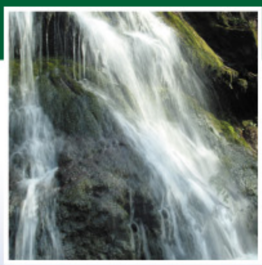
ELREN
European Leader+ Renewable Energy Network

LEADER

Carlow LEADER
Rural Development Co. Ltd.



Chapter 5
Solar Photovoltaic

TIPPERARY INSTITUTE

NDP NATIONAL DEVELOPMENT PLAN

EUROPEAN UNION STRUCTURAL FUNDS

LEADER is supported by the European Union & The Department of Community, Rural, and Gaeltacht Affairs under the National Development Plan 2000–2006.

First published 2007 by Carlow LEADER and Tipperary Institute
(electronically on the ELREN website [www.elren.net])

ISBN: 978-0-9546561-2-6

This publication may be cited as:

Tipperary Institute, 2007. *ELREN Renewable Energy Training Manual* [online at www.elren.net], published by Carlow LEADER and Tipperary Institute, Ireland.

Cover Design:	Ann Quinlan, Brosna Press Ltd., Ireland.
Editor:	Clifford Guest. Tipperary Institute, Ireland
Layout:	Una Johnston, Mementomori Ltd., Ireland

This publication is not for sale or resale as it has been solely funded through the ELREN project and the LEADER Programme. LEADER is supported by the European Union and the Department of Community, Rural and Gaeltacht Affairs under the National Development Plan 2000-2005, Ireland.

5 Introduction to Photovoltaics

Mathew Mather, Tipperary Institute

Table of Contents

List of Tables

List of Figures

List of Examples

5.1 Objectives

Having completed this section of the training course and manual, learners should:

- Understand the various features of photovoltaic technologies
- Have a good understanding of siting and orienting PV's
- Be able to calculate the energy output and rough cost of a specific PV system
- Have a good idea of Ireland's Potential and Policy for PV

5.2 Introduction to Solar Energy

It is obvious that solar energy refers to energy whose source is the Sun. What is not so obvious is the ways in which this energy manifests. With the exceptions of nuclear energy, the lunar component of tidal energy and true geothermal energy (heat energy originating in the Earth's core) the sun is responsible for all other forms of energy. It is responsible for solar heating and solar electricity and is also directly and indirectly responsible for geothermal applications. In addition it is indirectly responsible for wind, hydro, biomass, ocean current (expected to become an important resource in a decade or so) and even fossil fuel energy sources. The purpose of this chapter is to focus on solar photovoltaic applications.

5.3 Introduction to Photovoltaics

It is important to distinguish between Photovoltaics (PV) and Solar Hot Water Collectors (SHWC). Both these technologies convert solar energy into useful energy. However, SHWC's convert energy from the Sun, into useful Hot Water that can be used typically for Water Heating (and sometimes also for Space Heating). Photovoltaics, on the other hand, convert energy from the Sun into useful *electricity*. Economically, SHWC's are considerably more cost effective than PV's. Consequently, one would avoid using PV's for heating water or for Space Heating.

As an initial concern, it is important to know that PV's are generally configured in 3 different ways. Specifically, (a) stand-alone (off-grid), (b) grid-connected,

(c) grid-connected with battery back-up. Stand-alone systems are generally used in remote locations, where it is usually too expensive to have access to a utility. Grid connected systems are fairly common in many countries across the EU, and also in countries such as Japan, Australia and the USA.

5.4 Photovoltaics: The Technologies

Photovoltaic technology uses a specialised semiconductor material that converts energy from sunlight into useful electrical energy. This energy conversion is typically not very efficient with common values in the 10 - 15% range, depending on the specific technology.

The three most widely used PV technologies are:

- Polycrystalline
- Monocrystalline
- Amorphous

A brief comparison of these is illustrated in Table 5.1 below:

	Efficiency	Cost	Visual characteristics	Companies	Comments
Mono Crystalline	10-15%	Expensive manufacturing procedure	Uniform blue colour	BP Solar, Siemens	Oldest and most efficient
Poly Crystalline	9-13%	Less expensive manufacturing process	Irregular blue colour	Solarex, Kyocera	Can be damaged by partial shading
Amorphous	3-10%	Least expensive manufacturing process	Shimmery 'motherof pearl' look	Unisolar, Intersolar	Light and flexible

Table 5.1 Comparison of Photovoltaic Technologies

Other photovoltaic technologies such as 'string ribbon' from evergreen are also popular (see Section 5.6 – Useful Resources).

A photovoltaic system typically used for a home would be made up from a number of *modules* to form a photovoltaic *array*. For example: the array system in figure 5.1 uses 18 modules.

Figure 5.1 Roof Mounted Photovoltaics
(Krannich Solartechnik:, evergreensolar 2005)

Most photovoltaic panels are permanently mounted in a single position. This is referred to as a fixed mount. Alternatively, there are installations whereby the tilt angle can be adjusted to accommodate seasonal changes. More sophisticated *dual-axis* trackers also exist.

PV is not restricted to houses or small scale. There are large ‘PV farms’ and often large building mounted installations.

5.5.1 Characteristics of PV

PV is:

- Easily integrated into urban areas
- Can be building integrated (PV roof shingles)
- No moving parts (therefore more robust, compared to wind and hydro)
- Low maintenance
- Easy to install and work with

But:

- Most costly option
- Energy is seasonally extreme (summer-winter) in northern latitudes.
- Low energy efficiency

Yes, you do get power from a PV on a cloudy day (but not as much as on a sunny day). Remember also that being in northerly latitudes means long summer days and thus lots of PV power.

Cloudy weather degrades power output. From this it is clear that more sunlight (irradiance) results in more power. However, counter to our intuition, increasing temperature *decreases* power output of a PV, which is why we may not get the optimal performance we expected at midday.

A typical PV installation would consist of a number of PV modules configured in an array. For example, we can see from figure 5.1 that there are 18 PV modules mounted on this roof. When a system is designed, the choice of PV module and the particular configuration into an array of PV's will be based on the more detailed characteristics of the PV module. Figure 5.2 below of a 75 watt PV panel, gives an idea of what it physically looks like.

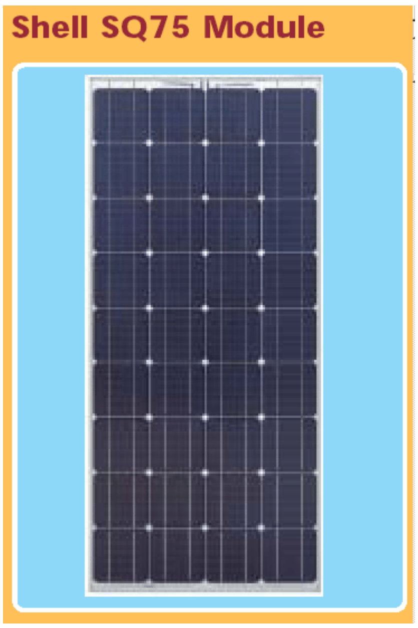


Figure 5.2 Shell Solar Product Information Sheet
(Shell SQ75 Photovoltaic Solar Module)

From Figure 5.2, we get an idea of the maximum power expected from such a module (in this case, it is rated at 75 watts). If we had 18 such modules in an array configuration, then its total power rating would be 18 x 75 watts = 1350 watts, or 1.35 kW.

However, to determine how many kWh such a configuration would deliver requires a few calculations.

5.5.2 Calculations with PV

The important quantity we require for electrical energy is usually kWh. This is the unit of energy that appears on our utility bill.

The kWh a PV module will deliver, obviously depends on the amount of sunshine (solar insolation) it gets as well as factors such as temperature and orientation. To perform this calculation, we use a metric known as "Peak Sun Hours".

"Peak Sun Hours" can be defined as the equivalent number of *ideal* hours of solar insolation available for a fixed mount configuration. This is typically much less than the *actual* number of sunlight hours of the same day.

For example, in theory a 75W module should deliver (75W x daylight hours) watt-hours in a day. In mid June in Clonmel (Ireland) we get 17.5 hours of sunlight. We may then expect to get, for an ideally sited 75W photovoltaic panel: 75w x 17.5 hours = 1,312.50 watt-hours for the day. In practice though, an ideally sited 75W photovoltaic panel is likely to deliver only 75W x *peak sun hours*. In mid June in Clonmel we get 75w x 4.8 hours = 360 watt-hours.

We may get further losses due to factors such as shading, inverter efficiency and battery efficiency (for off-grid) and so on.

When designing a system we therefore need to know the number of peak sun hours for a particular location, and for a particular time of year. To do this we make use of what is known as ‘solar insolation maps’.

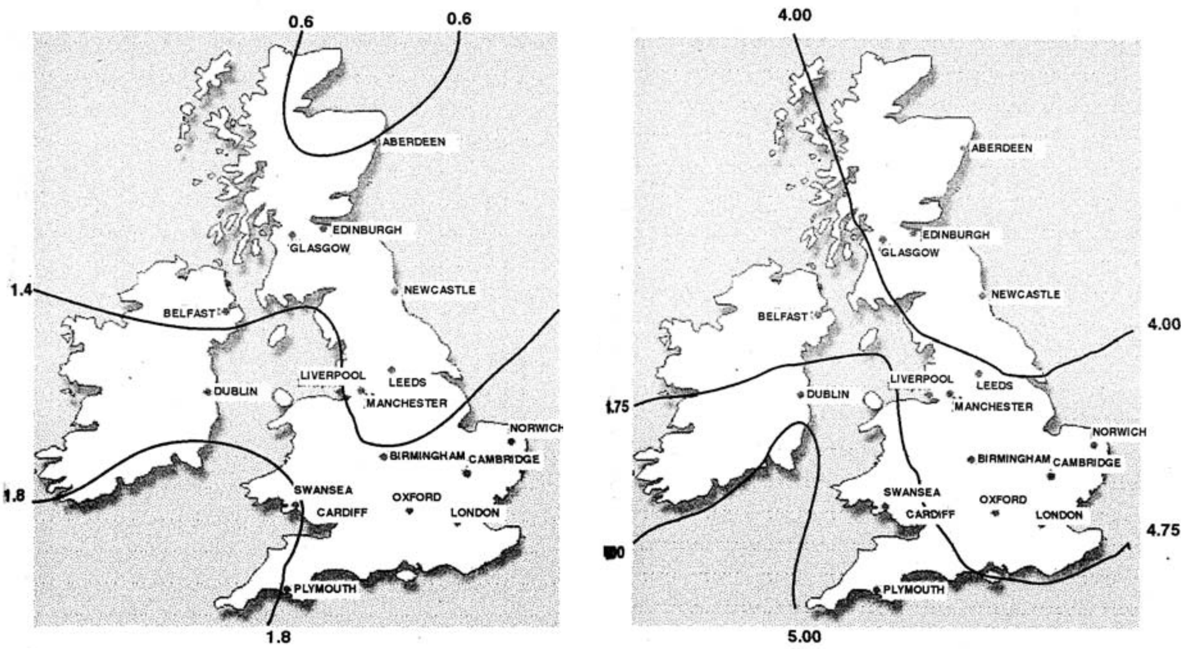


Figure 5.3 Solar Insolation Maps: Mid December, Mid June (greendragonenergy, 2005)

The two graphs above illustrate the ‘solar insolation maps’ for Ireland and the UK. The map on the left is for mid-December (winter) and the one on the right is for mid-June (summer). Based on these charts, we can calculate how many kilowatt-hours our 75watt module will deliver on a day in the middle of winter and on a day in the middle of summer.

We do this by first establishing the “peak sun hours” for the particular location we are interested in. For Clonmel, Ireland, in mid-winter, we can read off the map on the *left* and get an estimate of 1.8 peak sun hours. For Clonmel, in mid-summer, we can read off the chart on the *right* and get an estimate of 4.8 peak sun hours.

On a day in the middle of winter in Clonmel, the 75 watt PV module will deliver: 75 watts x peak sun hours = 75 watts x 1.8 = 135 watt-hours (or 0.135 kWh).

On a day in the middle of summer in Clonmel, the 75 watt PV module will deliver: 75 watts x peak sun hours = 75 watts x 4.8 = 360 watt-hours (or 0.360 kWh)

From this it is clear there is a vast seasonal variation in output, from photovoltaics. This effect is more marked the higher the latitude. This is a critical concern when designing with PV's. For grid connected systems, this must be anticipated by the utility company. For off-grid systems, the usual practice is to include a complementary power generating source, such as a wind turbine, or a diesel (or bio diesel) generator. If one does not include this for an off-grid system, then the storage (usually batteries) must make allowance for poor output in winter.

We now have a general idea of *peak sun hours* and how to calculate kilowatt-hours for a particular location and PV module. The design of a *utility* connected PV system would go further than this. It would require determining the number of expected kWh over the stretch of a year. To do this, we use a map that gives us *annual* peak sun hours.

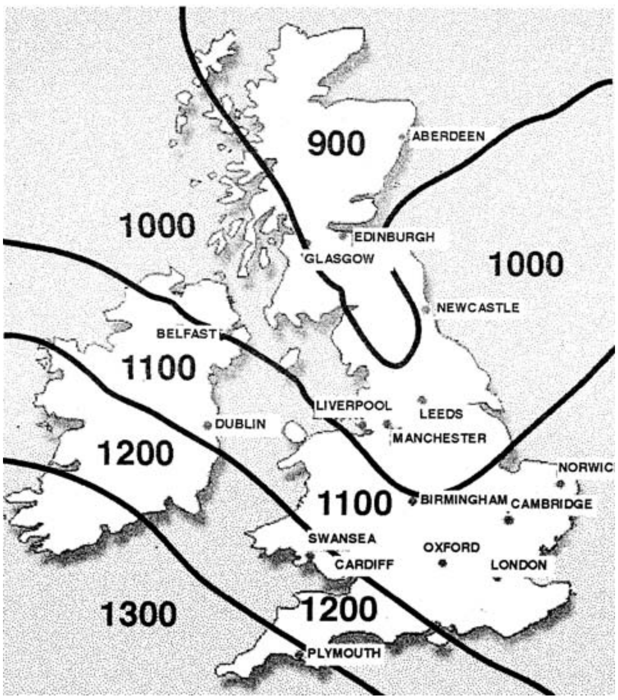


Figure 5.4 Annual Solar Insolation Map
(greendragonenergy, 2005)

For our example of Clonmel in Ireland, we can read off from the graph, and get: Annual peak sun hours = 1200.

We can then use this to determine the total kWh that our fixed mount 75 watt panel will deliver in a year. The calculation is simply:

75 watts x annual peak sun hours = 75 watts x 1200 = 90 000 watt-hours (or 90 kilowatt-hours).

Question:

If the PV system in figure 1 is comprised of 75 watt panels, and is mounted in Clonmel at a tilt angle of 52 degrees, then calculate the following:

(i) The total kW rating of this system.

(ii) The number of kWh it will deliver on,

(a) a typical day (mid-winter)

(b) a typical day (mid summer)

(iii) The total kWh it can deliver over a typical year.

(iv) The total cost of the system, if each panel costs c€400.

Answer:

(i) Each panel is 75 watts, and there are 18 of them. Total kilowatt rating is therefore: 75watt x 18 = 1350 watts, or *1.35 kW*.

(ii) (a) In mid winter: peak sun hours (from Figure 5.3) x kW rating.

1.35 kW x peak sun hours = 1.35 kW x 1.8 = *2.43 kW*

(ii) (b) In mid summer: peak sun hours (from figure 3) x kW rating.

1.35 kW x peak sun hours = 1.35 kW x 4.8 = *6.48 kWh*

Example 5.1 Determining Energy Output and Cost of a PV System

5.5.3 Siting Considerations

Correct siting of a photovoltaic is critical. The graphic below illustrates this. Ideally, one would like the PV's to track the sun *daily* from sunrise to sunset (known as *solar azimuth*). They should also track the sun's *seasonal* north-south shift variations (known as *solar declination*). This is possible by means of a technology known as a *dual axis tracker* .

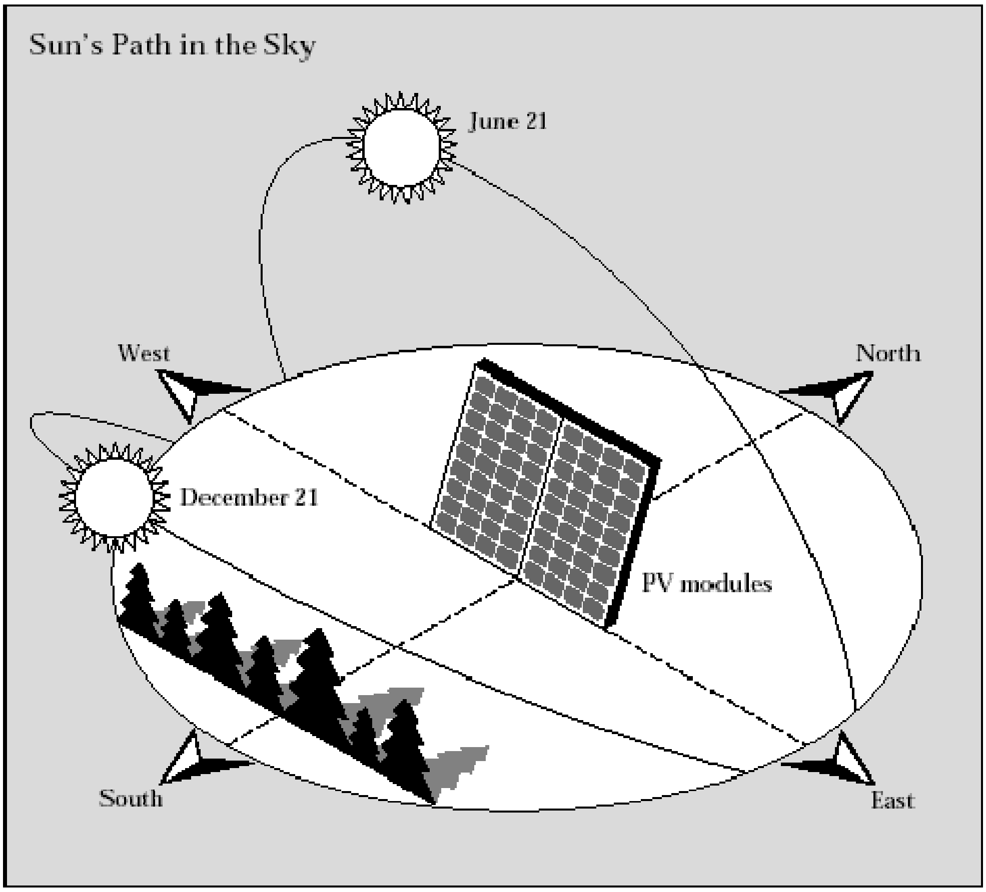


Figure 5.5 Solar Orientation
NREL, 1997 *Photovoltaics: Basic Design Principles and Components* (page 3)

More commonly photovoltaics would be "fixed mount". This means they are 'permanently fixed' at a particular orientation (usually south facing) and a particular declination (tilt angle). In this configuration they are typically mounted on a roof of a house or building, but can also be mounted on a dedicated frame away from the house or building.

The best *orientation* for fixed mount photovoltaics is south facing. The best *declination* (tilt angle) is usually based on a rule of thumb: tilt angle = degree of latitude[1]. Thus, if one were to position an array of photovoltaics at an abode in Clonmel, for example, then one would site them south facing, and with a tilt angle of 52° from level, as Clonmel is located at latitude 52° north.

Some photovoltaic installations also allow for an adjustable tilt angle, to accommodate seasonal shifts of the suns movement. The benefits of doing this are intuitively obvious if we study above.

Another consideration when siting photovoltaics concerns the issue of *shading*. If we look at figure 5.1, we see there is a shadow from the chimney onto the photovoltaics. Similarly, it is not uncommon for PV's to get shaded by trees at certain times of the day and certain times of the year. Ideally, designers should minimize shading, by careful placement. Shading can seriously degrade performance of a PV, and can even damage some PV technologies.

A final word on siting concerns the particular context of the installation. An off-grid system would generally want to optimize energy yield by very careful siting. On the other hand, a grid-connected PV system can be more versatile. Some utilities pay differential rates according to time of day. In light of this one could get a better rate in the afternoon than in the morning. It may be more cost effective to then orient the modules in a south westerly direction.

5.5 Photovoltaics in Ireland

Potential

Figure 5.6 below gives us an idea of the potential for solar-based technologies in Ireland, relative to some other EU countries. Note that we have a greater solar resource than both Germany and the UK. Germany has extensive photovoltaic installations, together with policies to support it. England has grant schemes for photovoltaics that can cover up to 50% of the cost. There is

[1] Optimal tilt angle is more complex than this, and requires specialist knowledge.

great potential for grid-connected PV, from a solar resource point of view, despite the fact that PV is considered an expensive form of renewable electricity.

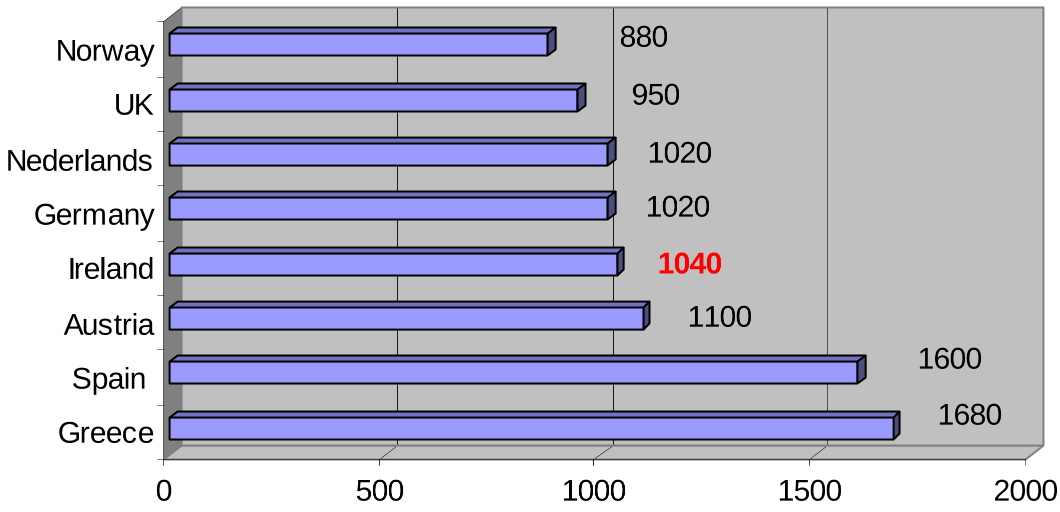


Figure 5.6 Annual Solar Energy Potential (Ireland and EU) Irradiation in kwh/m^2

5.5.4 Installed Capacity

Apart from very rare, isolated instances, Ireland has practically no installed photovoltaic modules.

5.5.5 Policy, Grants and Funding

At the present time of writing, it is not realistically possible to connect photovoltaics to the grid due to (a) exorbitant connection fees (for microgeneration) and (b) restrictive regulations. In light of escalating energy prices, there is substantial pressure to redress these restrictions. The Commission for Energy Regulation (CER) are in process of working on possible strategies for grid connection of microgeneration.

Concerning grants and funds, the UK supports costs up to 50% for PV installations. Unfortunately the Irish Government has yet to allocate a grant for any form of domestic renewable electricity generation.

5.6 Useful Resources

Solar Energy Societies (Local and International):

Irish Solar Energy Association ISEA www.irishsolar.com

British Photovoltaic Association www.pv-uk.org.uk/ (includes 44 page installers guide)

International Solar Energy Society www.ises.org/

Businesses in Ireland Supporting PV:

For a directory of businesses, see: www.sustainable.ie/directory/index.php

Selected Businesses Internationally supporting PV:

1) Photovoltaic Manufacturers:

Siemens (Germany)	http://www.siemens.com/
Kyocera (Japan)	http://www.kyocerasolar.com/
BP (British)	http://www.bpsolar.com/
Shell	http://www.shell.com/solar/
Unisolar	http://www.shell.com/solar/
Evergreen (USA)	http://www.evergreensolar.com/

2) Building Integrated PV (BIPV) http://www.solarcentury.co.uk/

3) Sun Trackers (dual axis) http://www.zomeworks.com/ and http://www.wattsun.com/

4) Miscellaneous:

Homepower magazine:http://homepower.com

5.7 References

Komp, R. J. 2001, Practical Photovoltaics: Electricity from Solar Cells 3rd Edition, revised, aatec publications, Ann Arbor, Michigan

Evergreensolar 2005 *Roof Mounted Photovoltaics* [online]. Accessed 20th September 2006 at http://www.evergreensolar.com/applications/index.html, (The facility was assembled and installed by Krannich Solartechnik)

GreenDragonEnergy, 2005 *Annual Solar Insolation Map,* Accessed in October 2005 from Course Materials compiled by Frank Jackson (www.greendragonenergy.co.uk)

GreenDragonEnergy, 2005 *Solar Insolation Maps: Mid December, Mid June* , Accessed in October 2005 from Course Materials compiled by Frank Jackson (www.greendrtagonenergy.co.uk)

NREL, 1997 *Photovoltaics: Basic Design Principles and Components*, [online] Accessed in October 2005 from www.nrel.gov (document commissioned by the U.S. Department of Energy, and written by the NREL National Renewable Energy Laboratory)

Roberts, S 1991, Solar Electricity: A Practical Guide to Designing and Installing Small Photovoltaic Systems, Prentice Hall

Shell Solar Product Information Sheet (Shell SQ75 Photovoltaic Solar Module), [online] Accessed in October 2005 at www.sunwize.com/info_center/pdfs/shell_SQ75.pdf

Solar Energy International, 2004, Photovoltaics: Design and Installation Manual, New Society Publishers