GRID-CONNECTED PV SYSTEMS
SYSTEM DESIGN GUIDELINES
for Accredited Designers

SITE VISIT

Prior to designing any Grid Connected PV system an accredited designer shall either visit the site or arrange for a work colleague to visit the site and undertake/determine/obtain the following:

1. Discuss energy efficient initiatives that could be implemented by the site owner. These could include:
   - replacing inefficient electrical appliances with new energy efficient electrical appliances
   - replacing off-peak electric hot water heaters with a solar water heater either gas or electric boosted.(If applicable)
   - replacing incandescent light bulbs with compact fluorescents
2. Assess the occupational safety and health risks when working on that particular site.
3. Determine the solar access for the site.
4. Determine whether any shading will occur and estimate its effect on the system.
5. Determine the orientation and tilt angle of the roof where the solar array will be mounted.
6. Determine the available area for the solar array.
7. Determine whether the roof is suitable for mounting the array.
8. Determine how the modules will be mounted on the roof.
9. Determine where the inverter, will be located.
10. Determine the cabling route and therefore estimate the lengths of the cable runs.
11. Determine whether monitoring panels or screens are required and determine a suitable location with the owner

Following the site visit the designers shall estimate the available solar irradiation for the array based on the Australian Solar Radiation Data Handbook and the tilt, orientation and effect of any shadows

QUOTATION DOCUMENTATION

When providing a quotation to a potential customer, the accredited designer should provide [as a minimum] the following information

- Full specifications of the system including quantity, make (manufacturer) and model number of the solar modules and inverter.
- An estimate of the yearly energy output of the system. This should be based on the available solar irradiation for the tilt angle and orientation of the array. If the array will be shaded at any time the effect of the shadows must be taken into account when determining the yearly energy output.
- The dollar savings this represents based on existing electrical energy pricing
- A firm quotation which includes all equipment and installation charges
- Warranty information relating to each of the items of equipment

If possible the savings in CO_2 (either tonnes or kg) could also be provided.

STANDARDS for DESIGN and INSTALLATION

The main standards required are …

AS/NZS 3000	Wiring Rules
AS/NZS 3008	Selection of Cables
AS 4777	Grid Connection of energy systems by inverters
AS/NZS 5033	Installation of PV Arrays
AS 4509	Stand-alone power systems NOTE some aspects of these standards are relevant to grid connect systems.
AS 3595	Energy management programs
AS 1768	Lightning Protection

SYSTEM DESIGN STEPS

The design of a PV grid-connect system requires a number of steps. A basic design method follows:

1. Determining the main design criteria
2. Obtaining relevant information based on critical design criteria.
3. Determining the size of the PV Array
4. Determining the size of the inverter
5. Determining the size of the interconnection cables to minimise system losses

SYSTEM DESIGN CRITERIA

A PV Grid-connect system will, in general, be designed in accordance with one of the following limiting design criteria:

6. Designed to meet yearly energy usage
7. Designed to meet maximum grant available
8. Designed to fit on available roof space
9. Designed to meet a budget

At times the design will be limited by two or more of the criteria and the final size of the PV array and therefore the inverter required will be dependent on which is the dominant limiting criteria.

In particular when designing a system to meet a budget or to meet the yearly energy usage, the final PV array must fit on the available roof space.

PV ARRAY SIZING

1. DESIGNED TO MEET YEARLY ENERGY USAGE

STEP ONE:
Determine the existing yearly energy usage

Obtain from the customer copies of their most recent electricity accounts. As a minimum, obtain records of their last 12 months and if possible obtain records for the last few years.

If the customer does not have 12 months records, they should request this information from their electricity retailer.

Use these records to estimate the average yearly energy usage in kWh.
If the house is new, then initially obtain records on their previous house (if applicable) and also conduct a full load assessment similar to that undertaken when designing an SPS design
refer to the SPS Design guidelines AS 4509.2

STEP TWO: Allowing for changes

If your energy audit recommended changes and these will be implemented, estimate the reduction these changes will have on yearly energy usage.

Discuss with customer what additional loads might be added to the house/building/site in the near future.

STEP THREE:
Estimated average yearly energy usage

From the information obtained in steps one and two, determine the average yearly energy usage which will be used to design the system.

STEP FOUR: Determining the size of the array

The size of the PV array should be selected to take account of:

- Inverter efficiency
- System losses (eg power loss in cable)
- Average solar radiation data for selected tilt angle and orientation
- Manufacturing tolerance of modules
- Temperature effects
- Effects of dirt on the modules

Solar radiation data is available from various sources, such as the Australian Radiation Data Handbook (from ANZSES or the Meteorological Bureau) The units used are often MJ/m²/day.
To convert to kWh/m²/day (PSH) divide by 3.6.

Note: PV grid-connect systems are typically mounted on the roof of the house or building The roof might not be facing true north or at the optimum tilt angle. The PSH figure for the roof orientation (azimuth) and pitch (tilt angle) shall be used when undertaking the design.

DAILY ENERGY REQUIREMENT FROM THE PV ARRAY

It is necessary to increase the energy required from the PV array to account for inverter efficiency and system losses, and still meet the average daily energy use.

The inverter efficiency should be obtained from the manufacturer and typically will vary between 90% and 96% (when inverter is above 10% of its rating).
If it is not known, we recommend that you use 92%. This figure takes into account the efficiency of the Maximum Power Point Tracking MPPT facility which is part of the inverter.

As an example lets assume the estimated yearly energy usage is 3285 kWh.
The average daily energy usage is ….

$$3285 \text{ kWh} \div 365 = 9\text{kWh}$$

This is the energy usage required from the PV Array at the A.C. switchboard.

Since the inverter includes an MPPT any voltage drop that occurs between the inverter and the switchboard and PV Array and the inverter will be reflected as a loss in power from the array and the energy from the array must allow for this loss.

This loss should therefore be as small as possible but the maximum allowable is 5%.

The daily energy required from the array shall allow for inverter efficiency (assume 90%) and the cable losses (assume 5%) . Using our example the daily energy requirement is …

$$9\text{kWh} \div 0.92 \div 0.95 = 10.3\text{kWh}$$

For the worked example, assume the yearly average solar radiation at the site is 5.12 PSH
e.g. Sydney at tilt angle 20 degrees

To size the PV array to provide the daily energy required …

The peak power required from the PV array is

$$10.3\text{kWh} \div 5.12 \text{ PSH} = 2.01 \text{ kW}$$

DE-RATING MODULE PERFORMANCE

1. Manufacturers Output Tolerance

The output of a PV module is specified in watts, with a manufacturing tolerance of (normally) ±5% and is based on a cell temperature of 25 degrees C The “worst case” adjusted output of a typical 160W PV module is therefore around 152W, or 5% loss from the rated 152W.
De-rating for 1 gives 152W

2. De-rating due to Soiling (Dirt)

The output of a PV module can be reduced as a result of a build up of dirt on the surface of the module. The actual value of this derating will be dependent on the actual location but in some city locations this could be high due to the amount of pollution in the air.
If in doubt, an acceptable derating would be 5% from the already derated figure of 152W
De-rating then for 1 and 2 gives **144.4W**.

3. De-rating Due to Temperature
In accordance with AS4059.2 the average temperature of the cell within the PV module can be estimated by the following formula:

$$T_{cell.eff} = T_{a.day} + 25$$

where
$T_{cell.eff}$ = average daily effective cell temperature, in degrees C
$T_{a.day}$ = daytime average ambient temperature (for the month of interest), in degrees C

The three different solar modules currently available on the market each have different temperature coefficients. These are:

A) Monocrystalline Modules
Monocrystalline Modules typically have a temperature coefficient of –0.45%/^{o}C. That is for every degree above 25^{o}C the output power is derated by 0.45%

B) Polycrystalline Modules
Polycrystalline Modules typically have a temperature coefficient of –0.5%/^{o}C.

C) Amorphous Modules
These types of modules have a different temperature characteristic, resulting in a lower coefficient , typically around - 0.2%/degree C.

NOTE: Some amorphous modules have found to have a zero value. Check with the manufacturer.

The de-rating of the array due to temperature will be dependent on the type of module installed and the average ambient maximum temperature for the location.

The temperature de-rating factors is calculated as follows:

$f_{temp} = 1 - (\gamma \times (T_{cell.eff\ y} - T_{stc}))$

where

f_{temp}	=	temperature de-rating factor, dimensionless
γ	=	absolute value of power temperature co-efficient per degree Celsius (see above)
$T_{cell.eff}$	=	average daily cell temperature, in degrees Celsius
T_{stc}	=	cell temperature at Standard Test Conditions, in degrees Celsius.

Note: The absolute value of temperature is applied – the formula determines whether the temperature factor is greater or less than 1 due to actual effective temperature of the cell.,

For the worked example, assume the average ambient temperature is 25 ° C ($T_{a.day}$) and the module is polycrystalline.

The average daily effective cell temperature is:

$$T_{cell.eff} = T_{a.day} + 25 = 25 + 25 = 50$$

In the above formula the absolute value of the temperature coefficient [γ] is applied, this is 0.5%/°C and cell temperature at Standard Test Conditions is 25 ° C [T_{stc})]

Therefore the effective derating factor due to temperature is:

1 - (50 – 25) x 0.5% = 1 -12.5% =0.875

The de-rating then for 1,2 and 3 above is 87.5% of 144.4 W, = **126.3 Watts**

MINIMUM ARRAY SIZE

The number of modules required in the array = the peak power required by the array *divided by* the adjusted output of the PV module

In the worked example,
the number of 160W modules required is

2.01kW ÷ 126.3 W ≅ 15.9

always round up to the next full module
i.e. 16 in this case

The 16 modules
will provide an array with a peak rating of

16 x 160W = **2.56 kW**

FINAL ARRAY CONFIGURATION

The array must be matched to the voltage window of the inverter and therefore the final array configuration will be dependent on the inverter selected and the allowable operating voltage window.

MATCHING ARRAY TO VOLTAGE WINDOW OF INVERTERS

The output power of a solar module is affected by the temperature of the solar cells.
In crystalline PV modules this effect can be as much as 0.5% for every degree centigrade variation in temperature.

for other PV cell technologies the manufacturers data must be used

The temperature de-rating factor for the output power is defined in AS 4509.2 equation 3.4.3.9(1)

$$f_{temp} = 1 - \left[\gamma \times \left(T_{cell\_eff} - T_{STC}\right)\right]$$

where

f_{temp}	=	temperature de-rating factor, dimensionless
γ	=	power temperature co-efficient per °C (typically 0.005 for crystalline cells)
$T_{cell.eff}$	=	average daily cell temperature, in °C
T_{stc}	=	cell temperature at Standard Test Conditions, measured in °C.

The maximum power point voltage and open circuit voltage are affected by temperature and the temperature co-efficient as a % is typically very similar to the power coefficient.

The - maximum - effective cell temperature
(AS 4509.2 equation 3.3.4.7)

$$T_{cell\_eff} = T_{ave\_amb} + 25^0\text{C}$$

where
T_{cell_eff} = the effective cell temperature in °C
T_{ave_amb} = the daytime ambient temperature in °C

So formula 3.4.3.9 (1) can also be applied to as the de-rating factor for open circuit voltage and maximum power point voltage.

With the odd exception (e.g. inverters that also connect with batteries) grid interactive inverters include Maximum Power Point (MPP) trackers.

Many of the inverters available will have a voltage operating window. If the solar voltage is outside this window the inverter will not operate and in the case where a maximum input voltage is specified and the array voltage is above the maximum specified then the inverter could be damaged.

Minimum and maximum input voltages will be specified by the manufacturer. The maximum voltage is the voltage where, above this, the inverter could be damaged. Some inverters will nominate a voltage window where they will operate and then a maximum voltage, higher than the maximum operating voltage of the window, which is the voltage where the inverter could be damaged.
It is critical that the output voltage of the solar array is matched to the operating voltages of the inverter and that the maximum voltage of the inverter is never reached.

As stated earlier the output voltage of a module is effected by cell temperature changes in a similar way as the output power. The PV module manufacturers will provide a voltage temperature co-efficient.
It is generally specified in V/°C (or mV/°C) but it can be expressed as a % of Voc.

To ensure that the output voltages of the array do not fall outside the range of the inverter's d.c. input operating voltages, the minimum and maximum day time temperatures for that specific site are required.

When the temperature is at a maximum then the maximum power point voltage (Vmp) of the array must never fall below the minimum operating voltage of the inverter. The actual voltage at the input of the inverter is not just the Vmp of the array, the voltage drop in the d.c. cabling must also be included when determining the actual inverter input voltage.
Formula 3.4.3.9 (1) can be adapted to determine the maximum power point voltage at a specified temperature …

$$V_{mp\_cell\_eff} = V_{mp\_STC} - \left[\gamma_v \times \left(T_{cell\_eff} - T_{STC}\right)\right]$$

where
$V_{mp\_cell.eff}$ = Maximum Power Point Voltage at effective cell temperature, volts
$V_{mp\text{-}stc}$ = Maximum Power Point Voltage at STC, volts
γ_v = voltage temperature co-efficient , V per °C
T_{cell_eff} = cell temperature at specified temperature, in °C
T_{stc} = cell temperature at STC, measured in °C

Though formula 3.3.4.7 defines the effective cell temperature - it is important that the array voltage never falls below the minimum inverter specification. The number of modules in the string must be selected to ensure that the maximum power voltage is determined for the highest temperature ever selected.
The daytime ambient temperature in many areas of Australia can reach, or exceed 45°C.
In these cases, a maximum effective cell temperature of 70°C should be used.

MINIMUM VOLTAGE

As an example , assume that the minimum voltage window for an inverter is 140V.
The module selected has a rated MPP voltage of 35.4V and a voltage co-efficient of 0.14V /°C
Using equation for $V_{mp\_cell.eff}$ above the minimum MPP voltage at maximum effective cell temperature of 70°C the temperature de-rating is

V_{min_mpp} = 35.4 - (0.14 × (70- 25)) = 29.1 V

If we assume a maximum voltage drop in the cables of 5% then the voltage at the inverter for each module would be

0.95 x 29.1 = 27.6 V

This is the effective minimum MPP voltage input at the inverter, $V_{min\_mpp\_inv}$

The minimum number of modules in the string can be determined by the following equation

$$N_{\min\_per\_string} = \frac{V_{inv\_\min}\ (\mathrm{V})}{V_{\min\_mpp\_inv}\ (\mathrm{V})}$$

where

V_{inv_min} = the minimum inverter input voltage
$V_{min\_mpp\_inv}$ = the effective minimum MPP voltage of a module at the inverter at maximum effective cell temperature

The minimum voltage allowed at the inverter, in this example, is 140V. The MPP voltage rises with increases in irradiance. Since the array is typically operating with irradiance levels less than 1kW/m² then the actual MPP voltage would be reduced

- the exact variation is dependent on the quality of the solar cell so it is recommended that a safety margin of 10% is used.

In the example above a minimum inverter voltage of

1.1 x 140V = 154V should be used

The minimum number of modules in a string is

$N_{min\_per\_string}$ = 154 / 27.6 = 5.6
rounded up to 6 modules

MAXIMUM VOLTAGE

At the coldest daytime temperature the open circuit voltage of the array must never be greater than the maximum allowed input voltage for the inverter. The Open Circuit voltage (Voc) is used because this is greater than the MPP voltage and it is the applied voltage when the system is first connected - prior to the inverter starting to operate and connecting to the grid.

NOTE
Some inverters provide a maximum voltage for operation and a higher voltage as the maximum allowed voltage. In this situation the MPP Voltage is used for the operation window and the open circuit voltage for the maximum allowed voltage

In early morning, at first light, the cell temperature will be very close to the ambient temperature because the sun has not had time to heat up the module.

NOTE : AS 4509.2 equation 3.3.4.7 does not apply

Therefore the lowest daytime temperature for the area where the system is installed shall be used to determine the maximum Voc.

This is determined by the following equation

$$V_{\max\_oc} = V_{oc\_STC} - \left[\gamma_v \times \left(T_{\min} - T_{STC}\right)\right]$$

where

V_{max_oc} = Open Circuit Voltage at minimum cell temperature , volts
V_{oc_STC} = Open Circuit Voltage at STC , volts
γ_v = voltage temperature co-efficient , V/°C
T_{min} = expected min. daily cell temperature, °C
T_{STC} = cell temperature STC, °C

In many areas of Australia the minimum daytime ambient temperature can reach 0°C.
In some areas of Australia can fall below this.

In our worked example, lets assume the minimum effective cell temperature is 0°C,

$V_{oc\text{-}stc}$ is 43.2 V and the maximum open circuit voltage - at minimum effective temperature – is

V_{oc_max} = 43.2 - (0.14 × (0 - 25))
= 43.26 - (0.14 x -25)
= 43.2 + 3.5
= 46.7 V

For our example, assuming the maximum voltage allowed by the inverter is 400V (V_{inv_max})

The maximum number of modules in the string, $N_{max\_per\_string}$, is determined by the following equation

$$N_{\max\_per\_string} = \frac{V_{inv\_\max}\ (\mathrm{V})}{V_{oc\_\max}\ (\mathrm{V})}$$

= 400 / 46.7 = 8.56
rounded down to 8 modules

In the example presented the PV string must consist of between 6 -8 modules only.

In our previous worked example then we required 16 modules. Therefore we could have two parallel strings of 8 modules.

It is important that the number of modules in a string is selected to ensure that the output voltage of the array is always within the voltage operating window of the inverter.

The above formulae can be used to determine the effect of temperature but it is necessary that the maximum and minimum daytime temperatures for the installation site are used

EFFECT OF SHADOWS

In towns and cities where grid connect systems will be predominant the roof of the house or building will not always be free of shadows during parts of the day. Care should therefore be taken when selecting the number of modules there are in a string.
Having modules in smaller string configurations could increase the output of the whole system when shadows are a problem.
In addition, if designing a system to meet the total energy demand this must be taken into account when selecting the PSH figure that is used in the design.

EFFECT OF ORIENTATION AND TILT

When the roof is not orientated true north and/or not at the optimum inclination the output from the array will be less than the maximum possible.

Included with this guide are tables showing the average annual daily total irradiation, for various orientations and tilt angles, represented as a percentage of the maximum value.

The tables provide values for a plane in 360 different orientations (azimuth) and inclination (tilt) angles. The orientations and inclinations are varied in increments of 10°. These tables have been derived from The Australian Radiation Data Handbook (Table 5.13)

These tables provide the system designer/installer with information on the expected output of a system (% of the maximum possible output) when it is located on a roof that is not facing the true north (± 5°) at an inclination equal to the latitude angle.

Tables have been provided for the following locations

Hobart	Brisbane	Darwin
Melbourne	Cairns	Perth
Canberra	Adelaide	
Sydney	Alice Springs	

EFFECT OF CUSTOMERS PURCHASING AGREEMENT WITH ELECTRICITY SUPPLIER

In designing the system based on the average solar radiation then there will be some months of the year when the output from the PV grid connect system would be greater than the energy usage and other months when the output would be less than the energy usage. So though the system should meet the typical average yearly energy usage this will not occur during each billing period
Therefore, though the system is designed such that the energy produced over the year equals their previous usage, whether the customer's energy bill is zero depends on the purchase agreement.

A table showing the expected output of the system each month, with respect to monthly average energy usage, would be beneficial to the customer. Using the example, the following table shows the monthly energy outputs of the system compared with the average monthly energy usage, shown below

Month	Avg Monthly energy use	Avg Monthly system output	Difference
January	279	399.52	120.52
February	252	314.25	62.25
March	279	339.59	60.59
April	270	254.53	-15.47
May	279	218.07	-60.93
June	270	199.76	-70.24
July	279	198.09	-80.91
August	279	263.02	-15.98
September	270	301.25	31.25
October	279	349.58	70.58
November	270	364.08	94.08
December	279	411.17	132.17
TOTALS	**3285**	**3612.90**	**327.9**

Note:
The excess at the end of year is due to the extra module being installed when rounding up to determine the number of parallel strings.

2. DESIGNED TO SUIT MAXIMUM REBATE

Rebates are generally based on a nominated $ per watt to a maximum installed wattage. Therefore in this situation the designers must assure the array will fit on the roof * see 3 below and then determine the actual energy output from the system for the actual site.

STEP ONE: Determining the output of the PV Array

The average energy output of the PV array can be calculated by the following formula:

$$E_{array} = P_{stc} \times f_{man} \times f_{temp} \times f_{dirt} \times H_{tilt} \times N$$

where

E_{array} = average daily energy output of the PV array, in watt-hours

P_{stc} = rated output power of the module under Standard Test Conditions, in watts

f_{temp} = temperature de-rating factor, dimensionless

f_{man} = de-rating factor for manufacturing tolerance, dimensionless

f_{dirt} = de-rating factor for dirt, dimensionless

H_{tilt} = irradiation, in peak sun hours for the specified orientation and tilt angle
Note: for stand alone systems this is typically daily but for grid connect systems it can be the yearly figure, in PSH 1 PSH = 1 kWh/m^2

N = number of modules in the array

The above formula can be used to determine the average daily energy output each month, where the monthly peak sun hours is applied or the yearly average daily output where the yearly peak sun hour figure is applied.

Further explanations of all these factors is contained in the previous section "Determining the size of the array" for systems designed to meet annual energy usage.

Note:
Peak Sun Hours (PSH) is the number of hours with solar irradiation equal to 1kW/m^2 1 PSH = 1 kWh/m^2

STEP TWO: Determining the output of the PV Grid Connect System

The energy that is delivered to the grid and/or loads within the building is the measured usable energy of a PV grid connect system.

The output energy from the array is de-rated by the inverter efficiency and the losses in the cables between the array and inverter and inverter and switchboard.

The inverter efficiency should be obtained from the manufacturer and typically will vary between 90% and 96% (when inverter is above 10% of its rating)
If it is not known we recommend that you use 92%. This figure takes into account the efficiency of the Maximum Power Point Tracking (MPPT) facility which is part of the inverter.
Where the inverter manufacturer quotes a 'euro-efficiency' this figure should be used as it takes account of the inverter performance over a range of operating conditions

Since the inverter includes an MPPT any voltage drop that occurs between the inverter and the switchboard and PV Array and the inverter will be reflected as a loss in power from the array and the energy from the array must allow for this loss. This loss should therefore be a small as possible but the maximum allowable is 5%.

The energy delivered to the grid by the PV grid connect system is:

$$E_{system} = E_{array} \times \eta_{inv} \times L_s$$

where

E_{system} = average daily Energy output of the PV grid system

E_{array} = average daily energy output of the PV array, in watt-hours

η_{inv} = efficiency of the inverter, dimensionless

L_s = losses in the system cabling, dimensionless

Note :
The "Effect of Shadows" and "The Effect of Orientation and Tilt" as detailed in the previous section is also applicable in this case.

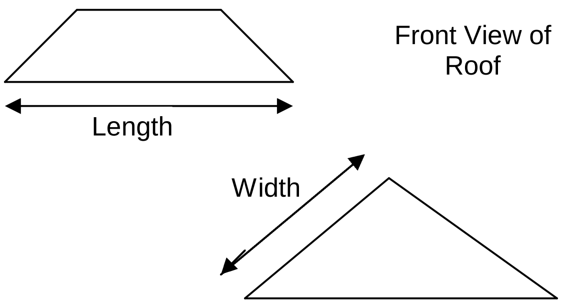
3 .DESIGNED TO FIT ON AVAILABLE ROOF SPACE

STEP ONE: Measure the available roof space

During the site visit either measure the actual available roof space and/or obtain a set of plans from the customer.

Determine the area in square metres that is suitable for the array such that it has minimal - preferably no - effect from any shadows.

In this guideline we will define the distance between the gutter of the roof and the ridge as the width and the length across the roof as the length, that is:



Side View of Roof

Record the actual dimensions of this area in length and width in metres

STEP TWO: Determine the ideal maximum number of modules that can fit on the available roof space

Select the solar module or laminate that will be used in the system design.

Using the manufacturers specifications note the length and width of the module and calculate its total area.

If the installation method allows for a gap between the modules add this to the module dimensions and calculate the effective area of each module installed.

The maximum number of modules that can be installed
= available roof area ÷
effective area of module installed.

For our worked example you will use an 160 watt module which has the dimensions 790mm wide and 1593mm in length. This has an effective area of

$0.790\text{m} \times 1.593\text{m} = 1.26\ \text{m}^2$.

Assume your typical framing system has a gap of 10mm between modules, therefore the effective dimensions of you module installed are 800mm wide and 1603mm in length with an effective area of

$0.800\text{m} \times 1.603\text{m} = 1.28\ \text{m}^2$

In this worked example you have measured the available roof space as 8 metres long and 3.5 metres wide. This has an effective area of

$8\text{m} \times 3.5\text{m} = 28\ \text{m}^2$

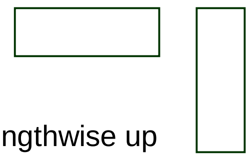
The maximum number of modules that can be installed in this area

$= 28\ \text{m}^2 \div 1.28\ \text{m}^2$ per module
= 21.8 modules

STEP THREE: Determine the maximum number of modules that can fit on the available roof space

The actual maximum number of modules that can be installed will be the larger of the number of modules that can be installed in any configuration on the roof.

A module has two fixed dimensions, length and width, and in general modules are in a rectangular shape. The modules could then be installed in an area either mounted lengthwise across,



or lengthwise up

In any available roof space these two installations methods must be compared to determine the actual maximum number of modules that can fit in the available area.

INSTALLATION LENGTHWISE ACROSS

The number of modules that can be installed "up " the roof = Width of Roof ÷ Width of Module

In our worked example:
The number of modules that can be installed "up " the roof = 3.5m ÷ 0.8m = 4.37 i.e. 4 modules (always round down).
The number of modules that can be installed "across " the roof
= Length of Roof ÷ Length of Module

In our worked example:
The number of modules that can be installed "across " the roof = 8m ÷ 1.603m = 4.99 i.e. 4
[possibly in this case the 5 could be squeezed on]

Therefore, the maximum number of modules that can be installed with the modules mounted lengthwise across the roof = 4 x 4 = 16 (maybe 20)

INSTALLATION LENGTHWISE UP

The number of modules that can be installed "up " the roof = Width of Roof ÷ Length of Module

In our worked example:
The number of modules that can be installed "up " the roof = 3.5m ÷ 1.603m = 2.18 i.e 2 modules (always round down)
The number of modules that can be installed "across " the roof
= Length of Roof ÷ Width of Module

In our worked example:
The number of modules that can be installed "across " the roof = 8m ÷ 0.800m = 10

Therefore, the maximum number of modules that can be installed with the modules mounted lengthwise up the roof = 2 x 10 = 20

The actual maximum number of modules that can be installed will be the larger of the number of modules that can be installed lengthwise across the roof compared with length wise up the roof.

In the worked example it was 20 modules.

STEP FOUR: Determine the string configuration and therefore the number of modules that **will** be installed in the available roof space

The final array configuration will be dependent on the inverter chosen.

After selecting the inverter and determining the number of modules allowed in the string the number of parallel strings is calculated as follows:

Number of parallel strings = the actual maximum number of modules that can fit on roof space ÷ number of modules in each string.

Note:
This number will be rounded down because the actual maximum number of modules is the limiting factor.

For our worked example lets say the inverter allows a string of 10 modules therefore :

The number of parallel strings = 20 ÷ 10 = 2

The number of modules that **will** be installed on the roof = number of parallel strings x number of modules in each string

In the worked example the number of modules that will be installed = 2 x 10 = 20

STEP FIVE: Determining the output of the PV Array

The average daily energy output of the PV array can be calculated by the following formula:

$$E_{array} = P_{stc} \times f_{man} \times f_{temp} \times f_{dirt} \times H_{tilt} \times N$$

Full explanation of this formula is provided in section 2 Designed to suit maximum rebate - Step One.

In the worked example we will use the yearly figure and the following values for all the factors

P_{stc} = 160W
f_{temp} = 0.875 (assuming ambient temperature is 25°C)
f_{man} = 0.95
f_{dirt} = 0.95
H_{tilt} = 5.12 (yearly average hours)
N = *20*

The average daily energy output of the PV array
= 160 × 0.95 x × 0.875 × 0.95 × 5.12 × 20
= 12,938 watt hrs

Note: The above formula is based on the selected inverter incorporating a MPPT.

STEP SIX: Determining the output of the PV Grid Connect System

The energy delivered to the grid by the PV grid connect system is:

$$E_{system} = E_{array} \times \eta_{inv} \times L_s$$

See section 2 - Designed to suit maximum rebate - Step One.

In the worked example

η_{inv} = 0.92
L_s = 0.95

The energy delivered to the grid by the PV grid connect system
= 12938 watt hrs x 0.90 x 0.95
= 11,307 watt hrs = 11.3 kWh

Note:
The "Effect of Shadows" and
"The Effect of Orientation and Tilt" as detailed in the previous section is also applicable in this case.

4. DESIGNED TO MEET A BUDGET

STEP ONE: Determine the size of the array

The customer's specified budget must allow for

- The PV array
- The inverter
- The installation of the array, inverter and associated cabling, switches, circuit breakers, signage and other ancillary equipment.
- Any fees that are incurred when connecting to the grid
  e.g. cost of meter, cost of inspection, etc

To determine the final size of the array, undertake a number of system configurations and determine the corresponding cost of equipment and installation until a suitable system is selected.

This design will determine the size of the array.

STEP TWO: Determine the output of the PV array

Refer to Step One
section 2 -Designed to suit maximum rebate.

STEP THREE: Determine the output of the PV Grid Connect System

Refer to Step Two
section 2 -Designed to suit maximum rebate.

Note:
The "Effect of Shadows" and
"The Effect of Orientation and Tilt" as detailed in the previous section is also applicable in this case.

INVERTER SELECTION

The selection of the inverter for the installation will depend on

- The energy output of the array
- The potential for an increase in the size of the array in the future
- The matching of the allowable inverter string configurations with the array power in kW and the voltage ratings - Vmp and Voc - of the individual modules within the array
- Whether the system will have one central inverter or multiple (smaller) inverters

WHY MULTIPLE INVERTERS?

1. If the array is spread over a number of roofs that have different orientations and tilt angles then the maximum power points and output currents will vary from roof to roof. If economic, installing a seperate inverter for each section of the array which has the same orientation and angle will maximise the output the total array.
2. Multiple inverters allow a portion of the system to continue to operate if one inverter fails.
3. Allows the system to be modular, so that increasing the system involves the adding a predetermined number of modules with one inverter.

The potential disadvantage of multiple inverters is that in general, the cost of a number of inverters with lower power ratings is generally more expensive than one single inverter with a higher power rating.

ALLOWING THE SYSTEM TO GROW

If one central inverter is installed, clarify with the customer whether they will want to install extra modules in the future. If so, then the inverter should be sized to allow for this growth
(generally a maximum of 20%
- any more may move the inverter into a less efficient mode, and the move is counter-productive).

INVERTER SIZING

Inverters currently available are typically rated for:

- Maximum DC input power.
  i.e. the size of the array in peak watts;
- Maximum DC input current; and
- Maximum specified output power
  i.e. the AC power they can provide to the grid

Once an array has been sized based on one of the following criteria:

1. **Designed to meet yearly energy usage;**
2. **Designed to suit maximum allowable grant;**
3. **Designed to fit on available roof space; and**
4. **Designed to meet a budget**

The maximum power of the array is calculated by the following formula

Array Peak Power
= Number of modules in the array x the rated maximum power (P_{mp}) of the selected module.

For the worked example on in section 1, "Designed to meet yearly energy usage" the array comprised qty 16 x 160 watt modules.

Therefore the array peak power = 16 x 160
= 2.56kW

The minimum sized inverter which can be selected must have a input power rating of 2.56kW.

In the section on PV ARRAY SIZING, the typical PV array output in watts is de-rated due to

- Manufacturers tolerance of the modules
- Dirt
- Temperature

based on figures of:

- 0.95 for manufacturer,
- 0.95 for dirt and
- 0.875 for temperature
  (based on ambient of 25^{o} C)

The de-rating is: 0.95 x 0.95 x 0.875 = 0.789

As a result of this type of de-rating being experienced in the field, it is commonly accepted that an inverter can be selected which has an output rating of 80% of the peak power of the array.

For the worked example above
The array peak power is 2.56kW.

This array can be connected to an inverter with an output rating of

0.80x 2.56kW = 2.04kW

MATCHING INVERTER OPERATING VOLTAGES WITH PV ARRAY OPERATING VOLTAGES

Grid interactive inverter have a specified operating voltage "window" on the DC input. This is the minimum and maximum DC voltages that the inverter will still function correctly
Note : higher than this maximum voltage could cause damage to the inverter. Lower than this minimum voltage will result in inverter switching off and the energy output of the system will be reduced

Please refer to section
MATCHING ARRAY TO VOLTAGE WINDOW OF INVERTERS in PV Array Sizing.

IMPORTANT NOTE:
INVERTERS WITH AMORPHOUS ARRAYS

Amorphous modules are rated at their stable power output, that is, the maximum power after the annealing process. This can take up to six months to occur after installation. The maximum output of the Amorphous Array could be up to 25% larger than the rated power. The inverter and all switches and circuit breakers must be sized for the initial output of the array.

ENERGY YIELD

The system energy output over a whole year is known as the system's "Energy Yield"

The average yearly energy yield can be determined as follows

$$E_{sys} = P_{array\_STC} \times f_{temp} \times f_{mm} \times f_{dirt} \times H_{tilt} \times \eta_{pv\_inv} \times \eta_{inv}$$

where H_{tilt} is the yearly irradiation value for the selected site (allowing for shadows and orientation)

SPECIFIC ENERGY YIELD

The specific energy yield is expressed in kWh per kW_p and is calculated as follows:

$$SY = \frac{E_{sys}}{P_{array\_STC}}$$

If the performance of systems in different regions is to be compared the shading loss must be estimated and eliminated from the calculation of energy yield.

PERFORMANCE RATIO

The performance ratio (PR) is used to access the installation quality. The PR provides a normalised basis so comparison of different types and sizes of PV systems can be undertaken.
The performance ratio is calculated as follows

$$PR = \frac{E_{sys}}{E_{ideal}}$$

where

E_{sys} = actual yearly energy yield from the system
E_{ideal} = the ideal energy output of the array.

The PV arrays ideal energy yield E_{ideal} can determined two ways.

Method 1

$$E_{ideal} = P_{array\_STC} \times H_{tilt}$$

where

H_{tilt} = yearly average daily irradiation, in kWh/m^2 for the specified tilt angle
$P_{array..STC}$ = rated output power of the array under Standard Test Conditions, in watts

Method 2

$$E_{ideal} = H_{pv} \times \eta_{pv}$$

where

H_{pv} = actual irradiation on the array surface area
η_{pv} = efficiency of the PV modules

and

$$H_{pv} = H_{tilt} \times A_{pv}$$

where

H_{tilt} = yearly average daily irradiation, in kWh/m^2 for the specified tilt angle
A_{pv} = Total area of the PV array

If the performance of systems in different regions is to be compared the shading loss must be estimated and eliminated from the calculation when determining the real energy yield.

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR BRISBANE

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	90%	95%	99%	100%	98%	94%	88%	80%	70%	59%
10	90%	95%	99%	100%	98%	94%	88%	80%	71%	60%
20	90%	95%	98%	99%	98%	94%	88%	80%	71%	61%
30	90%	95%	98%	98%	97%	93%	87%	80%	71%	61%
40	90%	95%	97%	97%	95%	92%	86%	79%	71%	61%
50	90%	94%	96%	96%	93%	90%	84%	78%	70%	61%
60	90%	93%	94%	94%	91%	88%	82%	76%	69%	60%
70	90%	92%	93%	92%	89%	85%	80%	74%	67%	59%
80	90%	91%	91%	89%	86%	82%	77%	71%	64%	57%
90	90%	91%	89%	87%	83%	79%	74%	68%	61%	55%
100	90%	90%	88%	84%	80%	75%	70%	64%	58%	52%
110	90%	89%	86%	82%	77%	71%	65%	60%	54%	48%
120	90%	88%	84%	79%	73%	67%	61%	55%	50%	44%
130	90%	87%	82%	76%	70%	63%	57%	51%	45%	40%
140	90%	86%	81%	74%	66%	59%	52%	46%	41%	36%
150	90%	86%	80%	72%	64%	56%	48%	42%	37%	32%
160	90%	85%	79%	71%	61%	53%	45%	39%	34%	30%
170	90%	85%	78%	69%	60%	51%	44%	37%	31%	28%
180	90%	85%	78%	69%	59%	51%	43%	36%	30%	27%
190	90%	85%	78%	69%	59%	51%	43%	37%	31%	27%
200	90%	85%	78%	70%	60%	52%	45%	38%	32%	29%
210	90%	85%	79%	71%	62%	54%	47%	41%	36%	31%
220	90%	86%	80%	73%	65%	57%	51%	45%	39%	35%
230	90%	86%	81%	75%	68%	61%	55%	49%	43%	38%
240	90%	87%	83%	77%	71%	65%	59%	53%	48%	42%
250	90%	88%	84%	80%	74%	69%	63%	57%	52%	46%
260	90%	89%	86%	82%	78%	73%	67%	61%	55%	49%
270	90%	90%	88%	85%	81%	76%	71%	65%	59%	52%
280	90%	91%	90%	87%	84%	79%	74%	68%	61%	55%
290	90%	92%	91%	90%	86%	82%	77%	71%	64%	56%
300	90%	92%	93%	92%	89%	85%	79%	73%	66%	58%
310	90%	93%	94%	94%	91%	87%	82%	75%	67%	59%
320	90%	94%	96%	96%	93%	89%	84%	77%	69%	59%
330	90%	95%	97%	97%	95%	91%	85%	78%	69%	60%
340	90%	95%	98%	98%	97%	93%	87%	79%	70%	60%
350	90%	95%	98%	99%	98%	94%	88%	80%	70%	59%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR CANBERRA										
Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	87%	94%	98%	100%	99%	96%	91%	83%	74%	64%
10	87%	94%	98%	99%	99%	96%	91%	83%	74%	64%
20	87%	93%	97%	99%	98%	95%	90%	83%	74%	64%
30	87%	93%	96%	98%	97%	94%	89%	82%	73%	64%
40	87%	92%	95%	96%	95%	92%	87%	80%	72%	63%
50	87%	92%	94%	94%	93%	89%	84%	78%	70%	62%
60	87%	91%	92%	92%	90%	86%	81%	75%	68%	61%
70	87%	90%	90%	89%	87%	83%	78%	72%	66%	59%
80	87%	89%	88%	87%	84%	80%	75%	69%	63%	56%
90	87%	88%	86%	84%	80%	76%	71%	65%	59%	53%
100	87%	87%	84%	81%	77%	72%	67%	61%	56%	50%
110	87%	86%	82%	78%	73%	68%	62%	57%	51%	46%
120	87%	85%	80%	75%	69%	63%	58%	52%	47%	42%
130	87%	84%	78%	72%	66%	59%	53%	48%	43%	38%
140	87%	83%	77%	70%	62%	55%	49%	44%	39%	35%
150	87%	82%	76%	68%	60%	52%	45%	40%	35%	32%
160	87%	82%	75%	66%	57%	50%	42%	36%	33%	29%
170	87%	82%	74%	65%	56%	48%	41%	35%	30%	28%
180	87%	81%	74%	65%	56%	48%	40%	34%	30%	27%
190	87%	81%	74%	65%	56%	48%	41%	35%	30%	28%
200	87%	82%	74%	66%	57%	50%	42%	36%	32%	29%
210	87%	82%	75%	67%	59%	52%	45%	40%	35%	32%
220	87%	83%	77%	69%	62%	55%	49%	43%	39%	35%
230	87%	84%	78%	72%	65%	59%	53%	48%	43%	38%
240	87%	84%	80%	74%	68%	63%	57%	52%	47%	41%
250	87%	85%	82%	77%	72%	67%	62%	56%	51%	45%
260	87%	86%	84%	80%	76%	71%	66%	61%	55%	49%
270	87%	87%	86%	83%	79%	75%	70%	65%	59%	52%
280	87%	89%	88%	86%	83%	79%	74%	68%	62%	55%
290	87%	90%	90%	89%	86%	82%	77%	71%	65%	58%
300	87%	91%	92%	91%	89%	85%	81%	74%	67%	60%
310	87%	91%	93%	94%	92%	88%	83%	77%	70%	61%
320	87%	92%	95%	96%	94%	91%	86%	79%	71%	63%
330	87%	93%	96%	97%	96%	93%	88%	81%	73%	63%
340	87%	93%	97%	98%	98%	95%	89%	82%	74%	64%
350	87%	94%	98%	99%	99%	95%	90%	83%	74%	64%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR DARWIN

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	96%	99%	100%	99%	94%	88%	79%	69%	58%	48%
10	96%	99%	100%	99%	94%	88%	79%	69%	58%	48%
20	96%	99%	100%	98%	94%	88%	80%	70%	59%	49%
30	96%	99%	100%	98%	94%	88%	80%	71%	61%	51%
40	96%	99%	99%	97%	93%	88%	80%	71%	62%	53%
50	96%	98%	99%	96%	93%	87%	80%	72%	63%	55%
60	96%	98%	98%	96%	92%	86%	80%	72%	64%	56%
70	96%	97%	97%	94%	91%	85%	79%	72%	64%	56%
80	96%	97%	96%	93%	89%	84%	78%	71%	63%	56%
90	96%	96%	95%	92%	87%	82%	76%	69%	62%	55%
100	96%	96%	93%	90%	85%	79%	73%	67%	59%	52%
110	96%	95%	93%	88%	83%	77%	70%	63%	56%	49%
120	96%	94%	91%	86%	80%	74%	67%	59%	52%	46%
130	96%	94%	90%	84%	78%	70%	63%	56%	48%	41%
140	96%	93%	89%	82%	75%	67%	59%	51%	44%	37%
150	96%	93%	88%	81%	73%	64%	55%	46%	39%	33%
160	96%	93%	87%	80%	71%	61%	51%	43%	36%	30%
170	96%	93%	87%	79%	70%	59%	49%	41%	34%	28%
180	96%	92%	86%	78%	69%	58%	48%	40%	33%	27%
190	96%	92%	86%	78%	69%	59%	48%	41%	33%	27%
200	96%	93%	87%	79%	70%	60%	50%	42%	35%	29%
210	96%	93%	87%	80%	71%	63%	53%	45%	38%	32%
220	96%	93%	88%	81%	74%	65%	57%	49%	42%	36%
230	96%	93%	89%	83%	76%	68%	60%	53%	46%	40%
240	96%	94%	90%	85%	78%	71%	64%	57%	50%	44%
250	96%	94%	91%	86%	81%	74%	67%	61%	54%	47%
260	96%	95%	92%	88%	83%	77%	70%	64%	57%	50%
270	96%	96%	93%	90%	85%	79%	73%	67%	60%	52%
280	96%	96%	95%	91%	87%	81%	75%	68%	61%	54%
290	96%	97%	96%	93%	89%	83%	77%	70%	62%	55%
300	96%	97%	96%	94%	90%	84%	78%	70%	63%	55%
310	96%	98%	97%	95%	91%	85%	78%	70%	62%	54%
320	96%	98%	98%	96%	92%	86%	78%	70%	61%	52%
330	96%	99%	99%	97%	93%	86%	78%	70%	60%	51%
340	96%	99%	100%	98%	93%	87%	79%	69%	59%	49%
350	96%	99%	100%	98%	94%	87%	79%	69%	58%	48%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR HOBART										
	Plane Inclination (degrees)									
Plane Azimuth (degrees)	0	10	20	30	40	50	60	70	80	90
0	82%	90%	95%	99%	100%	99%	95%	89%	81%	72%
10	82%	89%	95%	98%	99%	98%	95%	88%	81%	72%
20	82%	89%	95%	98%	99%	97%	94%	88%	81%	72%
30	82%	88%	93%	96%	97%	96%	92%	87%	79%	70%
40	82%	88%	92%	95%	95%	93%	90%	84%	78%	69%
50	82%	87%	90%	92%	92%	90%	87%	81%	75%	67%
60	82%	86%	88%	90%	89%	87%	83%	78%	72%	65%
70	82%	85%	87%	87%	85%	83%	79%	75%	69%	62%
80	82%	84%	84%	84%	82%	79%	75%	70%	65%	59%
90	82%	82%	82%	80%	78%	75%	71%	66%	61%	55%
100	82%	81%	79%	76%	73%	70%	66%	61%	56%	52%
110	82%	80%	77%	73%	69%	65%	61%	56%	52%	47%
120	82%	79%	75%	70%	65%	60%	56%	52%	47%	42%
130	82%	78%	72%	66%	61%	55%	51%	47%	42%	38%
140	82%	76%	70%	64%	57%	51%	46%	42%	38%	35%
150	82%	76%	68%	61%	54%	47%	42%	38%	35%	32%
160	82%	75%	67%	59%	52%	45%	39%	35%	32%	29%
170	82%	75%	67%	58%	50%	43%	37%	32%	30%	28%
180	82%	75%	66%	58%	50%	43%	36%	32%	29%	27%
190	82%	75%	67%	58%	50%	43%	37%	33%	30%	28%
200	82%	75%	67%	59%	52%	45%	39%	35%	32%	29%
210	82%	76%	68%	61%	54%	47%	42%	38%	35%	32%
220	82%	76%	70%	63%	56%	51%	46%	42%	38%	35%
230	82%	77%	72%	66%	60%	55%	51%	47%	42%	38%
240	82%	78%	74%	69%	64%	60%	56%	52%	47%	42%
250	82%	79%	76%	73%	68%	65%	61%	56%	52%	46%
260	82%	81%	79%	76%	73%	69%	65%	61%	56%	50%
270	82%	82%	81%	79%	77%	74%	70%	65%	61%	55%
280	82%	83%	84%	83%	81%	78%	75%	70%	64%	58%
290	82%	85%	86%	86%	85%	82%	79%	74%	68%	61%
300	82%	85%	88%	89%	88%	86%	82%	78%	72%	64%
310	82%	87%	90%	92%	92%	90%	86%	81%	74%	67%
320	82%	88%	92%	94%	95%	93%	89%	84%	76%	68%
330	82%	88%	93%	96%	96%	95%	92%	86%	79%	70%
340	82%	89%	95%	98%	98%	97%	93%	87%	80%	71%
350	82%	89%	95%	98%	99%	98%	95%	88%	81%	72%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR SYDNEY

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	87%	94%	98%	100%	99%	97%	91%	84%	75%	64%
10	87%	94%	98%	100%	99%	96%	91%	84%	75%	64%
20	87%	93%	97%	99%	98%	95%	90%	83%	74%	64%
30	87%	93%	96%	98%	97%	94%	88%	81%	73%	63%
40	87%	92%	95%	96%	95%	91%	86%	79%	71%	63%
50	87%	91%	94%	94%	92%	89%	84%	77%	69%	61%
60	87%	90%	92%	91%	89%	86%	80%	74%	67%	60%
70	87%	89%	90%	89%	86%	82%	77%	71%	64%	57%
80	87%	88%	88%	86%	82%	78%	73%	68%	61%	55%
90	87%	87%	86%	82%	79%	74%	69%	64%	58%	52%
100	87%	86%	84%	80%	75%	70%	65%	60%	54%	48%
110	87%	85%	81%	77%	71%	66%	61%	55%	50%	44%
120	87%	84%	79%	73%	68%	62%	56%	51%	45%	40%
130	87%	83%	77%	71%	64%	57%	52%	46%	41%	37%
140	87%	82%	76%	68%	61%	54%	47%	42%	37%	34%
150	87%	81%	74%	66%	58%	50%	44%	38%	34%	30%
160	87%	81%	73%	65%	56%	48%	41%	35%	31%	28%
170	87%	81%	73%	64%	55%	47%	39%	34%	29%	27%
180	87%	81%	73%	63%	54%	46%	39%	33%	28%	26%
190	87%	81%	73%	64%	55%	47%	40%	34%	29%	27%
200	87%	81%	74%	65%	56%	48%	41%	35%	31%	28%
210	87%	82%	74%	66%	59%	51%	44%	38%	34%	30%
220	87%	82%	76%	69%	61%	54%	48%	43%	38%	34%
230	87%	83%	78%	71%	65%	59%	52%	47%	41%	37%
240	87%	84%	80%	74%	69%	63%	57%	52%	46%	41%
250	87%	85%	82%	77%	72%	67%	62%	56%	51%	45%
260	87%	86%	84%	80%	76%	71%	66%	61%	55%	49%
270	87%	87%	86%	84%	80%	76%	71%	65%	59%	53%
280	87%	88%	88%	87%	84%	79%	74%	69%	62%	56%
290	87%	89%	90%	89%	87%	83%	78%	72%	66%	59%
300	87%	90%	92%	92%	90%	87%	81%	76%	69%	61%
310	87%	91%	94%	94%	93%	89%	85%	78%	71%	62%
320	87%	93%	95%	96%	95%	92%	87%	80%	72%	63%
330	87%	93%	97%	98%	97%	94%	89%	82%	74%	64%
340	87%	94%	97%	99%	98%	96%	90%	84%	75%	65%
350	87%	94%	98%	100%	99%	97%	91%	84%	75%	65%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR MELBOURNE

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	86%	93%	98%	100%	100%	98%	93%	86%	77%	67%
10	86%	92%	97%	99%	99%	97%	92%	85%	77%	67%
20	86%	92%	96%	99%	98%	96%	91%	84%	76%	67%
30	86%	92%	95%	97%	96%	94%	89%	83%	75%	66%
40	86%	91%	94%	95%	95%	92%	87%	81%	74%	65%
50	86%	90%	92%	93%	92%	89%	85%	79%	71%	63%
60	86%	89%	91%	91%	89%	86%	81%	76%	69%	61%
70	86%	88%	89%	88%	86%	82%	78%	73%	66%	59%
80	86%	87%	87%	85%	82%	78%	74%	68%	63%	56%
90	86%	85%	84%	82%	78%	74%	70%	64%	59%	53%
100	86%	84%	82%	78%	74%	70%	65%	60%	55%	49%
110	86%	84%	80%	75%	71%	65%	61%	56%	50%	45%
120	86%	82%	78%	72%	67%	61%	56%	51%	46%	42%
130	86%	81%	76%	69%	63%	57%	51%	46%	42%	37%
140	86%	81%	74%	67%	59%	53%	47%	42%	38%	34%
150	86%	80%	73%	65%	57%	49%	43%	38%	35%	31%
160	86%	80%	72%	63%	54%	47%	40%	35%	32%	29%
170	86%	80%	71%	63%	54%	46%	39%	33%	29%	27%
180	86%	80%	71%	62%	54%	46%	39%	33%	29%	27%
190	86%	80%	72%	63%	54%	47%	40%	33%	30%	28%
200	86%	80%	73%	64%	56%	49%	42%	36%	33%	30%
210	86%	81%	74%	66%	58%	51%	45%	40%	36%	33%
220	86%	81%	75%	68%	62%	55%	50%	44%	40%	36%
230	86%	82%	77%	71%	65%	60%	54%	49%	44%	40%
240	86%	83%	80%	75%	70%	64%	59%	54%	49%	44%
250	86%	84%	82%	78%	74%	69%	64%	59%	54%	49%
260	86%	85%	84%	81%	78%	74%	69%	64%	58%	53%
270	86%	87%	87%	85%	82%	78%	74%	68%	63%	56%
280	86%	88%	88%	88%	85%	82%	78%	73%	67%	59%
290	86%	89%	91%	91%	89%	86%	82%	76%	70%	62%
300	86%	90%	92%	93%	92%	89%	85%	80%	73%	64%
310	86%	91%	94%	95%	95%	92%	88%	82%	74%	66%
320	86%	92%	95%	97%	97%	95%	90%	84%	76%	67%
330	86%	92%	96%	99%	98%	96%	92%	85%	77%	68%
340	86%	92%	97%	99%	99%	97%	93%	86%	78%	68%
350	86%	93%	98%	100%	100%	98%	93%	87%	78%	67%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR ADELAIDE

	Plane Inclination (degrees)									
Plane Azimuth (degrees)	0	10	20	30	40	50	60	70	80	90
0	87%	94%	98%	100%	99%	96%	91%	83%	74%	63%
10	87%	94%	98%	100%	99%	96%	90%	83%	74%	63%
20	87%	94%	97%	99%	98%	94%	89%	82%	73%	63%
30	87%	93%	96%	97%	96%	93%	87%	80%	72%	62%
40	87%	92%	95%	95%	94%	91%	85%	78%	71%	61%
50	87%	91%	93%	93%	91%	88%	83%	76%	69%	60%
60	87%	91%	92%	91%	89%	85%	79%	74%	66%	58%
70	87%	89%	90%	88%	85%	81%	76%	70%	63%	56%
80	87%	88%	87%	85%	82%	77%	73%	67%	60%	53%
90	87%	87%	85%	82%	78%	74%	69%	63%	57%	50%
100	87%	86%	83%	79%	75%	70%	64%	59%	53%	47%
110	87%	85%	81%	76%	71%	65%	60%	54%	49%	44%
120	87%	84%	79%	74%	67%	61%	55%	50%	45%	40%
130	87%	83%	77%	71%	64%	57%	51%	46%	41%	36%
140	87%	82%	76%	68%	60%	53%	47%	41%	37%	33%
150	87%	82%	75%	67%	58%	50%	43%	37%	33%	30%
160	87%	81%	74%	65%	56%	48%	40%	34%	30%	27%
170	87%	81%	74%	64%	55%	47%	39%	32%	28%	26%
180	87%	81%	74%	64%	55%	47%	39%	32%	27%	25%
190	87%	81%	74%	65%	55%	47%	39%	33%	28%	26%
200	87%	82%	75%	66%	57%	49%	41%	35%	31%	28%
210	87%	82%	75%	68%	59%	51%	44%	39%	34%	31%
220	87%	83%	77%	70%	62%	55%	49%	43%	38%	34%
230	87%	84%	78%	73%	66%	59%	53%	48%	42%	38%
240	87%	85%	80%	75%	70%	64%	58%	52%	47%	42%
250	87%	86%	83%	78%	74%	68%	63%	57%	51%	46%
260	87%	87%	85%	81%	77%	73%	67%	61%	55%	49%
270	87%	88%	87%	84%	81%	76%	72%	66%	59%	53%
280	87%	89%	89%	87%	85%	80%	75%	70%	63%	56%
290	87%	90%	91%	90%	88%	84%	79%	73%	66%	59%
300	87%	91%	93%	93%	91%	87%	82%	76%	69%	61%
310	87%	92%	95%	95%	94%	90%	85%	79%	71%	62%
320	87%	93%	96%	97%	96%	93%	88%	81%	73%	64%
330	87%	93%	97%	98%	98%	94%	89%	82%	74%	64%
340	87%	94%	98%	100%	99%	96%	90%	83%	74%	64%
350	87%	94%	98%	100%	99%	96%	91%	83%	74%	64%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR ALICE SPRINGS

	Plane Inclination (degrees)									
Plane Azimuth (degrees)	0	10	20	30	40	50	60	70	80	90
0	90%	96%	99%	100%	98%	94%	87%	78%	68%	57%
10	90%	96%	99%	100%	98%	94%	87%	79%	69%	57%
20	90%	96%	99%	100%	98%	93%	87%	79%	69%	58%
30	90%	96%	98%	99%	97%	93%	87%	78%	69%	59%
40	90%	95%	98%	98%	96%	91%	86%	78%	69%	60%
50	90%	94%	96%	96%	94%	90%	84%	77%	69%	60%
60	90%	93%	95%	94%	92%	88%	82%	76%	68%	60%
70	90%	93%	93%	92%	89%	85%	80%	73%	66%	59%
80	90%	92%	91%	90%	87%	82%	77%	71%	64%	57%
90	90%	91%	90%	87%	84%	79%	73%	67%	61%	54%
100	90%	90%	88%	84%	80%	75%	69%	63%	57%	51%
110	90%	89%	86%	82%	76%	71%	65%	59%	53%	47%
120	90%	88%	84%	79%	73%	67%	60%	54%	48%	42%
130	90%	87%	82%	76%	69%	62%	55%	49%	43%	38%
140	90%	86%	80%	73%	65%	58%	50%	44%	38%	33%
150	90%	86%	79%	71%	62%	53%	46%	39%	34%	29%
160	90%	85%	78%	69%	60%	50%	42%	36%	30%	26%
170	90%	85%	77%	68%	58%	48%	40%	33%	28%	24%
180	90%	84%	77%	67%	57%	47%	40%	33%	27%	22%
190	90%	84%	77%	68%	57%	48%	40%	33%	27%	23%
200	90%	85%	78%	69%	59%	49%	41%	34%	29%	25%
210	90%	85%	78%	70%	61%	52%	44%	38%	33%	29%
220	90%	86%	80%	72%	64%	56%	49%	42%	37%	32%
230	90%	87%	81%	74%	67%	60%	53%	47%	42%	37%
240	90%	87%	83%	77%	71%	64%	58%	52%	46%	41%
250	90%	88%	84%	80%	75%	69%	63%	57%	51%	45%
260	90%	89%	87%	83%	78%	73%	67%	61%	55%	49%
270	90%	90%	89%	85%	81%	77%	71%	65%	59%	52%
280	90%	91%	90%	88%	84%	80%	75%	69%	62%	55%
290	90%	92%	92%	91%	87%	83%	78%	71%	64%	57%
300	90%	93%	94%	93%	90%	86%	80%	73%	66%	58%
310	90%	94%	95%	95%	92%	88%	82%	75%	67%	58%
320	90%	95%	97%	96%	94%	90%	84%	76%	68%	58%
330	90%	95%	98%	98%	96%	91%	85%	77%	68%	58%
340	90%	96%	98%	99%	97%	93%	86%	78%	68%	58%
350	90%	96%	99%	100%	98%	93%	87%	78%	68%	57%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR PERTH

	Plane Inclination (degrees)									
Plane Azimuth (degrees)	0	10	20	30	40	50	60	70	80	90
0	88%	94%	98%	100%	99%	95%	89%	81%	72%	61%
10	88%	94%	98%	100%	99%	95%	89%	81%	72%	61%
20	88%	94%	98%	99%	98%	94%	89%	81%	72%	62%
30	88%	94%	97%	98%	97%	93%	88%	81%	72%	62%
40	88%	93%	96%	96%	95%	92%	86%	80%	71%	62%
50	88%	92%	94%	94%	93%	89%	84%	78%	70%	62%
60	88%	91%	93%	93%	90%	87%	82%	76%	69%	61%
70	88%	90%	91%	90%	88%	84%	79%	73%	66%	59%
80	88%	89%	89%	88%	85%	81%	76%	70%	63%	56%
90	88%	88%	87%	84%	81%	77%	72%	66%	60%	54%
100	88%	87%	85%	81%	77%	73%	68%	62%	56%	50%
110	88%	86%	83%	78%	74%	68%	63%	57%	51%	46%
120	88%	85%	81%	75%	69%	63%	58%	52%	47%	42%
130	88%	84%	79%	73%	66%	59%	53%	47%	42%	38%
140	88%	83%	77%	70%	62%	55%	48%	42%	38%	33%
150	88%	83%	76%	68%	59%	51%	44%	38%	33%	30%
160	88%	82%	75%	66%	57%	48%	40%	34%	30%	27%
170	88%	82%	75%	65%	56%	47%	39%	32%	27%	25%
180	88%	82%	74%	65%	55%	46%	38%	31%	26%	24%
190	88%	82%	75%	65%	56%	47%	39%	32%	27%	25%
200	88%	82%	75%	66%	57%	49%	41%	34%	30%	27%
210	88%	83%	76%	68%	59%	51%	44%	38%	34%	30%
220	88%	84%	77%	70%	63%	55%	49%	43%	38%	34%
230	88%	84%	79%	73%	66%	60%	53%	48%	43%	38%
240	88%	85%	81%	75%	70%	64%	58%	53%	48%	43%
250	88%	86%	83%	79%	74%	69%	63%	58%	52%	47%
260	88%	88%	85%	82%	78%	73%	68%	63%	56%	50%
270	88%	88%	87%	85%	81%	77%	72%	67%	60%	54%
280	88%	89%	89%	88%	85%	81%	76%	70%	64%	57%
290	88%	91%	91%	90%	88%	84%	79%	74%	67%	59%
300	88%	92%	93%	93%	91%	87%	82%	76%	69%	61%
310	88%	92%	94%	95%	93%	90%	85%	78%	70%	62%
320	88%	93%	96%	97%	95%	92%	87%	80%	71%	62%
330	88%	94%	97%	98%	97%	94%	88%	81%	72%	62%
340	88%	94%	98%	99%	98%	94%	89%	81%	72%	62%
350	88%	94%	98%	100%	99%	95%	89%	81%	72%	61%

ANNUAL DAILY IRRADIATION ON AN INCLINED PLANE EXPRESSED AS % OF MAXIMUM VALUE FOR CAIRNS										
	Plane Inclination (degrees)									
Plane Azimuth (degrees)	0	10	20	30	40	50	60	70	80	90
0	95%	99%	100%	99%	96%	90%	82%	73%	62%	52%
10	95%	99%	100%	99%	95%	90%	82%	73%	62%	52%
20	95%	98%	100%	98%	95%	90%	82%	73%	63%	53%
30	95%	98%	99%	98%	94%	89%	82%	73%	64%	54%
40	95%	98%	99%	97%	94%	88%	81%	73%	64%	55%
50	95%	97%	98%	96%	93%	87%	80%	73%	64%	56%
60	95%	97%	97%	95%	91%	86%	79%	72%	64%	56%
70	95%	96%	96%	94%	90%	84%	78%	71%	63%	55%
80	95%	96%	95%	92%	88%	82%	76%	69%	62%	54%
90	95%	95%	94%	90%	85%	80%	74%	67%	60%	53%
100	95%	95%	92%	89%	83%	78%	71%	64%	58%	51%
110	95%	94%	91%	87%	81%	75%	68%	61%	54%	48%
120	95%	94%	90%	85%	79%	72%	65%	58%	51%	45%
130	95%	93%	89%	83%	76%	69%	62%	54%	48%	41%
140	95%	93%	88%	82%	74%	66%	58%	50%	44%	38%
150	95%	92%	87%	80%	72%	63%	55%	47%	40%	35%
160	95%	92%	87%	79%	71%	61%	52%	45%	38%	33%
170	95%	92%	87%	79%	70%	60%	51%	44%	37%	31%
180	95%	92%	86%	79%	69%	60%	51%	43%	36%	31%
190	95%	92%	87%	79%	70%	60%	51%	44%	37%	31%
200	95%	92%	87%	80%	71%	62%	53%	45%	38%	33%
210	95%	92%	88%	81%	73%	64%	55%	48%	41%	36%
220	95%	93%	88%	82%	75%	67%	59%	51%	45%	39%
230	95%	93%	89%	83%	77%	69%	62%	55%	48%	42%
240	95%	94%	90%	85%	79%	73%	65%	59%	52%	46%
250	95%	94%	91%	87%	81%	75%	69%	62%	55%	49%
260	95%	95%	93%	89%	84%	78%	72%	65%	58%	51%
270	95%	95%	94%	91%	86%	80%	74%	67%	61%	53%
280	95%	96%	95%	92%	88%	83%	76%	69%	62%	55%
290	95%	97%	96%	94%	90%	84%	78%	71%	63%	55%
300	95%	97%	97%	95%	91%	86%	79%	72%	64%	56%
310	95%	98%	98%	96%	93%	87%	80%	73%	64%	55%
320	95%	98%	99%	97%	94%	88%	81%	73%	64%	55%
330	95%	98%	99%	98%	94%	89%	81%	73%	63%	54%
340	95%	98%	100%	98%	95%	90%	82%	73%	63%	53%
350	95%	99%	100%	99%	95%	90%	82%	73%	62%	52%