Current PV Technology

Photovoltaics (PV) or solar cells as they are often referred to, are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads. With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional appliances, and operate in parallel with and interconnected to the utility grid.

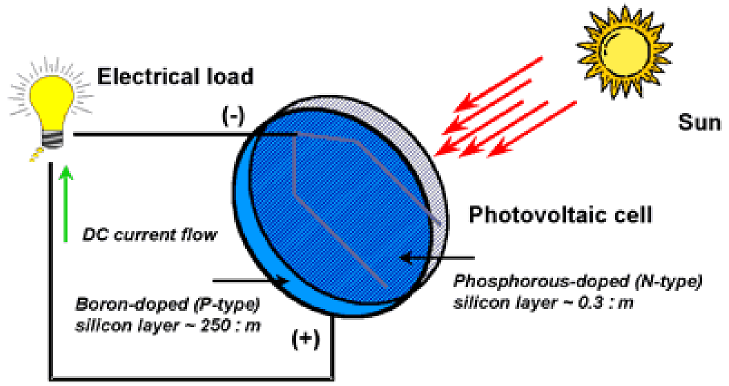
History of Photovoltaics

The first conventional photovoltaic cells were produced in the late 1950s, and throughout the 1960s were principally used to provide electrical power for earth-orbiting satellites. In the 1970s, improvements in manufacturing, performance and quality of PV modules helped to reduce costs and opened up a number of opportunities for powering remote terrestrial applications, including battery charging for navigational aids, signals, telecommunications equipment and other critical, low power needs.

In the 1980s, photovoltaics became a popular power source for consumer electronic devices, including calculators, watches, radios, lanterns and other small battery charging applications. Following the energy crises of the 1970s, significant efforts also began to develop PV power systems for residential and commercial uses both for stand-alone, remote power as well as for utility-connected applications. During the same period, international applications for PV systems to power rural health clinics, refrigeration, water pumping, telecommunications, and off-grid households increased dramatically, and remain a major portion of the present world market for PV products. Today, the industry's production of PV modules is growing at approximately 25 percent annually, and major programs in the U.S., Japan and Europe are rapidly accelerating the implementation of PV systems on buildings and interconnection to utility networks.

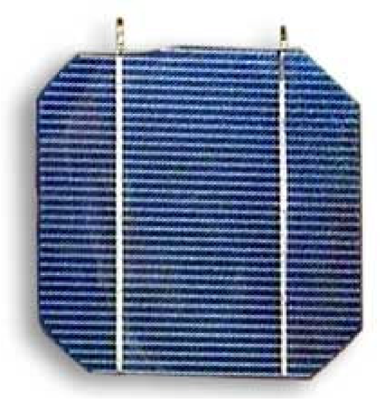
How PV Cells Work

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load

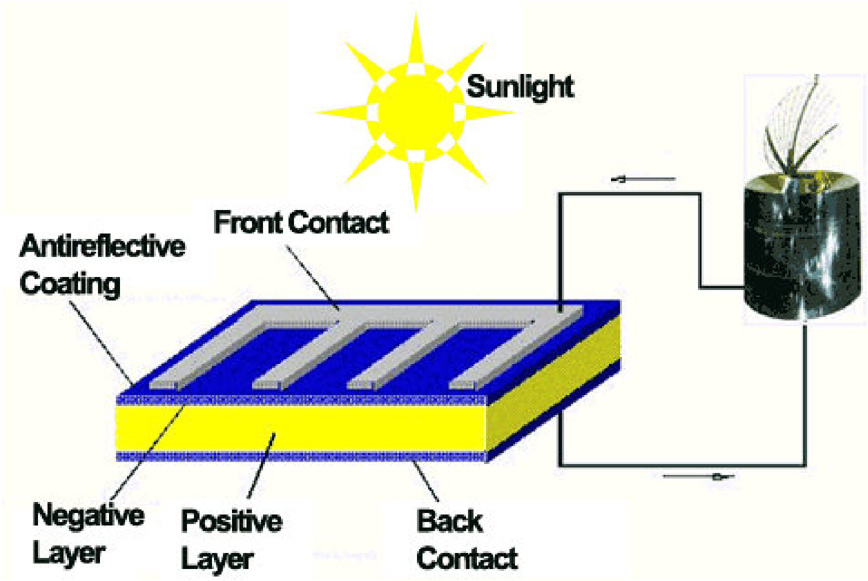


Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of 160 cm^2 (~25 in^2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts

How PV Cells Are Made

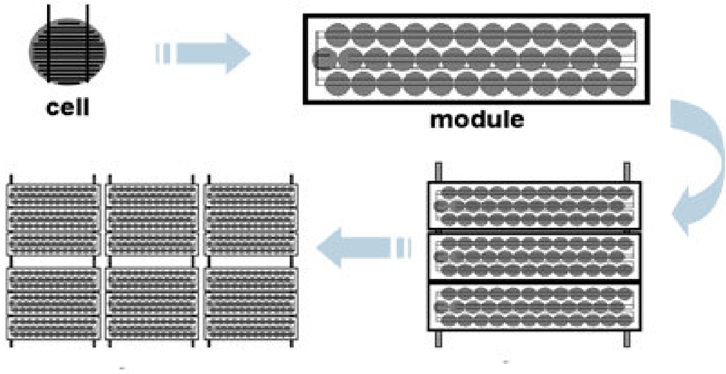


The process of fabricating conventional single- and polycrystalline silicon PV cells begins very pure semiconductor-grade polysilicon - a material processed from quartz and used extensively throughout the electronics industry. The polysilicon is then heated to melting temperature, and trace amounts of boron are added to the melt to create a P-type semiconductor material. Next, an ingot, or block of silicon is formed, commonly using one of two methods: 1) by growing a pure crystalline silicon ingot from a seed crystal drawn from the molten polysilicon or 2) by casting the molten polysilicon in a block, creating a polycrystalline silicon material. Individual wafers are then sliced from the ingots using wire saws and then subjected to a surface etching process. After the wafers are cleaned, they are placed in a phosphorus diffusion furnace, creating a thin N-type semiconductor layer around the entire outer surface of the cell. Next, an anti-reflective coating is applied to the top surface of the cell, and electrical contacts are imprinted on the top (negative) surface of the cell. An aluminized conductive material is deposited on the back (positive) surface of each cell, restoring the P-type properties of the back surface by displacing the diffused phosphorus layer. Each cell is then electrically tested, sorted based on current output, and electrically connected to other cells to form cell circuits for assembly in PV modules.



PV Cells, Modules, & Arrays

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building block of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.



Photovoltaic cells, modules, panels and arrays.

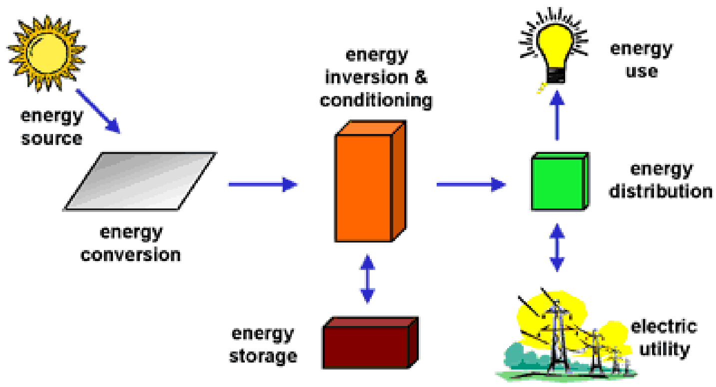
The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25o C (77 F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of twenty or more years for maintaining a high percentage of initial rated power output.

How a PV System Works

Simply put, PV systems are like any other electrical power generating systems, just the equipment used is different than that used for conventional electromechanical generating systems. However, the principles of operation and interfacing with other electrical systems remain the same, and are guided by a well-established body of electrical codes and standards.
Although a PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.

Depending on the functional and operational requirements of the system, the specific components required, and may include major components such as a DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and sometimes the specified electrical load (appliances). In addition, an assortment of balance of system (BOS) hardware, including wiring, overcurrent, surge protection and disconnect devices, and other power processing equipment. Figure 3 show a basic diagram of a photovoltaic system and the relationship of individual components.



Major photovoltaic system components.
Why Are Batteries Used in Some PV Systems?
Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and overdischarge

Types of PV Systems

How Are Photovoltaic Systems Classified?

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principle classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.1.7.1 Grid-Connected (Utility-Interactive) PV Systems.

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back onto the utility grid when the grid is down for service or repair.

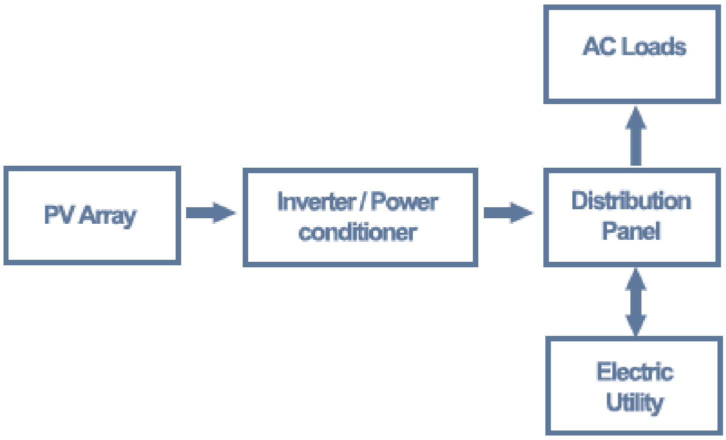


Diagram of grid-connected photovoltaic system.

Stand-Alone Photovoltaic Systems

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 5). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT) is used between the array and load to help better utilize the available array maximum power output.

In many stand-alone PV systems, batteries are used for energy storage. Figure 6 shows a diagram of a typical stand-alone PV system powering DC and AC loads. Shows how a typical PV hybrid system might be configured.

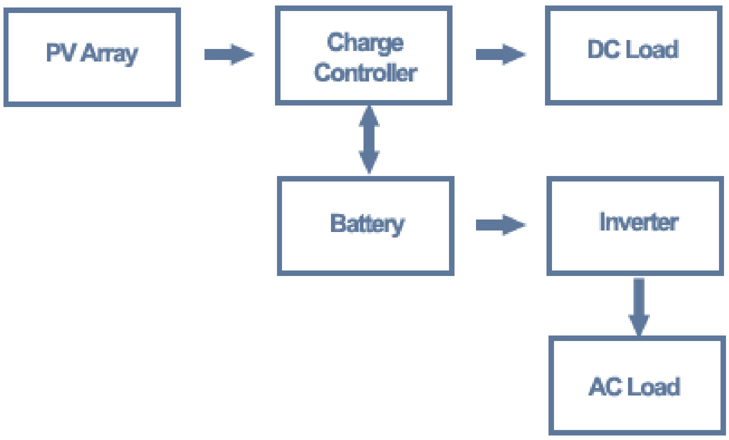


Diagram of stand-alone PV system with battery storage powering DC and AC loads.

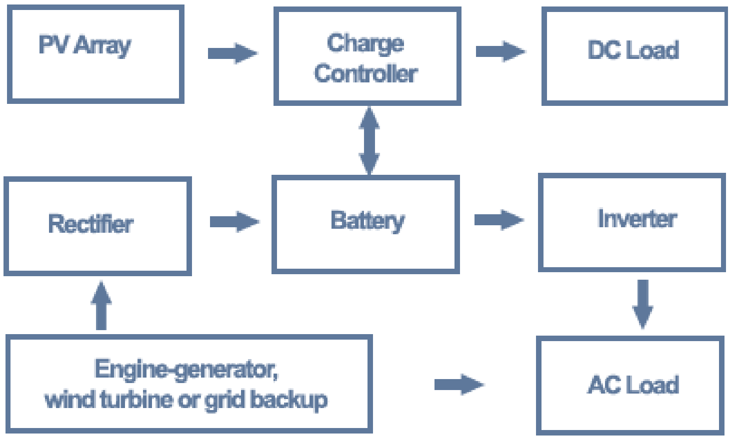
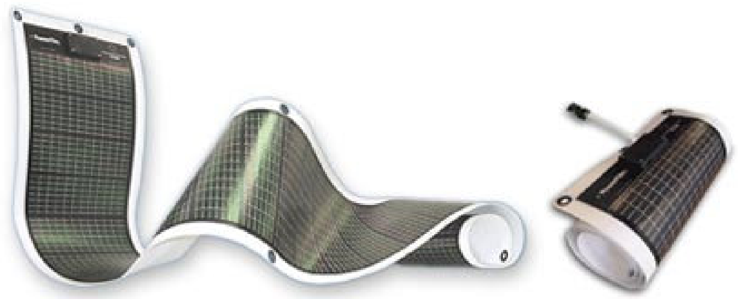


Diagram of photovoltaic hybrid system

Thin-Film Photovoltaics

Thin-film photovoltaic modules are manufactured by depositing ultra-thin layers of semiconductor material on a glass or thin stainless-steel substrate in a vacuum chamber. A laser scribing process is used to separate and weld the electrical connections between individual cells in a module. Thin-film photovoltaic materials offer great promise for reducing the materials requirements and manufacturing costs for PV modules and systems.



Why should I put PV on my roof?

Installing your own solar photovoltaic (PV) system means that you can generate your own electricity from the free and inexhaustible energy from the sun. A photovoltaic system never needs refuelling, emits no pollution, and can be expected to operate for over 30 years while requiring minimal maintenance. A typical PV system on a house roof could prevent over 34 tonnes of greenhouse gas emissions during its lifetime.

Today photovoltaic systems are recognized by governments, environmental organizations and commercial organizations as a technology with the potential to supply a significant part of the worlds energy needs in a sustainable and renewable manner. Organizations such as Shell and BP have set up large photovoltaic manufacturing plants and environmental organizations such as Greenpeace strongly support the use of solar energy.*

Installing a photovoltaic system is one of the ways householders and other building owners can contribute towards a sustainable future for everyone.

With global climate change threatening all our futures, we need to switch to clean, renewable forms of energy and electricity production. Solar electric panels can generate electricity that is free from pollution, fuelled by the natural resource of the sun, which is free, abundant and inexhaustible. Greenpeace strongly supports solar energy.'

The key benefits of a solar roof are:
- Your own clean power source that helps reduce global warming
- Reduces your electricity bills, since daylight is free
- Increases the value of your property
- Extremely low maintenance, with a long functional lifetime of 30 years or more
- Silent in operation
- Increases your awareness of electricity use and encourages more energy efficient behaviour

Photovoltaic means electricity from light. Photovoltaic systems use daylight to power ordinary electrical equipment, for example, household appliances, computers and lighting. The photovoltaic (PV) process converts free solar energy - the most abundant energy source on the planet - directly into electricity. Note that this is not the familiar solar thermal technology used for heating and hot water.

A PV cell consists of two or more thin layers of semi-conducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated and this can be conducted away by metal contacts as direct current (DC). The electrical output from a single cell is small, so multiple cells are connected together and encapsulated (usually behind glass) to form a module (sometimes referred to as a "panel"). The PV module is the principle building block of a PV system and any number of modules can be connected together to give the desired electrical output.

PV equipment has no moving parts and as a result requires minimal maintenance. It generates electricity without producing emissions of greenhouse or any other gases, and its operation is virtually silent. These pages contain information on what PV power is used for, types of PV cell, and a typical system configuration.

PV systems supply electricity to many applications, ranging from systems supplying power to city buildings (which are also connected to the normal local electricity network) to systems supplying power to garden lights or to remote telecom relay stations.

The main area of interest today is grid connect PV systems. These systems are connected to the local electricity network. This means that during the day, the electricity generated by the PV system can either be used immediately (which is normal for systems installed on offices and other commercial buildings), or can be sold to one of the electricity supply companies (which is more common for domestic systems where the occupier may be out during the day). In the evening, when the solar system is unable to provide the electricity required, power can be bought back from the network. In effect, the grid is acting as an energy storage system, which means the PV system does not need to include battery storage.

Grid connect PV systems are often integrated into buildings. PV technology is ideally suited to use on buildings, providing pollution and noise-free electricity without using extra space. The use of photovoltaics on buildings has grown substantially in the UK over the last few years, with many impressive examples already in operation.

PV systems can be incorporated into buildings in various ways. Sloping rooftops are an ideal site, where modules can simply be mounted using frames. Photovoltaic systems can also be incorporated into the actual building fabric, for example PV roof tiles are now available which can be fitted as would standard tiles. In addition, PV can also be incorporated as building facades, canopies and sky lights amongst many other applications. This is a rapidly growing market in the UK and throughout Europe and it is mainly this type of system which the UK Photovoltaic Demonstration Programme provides funding for.

Stand-alone photovoltaic systems have been used for many years in the UK to supply electricity to applications where grid power supplies are unavailable or difficult to connect to. Examples include monitoring stations, radio repeater stations, telephone kiosks and street lighting. There is also a substantial market for PV technology in the leisure industry, with battery chargers for boats and caravans, as well as for powering garden equipment such as solar fountains. These systems normally use batteries to store the power, if larger amounts of electricity are required they can be combined with another source of power - a biomass generator, a wind turbine or diesel generator to form a hybrid power supply system.

PV technology is also widely used in the developing world. The technology is particularly suited here, where electricity grids are unreliable or non-existent, with remote locations often making PV power supply the most economic option. In addition, many developing countries have high solar radiation levels year round.

Types of PV Cell:
Monocrystalline Silicon Cells:
Made using cells saw-cut from a single cylindrical crystal of silicon, this is the most efficient of the photovoltaic (PV) technologies. The principle advantage of monocrystalline cells are their high efficiencies, typically around 15%, although the manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

Multicrystalline Silicon Cells:
Made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon, these ingots are then saw-cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 12%., creating a granular texture.

Thick-film Silicon:
Another multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, this is encapsulated in a transparent insulating polymer with a tempered glass cover and usually bound into a strong aluminium frame.

Amorphous Silicon:
Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer rather than a crystal structure. Amorphous silicon absorbs light more effectively than crystalline silicon, so the cells can be thinner. For this reason, amorphous silicon is also known as a "thin film" PV technology. Amorphous silicon can be deposited on a wide range of

substrates, both rigid and flexible, which makes it ideal for curved surfaces and "fold-away" modules. Amorphous cells are, however, less efficient than crystalline based cells, with typical efficiencies of around 6%, but they are easier and therefore cheaper to produce. Their low cost makes them ideally suited for many applications where high efficiency is not required and low cost is important.

Other Thin Films:
A number of other promising materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. New technologies based on the photosynthesis process are not yet on the market.

Can a PV system be installed on my building?

The most important questions to consider in deciding whether or not a PV system can be installed on a building and what type of system should be installed are:

- is there a suitable place on the building where the solar array could be mounted (taking into account orientation, shade, and available area)
- what type of photovoltaic system would be suitable
- is planning permission required

Photovoltaic modules can be placed on almost any building surface which receives sunshine for most of the day. Roofs are the usual location for PV systems on houses but photovoltaic modules can also be placed on facades, conservatory or atrium roofs, sun shades, etc.

The surface on which the PV array is mounted should receive as much light as possible. The more light the solar array receives the more electricity will be generated. The three issues which affect how much light a surface receives are:

1. Orientation: Due south is the best possible orientation. If the PV is to be mounted on a vertical façade the orientation should preferably be between South East and South West. If the PV is to be mounted at a tilt a wider range of orientations will still give a reasonable energy yield. North facing orientations should be avoided.

2. Tilt: A tilted array will receive more light than a vertical array. Any angle between vertical and 15o off horizontal can be used. A minimum tilt of 15o off horizontal is recommended to allow the rain to wash dust off the array. The optimal tilt angle is 30o - 60o for a south facing array in Europe. Shallower tilt angles are better for east or west facing arrays.

3. Shadowing: Shadows cast by tall trees and neighbouring buildings must also be considered. Even minor shading can result in significant loss of energy. If shading is unavoidable, your system designer can advise on how to minimize the effect of shade on the amount of electricity produced.

The area required for mounting a PV array depends on the output power desired and the type of module used. An area of around 8 m2 will be required to mount an array with a rated power output of 1kW, if monocrystalline modules are used (the most efficient modules type). If multicrystalline modules are used an area of around 10 m2 will be required for a 1kWp system and if amorphous modules are used an area of about 20 m2 will be required. These areas can be scaled up or down depending on the output power desired. 1 - 3 kWp is a typical power output for a domestic system, although smaller or larger systems can be installed.

There are various ways in which a PV array can be mounted on a building. The various options offer different appearances and vary in cost. The commonest way of mounting an array on a house is to place it on the roof either with modules mounted in a frame above the existing roof tiles or integrated into the roof. If the array is to be integrated into the roof PV roof tiles may be used instead of modules.

PV arrays can also be mounted on flat roofs, on walls, in conservatory roofs, on sun shades or on other structures such as pergolas or car parking bays.

PV roofs do not usually require planning permission unless the building is listed or in a conservation area. However you should call your council to check on local policy.

How much electricity will a system generate?

A system with a PV array tilted towards the south would generate approximately 750/1500kWh/year per kWp installed (in Europe). So a typical 2 kWp system (around 20 m2 of multicrystalline modules) would generate around 1500/3000 kWh per year. Output will be reduced by shade or non-optimal orientations or tilt angles.

How much will a system cost?

A typical price for a grid connected, building integrated PV system is between Euro 6 and Euro 7 per Wp, this works out at Euro 12.000 - Euro 14.000 for a 2 kWp system for a house.

There are a number of factors that will influence the cost of a system:

· Whether or not the system is being installed while the building is being built or as a retro-fit to an existing building. If the system is being installed on a new building some savings may be made, eg the number of roof tiles that need to be purchased could be reduced.

· The number of PV systems being installed at a time. A house builder installing systems on a group of houses can expect a price nearer the bottom of the quoted range than an individual householder.

· The size of the system being installed, a larger system may be cheaper per kWp while a small system may be more expensive.

· How difficult or easy it is to access the area where the PV system is being installed. The typical price quoted applies to installation on a typical house roof, if the roof is a complicated shape or requires complicated scaffolding costs will be higher.

· The module type used will significantly impact on the costs. The typical price quoted is based on standard modules, tile type systems are somewhat more expensive. The most expensive systems use semi-transparent glass modules in facades or conservatory roofs.