CHAPTER III

RESEARCH METHODOLOGY

Study plan

SIPV is an integrated system appliance consisting of shading, daylight control and electricity production. It depends only on one energy resource which is solar radiation from the sun and sky shining down on shading devices.

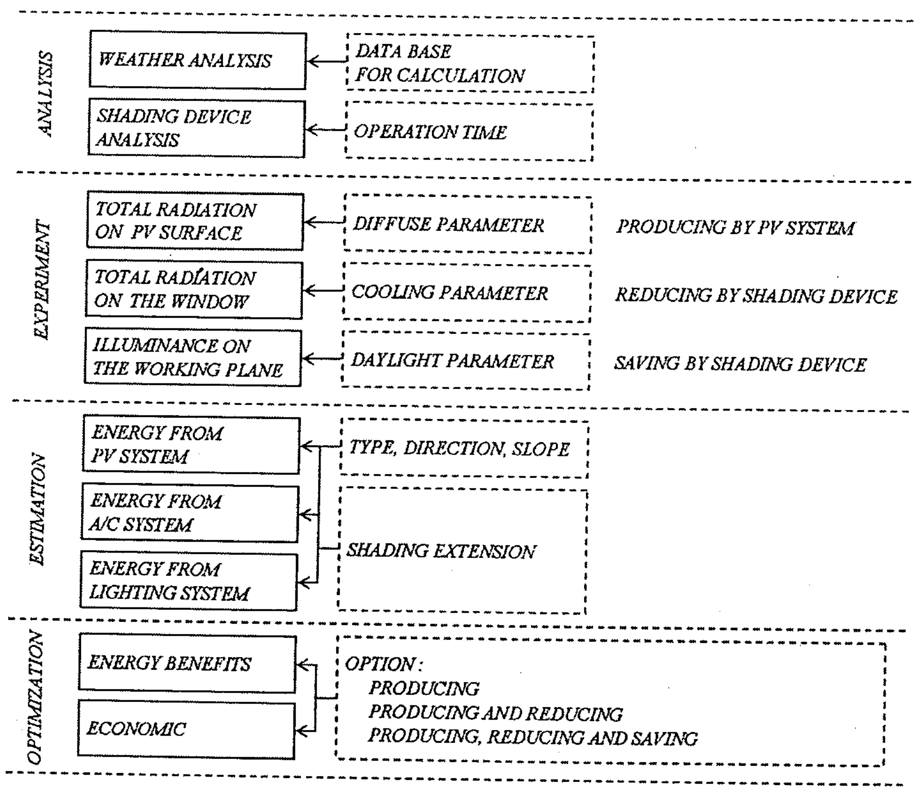


Figure 88 The study diagram

The process of this research trying to search for ideas of designing shape and installation of SIPV with energy suitability is divided into parts as follows:

1. The analysis part is to search for weather database referred to calculation, form of shading device and period of appraisal

2. The experiment part is to improve equations for value calculation in order to make it suitable according to the conditions of system installation

3. The estimation part is to estimate energy values in all kinds of systems annually in order to acknowledge all influences due to the design

4. The optimization part is to look for forms that create the highest level of energy saving in the conditions of establishing the most possible angles and avoiding glare effects. It is also concerning appraisal in the matter of economics to make the highest level of value

The definitions

1. The window functions

The function of a window is to be a source of natural daylight connecting the view between inside and outside. This research is to study only windows being a light channel considering data of heat radiation, daylight and area for view angles, as shown in Figure 89

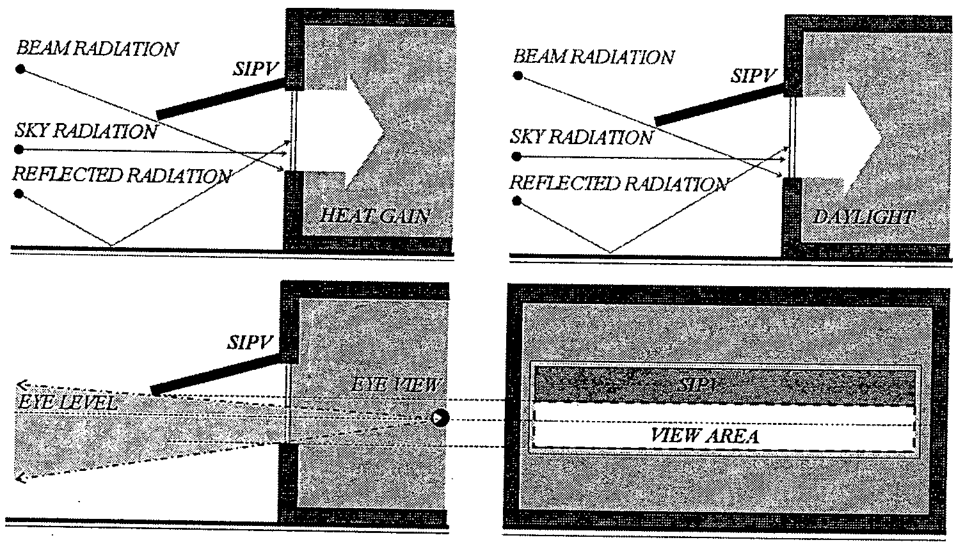


Figure 89 The window functions

2. The shading functions

The functions of shading are to reduce the amount of direct solar radiation and diffuse solar radiation. However, radiation reflecting from the ground still gets in. For estimating the value of received solar heat gain from both heat and light, the isotropic sky model is used.

2.1 The function of preventing heat from solar radiation is shown in Figure 90

2.2 The function of light control is shown in Figure 91

This does not consider direct solar radiation due to determination of design conditions to fully prevent direct solar radiation in the period of time of consideration.

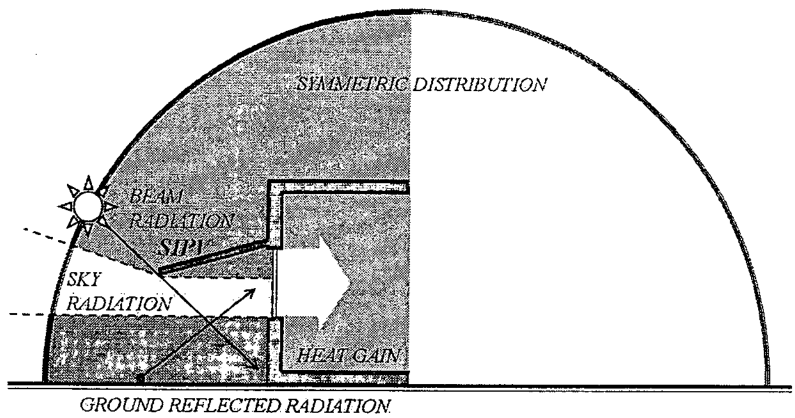


Figure 90 The shading function to protect the sun

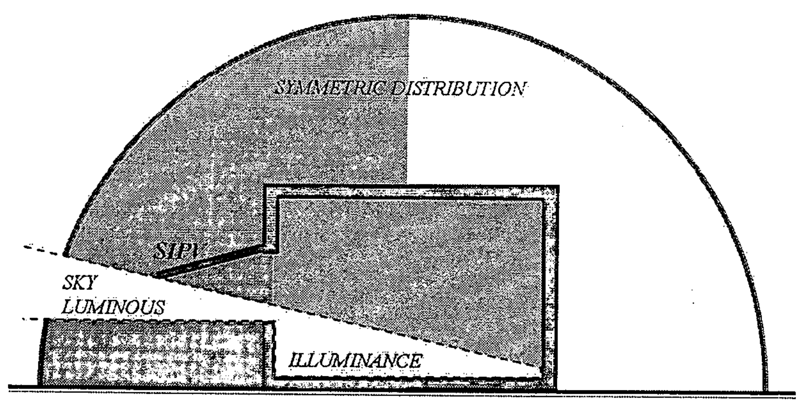


Figure 91 The shading function to control the luminous source

3. The generator function

The function of a solar module is to generate energy by transforming solar radiation into electricity. It depends on direction and inclined angle of the module. The hypothesis of this study is that the total energy produced resulting from the system is able to be used continuously by using a dummy load of a building and having no barriers in front of or on the solar module.

4. The benefits of SIPV

The benefits of SIPV are integrated advantages between shading devices, light control devices and energy production devices as shown below:

4.1 Reducing heat gain from solar radiation in a pattern of cooling load of the air conditioning system (The only focus is on glass under the pattern of shading device and direction of window).

4.2 Saving electricity of lighting systems by using control systems of on-off or dimming techniques under the pattern of shading device and direction of the window.

4.3 Producing electricity by converting solar radiation into electricity due to shading device installation.

5. Benefit options and conditions of study time

There are 3 patterns of benefits the change according to shape as follows:

Option 1; the producing option is the benefit from electricity production.

Option 2; the producing and reducing option is the benefit resulting from electrical energy production and reducing the cooling load of the air conditioning system.

Option 3; the producing, reducing and saving option is the benefit resulting from electrical energy production, reducing the cooling load of the air conditioning system, and saving energy in lighting system due to the use of daylight.

Data collection of this study was in the daytime during 8.00-16.00 for the suitable reasons presented in chapter IV. It is also because the time is suitable for the use of air conditioning systems to create the comfort zone. The consideration to operate the mentioned matter for 365 days was for the highest level of benefit.

Parameter and experimental setting

The study of optimization in SIPV design can be concluded as shown in Figure 92 which is separated into 4 main parts as below:

Part A is to study conditions of parameters depending on location, direction, tilt angle, and technique of PV module setting.

Part B is to collect data on the parameters from the experiments in the matter of total solar irradiance on slope surface, relation of daylight and relation of cooling load because of shading devices outside and inside the building, using basic equation improvement.

Part C is the estimation from calculation appearing in annual energy consumption, reflecting benefits due to light prevention and the use of daylight, and by using an improved equation to respond to the first purpose.

Part D is economic estimation to respond to the second purpose.

In parameter determination, the reference of standard value and use in the real situation should be considered.

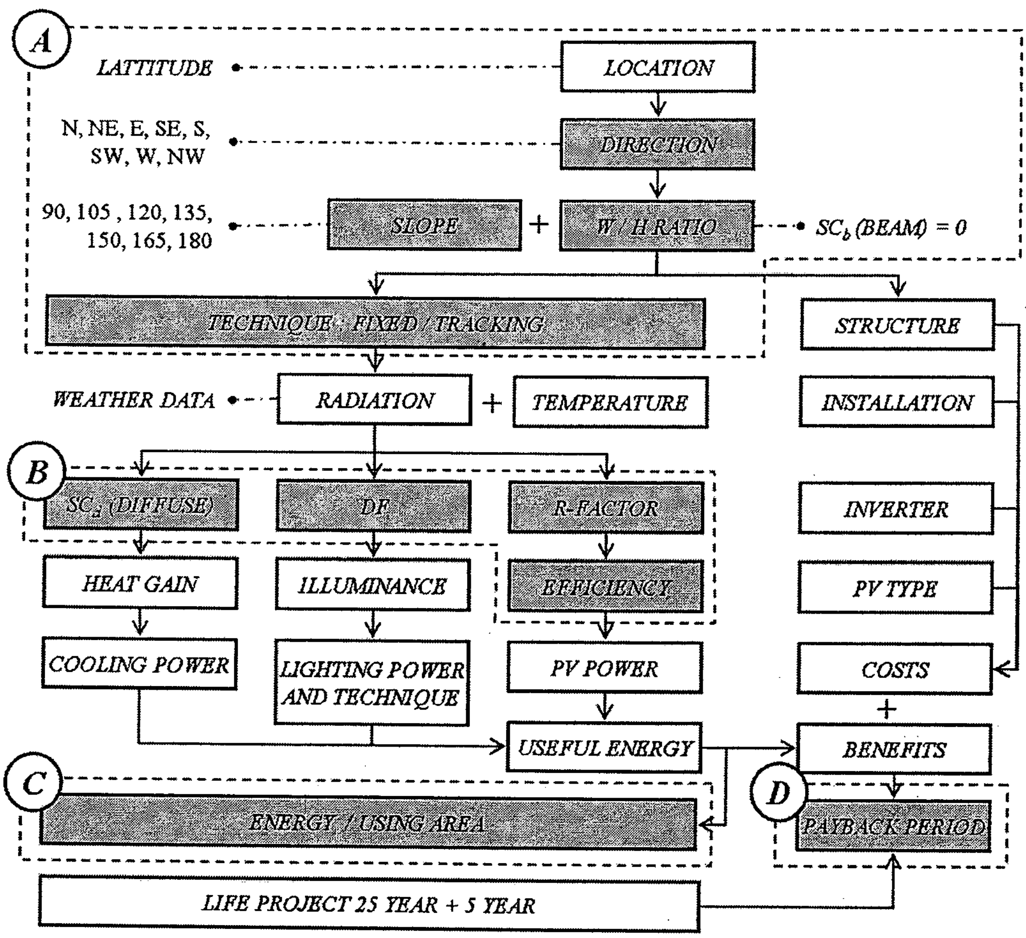


Figure 92 The flow diagram of parameters

1. The form of SIPV parameters

To respond with solar prevention in the form of shading coefficient, the shading coefficient value should be zero for the full-functioned beam solar radiation prevention for the whole period considered and for suitability in avoiding shade on the solar module, as shown in Figure 93. Therefore, a horizontal shading device was designed instead of a vertical module, which causes overlapped shading more easily.

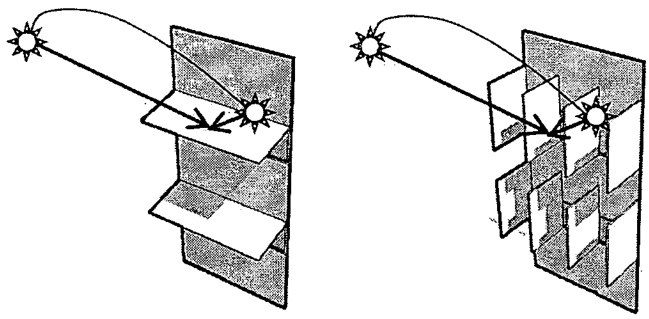


Figure 93 The shelf shading of the horizontal and vertical shading device

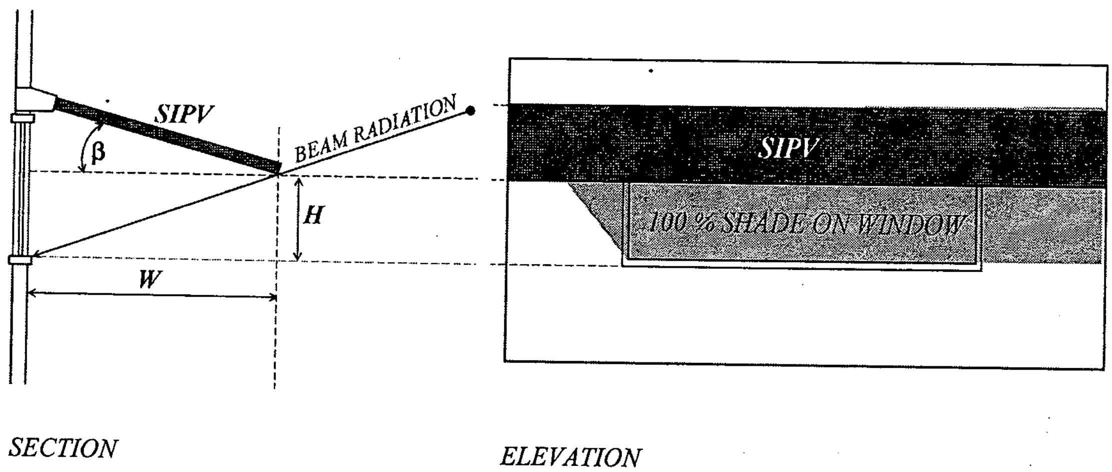


Figure 94 The study form of SIPV

The research specified a form of SIPV considering the outstretched part of the module which affects the shading coefficient used in calculation of the cooling load of the air conditioning system and the daylight factor used in calculation of illuminance on the working plane. The details are as follows:

1.1 Shading extending ratio (W/H): W is the extending part of the shading device and H is the height of the clear window under the horizontal shading device. The relation is shown in Figure 94.

1.2 The shading coefficient of the beam radiation can be found in the form of direct solar radiation on the glass plane. The comparison was the ratio of with shading device to without shading device. The shading coefficient of the diffuse radiation can be found in the form of diffuse solar radiation on the glass plane. The comparison was the ratio of with shading device to without shading device.

1.3 Tilt angle of the shading device was compared to a flat plane as shown in Figure 94.

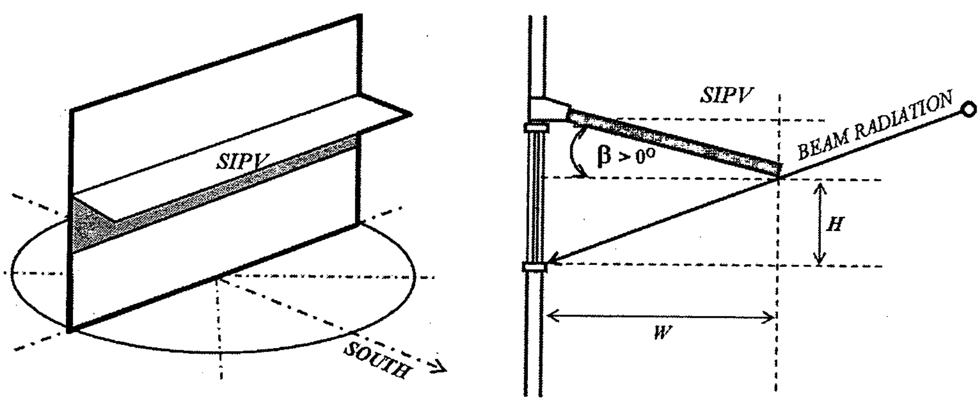
1.4 Directions used for shading device installation were North, North East, East, South East, South, South West, West and North West.

2. SIPV installation parameter

From part A in Figure 95, the forms of SIPV were installed in 2 patterns: fixed and tracking patterns. Each installation technique was a study to optimize installation for practical use as a building shading device. The details of the study were as below:

2.1 ·The fixed SIPV, shown in Figure 95

2.2 The tracking SIPV, shown in Figure 96

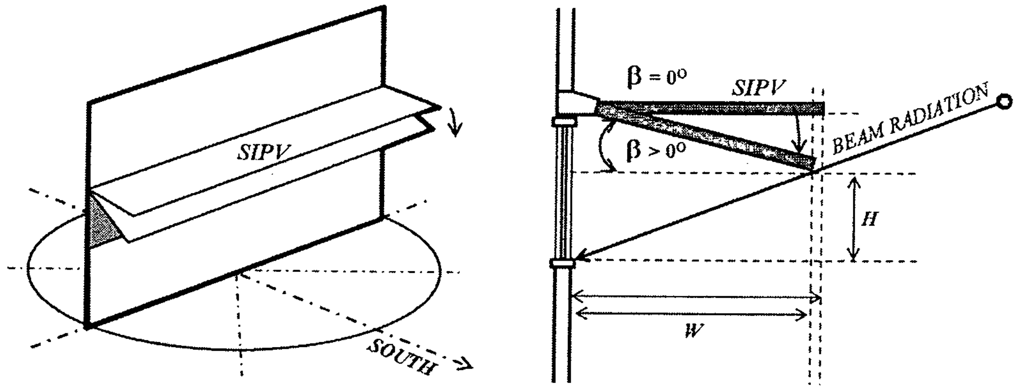


Beam radiation protection during operation time : 100% ($SC_b = 0$)

Direction : N,NE, E, SE, S, SW, W and NW

Slope (β) : 90, 105, 120, 135, 150, 165 and 180

Figure 95 The condition of the fixed SIPV technique



Beam radiation protection during operation time : 100% (SCb = 0)

Direction : Some direction that are optimized

Slope (β) : Tracking follow from the window function

Figure 96 The tracking condition of SIPV

3. Constant parameters

To estimate, constant parameters were calculated to determine energy of air conditioning systems, light systems and energy generation systems as shown in Figure 97. The parameters used in system design are as follows:

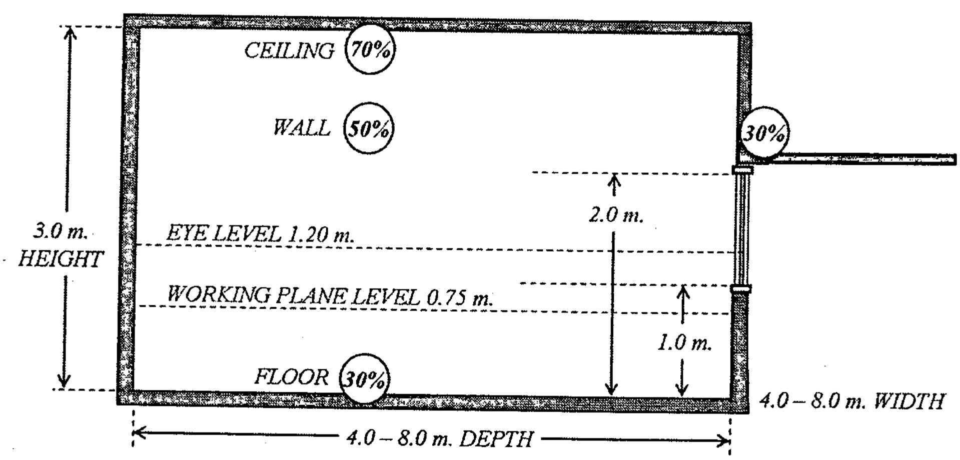
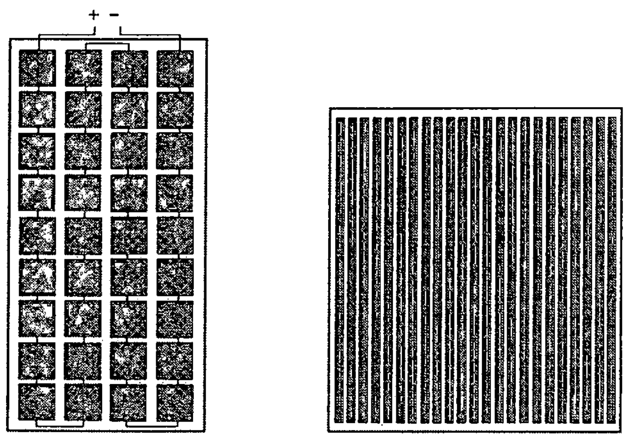


Figure 97 The constant parameters of the working space

3.1 PV technologies are a type installed for study and data collection at SERT since 2005 consisting of 2 types as shown in Figure 98.



Technology	*Polycrystalline Silicon (p-Si)*	*Amorphus Silicon (a-Si)*
Power of installation (W_p)	*80*	*54*
Area (m^2, dimension)	*0.64,*	*0.85*
Weight (kg)	*N/A*	*N/A*
Efficiency (STC)	*11.53*	*5.74*
Temperature coefficient	*N/A*	*N/A*
Frame / substrate	*Aluminium / White plastic sheet*	*N/A*

Figure 98 The PV technologies of the study

3.2 The air conditioning system gained a Coefficient of Performance (COP) of 3.22 referred from the law of energy conservation in buildings in Thailand. In medium mass construction, the internal temperature system operation was determined at above 25°C.

The thickness of clear glass was also determined at 6 mm with overall heat transfer coefficient (U) at 5.874 W/m^2-°C, solar heat gain coefficient (SHGC) at 0.73 and visible transmittance at 0.88.

3.3 The lighting system consisted of T5 fluorescent 28 W bulbs with a loss of Ballast Electronic 4 W installed and a bat wing reflector. The coefficient of utilization were as follows:

LLD=0.95, LDD=0.90, Fsa=1.14, Ful=0.85

Design conditions were at the minimum of 300 lux, and the working plane was at 0.75 m according to the standards of light design for a general working area. The light control techniques used were on-off and dimming techniques.

4. Room parameters

To calculate the energy of air conditioning systems and light systems, it is necessary to specify the size of the using area. For lighting system design for rooms with different sizes, the number of light bulbs needs to be decided according to different Lumen method calculation. The primary scope of the study was determined to design a general room with 4 m, 6 m and 8 m width of A dimension which is the same to room B dimension with depths of 4 m, 6 m and 8 m. the size and number of light bulbs is shown in Figure 99 and Table 20. To specify the size of the room relation of A x B, there are 9 cases in total.

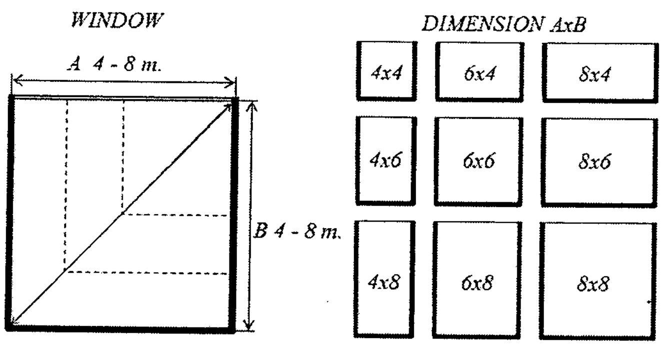


Figure 99 The dimension of study rooms

Table 20 The lighting installation by lumen method

Room dimension A x B	Direction A	Direction B
R 4x4	2 Lamp	3 Lamp
R 4x6	2 Lamp	4 Lamp
R 4x8	2 Lamp	5 Lamp
R 6x4	3 Lamp	3 Lamp
R 6x6	3 Lamp	4 Lamp
R 6x8	3 Lamp	5 Lamp
R 8x4	5 Lamp	2 Lamp
R 8x6	5 Lamp	3 Lamp
R 8x8	5 Lamp	4 Lamp

Experimental installation

The experiment can be divided into 3 parts as follows:

1. PV generator production

The main equation for calculation under the isotropic sky model was able to be explained in accordance with Eq. 15, which is the basic equation used in calculating total irradiance on a sloped surface under the isotropic sky model. The parameters of the mentioned equation were improved in the diffuse radiation factor and added in terms of solar radiation due to the reflection of the building wall. It is because of the difference of installation from the formal basis, as shown in Figure 100.

$$P_{SIPV} = \eta_{inv}\,\eta_{SIPV}\,E_{t\text{-}SIPV} \qquad Eq.102$$

$$E_{t\text{-}SIPV} = (R_b)E_G + (R_{sd}R_d)E_d + (R_{rG})E_G + (R_{rB})\,E_V \qquad Eq.103$$

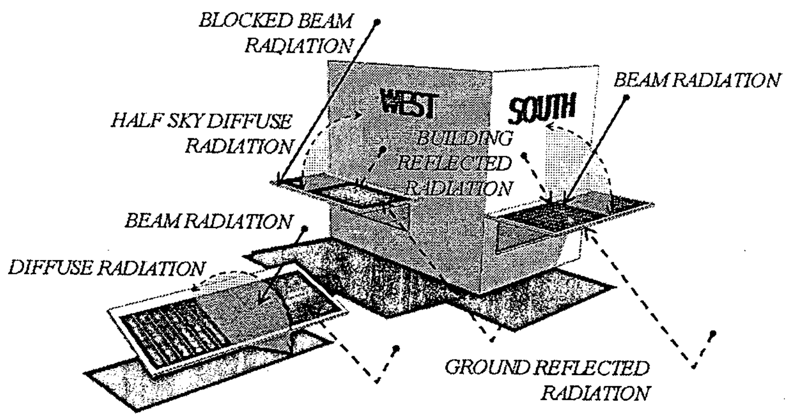


Figure 100 The difference of the installation effects

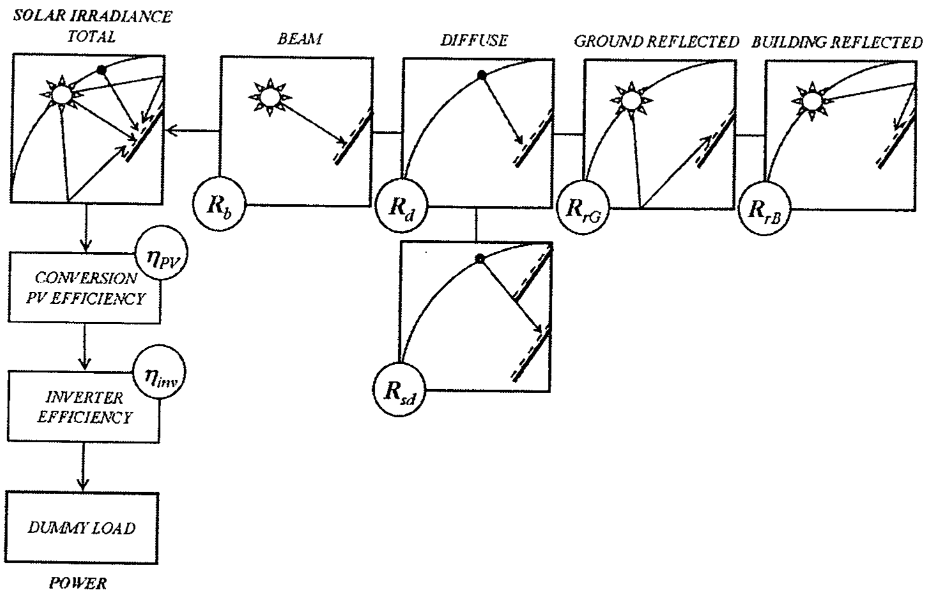
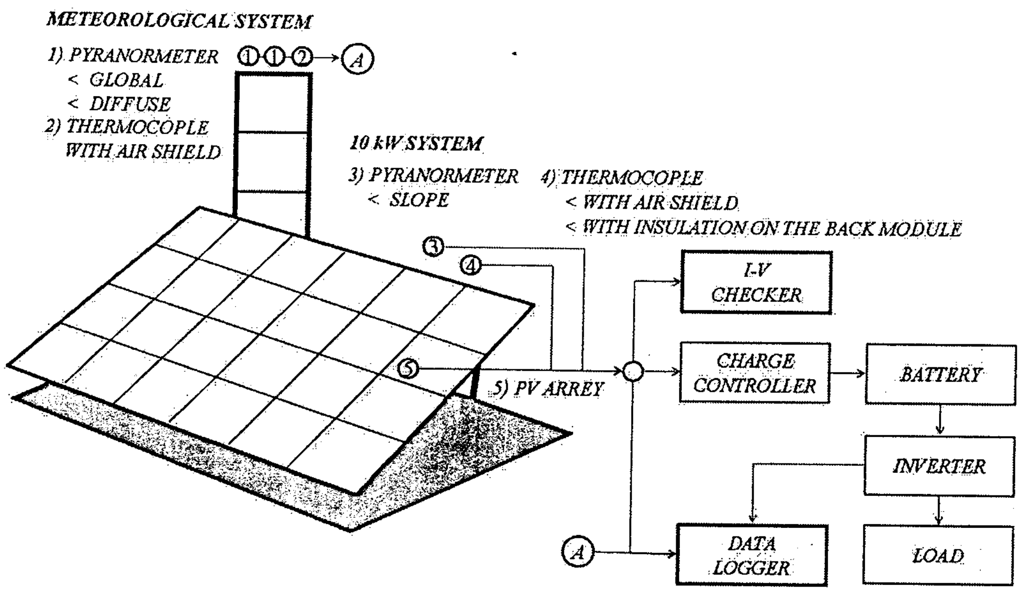


Figure 101 The relative factor of the power from SIPV system



Sensors	*Data collected*	*Logger*	*Data collected*
Global pyranormeter	E_G	*I-V checker*	E_{tS}, T_{amb}, T_m, I, V
Diffuse pyranormeter	E_d	*Data logger*	E_G, E_D, E_{tS}, T_{amb}, I, V
Slope pyranormeter	E_{tS}		
Thermocopple with air shield	T_{amb}		
Thermocopple with insulation	T_m		

Figure 102 The PV system at SERT

The parameters of solar radiation in part A (shown in Figure 102) were solar radiation and weather condition data collected by a data logger attached to sensors. These parameters include the following:

1.1 Module temperature (T_m)

Module temperature was used to study the effects of temperature on PV array efficiency in both cases of amorphous silicon technology and polycrystalline silicon technology and parameters were analyzed by regression analysis using least square curve fitting to be used in prediction in the form of linear curve as shown in Eq.104.

$$T_m = aX_1 + bX_2 + c \qquad Eq.104$$

The information recorded was from meteorological information about weather and solar radiation for a 10-kW electrical system, as shown in Figure 102.

1.2 PV efficiency case of full sky condition (η_{PV})

Electricity converted from solar radiation depends on PV system efficiency. The experiment was analyzed by regression equation and was used to predict the value by the linear curve equations shown in Eq.105. The information collected was from meteorological information about weather and solar radiation for a 10-kW electrical system, as shown in Figure 102.

$$\eta_{PV} = aX_1 + bX_2 + c \qquad Eq.105$$

1.3 PV efficiency case of half sky condition (η_{SIPV})

In this case, the PV module received some part of solar radiation while there is an existence of air temperature similar to the case of having no shade. This experiment, therefore, was to analyze the relation of current and volt via the relation between I-V curve and P-V curve at STC, at solar irradiance of 1,000 W/m^2 containing cell temperatures at 25°C and air mass at 1.5. Then it is managed to adjust the parameters of solar irradiance, ambient temperature, and module temperature which were predicted due to Eq.104 from the case of half sky condition to find the predicting equation from the trend line according to regression analysis as shown in Eq.106. The information collected was from meteorological information about weather and solar radiation for a 10-kW electrical system, as shown in Figure 102.

$$\eta_{SIPV} = aX_1 + bX_2 + c \qquad Eq.106$$

1.4 Efficiency of the inverter system (η_{inv})

The information on efficiency of inverter systems was from the research belonging to Tharika Bunpan [53]. Efficiency of the inverter system depending on solar irradiance leads to the process of building data analyzed via a linear curve regression equation to be used in prediction using linear curve regression analysis as presented in Eq. 107.

$$\eta_{inv} = aX + c \qquad Eq.107$$

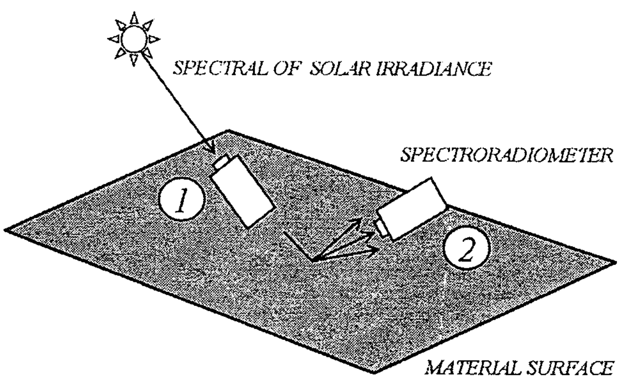
1.5 Efficiency of Power degradation for a long period (η_D)

It is considered from the guarantee of the production company leading to create a linear curve predicting equation as shown in Eq.108.

$$\eta_D = aX + c \qquad Eq. 108$$

1.6 Coefficient of solar reflectance (ρ)

Experimental materials tested included white wall and dark wall substitutes in order to cut out factors of reflection in unwanted directions as much as possible by measuring spectral solar irradiance, as shown in Figure 103, at wavelengths of 350-1050 nm. Spectroradiometer was used in record to find solar irradiance reflection from calculating the ratio of spectral solar irradiance reflecting from material skin to direct spectral solar irradiance averagely through wavelength.



The measurement of spectral irradiance, position of the meter against the surface being measured and slowly retract the meter to a position 10 centimeter.

Figure 103 The experiment of the reflectance value

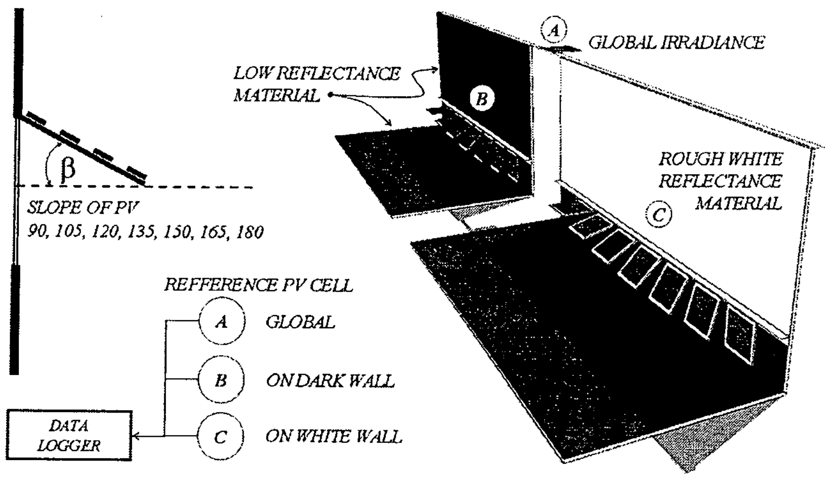
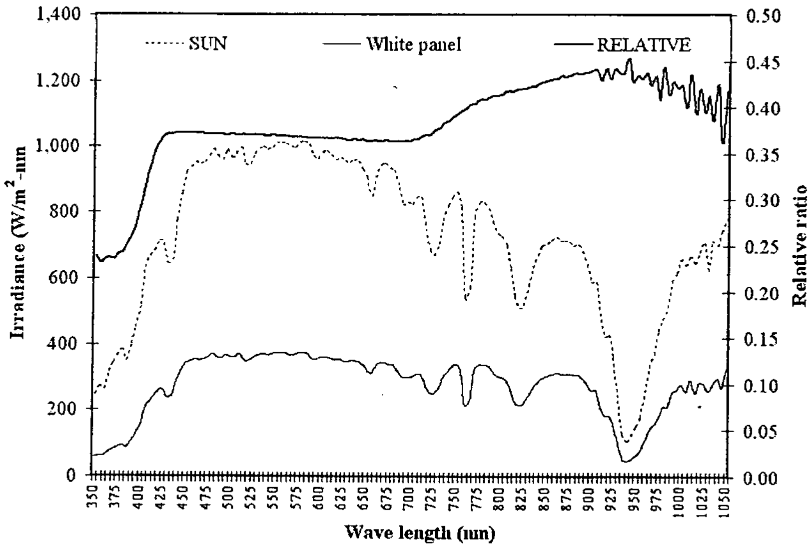


Figure 104 The experimental installation of the relative factors

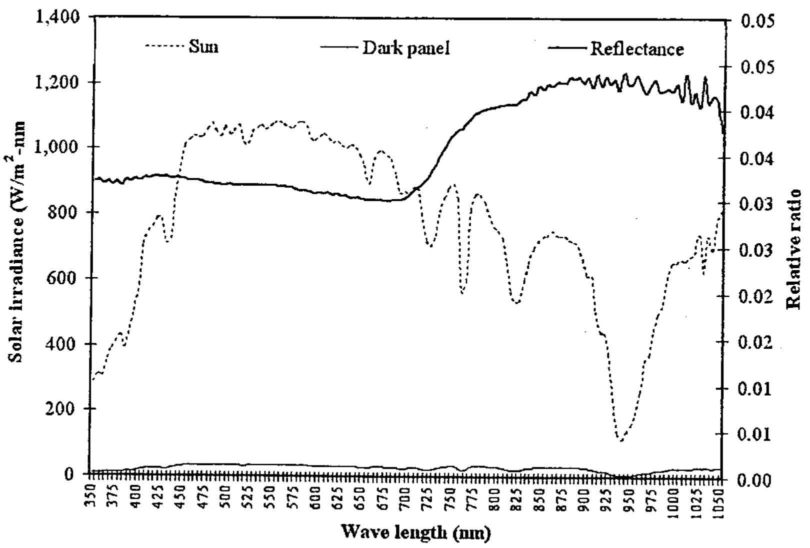
1.7 Relative diffuse radiation factor (R_d) and relative reflected radiation factor (R_{rB}) falling down on solar module

General building envelope can reflect solar radiation in the form of diffuse radiation reflection due to the rough envelope, unlike glass, resulting in an unclear direction of solar radiation and affecting visual comfort. In Thailand, buildings are controlled by the Building Control Act, B.E. 2522 (1979), assigning the reflection on the envelope of high-rise building or large building not more than 30%, as shown in Figure 105 (above) indicating spectral solar irradiance reflecting from a white wall, from which solar reflectance can be calculated equivalent to 38%. Figure 105 (below) indicates a dark wall, from which solar reflectance can be calculated equivalent to 4% throughout the wavelength of 350-1050 nm.

The installed experiment reflecting black low solar irradiance as shown in Figure 104 was to cut out factors of solar irradiance reflecting from the floor as much as possible leading to study only part of the solar irradiance from the sky. In the case of the white wall, it was used to compare influence as a result of reflection when compared to the dark wall with low solar reflectance. The experiment was installed at SERT, Naresuan University, Thailand for 2 consecutive weeks in February 2011.



White panel



Dark panel

Figure 105 The solar reflectance experiments of the white and dark panel

The equipment set was placed towards North and West in a period of no direct solar irradiance to collect only diffuse data. It was also placed towards West and South in case of direct solar irradiance appearance to collect data compared to reflectance of solar irradiance.

The relative diffuse radiation factor: R_d was to be calculated from the ratio of receiving diffuse solar irradiance on the reference cells with different tilt angles to the reference cells with tilt angles on a horizontal plane (or 0 degree) in the condition of half sky equivalent to 0.5 compared to full sky on the dark plane.

The relative reflected radiation factor: R_{rB} was calculated from the ratio of receiving solar irradiance reflected from the white wall on the reference cells with different tilt angles to the reference cells with different tilt angles located on the same angles on the dark plane and compared to reference cell with tilt angle of 90 degrees, equivalent to 1.0.

Both experiments were analyzed by calculating the average data change according to solar attitude and creating an equation to predict it. A regression equation was analyzed by least square curve fitting to be used in prediction via a linear curve as shown in Eq.109 and Eq.110 respectively.

$$R_d = m(X) + C \qquad Eq.\ 109$$

$$R_{rB} = m(X) + C \qquad Eq.\ 110$$

1.8 Relative diffuse radiation factor under self shading: (R_{sd})

For vertical self-shading SIPV installation, as shown in Figure 106, relative diffuse radiation was decreased by view angles opened towards the sky according to each case of installation with the outstretched part and distance between modules. Direct solar irradiance was also decreased due to shade of SIPV modules covering each other as shown in Figure 106, indicating that the reference cells installed on the dark vertical plane provided low levels of solar irradiance reflectance to reduce the influence of reflectance by using electric measurement in the form of mV, which is the ratio between covered lower module (B) and uncovered upper module (A) in every case of change in extended distance (W) and covered distance (S) under clear sky and overcast sky. This experiment was installed at the Faculty of Architecture, Chiang Mai University, Thailand from July to September 2011.

The experiment was analyzed by calculating average data change according to extended distance and covered distance between vertical modules to compare the decrease of diffuse solar irradiance in each design.

$$R_{sd} = mX + C \qquad \textit{Eq. 111}$$

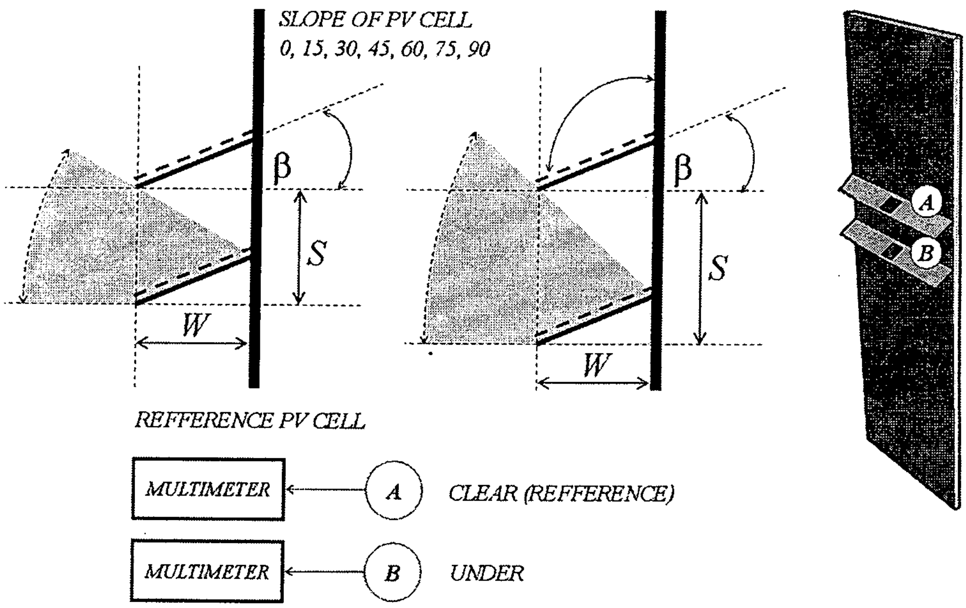


Figure 106 The relative factor of diffuse radiation under the SIPV

2. The daylight factor (DF)

The CIE sky model was used in calculation. The DF method was used in illuminance level estimation on the working plane in buildings and separated for consideration into 2 groups, namely the sky component: SC and internal reflected component: IRC without considering the external reflected component: ERC. Illuminance level on the working area inside the room is the sum total of SC and IRC, as shown in Figure 107. In addition, data collection was used to calculate the mean DF, as shown in Eq.112.

$$DF = C\text{; vary by distance of the dept of working space} \qquad \textit{Eq. 112}$$

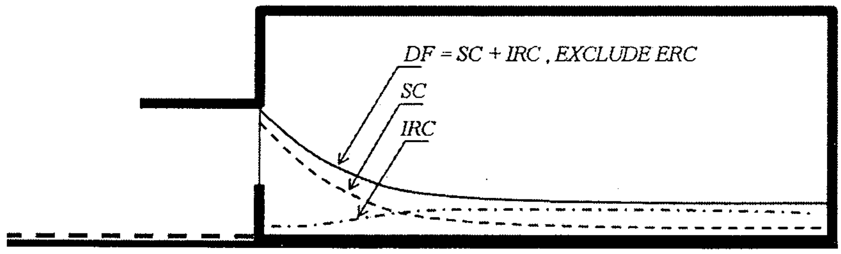


Figure 107 The combination of the daylight components

2.1 The sky component of the daylight factor (SC)

Influence from sky was shown in the form of SC. The experimental models were at the scale of 1:15 in measure of illuminance level at all levels of length shown in Figure 108 under clear sky and overcast sky. Inside wall models were painted black providing low solar irradiance reflectance to reduce the influence of IRC. In addition, illuminance levels in the buildings were measured and collected at all distances. It was also compared to the model's exterior in the case of having no covering and being under a band ring to confute the value gained from direct solar irradiance. The experiment was located at Faculty of Architecture, Chiang Mai University, Thailand from July to September 2011.

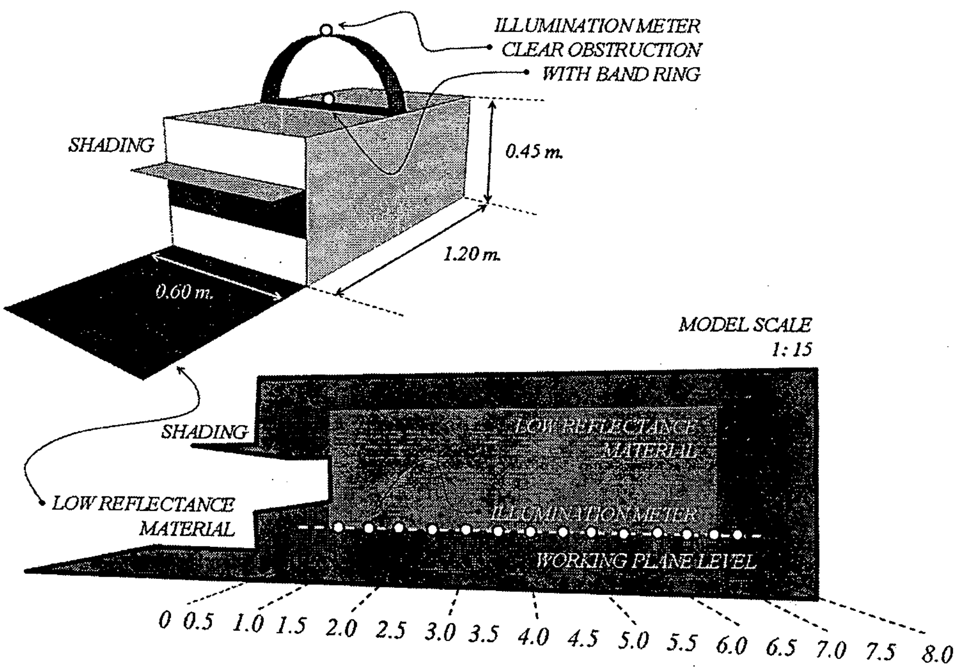


Figure 108 The sky component experiment

2.2 The internal reflected component of the daylight factor (IRC)

It is an experiment using a model at the scale of 1:20 which is smaller due to the limitation of the mirror box, the tool used for reproduction of an overcast sky, as shown in Figure 109. The model contains ceiling material, internal walls and flooring with reflectance ability at 70%, 50% and 20%, respectively. The experiment was kept in a laboratory at the Faculty of Architecture, Chiang Mai University, Thailand.

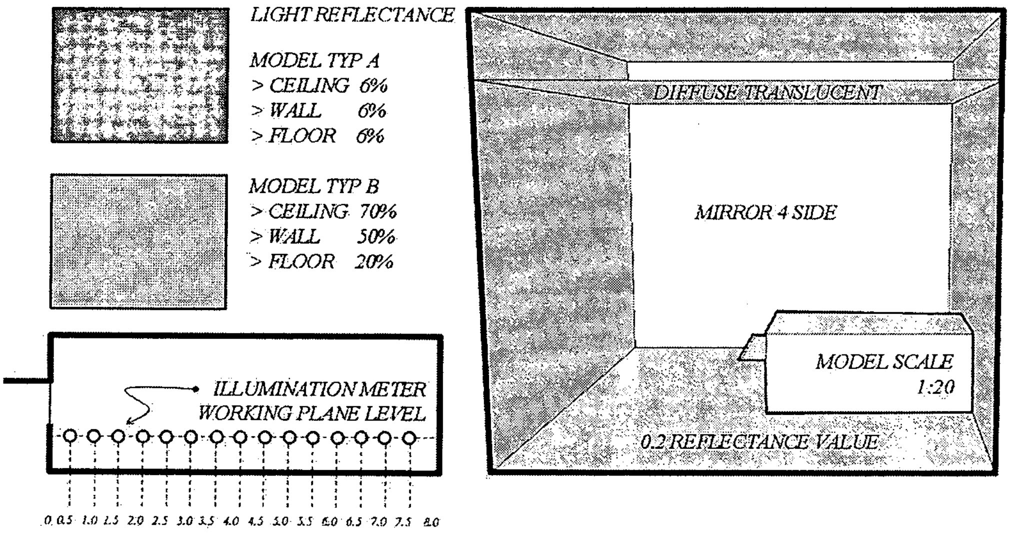


Figure 109 The internal reflected component experiment

3. The shading coefficient of the diffuse radiation (SC_d)

The W/H ratio of SIPV can prevent direct solar irradiance, which is related to Cosine's law and some part of diffuse irradiance using view factors. SIPV in this study was determined to have fully prevented direct solar irradiance. Therefore, the experiment was a study of SC_d only.

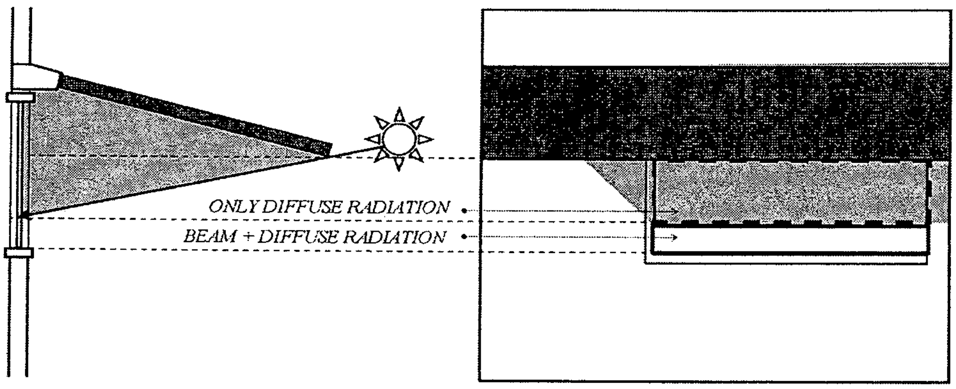


Figure 110 The shading effect from the beam and the sky

The model shown in Figure 111 was used in an experiment to compare forms of shading devices with ratios of W/H installed on the dark wall and dark floor providing low solar irradiance reflectance to eliminate influence of reflected irradiance as much as possible. Collected data from the reference cells was compared as a ratio of being under the shading device to having no shading device. The experiment was located at SERT, Naresuan University, Thailand for two consecutive weeks constantly in February 2011. An equation was created for prediction through analyzing the regression equation using least square curve fitting, which was used in linear curve prediction, as shown in Eq.113.

$$SC_d = m(W/H) + C \qquad \text{Eq. 113}$$

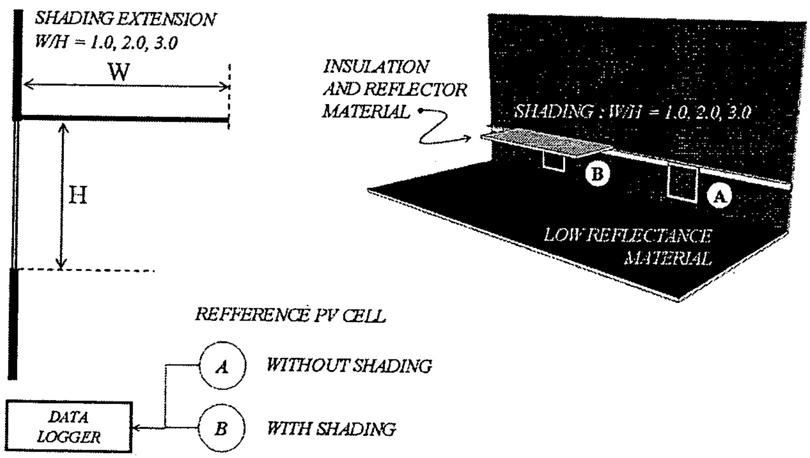


Figure 111 The Shading Coefficient of the diffuse radiation experiment

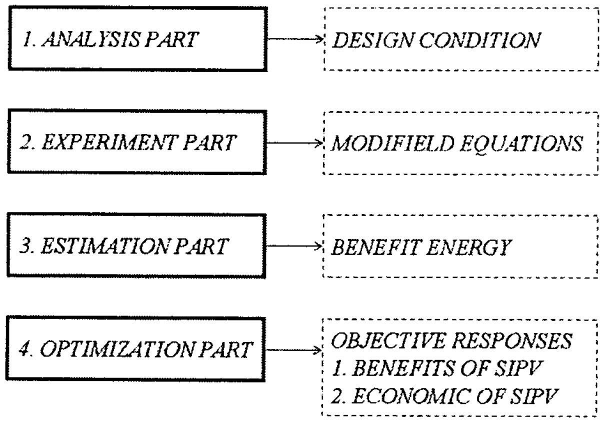


Figure 112 Summary of the study process

Summary of the study process

The study process can be divided into 4 parts as follows:

1. The analysis part is to search for condition of SIPV design and database concerning weather and solar radiation

2. The experiment part is to determine and study parameter by improving every factors used in calculation of energy of air conditioning system, lighting system and energy generation system

3. The estimation part is to estimate annual energy consumption in every system

4. The optimization part is to prove objectives from study in order to design proper SIPV system