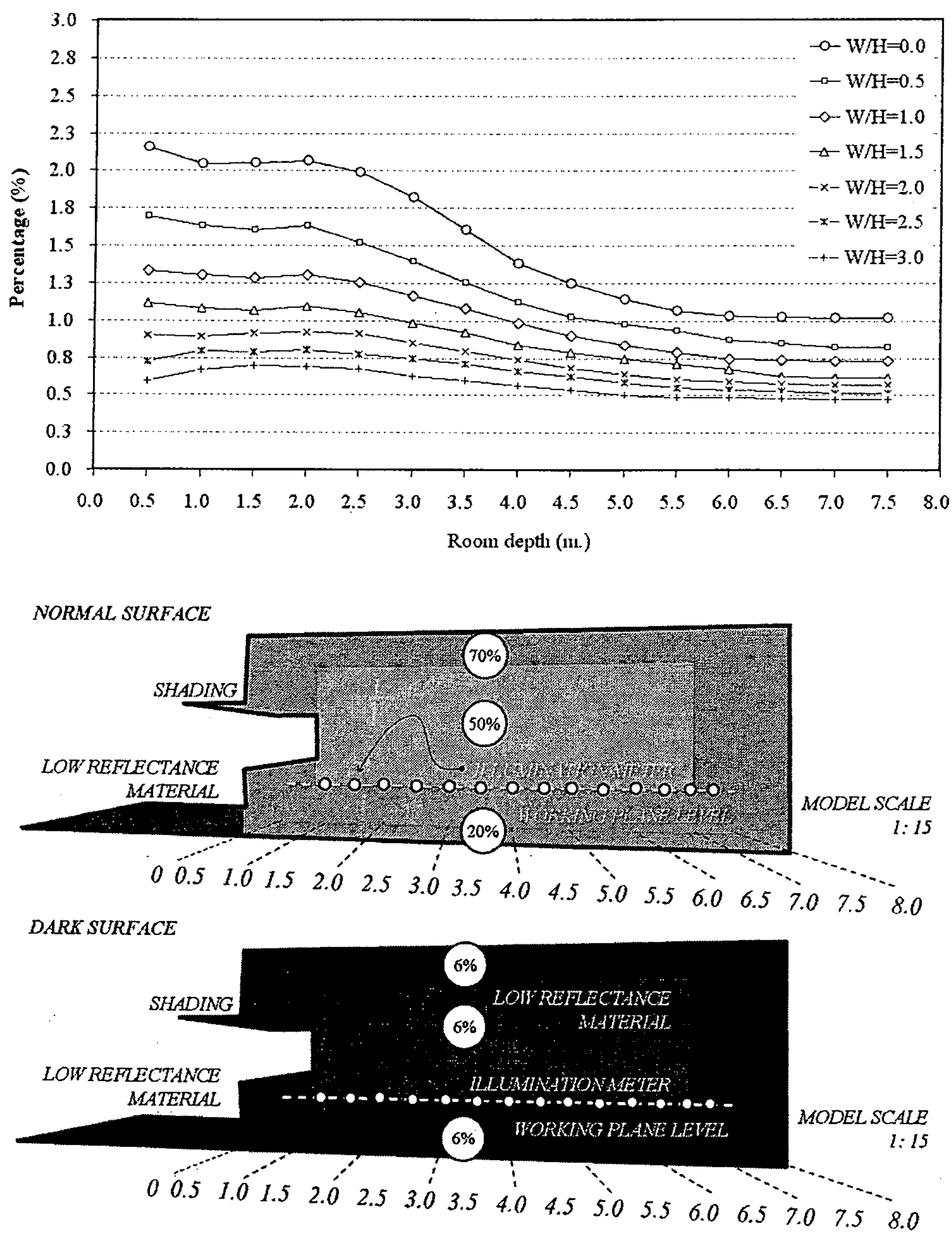


Figure 162 The IRC every W/H ratio of mirror box condition

4.3 Total Daylight Factor (DF)

For the usability, clear sky case is considered in estimation due to the fact that it is the condition allowing SIPV to work normally as shown in Figure 163. Sum total of SC and IRC is shown in Table 25 in every forms of W/H of shading devices in each position of distance from the window using Eq.112.

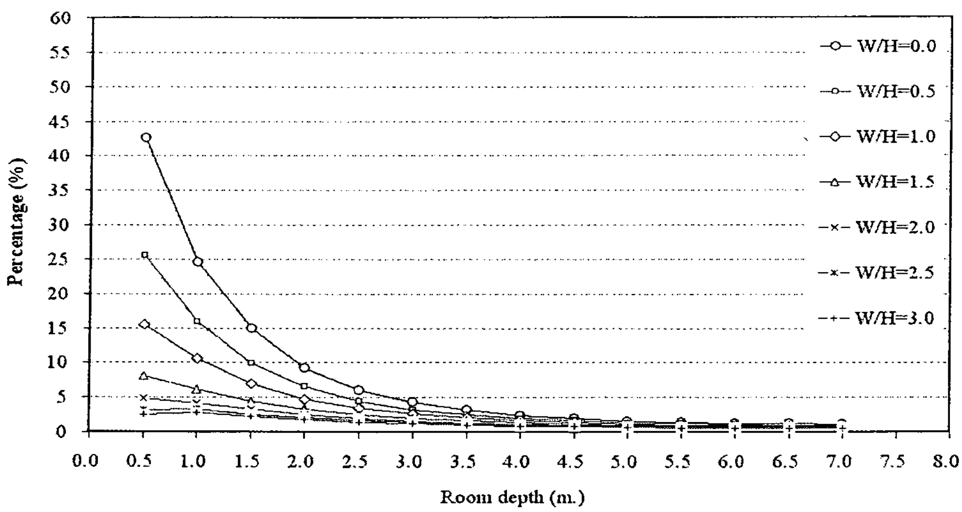


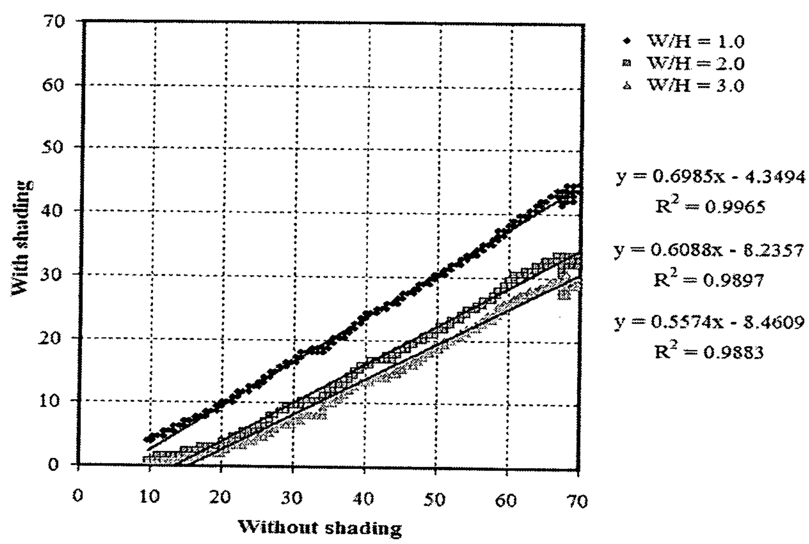
Figure 163 The DF every W/H ratio of average sky condition

Table 25 The SC and IRC every W/H ratio of average sky condition

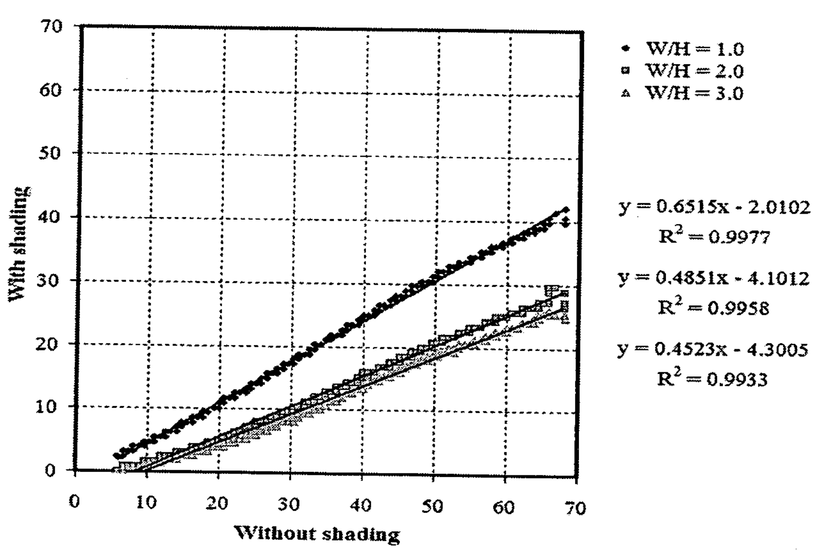
SC							**Room dept**							
W/H	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
0.0	40.37	23.90	14.1	6.99	4.01	2.54	1.92	40.37	23.90	14.14	6.99	4.01	2.54	1.92
0.5	22.52	14.25	9.34	5.11	3.29	2.49	2.06	22.52	14.25	9.34	5.11	3.29	2.49	2.06
1.0	12.81	8.28	5.72	3.35	2.49	1.77	1.49	12.81	8.28	5.72	3.35	2.49	1.77	1.49
1.5	7.20	4.86	3.48	2.19	1.53	1.22	1.06	7.20	4.86	3.48	2.19	1.53	1.22	1.06
2.0	4.08	3.00	2.23	1.48	1.07	0.86	0.78	4.08	3.00	2.23	1.48	1.07	0.86	0.78
2.5	2.47	1.84	1.46	0.94	0.73	0.62	0.57	2.47	1.84	1.46	0.94	0.73	0.62	0.57
3.0	1.59	1.24	1.00	0.69	0.53	0.46	0.42	1.59	1.24	1.00	0.69	0.53	0.46	0.42
IRC	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
0.0	2.16	1.70	1.33	1.11	0.90	0.73	0.59	2.16	1.70	1.33	1.11	0.90	0.73	0.59
0.5	2.04	1.63	1.31	1.08	0.89	0.79	0.67	2.04	1.63	1.31	1.08	0.89	0.79	0.67
1.0	2.05	1.60	1.28	1.07	0.91	0.79	0.70	2.05	1.60	1.28	1.07	0.91	0.79	0.70
1.5	2.06	1.63	1.30	1.09	0.92	0.80	0.69	2.06	1.63	1.30	1.09	0.92	0.80	0.69
2.0	1.99	1.52	1.25	1.05	0.91	0.78	0.67	1.99	1.52	1.25	1.05	0.91	0.78	0.67
2.5	1.82	1.39	1.17	0.98	0.85	0.75	0.63	1.82	1.39	1.17	0.98	0.85	0.75	0.63
3.0	1.60	1.25	1.08	0.92	0.79	0.71	0.60	1.60	1.25	1.08	0.92	0.79	0.71	0.60

5. The Shading Coefficient of diffuse radiation (SC_d) [Chapter III; page 107]

SC_d is a value indicating shading coefficient. From the result of experiment, the comparison is between sky in the North shown in Figure 164 (top) and West shown in Figure 164 (below) by testing with shading devices with 3 types of W/H ratio as follows: 1.0, 2.0 and 3.0. The results shows that two sky conditions provide similar experiment result and when compared as SC_d as shown in Figure 165 by considering the average between 2 sky curve to be used in creating predicting equation and to conclude as a constant for each W/H ratio of shading devices as shown in Table 26.



NORTH



WEST

Figure 164 The solar irradiance ratio with shading to without shading

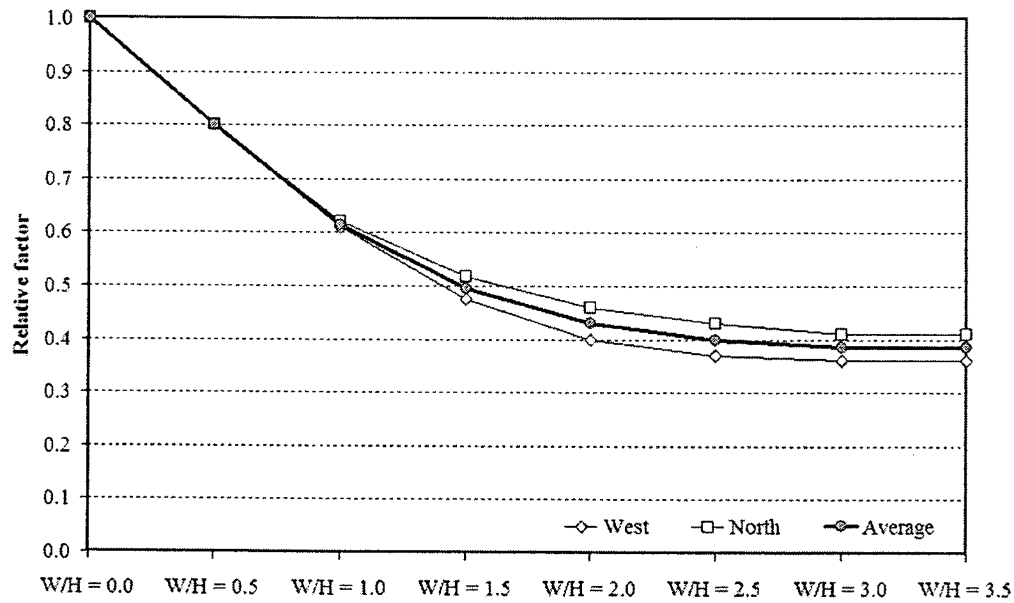


Figure 165 The Shading Coefficient of diffuse radiation comparisons

Table 26 Shading Coefficient of diffuse radiation (SC_d)

	Shading Coefficient of diffuse radiation (SC_d)			
		Clear sky		**Overcast sky**
W/H	**North**	**West**	**Average**	
0.0	1.00	1.00	1.00	1.00
0.5	0.80	0.80	0.80	0.52
1.0	0.62	0.61	0.62	0.30
1.5	0.52	0.48	0.50	0.21
2.0	0.46	0.40	0.43	0.15
2.5	0.43	0.37	0.40	0.13
3.0	0.41	0.36	0.39	0.13
3.5	0.41	0.36	0.39	0.13

However, trend of SC_d in the case of clear sky is a little lower than the case of overcast sky. It is also found that SCd of W/H ratio at more than 2.5 is quite stable and tends not to decrease staying permanently at about 0.39 which means no matter how much longer the shading devices are, SC_d will not decrease.

Figure 166 shows the comparison of clear sky condition and overcast sky condition. It is found that SC_d is different. Due to the fact that overcast sky might affect cooling load quite a little and it doesn't need to open air conditioning system. This research is, therefore, considering using clear sky condition in estimation. The equation created by using regression analysis is linear equation with R square at 0.9995.

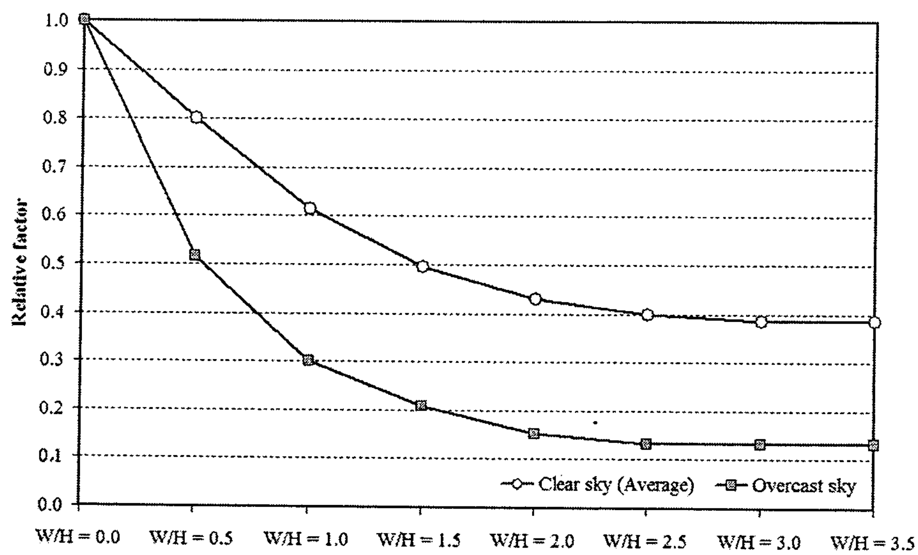


Figure 166 The comparisons between clear sky and overcast sky conditions

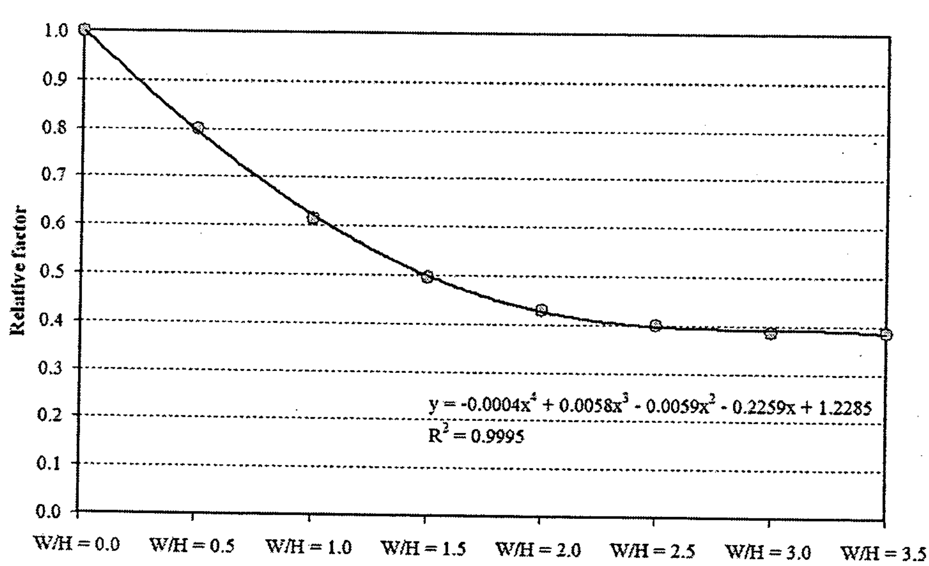


Figure 167 The Shading Coefficient of diffuse radiation trend

$$SC_d = 0.0004\,X^4 + 0.0058\,X^3 - 0.0059\,X^2 - 0.2259X + 1.2285 \qquad Eq109$$

$$X = 2(W/H) + 1$$

6. Summary of the experimental part

It is the study to improve equation for prediction of energy systems as follows:

6.1 To predict total solar irradiance using basic equation of ASHRAE (ASHREA's equation) improved by Eq.109 and Eq.110 in the case of SIPV design

6.2 To predict electric power using equations gained from experiment. Eq.105 is for the case of half sky condition as it is when total irradiance consists of beam radiation and sky irradiance. Eq.106 is for the case of half sky as it is when total irradiance consists of only sky irradiance

6.3 To predict electric power from using inverter by using Eq.107

6.4 To predict electric energy used for the whole 30 years and during 8.00 to 16.00

6.5 To predict illuminance level on working plane using Eq.112

6.6 To predict shading coefficient for shading devices located in each direction using Eq.113

Estimation part

The study in this part is to estimate from improved equation in order to predict the use of energy in air conditioning, light and SIPV energy production systems.

1. The total solar irradiance on slope surface

Procedure in estimation of total solar irradiance on slope surface is shown in Figure 168 using Eq.109 and Eq.110 in improving ASHREA's equation.

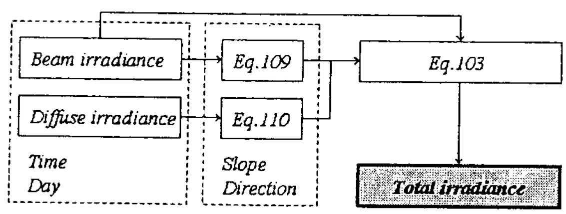


Figure 168 The process of total solar irradiance on slope surface calculation

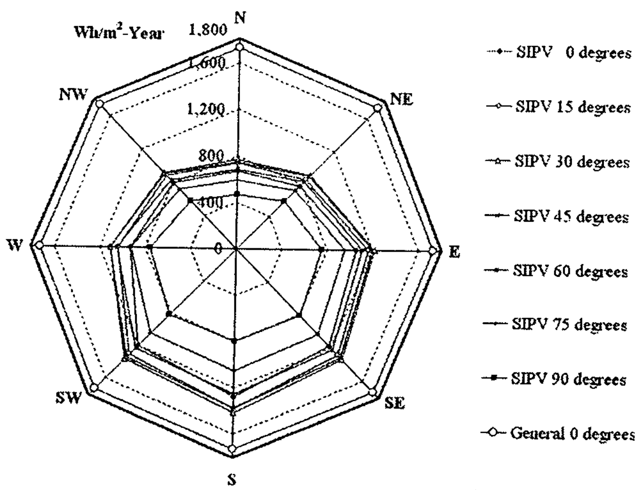


Figure 169 The estimation of the total solar irradiance on slope surface

From annual solar radiation falling down on SIPV plane in each direction and angle, it is found that SIPV in the south makeing tilt angle of 30 degrees to horizontal plane receives the highest level of annual solar radiation. The installation on the East, South East, South, South West and West should be considered due to the similar high values clearly unlike the installation on the North East, North and North West as shown in Figure 169.

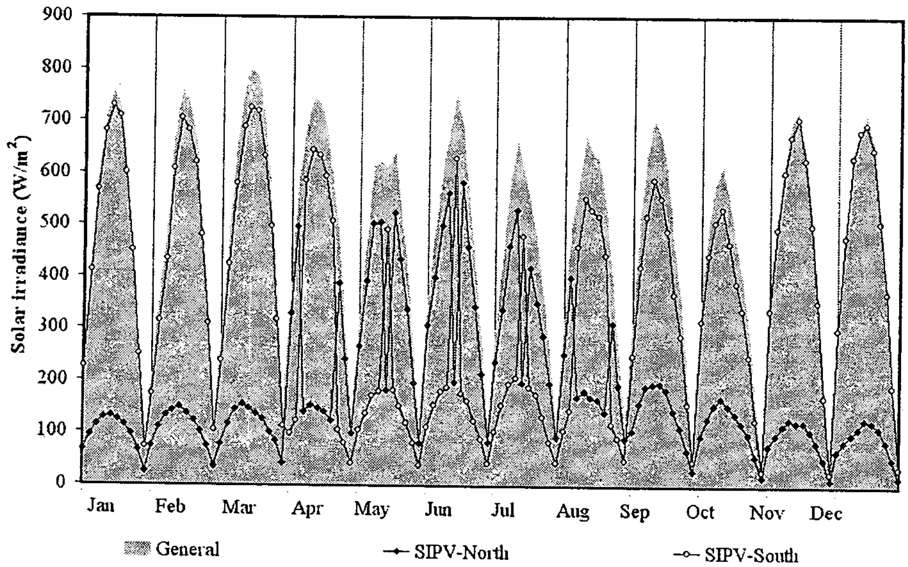


Figure 170 The total solar irradiance on slope surface of N and S

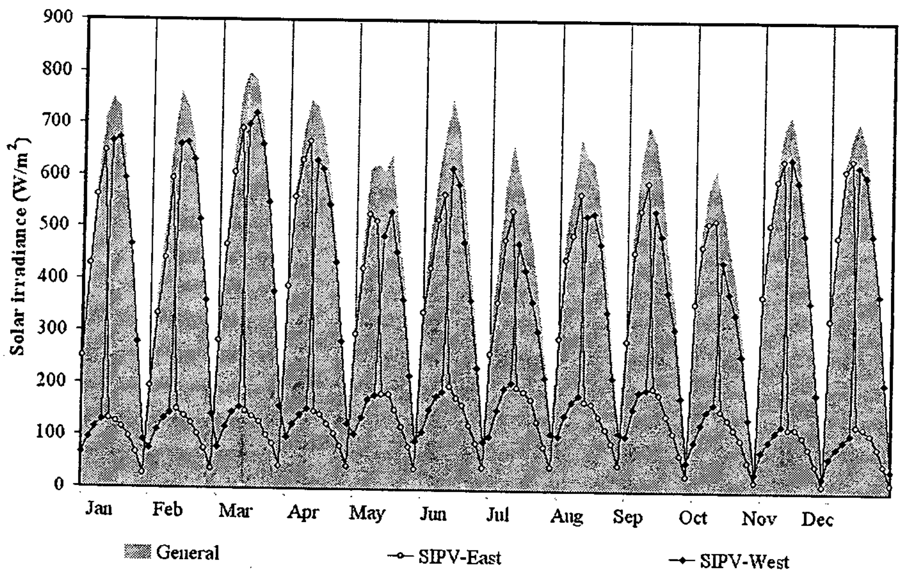


Figure 171 The total solar irradiance on slope surface of E and W

Hourly solar irradiance shown in Figure 170 and Figure 171 of SIPV is to compare PV regular installation on horizontal surface turning towards south which is considered as the best case. It is found that in the cases of North and South, the values are decreased in month of sun position getting behind the buildings. In addition, in the cases of East and West, the values are decreased in the afternoon and in the morning respectively.

In the cases of North East / South East and North West / South West, the values are also decreased due to lesser shade of building than in the cases of North, South, East and West as shown in Figure 172 and Figure 173 respectively.

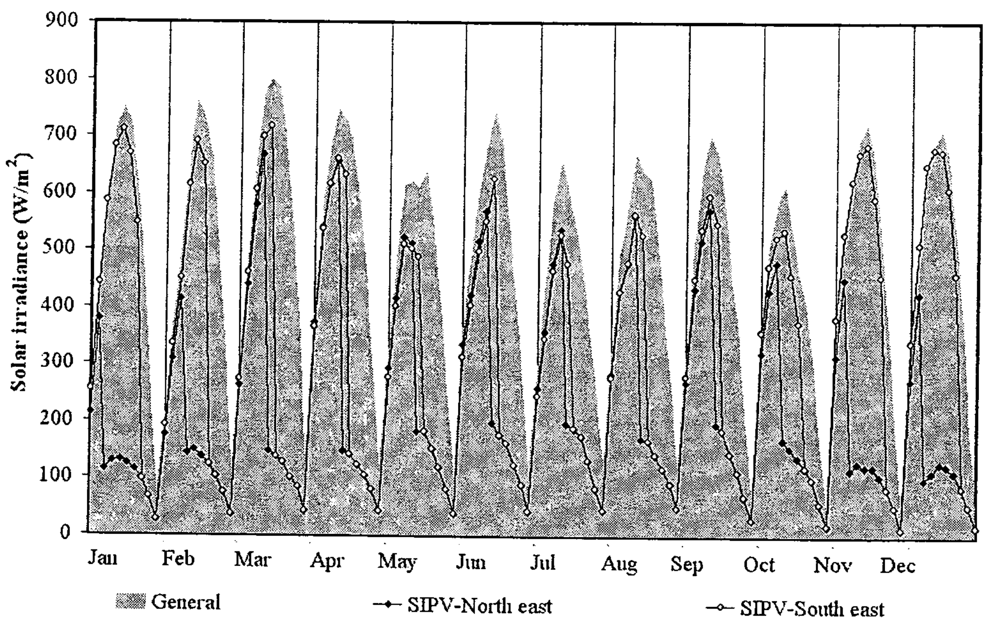


Figure 172 The total solar irradiance on slope surface of NE and SE

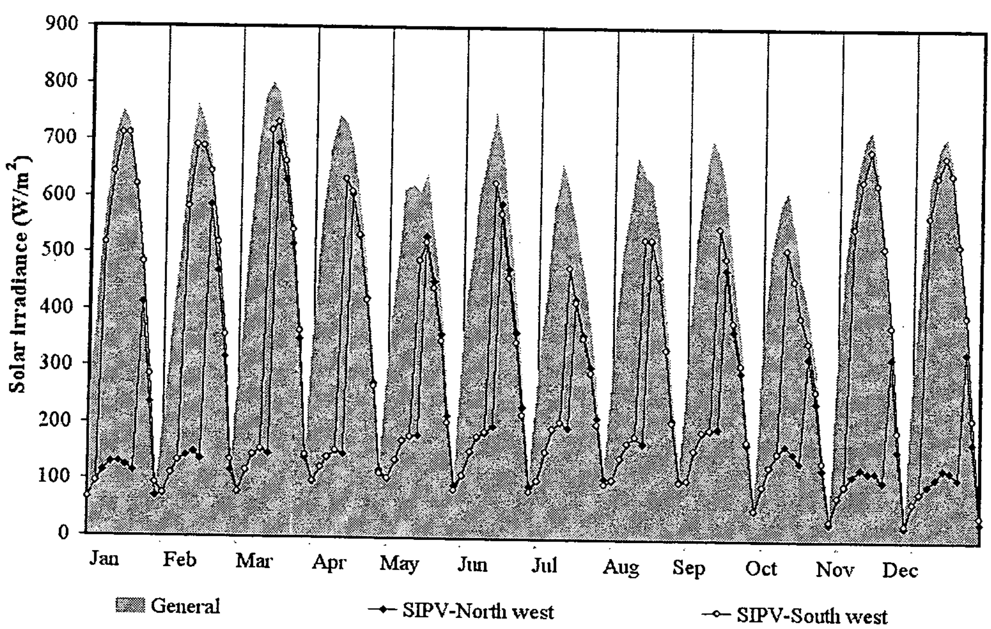


Figure 173 The total solar irradiance on slope surface of NW and SW

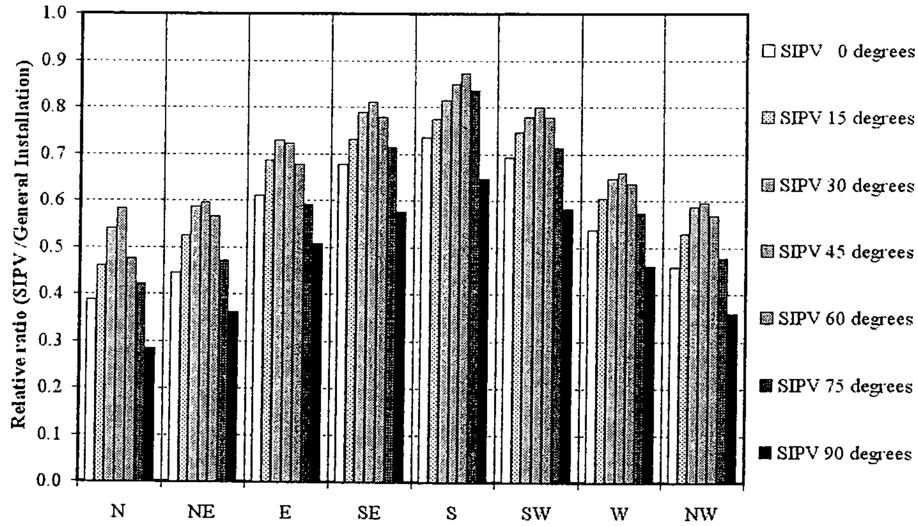


Figure 174 The annual solar radiation ratio of general and SIPV installation

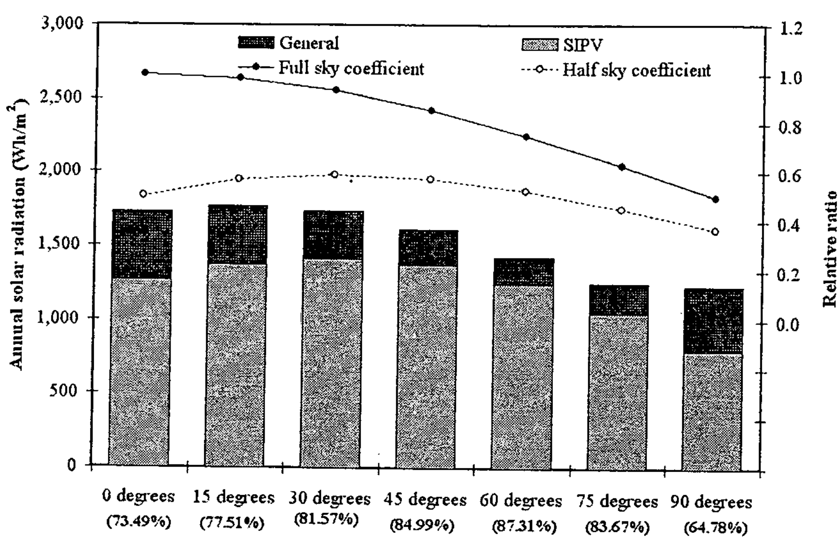


Figure 175 The annual solar radiation comparisons of South direction

Comparing between installation of SIPV and regular installation at the same tilt angle shows ratio as in Figure 174. It is also found that the ratio of North East, North and North West is decreasing more than 40%. Ratio of the South is decreasing the least which contains tilt angle of 30 degrees to 75 degrees.

Building is parameter causing SIPV to receive lower solar irradiance when compared to regular installation. As Figure 175 shows the ratios for installation turning towards south, it is found that the decrease ratio is corresponding to relative coefficient of diffuse solar radiation in the case of half sky condition.

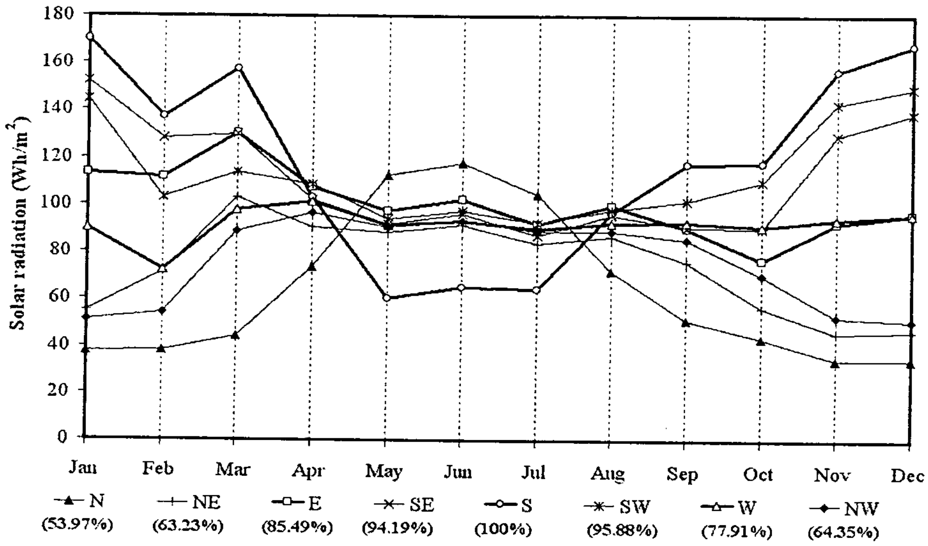


Figure 176 The solar radiation comparisons every month on SIPV surface

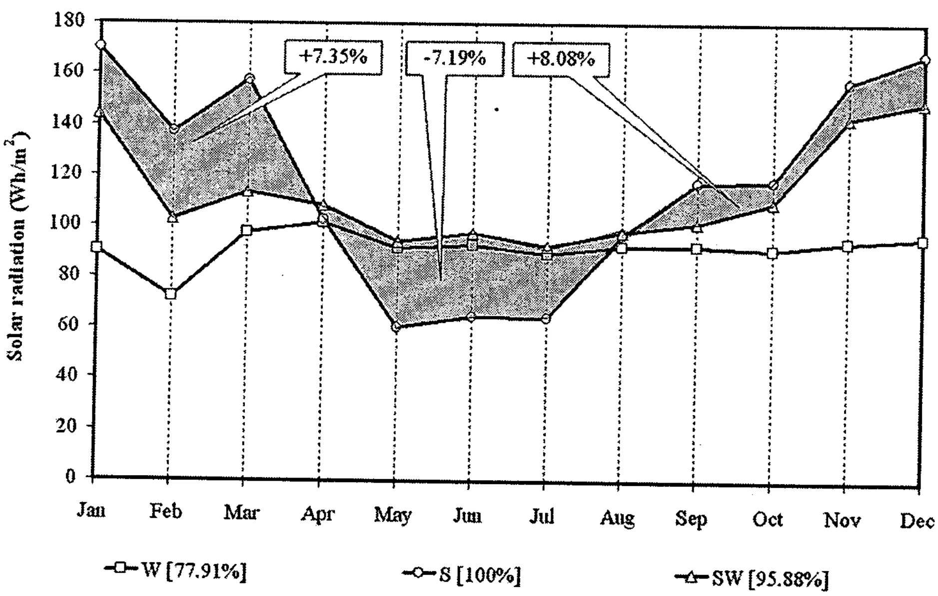
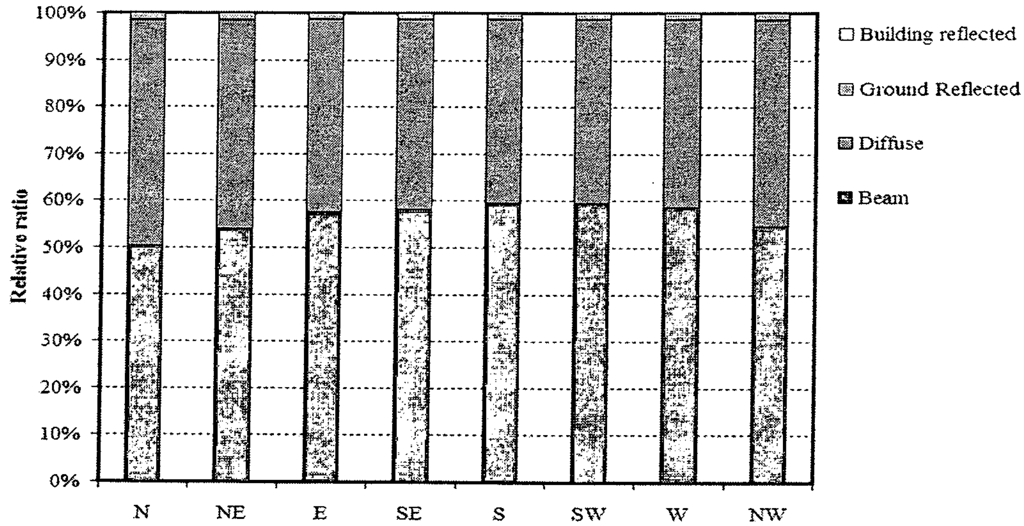
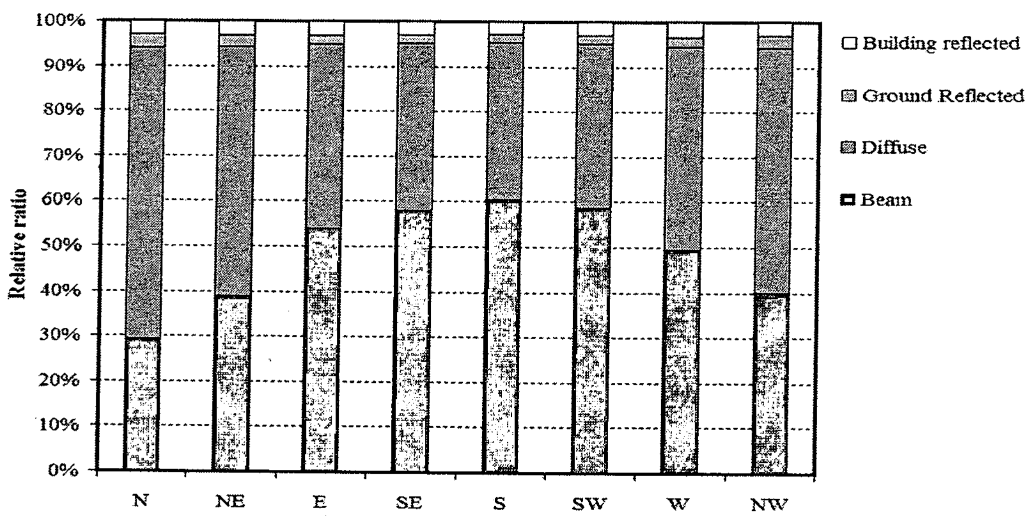


Figure 177 The solar radiation comparisons of East, South and West direction

Although installation in the South receives the highest level of energy, sun encircling towards North in summer time of a year can cause the decrease of solar irradiance and the increase in the winter as shown in Figure 176. Installation in the south in summer provides total solar irradiance less than installation in the South West at about 7.19% and only 4.12% higher for the whole year while installation in the South West is more stable for the whole year as shown in Figure 177.



General installation



SIPV installation

Figure 178 The comparisons of annual solar radiation on SIPV every direction

Figure 178 shows ratio of solar irradiance falling down on module. It is found that in the case of general installation, most effects cause from solar direct irradiance. In contrast to the case of SIPV installation only in the East, South East, South, South West and South, most effects cause from solar direct irradiance and a little bit of effects from building reflected solar irradiance at about 2.5%.

2. Energy production from SIPV

To convert energy gain from solar irradiance, the following equations are used: Eq. 104, Eq. 105, Eq. 106 and Eq. 107. This is to predict electric power by SIPV as shown in Figure 179.

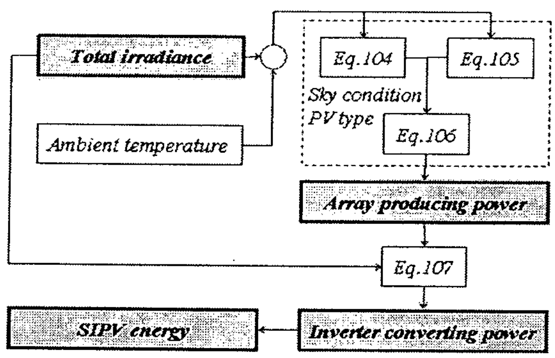
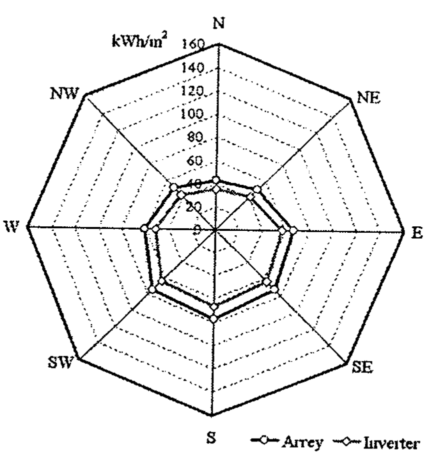
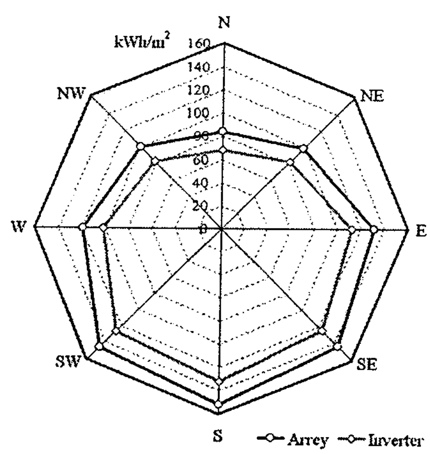


Figure 179 The process of SIPV energy calculation



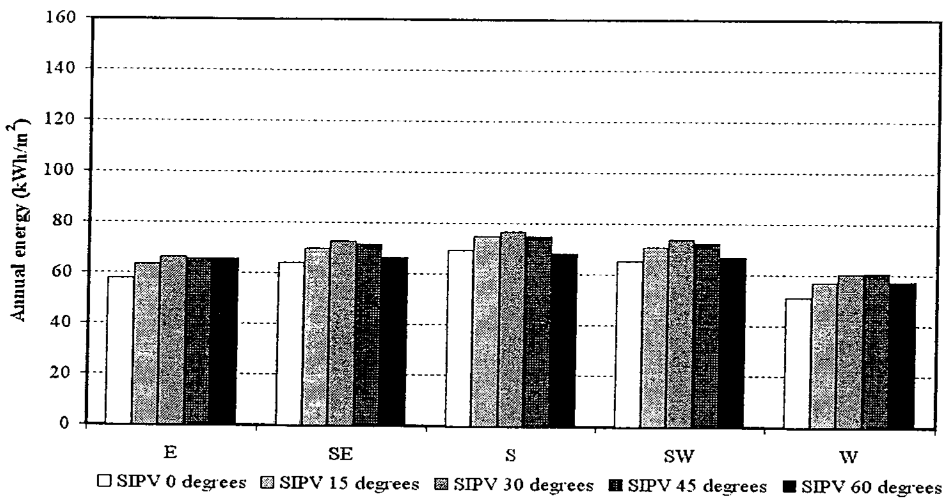
a-Si technology



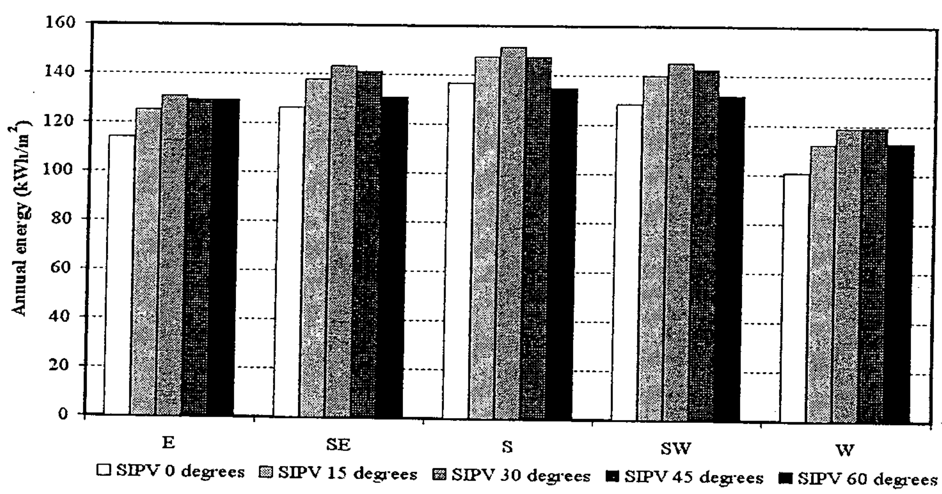
p-Si technology

Figure 180 The annual producing comparisons between array and inverter yield

The estimation is for both technologies such as amorphous silicon technology, a-Si and polycrystalline silicon technology, p-Si, technologies in order to compare benefits gained. Figure 180 shows that installation turning towards South with tilt angle of 30 degrees is still the best option. When comparing energy generation per area, polycrystalline silicon technology can generate more energy due to a clear higher efficiency. When considering the need to use the area for shading devices installation, solar cells technology with high efficiency can be chosen as suitable option throughout the year for the best installation. Amorphous silicon technology, a-Si and polycrystalline silicon technology can generate energy 77 and 152 kWh/m^2 respectively and the energy generation can be decreased due to electricity conversion of inverter.



a-Si technology



p-Si technology

Figure 181 The annual energy from SIPV array

Figure 181 shows the amount of energy generated from SIPV of amorphous silicon technology, a-Si and polycrystalline silicon technology in each direction and tilt angle of module.

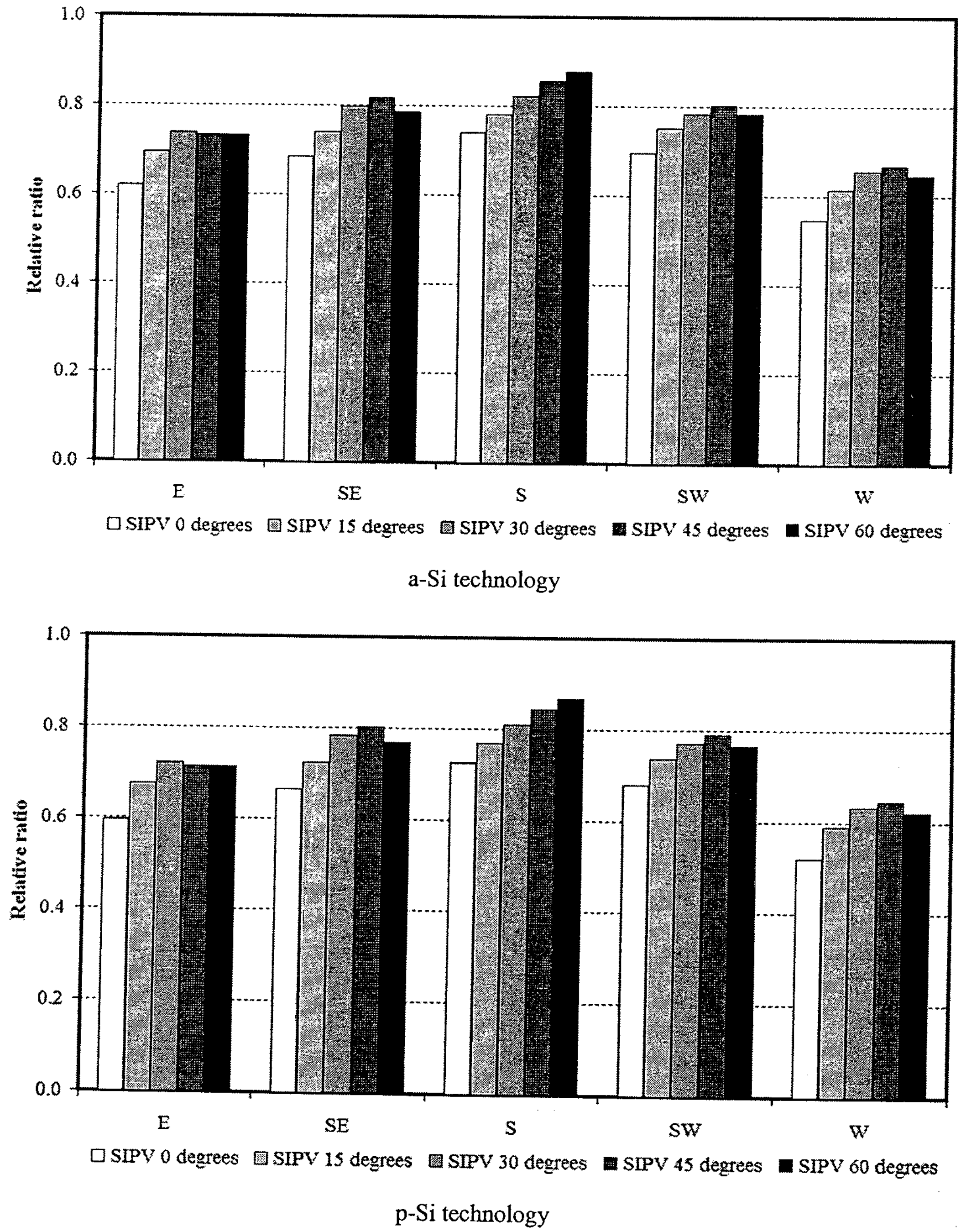
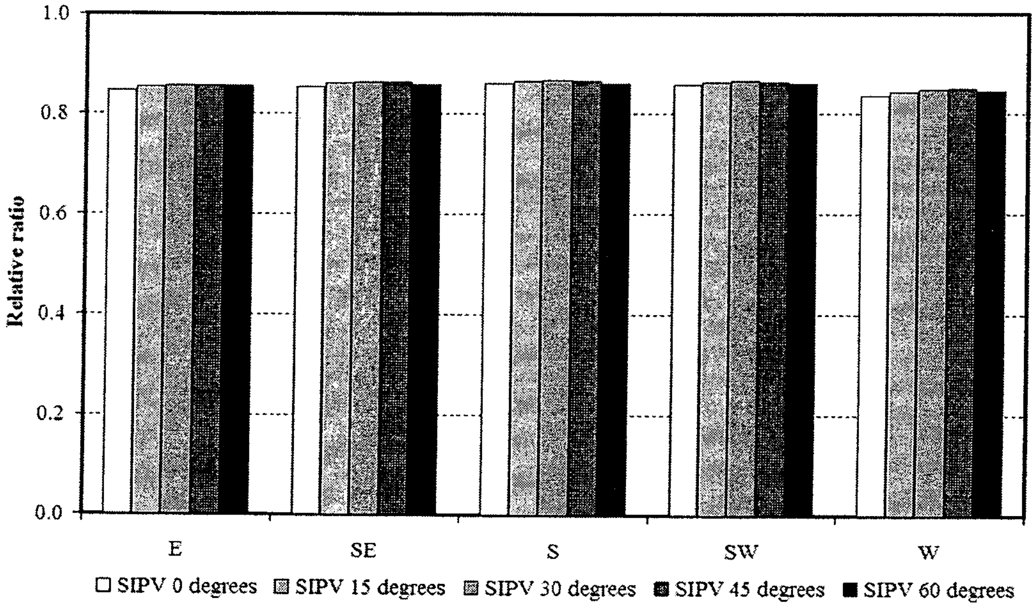
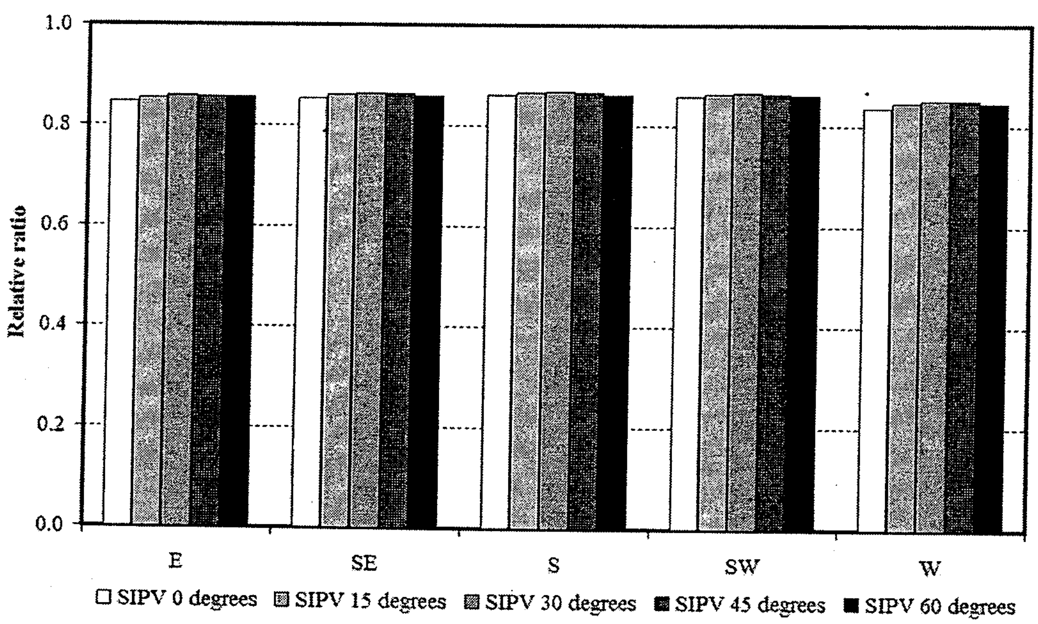


Figure 182 The annual array yields ratio of SIPV to general installation

Figure 182 shows ratio of comparing the amount of energy produced by SIPV of amorphous silicon technology, a-Si and polycrystalline silicon technology and general installation in each direction and tilt angle of module.



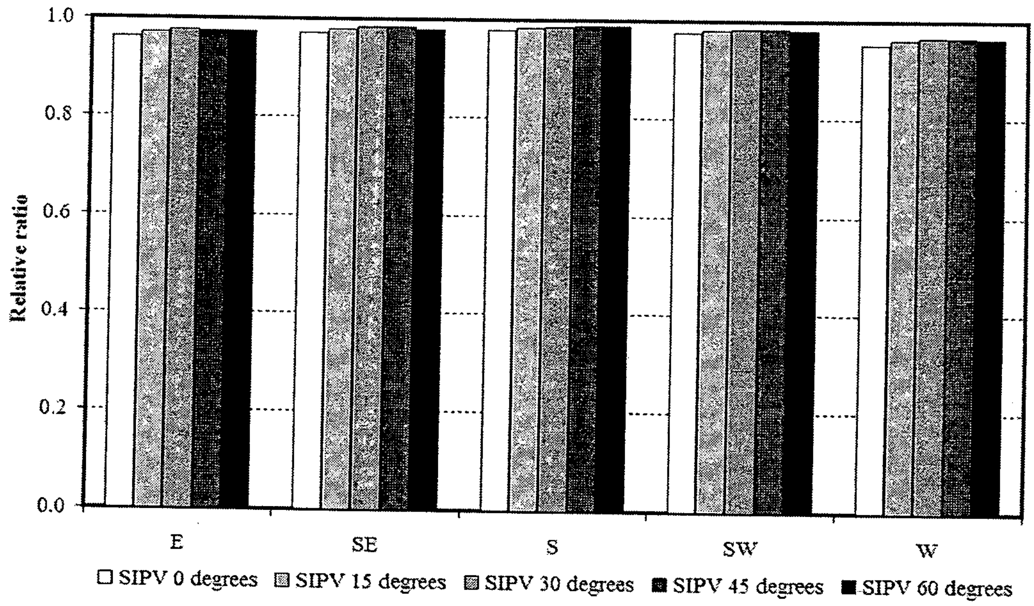
a-Si technology



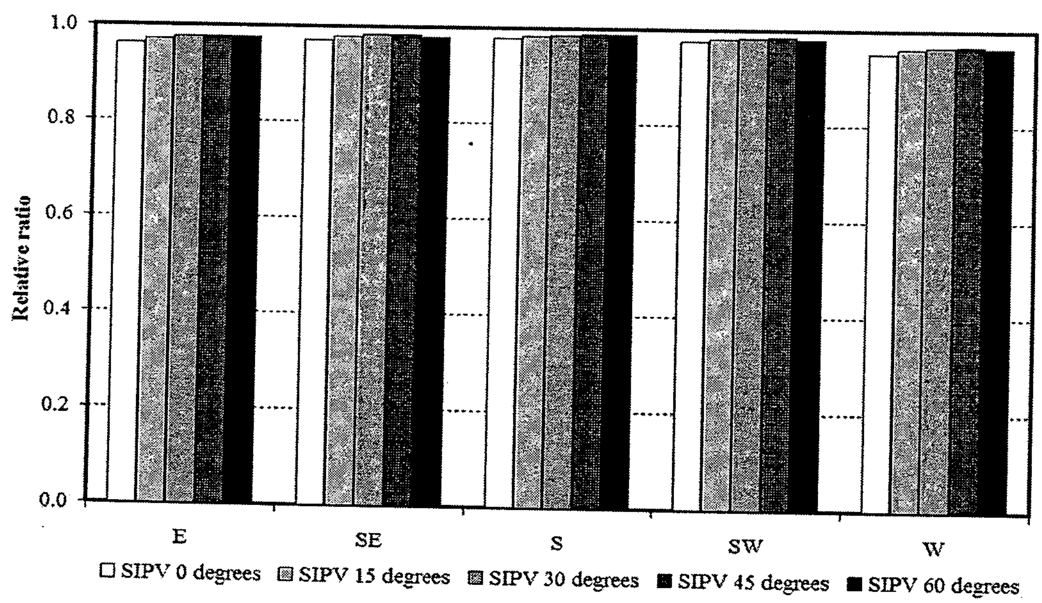
p-Si technology

Figure 183 The annual yields ratio of inverter to array conversion

Figure 183 shows ratio of the decrease because of converting electric current from inverter of amorphous silicon technology, a-Si and polycrystalline silicon technology in each direction and tilt angle of module. It is found that the ratio of both technologies is similar.



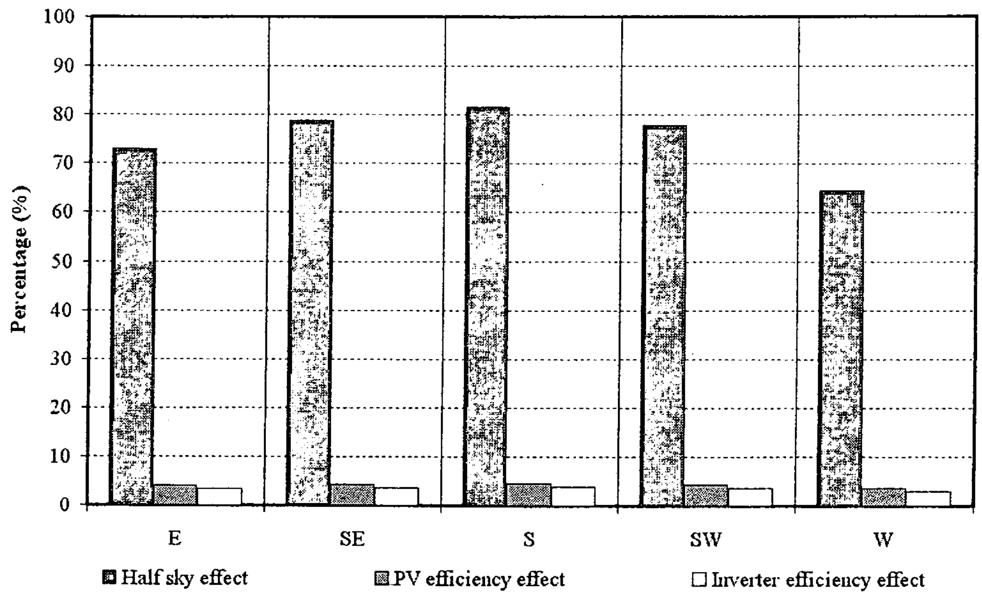
a-Si technology



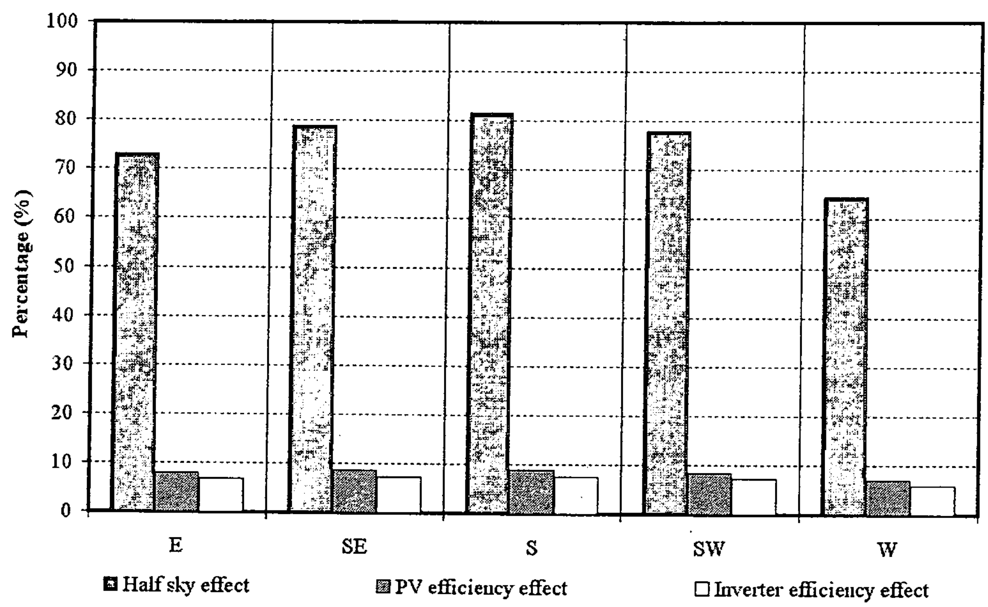
p-Si technology

Figure 184 The annual inverter yields ratio of SIPV to general installation

Figure 184 is to compare ratio of the decrease because of electric current conversion from inverter between SIPV installation and general installation of amorphous silicon technology, a-Si and polycrystalline silicon technology in each direction and tilt angle of module.



a-Si technology



p-Si technology

Figure 185 The percentage of reducing in conversion process

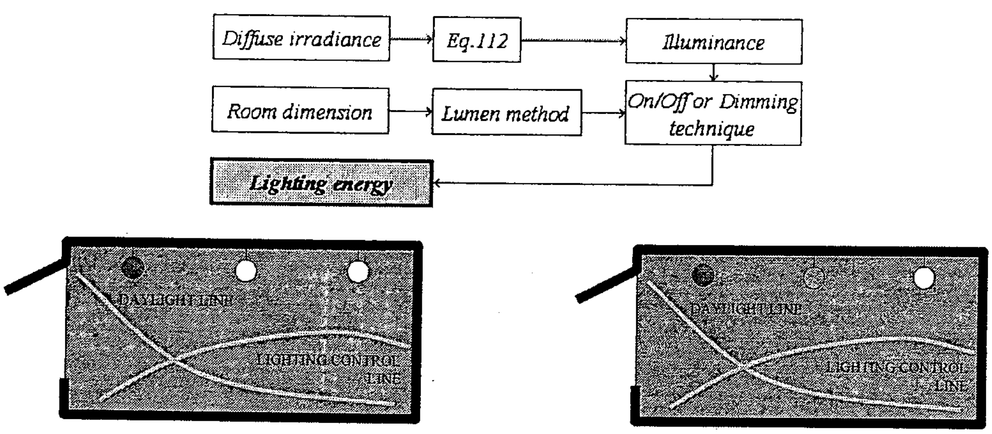
Figure 185 is to compare ratio of energy conversion due to installation under half sky condition, cell efficiency and inverter efficiency which all are considered as shading effects.

Table 27 The percentage of energy conversion

Direction	Percentage of energy conversion				
	Half sky	Technology		Inverter	
		a-Si	p-Si	a-Si	p-Si
E	27.05	94.52	89.17	14.36	14.33
SE	20.99	94.55	89.22	13.75	13.74
S	18.43	94.56	89.26	13.34	13.32
SW	22.07	94.56	89.27	13.59	13.55
W	35.27	94.52	89.21	15.08	15.02

3. Energy saving in lighting system

One of benefits gained from shading function by using daylight within buildings to replace light from light bulbs. To estimate electric energy, Eq. 112 is used to estimate illuminance level on working plane with the minimum of 300 Lux as shown in Figure 186.



On/Off technique

Dimming technique

Figure 186 The process of lighting system energy calculation

When there is not enough daylight in any position of room, energy from light bulbs is considered as options with the use of control techniques as follows:

1. On/off technique
2. Dimming technique

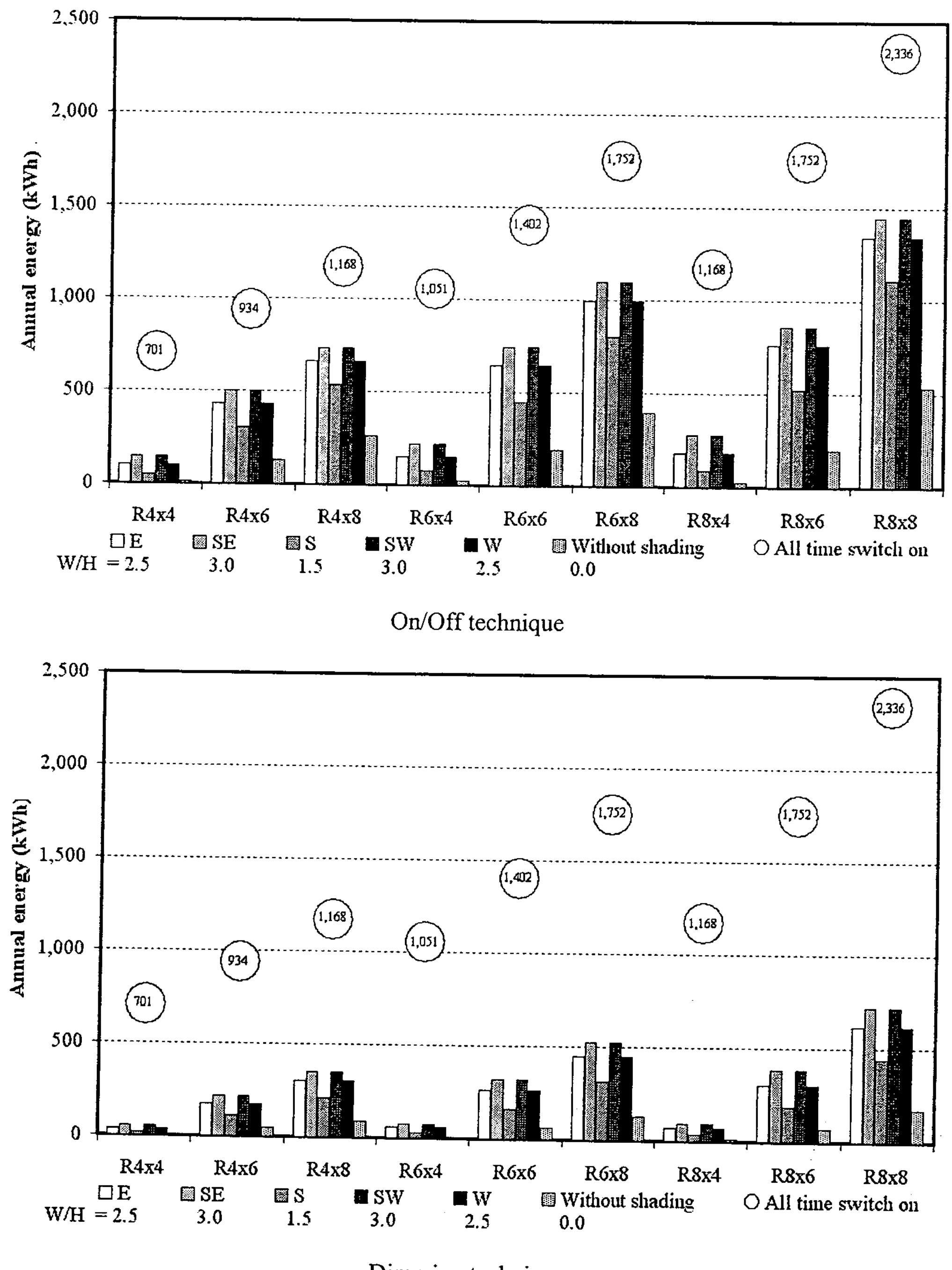
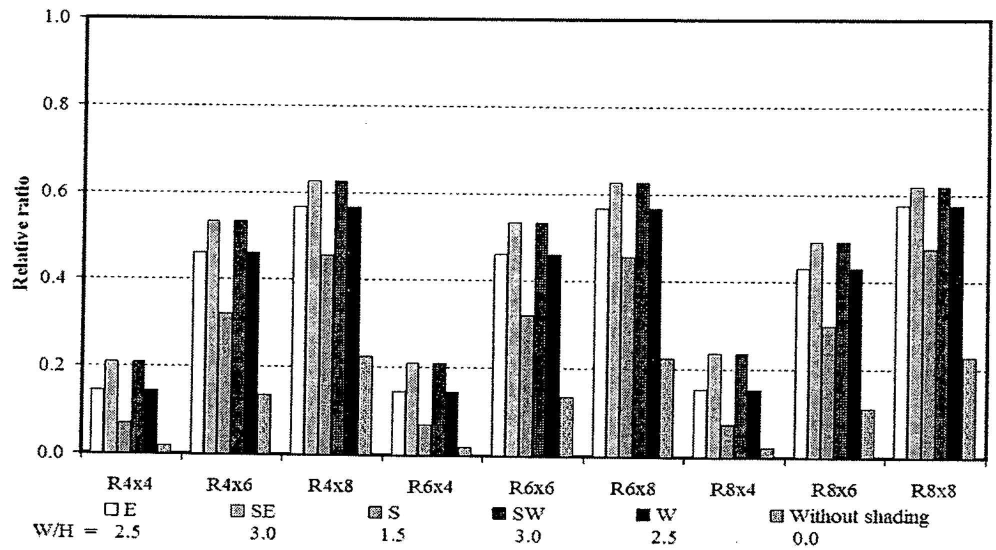
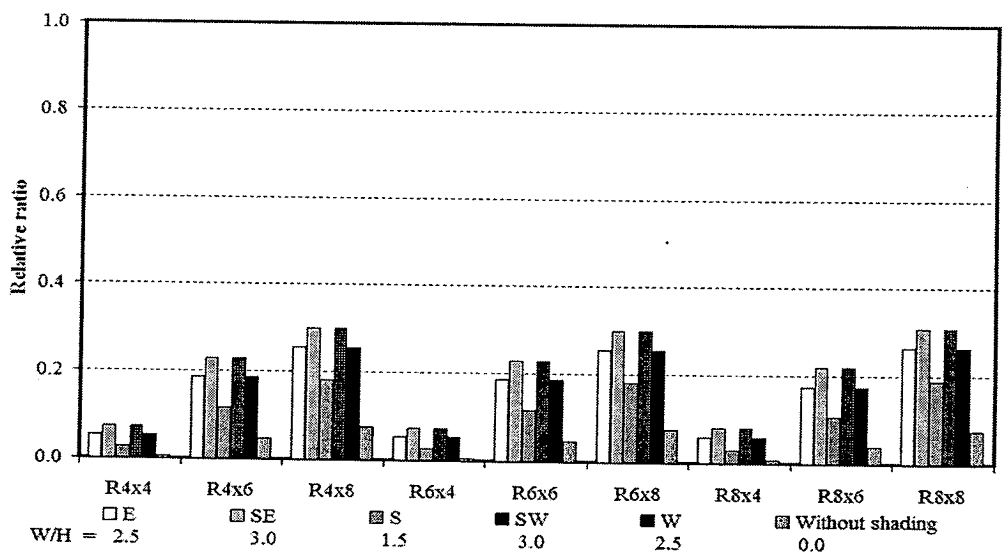


Figure 187 The using energies of lighting system with lighting controls

Figure 187 shows the comparison of energy saving by using on/off technique and dimming technique in electric energy control. It is found that dimming technique can save more energy; especially without shading devices will save the most and shading devices being installed in the south will save the second most.



On/Off technique



Dimming technique

Figure 188 The using energies ratio of control technique to switch on all time

Figure 188 shows ratio of the use of electricity in lighting system. It is found that room with depth of 4.0 m. 6.0 m. and 8.0 m. can save electricity respectively from most to least using both control techniques due to receiving more daylight from position near window.

4. Cooling load reduction of air conditioning system

Air conditioning system is another system with the use of energy depending on cooling load. In the process of calculating cooling load gained from solar irradiance, outside temperature coming through glass of window and heat from light bulbs, Eq. 109 is used with ASHRAE's equation under the condition of COP at 3.22 in electric energy use to make a cooling as shown in Figure 189.

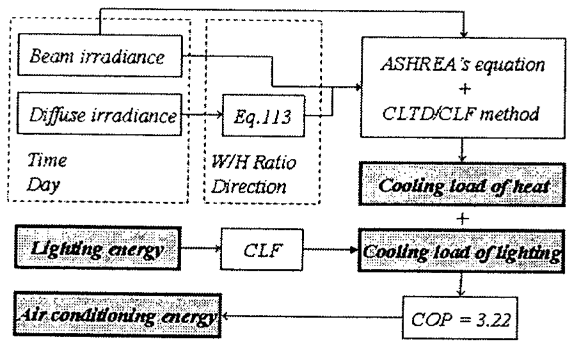


Figure 189 The process of air conditioning system energy calculation

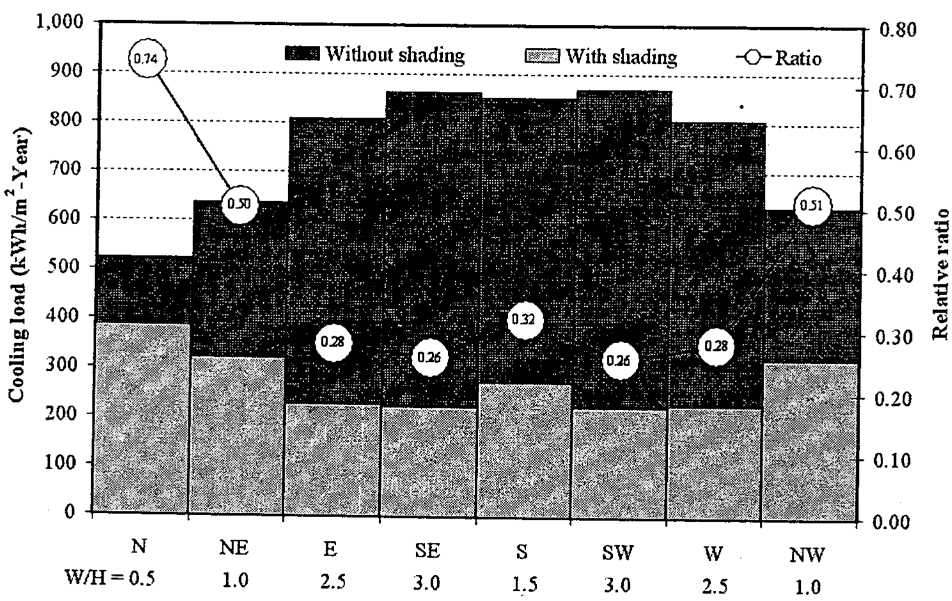


Figure 190 The cooling load ratio of the design with shading to without shading

Figure 190 shows the decrease of cooling load due to the sizes of shading devices determined by W/H ratio. As for direction calculated to prevent direct solar irradiance for the whole considered period of time, it is found that in the South East, South West, East, West, South, North East, North West and North provide the values from the least to the most respectively. The case of being installed in the South provides the value different from the best case only 0.06.

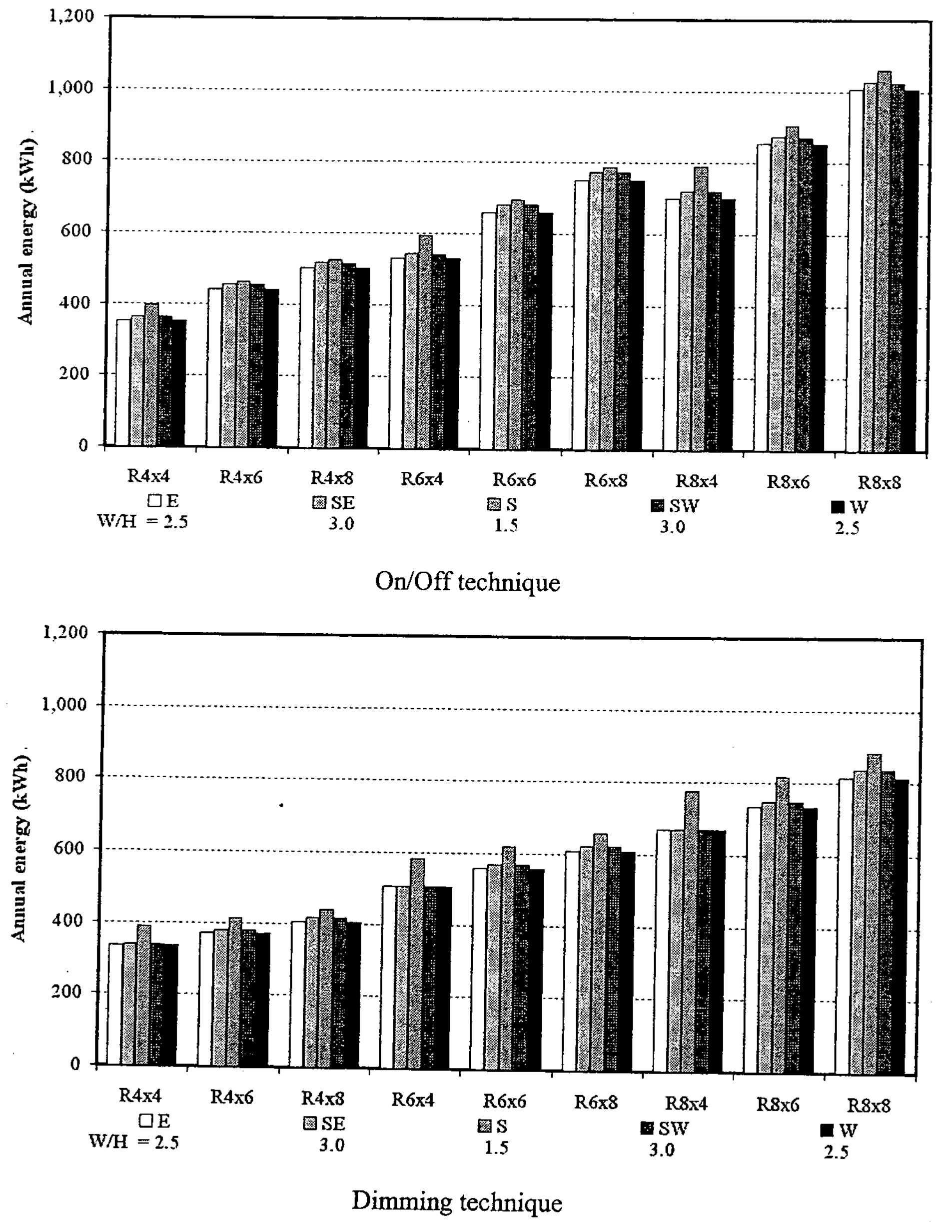
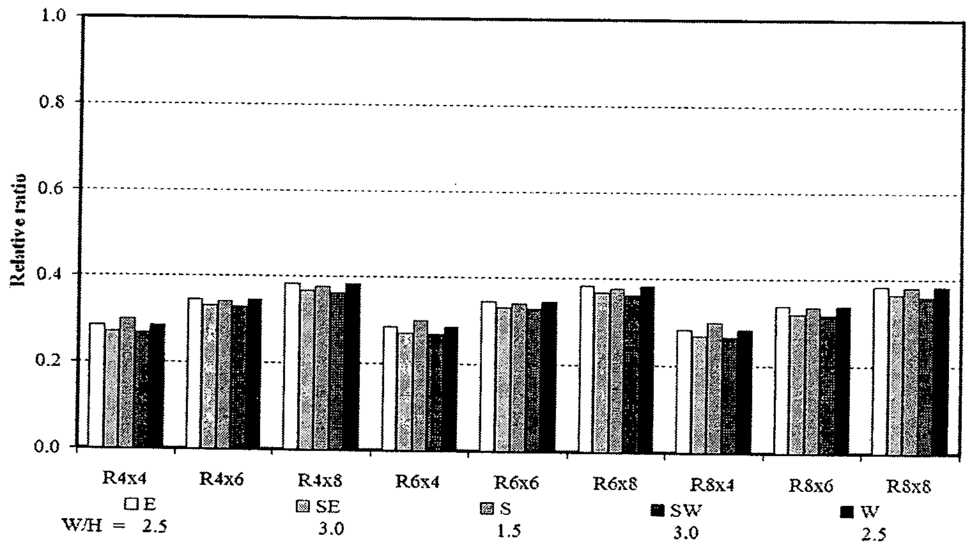
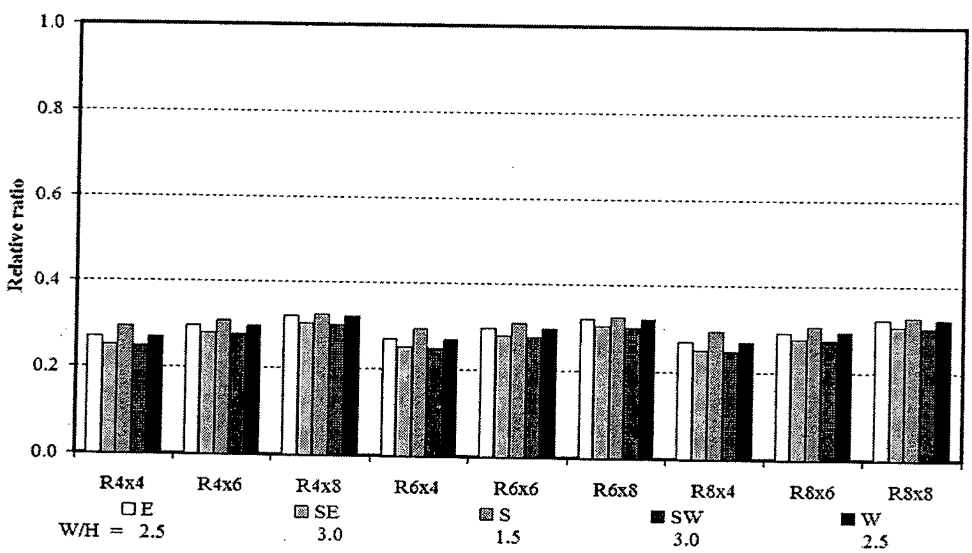


Figure 191 The using energies of air conditioning system with lighting controls

Figure 191 shows annual total energy use of air conditioning system separated by room size and direction. It is found that the use is changed according to room sizes due to the glass sizes and the number of light bulbs.



On/Off technique



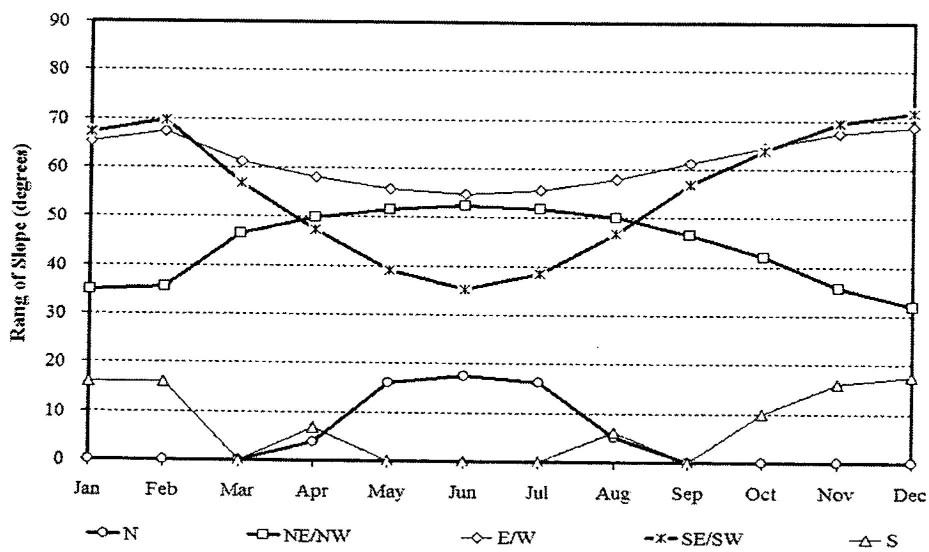
Dimming technique

Figure 192 The reducing ratio of the design with shading to without shading

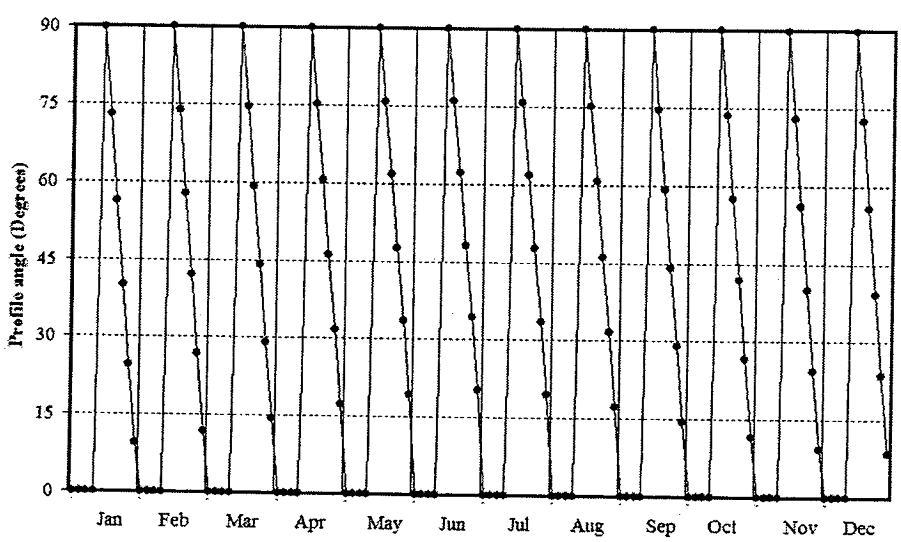
Figure 192 shows decreasing ratio of energy use when compared to the case of without shading devices and with light control system. It is found that room with depth of 4.0 m. 6.0 m. and 8.0 m. can save electricity respectively from most to least using both control techniques like the case of lighting system.

5. Tracking technique

In the case of system being installed in the East and West with the widest space of solar altitude as shown in Figure 193 of more than 50 degrees throughout the year and quite stable degree throughout the day as shown in Figure 193, energy generation of SIPV tracking system is estimated when being installed in the mentioned directions.



The comparison of the angle every direction



The profile angle of West direction

Figure 193 The moveable effect of the sun angle every month

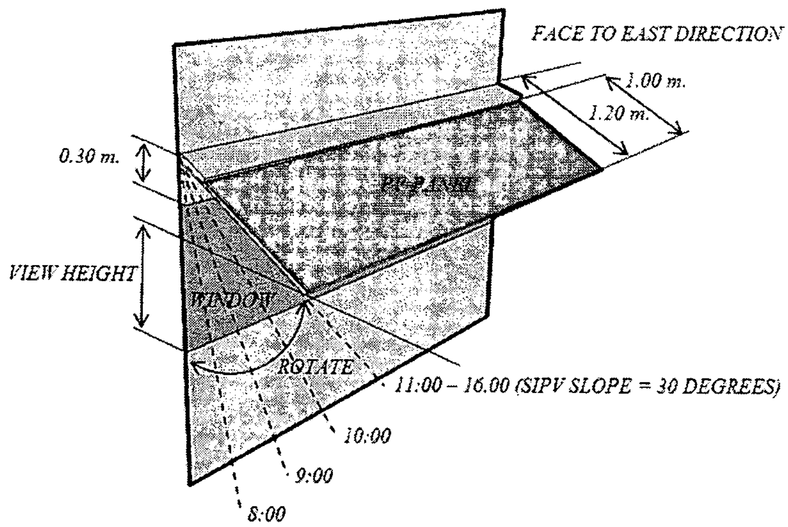


Figure 194 The shading design guideline

Table 28 The estimation of SIPV tracking design

Solar Time	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
SIPV Slope	75	60	45	30	30	30	30	30	30
W/H ratio	2.2	2.3	1.89	1.49	1.49	1.49	1.49	1.49	1.49
View area					(%)				
Tracking	14	26	45	70	70	70	70	70	70
Fixed	40	40	40	40	40	40	40	40	40

Room dimension		R4x4	R4x6	R4x8	R6x4	R6x6	R6x8	R8x4	R8x6	R8x8
SIPV energy						kW-hr/m^2-Year				
Fixed		448	448	448	672	672	672	896	896	896
tracking		447	447	447	670	670	670	894	894	894
Lighting energy	All time	701	934	1168	1051	1402	1752	1168	1752	2336
	On/Off	58	325	559	88	487	838	112	583	1167
	Dimming	20	119	224	29	179	337	37	206	470
A/C energy	All time	557	619	680	835	928	1020	1052	1206	1360
	On/Off	387	458	519	581	687	779	773	898	1052
	Dimming	377	403	431	566	605	647	754	798	868

From the calculation result in Table 28 and installation example as shown in Figure 194 shows that the result of total energy generation throughout the year is not different when compared to fixed installation. However, there is an opportunity of more view opening. Therefore, it is not considered for design due to the need of maintenance and more complicated design with indifferent result.

6. Summary of the estimation part

From estimation, the points concluded are as follows:

6.1 p-Si technology is suitable for usability because it has a smaller area than a-Si technology for installation. It is designed to use the area of building envelope efficiently

6.2 The tilt angle of module should be between 0-45 degrees for beauty design. At 30 degrees is considered the best angle in energy generation

6.3 The suitable installing directions of SIPV include E, SE, S. SW. W. The best direction is in the South for energy generation

6.4 Suitable size of the room for energy saving should not be deep. The depth of the room at 4.00 m. can save energy the most

6.5 The best lighting system control technique is dimming technique

6.6 Fixed installation should be considered for SIPV installation because the maintenance is easier when compared to similar benefits gained

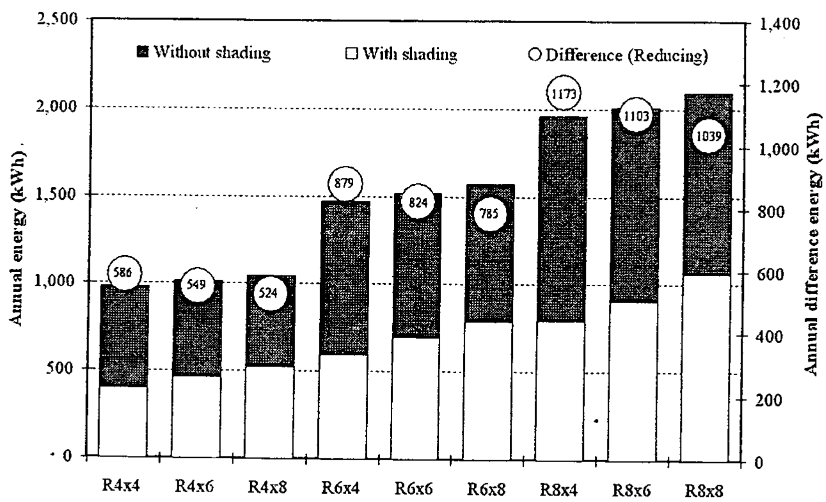
Optimization part

1. Optimization of shading design

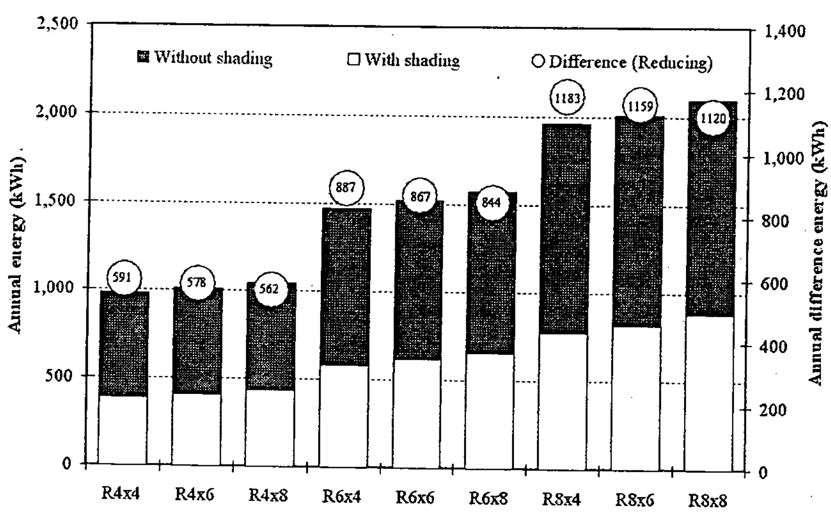
The first objective of the study is to optimize shading in order to decrease heat gain and increase daylight of shading devices integrated photovoltaic system

1.1 Benefits gained from the comparison of energy usability

1.1.1 Reducing cooling load of air conditioning system



On / Off technique



Dimming technique

Figure 195 The annual of air condition system energy comparisons between the design with shading and without shading

Figure 195 shows the comparison of decreasing energy usability due to SIPV installed in the South. It is found that room with small depth can reduce the use of energy more when compared with the equal width of the room. It is because of the decrease in heat caused from light bulbs as a result from daylight used in both cases of light control techniques and with the same appearances when being installed in other directions

1.1.2 Saving energy of lighting system

Figure 196 shows the comparison of lighting energy saving results due to SIPV installed in the South. It is found that in the case of light control using on/off technique from room with wide format of 4.0 m. and 6.0 m. Room with small depth can save more energy. In the case of room with large width but with more depth can save even more energy which shows the same appearances as the case of light control technique using dimming technique

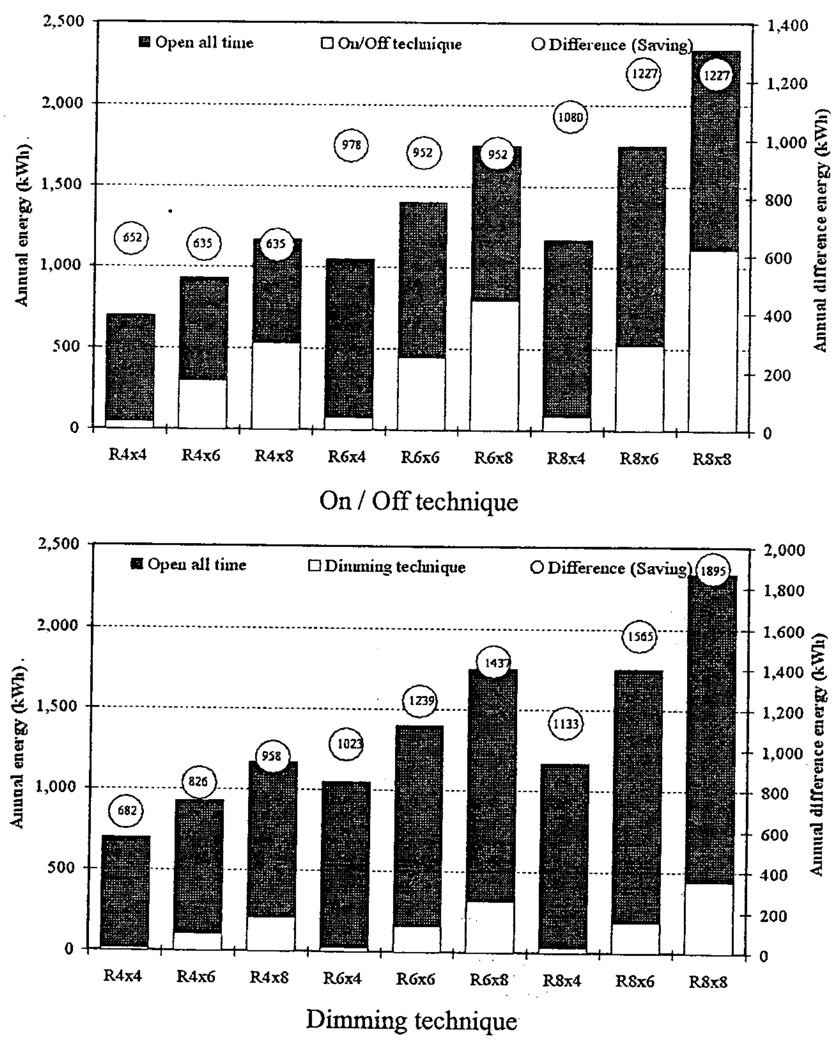


Figure 196 The annual of lighting system energy comparisons of the lighting control techniques

1.1.3 Producing energy using photovoltaic system

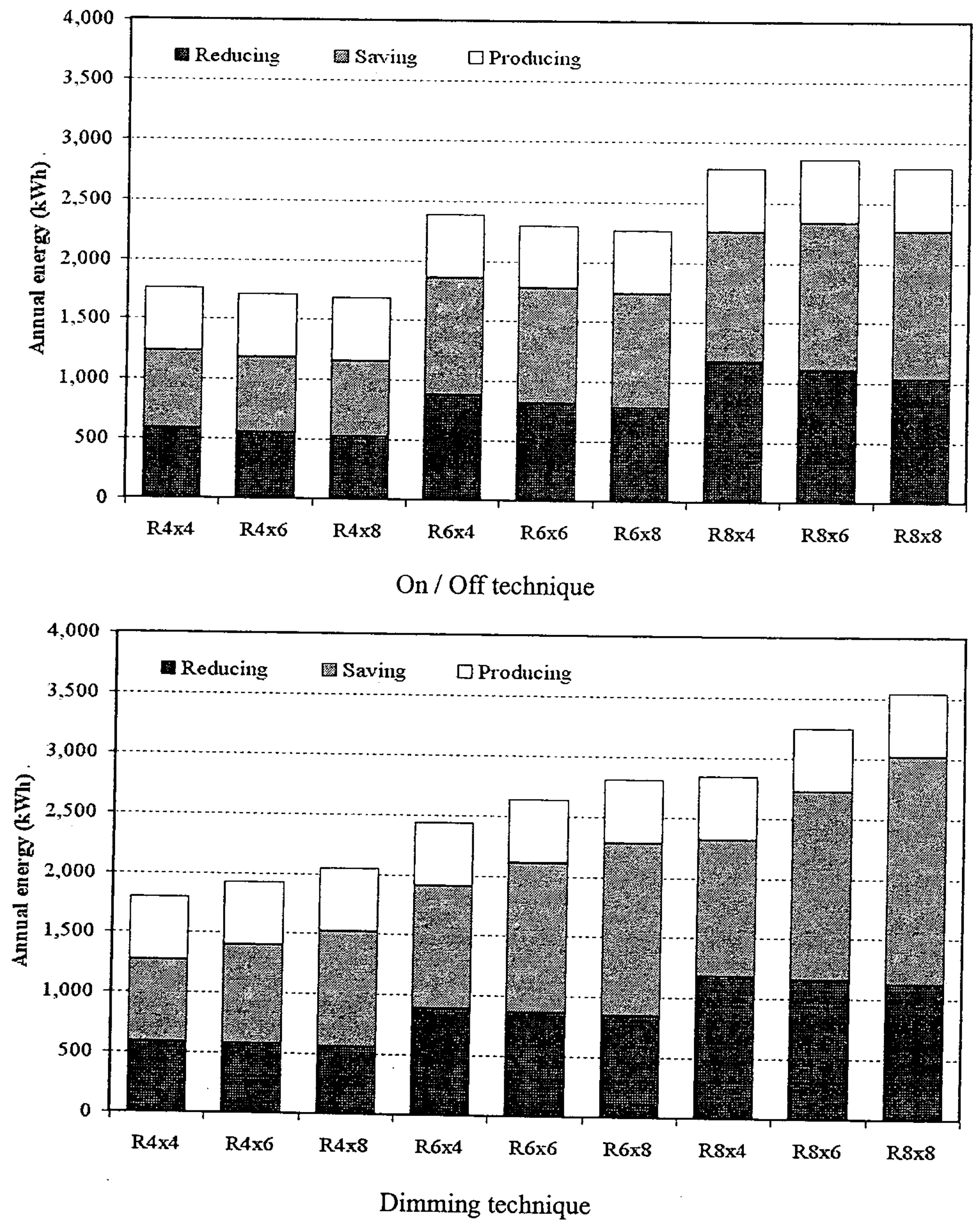
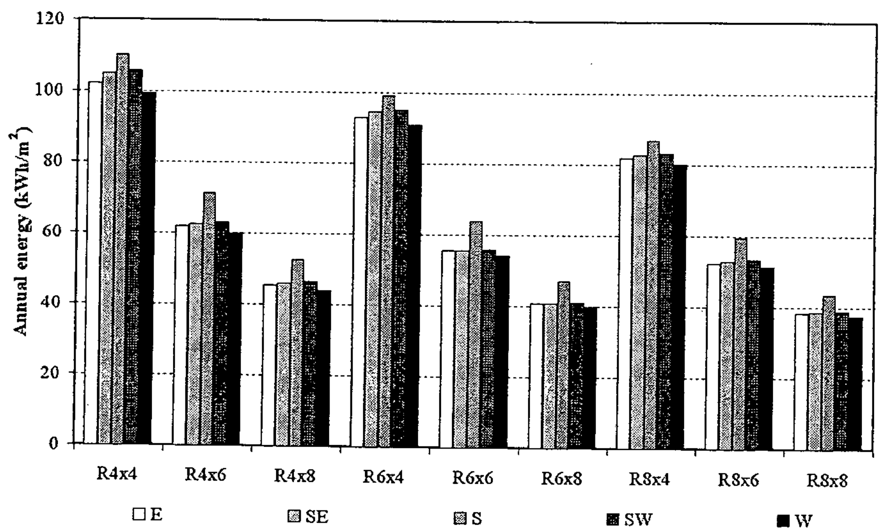


Figure 197 The annual of SIPV system of slope 30 degrees comparisons with the reducing and saving energies

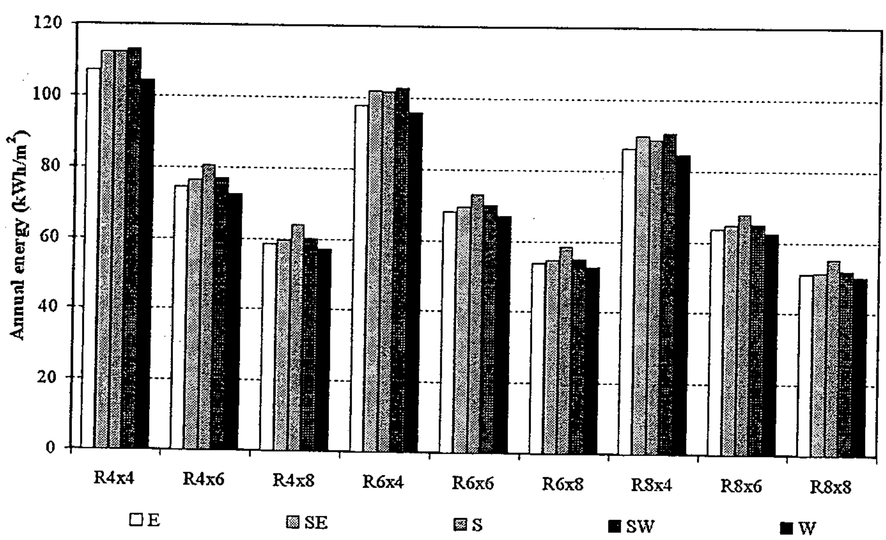
Figure 197 shows the comparison of electrical energy production results due to the use of SIPV installed in the south with tilt angle of 30 degrees. It is found that the use of on/off technique provides less total benefit ratio gained from energy production than the use of dimming technique.

1.2 Comparison of installing directions

Figure 198 show the best case of installation with tilt angle of 30 degree. It is found that the highest benefit per using area is the case of room with small depth using both cases of light control techniques. However, installation using on/off technique turning towards the South receives the highest benefit. As for dimming technique in room with small depth of 4.0 m., the best option of installation must be in the South East and South West. The installation must be in the South for room with more depth for the best result



On / Off technique

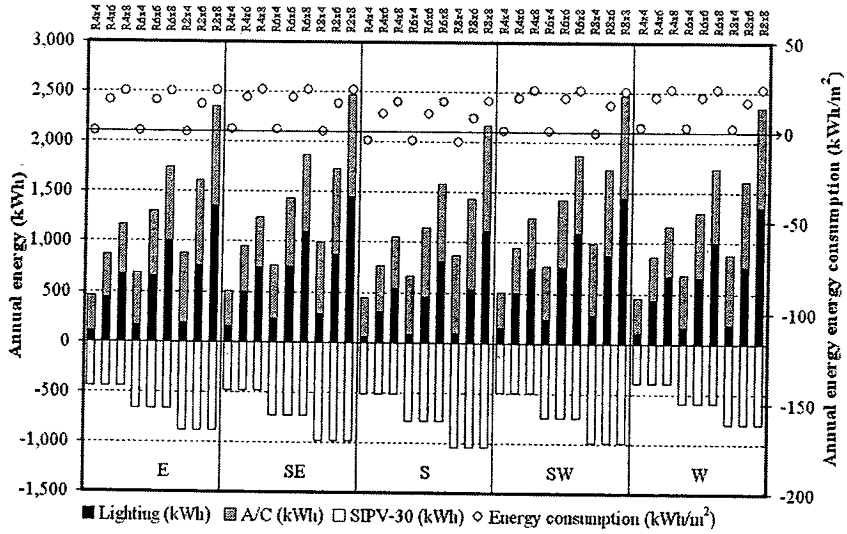


Dimming technique

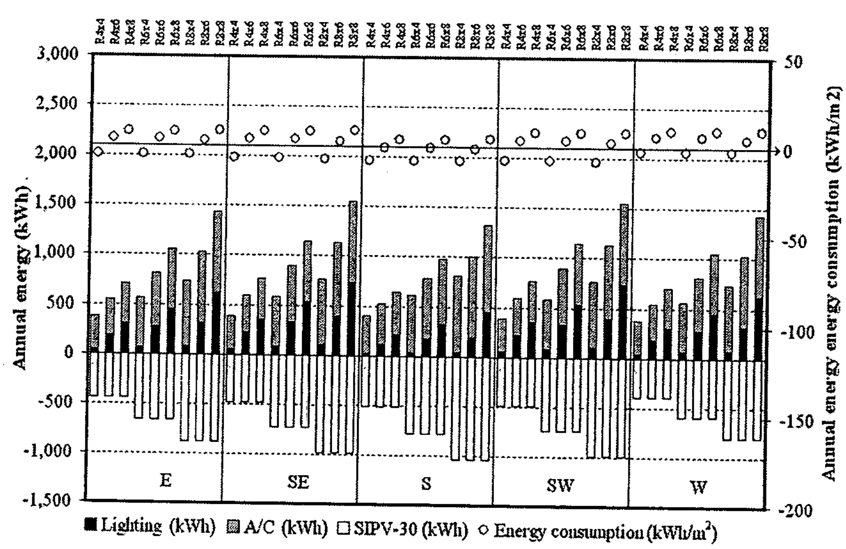
Figure 198 The annual energy saving of comparisons SIPV slope 30 degrees

1.3 The comparison to replace the use of energy

Figure 199 shows the comparison of the factors of SIPV design providing benefits in each part of the use of energy from air conditioning system and lighting system and part of energy production to replace the use of energy causing the decrease in total energy. It is found that for the on/off technique, the best ways to use the benefit from renewable energy production are the system being installed in the South and system being used in room with small depth (4.0 m.)



On/Off technique



Dimming technique

Figure 199 The energy consumption comparisons of air conditioning system, lighting system and SIPV system

In contrast to dimming technique, the installation can be in any direction because ratio of benefit occurred in the part of air conditioning and lighting systems is more than benefits gained from energy production system. However, in order to make the best case, room with small depth (4.0 m.) is considered. As for the case of being energy producing tools, the suitable installing direction is in the South for the most of energy production

1.4 Visual comfort

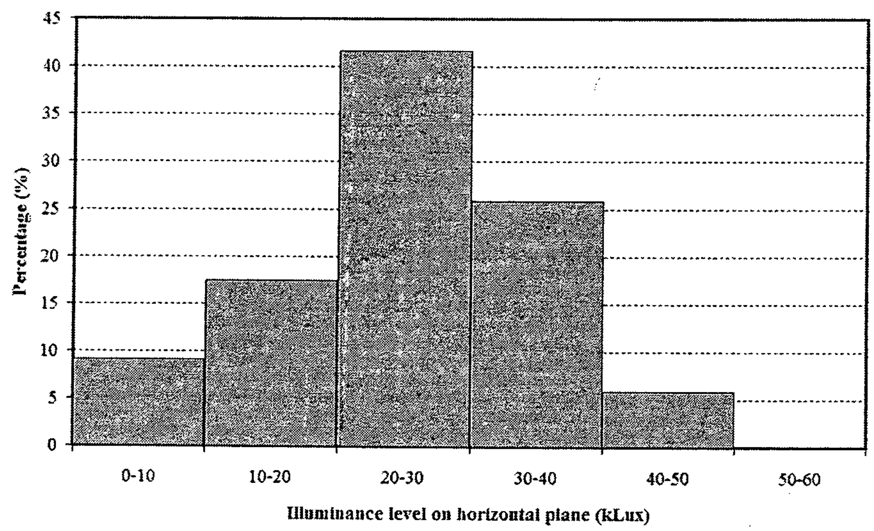


Figure 200 The percentage of illumminance level on horizontal plane

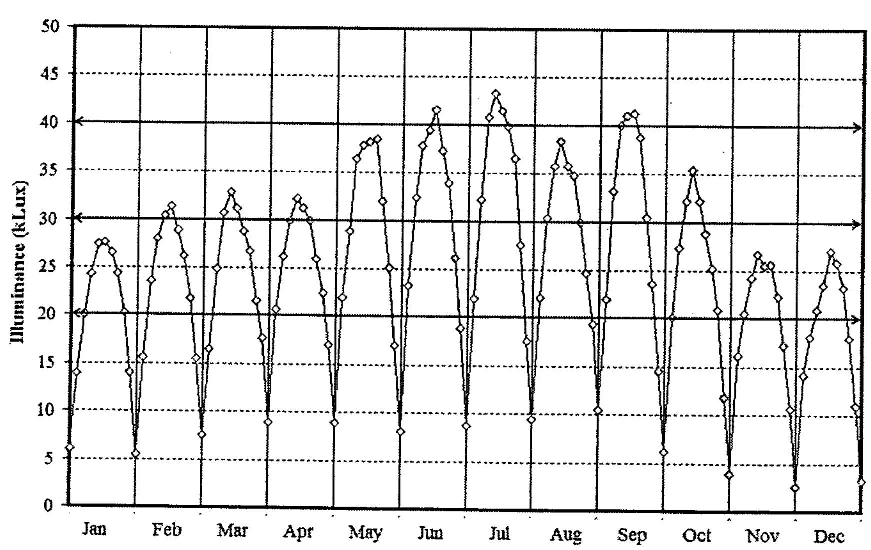


Figure 201 The monthly average of illumminance level on horizontal plane

In order to create proper usability corresponding to window function, there must be a consideration of glare conditions which is a qualitative measurement. In Figure 200, it is found that mostly illuminance level on horizontal plane of sky at 20-30 klux is about 40% and at 20-40 klux is about 65% as shown in Figure 200. Illuminance level at 30 klux is the highest average found almost throughout a year as shown in Figure 201. Besides, illuminance level at 50 klux is the highest value for this consideration.

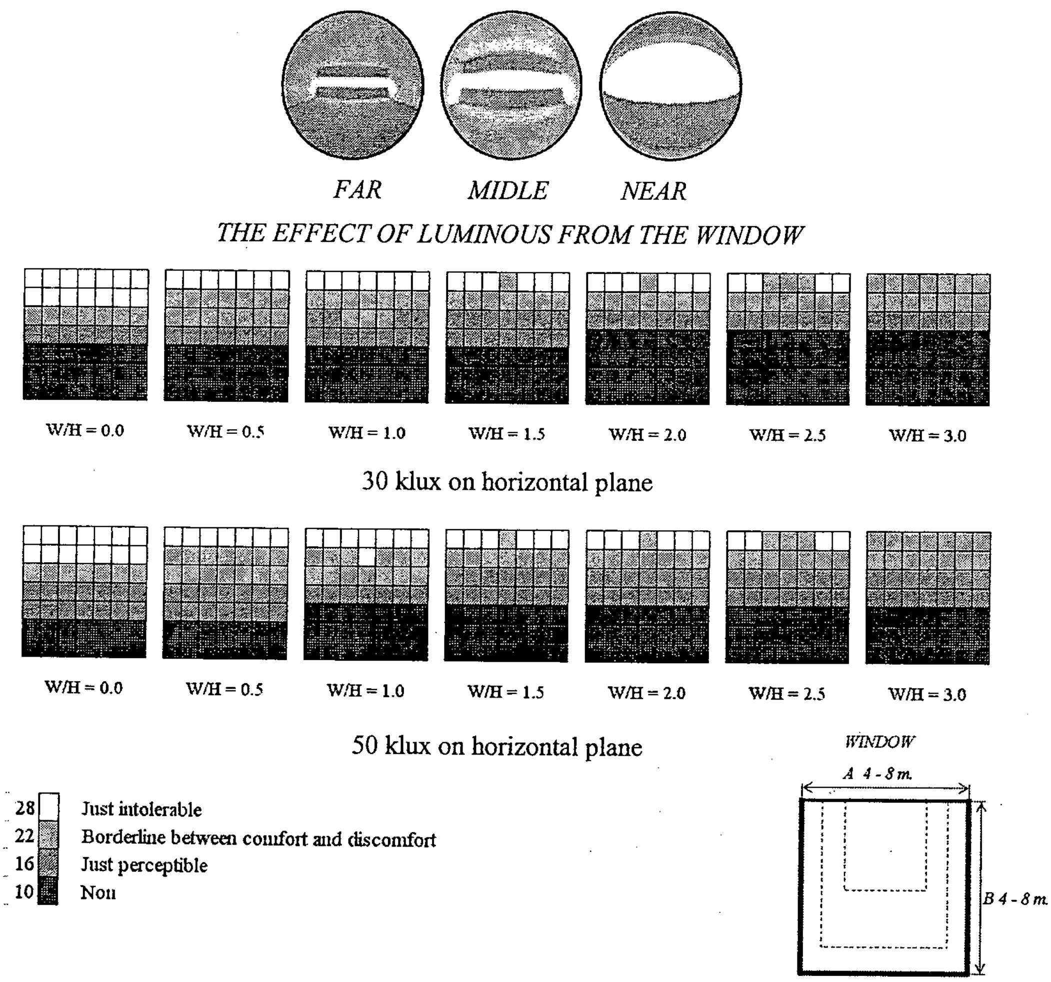
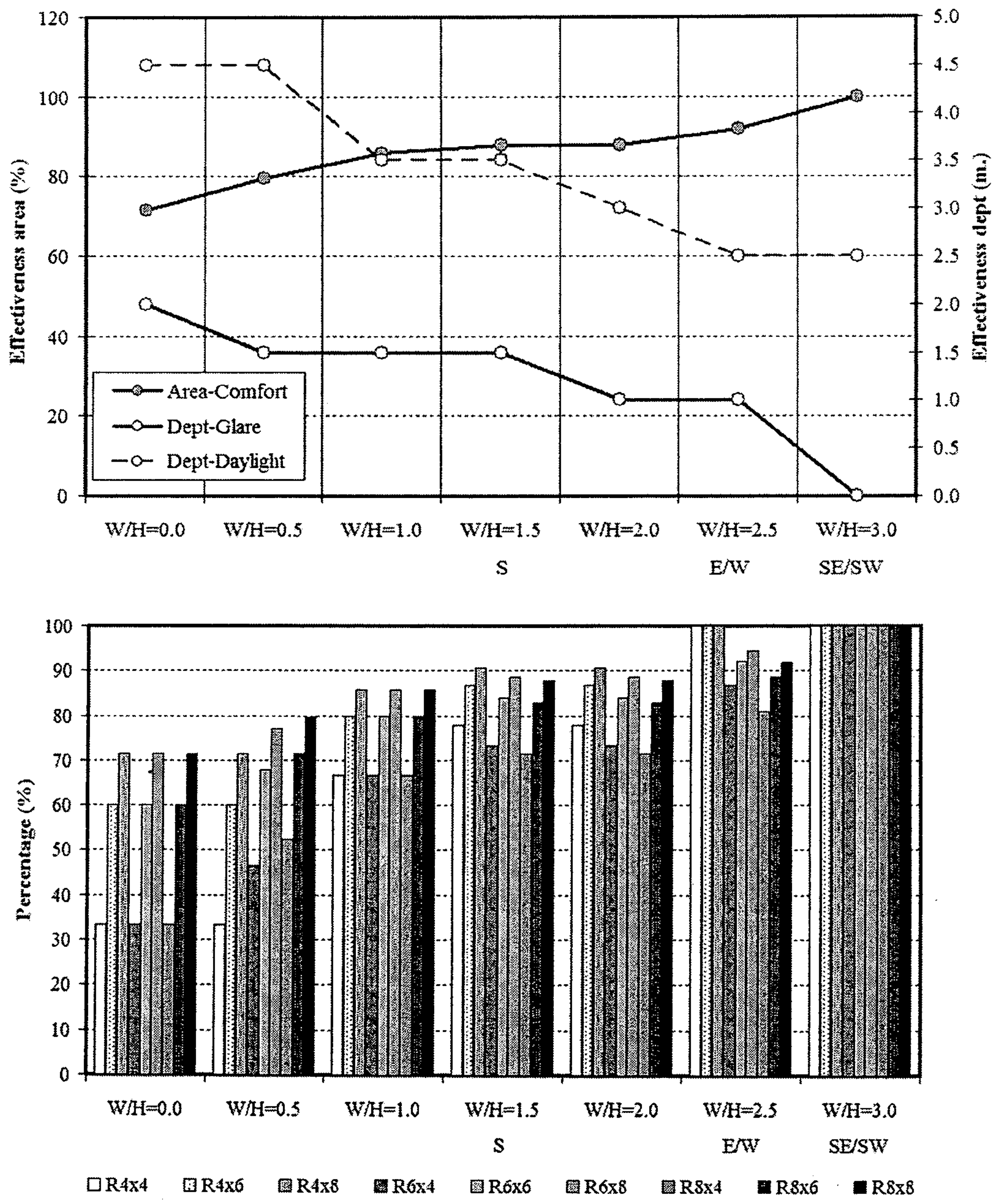


Figure 202 The DGI planning every W/H ratio

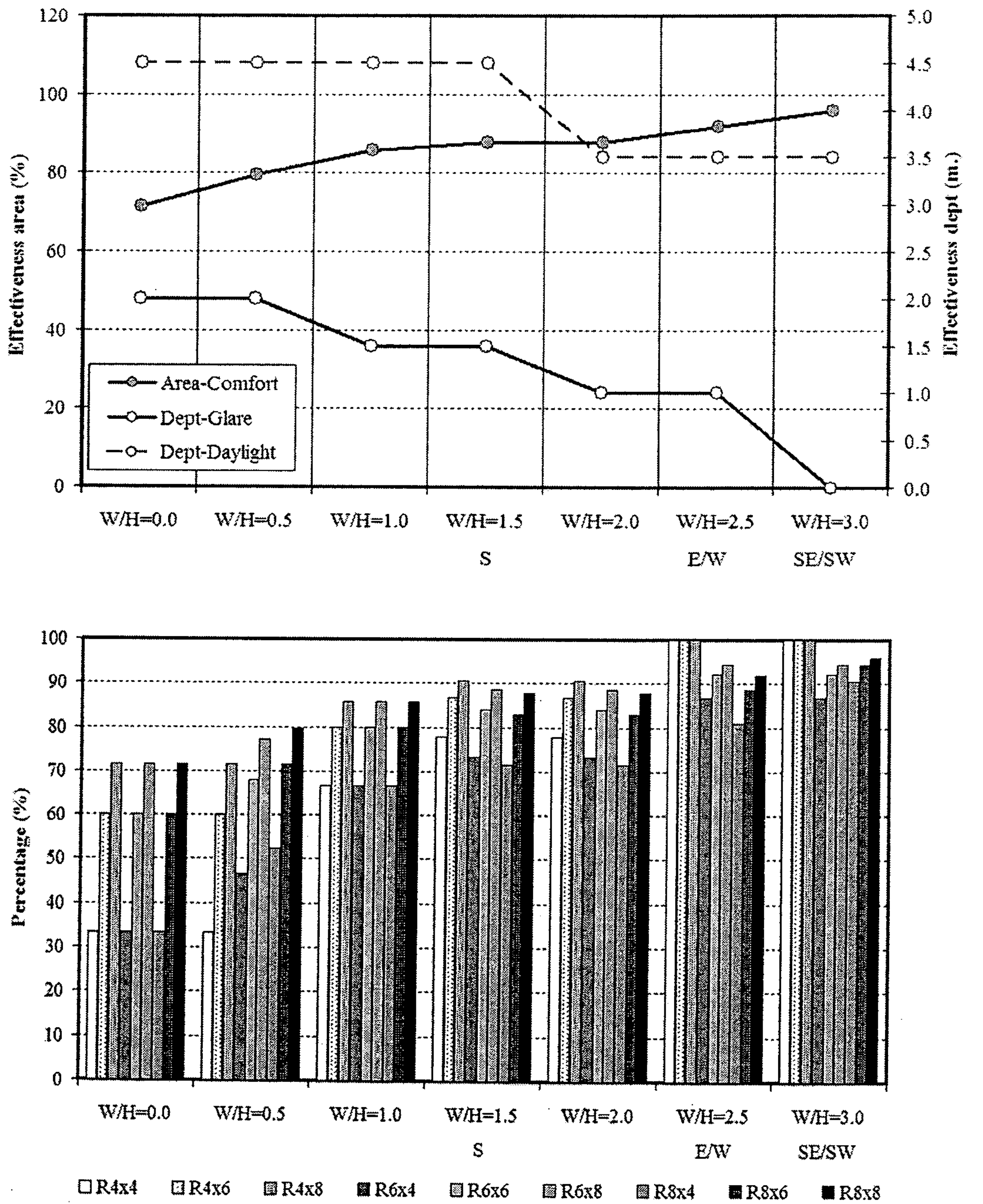
Figure 197 shows DGI in each area of room turning towards window. It is found that area nearby the window is not proper in every case except the case of shading devices with W/H ratio equivalent to 2.5 in room with width of 4.0 m. and the case of shading devices with W/H ratio equivalent to 3.0.



30 kLux on horizontal plane

Figure 203 The performance of visual comfortable every W/H ratio from 30 klux

Figure 203 shows the comparison of benefits of daylight and the area usability in the case of illuminance level outside is at 30 klux. It is found that the more the shading devices has W/H ratio, the less of the area usability because of glare is. In the same way, the benefit from daylight is also less. However, shading devices with W/H ratio = 1.5 is installed in the south is considered the most suitable



50 kLux on horizontal plane

Figure 204 The performance of visual comfortable every W/H ratio from 50 klux

Figure 204 shows the comparison of benefits of daylight and the area usability in the case of illuminance level outside is at 50 klux. It is found that the more the shading devices has W/H ratio, the less of the area usability because of glare is. In the same way, the benefit from daylight is also less. However, shading devices with W/H ratio = 1.5 is installed in the south is considered the most suitable as well

2. Optimization of economical impact

Another objective is to optimize cost and benefits of shading devices integrated photovoltaic system.

2.1 SIPV (Cost of SIPV system)

2.1.1 Price of solar module

In present, world market has explored that the price of p-Si technology is determined at 23 THB/W_p – 40 THB/W_p. As for Thailand market, the price of p-Si technology is determined at 45 THB/W_p as shown in Figure 205 showing that devices with defect is not considered in searching for cost because of its low price

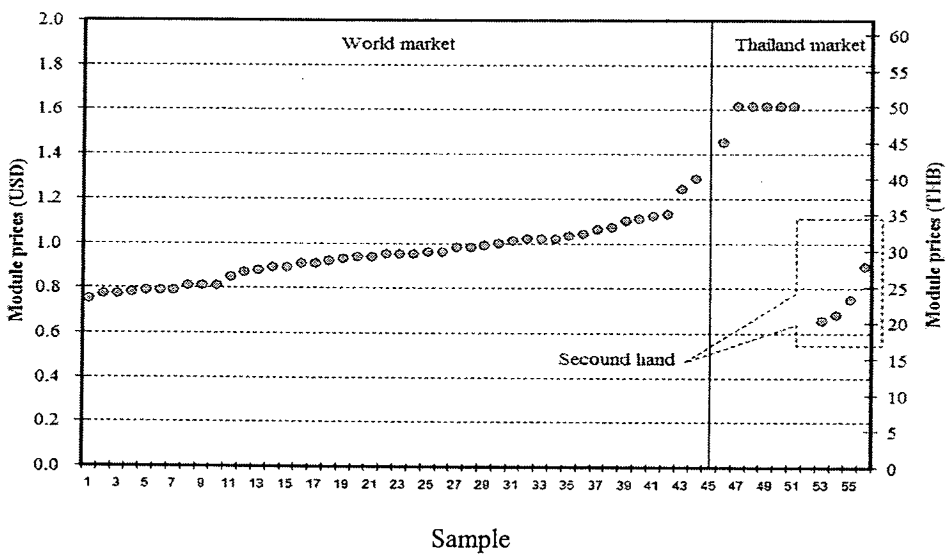


Figure 205 The price of PV modules

Source: Amornsolar [57]; Benefit media Co.ltd [60]; Blogger [61]; Chawna [64]; Ecobusinesslinks [66]; Kamsopha, Sarawut [71]; Mechashop [76]; MJ Shiao [79]; Solartech center limited partnership [84]; tarad.com [85]; Vera [92]

2.1.2 Total cost of SIPV

Cost of SIPV is different from PV with general installation. There are several reasons as follows:

1) The support of structure is different. The cost of land price is not included

2) Some parts of expenses are included with budget for building construction

To calculate cost of system, it is to consider from cost proportion of normal system by deducting some parts off and adding some parts in as shown in Figure 206 causing the decrease in cost of system. The price is separated into 2 levels according to market trend as shown in Table 29 for world market and Table 30 for domestic market

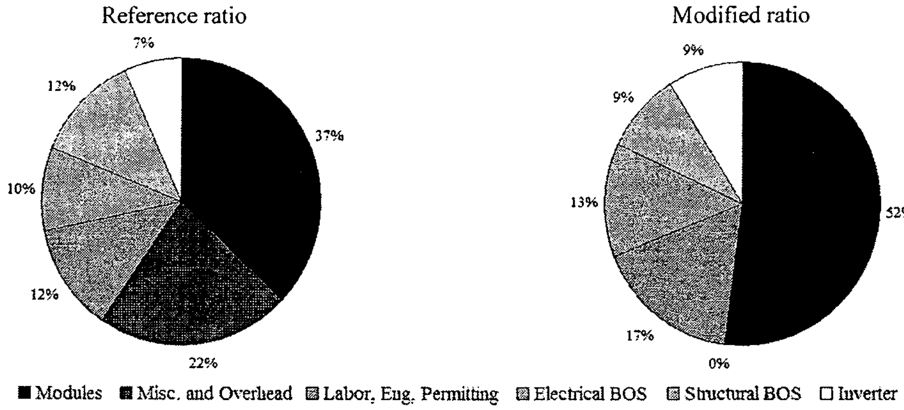


Figure 206 The ratio of system costs

Source: Martin LaMonica [75]; Michael S. Davies [77]; MJ Shiao [79]

Table 29 The SIPV system costs of the world market prices

	Bath	%	Remark
Modules	3,750	49	30 THB/ Wp and 125 W/m^2
Misc. and Overhead	-	-	Include with building investment
Labor, Eng, Permitting	1,731	16	Reference ratio
Electrical BOS	1,406	13	Reference ratio
Structural BOS	1,000	13	Aluminum cladding
Inverter	948	9	Reference ratio
Total	8,835	100	
Total adjustable prices	8,800		For minimum estimation
SIPV system prices	**70 THB/W$_p$**		

Table 30 The SIPV system costs of Thailand market prices

	Bath	%	Remark
Modules	5,625	52	45 THB/ Wp and 125 W/m^2
Misc. and Overhead	-	-	Include with building investment
Labor, Eng, Permitting	1,839	17	Reference ratio
Electrical BOS	1,406	13	Reference ratio
Structural BOS	1,000	9	Aluminum cladding
Inverter	948	9	Reference ratio
Total	10,818	100	
Total adjustable prices	10,800		For maximum estimation
SIPV system prices	**86 THB/W$_p$**		

2.2 Interest

From statistic 5 years back of the Bank of Thailand as shown in Figure 207 found that interest in the case of minimum retail rate: MRR was at about 8.0 to 8.5. For this study, constant at 8.0 was chosen because of its suitability in investment choice.

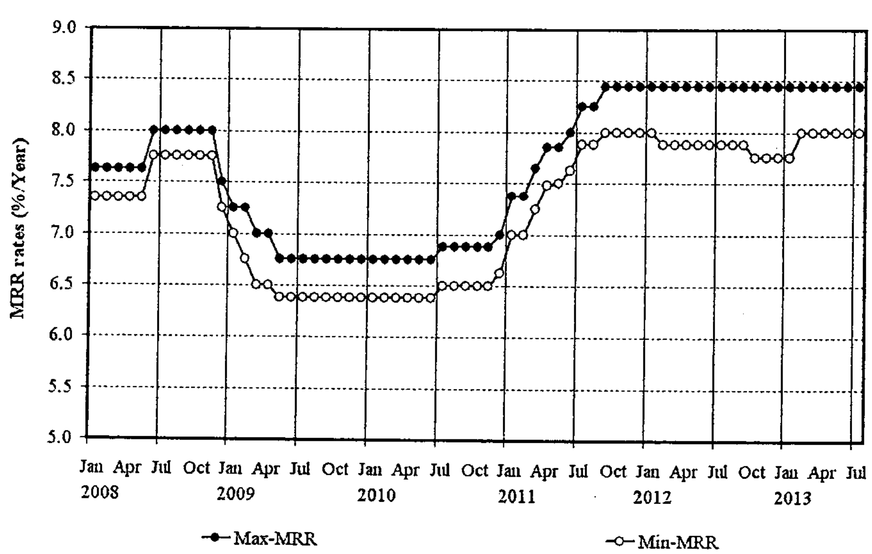


Figure 207 The minimum Retail Rates of Thailand banking

Source: Nitidow [80]

2.3 Price of electricity

Figure 207 shows price of electricity tends to be stable at 4 Baht with condition of Ft at 0.9255. The use of electricity was more than 1,000 units

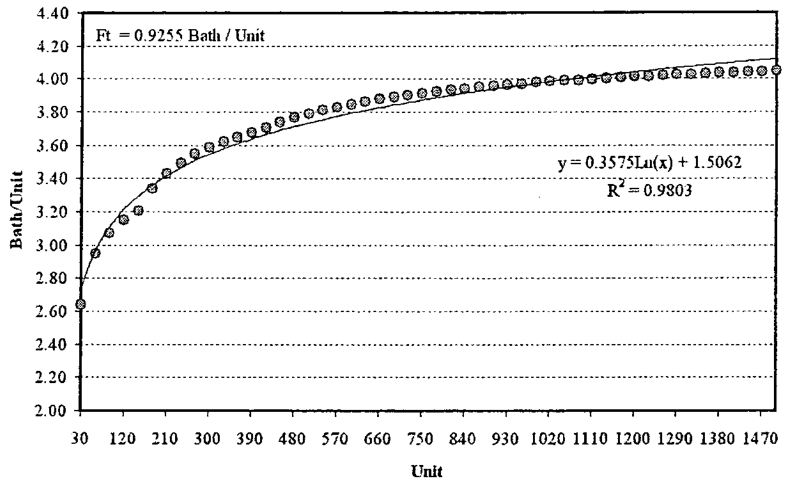


Figure 208 The electricity prices trend

2.4 SIPV degradation

Long term SIPV degradation is considered in Figure 209 as it is guaranteed by company in charge of module selling business mentioning SIPV degradation of not less than 80% in year 25th leading to the estimation of degradation of energy produced annually in a form of linear

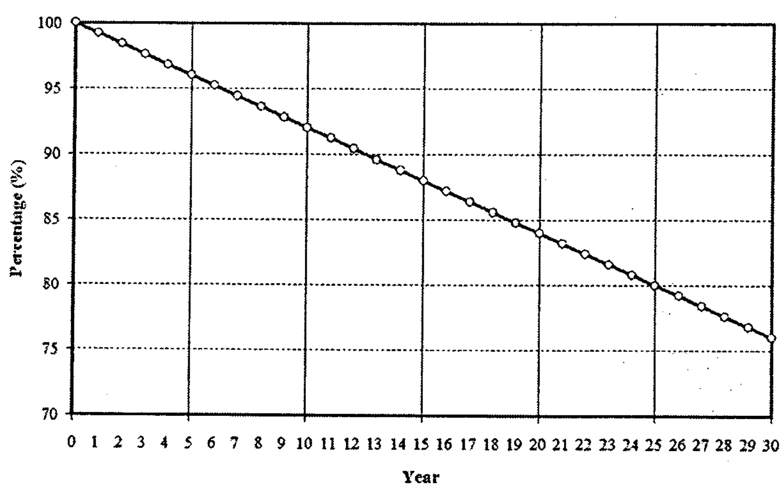


Figure 209 The degradation of PV efficiency

2.5 Benefits-Costs ratio (B/C)

The conditions of SIPV price at 70 THB/Wp and 86 THB/Wp are compared as 3 following options:

2.5.1 Only producing benefits

2.5.2 Producing and reducing benefits

2.5.3 Producing, reducing and saving benefits

From estimating B/C ratio, it is found that only producing benefit option is not suitable in the matter of investment due to the value of less than 1 in every case of design. Producing and reducing benefits option is suitable for investment in several cases of design. Besides, producing, reducing and saving benefits option is suitable for investment in all cases of design. However, the best case for investment of each option is shown in Table 31 which is SIPV system installation turning towards south with tilt angle of 30 degrees.

Table 31 the optimization of SIPV benefits

Direction	E	SE	S	SW	W
Shading form : W/H	2.50	3.00	1.50	3.00	2.50
Reducing heat ratio : HR	0.280	0.259	0.319	0.257	0.280
Saving lighting ratio : LR	0.26	0.30	0.18	0.30	0.26
Producing ratio	4 (0.85)	3 (0.94)	1 (1.00)	2 (0.96)	5 (0.77)
Reducing ratio	4 (0.92)	2 (0.99)	3 (0.94)	1 (1.00)	4 (0.92)
Saving ratio	2 (0.91)	3 (0.86)	1 (1.00)	3 (0.86)	2 (0.91)

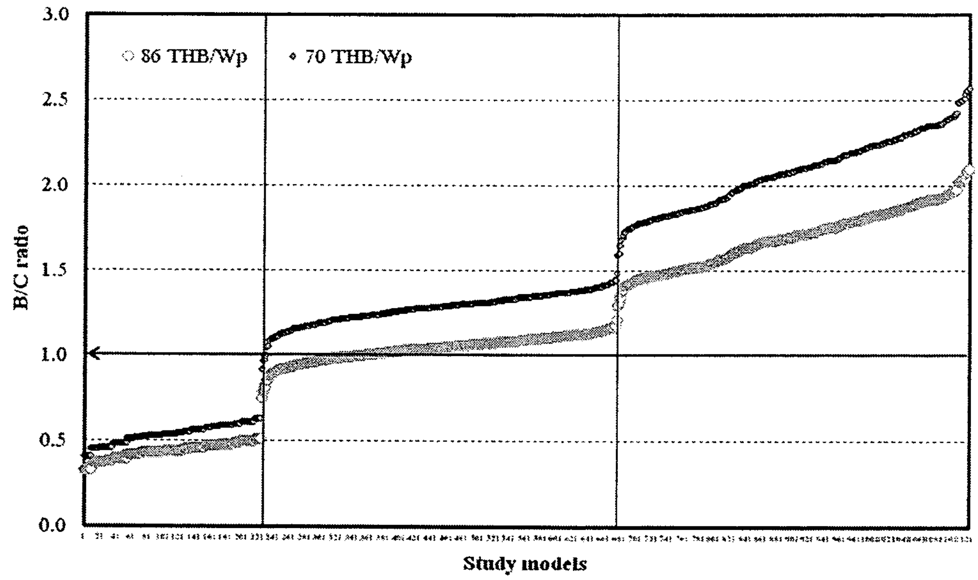


Figure 210 The B/C ratio comparison between 70 and 86 THB/Wp

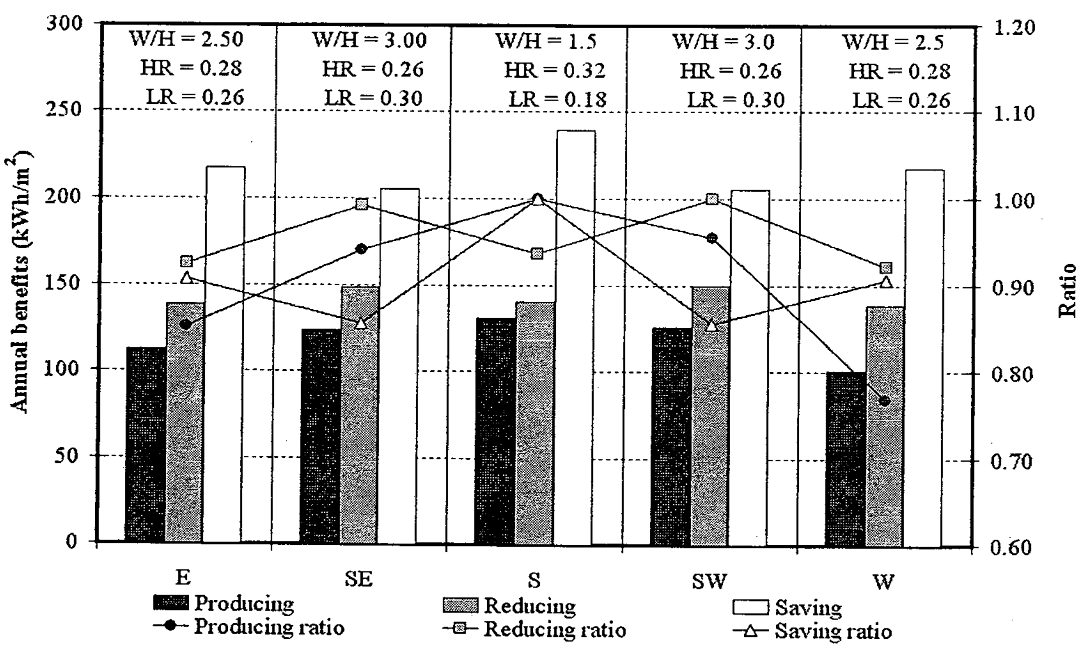
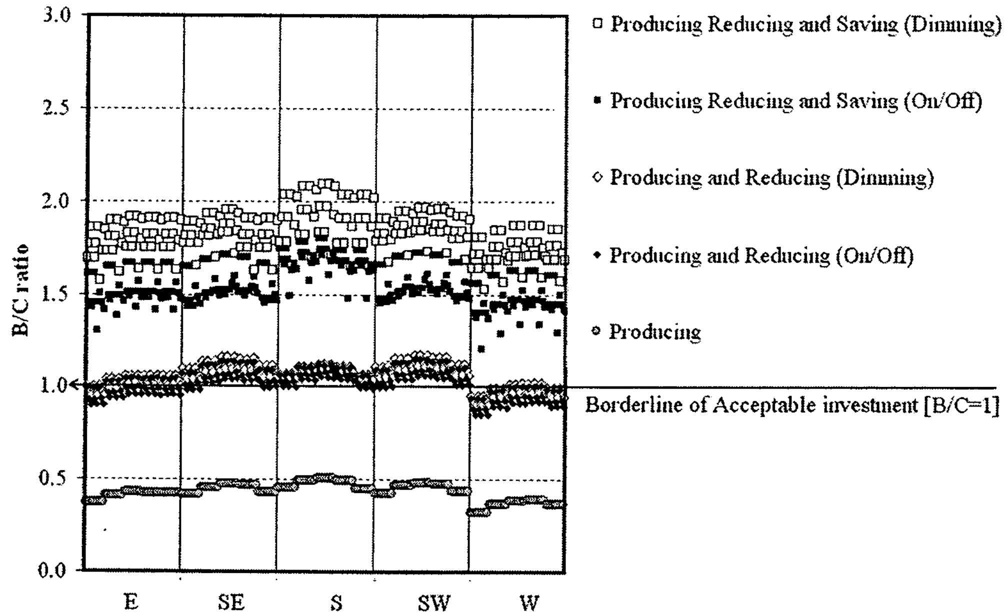
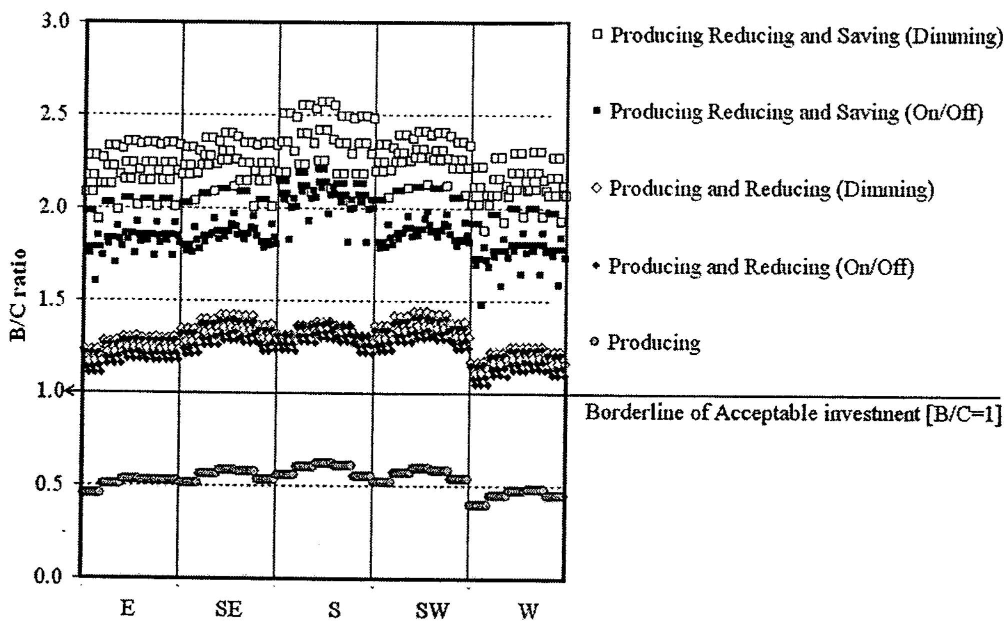


Figure 211 The impact of benefit options



86 THB/W_p



70 THB/W_p

Figure 212 The B/C ratio comparison of the SIPV benefit options

Figure 212 shows trend of B/C ratio divided according to installation in all directions. It is found that only benefits from electricity production of SIPV are not suitable for investment. Considering producing and reducing benefits option of both cases of lighting control techniques, there is the similar B/C ratio. For producing, reducing and saving benefits option, dimming technique is the most suitable

2.6 Payback period

The optimization from considering payback period is divided into 3 following options:

2.6.1 The producing option

Payback period cannot be made in determined period of time for this option as shown in Figure 213 showing the comparison in a form of B/C ratio with value of less than 1.0 in all cases. It is found that the most suitable design is to install turning towards South with tilt angle of 30 degrees to create the highest level of energy generation

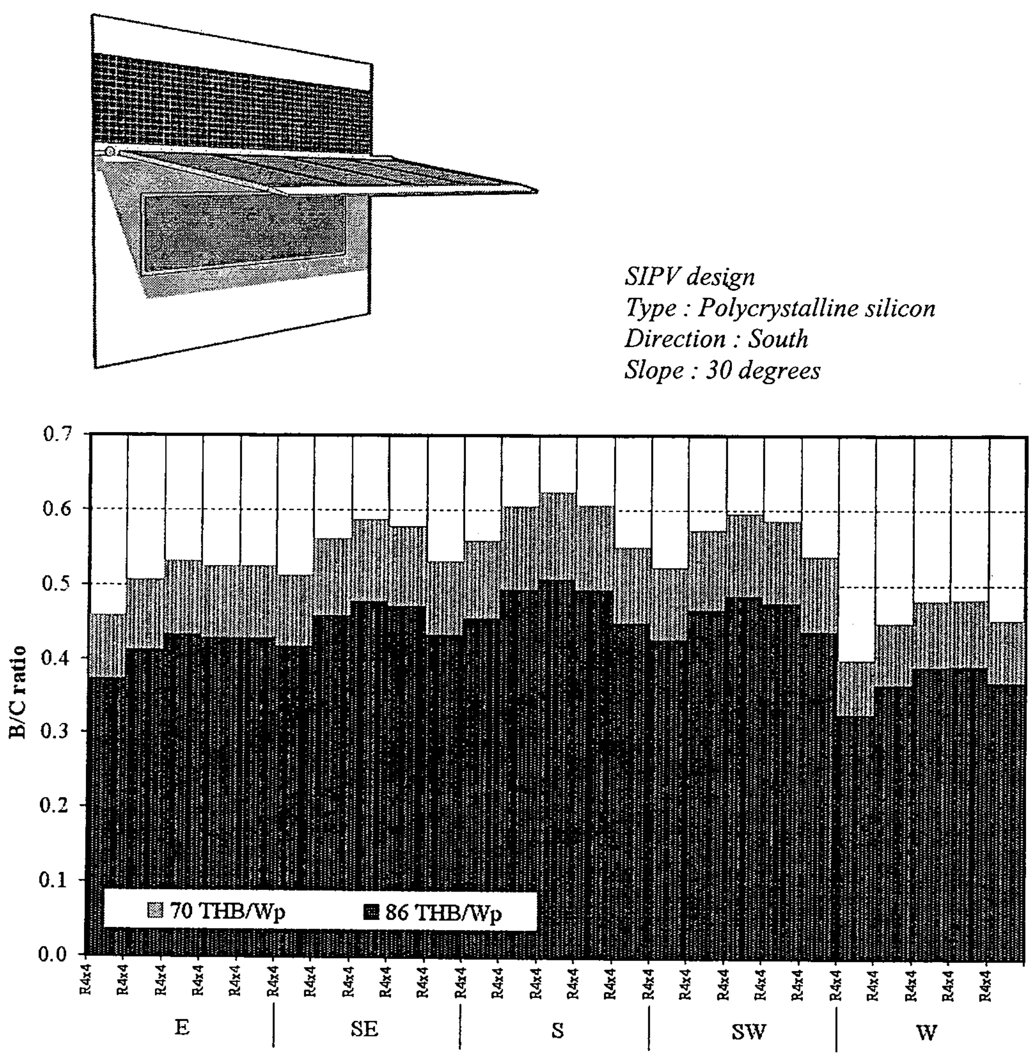
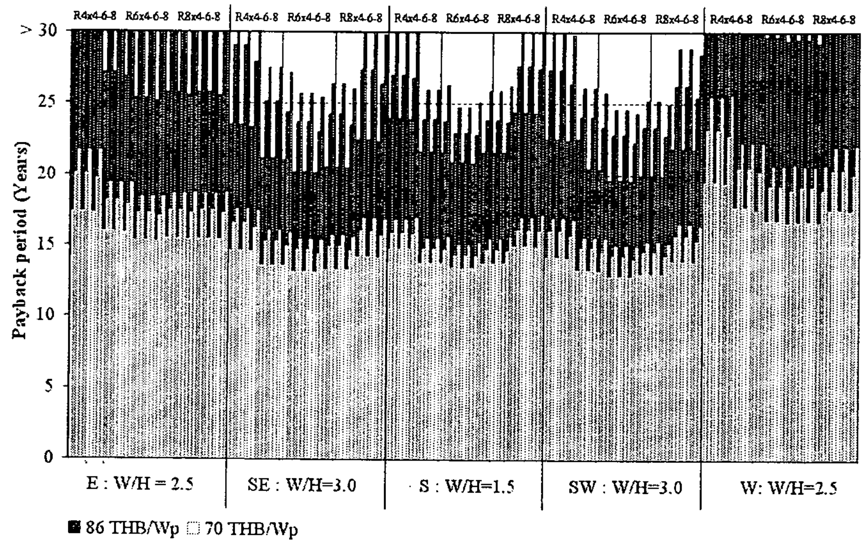
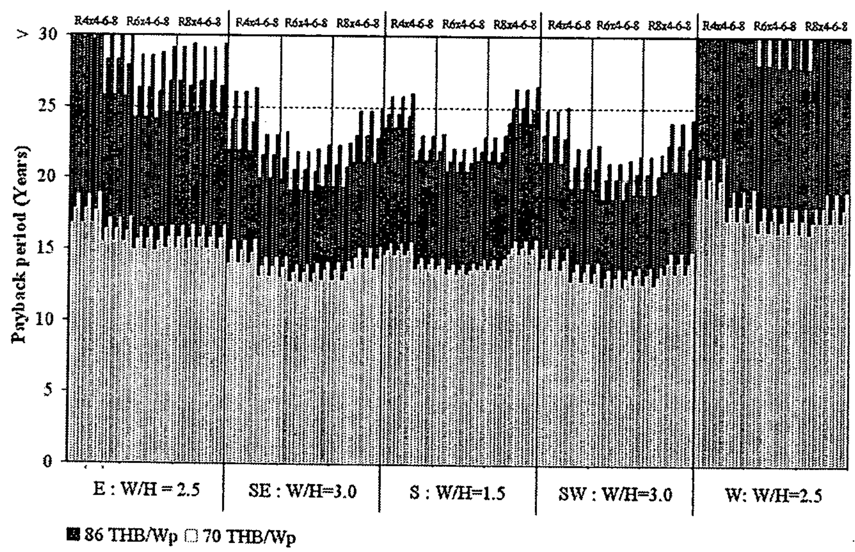


Figure 213 The B/C ratio of producing option

2.6.2 Producing and reducing option



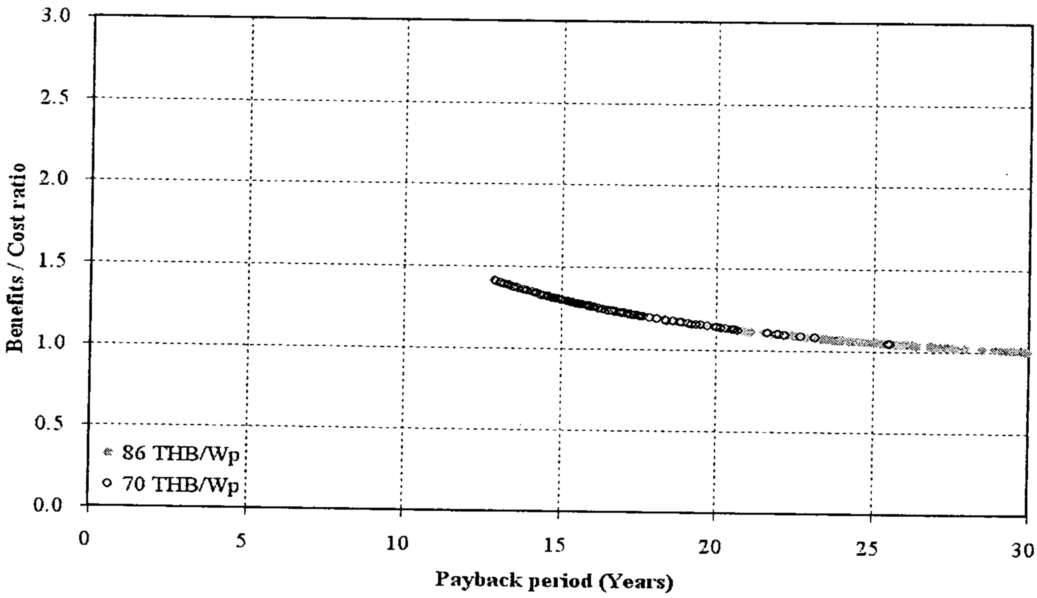
ON/Off technique



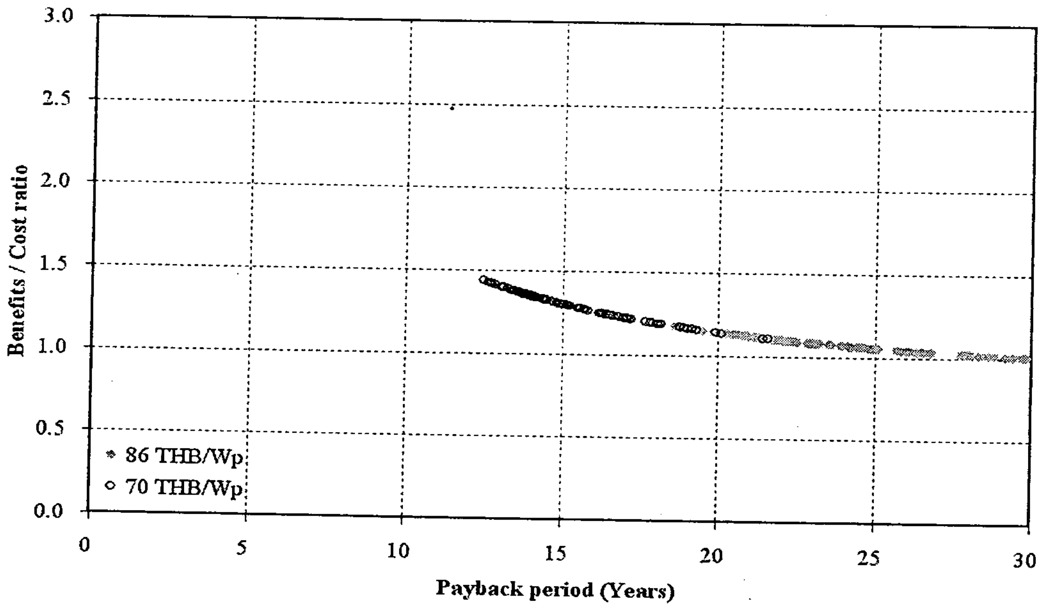
Dimming technique

Figure 214 The payback period of producing and reducing option

Figure 214 shows the payback of producing and reducing benefits option. It is found that the SIPV installed in the South West / East can make the fastest payback. However, it is the same to the installation in the south east and south arranged from the fastest to the slowest in both cases of lighting control techniques and in room with small depth. Figure 215 shows the resemble relation of both lighting control techniques



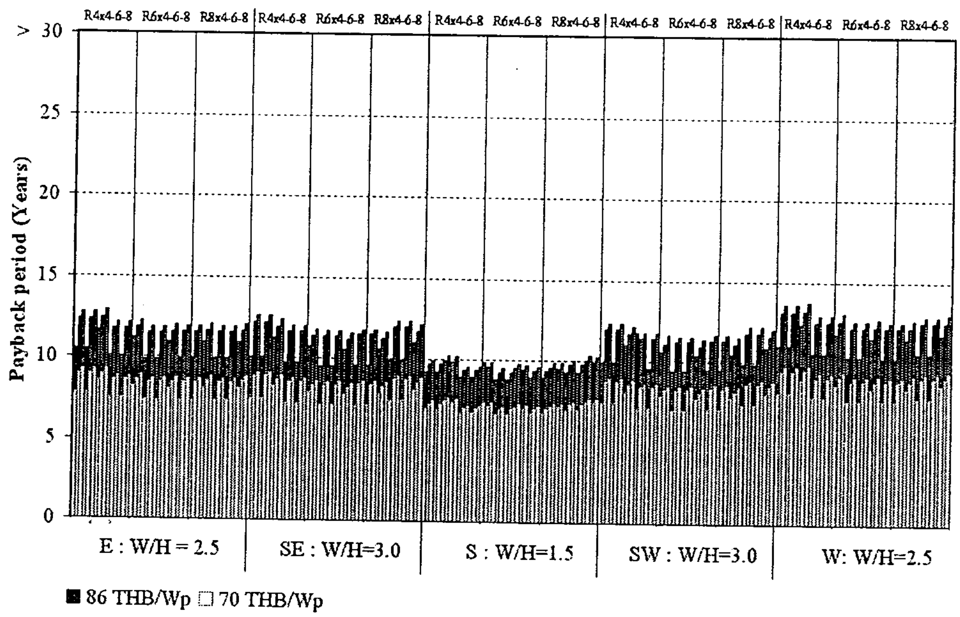
On/Off technique



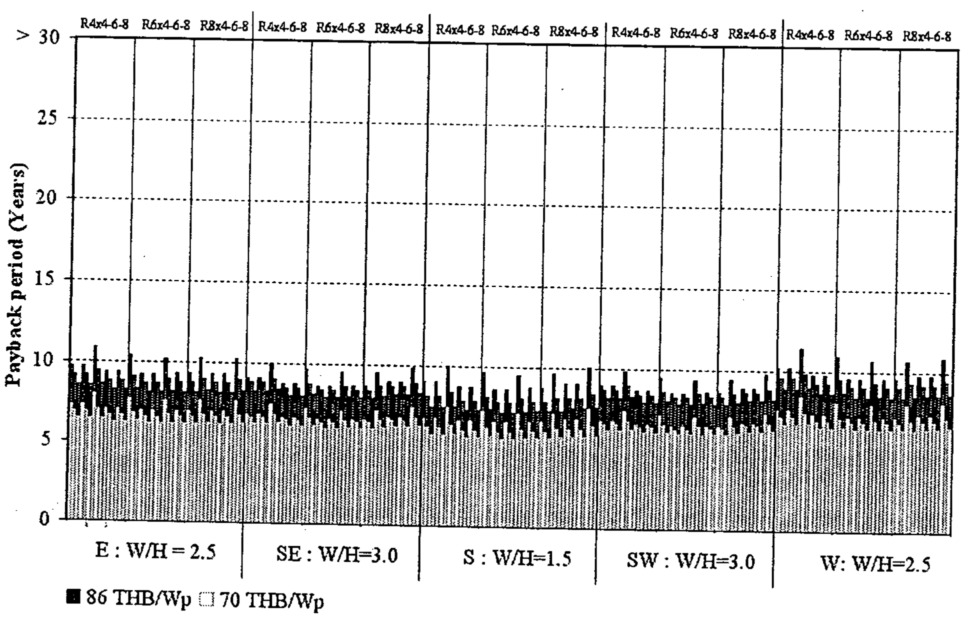
Dimming technique

Figure 215 The relations of B/C ratio and payback period of producing and reducing option

2.6.3 Producing reducing and saving option



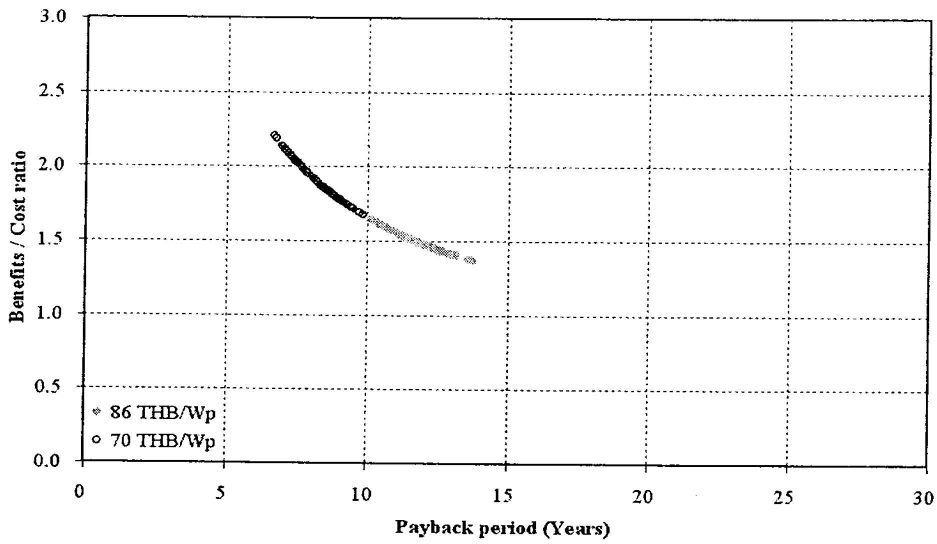
ON/Off technique



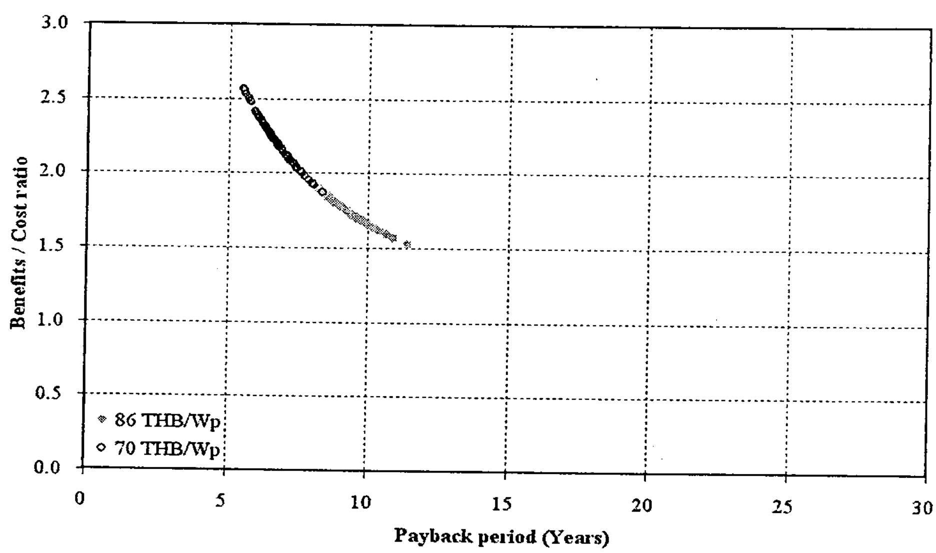
Dimming technique

Figure 216 The payback period of producing, reducing and saving option

Figure 216 shows payback of producing reducing and saving option. It is found that room with small depth of 4.0 m. using dimming technique can get payback sooner than room with big depth of 6.0 m. and 8.0 m. using on/off technique and being installed tuning towards South



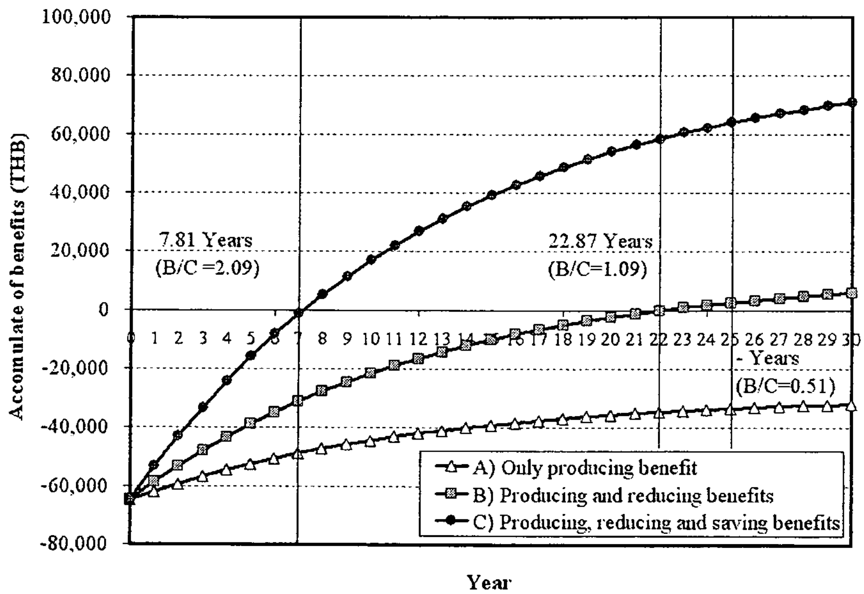
On/Off technique



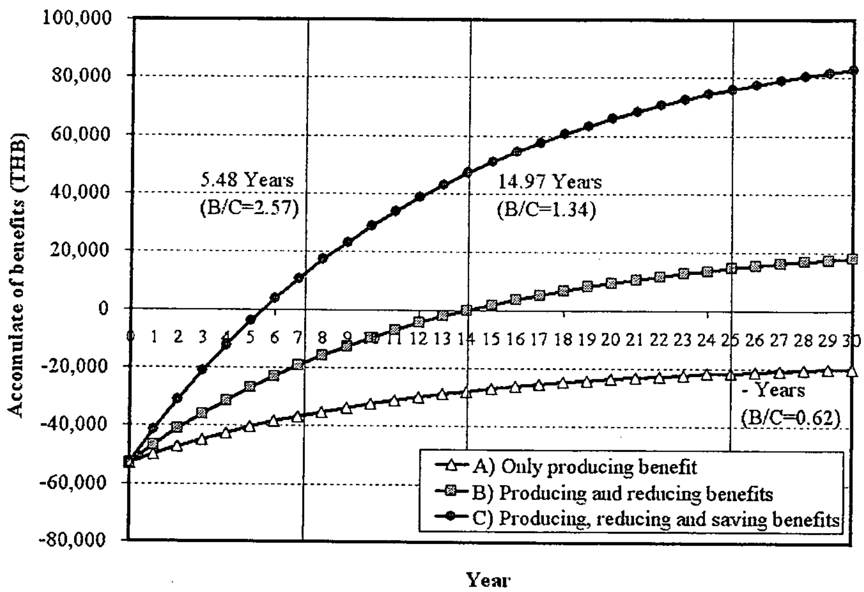
Dimming technique

Figure 217 The relations of B/C ratio and payback period of producing, reducing and saving option

Figure 217 shows the trend line which is clearly different. Dimming technique clearly shows the better trend



System cost = 86 THB/W_p



System cost = 70 THB/W_p

Figure 218 Trends of SIPV benefit options

Figure 218 indicates the best design conditions divided according to cost of system. It is found that the best case for option C is payback in 7.81 years for the cost of 86 THB/W_p and 5.48 years for cost of 70 THB/W_p

Table 32 The summary of design guild line

Option	control	B/C	Payback (Years)	Price (THB/Wp)	Slope (Degrees)	Direction	Room Ranking (1-3)
producing	Both	0.51	-	86	30	S	All
	Both	0.62	-	70	30	S	All
Producing and reducing	On/Off	1.1	19.6	86	30	SW	8x4 6x4 4x4
	On/Off	1.4	12.9	70	30	SW	8x4 6x4 4x4
	Dimming	1.2	18.7	86	30	SW	8x4 6x4 4x4
	Dimming	1.4	12.5	70	30	SW	8x4 6x4 4x4
	On/Off	1.1	20.8	86	30	S	8x4 6x4 4x4
	On/Off	1.4	13.5	70	30	S	8x4 6x4 4x4
	Dimming	1.1	20.6	86	30	S	8x4 6x4 4x4
	Dimming	1.4	1.3.3	70	30	S	8x4 6x4 4x4
Producing reducing and saving	On/Off	1.8	8.9	86	30	S	6x4 4x4
	On/Off	2.2	6.7	70	30	S	6x4 4x4
	Dimming	2.1	7.2	86	30	S	6x8 4x8 8x8
	Dimming	2.6	5.5	70	30	S	6x8 4x8 8x8

The determination of 2 rates of system price has the same trend in design. Benefits of SIPV system gained from shading function and PV function is considered attractive for investment despite the drawback of receiving lower solar irradiance on solar module. However, there are still the benefits from shading function

Therefore, SIPV system can reduce cooling load of air conditioning system and use daylight to save energy from lighting load. There are also clear angles for buildings in Thailand

The suitability of design is to install turning towards south with tilt angle of 30 degrees in order to reduce heat gain and increase daylight usability of shading device integrated photovoltaic system as much as possible. It is also to create the suitability of price and benefits of shading device integrated photovoltaic system due to benefits gained from air conditioning system, lighting system and energy generation system by using dimming technique to control light within the