SEAI SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Best Practice Guide

Photovoltaics (PV)

Best Practice Guide – Photovoltaics (PV)

Acknowledgements:

This guide was adapted from Photovoltaics in Buildings A Design Guide (DTI), Guide to the installation of PV systems 2nd Edition the Department for Enterprise DTI/Pub URN 06/1972.

Note to readers:

One intention of this publication is to provide an overview for those involved in building and building services design and for students of these disciplines. It is not intended to be exhaustive or definitive and it will be necessary for users of the Guide to exercise their own professional judgement when deciding whether or not to abide by it.

It cannot be guaranteed that any of the material in the book is appropriate to a particular use. Readers are advised to consult all current Building Regulations, EN Standards or other applicable guidelines, Health and Safety codes, as well as up-to-date information on all materials and products.

Index

1 Introduction

If the 19th century was the age of coal and the 20th of oil, the 21st will be the age of the sun.

Solar energy is set to play an ever-increasing role in generating the form, and affecting the appearance and construction, of buildings. The principal reason for this is that photovoltaic (PV) systems which produce electricity directly from solar radiation are becoming more widespread as their advantages become apparent and as costs fall. PVs are an advanced materials technology that will help us design buildings which are environmentally responsible, responsive and exciting. PV installations can take a variety of forms as shown in the following figures.

There are many applications for PVs and some are already in widespread use here in Ireland. Others represent potential uses that are likely to be seen in the near future. These are listed in the table below:

End users	Typical Applications
Waterway Authorities / Environmental Protection Agency	Lock & Sluice operation Water pumping Water quality monitoring
Local Authorities	Parking meters Car park security lighting Street / path lighting Bus stop and shelter lighting
Road Authorities	Emergency phones Roadside information and hazard warning signs Mobile units for temporary warning signs Speed cameras Remote junction / crossroads lighting Powered cats eyes Traffic and pollution monitoring
Rail Network	Remote rail stations – lighting Point greasers Signalling and warning signs
Harbour & Light House Authorities	Lighthouses Offshore (buoy-mounted) navigation beacons Harbour navigation beacons and warning signs
Met Office	Weather stations – wind speed, temperature etc Air quality monitoring
Heritage and National Monument Sites	Remote visitor centres
Youth Hostels	Remote hostels
Universities / Research Laboratories	Remote monitoring equipment
Gas / Electricity / Water Utility Companies / Suppliers	Remote meter reading Pressure and flow measurement Valve operation Anti-freeze heating Monitoring HV cable insulation Water level measurement Water treatment, pumping and purification
Phone Network Operators	Mobile phone local transmitters Telecoms repeater stations
Farming & Agriculture	Electric fencing Pest control – flashing lights, bird scarers Water pumping for livestock & drinking water Lighting for stables and out-houses Fish farm pond aeration Fish farm feeding systems Greenhouse lighting and heating

End users	Typical Applications
Domestic Buildings	Lighting and general power
Industrial Buildings	Lighting, general power and process equipment
General	Alarms for remote buildings Area lighting CCTV Advertising
Leisure Boats	Electric boat battery charging Battery charging (lighting & TV)
Camping & Remote Homes	Battery charging (lighting & TV)
Commercial Buildings	Lighting and general power

Table 1.1 : Typical applications of photo voltaic technology[1]

Many of the applications listed in the table above can be considered small scale.
Application of PVs in buildings has a very large potential and this best practice guide is focused on this area of use.

PVs can form part of the roof structure, walls or be floor mounted. Different types will lend themselves to different buildings.

This Guide provides an overview of how PVs work and are incorporated in the design of buildings; it gives the information that building owners, designers and, in particular, architects, need. It is for those who wish to assess the feasibility of using PVs in a specific project, for those who have already decided to use PVs and want to know how to do so and for those with the foresight to want to plan their buildings for PVs in the future.

New buildings have been addressed especially and covered by a number of building types and sectors; much of the technology could be applied as a retrofit to existing buildings. The focus is on PV systems which are building-integrated and grid-connected. PVs are a proven, commercially-available technology. In grid-connected systems, the PVs operate in parallel with the grid, so if the PV supply is less than demand the grid supplies the balance; when there is excess energy from the PV system it can be fed back to the grid. Building-integrated, grid-connected systems have the following advantages:

- The cost of the PV wall or roof can be offset against the cost of the building element it replaces.
- Power is generated on site and replaces electricity which would otherwise be purchased through the national grid from utility suppliers.
- By connecting to the grid the high cost of storage associated with stand-alone systems is avoided and security of supply is ensured. If the facility for selling excess electricity is available, then connecting to the grid will ensure that the high cost of storage associated with stand-alone systems is avoided and that security of supply is ensured.
- There is no additional requirement for land.

PVs should be considered as an integral part of the overall environmental strategy of energy-efficient building design. PVs will be a key element in furthering this approach to building and will help us move towards lower carbon, carbon neutral and carbon negative buildings.

1 Adapted from International Energy Agency Cooperative Programme on Photovoltaic Power Systems – Task 1: Exchange and dissemination of information on PV power systems: National Survey Report of PV Power Application in the United Kingdom 2007 (Department for Business Enterprise and Regulatory Reform).

This guide has been produced with Ireland in mind. The Guide deals with its weather conditions. However, as can be seen from *Figure 1.1*, annual irradiation is similar in much of Northern Europe.

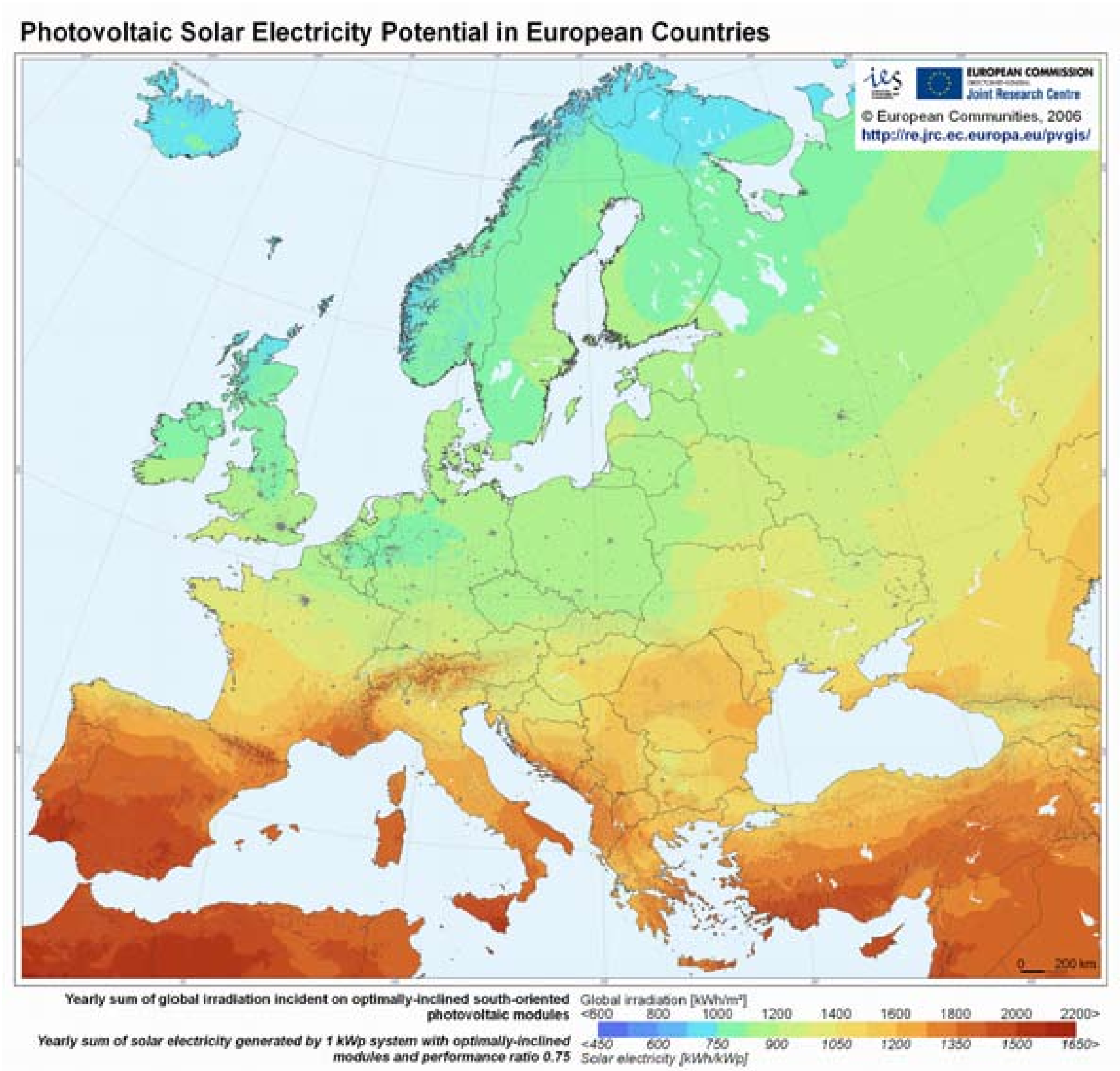

Figure 1.1- Solar irradiation over Europe (kWh/m²/y)

The Guide is set out in a way that mimics the design process:

- Chapter 2 introduces some basic PV concepts.
- Chapter 3 discusses the site and building and the design options.
- Chapter 4 examines costs and sizing.
- Chapter 5 looks at the integration of PVs inside the building.

Included at the end of this guide is an example commercial case study, an appendix setting out a number of technical points and a glossary of terms commonly encountered in relation to photo voltaics.

The Guide is intended to give an idea of the variety and flexibility of PVs and of their design and aesthetic potential; if we as a design community are successful, our local and global environments will be enhanced.

2 What are photovoltaics?

2.1 Introduction

PV systems convert solar radiation into electricity. They are not to be confused with solar thermal panels which use the sun's energy to heat water (or air) for water and space heating. This chapter looks at PVs and examines a number of issues of interest to designers including:

- PV module size and shape.
- Colour.
- Manufacturing technology.
- Environmental issues.
- Energy production.

2.2 PVs

The most common PV devices at present are based on silicon. When the devices are exposed to the sun, direct current (DC) flows as shown in *Figure 2.1*. Appendix A provides a more detailed technical description of how PVs work.

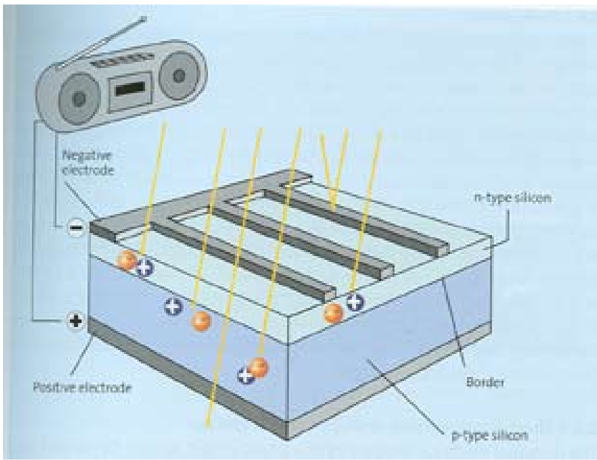

Figure 2.1 – Diagram of PV Principle

PVs respond to both direct and diffuse radiation (*Figure 2.2*) and their output increases with increasing sunshine or, more technically, irradiance, or solar "power", which is measured in W/m^2.

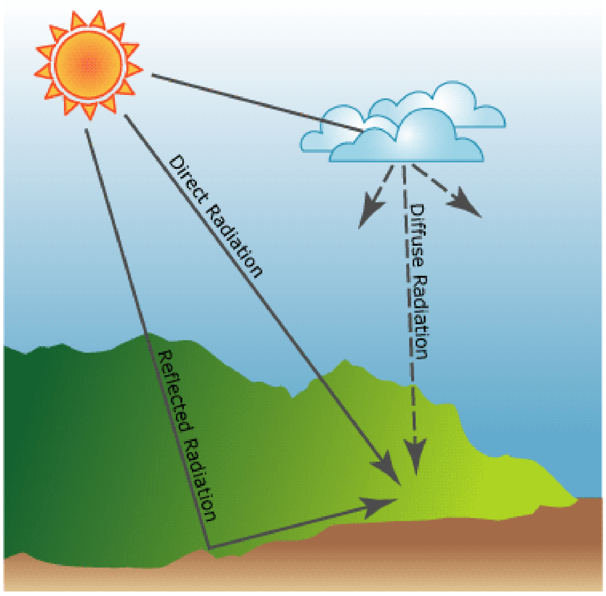

Figure 2.2 – Direct and diffuse radiation

PVs can be seen everywhere. They power calculators and navigation buoys, form the wings of satellites and solar planes, and are beginning to appear on cars such as the Bluecar from Bolloré/Pininfarina (See figure 2.3). Irish PV installations are also becoming more common, with installations such as that in the Irish Lights building (see *Figure 2.4*).

Figure 2.3 – Bluecar from Bolloré/Pininfarina

Figure 2.4 – Irish Lights PV installation

Common types of PV available are:

- ***Crystalline silicon*** – sliced from ingots or castings or grown from ribbons
- ***Thin film*** – photo-sensitive materials deposited in thin layers on a low cost backing, e.g. glass, stainless steel (produces lower efficiency cell than crystalline silicon). Typical photo-sensitive materials include amorphous silicon (a-Si), copper indium diselenide (CIS, CIGS) and cadmium telluride (CdTe).

In 2007, approximately 90% of PVs produced were of the crystalline silicon type. Thin film PVs are set to take a much larger market share in the future as advances in manufacturing techniques increase thin film efficiencies due to advantages of the need for less raw materials, low weight and a smoother appearance.

A typical crystalline cell might be 100 x 100mm. Cells are combined to form modules.

Table 2.1 shows typical efficiencies.

Cell material	Module efficiency [1]	Surface area needed for 1 kWp
Mono-Si	13-15%	c.7 m2
Poly-Si	12-14%	c.8 m2
Thin-film (CIS)	10-11%	c.10 m2

Table 2.1 Typical PV efficiencies[1]. (Standard Testing Conditions: 25°C, 1,000 W/m²)

Efficiencies are determined under standard test conditions (STC).
Theoretical maximum efficiencies are about 30%. Actual efficiencies are improving. In solar car races PVs with efficiencies of about 25% are being used. Novel approaches such as producing multi-junction cells which use a wider part of the solar spectrum are another aspect of a drive to increase efficiency.

It is also useful to keep efficiencies in perspective. A tree relies on photosynthesis, a process which has been functioning in seed plants for over 100,000,000 years and only converts 0.5-1.5% of the absorbed light into chemical energy[2].

A more hi tech example are power stations and the national electricity grid. Typically between 40 and 45% of the energy in the fuel burnt at the power station is converted into useful energy by the time it reaches your home.

Crystalline silicon cells consist of p-type and n-type silicon and electrical contacts as shown schematically in *Figure 2.5*.

1 European Photovoltaic Association (2008), Solar Generation V – 2008 – solar electricity for over one billion people and two million jobs by 2020.
2 Bowen, H.J.M., (1965), Introduction to Botany. Newnes, London, p.119.

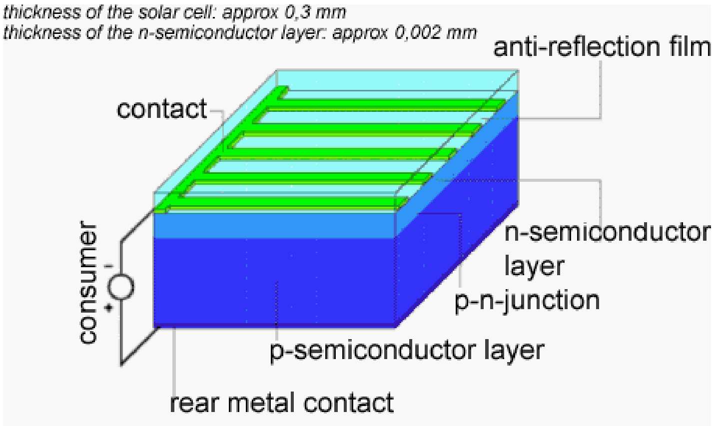

Figure 2.5 - Crystalline silicon Cell

The cells, which are of low voltage, are joined in series to form a module of a higher, more useful voltage. The modules (*Figure 2.6*) are constructed like a sandwich (and sometimes referred to as laminates) have a backing sheet and a cover of low-iron glass which protects the front surface of the material while maintaining a high transmissivity. A structural frame is used in a number of designs to protect the glass.

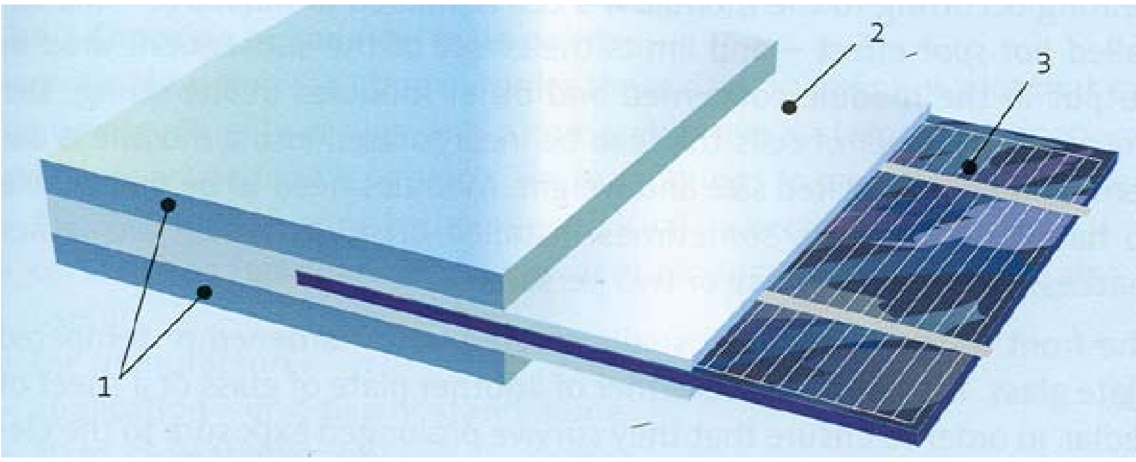

Figure 2.6 - Typical Module Constructions

The backing sheet need not, however, be opaque. The PV cells can be encapsulated between two layers of glass with transparent spacing between cells so that light passes through the transparent areas. This produces an effect inside the building which is similar "sunlight filtered through trees". Irish Lights Head Quarters uses this type of PV, as can be seen from *Figure 2.4*.

Thin film silicon (TFS) PVs using amorphous silicon are manufactured by a vapour deposition process. Between the p and n layers is the i (for intrinsic) layer. Overall, thickness is much less than with crystalline technologies, hence the name. Typically, the cells are laminated into glass but modules can also be made flexible by using plastics or metal.

Figure 2.7 - TFS using amorphous silicon

Modules electrically connected together in series (*Figure A.3*) are often referred to as a string and a group of connected strings as an array. An array is also a generic term for any grouping of modules connected in series and/or parallel. Power from the array (*Figure 2.8*) goes to a Power Conditioning Unit (PCU). PCU is a general term for the device (or devices) which converts the electrical output from the PV array into a suitable form for the building. Most commonly, the PCU has a principal component, an inverter (which converts DC to alternating current, AC) and associated control and protection equipment. PCU and inverter are sometimes loosely used interchangeably. The AC output from the PCU goes to a distribution board in the building or to the grid if supply exceeds demand.

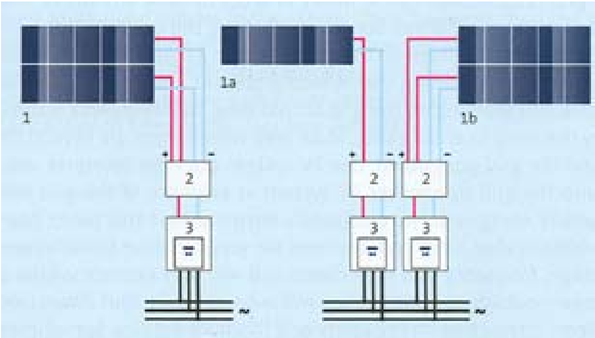

Figure 2.8 Schematic of a typical grid-connected PV system

Generally, grid-connected PV systems are most efficient when the array experiences uniform conditions. This tends to favour the same orientation and tilt for all modules, similar module and cell types and sizes, uniform temperature conditions and so forth.

Crystalline silicon modules come in a variety of sizes and shapes, although rectangular patterns of 0.3 m^2 to 1.5 m^2 have been most common.

Figure 2.9 shows the build up of a solar PV array from cell to module to panel to final array.

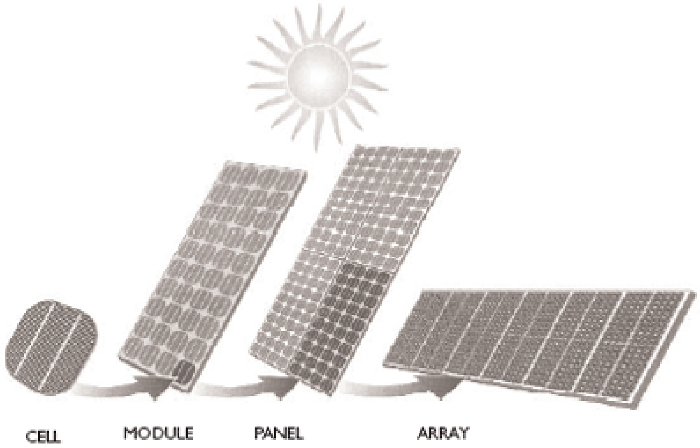

Figure 2.9 – Cell/Module/Panel/Array

The weight of a 0.5 m by 1.2 m framed module is about 7.5kg. The laminate (without the frame) is about 4.5kg. Larger modules are available to meet the needs of the building market. With larger modules cost reductions are possible through lower wiring costs and simpler framing arrangements.

Thin film modules are generally available up to 1.2m wide by 1.7m long. As an example, the modules at the BRE building in the UK are 0.93m by 1.35m. At the smaller end of the scale, in the US, amorphous silicon is being used for flexible PV roof tiles.

Monocrystalline silicon modules normally appear as a solid colour, ranging from blue to black. A wider variety of colours is available but at a cost of lower efficiency since their colour comes from reflection of some of the incident light which would otherwise be absorbed. As an example, magenta or gold results in a loss of efficiency of about 20%. Polycrystalline modules are normally blue (but again other colours are available) and have a multifaceted appearance which has a certain 'shimmer'. The appearance of TFS is uniform, with a dark matt surface, in some ways like tinted glass; colours include grey, brown and black. For all PV types it is best to see several installations to appreciate their varying aesthetics.

PVs have long lifetimes. Manufacturers generally guarantee module outputs of 80% of the nominal power for 20 – 25 years. Guarantees are designed to ensure, for example, that electrical integrity is maintained in a wide variety of varying weather conditions; the PV mechanism at the cell level itself is not the issue and will function, in principle, indefinitely.

Environmentally, PVs have the significant advantages of producing no pollutant emissions in use and, by replacing grid-generated electricity with solar energy used mainly on site, reducing CO_2, NO_x (nitrogen oxides) and SO_x (SO_2 and SO_3) emissions.

Energy is, of course, required for their production but the energy payback period (the time for the PV installation to produce as much energy as is required for manufacture) is in the order of 5 to 7 years.

A life cycle analysis has been carried out to examine other potential environmental impacts of PVs. In general for the manufacturing processes for crystalline silicon and amorphous silicon there are no environmental issues which raise concern[1].

Some reservations have been expressed about the environmental impact of new materials, particularly cadmium telluride (CdTe). However, the production process can be designed so that cadmium is not emitted and manufacturers are actively developing recycling techniques to avoid disposal problems. The prudent approach is to keep the situation under review.

2.3 How much energy do PV systems produce?

The output from a PV installation is the output of the PV array less the losses in the rest of the system. The output from the array will depend on:

- The daily variation due to the rotation of the earth and the seasonal one (due to the orientation of the earth's axis and the movement of the earth about the sun).
- Location i.e. the solar radiation available at the site.
- Tilt (*Figure 2.10*).
- Azimuth i.e. orientation with respect to due south (*Figure 2.10*).
- Shading.
- Ambient temperature (the efficiency of PVs is lower in higher temperature surroundings).

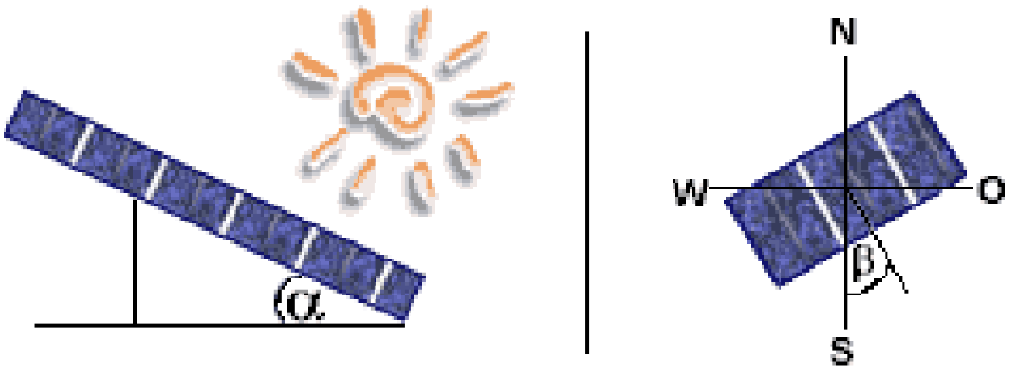

Figure 2.10 - Tilt (alpha) and azimuth (beta) for clarity

For purposes of standardisation and comparison, PV modules are tested at Standard Temperature Conditions (STCs) of 1000 W/m^2 and 25^{0}C. Thus a module of 1m^2 with an efficiency of 15% is rated at 150 W peak (Wp); note that this is DC (and is before conversion to AC).

Commonly used test standards within Europe are:

- IS EN 61215 Terrestrial Photovoltaic (PV) modules with Crystalline Solar Cells – Design Qualification and Type Approval
- BS EN 61646 Thin-film terrestrial photovoltaic (PV) modules – Design Qualification and Type Approval
- EN 61215 (2005) : Terrestrial Photovoltaic (PV) modules with Crystalline Solar Cells – Design Qualification and Type Approval
- EN 61646 (1977) : Thin-film terrestrial photovoltaic (PV) modules – Design Qualification and Type Approval
- IEC 61853-3 : Performance testing and energy rating of terrestrial PV modules
- EN 50380 – Data sheets

1 Environmental Resources Management, (1996), A Study Into Life Cycle Environmental Impacts of Photovoltaic Technologies. ETSU S/P2/00240/REP. ETSU: Harwell.

Manufacturers will often quote the kWp output of a PV panel tested to one of these standards in brochures and trade literature. For Building Energy Rating (BER) purposes, a test certificate is required to allow the benefits of PV systems to be recognised.
It is therefore recommended that the certificate or report is checked before purchasing any modules and is preferably obtained at the design stage before any time is committed to the design process. The certificate or report should be from a body which is accredited to carry out the tests. Further avialable is in the BER Dwelling Energy Assessement Procedure (DEAP) manual (Appendix M) available under http://www.sei.ie/DEAP.

Note that PV can help a new dwelling comply with the renewables requirement in Part L of the Building Regulations

The maximum power an installation can produce will usually be significantly lower than the peak power. One reason for this is that 1000 W/m^2 is a high level of solar radiation achieved only in very sunny conditions. The actual solar radiation received will often be less than this and will also be dependent on other such collector temperature, less than optimal orientation, overshading and so forth.
The ratio of the actual power output to the peak power output is known as the performance ratio.

For example, Ireland typically receives 900 kWh/m^2/year. This equates to an average of 100 W/m^2. Of course, this would be zero during the night and vary throughout the day. Some examples of hourly average solar radiation for representative months of the year for Dublin are provided in *Figure 2.11* below.

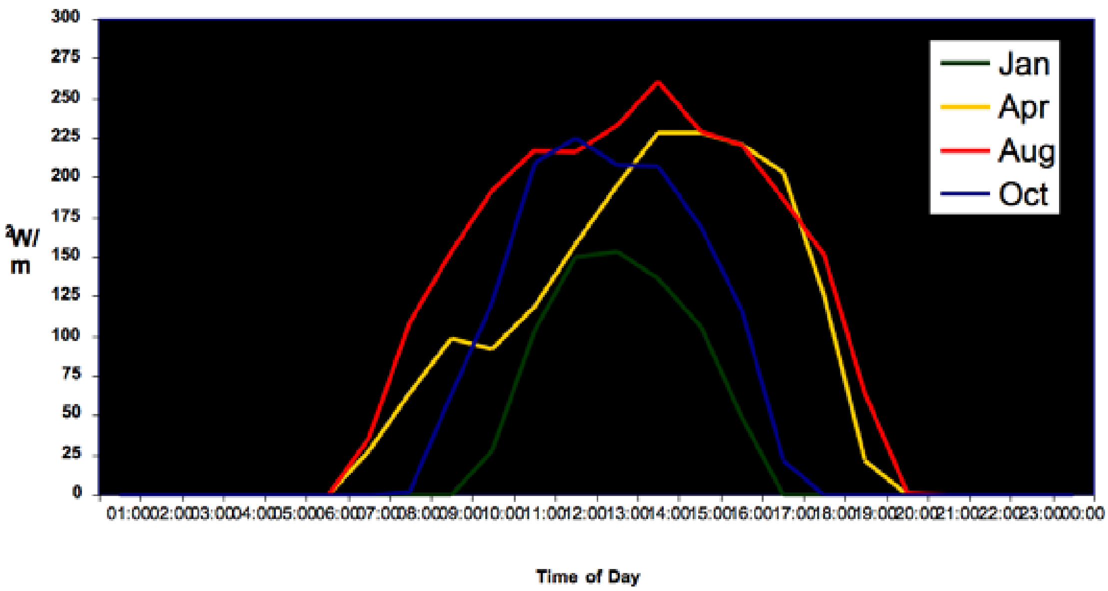

Figure 2.11 – Hourly Average Solar Radiation – Dublin (W/m^2)

2.3.1 Location, tilt, orientation and output

While the maximum theoretical output is of value, the more important figure for grid-connected systems is the annual energy production. *Figure 2.12* shows a solar map of Ireland and the UK and gives the maximum annual amount of energy available on a horizontal surface.

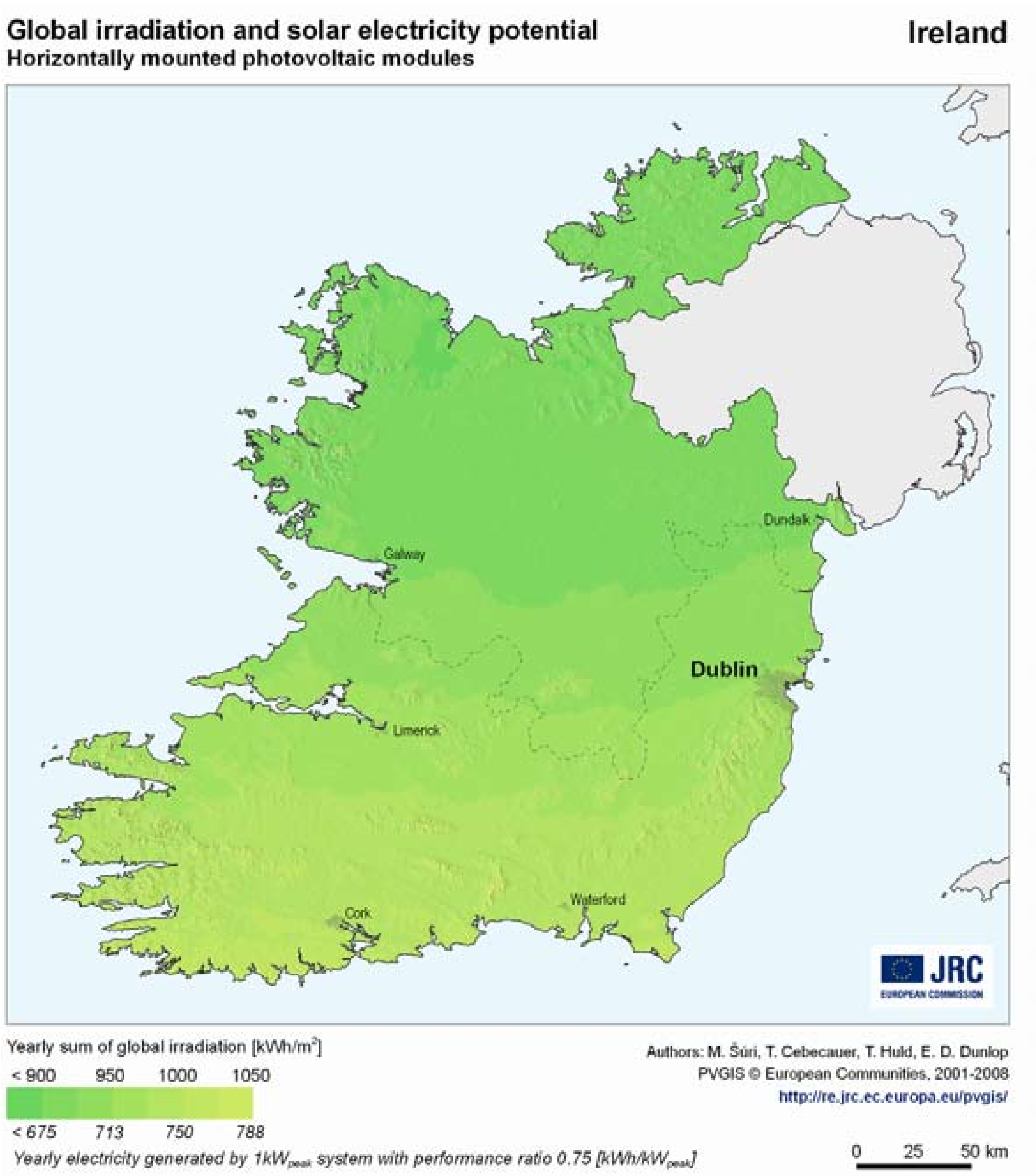

Figure 2.12 - Ireland annual average solar radiation (kWh/ m²/day)

While this is useful as a guide to the energy available what we need to know is the total annual solar radiation on a surface tilted so that the output is maximised.
Specialist computer software is available for estimating the output of solar PV systems. It is recommended that this approach is used at a detailed design stage for larger commercial installations. Suppliers will often be able to assist in this respect. For domestic installations and at an early design stage for commercial sized installations, T*able 2.2* can be used for estimating available solar radiation in Ireland.

Tilt of Collector	Orientation of Collector				
	S	SE/SW	E/W	NE/NW	N
Horizontal	963	963	963	963	963
15º	1036	1005	929	848	813
30º	1074	1021	886	736	676
45º	1072	1005	837	644	556
60º	1027	956	778	574	463
75º	942	879	708	515	416
Vertical	822	773	628	461	380

Table 2.2 : Annual Solar Radiation[1] (kWh/m²)

The maximum annual incident solar radiation (and hence output) is achieved at an orientation of due south and at a tilt from the horizontal of 30º. Slight deviations from these optimums will not have a significant effect on the solar availability. An encouraging aspect is that the total annual output is of the order of 95% of maximum over a surprisingly wide range of orientations and tilts.

The output of a solar PV array can be approximated by:

$$Output\ (kWh) = 0.8 \times kW_p \times S \times Z_{pv}$$

Where :

KW_p = installed peak power
S = annual solar radiation (from *Table 2.2*)
Z_{pv} = over shading factor (typically a value of 1 where placed on a roof with no shading)

Worked example:

For an array of 8 monocrystalline silicon panels (approx. 1.3 m² per panel) each with a peak power of 170 Wp, mounted on a roof with a 45º pitch facing directly south with no overshading, the total installed capacity would be:

0.170 x 8 = 1.36 kWp

The annual output would be:

0.8 x 1.36 x 1,072 x 1 = 1,166 kWh

1 DEAP Manual 2008, SEI

2.3.2 Overshading and temperature

Shading will depend on the geography of the site, neighbouring buildings and self-shading by the architectural forms, all of which are considered in the next chapter; the effects of overshading can be mitigated somewhat through system design.

Typical overshading factors as used in the previous worked example are provided in the Table below.

Overshading	% sky blocked by obstacles	Overshading factor
Heavy	> 80%	0.50
Significant	60% - 80%	0.65
Modest	20% - 60%	0.80
None or very little	< 20%	1.00

Table 2.3 - Overshading Factors[1]

The performance of PV modules decreases with increasing temperature (the drop in performance is more significant for crystalline silicon than amorphous silicon (Appendix A)).
Designs for building-integrated PVs need to consider this from the outset in order to allow air to flow over the backs of the modules to maintain high performance. It is also likely to be necessary with all types of module to avoid unwanted heat gain into the occupied space (which could cause discomfort and increase any cooling load).

Building-integrated modules can reach 20-40^{0}C above ambient in conditions of high radiation (Chapter 3). For each 10°C increase in cell temperature above 25^{0}C the power output decreases by about 0.4-0.5% (Appendix A). It is therefore important to ensure excessive temperature is avoided as far as possible.

The output is also related to the peak rating of the installation. As with the worked example above, the array of 8 panels is capable of producing 1,166 kWh/year or an average 3.2 kWh/day. If this is divided by the peak power of 1.36 kWp we have what is known as the final yield of 2.35 kWh/kWp/day; this is also sometimes seen expressed on an annual basis, in this case, approximately 857 kWh/kWp. Such figures are used to compare PV systems of varying characteristics, e.g. size.
So, the higher the expected kWh / kWp for an installation, the better.

Another common way of assessing installations is the Performance Ratio which is briefly mentioned in *section 2.4* and discussed in Appendix A.

1 DEAP Manual 2008, SEI

KEY POINTS

1. PVs produce DC which in grid-connected systems is converted to AC.
2. PVs respond to direct and diffuse radiation.
3. The more sunshine, the greater the output.
4. Efficiencies range roughly from 5-15%.
5. PV cells do not let light through but modules can be constructed so that some areas are transparent and some are opaque.
6. PV systems tend to be most efficient when the array experiences uniform conditions Designers can facilitate this.
7. Modules come in various sizes and shapes. Appearance varies with the type of PV.
8. A number of PV installations have been in operation for 15 years or more.
9. Energy payback periods for PVs are short provided the system is installed to optimise performance.
10. Designers have a key influence on the following factors that affect PV output:
    – Tilt.
    – Azimuth.
    – Shading.
    – Temperature.
11. For grid-connected systems the annual energy production is the key figure.
12. Exact orientation is not critical. A range of orientations and tilts give 95% of the maximum output.
13. Shading is to be avoided wherever possible.
14. Ventilation needs to be provided to remove heat from the modules.

FURTHER READING

1 Hill, R., (1998), PV Cells and Modules. Renewable Energy World, 1 (1), pp.22-26.

2 Anon. (undated), Photovoltaic Technologies and their Future Potential. Commission of the European Communities Directorate-General for Energy (XVII). EAB Energie - Anlagen, Berlin.

3 Studio E Architects, (1995), Photovoltaics in Buildings - A Survey of Design Tools, ETSU S/P2/00289/REP. ETSU: Harwell.

3 PVs on buildings

3.1 Introduction

For commercial buildings, the use of PVs may significantly influence the geometry, positioning and orientation of the builĺding to maximise their viability.

For domestic properties there is normally a part of the building, usually the roof, that lends itself to the location of PVs. However, if the opportunity exists it is worth thinking about the building design where it can be influenced to maximise the potential of PVs wherever possible. This is especially true where solar thermal panels are also being considered as there may be a limited amount of space suitable for mounting the panels.

PVs need to be considered as an integral part of the energy strategy of the building and of its functioning. The integration of PVs with the other building elements is critical to success. Appearance and aesthetics are, as ever, especially important. This chapter looks at the site, building type and load analysis - all factors in assessing the suitability of PVs. It then looks at the influence of PVs on the building. Because PVs are a high capital cost technology it is important to use them as optimally as possible.

3.2 The Brief

It is very important to start with a well-defined brief, i.e. a clear idea of what the objective is, and then to determine if PVs are applicable. If they are, they need to be part of the initial building concept and must comply with the architect's design needs as well as the engineer's functional ones.

Reasons to use PV include:

1. Energy costs
2. Environment
3. Security of supply
4. Demonstration / Education purposes
5. Architectural design / feature

The use of PVs should be part of the overall energy strategy for the building. Each project needs careful thought as the PV area required can vary enormously according to the desired objective.

PVs are worth considering if the following key factors are right:

- Location: The solar radiation at the site is important and the building on the site needs to have good access to it.
- Demand: The PV installation should be sized so as to optimise (in practical and economic terms) the amount of electricity which can be contributed to the overall electrical demand, e.g. Storage or stand-alone system?, grid-tied system?
- Design: PVs will affect the form and aesthetics - the community, the client and the designers all need to be satisfied with the result.

3.3 Site considerations

In brief, the more solar radiation and the more uniform the radiation is on the array, the better. The location of the site is of importance generally, as one goes farther north there is less solar energy available (*Figure 2.12*), e.g. Letterkenny receives less solar radiation than Cork on average over the course of a year.

The topography of the site should be studied. The local wind regime should be considered as part of the strategy for ventilating the building. The matter is complex because in the winter a microclimate with low wind speeds is to be preferred as it reduces heat loss due to infiltration. In the summer, some wind is preferable as it can improve comfort during the day, assist night-time cooling, and depending on the design, improve PV performance by reducing the temperature of the PV panels (see below). The strategy should be to achieve the right balance.

It is desirable to have a site with as little shading by hills and other geographical features as possible as this reduces the electrical output. Overshadowing by trees is to be similarly avoided wherever feasible. Because of the way PV modules are wired, shadowing from any source can have what might seem to be a disproportionate effect. This is explained in more detail in Appendix A. The implications for the architectural design are that obstructions are to be avoided wherever possible, whether they are telephone poles, chimneys, trees, other buildings or even other parts of the array itself. Where shading is unavoidable careful selection of components and configuration of the array can help minimise losses. In urban areas overshadowing by other buildings is common.

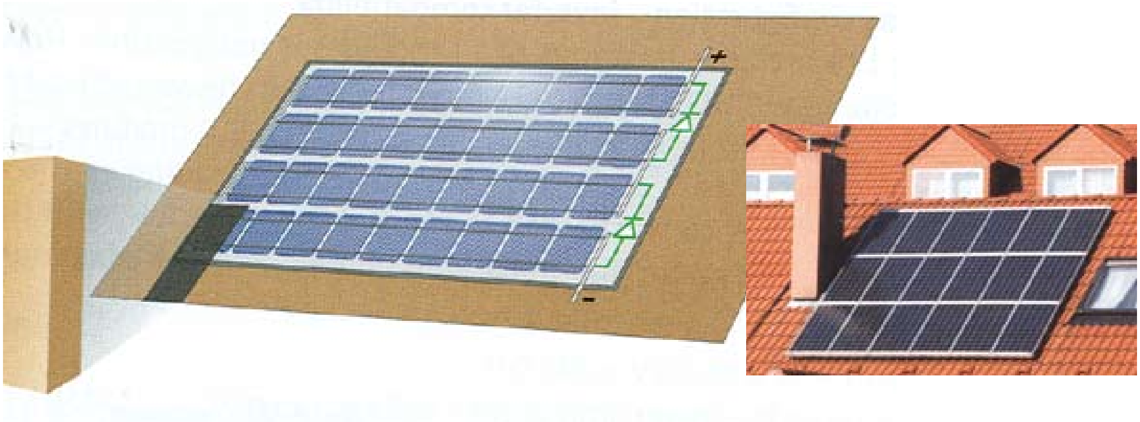

Figure 3.1 - Shading effects from building fixtures

Figure 3.2 - Self shading of PV modules

Orientation is important but there is some flexibility for designers. It is desirable to locate the building on the site so that a suitable PV mounting position is within ±20° of due south; this will permit collection of about 95% or more of the energy available at a variety of tilt angles (*See Table 2.2*); within ±30° of due south, the figure drops slightly. The principal difference between a surface orientated 15° east of south and 15° west of south is in the period of time the radiation is received rather than its total amount.

3.4 Building type

Generally, using as much of the energy produced by PVs in the building makes sense.
For domestic customers, there is a tariff available for installations in the microgeneration category *(see section 5.2).*

The amount of PV energy usable on site is related to the size of the array and the magnitude and pattern of the demand (Chapter 4).

A wide range of building types from offices to hotels to houses can use PVs. Office blocks have good PV potential because their electricity demand is significant year-round (including the summer) and because demand is highest between 9am and 5pm. Thus, the match between demand and PV supply is good.

Residential properties, on the other hand, are more challenging because the times of required demand are more intermittent and highly dependable upon the way in which occupants use the house. Grid connected systems work best with dwellings as the grid in effect acts as a storage device.

Feed in tariffs were introduced in Ireland in 2009 making this a good possibility for most installations. On-site storage using battery systems is a possibility but increases capital costs and complexity thus lowering the financial attractiveness of PV systems.

Commercial and industrial buildings with large roof areas available also offer significant scope for PVs.

Energy consumption varies with both type and the individual building, so a design should be carried out at an early stage of the design process. *Table 3.1* gives some indicative electrical energy demands.

Building Type	Electrical Energy Requirement (kWh/m²/year)
UK example : BRE Environmental building	36
Good Practice Office Building	53
Average Irish Dwelling	50
Low Energy House	15 - 25
Schools	20

Table 3.1 Annual approximate electrical energy requirement .

Figure 3.3 shows the electrical load pattern for the BRE Environmental Building in the UK which was designed to improve on 'best practice' by 30%. The building is not air-conditioned and the load is slightly higher in winter than in summer because of the need to run additional plant such as circulation pumps for the heating system.

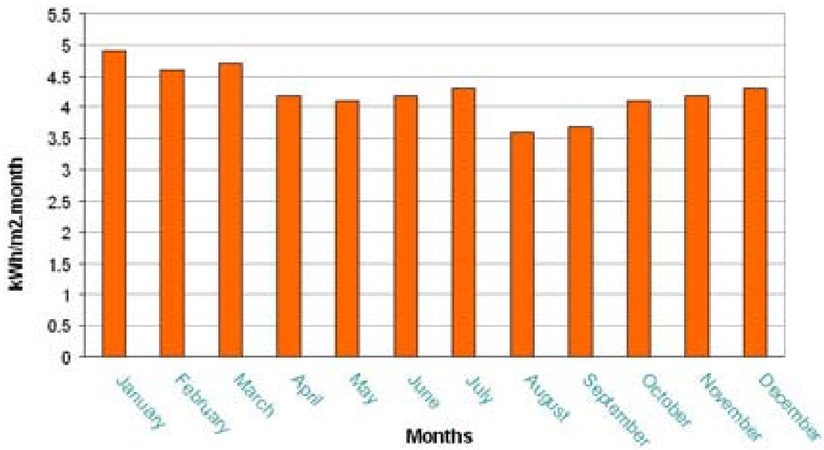

Figure 3.3 - Electrical energy demand of the BRE Environmental Building

Figure 3.4(a) shows a representative annual load pattern for a house (with non-electric heating) and the output from a 1.8kWp PV installation.

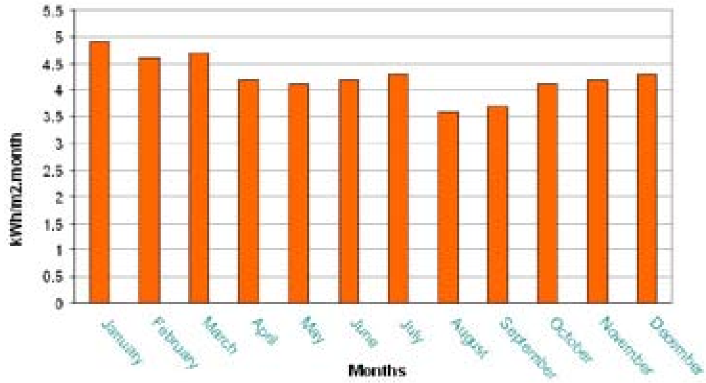

Figure 3.4(a) - Domestic electrical demands and PV outputs

Figure 3.4(b) looks at a representative daily power demand pattern for a five-person household (no two households are identical) and compares it with the output from a 3kWp PV installation.

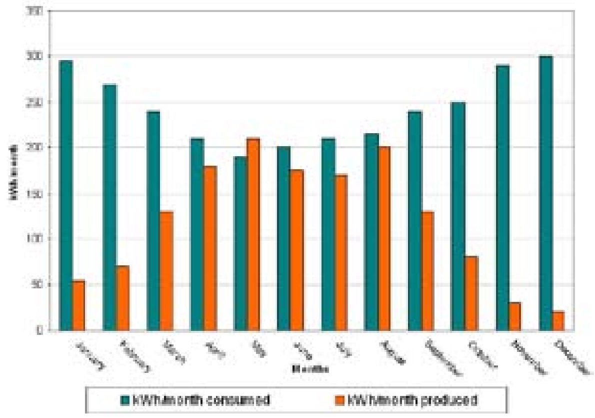

Figure 3.4(b) - Domestic electrical demands and PV outputs for a five person household

Note the variability of the daily load (due in part to some appliances with high power requirements being used but only for short periods) and the significant evening demand when the PV output is negligible.

If the site has good solar exposure and if the demand and supply pattern are reasonably matched, the design can be developed further.

Figure 3.5 shows the electrical load pattern for a junior and infant school with 300 pupils compared with the predicted output from a 440m^2 PV array. The school has a very low installed lighting load (12W/m^2). Note the much lower electricity consumption in August during school holidays.

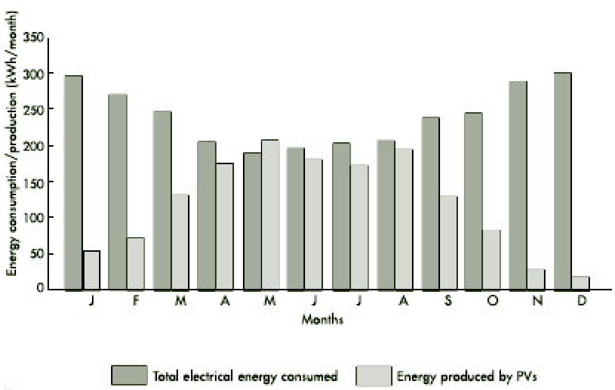

Figure 3.5 - Electrical demand and PV output for a school

3.5 Design and construction

A brief guides (or effectively constrains) the design process. A certain amount of floor area will need to be located on a particular site, access to daylight will be required in many of the spaces, costs will limit floor-to-ceiling heights, and so forth. An 'image' of the building usually results from the brief.
What PVs provide an additional use of the sun's energy to produce electricity.

If the question, "What difference do PVs make to a building" was asked, what would the response be?

Firstly, in construction terms, building-integrated PV systems need to play the same role as the traditional wall and roofing cladding elements they replace. Consequently, they must address all the normal issues, for example:

- Appearance.
- Weather tightness and protection from the elements.
- Windloading.
- Lifetime of materials and risks and consequences of failure.
- Safety (construction, fire, electrical, etc.).
- Cost.

In addition, there are a number of more particular aspects, often associated with being able to use the electricity produced, namely:

- Avoidance of self shading (as mentioned above).
- Heat generation and ventilation.
- Provision of accessible routes for connectors and cables (discussed in Chapter 5).
- Maintenance (discussed in Chapter 5).

As PVs can have a marked impact on a building's appearance it is important to consult with the planning authorities at an early stage to obtain their views on the proposals. However, smaller domestic installations are generally exempt from planning requirements if some simple design constraints are followed.

A summary of the planning exemptions is given below :

Statutory Instruments (S.I.) No's. 83 of 2007 and 235 of 2008 outline the exemptions which apply to PV installations on domestic premises and agricultural / business / commercial premises respectively. These S.I. documents can be found in the planning area of the legislation section on the Department of Environment website : www.environ.ie

However, Statutory Instrument No. 600 of 2001, outlines conditions and situations where the exemptions for solar PV do not apply. Local Authorities should still be contacted even if the proposed installation appears to be meeting the criteria of the planning exemptions, to investigate if Statutory Instrument No. 600 of 2001 is applicable or not. It is recommended that Local Authorities are contacted early on in the design stages so that unforeseen planning issues do not disrupt the project timeline.

Each local authority has drawn up development plans which designate areas, for example, as areas of special conservation, natural amenity or development potential. Should you go ahead with an installation and adhere only to the exemptions as per SI No. 83 of 2007 and SI No. 235 of 2008 you may still be in contravention of planning laws as outlined in SI No. 600 of 2001.

If we look at heat generation and ventilation there are three aspects of particular interest:

- The effect of potentially high temperatures.
- The desirability of ventilating the back of the modules to improve efficiency.
- The possible use of the heat from the back of the modules.

Potentially high temperatures

The potentially high temperatures associated with building elements specifically designed to capture the sun's radiation need careful consideration. The lifetime of materials, thermal movement, temperature cycling, suitability of electrical cables in high temperatures and so on need to be thought about carefully. In general, as long as the heat from PV modules does not build up and is removed by ventilation (normally, natural ventilation), there should not be a problem. As mentioned in Chapter 2, in conditions of high radiation, say 700-750 W/m^2, modules can reach up to 40°C above ambient temperature levels, approximately 70°C, but this will obviously depend on module design and building context. Higher temperatures can, however, occur and this should be discussed with the manufacturers or suppliers when considering modules.

Ventilation and modules

Chapter 2 also pointed out the importance of adequate ventilation to keep the temperatures as low as possible to improve module performance.
There are many ways of doing this, varying from ventilation gaps in rainscreen cladding (discussed below) to combining the module ventilation with the building ventilation (see case study in Chapter 6). A rule of thumb is to provide an air gap of 100mm. However, at least one study indicates that performance is improved with gaps up to 200mm or more[1].

Use of the module heat

For large scale installations, it is a possibility that heat given off at the back of the panels is of value during the heating season. It is possible to use it directly or to recover it by a system of ducting. However, an important question remains about the economical viability of doing this and there are not many examples in practice.

Other possibilities of using the waste heat also exist. For example, PV panels could incorporate water pipes linked to space or domestic hot water systems but tend to increase cost and complexity.

Outside the heating season, or more precisely anytime the heat is not needed, it is important that any heat recovery does not cause overheating and contribute to the building's cooling load. This requires consideration of the ventilation patterns in the building.

Thought should be given to ensuring that in windy conditions in summer heat from the modules does not lead to discomfort.

1 Brinkworth, B.J., Cross, B.M., Marshall, R.H. and Yang, H., (1997), Thermal Regulation of Photovoltaic Cladding. Solar Energy, 61(3), pp. 169-178.

3.6 Forms and systems

Continuing with the effect of introducing PVs into the brief, the next step might be to consider the design options.

There are three basic ways of integrating PVs in buildings:

- Roof-based systems.
- Facade systems.
- Sunshades and sunscreens.

Figure 3.6 shows a number of these; non-integrated options such as PVs on independent frames on roofs and PVs on walkways and other ancillary structures are not covered here but much of this Guide is also applicable to them.
The path to successful design lies between PVs imposing too great a constraint on the building and simply tacking PVs on to a form (most likely a box) that has already been designed. Real buildings have forms and angles that need to respond to more than the PV array output and this needs to be acknowledged in developing the design.

Figure 3.6 - Building-integrated PVs

Inclined roof

Roof with integrated tiles

Saw-toothed north light roof

Curved roof/wall

Atrium

Vertical

Vertical with windows

Inclined PVs with windows

3.6.1 Roof-based systems

Roofs have a number of attractions as sites for PVs:

- They are often free from overshading.
- The roof slope can be selected for high performance (*Figure 2.14*).
- It may be easier to integrate PVs aesthetically and functionally into a roof than a wall.

Table 3.2 lists the main systems available.

Position of PVs	System	Characteristic
1. Inclined roof	a. PV roof panels b. PV roof tiles	Combined with roof structural system. Roof tiles are familiar products and are likely to find easy acceptance.
2. Saw-tooth north light roofs	PV panels	Allow daylighting.
3. Curved roof	Opaque PV Extends design flexible substrate possibilities. (sheet metal or synthetic material) or rigid modules arranged on a curve	Extends design possibilities
4. Atrium	PV roof panels	As for the inclined roof. Variations include part-glazing, part-opaque PVs and semi-transparent PVs.

Table 3.2 - Roof systems

Note that saw-toothed roofs represent a family of designs. The most common has a north-facing vertical glazed surface for daylighting. Another design in the family is transparent PV skylights set into a 'flat' roof.

Ventilating roof systems

Roof systems are likely to be easier to ventilate than facade systems and any unwanted heat gains, being above the occupancy height, are likely to have less effect than for facade systems.
For inclined roof designs one approach is to have a sub-frame for mounting the PV modules onto the roof structure.

This allows an air space (at least 100mm if possible) between the modules and the roof structure (which can incorporate insulation). For many saw-toothed commercial and industrial roof designs, opening north lights can take away the heat.

3.6.2 Facade systems

Facades have significant potential. Much PV cladding can be considered to be panes of glass to which PV cells are applied and so the extensive experience of glazed facades can be built upon. In addition, modules can be easily incorporated into other proven systems such as rain-screen cladding. *Table 3.3* lists the main systems available.

Position of PVs	System	Characteristics and Comments
Vertical Wall	Curtain walling	Standard, economical construction. PVs can be mixed, i.e. some being opaque, some being semi-transparent
Vertical Wall	Rainscreen cladding	Rainscreen designs incorporate a ventilation gap which is advantageous in dissipating heat; the gap can also be used for running cables
Vertical Wall with Inclined Panels	Glazing or rainscreen cladding	PV efficiency improved. Complexity of construction increased. Potential to provide shading windows (if desired) but a degree of self-shading.
Inclined Wall	Glazing	Potentially enhanced architectural interest. PV output is improved compared with a vertical wall. Less efficient use of building floor area.
Fixed Sunshades	Glazing	Can enhance architectural interest. Entails a loss of daylight.
Moveable sunshades	Glazing	Can enhance architectural interest. Entails some loss of light but less than with fixed shades. Increased PV output compared with all fixed systems.

Table 3.3 - Facade systems

Curtain walling systems

Curtain walling systems are a well-established technology used in numerous prestige projects such as city centre offices. The mullion/transom stick system is the most common. Vision areas are normally double-glazed and non-vision areas are either opaque glass or insulated metal panels. PV modules can be incorporated easily as factory-assembled double-glazed units. The outer pane might be laminated glass-PV-resin-glass and the inner pane, glass, with a sealed air gap between; the overall thickness of the module would typically be under 30mm.
Numerous design options are available. For example, a facade could consist of a combination of glazed areas for vision and opaque PV panels or it could have PV modules with opaque areas and transparent ones.

Careful consideration needs to be given to the junction box positions and cable routing.

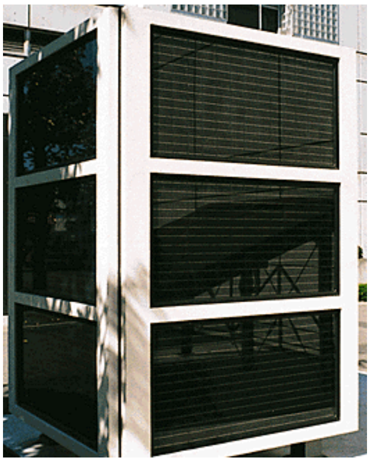

Figure 3.7 - Curtain walling detail

Rainscreen cladding systems

Rainscreen cladding systems normally consist of panels (often coated aluminium) set slightly off from the building (on, for example, cladding rails) to allow for drainage and ventilation. As such they are very suitable for PV integration. The ventilation gap (which needs to be adequate, e.g. 100mm or more if possible, and unobstructed) has the beneficial effect of reducing temperatures, thus enhancing performance; it also provides space for cable routes.

Figure 3.8 - Rainscreen cladding

3.7 What difference do PVs make?

Having reviewed the various systems, we can now return to the question of 'What difference do PVs make to building design?'

The main points to address are:

- Orientation.
- Footprint.
- Facade.
- Section.

A building orientated to the south for daylighting, passive solar gain and free of overshading is eminently suitable for PVs. Similarly, a footprint with the long axis running east-west thus giving a large south-facing wall area and potentially a large south-facing roof is advantageous for PVs.

The façade of a building is more complex.
It is important to remember that PV can be wall mounted as well as roof mounted, but can still be very beneficial in terms of contribution to the overall energy requirement of a building. A similarity can be drawn to a window, which is a very simple "passive" element of a building, which provides free energy gains to a building (heat and light).
How much of a south facade should be glazed for daylighting and how much allocated to PV modules? Should a roof be all PV panels? Or none? Or something in between?

In practice the conflicts are resolved during development of the design and the solutions are building-specific and relate back to the brief. For example, one reason a south-facing facade is unlikely to be 100% glazed is that it would probably lead to overheating (or high energy consumption for cooling) in summer. Low-energy offices, for example, have approximately 30-45% of the south facade as glazing. Thus, PVs could readily be used in much of the 55-70% of the wall that is normally opaque.
The effect on the section will depend on the size of the PV array and the system selected. Taking the easier case of the roof first, if the PVs are roof-mounted the section will tend to offset the east-west ridge to the north and perhaps vary the roof tilt angle to improve PV performance. The south facade could remain vertical or might be tilted back. The impact of façade and roof mounted PV on the design U-Values of wall / roof should also be investigated.

In the case of dwellings which must comply with Part L 2008, PV can help achieve the requirement for renewable energy contribution of 4 kWh/m2a of electrical renewable energy as per the Technical Guidance Document Part L 2008 for dwellings (www.environ.ie/en/TGD)

For all buildings which fall under the buildings regulations part L 2008, It should be noted that the building as a whole, incorporating these products, must comply with all Parts of the Building Regulations.

Issues of particular relevance where, for example, roof mounted PV is fitted may include: weather tightness, fire safety, structural safety etc. Third party certification bodies e.g. NSAI/IAB are available to assess compliance with all parts of the Building Regulations.
When installing these products, reference should be made to the following :

-BRE Digest 489 : Windloads on roof-based photovoltaic systems.
-BRE Digest 495 : Mechanical installation of roof-mounted photovoltaic systems.

KEY POINTS

- PVs need to be considered as an integral part of the energy strategy of a building.
- Appearance and aesthetics are key issues.
- PVs make a positive contribution to the environment.
- It is essential that shading (by topographical features, other buildings, or features of the PV building itself) be minimised so as not to impair performance.
- There should be a good match between the building's energy demand pattern and the energy available from the PV array.
- PV modules need to be adequately ventilated so as to lower temperatures and thus maintain good performance.
- There are a wide range of architectural ways of successfully integrating PVs with buildings and, in particular, roof and facade systems.
- PVs can affect the orientation, the footprint, the facade and the section of buildings.

FURTHER READING

Photovoltaics for professionals – Solar Electric Systems Marketing, Design and Installation.

4 Costs and sizing

4.1 Introduction

This chapter discusses the inter-related issues of costs and sizing.

4.2 Costs

Costs and returns will be project specific and will largely depend on the way the building is used.

It is always recommended that a suitable professional is used to carry out a feasibility assessment of any installation. PV supply and installation companies will normally be well placed to offer this service as part of the overall package for domestic and small commercial installations. For larger installations, consultants specialising in renewable technologies or the supply / installation companies are well placed for carrying out a feasibility study.

The same general approach can be used in most situations when carrying out an initial feasibility assessment.

As a rough guide, a typical domestic installation will cost in the region of €1,000 / m^2 or €10 / Wp of PV panel installed including associated equipment, grid connection and installation. Approximate cost breakdown of total system component costs is provided in *figure 4.1*.

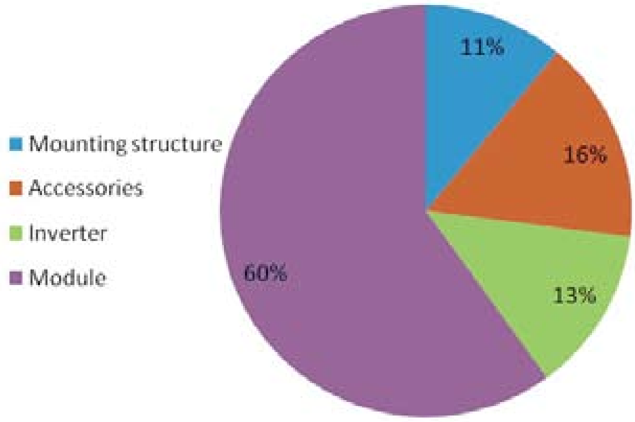

Figure 4.1- Approximate cost breakdown of domestic PV system

For commercial size installations the unit costs will be lower but these are more difficult to predict because the buildings will be less standardised.

One benefit of building-integrated PVs is that the cost of the elements they replace can be offset against the PV cost. For a domestic installation this would be the saving in cost of roof tiles where the PV panels are located. For a 10 m^2 array this would be in the region of a €250 saving in materials in terms of tiles.

Hardware costs for PV systems have fallen over recent decades. This trend can be expected to continue as production output increases and manufacturing techniques improve.

Other cost issues, energy saved over the lifetime of the installation and cost per kWh are examined below.

4.3 Sizing the array

In sizing a grid-connected PV array there are a number of key points to keep in mind:

- On-site use of energy: For a given installation the more of the energy that can be used on site the better; this is principally because, given the current price differential between purchased and sold electricity, using the energy on site makes more financial sense.
- Contribution to the overall load: Sizing is usually on the basis of a contribution to the overall load for the building rather than to meet a particular load (e.g. lighting).
- Contribution to the annual load: Usually, sizing is to determine the contribution to the total annual load but one can also consider the contribution to the annual load during daylight hours.
- Available area: The available roof and facade area may restrict the array size, particularly in smaller installations such as houses.
- Budget: Often the available budget is the dominant constraint.

The approach outlined below is to help designers make broad decisions; actual sizing is normally done with a computer model (often a PV manufacturer or supplier) and real weather data. However, for domestic installations it is normally more cost effective to use a rule of thumb approach based on feedback over a number of years from actual installations or a simplified approach. Experienced installers will be able to provide good estimates of the size of panels that make economic and practical sense for domestic installations.

Given a particular location with its solar input, a PV module type and a brief for a building, what is a sensible size of array and what will its output be? And what are the costs?

Two examples are given below. One for a commercial office installation and one for a typical domestic installation.

Example 1: Commercial Office Installation

In this example, the objective is to provide a reasonable quantity, 40%, of annual electricity demand for a 1,000 m^2 commercial office building with an annual electricity demand of 28,800 kWh. Base summer and winter loads are 15 kW and 20 kW respectively.

Assume:

- 170 Wp / panel
- 1.3 m^2 / panel
- €1,500 /m^2 building construction costs.
- €800 / panel PV panel installation costs
- PV panels south facing with 30° tilt
- Electricity Cost = €0.1733 / kWh (based on standard business tariff October 2009 www.sei.ie/statistics - Fuel Cost Comparison)
- PV panel life = 25 years

Step 1: Area of PV panel required to provide 40% annual electrical demand.

For panels facing south with a 30° tilt the annually available irradiation is *1,074 kWh/m^2/year.*

One m^2 of PV panel is capable of providing:

0.8 x (0.17/1.3) x 1,074 x 1 = 112 kWh/year

40% of annual demand = *0.4 x 28,800 = 11,520 kWh*

Size of panels required to provide 40% demand
11,520 / 112 = 103 m^2

Peak Output
103 x (0.17/1.3) = 13.4 kW

PV System Cost
*(103/1.3) * €800 = €63,384*

Electricity Produced Over 25 Years
11,250 x 25 = 281,250 kWh

Cost per kWh Produced
63,384 / 281,250 = €0.225/kWh

The unit cost of all PV electricity produced falls with increasing array size because of economies of scale. More altruistic clients who would like to reduce CO_2 emissions for society as a whole could opt for larger arrays.

Table 4.1 summarises this and some related data

Building floor area	900 m^2
PV array area	103 m^2
PV nominal array rating	13.4 kW_p
Installed cost of the PV system	€63,384
PV output used within the building	11,250 kWh/y
Contribution to annual electrical demand	40%
PV output used within the building over a 25 year lifetime	281,500 kWh
Simple cost (per kWh) of installation over lifetime	€0.225/kWh

Table 4.1 - Basic data for an example commercial office building PV installation

Example 2: Domestic Installation

In this example, the objective is to provide 15% of annual electricity demand using PV panels for a domestic house with an annual electricity demand of 7,500 kWh.

Assume:

- 170 Wp / panel
- 1.3 m^2 / panel
- €1,700 /m^2 building construction costs.
- €1,000 / panel PV panel installation costs

- PV panels south facing with 30° tilt
- Electricity Cost = €0.19 / kWh (based on standard tariff December 2008)
- PV panel life = 25 years

Step 1: Area of PV panel required to provide 15% annual electrical demand.
For panels facing south with a 30° tilt the annually available irradiation is 1,074 kWh/m^2/year.

One m^2 of PV panel is capable of providing :
0.8 x (0.17/1.3) x 1,074 x 1 = 112 kWh/year

15% of annual demand = 0.15 x 7,500 = 1,125 kWh

Size of panels required to provide 15% demand
1,125 / 112 = 10 m^2

Peak Output
10 x (0.17/1.3) = 1.31 kW

PV System Cost
*(10/1.3) * 1000 = €7,692*

Electricity Produced Over 25 Years
1,125 x 25 = 28,125

Cost per kWh Produced
7,692 / 28,125 = €0.274/kWh

Table 4.2 summarises this and some related data.

PV array area	10 m^2
PV nominal array rating	1.31 kW_p
Installed cost of the PV system	€7,692
PV output used within the building	1,125 kWh/y
Contribution to annual electrical demand	15%
PV output used within the building over a 25 year lifetime	28,125 kWh
Simple cost (per kWh) of installation over lifetime	€0.274/kWh

Table 4.2 - Basic data for an example domestic building PV installation

4.4 The future of PV costs

Costs have fallen significantly over the past 10-15 years and are expected to continue to do so. The driving forces for this include:

- Increased module efficiencies. For example, efficiencies of crystalline silicon modules.
- Development of lower-cost thin film and other technologies.
- Lower production costs as a volume market leads to, for example, improved manufacturing techniques and starts to drive costs down.
- Reduced system costs. For example, the costs of components such as PCUs are expected to fall.
- Reduced installation costs as the market develops and experience is gained.

In the meantime, PVs in buildings provide direct environmental advantages and also serve as a statement of environmental interest.

An important environmental benefit is a reduction in CO_2 emissions. In the examples above, which can be taken as representative, each square metre of PV panel will prevent approximately *1,500 kg of* CO_2 emissions over a 25 year lifetime[1]. (This includes the CO_2 emissions avoided by exported energy.) At present, it is rare to find projects where the environmental cost of CO_2 pollution has been attributed as a real cost. However, with the advent of energy rating labelling of buildings, the contribution to CO_2 emissions will be more apparent.
The current Building Regulations Part L (New Dwellings) require that a minimum quantity, expressed in kWh/m^2/year, of delivered energy consumption as calculated using the Dwelling Energy Assessment Procedure (DEAP) is provided using a renewable source.
Common technologies that are able to contribute to this requirement include biomass boilers, biomass stoves, solar thermal systems, small scale wind and PVs. The amount of electrical energy required is less than for heating technologies, e.g. 10 kWh/m^2/year for heat energy, 4 kWh/m^2/year for electrical energy.

The building regulations are revised on a regular basis. A detailed description of requirements is therefore not given here. Current and previous versions of the building regulations can be freely downloaded from www.environ.ie/en/TGD.
On-site electrical micro-generation can have a significant impact on a dwellings carbon emissions and are capable of meeting the building regulation requirements as standalone technologies. The use of PV will generally also give a significant boost to the energy rating (BER) of a dwelling.

1 Based on 0.533 kg CO_2/kWh electricity emission factor for 2008 (Source : EPSSU, 2010)

KEY POINTS

- The cost of PVs can be offset against the cost of the building elements they replace. Nonetheless, PV costs are presently high.
- Sizing a PV installation tends to be an iterative process in which energy requirements, area available and costs are examined.
- PV electricity replaces conventionally-generated power and so provides an environmental benefit of reduced CO_2 emissions. At present this is difficult to evaluate monetarily.
- PV systems can make a significant contribution to meeting the requirements of Part L of the building regulations with respect to renewables requirments while also improving the building energy rating (BER).

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2. ECOTEC, ECD and NPAC, (1998), The Value of Electricity Generated from Photovoltaic Power Systems in Buildings. ETSU S/P2/00279/REP. ETSU: Harwell.
3. Ibid., p. 23.
4. Ibid., p. 23.
5. Ibid., p. Case 2a.wk4.
6. Greenpeace with original research by Halcrow Gilbert Associates, (1996), Building Homes with Solar Power. Greenpeace, London.
7. Solar Radiation data is available from a number of sources including the CIBSE Guide.
8. See reference 2, p. 84.
9. See reference 2, p. 52.

5 PVs in buildings

5.1 Introduction

Having determined that PVs are suitable, and having done an approximate load analysis and sizing of the array, the designer can move on to selecting the components and developing their integration within the building. This chapter examines a number of these aspects of the PV system.

5.2 Grid-connection and metering

Figure 5.1 shows a grid-connected PV installation.
The actual design will require the services of electrical engineers. Note that the inclusion and arrangement of components will also vary with the system and the manufacturers.

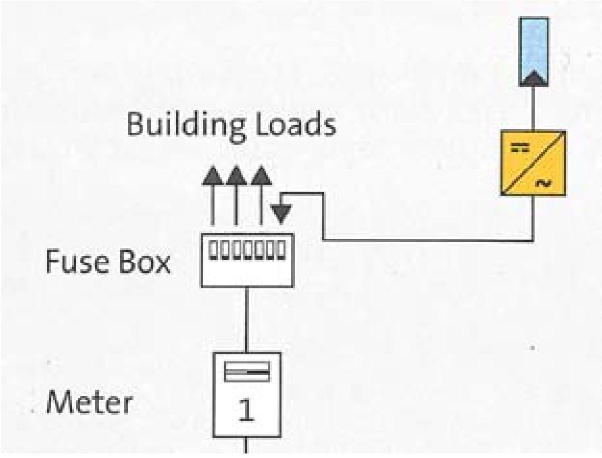


Figure 5.1 - A grid-connected PV installation

Starting with the grid, it is essential to contact the electricity supplier and / or national grid company early on and obtain its permission to connect, whether or not any electricity will be exported to the grid. Clients with grid-connected PV buildings will need to ensure that the installation will cause no safety hazards and will comply with technical regulations and recommendations, and that the quality of the power will be acceptable for export to the grid. For example, the grid's electricity suppliers are likely to require that, in the event of a loss of mains power, the PV installation will close down automatically. This is to give the grid maintenance engineers a non-live system on which to carry out repairs.

It is also important to check early on whether your electricity supply company will pay for any electricity exported as this has an impact on the economics of the system (as mentioned in Chapter 4). From 2009, electricity suppliers in Ireland will be making export tariffs available to micro-generators representing a significant step forward for the micro-generating technologies.

Whether there will be any significant additional charges for operating a grid connected micro-generator should also be checked.

Metering grid-connected systems is an area currently in flux. Smart meters are now generally available but the cost responsibilities should be clarified with the electricity supply company. Leaving aside the more technical considerations, the basic options are:

- One-way metering: Metering on the incoming supply and no metering on the PV output.
- Smart meter – records imports and exports as well as time of day of the import or export.

The metering strategy to adopt will follow from discussions with the supplier and be influenced by end user requirements. A smart meter would be recommended as it will be cheaper to install during the initial build rather than retrofitting one in the future.

Getting set up for a grid connection in Ireland is straightforward.
Your chosen supplier could take care of the documentation necessary. It is a straightforward form so should be done at no extra cost. They should also take care of the hiring of a RECI or ECSSA certified electrician to carry out the connection to ETCI standards as part of their service.

Form NC6, available from the ESB Networks website, should be submitted well in advance of any grid tie-in.

NC6 is a straight forward one page form which includes:

- Name, address and co-ordinates of the site
- Contact details
- MPRN number
    - Unique number assigned to each meter point
    - Printed on the top of your bill
- Installer contact details
- Make, model and serial number of inverter (grid connected electronics)
- Declaration of conformance with "Conditions governing the connection and operation of microgeneration" including EN 50438.
- Details of generating unit
    - Make and model
    - Type of technology (wind, PV, micro-hydro, micro-CHP etc.)
    - Unit Rating and phases generated
- Details of inverter unit.

Type-test certification for the inverter (the unit tying the system into the grid) should accompany the NC6 form. The certification required should declare conformance with EN50438 which is the appropriate standard for grid connected units. The suppliers should provide you with this paper work if you are submitting the NC6 form yourself.

You will need an import/export meter to avail of any payment for exported energy. The import/export meter currently available in Ireland is referred to as an 'interval meter'. It is now supplied automatically and for free to customers when they submit the NC6 form.

Feed-In-Tariff

ESB Customer Supply and ESB Networks both intend to offer payment for export to domestic customers from 2009. An import/export meter must be installed to avail of payment.

Details of the proposal from ESB Customer Supply can be viewed on their website. An application form must be filled out and sent to ESB Customer Supply. Before applying for the export payment you must have concluded the 'inform and consent' process with ESB Networks.

- **9c/kWh** available from ESB Customer Supply
- Scheme is only open to ESB Customer Supply domestic customers
- Scheme has upper limit of 11kW generating unit (as per rating (kWp) of installation)
- Installation of interval meter (import/export meter) required (free to first 4,000 applicants)
- Payment for export will be settled once every 12 months
- Expansion of the scheme to commercial or agricultural customers being considered.

Customers of other electricity suppliers should contact their suppliers to request a similar facility.

The Comission for Energy Regulation (CER : www.cer.ie) has a list of active electricity suppliers on its website. Airtricity and Bord Gáis Energy are the other suppliers to the Irish domestic market at present.

Further to the 9c/kWh offering from ESB Customer Supply a further **10c/kWh** payment from ESB will be available to a portion of the output from the first 4,000 microgenerators connecting in the next 3 years. The payment will be available to all microgenerators and not just ESB Customer Supply customers. The 10c/kWh payment will apply to the first 3,000 kWh exported each year for the next 5 years. This will bring the total export payment available to domestic customers to **19c/kWh** for the first 3,000 units exported, reducing to 9c/kWh thereafter.

5.3 System considerations

The building main switchboard in a typical domestic installation is single phase 230V AC and, in larger buildings, three phase 415V AC. Thus, the DC output of the PV arrays (*Figure 5.1*) needs to be converted to AC. PV modules are output at 12v (approx) or 24v (approx) (this may in fact be 18.5V at maximum power for a typical monocrystalline module). The modules are normally connected in such a way as to produce a higher voltage from the array (*Figure A.4*) with the exact voltage depending on the system. In electrical systems, up to 120V DC is defined as extra low voltage and from 120V to 1500V DC is low voltage. A broad range of voltages from, say, 50V to over 700V is in use in building-integrated PV applications. The choice of voltage is determined by a number of conflicting factors. Higher voltages are favoured because of lower power losses but lower voltages tend to be safer. Array configuration, PCU selection and cable selection are also important considerations.

Figure 5.2 – PCU

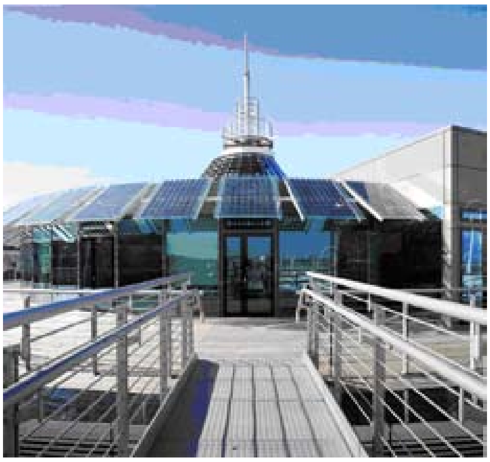


Figure 5.3 – Irish Lights PV installation (2nd image)

Power Conditioning Units

A PCU such as the one shown in *Figure 5.2* is integral to the optimal and safe operation of the PV installation. In grid-connected systems it is likely to contain:

- An inverter for DC to AC conversion.
- A maximum power point tracker (MPPT) (Appendix A) which may be part of the inverter.
- Protection devices on the DC side.
- Protection devices on the AC side/utility interface.

The inverter converts the DC output of the array to an AC which is compatible with the grid's voltage, phase, power factor and frequency characteristics. Inverters can operate over a range of voltages - for example, an inverter set at a voltage range of 75-150V DC and converting to 240V 50Hz AC.

The array has been divided into two halves, or sub-arrays, each supplying one inverter. This can be a way of reducing DC cabling losses but needs to be balanced against the cost of two inverters rather than one.

In *Figure 5.3(b)* string inverters are shown. These can similarly help reduce the amount of DC wiring required for larger installations and also lead to lower voltages.

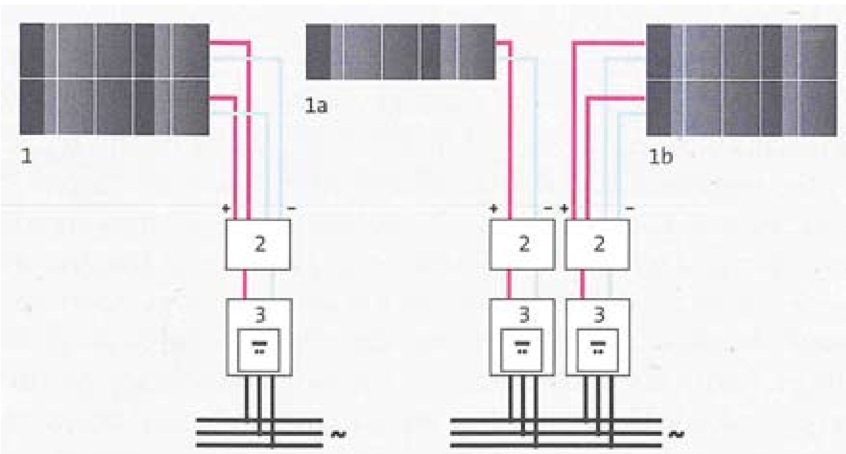


Figure 5.4 - Alternative inverter arrangements

Correct inverter selection is essential because the electrical output of the system depends greatly on its performance. Given the high capital cost of PV systems it is important to optimise the value of all components including the inverter.

The choice of inverter depends on a number of factors including the module configuration, accessibility, cost, overshading, and the space required for the equipment.

In Ireland the installation will usually be operating at well below the nominal array power. An approximate estimate is that the average output during daylight hours might be only 15-20% of the nominal array rating. Normally an inverter will be selected on the basis of the following:

- Rated power: The inverter rating is normally 75-80% of the array rating. This is discussed in Appendix A.
- Efficiencies: Modern inverters can achieve efficiencies of over 90%.
- Self consumption losses: A small amount (say 0.5 - 4%) of the rated DC power is needed for the inverter to operate.

Inverters may also incorporate the utility grid interface and provide an automatic disconnect feature if the grid supply is lost and automatic restart after the grid fault is cleared.

Although inverters are electronic solid state devices and have no moving parts they can produce a humming noise. This and their need for ventilation are discussed below.

PV systems (as other electrical systems) have some significant advantages over water-based solar heating systems in that they are easier to design, install, operate and maintain. In addition, compared to other electrical systems, PVs with their lack of moving parts and high reliability of components require little maintenance. Maintenance of the array exterior simply consists of cleaning the glass to remove grime and dust occasionally as part of a normal building maintenance programme.
The PCU should be checked from time to time in accordance with the manufacturers' instructions. PCUs are normally guaranteed for one or two years and have an expected lifetime of 20 years or more. PV modules and PCUs specified should meet the relevant international standards.

Safety

The integration of PVs with the building should be considered in terms of construction and access for maintenance, in the normal way.

Safety is a standard consideration with all electrical installations. Contact with the front surfaces of the modules poses no danger. The particular issues that apply to PVs are:

- Electrical current is produced during a wide variety of light conditions and so to 'switch off' the installation one needs, for example, to cover the modules with something opaque.
- There is less familiarity within the building industry with DC compared with AC.
- Voltages can be higher than the commonly seen 240V single phase AC.

Safety issues should be well documented for both installers and maintenance personnel.

Earthing and Lightning Protection

The basic issues are set out briefly in Appendix A.

Monitoring

Monitoring of the installation is useful because, as a minimum, it allows identification of any problems in operation and helps the performance of the system to be reviewed. More extensive monitoring will provide additional information such as a detailed comparison of actual output with initial predicted figures.

5.4 Modules and cables

Normally PV modules have junction boxes at the rear which contain space for connections and may contain bypass diodes (see Glossary). The modules are normally linked by 'daisy chains' (i.e. cables loop in to one module and then out to another).

Figure 5.5 - Junction / combiner boxes

Cables join the PV components together and as for any electrical installation they need to be suitable for their environment and for the loads carried. Thus, where cables are run in areas subject to heat build-up at the rear of modules, their size will need to be increased to allow for the higher temperatures. Similarly, if cables are run where water vapour can enter, e.g. in rain screen cladding systems, the cables, cable ways and junction boxes must be suitably selected.
Cables should generally be inaccessible to occupants but accessible to maintenance personnel.

Cables are usually double insulated and may be single core or multi-core. A technical issue worth mentioning here is that, with PVs, protection against certain potential conditions such as faults to earth need to be dealt with at the design and installation stage -specialists will advise on the measures (which are likely to include double electrical insulation) to be taken.

Wiring routes should be as short as practical to facilitate installation and to minimise cost and voltage drop. A rule of thumb is to limit the voltage drop from array to PCU to 2.5% or less. An example of cable size is given in Chapter 6.

The numerous cables involved obviously need to be considered carefully to avoid marring the building's aesthetics. This is a particularly important issue with PV cladding systems and also where arrays are semi-transparent.

5.5 Plant / Equipment Rooms

Ideally the plant room will be as close to the PV array as possible for ease of routeing and to minimise energy losses in the cables.
In a domestic installation of say 3kWp the PCU might be wall-mounted inside a closet along with the incoming mains supply and meter. The PCU might take up a space 600mm high by 400mm wide by 150mm deep.

In larger buildings the plant room is likely to have the following:

- The DC switchgear.
- The PCU.
- The main AC switchgear.
- The mains incomer and meters.

If the PV installation is monitored as is recommended, space should also be allocated for the equipment.

The space requirement for the DC switchgear and the PCU is obviously additional to that of the normal electrical plant room and will vary with the size of the installation.

At the 2kWp BRE Environmental Building in the UK, the DC switches and PCUs are wall mounted and the additional space requirement is no more than, say, 1.5m^2 of floor space.

At the 39.5kWp Northumberland Building (*Figure 3.6(h))* the approximate dimensions of the DC switch panel and the PCU are 2.0m W x 2.0m H x 0.4m D and 2m W x 2m H x 0.6m D, respectively. The floor area used is about 12.5m^2 (but perhaps could be reduced slightly especially in the light of the installation being over 10 years old and significant technology advances have reduced the size of equipment since its installation). A very rough rule of thumb is an additional plant room area equal to 3-5% of the array area is required if a single PCU or several large sub-array PCUs are used.

Small PCUs are generally quiet in operation but larger units can produce a significant 'hum' as mentioned above. One guideline for specifiers suggests a limitation of 55dBA for PCUs (a modern, "quiet" dishwasher produces about 45-50dBA).

Switchgear is robust and will function adequately at temperatures from -4^{0}C to 40^{0}C; it must of course be protected from the weather. The manufacturers' requirements should be checked for both switchgear and PCUs. A typical large PCU might require a temperature range of 1^{0}C to 38^{0}C. As much as 5-10% of a PCU's nominal output can be lost as waste heat and so ventilation will be required to prevent excessive temperatures. Normally, supplementary heating will not be needed but, as this depends on the building construction, the ventilation system etc it needs to be checked for each building.

Access to the plant room should be restricted as is common practice.

KEY POINTS

- Grid-connected PV installations convert DC from the PV arrays into AC for use in the building with any unused power being exported to the grid.
- There are a number of alternative array configurations and inverter arrangements. The selection will depend on factors such as module configuration, accessibility, cost, overshadowing and plant room planning.
- PCUs have an expected lifetime of 20 years or more.
- Safety is very important. The nature of PV is such that it always produces energy when exposed to light, so it is crucial that experienced, qualified and trained personnel and products are used to design and install the system. See the SEI microgeneration register of products and installers on the microgeneration page of the SEI website for further information : www.sei.ie/microgeneration
- Monitoring of the installation is useful for identifying any problems and for reviewing performance.
- PV cable runs need to be integrated with the building design.
- Plant room space needs to be allotted for the PCU and associated equipment. The plant room needs to be ventilated.

FURTHER READING

- Halcrow Gilbert Associates, (1993), Grid Connection of Photovoltaic Systems. ETSU S 1394-P1, ETSU: Harwell.
- Halcrow Gilbert Associates, (1993), Guidelines on the Grid Connection of Photovoltaic Systems. ETSU S 1394 -P2, ETSU: Harwell.
- Munro, D. and Thornycroft, J., (Undated), Grid Connecting PV Buildings. In 21 AD Architectural Digest for the 21st Century Photovoltaics, Eds. Roaf, S and Walker, V. Oxford Brookes University.
- Sacks, T., (1997), Shadows Loom Over the Solar Era. Electrical Review 27 May - 4 June, pp.25-28.
- Newcastle Photovoltaics Applications Centre. Architecturally Integrated Grid-Connected PV Facade at the University of Northumbria. ETSU S/P2/00171/REP, ETSU: Harwell.

6 Case Study

CASE STUDY : Sports Complex Kilkenny

6.1 Introduction

This chapter discusses the preliminary design of a building-integrated PV system. It is broadly based on an example project in the UK for the Cambridge Botanic Gardens but has been adapted to describe a similar Irish situation.

The case study describes the design and planning of a theoretical sports complex with indoor tennis courts and outdoor astroturf pitches.

The hypothetical situation described is one where a developer is intent on using PV in a project which also will include low energy or "near passive" design elements.

The location has been chosen as close to Kilkenny, which has similar latitude and climate characteristics to Cambridge.

For the purposes of this guide, we will concentrate the area related to the design and planning of the PV installation, including the integration of PV into the building.

6.2 Site and brief

Kilkenny enjoys a moderate amount of sunlight (978 kWh/m^{2}y on a horizontal surface), is temperate (mean annual temperature 9.3°C; mean temperature June to August 14.4°C), and is typically wet during the winter months, and fairly dry during the summer months (mean annual rainfall 822 mm).

Project brief / details :

The complex has a total gross floor area of about 3950 m^2 which is divided into:

- A gym complex area of 650 m^2
- Administrative offices of 1300 m^2
- 5 x indoor tennis courts with associated changing rooms and WCs; area approximately 1600 m^2
- Cafe/bar of 400 m^2.
- 2 x external astro-turf pitches .
- Car parking facilities.

Environmental design is key to the client's vision, and the aim is to develop an integrated, low-energy / near passive design approach and examine energy, materials, water use and waste recycling in detail. Under the energy topic, 4 areas were identified for investigation:

- The use of PVs.
- Daylighting of the indoor tennis courts (to reduce the artificial lighting energy demand).
- Design for "passive" building features as far as is practically possible.
- Use natural ventilation where possible.

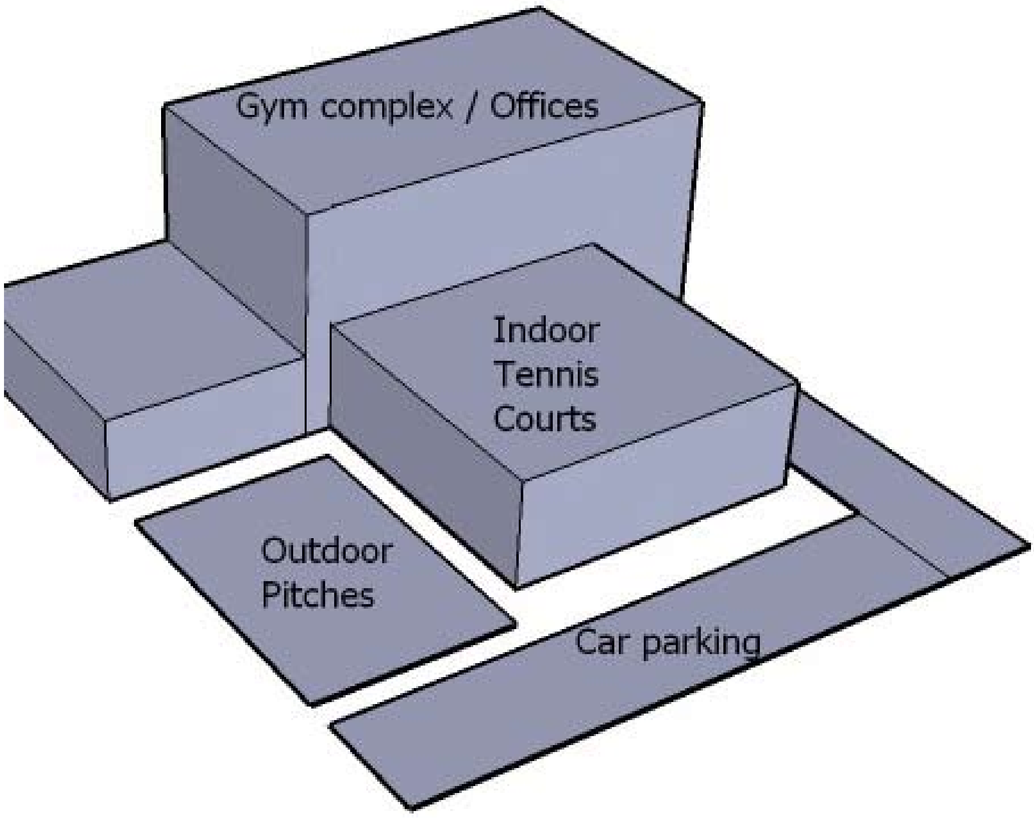


Figure 6.1 :
Building massing

Initial Investigations

The design team investigated the options for building form with regard to PV and daylighting.
From the brief it was possible to develop the design.
Daylighting of the tennis courts needed to be as uniform as possible, and the tennis court ceiling needed to be at least 6 m high (just over 2 storeys, to allow for clearance during normal play), and to incorporate a fully-functional gym and offices, the accompanying building was expected to be higher than this.
So consideration was required in terms of how the building would fit into its surroundings.

The proposed massing shown in Figure 6.1 resulted from discussions with all parties, including planners.
Building design was intended to fit in place with its surroundings, however the wooded walking path and grounds needed to be kept quiet and unspoiled.
The tall trees in the wooded area surrounding the complex on the north side were considered to be adequate enough to "hide" the complex from view of the nearby walking routes.

Internal planning was also considered and, particularly, the area to the north of the wall separating the astroturf pitches and the gym complex. It was thought that this zone would be used for spaces without a daylighting requirement such as WC's or with a need for blackout such as conference rooms.

The passive design element of the building was examined also, and the design team used the SEI publication : "Passive Design and Construction for Commercial Buildings" as part of the process, in conjunction with the Passive House Planning Package.
The team also visited the Tesco supermarket in Tramore and examined the various techniques used.

In terms of the photovoltaic installation, a number of factors were examined in this respect, including:

- Suitability of the site in general for PV.
- Availability of surface area.
- Occupancy of the building and load.
- Likely array size, cost and generation pattern.

The site is free of obstructions on the south side and was judged to be very suitable.
There is some potential loss of north sky diffuse radiation due to the nearby tall trees but this is not significant, and as mentioned earlier, even though it was paramount to design the complex so as to integrate it as seamlessly as possible into the surroundings, the trees on the north side were to serve as a "cover" for the building aesthetically.

However, since the buildings face south and the car park and road are not a concern with regard to walkers, sightseers, there is very good solar access.

Preliminary discussions took place with local planners and the ESB in order to assess whether PV proposals were likely to be considered favourably in terms of planning and payment for electricity export respectively. The response from planners was very encouraging, however the ESB do not offer a structured feed-in-tarriff for non-domestic installations.

On the other hand, considering the large electrical demand of the complex, and the economic and physical constraints of the PV installation itself, it was unlikely that even a sizeable PV installation would produce more electricity than was being consumed in the complex itself during daylight hours.

Therefore the consideration of exported electricity was not that relevant to the project. It is hoped, however, that there will be a feed-in-payment structure in place in the future for installations which are non-domestic.

At the moment, in Ireland, for non-domestic situations such as this project, the business in question will need to negotiate with their electricity supplier with regard to payment for exported electricity (if the installation is designed to produce excess electricity).

Currently, feed-in-payments are available only for domestic installations in the micro-generation (below 6kW in single phase or 11kW in three phase) category.

Surface area of PV required

To assess this required further development of the building form. Based on good practice in low-energy / passive design (See SEI passive building guidelines) it was decided that the gym complex / offices should aim at a floor width of about 15m at most to allow for natural ventilation. Thus, the form of the gym complex/office area was confirmed as a rectangular block with the long axis running east-west.

As for the indoor tennis courts, it was necessary to study the daylighting in more detail to determine the area left for PVs on either the roof or south wall. Good uniformity of daylight over all courts would be required, thus, a roof lighting scheme was selected. For architectural interest, to avoid the factory-like appearance of normal saw-tooth northlight roofs and potentially to increase the PV capacity a concept sketch of successive 'waves' was drawn.

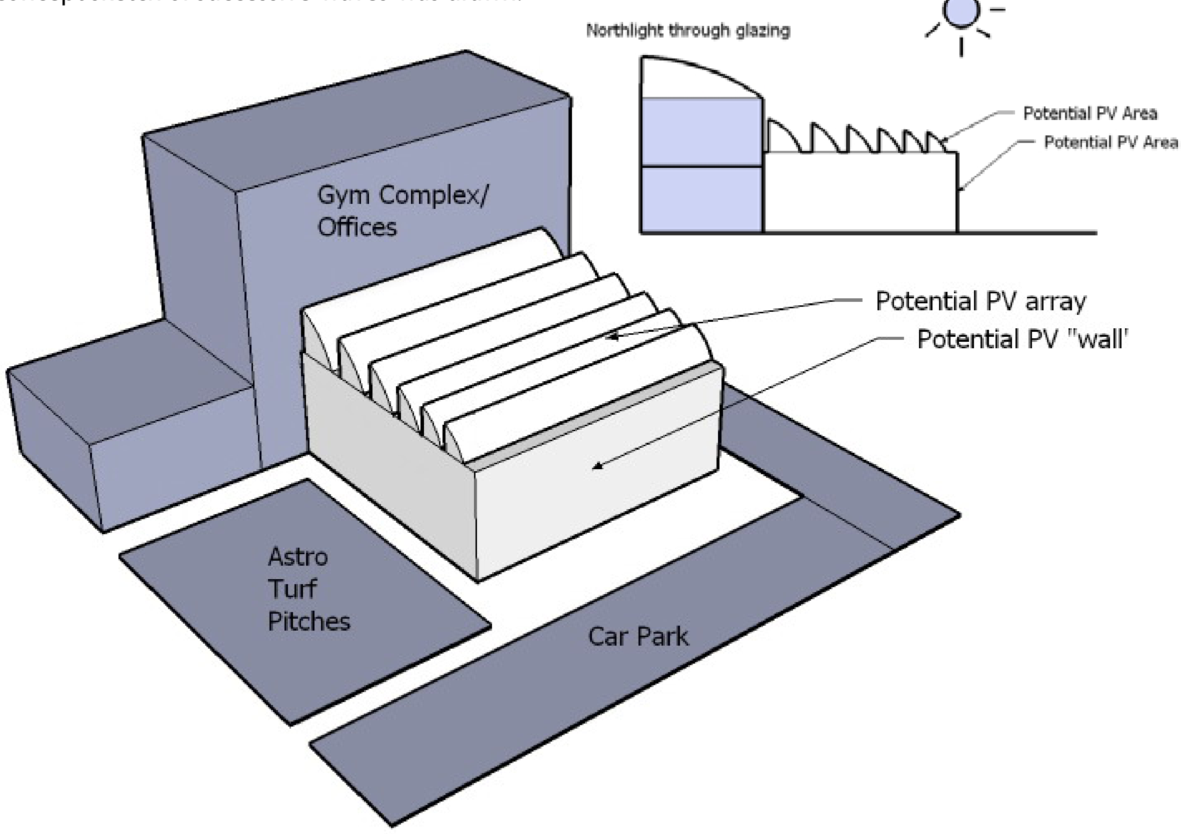


Figure 6.2 (a) - "Wave"Roof Proposal (3D)

Figure 6.2 (b) - Roof Proposal (End Elevation)

The daylight factor (DF) is a very common and easy to understand measure for expressing the daylight availability in a room. It describes the ratio of outside illuminance over inside illuminance, expressed in per cent. The higher the DF the more natural light is available in the room. Rooms with an average DFs of 2% give us a feeling of daylight. However, it is only when the DF rises above approx 5% that we perceive it as well daylit.

The daylight factor of 6-8% required to provide 500 lux for tennis much of the time without artificial lighting meant that the tennis courts roof area available for PVs was about 750 m^2. In addition the upper portion of the south facade (leaving the lower part free because of shading by cars) with an area of 60 m^2 was available and the roof of the gym complex / offices with a plan area of 650 m^2 was potentially available. The module loads were assessed structurally and it was considered that they could easily be accommodated.

Occupancy and load

The likely occupancy of the building is favourable to PV's as indoor tennis takes place from 9am until 9pm seven days a week throughout the year. The gym complex will also be in operation seven days a week throughout the year and the offices will be occupied on weekdays. Overall, this means that there will always be a load on site for the PVs to supply and therefore there will be little or no opportunities to export excess electricity to the grid.

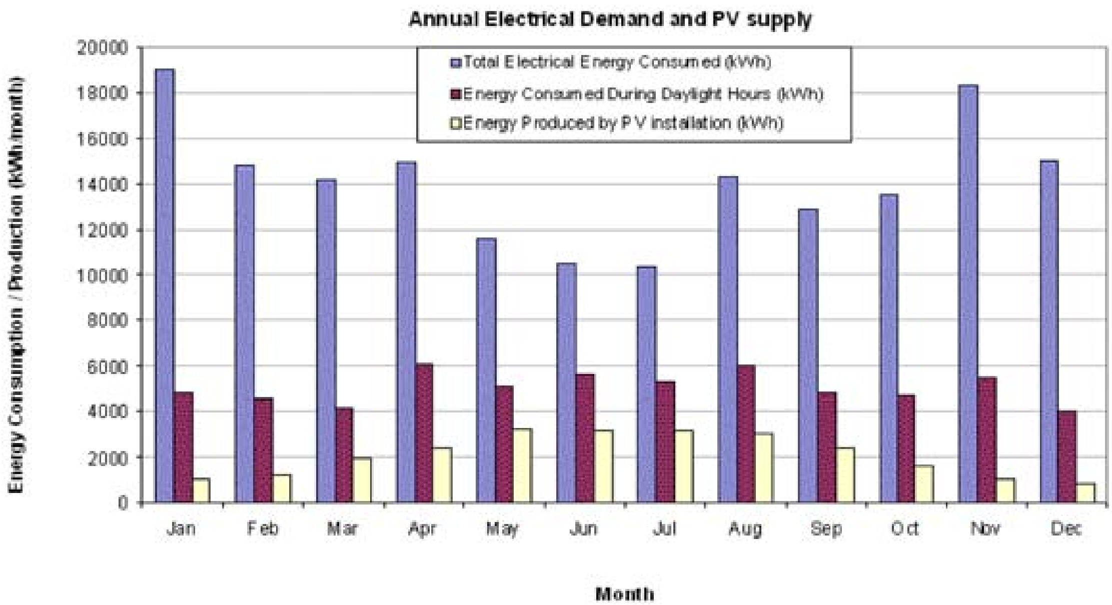


Figure 6.3 - Annual electrical demand and PV supply

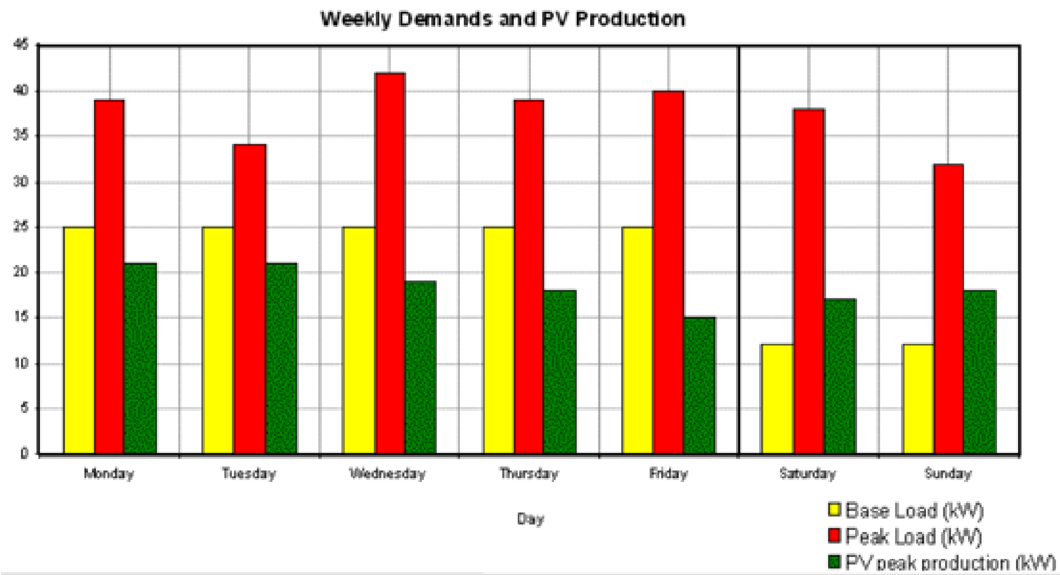


Figure 6.4 - Weekly peak and base loads compared to peak PV production - Summer

Note : The diagram above does not show PV average production per day

The loading of the building had to be examined in detail. For the gym complex and office area an electrical consumption of 30-35kWh/m^2y was estimated based on an energy-efficient building (Chapter 3).
For the tennis courts each aspect (artificial lighting, small power for cafe/bar, etc.) was studied resulting in an estimate of 35-40kWh/m^2y.
Figure 6.4 above shows a typical weekly power demand in summer.

So, for instance, taking Monday as an example :

- The average or base load (all day) is 25kW (yellow)
- The maximum loading or demand which occurs on Monday is 38kW (red)
- The highest production by the PV installation on Monday is 22kW (green)

Array size and cost

The typical summer daytime minimum power demand or base load is 25kW during the week and 12kW at weekends; during the winter it is slightly higher because of additional lighting and plant loads, eg heating pumps.
If the PV installation were sized to provide an on-site maximum of 25kW in summer we would be fairly confident of being able to use most of the energy produced on site (because supply from the PV panels will usually be less than the base demand). At this stage assuming a performance ratio of 0.75 (to account for system losses) leads to a nominal required array rating of about 33kWp to meet the summer base load. The output from this array for a typical week in June is also plotted in Figure 6.4. If monocrystalline silicon cells were used this might require an area of approximately 235 m^2 and might entail an installed cost of about €175,000.

6.3 Design development

The following aspects of the design were then developed:

- Optimisation of the daylighting and PV capability of the roof.
- PVs and the natural ventilation strategy.
- Choice of module.
- Sizing and costing.
- System considerations.
- The PV installation inside the building.

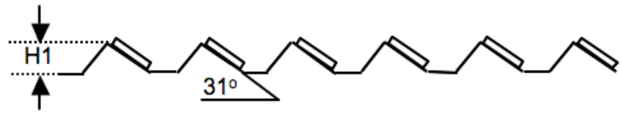
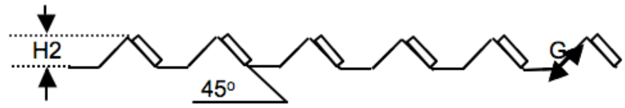
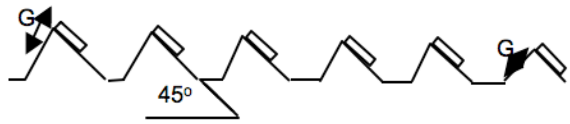
Glazing Area [G] (m^2)	PV Area (m^2)	Daylight Factor	Energy Used for Artificial Lighting (MWh/yr)	PV Array Total (MWh/yr)	
510	696	6.1	56	101.5	 (a) Uniform height (H1), each south face 100% PV, each north face 100% glazing, PV tilt = 31°
684	684	8.0	42	94	 (b) Uniform height (H2), each south face 100% PV, each north face 100% glazing, PV tilt = 45°
684	684	7.8	43	95.2	 (c) Increasing height, front (smallest) tooth identical to any tooth in (b), subsequent teeth have equal areas of PV and glazing to front tooth, PV tilt = 45°

Figure 6.5 : Roof configurations (not to scale)

Daylighting and PVs

The initial assumption of a daylight factor of 6-8% was maintained as mentioned earlier.

Numerous configurations were studied using computer modelling - *Figure 6.5* above shows three of the options.

The main conclusions of the exercise (which looked at electrical energy but did not go into energy for space heating which was thought to be a lesser consideration in a building with such a low space heating requirement) were:

- The optimum angle for a stand-alone array in Kilkenny is about 31/32° : this is consistent with the rule-of-thumb : latitude - 20°. A uniform roof based on this has a comparatively low daylight factor, thus higher electrical costs.
- By increasing the angle to 45° daylight is improved; the PV output, however, drops because the angle is not optimal and self-shading losses are higher.
- If the 45° tilt is maintained, increasing the height of successive ridges reduces self-shading and increases the PV output. The daylight factor, however, drops slightly.

The design team then met the client to present its findings. There was some surprise at the cost and the fact that the entire roof would not be PV modules.
It was explained that a kWp of PV can cost anywhere between €6,000 and €8,000, and that anywhere from 7-10m^2 of PV installed area is required to produce a kWp of electrical power.
The client accepted these findings, and the additional cost was judged to be acceptable and worthwhile on the basis of the percentage of the building cost, the environmental benefits and the educational value.

At this point the design team knew the area required was available but did not know if the client had the money. In the meantime, the approximate cost of the building was estimated at €1000/m^2 or €3,950,000 without PVs, so the PV cost would represent very roughly (allowing for partial replacement of the metal roofing system that had been costed) about 5% of the building cost.
It is worth mentioning that solar thermal was considered also, due to the fact that showers and hot water demand would be above average, and in the near future, it is hoped that the roof of the gym/offices will lend itself to this purpose.

Figure 6.7(c) suited the initial 'wave' concept, provided good daylighting and offered significant PV potential. There was a great deal of discussion about the increased structural complexity and costs resulting from non-uniformity and the appearance of the roof from the inside but, in the end, it was agreed to take forward this design.

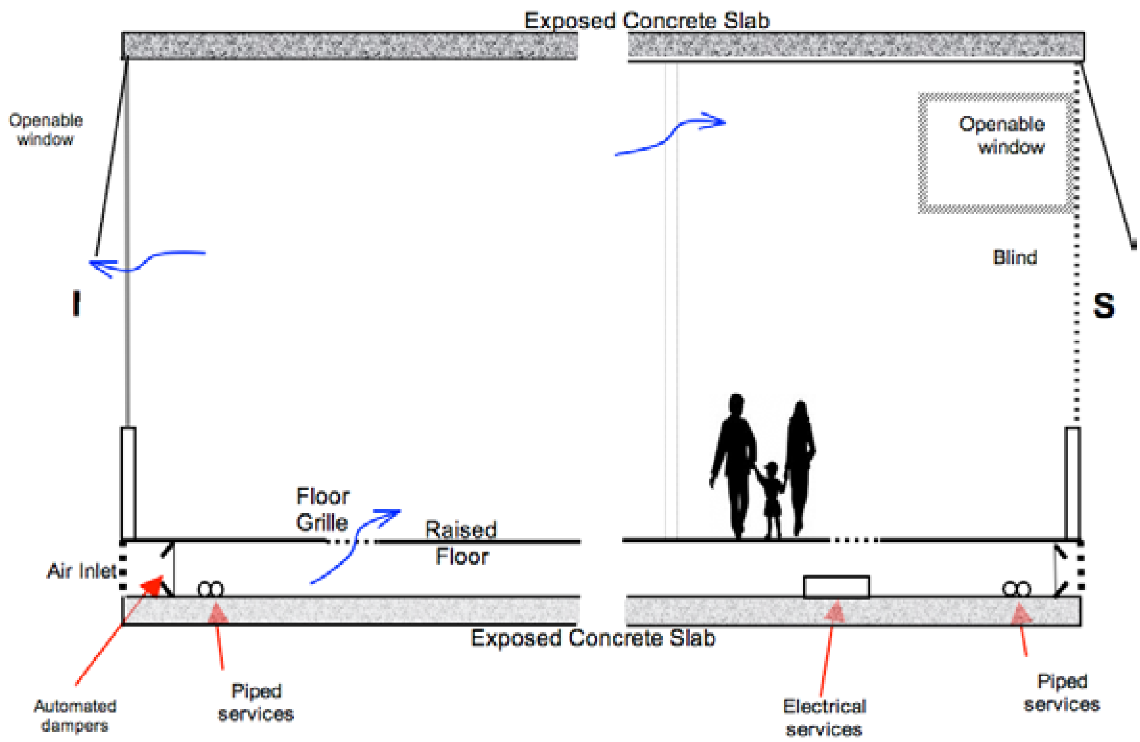


Figure 6.6 - Services strategy and notional air paths

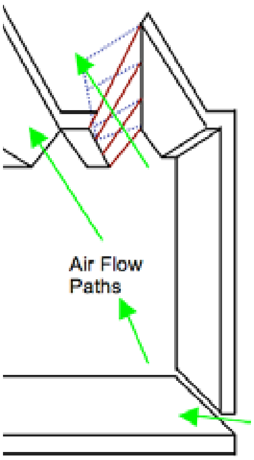


Figure 6.7 - Tennis court ventilation strategy

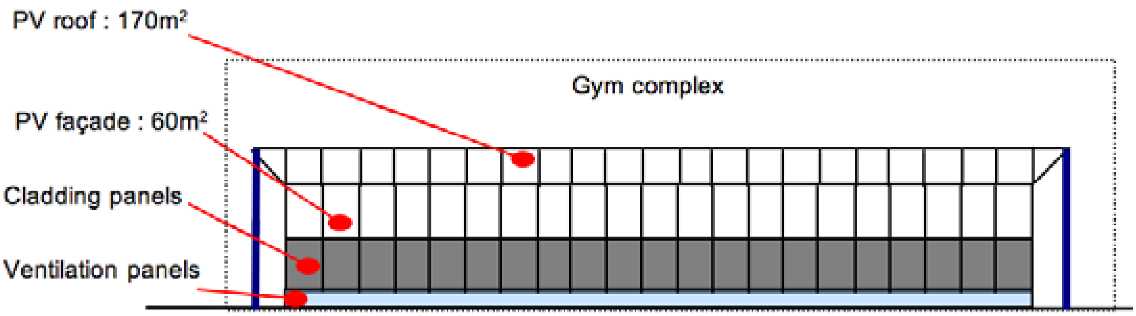


Figure 6.8 - South Elevation

PVs and the natural ventilation strategy

The need to provide conference room facilities in the gym / offices area and future flexibility led to a strategy of a raised floor for services and air distribution as indicated in *Figure 6.8*.
The tennis court ventilation strategy *(Figure 6.9)* was developed to both ventilate the internal space and take the heat away from the back of the PV modules to prevent a layer of hot air forming at high level.

The architect considered a variety of wall constructions and favoured, on grounds of appearance and functional performance, a rainscreen cladding system *(see figure 3.8)*. As this was also perfectly suited to PV panels on the front facade of the tennis courts, it was thus chosen.

Choice of module

For the building the architect chose an elegant white steel frame with green rainscreen cladding panels. Monocrystalline modules were selected on the basis of cost and an appearance which complemented that of the building.

Sizing and costing

The design was reviewed and it was decided to adopt the tennis court south facade shown in *Figure 6.10*. This allowed 60m^2 of PV modules on the facade or 8.8kWp.
On the roof using the basic design of *Figure 6.7(c)* it was possible to put in 114m^2 of PV modules per saw-tooth or 16.8kWp. It was decided to have PVs on the front roof and the upper half of the second saw-tooth as well as the south facade, thus giving a total of 34kWp or about 23kW on a sunny June afternoon (the output is slightly lower than the 25kW aimed for because of the reduced performance of the south facade modules, due to the fact that they are not inclined to an optimum angle, unlike the roof-mounted modules). The annual output from this PV installation is shown in *Figure 6.5*.

Sketches and a rough schematic were sent to manufacturers for review, costing and an analysis of the output. The manufacturers were asked to keep in mind the client's intention to expand the installation in the future.

The manufacturers' responses varied and some quotes were higher than initial estimates. It was decided to proceed optimistically and use the €175,000 figure cited above and an expected output of 25,000kWh/y. Although no detailed analysis was carried out, rough checks indicated that we would be in Zone A of *Figure 4.3*.

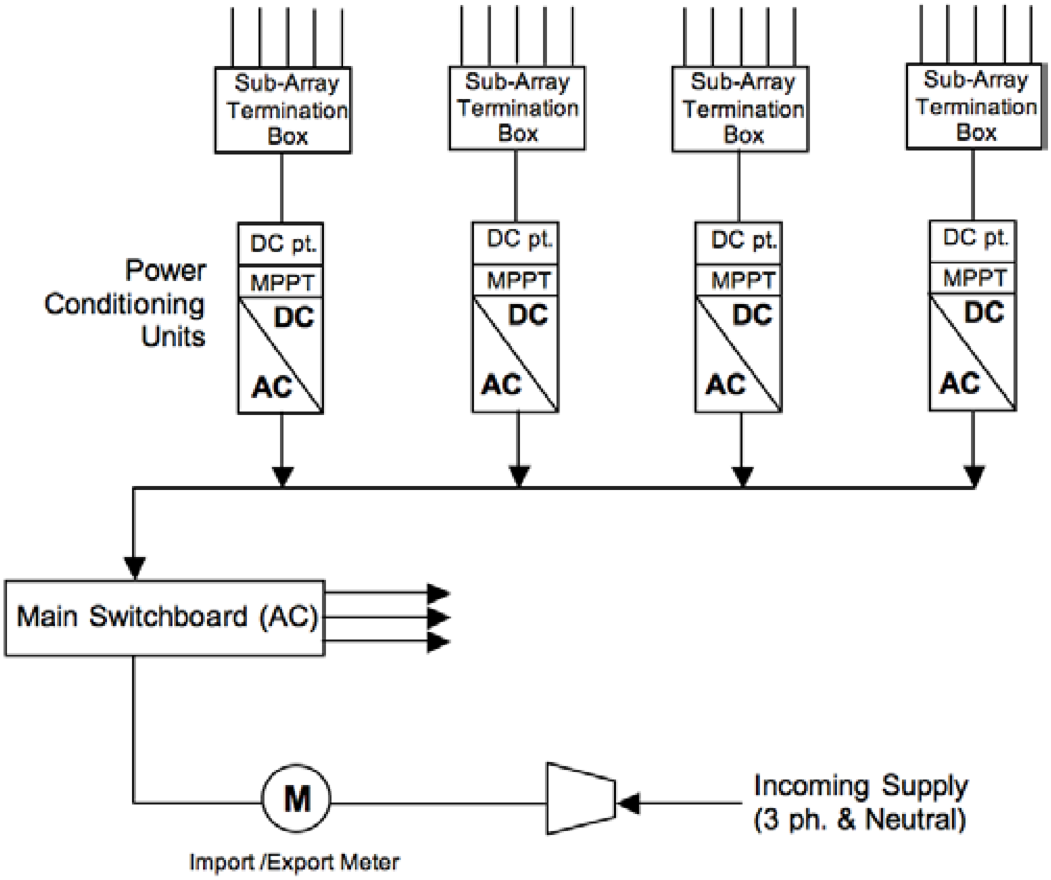


Figure 6.9 : Basic System Schematic (Note : Earthing Arrangements not shown)

The preliminary PV system design assumed that the PVs would be split into sub-arrays each with its own inverter and that the incoming electrical supply, main switchgear, meters, power conditioners and various data, communications and control panels would all be located in the electrical switchgear room.

Starting at the mains incomer there is a three phase and neutral cable. One interval import / export meter included in the schematic (however, the export function is not likely to be used).
There are four Power Control (conditioning) Units (each with their own maximum power point tracker - MPPT) included.
The maximum power point (MPP) of a solar PV cell is the point at which current and voltage produce the maximum power.
The maximum power point tracker finds the Maximum Power Point (MPP) in order to draw the maximum power from the solar array.

Each MPPT is rated at approximately 7kW. One PCU is for the vertical south facade which will receive less irradiation than the PVs mounted on the inclined roofs. The remaining three PCUs have been included in order to modularise the system based upon sub-arrays of equal area.
Each sub-array has five strings and each string has eight modules. The modules are connected together so that each string operates at a system voltage of 280V. The voltage was kept reasonably low for safety. Sub-array termination boxes, approximately 0.5m x 0.5m x 0.2m, are housed at high level in the tennis courts at the east end of each sub-array. The sub-array termination boxes are then connected back to the appropriate inverter, thus reducing the number of cables running through the bowling green. The sub-array termination boxes contain isolation switches for individual strings, blocking diodes for the strings, DC fuses and testing points. Good access was provided to the roof to allow for cleaning of the modules and the northlight windows, for maintenance of the opening light mechanisms, and for inspection of all electrics.

When planning the PV installation inside the building, the architect needed to know:

- The size and the position of the plant room.
- Where the cables were going to run.
- How big they were.

The mechanical and electrical plant rooms were both positioned just to the north of the north-east corner of the indoor tennis courts hall to allow for ventilation for the boilers and the PV switchgear room *(Figure 6.13)*. This fairly central position, although distant from the first PV modules, was thought to be appropriate over the life of the building when other PV sub-arrays will be positioned much closer to it. It was also thought that if more space for PV equipment became necessary in the future it could come from the adjacent storeroom.
In the electrical switchgear room, approximately 40m^2 is required for standard equipment and approximately 10m^2 of additional space is required for PV related equipment. Thus, the PV plant floor area is about 4-5% of the total array area. All cables were run internally mainly within the supporting framework.

In the indoor tennis courts hall, cables run to the plant room from the sub-array termination boxes within two compartment trunking (50mm x 100mm overall) elegantly concealed at high level. The eight cables are each approximately 15mm overall diameter.

6.4 Future detailed design

It was anticipated that the detailed design stage would address the following points:

- A roof construction detail that would allow for easy substitution of PV modules for metal sheeting.
- Design of the office roof to allow incorporation of PV modules.
- Bonding and lightning protection.

6.5 Project data

<table>
<tr><th colspan="5">Floor area (m²) 3,950</th></tr>
<tr><th colspan="5">Electrical demand (kWh/y) 137,000</th></tr>
<tr><td colspan="2">PV System</td><td>Roof</td><td>South Facade</td><td>Total</td></tr>
<tr><td colspan="2">Nominal array rating (kWp)</td><td>25.2</td><td>8.8</td><td>34.0</td></tr>
<tr><td colspan="2">Area of PVs (m²)</td><td>170</td><td>60</td><td>230</td></tr>
<tr><td rowspan="2">System rating</td><td>(W/ m² (array)</td><td>110</td><td>80</td><td>102</td></tr>
<tr><td>(W/ m² (floor area) [a]</td><td>-</td><td>-</td><td>6</td></tr>
<tr><td colspan="2">Assumed performance ratio</td><td>0.75</td><td>0.75</td><td>0.75</td></tr>
<tr><td colspan="2">Solar energy available (kWh/y)</td><td>193,000</td><td>48,500</td><td>241,500</td></tr>
<tr><td colspan="2">Total energy provided by PV system (kWh/y)</td><td>20,000</td><td>5,000</td><td>25,000</td></tr>
<tr><td colspan="2">Estimated energy use on site (kWh/y) [a]</td><td>-</td><td>-</td><td>22,500</td></tr>
<tr><td colspan="2">Total avoided CO_2/a due to PV (kg)</td><td>12,400</td><td>3,100</td><td>15,500</td></tr>
<tr><td colspan="2">Estimated installed cost of PV system (€) [a]</td><td>-</td><td>-</td><td>€ 175,000</td></tr>
</table>

Table 6.1 : Data summary [a] The total figure has not been separated into components

Case Study References :

- DTI : Photovoltaics in Buildings : A design guide
- The Botanic Garden of the University of Cambridge case study
- SEI : Passive Construction of Commercial and Public Buildings : guidelines - 2009
- Max Fordham and Partners
- Photovoltaics for professionals : Solar Electric Systems – Marketing, Design and Installation : Antony, Durschner, Remmers
- The Irish Meteorological Service
- PV-GIS (from EU-JRC website)
- www.xsports.com (recommended overhead clearance for indoor tennis courts)

Disclaimer :

For the purposes of this Guide, assumptions and simplifications have been made.

This is an adaptation of an original case study from the DTI publication "Photovoltaics in Buildings: A design guide".

The climate data used is representative of the actual location used, however the actual site and the project described is entirely hypothetical. Kilkenny was used as the project location, as the levels of global solar irradiation are very similar to that described by the original DTI case study, and therefore PV outputs would be similar to those described in the original DTI guide.

The various diagrams and sketches of the building and the surrounding areas are not to scale.

Load profiles and graphs were adapted from the original DTI guide, occupancy patterns, daylighting factors, on-site energy consumption, lighting requirements, building form and PV design details reflect those from the original DTI guide.

Cost estimates and design steps described are intended to be representative of a practical situation.

This case study is intended to be informative only. When planning and designing such a project involving PV, it is recommended that a professional, experienced design team is engaged, as it is important to remember that every project is unique.

6 Appendix A

A.1 The Photovoltaic Effect

This is the basic process by which a PV cell converts solar radiation into electricity. In crystalline silicon cells a p-n junction ('p' for positive, 'n' for negative) is formed (*Figure 2.1*) by diffusing phosphorous into the silicon and introducing a small quantity of boron. This results in an electric field being formed. When photons, 'particles' of solar energy, are absorbed by a PV cell, electrons under the influence of the field move out towards the surface. This flow or current is 'harnessed' by an external circuit with a load.

A typical monocrystalline cell of, say, 100mm by 100mm in bright sunshine of 1000W/m^2 might produce a current of 3 amps at 0.5 volts giving 1.5 watts of power.

A.2 The Environment and PVs

Figure A.1 shows the spectral distribution, i.e. the amount of radiation at various wavelengths, of solar radiation.

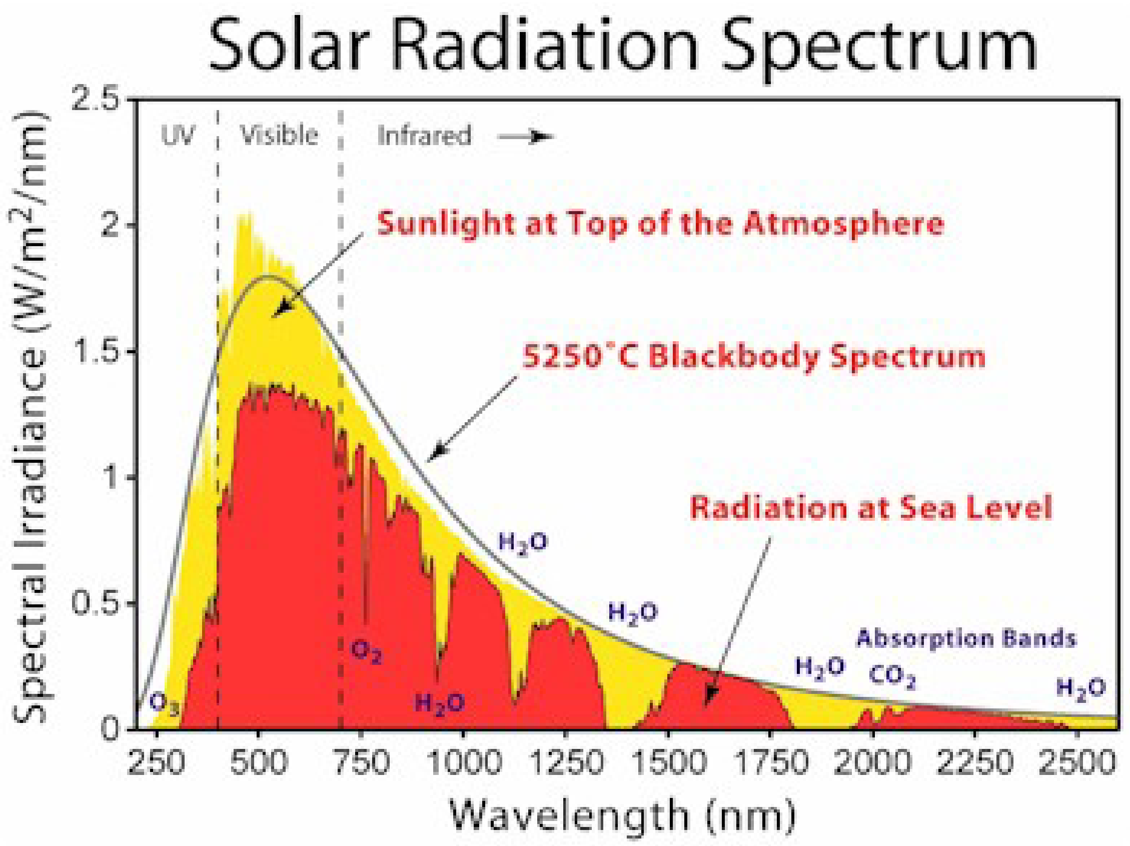


Figure A.1 - Spectral distribution of solar radiation at the earth's surface

Solar radiation can be divided into direct and diffuse radiation. In Ireland the diffuse component is high, approximately 60% of the total annual irradiation on a horizontal surface is diffuse.
The radiation climate is also very variable and can quickly change from bright sunshine to heavy clouds. Ideally, the total PV installation from array to inverter will react optimally to all the characteristics of the environment.
PV cells respond mainly to visible radiation (wavelengths of approximately 400nm-700nm) but also to some UV (below 400nm) and some infrared (above 700nm).
Fortunately, PVs respond to diffuse radiation as well as direct radiation.
The overall radiation is called the "global" radiation.

Figure A.2 shows the response of a monocrystalline cell; amorphous silicon cells have a somewhat different curve with a peak between 500nm-600nm. (The absorption characteristics of PV cells affect the design. For example, normal glass contains traces of iron which cause the glass to absorb strongly in the visible green range. Since PV cells can use this energy, PV modules incorporate low-iron glass.)

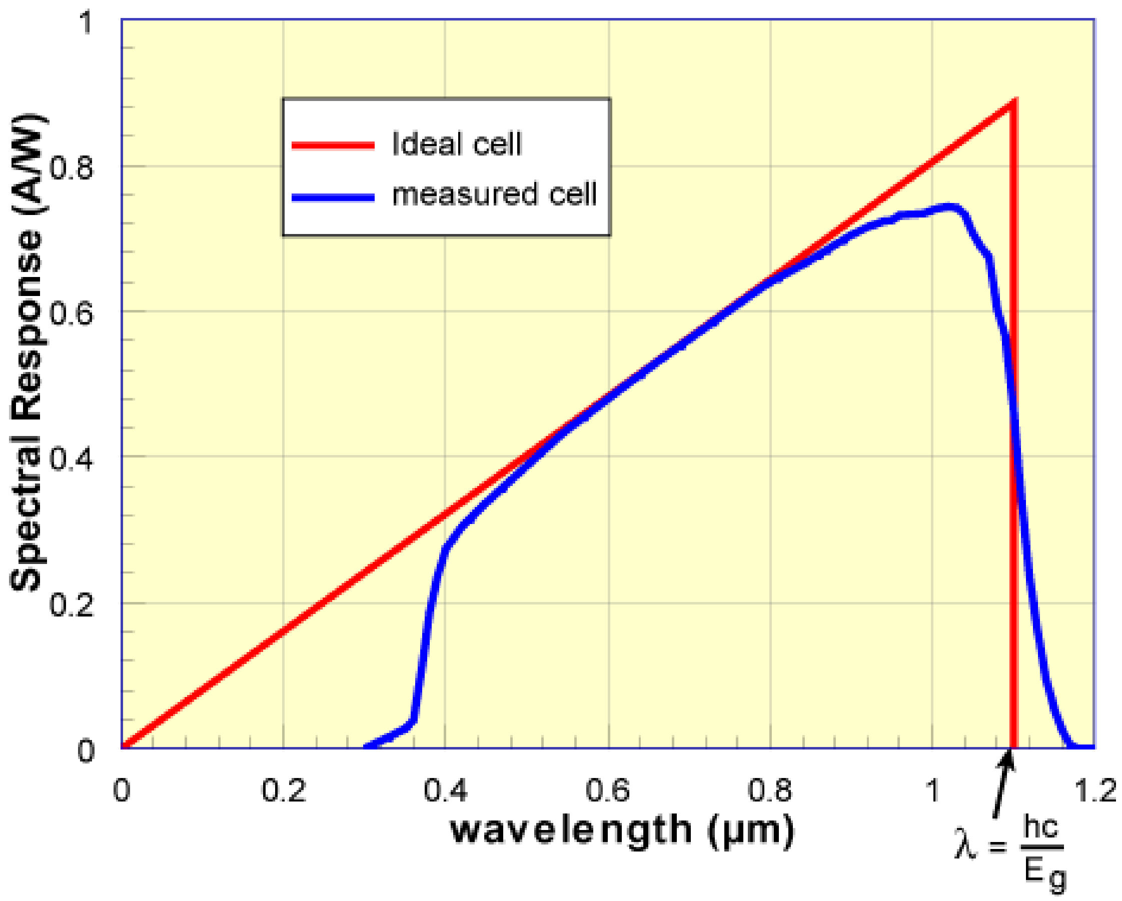


Figure A.2 Spectral response of a monocrystalline PV cell

A heavily overcast sky might have an intensity of 50W/m^2 with a diffuse component of 95-100% and a cloudless blue sky might have an intensity of 900W/m^2 with a diffuse component of 20%.

Efficiency also varies somewhat with intensity with slightly lower values at lower intensities.

A.3 How to read a PV module data sheet

In addition to the construction and physical characteristics and warranty conditions, the following items are likely to be included:

- Cell type, e.g. monocrystalline silicon.
- Cell specifications, e.g. 36 series-connected cells. (See *Figure A.3* for series and parallel arrangements.)
- Physical Conditions There may be an indication of the wide-ranging conditions in which PV modules can be used. For example: Temperature: - 40^{0}C to 85^{0}C Relative humidity: 0% to 100% Wind loading: Up to 80km/h.
- Electrical characteristics (e.g. for a module of 1.2m x 0.5m) Nominal peak power 90.0W Voltage at peak power 18.5V Current at peak power 4.9A Short circuit current 5.2A

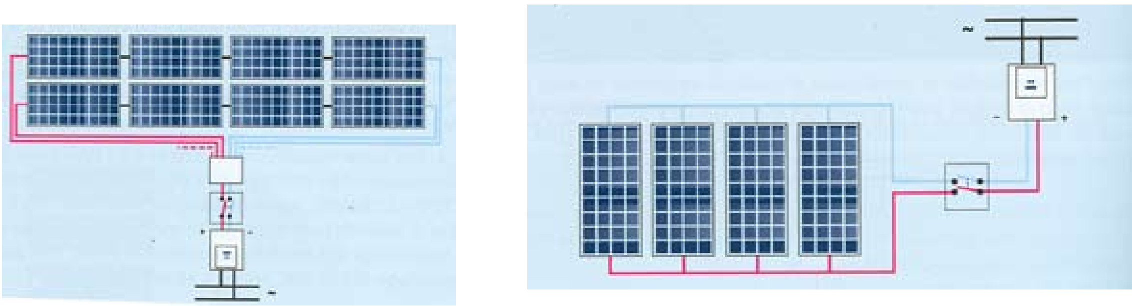


Figure A.3 - Series and parallel arrangements

Figure A.4 shows a typical curve of module performance under STCs.

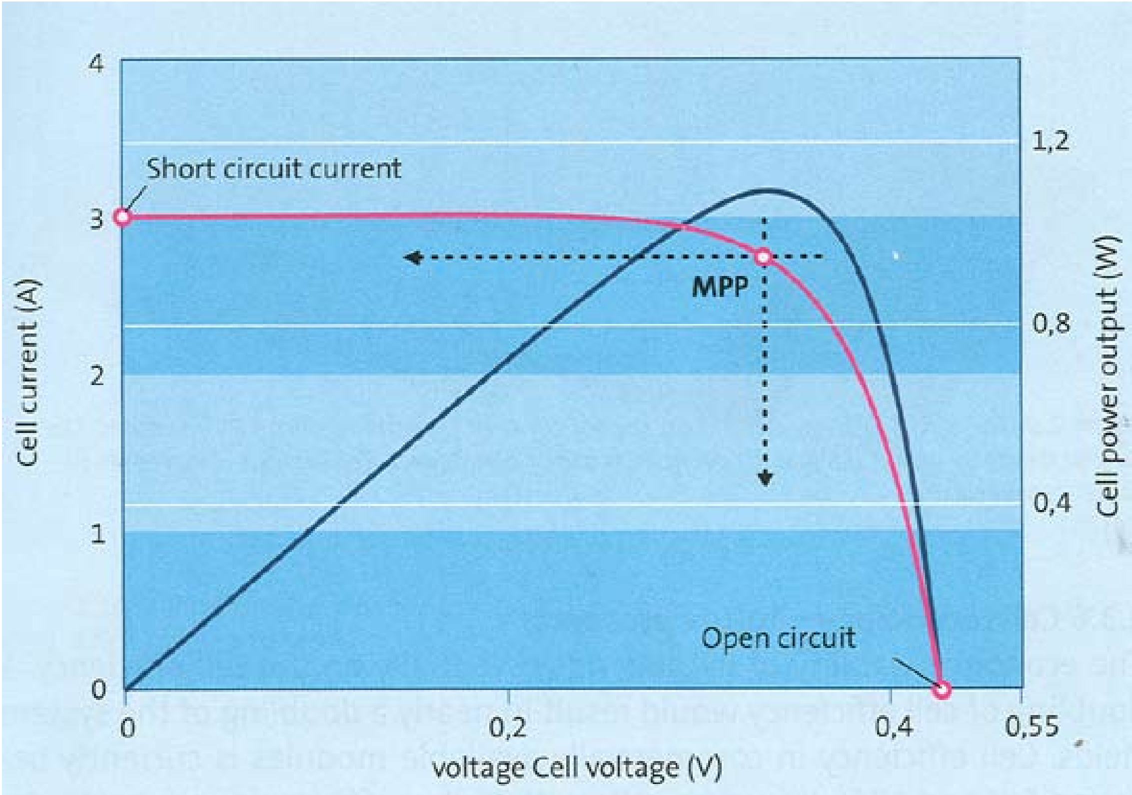


Figure A.4 Current/voltage (I-V) curve

The short circuit current is the current at zero voltage. The corresponding point of zero current, i.e. 'no connected loads', is the open circuit voltage. Power is the product of current and voltage and from the curve it can be determined that the maximum power of 90W is produced at a voltage of approximately 18.5V and a current of 4.9A.

At lower irradiances, power falls as shown in *Figure A.5*.

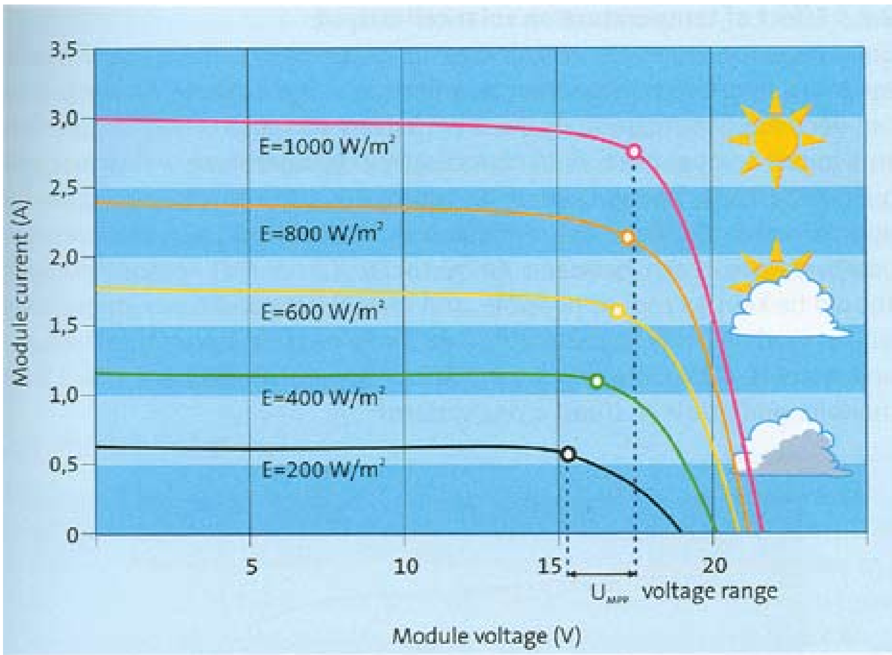


Figure A.5 - Typical I-V curves at varying irradiances

Note that the effect of varying temperature is also included. At higher temperatures efficiency falls, and more so with crystalline silicon cells than amorphous silicon cells.
The PV module data sheet should give a value for this variation of efficiency with temperature.

The function of a maximum power point tracker (Chapter 4) is to alter the effective load resistance so that the array will operate near the maximum power point in variable input conditions, i.e. under changing skies with their varying irradiances and in varying temperatures.

A.4 Shading

The effect of shading can be understood by referring to the series arrangement in *Figure A.4*. Because the cells are in series, if the performance of one cell is impaired by shading, the output current from the whole string is affected and minor shading can result in a major loss of energy.

A.5 Mismatch

Mismatch refers to the losses due to differences in the I-V characteristics (*Figure A.4*) of the modules in a PV array.

A.6 Balance of system losses

In Chapter 2 the balance of system (BOS) loss was mentioned. It accounts for factors such as the following, which are listed with very approximate values (expressed as a percentage of the array output:

- Cable losses – 1-3%
- Losses at the PCU and particularly at the inverter – say 10-15%
- Metering and utility interface control losses – less than 1%.

Thus, an overall figure of 0.8 for BOS losses is a reasonable starting point.

A.7 Performance ratio and sizing

The following discussion continues the procedure started in Chapter 2.

The Performance Ratio (PR) is the final yield (kWh/kWp/day) divided by the reference yield. It can be expressed either as a decimal fraction or as a percentage.
The reference yield is based on the in-plane irradiance and represents the theoretically available energy per day per kWp installed. Typical PR values are 60-75% but higher values are achieved.
Rough array sizing is sometimes done using estimates of the PR in the following way:

- Assume a value for the PR, say, 0.7.
- Determine the solar irradiation on the actual array. For example, 920kWh/m^2/y x 0.15 (module efficiency) x 0.95 correction factor for tilt and azimuth or 131kWh/m^2/y.
- The output of the PV system, then, will be:
  0.7 x 131kWh/m^2/y = 92kWh/m^2/y.

A.8 Inverter selection

As mentioned in Chapter 5, inverter selection is a key element in the PV system design process.

Figure A.6 shows generalised inverter performance.

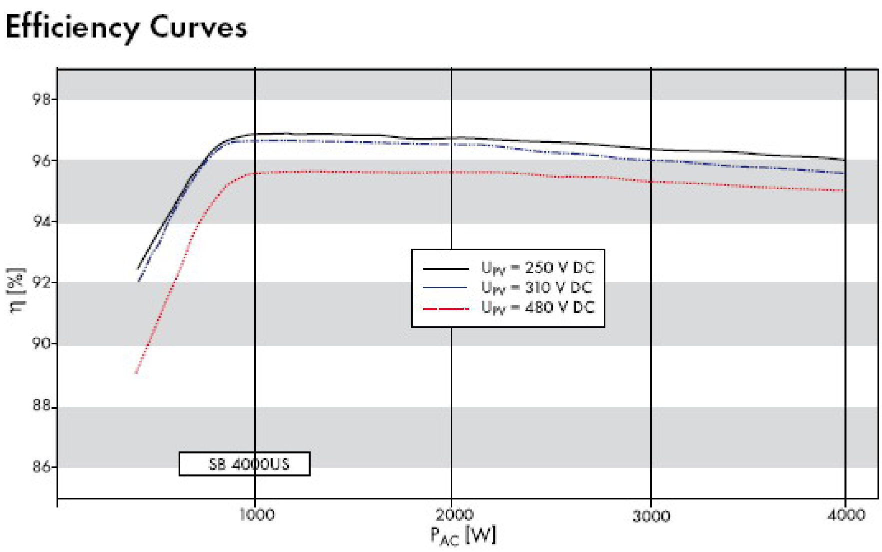


Figure A.6 – Generalised Inverter Performance

With all inverters, efficiency is impaired at very low levels of irradiance and, since there are energy losses in the inverter, there is a point below which it does not make sense to use the PV DC electricity.

Similarly, with all inverters, operating conditions in the UK mean that for a significant part of the time efficiency is in the 20-80% range. In practice, this means that a balance needs to be struck between losing some of the available energy at very high irradiance levels and operating at a somewhat higher efficiency in lower irradiation levels. Current experience indicates optimal performance is at a sizing of approximately 75-80% of the array rating (2). This is broadly in line with a European suggestion that optimal performance may be obtained using inverters with a rating of 70-90% of the nominal rating of the array (3); however, as the authors say, "this will depend on the climate and the shape of the inverter performance characteristic."

Again, each situation needs to be analysed and this is normally done at a later detailed design stage.

A.9 Earthing and lightning protection

Earthing and lightning protection is an area that requires an engineering assessment of the building's construction and electrical system and advice from an electrical engineer.

The design of PV modules isolates the electrical system from the supporting structure, e.g. the module frame. Broadly speaking, most PV systems do not connect the DC side of the electrical system to earth. The supporting structure, on the other hand, in most systems is earthed. The AC side of the system is connected to the building's normal electrical system's earth.

With regard to lightning protection, PV installations do not require lightning protection systems per se. Protection against deleterious effects to sensitive parts of the installation is often provided by surge protection devices. If the building has a lightning protection system, common practice is to connect the supporting structure to the lightning protection system.

REFERENCES

1. Mason, N.B., Bruton, T.M. and Heasman, K.C, (1997), kWh/kWp Energy Production from LGBG Cell Modules in Northern Europe. Paper presented at the 12th German National PV Symposium Staffelstein.
2. N. Pearsall, Newcastle Photovoltaics Applications Centre, (1998), Private communication.
3. Anon. (undated), Photovoltaic Technologies and their Future Potential. Commission of the European Communities, Directorate-General for Energy (XVII). EAB Energie - Anlagen, Berlin.

FURTHER READING

- Laukamp, H. (1994), The Basic German Electric Safety Standard and its Application to PV Systems. 12th European Conference PVSEC, Amsterdam.
- Halcrow Gilbert Associates, (1993), Grid Connection of Photovoltaic Systems. ETSU S 1394-P1. ETSU: Harwell.

7 References and Bibliography

Listed below a number of sources of information (in most cases previously referred to in the text) that are useful.

Publications

- Newcastle Photovoltaics Applications Centre. Architecturally Integrated Grid-Connected PV Facade at the University of Northumbria. ETSU S/P2/00171/REP, ETSU: Harwell.
- 21 AD Architectural Digest for the 21st Century Photovoltaics. Eds. Roaf,
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- Halcrow Gilbert Associates, (1993), Grid Connection of Photovoltaic Systems. ETSU S 1394-P1, ETSU: Harwell.
- Laukamp, H., (1994), The Basic German Electric Safety Standard and its Application to PV Systems. 12th European Conference PVSEC, Amsterdam.

8 Glossary

A number of terms are included in the glossary of the original text (did not copy through when original pdf was converted to a text document). Needs to be reviewed.

Notes:

1. This glossary is almost entirely the work of the National Photovoltaic Applications Centre. The present authors have made only minor alterations to certain terms or introduced a small number of others indicated by an asterix. The definition of blocking diodes comes from Photovoltaics in Buildings (see bibliography) whilst the definition of bypass diodes come from 'Stand alone PV systems: Guarantee of Results', ETSU S/P2/00237/REP.
2. 'Light' is used in common speech and in the text in a number of overlapping ways; the same is true for 'sunlight'. Visible radiation (400-700nm) is commonly called light but 'light' is also used to describe a broader range of the electromagnetic spectrum. Similarly, 'sunlight' is also referred to as sunshine or solar radiation. 'Sunlight' is normally broken down into three components: ultraviolet, visible light and infrared.

9 Illustration Acknowledgements

The author and publishers would like to thank the following individuals and organisations for permission to reproduce material. We have made every effort to contact and acknowledge copyright holders, but if any errors have been made we would be happy to correct them at a later printing.
A number of the original illustrations have been redrawn for uniformity of style.

10 Contacts

Information on photovoltaics

- The British Photovoltaic Association (PV-UK) The Warren, Bramshill Road, Eversley, Hants. RG27 0PR Tel: 0118 932 4418 Fax: 0118 973 0820
- ETSU Harwell, Didcot, Oxon OX11 0RA Tel: 01235 432450 Fax: 01235 433131
- Dealers and manufacturers
- Beco Batteries Ltd. 8-10 Speedwell Units, Nelson Road, Dartmouth, Devon, TQ6 9SZ Tel: 01803 833 636 Fax: 01803 835 379 UK distributor of Solarex products.
- BP Solar Ltd. PO Box 191, Chertsey Road, Sunbury-on-Thames, Middlesex TW16 7XA Tel: 01932 779 543 Fax: 01932 762 686 Manufacturer of PV cells, modules and systems.
- Colt Group Ltd. New Lane, Havant, Hants. PO9 2LY Tel: 01705 451 111 Fax: 01705 454 220 Manufacturers and developers of architecturally integrated PV systems.
- Intersolar Ltd. Cock Lane, High Wycombe, Bucks HP13 7DE Tel: 01494 452 941 Fax: 01494 437 045 Manufacturer of PV modules and consumer products.
- Marlec Engineering Co. Ltd. Rutland House, Trevithick Road, Corby, Northants NN17 1XY Tel: 01536 201 588 Fax: 01536 400 211 Manufacturer of renewable energy systems. Agents for Solarex products.
- NAPS (UK) Neste Advanced Power Systems (UK), PO Box 83, Abingdon, Oxon OX14 2TB Tel: 01235 529 749 Fax: 01235 553 450 Module manufacturers and system suppliers.
- Pennmaritime Solar Baxter House, 48 Church Road, Chavey Down, Ascot, Berks SL5 8RR Tel: 01344 891 118 Fax: 01344 891 119 System suppliers and UK distributor for Siemens Solar products.
- Pilkington Solar International Fourth Avenue, Deeside Industrial Park, Deeside, Clwyd CH5 2NR Tel: 01244 833 265 Fax: 01244 288 473 Suppliers of OPTISOL brand architectural PV products.
- Schuco International KG Whitehall Avenue, Kingston, Milton Keynes, Bucks MK10 0AL Tel: 01908 282 111 Fax: 01908 282 124 Manufacturers and suppliers of PV facades.
- System installers/building integration
- Energy Equipment Testing Service (EETS) 104 Portmanmoor Road Industrial Estate, Cardiff CF2 2HB Tel: 01222 490 871 Fax: 01222 454 887
- Wind and Sun The Howe, Watlington, Oxon OX9 5EX Tel: 01491 613 859 Fax: 01491 614 164
- Windsund Energy Systems Ltd. Unit 3, Industrial Estate. Spott Road, Dunbar East Lothian EH42 1RS Tel: 01368 863 981 Fax: 01368 863 981
- Delap and Waller Eco-Co, Cork, Ireland : www.dwecoco.ie
- Solarpraxis AG : www.solarpraxis.de
- www.solarserver.de
- Sustainable Energy Ireland : Renewable Energy Information Office
- XD Consulting
- www.bluecar.fr