Solar Photovoltaic Froducts: A guide for development workers

By: Anthony Derrick, Catherine Francis, & Varis Bokalders

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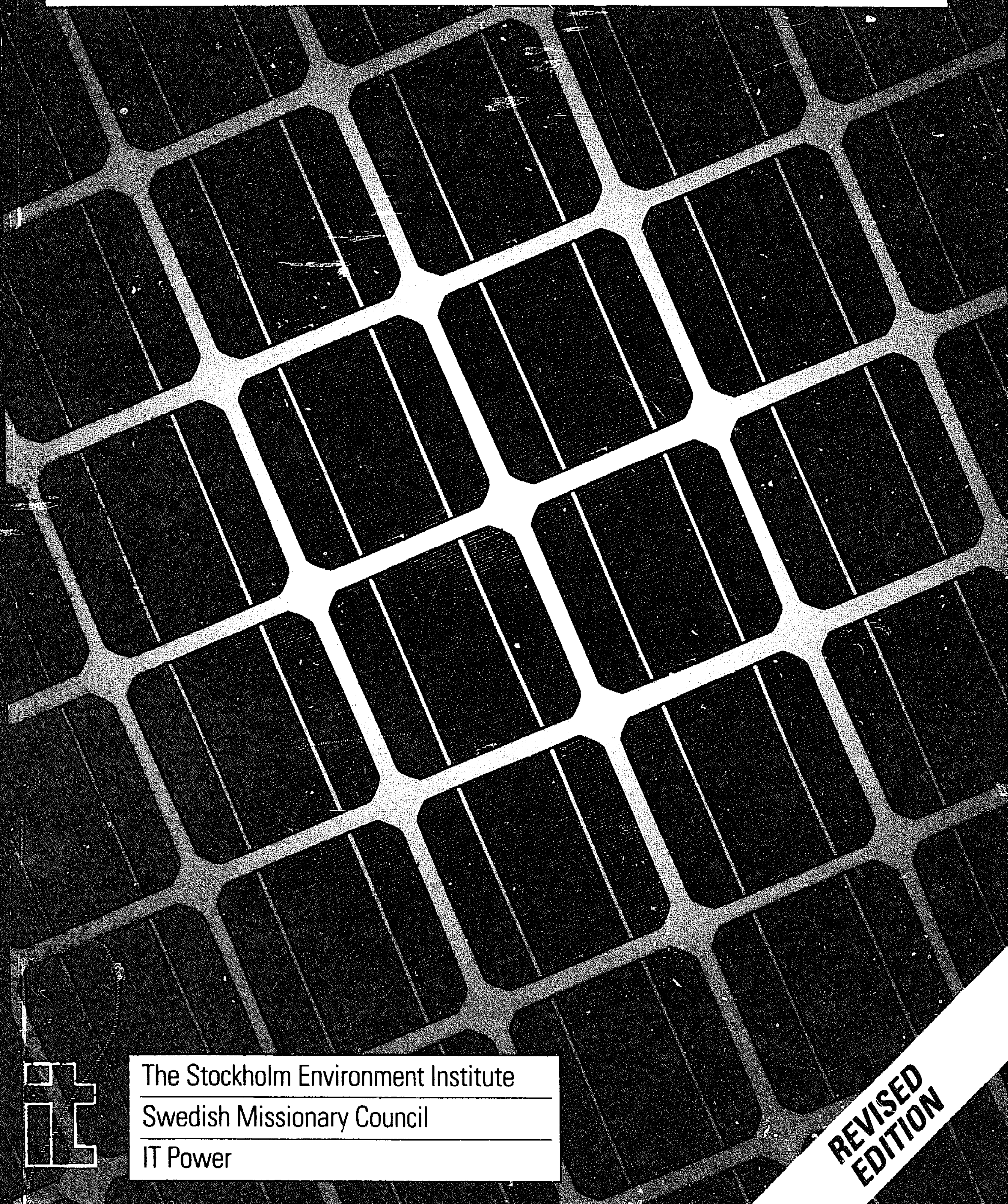

The Stockholm Environment Institute
Swedish Missionary Council
IT Power

REVISED EDITION

# SOLAR PHOTOVOLTAIC PRODUCTS

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# FOREWORD

This book is the result of a cooperative project involving I.T. Power Ltd, the Stockholm Environment Institute and SMC, the Swedish Missionary Council, and is sponsored by SIDA, the Swedish International Development Authority. Its origin stems from the needs of SMC field staff who have found much of the information currently available on photovoltaics to be fragmented and often incompatible.

This book is an updated version of the 1988 publication with the same name, produced jointly by IT-Power, the Beijer Institute and the Swedish Missionary Council. During 1989, the Beijer institute was integrated into the new Stockholm Environment Institute .

The Stockholm Environment Institute, which has close working contacts with the SMC in the field of renewable energy, runs an information programme on renewable energy for development which has resulted in a series of publications and seminars. I.T. Power has substantial experience of renewable energy matters and for many years has taken a particular interest in photovoltaics.

Photovoltaics (PV) were a natural choice as the subject of the first cooperative project. PV is a mature technology which has already proven its reliability in several important niches, not least in many small scale applications in developing countries such as water pumping, refrigeration, lighting and telecommunications. Large numbers of PV systems are currently being installed. This proliferation of the technology has, however, created a need for accurate, reliable and objective information among field workers who seldom have time to grasp the intricacies of all the various gadgets offered to them by manufacturers and agents. PV thus differs from several other renewable energy technologies in that it has already been proven under widely varying circumstances, and that a major bottleneck to its dissemination is not connected to the technology as such (as is the case with many other renewable energy sources), but rather to the lack of availability of reliable information on its operation, cost and range of applications.

This book aims at addressing this shortfall of information, and we hope that the combined experience of our three organizations will be of assistance to other workers in the field.

**Lars Kristoferson**
**Stockholm Environment Institute**

**December 1990**

## CONTENTS

## PREFACE

This handbook aims to assist anyone with a little technical experience, but probably no previous knowledge of photovoltaic (PV) systems to decide:

- if a power supply is suitable for the purpose in mind
- the type of equipment needed;
- how to proceed in implementing a project using PV products

This guidebook has been prepared by I.T. Power Ltd of Eversley, UK and the Stockholm Environment Institute, Sweden for the Swedish Missionary Council Office for International Development Cooperation.

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# 1. INTRODUCTION

## 1.1 WHAT IS PHOTOVOLTAICS?

Photovoltaics is a technology that can convert light directly into electricity. (The term photovoltaic is often abbreviated to PV.)

The sunniest regions of the world receive a vast amount of energy from the sun every day. At the peak of the day the power from the sunshine falling over one square kilometre of Kenya is equivalent to the total being supplied by the country's electric grid. Solar energy can be converted directly into electricity. The technology used to do it is called photovoltaics.

Photovoltaic systems are being used in developing countries to provide power for water pumping, lighting. vaccine refrigeration, electrified livestock fencing, telecommunications cathodic protection, water treatment and many other applications.

Some tens of thousands of systems are currently in use yet this number is insignificant compared to the vast potential for PV applications.

**Installing the Solar Array of a Solar Powered Refrigeration and Lighting System for a Health Centre in Zaire ( I T Power)**

## 1.2 WHY PHOTOVOLTAICS?

The majority of the population in developing countries live in dispersed communities in rural areas. The provision of an electricity supply to these areas is difficult and costly; extension of the mains grid over difficult terrain is generally not economic for small power loads and the use of diesel generator sets relies on the availability of fuel supplies and maintenance skills.

Photovoltaic modules provide an independent, reliable electrical power source at the point of use making it particularly suited to remote or inaccessible locations. PV systems are technically and economically viable. Their principal advantages are:

- **PV systems have no fuel requirements:**
  In remote areas diesel or kerosene fuel supplies are erratic and often very expensive. The recurrent costs of operating and maintaining PV systems are small.

- **PV systems are modular:**
  A solar array is composed of individual PV modules so each system can be sized to meet the particular demand.

- **PV systems can be used to improve quality of life:**
  For example, the provision of lighting in a rural school allows evening educational or community activities. Refrigeration at a health centre improves effectiveness of immunization programmes.

- **PV systems are highly reliable:**
  The reliability of PV modules is significantly higher than of diesel generators or wind generators.

- **PV systems are easy to maintain:**
  Operation and routine maintenance requirements are simple.

- **PV modules have a long life:**
  There is little degradation in performance over 15 years.

- **PV systems provide national economic benefits:**
  Reliance on imported fuels such as coal and oil is reduced.

- **PV systems are environmentally benign:**
  There is no harmful pollution through the use of a PV system and no contribution to "greenhouse gases".

- **PV systems are economically viable:**
  On a life cycle cost basis and taking into consideration the higher reliability of PV, many small scale applications can be more economically powered by PV than with diesel systems, or other small power supplies.

# 2. OVERVIEW OF PHOTOVOLTAICS

## 2.1 BRIEF HISTORY

Until recently, price has been the main barrier to the widespread use of photovoltaics. In 1975, this was over $30/Watt. Since then, improvements in manufacturing technology and production volumes have reduced prices to their present 1991 level of around $4 per Watt. This has resulted in making photovoltaic power economic in areas remote from mains electricity grids.

The photovoltaic effect was first observed by the French scientist Becquerel in 1839 who noticed that when light was directed onto one side of a simple battery cell, the generated current could be increased.

The first practical photovoltaic devices were selenium and cuprous oxide cells used for photographic exposure meters and light sensors. Light to electricity efficiencies of about 1 per cent were achieved in the early 1940s.

It was not until the late 1950s, however, that crystalline silicon solar cells were developed with high enough conversion efficiencies to be used for power generators. A major impetus for the development of these cells was the space programme. The first solar-powered satellite, Vanguard I, was launched by the USA in 1958. The output for terrestrial PV modules matured in 1983 with the introduction of automated PV production plants (see Figure 2.1).

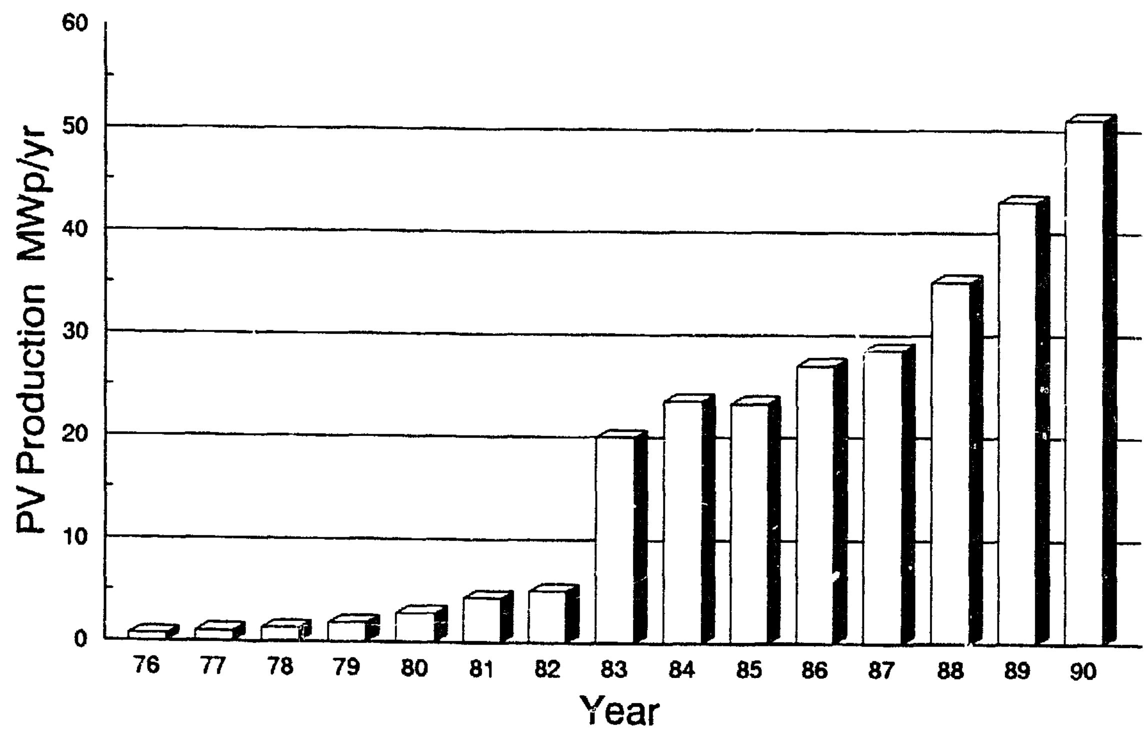



**Figure 2.1 PV Module Production in Recent Years**

### 2.1.1 Technology and Prices

Over the last ten years, the price of photovoltaic modules and systems has been steadily falling in real terms. Module prices for both forms of crystalline silicon are currently around $4/Wp (exclusive of delivery or taxes) for large orders. Bearing in mind that the cells account for about 60 per cent of the module price, some further price reductions, possibly down to about $2-$3/Wp, are foreseen through the introduction of cheaper silicon and larger, fully automated manufacturing plants. Much lower costs, even down to $1/Wp or less, are potentially attainable with thin film cells. In view of the large efforts being made world-wide to develop different thin film technologies including Cadmium Telluride, CIS and Multijunction devices, it is probable that large-area thin film cells will become available with much improved efficiency and stability compared with current products. Some researchers maintain that crystalline silicon cells could continue to be competitive with thin film processes for several years.

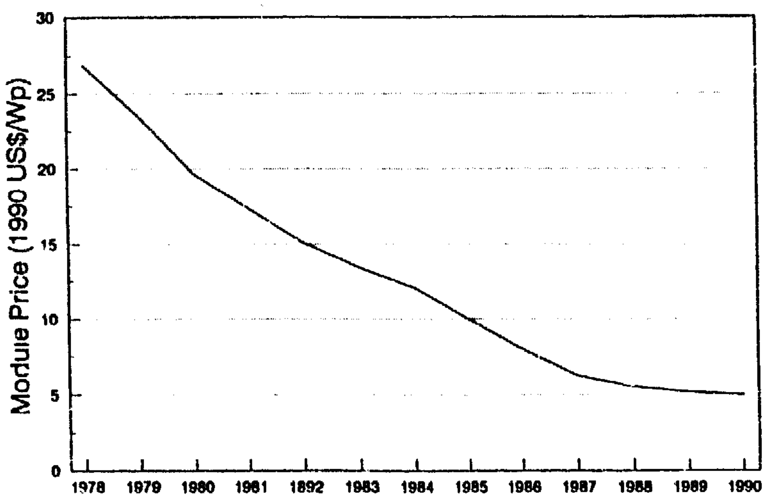



**Figure 2.2**
**PV Price History**

### 2.1.2 The Future Market

Market prospects are largely dependent on prices of photovoltaics in relation to alternative energy sources, but other factors are important, such as government incentives, availability of finance and the general perception of the technology held by

| YEAR | LOW PRICE SCENARIO | | | HIGH PRICE SCENARIO | | |
|---|---|---|---|---|---|---|
| | Modules $/Wp | Systems $/Wp | Sales MWp/yr | Modules $/Wp | Systems $/Wp | Sales MWp/yr |
| 1990 | 4.0 | 8-15 | 52 | 4.0 | 8-15 | 52 |
| 1995 | 2.0 | 3-7 | 700 | 3.0 | 6-10 | 100 |
| 2000 | 1.5 | 2.5-5 | 1000 | 3.0 | 5-9 | 200 |

**Table 2.1 Projection of PV Prices and Sales to - 2000 (1990 US$)**

potential customers. Although it is not possible to predict with precision what the future market will be, Table 2.1 indicates what the future sales of photovoltaic systems worldwide might be for two scenarios. The low price scenario assumes that large area thin film cells with adequate performance are utilised for power applications within the next two to three years; the high price scenario is based on the assumption that the technical or cost targets for thin film cells remain elusive, leaving crystalline silicon as the dominant technology for power applications.

For the low price scenario, with module prices falling to around $1.5/Wp, total annual sales are projected to grow rapidly, from the 1990 level of about 52 MWp to as high as 1000 MWp by AD2000, with continued expansion thereafter. Most of the output would be in and for developing countries for rural off-grid applications using stand-alone systems, but there would also be many applications in industrialized countries for consumer systems, professional systems and remote houses and villages. Grid-connected applications (central power and distributed) could begin to become a significant market in some countries by the late 1990s.

For the high price scenario (now increasingly looking a pessimistic scenario), with crystalline silicon modules prices falling to about $3/Wp and thin film cells not able to compete for power applications, the total market would grow much more slowly, possibly levelling out at about 200 MWp per annum by AD2000. Most of the sales would be for consumer systems and professional systems, with relatively little going to rural electrification, because of the high capital costs involved. However, in some countries, there would be good markets among more wealthy private customers for powering isolated houses and for consumer systems, particularly for the tourist and leisure markets. This scenario also assumes systems installed by national governments and public utilities would be relatively limited, probably only a few megawatts per annum.

### 2.1.3 Market Development

Developing countries have always been considered as a very large potential market but, due to financing problems, actual commercial sales in these countries are at present very small In fact, the greater part of the systems installed to date in developing countries has been assisted by foreign governments and/or the international aid agencies. Developing countries are rightly concerned to ensure that at the right time photovoltaic technology is transferred to them, rather than find themselves dependent yet again on an imported energy technology. In due course, it is likely that most developing countries will have their own PV industry, but this will take many years to establish, during which time there will be a need to import systems for demonstration projects, professional applications and key community applications. At present photovoltaics are manufactured in Brazil, China and India on a commercial scale in the developing world.

Significant markets can be expected to develop for professional systems, particularly for telecommunications, village water supplies and generators for police posts and health centres. If system costs can be brought down to about $5/Wp rural electrification using photovoltaics will become a viable option in many situations, with market potential reckoned in many hundreds of megawatts per annum.

## 2.2 THE PHOTOVOLTAIC PROCESS

When light falls on the active surface, the photons in a solar cell become energised, in proportion to the intensity and spectral distribution of the light. When their energy level exceeds a certain point a potential difference, or open circuit voltage (Voc), is established across the cell. This is then capable of driving a current through an external load.

Most modern photovoltaic devices use silicon as the base material mainly as mono-crystalline or multi-crystalline cells but recently also in amorphous form.

The main features of a mono-crystalline silicon cell are shown in Figure 2.3. It is made from a thin wafer of a high purity silicon crystal, doped with a minute quantity of boron. Phosphorus is diffused into the active surface of the wafer. The front electrical contact is made by a metallic grid and the back contact usually covers the whole surface. An anti-reflective coating is applied to the front surface.

The process of producing efficient solar cells is costly due to the use of expensive pure silicon and the energy consumed. Research work to develop new manufacturing technologies continues.

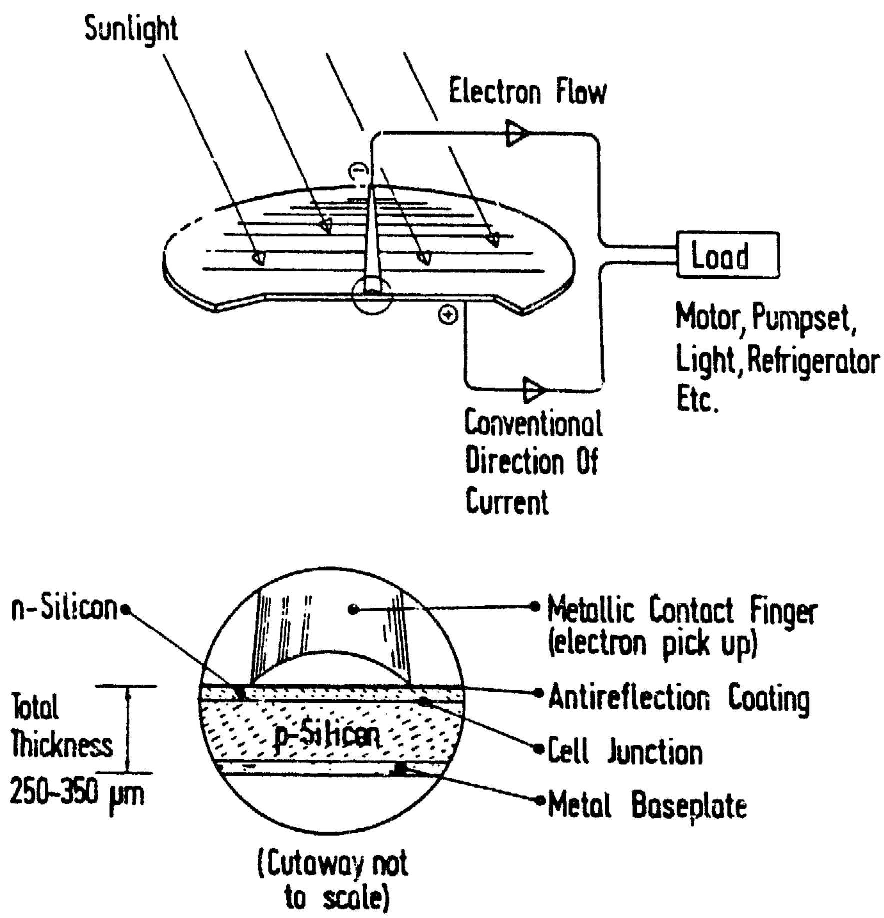



**Figure 2.3 Features of a Mono-Crystalline Silicon Solar Cell**

## 2.3 MODULES AND ARRAYS

**Solar cells** are interconnected in series and in parallel to achieve the desired operating voltage and current. They are then protected by encapsulation between glass and a tough resin back. This is all held together by a stainless steel or aluminium frame to form **a module.** These modules form the basic building block of a **solar array**. Modules may be connected in series or parallel to achieve the required solar array characteristics.

Thus, with no moving parts and all delicate surfaces protected, the modules can be expected to provide power for 15 years or more. Many suppliers give warranties of 10 years or more.

Commercially available modules fall into four types based on the solar cells used. These are:

- **mono-crystalline cell modules** where highest cell efficiencies of around 16% are obtained. Figure 2.4 shows the construction of a mono-crystalline silicon PV module. The cells are cut from a mono-crystalline silicon crystal.

- **multi-crystalline cell modules** where the cell manufacturing process is of lower cost but cell efficiencies of only around 13% are achieved. A multi-crystalline cell is cut from a cast ingot of multi-crystalline silicon and is generally square in shape.

- **amorphous silicon modules** are made from thin films of amorphous silicon where efficiency is much lower (5-9%) but the process uses less material. The potential for cost reduction is greatest for this type. Unlike mono-crystalline and multi-crystalline cells with amorphous silicon there is some degradation of power output with time.

- **multijunction types** where different layers of thin film photovoltaic material are used with each layer receptive to a particular part of the solar spectrum therby achieving higher efficiencies.

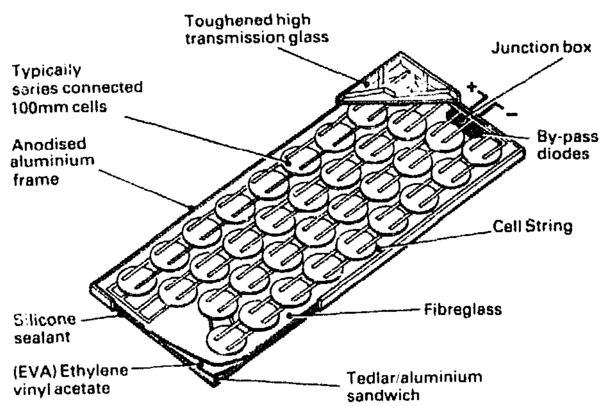



**Figure 2.4 Construction of Mono-crystalline PV Module (BP Solar)**

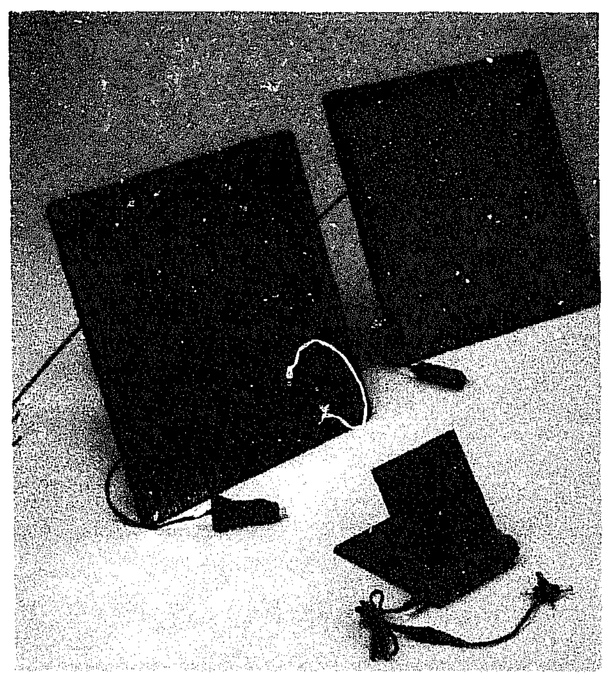


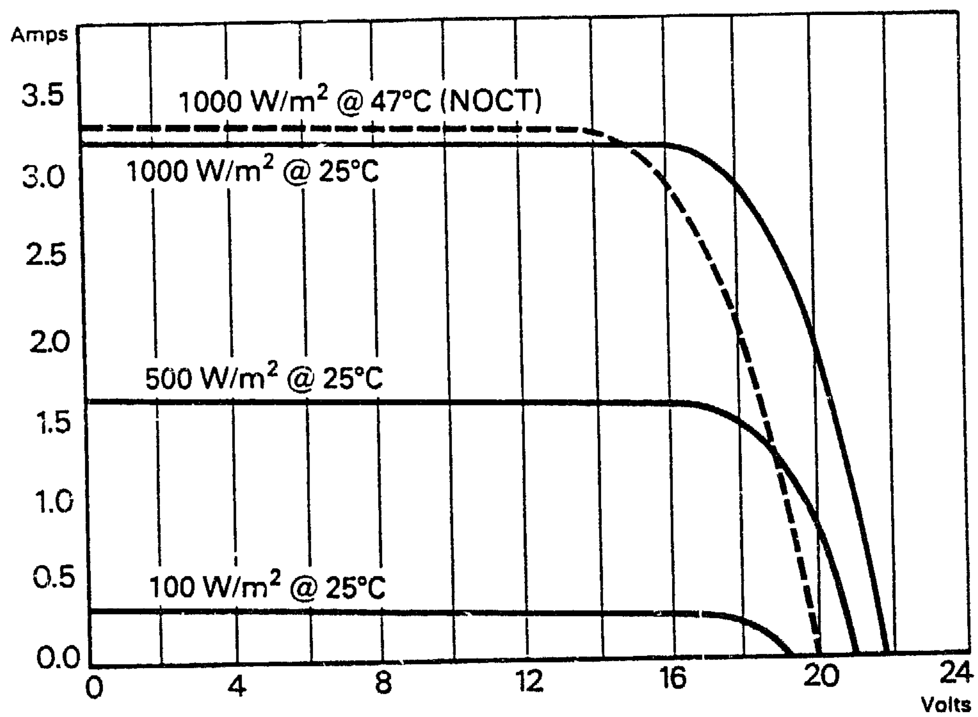
**Figure 2.5 Amorphous Silicon Modules**

The current-voltage relationship (I-V) for a typical module is dependent on solar irradiance and temperature. As the level of solar irradiance increases so the output current will increase proportionately. Conversely, as cell temperature increases, the current will increase slightly but the voltage will decrease significantly, resulting in a decrease in power. Figure 2.6 illustrates these characteristics.

The main importance of Figure 2.6 is to show that:

- It is desirable to operate the cells at as low a temperature as possible.
- The maximum power output realisable from a PV cells is when the operating conditions are at the "knee" of the I-V curve. This is referred to as the "Watt Peak" - Wp - of the cell. For comparative purposes, this is measured at an irradiance level of 1000 $W/m^2$ and a temperature of 25°C.

An array can vary from one or two modules with an output of 10W or less, to a vast bank of several kilowatts. Figure 2.7 shows a typical installation for a remote dwelling with a few modules on the roof to charge a battery typically for lighting use. This can be compared to the array shown in Figure 2.8 which provides the needs of a community and requires large battery storage, power conditioning equipment and a mini-grid distribution system.




NOCT = Nominal Operating Cell Temperature

**Figure 2.6 Electrical Characteristics of a Typical PV Module**

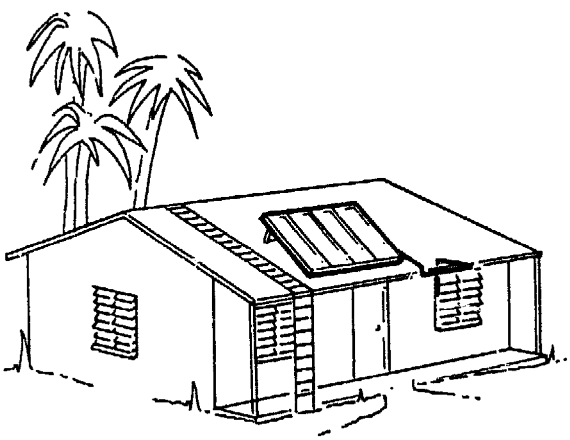


Figure 2.7 **Individual Dwelling Electrifiction**

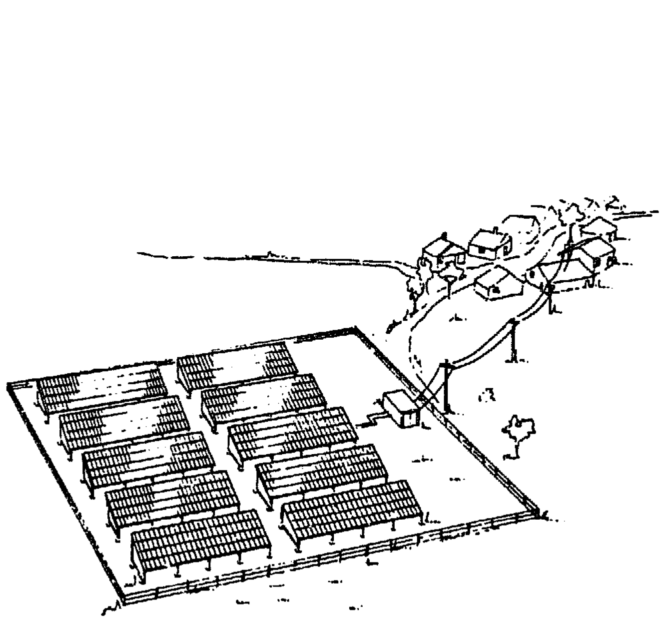


Figure 2.8 **Photovaltaic Array Supplying a "Mini - Grid"**

**Flat plate arrays** which are held fixed at a tilted angle and face towards the equator are most common. The angle of tilt should be approximately equal to the angle of latitude for the site. A steeper angle increases the output in winter; a shallower angle gives more output in summer. It should be at least 10 degrees to allow for rain runoff (Figure 2.9).

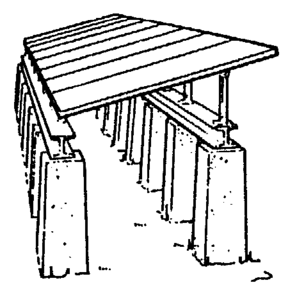


Figure 2.9 **Fixed Flat Plate Array**

**Tracking arrays** follow the path of the sun during the day and thus theoretically capture more sun. However, the increased complexity and cost of the equipment rarely makes it worthwhile.

**Mobile (portable) arrays** (Figure 2.10) can be of use if the equipment being operated is required in different locations such as with some lighting systems or small irrigation pumping systems.

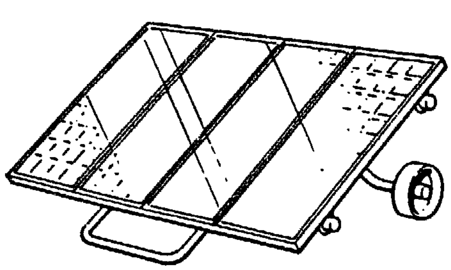


Figure 2.10 **Mobile Array**

## 2.4 SYSTEMS

The term "system" is used to describe the complete set of equipment used in converting solar energy to the final requirement, eg light, pumped water or refrigeration. PV systems are mainly used as stand-alone systems to provide a power supply independent of any grid. They are the main concern of this guide. However, PV arrays may also be used as a central generator connected to a local grid network or as a power station for a mains grid.

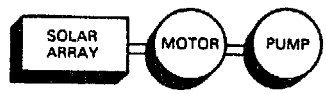
A stand-alone system can notionally be divided into three parts:

**The PV array** (comprising the photovoltaic modules and support structure) which converts solar energy to d.c. electricity.

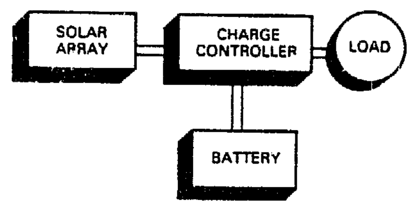
**The power conditioning equipment** which is optional, but typically includes:

- cabling
- 
- controller which may include battery overcharge protection to prevent gassing and loss of electrolyte from the battery, an automatic load disconnect facility for when battery voltage is low (to prevent damage to the load) and maximum power point tracking (array/load impendence matching).
- batteries: these should only be included when storage of electrical energy is required, eg,for lighting. When not essential batteries should be avoided due to the additional cost and maintenance requirements batteries impose.
- an inverter: to convert d.c. to a.c. electricity. As significant energy losses are always incurred in the conversion process it is preferable to use d.c. appliances and avoid the need for an inverter.

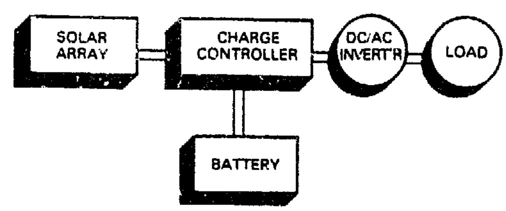
**Load or end use equipment,** eg lights, pumps and refrigerators. Most commercial suppliers now prefer to supply complete systems rather than individual components. These are sized for the specific location and energy demand required.



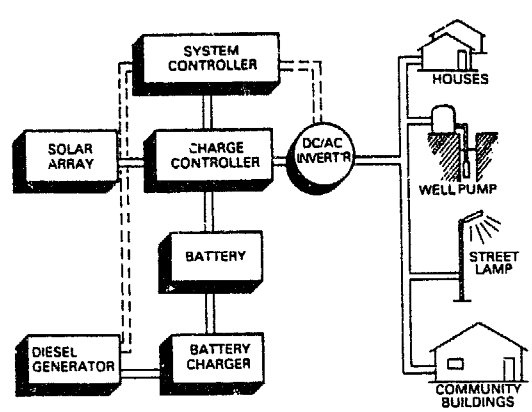

**PV System Without Batteries (Solar Pump)**




**PV System with Battery**




**PV System with Inverter**

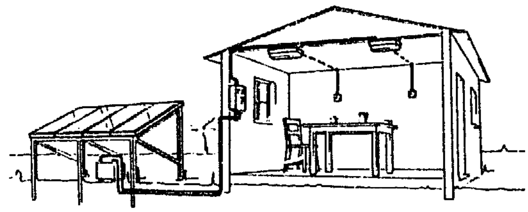



**PV System with Multiple Load and Diesel Back-up**

# Applications of Photovoltaics

## RURAL ELECTRIFICATION

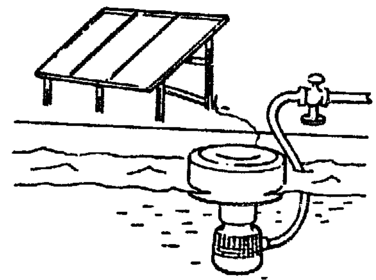
- lighting and power supplies for remote buildings (mosques, farms, schools, mountain refuge huts)
- power supplies for remote villages
- battery charging stations
- portable power for nomads



PV lighting for a Community Building

## WATER PUMPING AND TREATMENT SYSTEMS

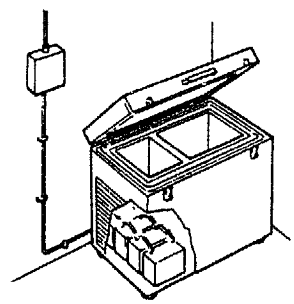
- pumping for drinking water
- pumping for irrigation
- de-watering and drainage
- ice production
- saltwater desalination systems
- water purification
- water circulation in fish farms



Floating Solar Powered Pump

## HEALTH CARE SYSTEMS

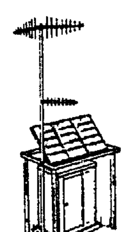
- lighting in rural clinics
- UHF transceivers between health centres
- vaccine refrigeration
- ice pack freezing for vaccine carriers
- sterilisers
- blood storage refrigerators



PV Refrigerator for Vaccine Storage

## COMMUNICATIONS

- radio repeaters
- remote TV & radio receivers
- remote weather measuring
- mobile radios
- rural telephone kiosks
- data acquisition and transmission (river levels, seismographs)
- emergency telephones



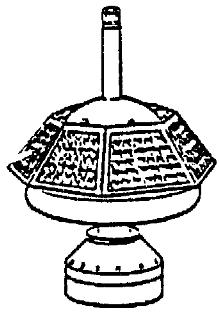
PV Power for a Radio-Telephone Systems

## AGRICULTURE

- livestock watering
- irrigation pumping
- electrical livestock fencing
- stock tank ice prevention

## TRANSPORT AIDS

- road sign lighting
- railway crossings and signals
- hazard and warning lights
- navigation buoys
- fog horns
- runway lights
- terrain avoidance lights
- road markers



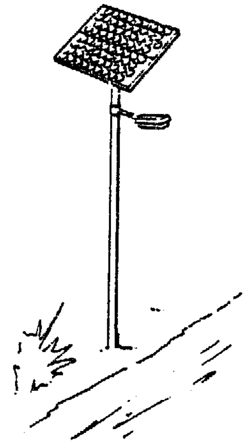
PV Powered Navigation Buoy

## SECURITY SYSTEMS

- security lighting
- remote alarm system

## CORROSION PROTECTION SYSTEMS

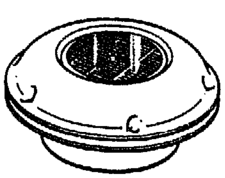
- cathodic protection for bridges
- pipeline protection
- well-head protection
- lock gate protection
- steel structure protection



PV Street Lamp

## MISCELLANEOUS

- ventilation systems
- camper and recreational vehicle power
- calculators
- automated feeding systems on fish farms
- solar water heater circulation pumps
- path lights
- yacht/boat power
- vehicle battery trickle chargers
- earthquake monitoring systems
- battery charging
- fountains
- emergency power for disaster relief
- aeration systems in stagnant lakes



PV Powered Ventilator

## INCOME GENERATION

- battery charging stations
- TV and video pay stations
- village industry power
- refrigeration services

## 2.5 OVERVIEW OF THE ECONOMICS

**In an analysis of a potential PV system its viability must be assessed relative to the alternatives. In general, PV is most competitive where relatively small amounts of energy are required in areas remote from the grid. Typical viable demands are less than 50 kWh/day.**

The economic characteristics of PV systems are different to that of most small power systems in that:

- **the initial outlay** on purchasing the equipment (the capital cost) is high
- there are **no fuel costs**
- **maintenance costs are low**
- **reliability is high** such that replacement costs are low
- the output of a system depends on its location, so its economic viability has to be assessed, for each case.

In undertaking an economic evaluation, the following parameters should be considered:

- the life cycle costs-which are the sum of the costs and benefits of the system accrued over its lifetime, expressed in present day value
- payback period - which is the length of time it takes for the total costs to be "paid for" by the value of benefits gained from the system
- rate of return - which is the value of the benefits gained from the system compared to the initial investment made.

**The viable applications** for photovoltaics include village water supplies, and livestock water pumping, lighting and refrigeration. The relative economics will, however, be dependent on local conditions including the solar resource at the site, local fuel costs and the particular application. Figure 2.11 shows how the comparative costs of PV, diesel generator and grid supplied electricity vary with solar energy received, fuel cost, demand and remoteness, from a grid.

**Life cycle costing is the most complete analysis** and normally undertaken to determine if an application is economic. A brief description of how to undertake life cycle costing is given in Appendix 1.

In practice, it is necessary to take into account the availability of funds. Larger amounts of money are required initially for PV systems to cover capital costs but then recurrent costs are lower. Hence, if there is uncertain funding in the future for fuel or maintenance, PV has an advantage. The World Health Organisation for example is promoting the use of PV to provide income generation for sustaining rural health care.

**PV also offers less financially quantifiable advantages** arising from its high reliability such as improved immunisation programmes (from more reliable vaccine refrigeration).

A brief description of the economic viability of each application is covered in the applications sections of this book.

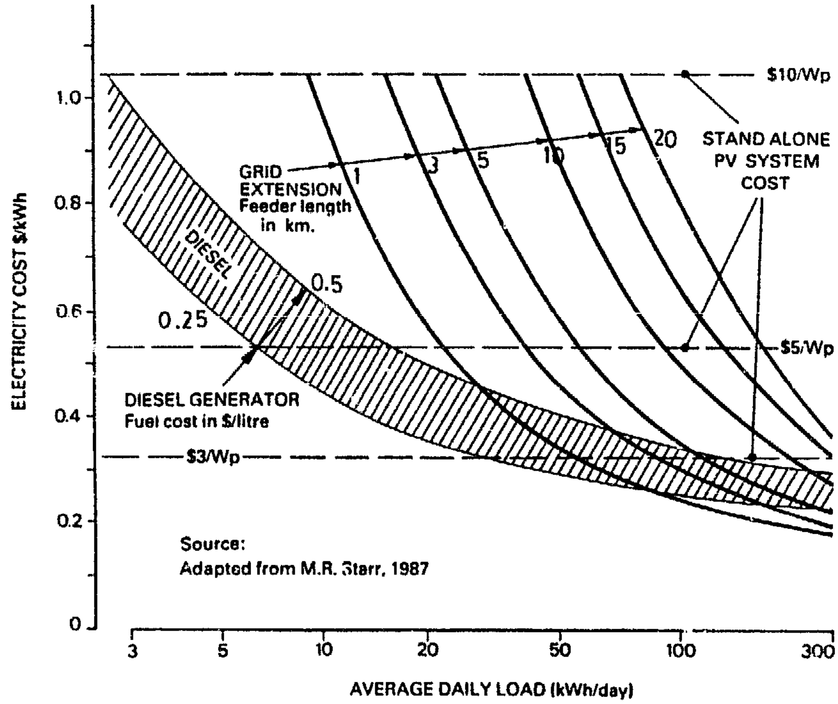



**Figure 2.11 Comparative Costs of PV and Diesel Power**

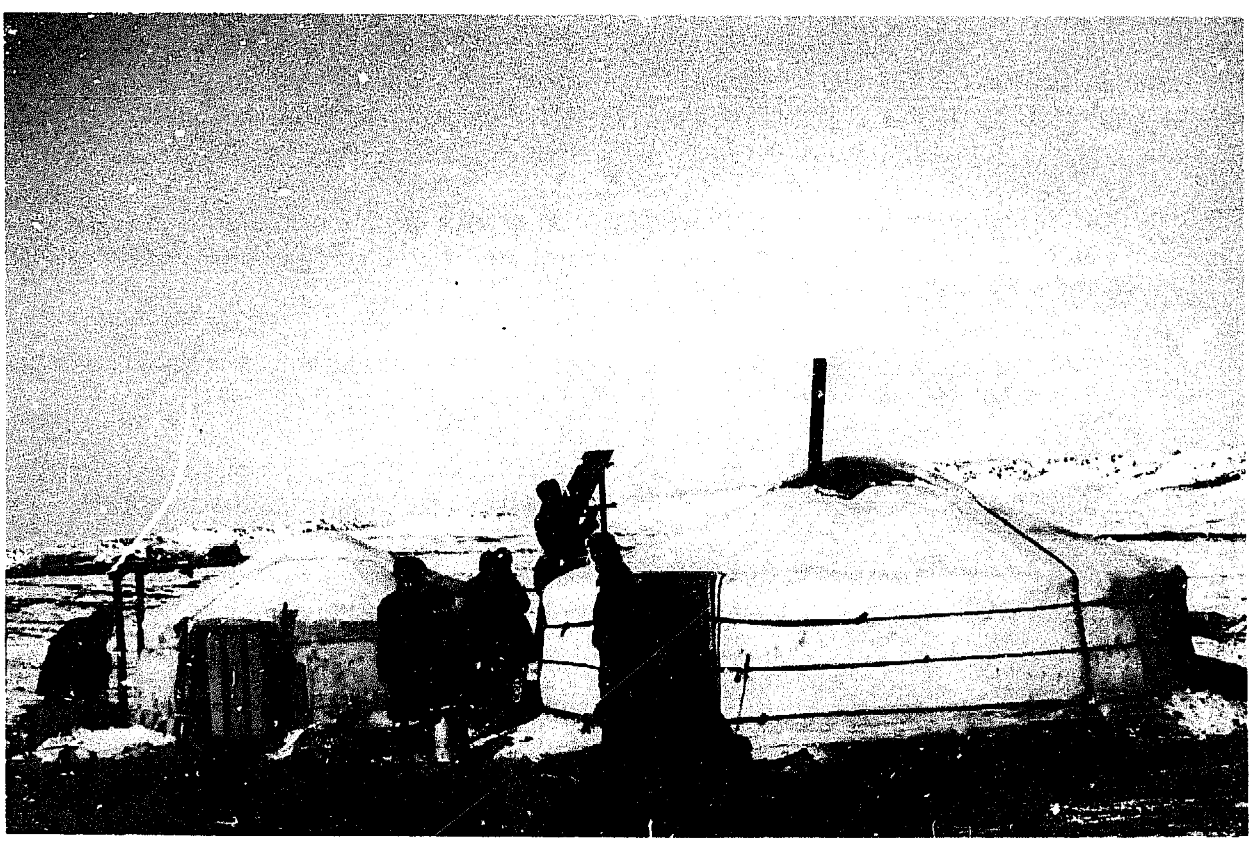


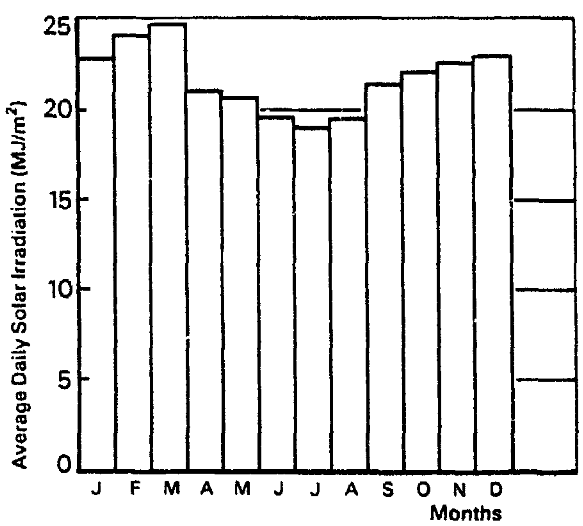
**Figure 2.12 An Economic Application: Household Electricity in Mongolia**

## 3.1 THE SOLAR RESOURCE

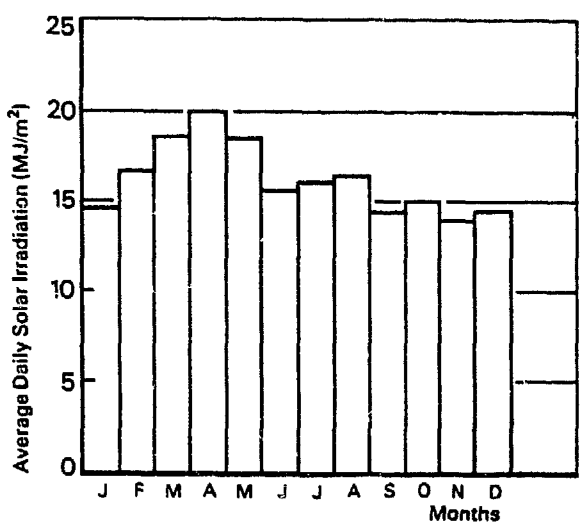
**The output of a solar array depends on the amount of sunlight or solar irradiance, falling on it, so it is important to determine how much solar energy is available at the site. Solar irradiance levels vary during the day with the angle of the sun, with season, with latitude and with climate.**

The solar irradiance at ground level is made up of a direct component and a diffuse component. The sum of these two components on a horizontal plane is termed the 'global irradiance'. The diffuse component can vary from about 20 per cent of the global on a clear day, to 100 per cent in heavily overcast conditions. On a clear day in the tropics, with the sun high overhead, the global irradiance can exceed 1000 $W/m^2$, but in northern Europe it rarely exceeds 900 $W/m^2$, falling to less than 100 $W/m^2$ on a cloudy day.

Of most interest to potential users of photovoltaic systems is not, however, the instantaneous solar irradiance at a site but the total solar energy received in a day over a specific area. This is known as the daily solar irradiation or insolation. On the horizontal surface, this is typically 5 to 7 kWh per square metre per day in the tropics but can be less than 0.5 kWh per square metre per day on a winter's day in northern Europe. An example of the variation in the solar resource from month to month and day to day is shown in Figures 3.1 and 3.2.




Arid Equatorial Location




Humid Tropical Location

**Figure 3.1 Typical Monthly Variations of Solar Energy Availability**

As discussed earlier, it is normal to tilt a solar array to maximize the solar energy received. The world distribution of solar energy received on an array tilted at latitude angle is shown in Figures 3.3 to 3.6. In order to determine the required size of a PV system, it is necessary to know the levels of solar irradiation and temperatures that can be expected throughout the year. This is specified in terms of the average daily insolation and average ambient temperature for each month.

It must be emphasised that all leading and reputable suppliers of PV systems have detailed data files on the solar resources throughout the world. Thus, it is only necessary to specify to a supplier where you wish to use the PV system. However, it is important that the location should be specified quite accurately as the solar resource can vary within some countries quite significantly between, for example, the coastal, inland or highland areas.

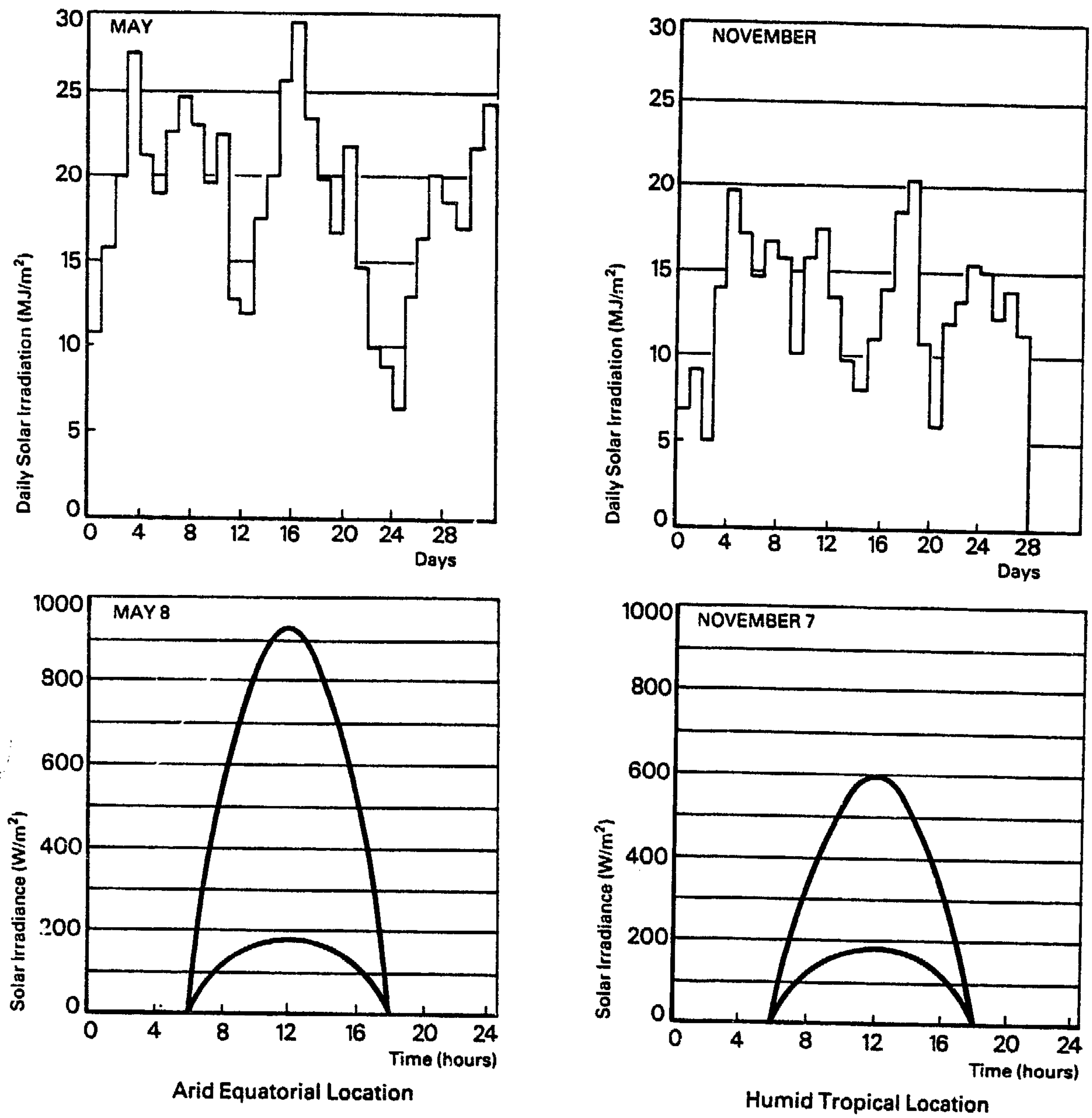



**Figure 3.2 Typical Hourly and Daily Variations in Solar Energy Availability**

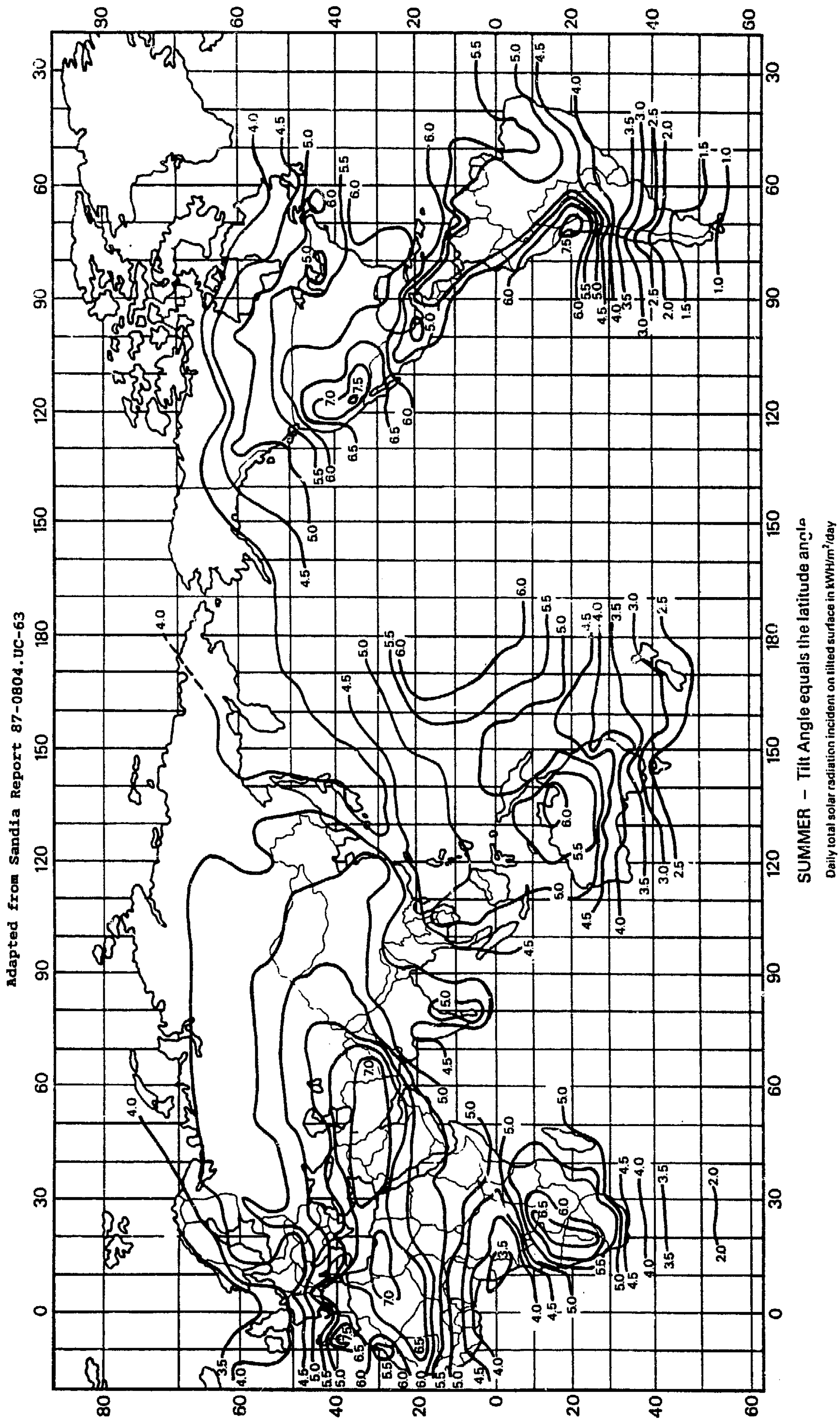



**Figure 3.3 Solar Energy Distribution in Summer (June to August)**

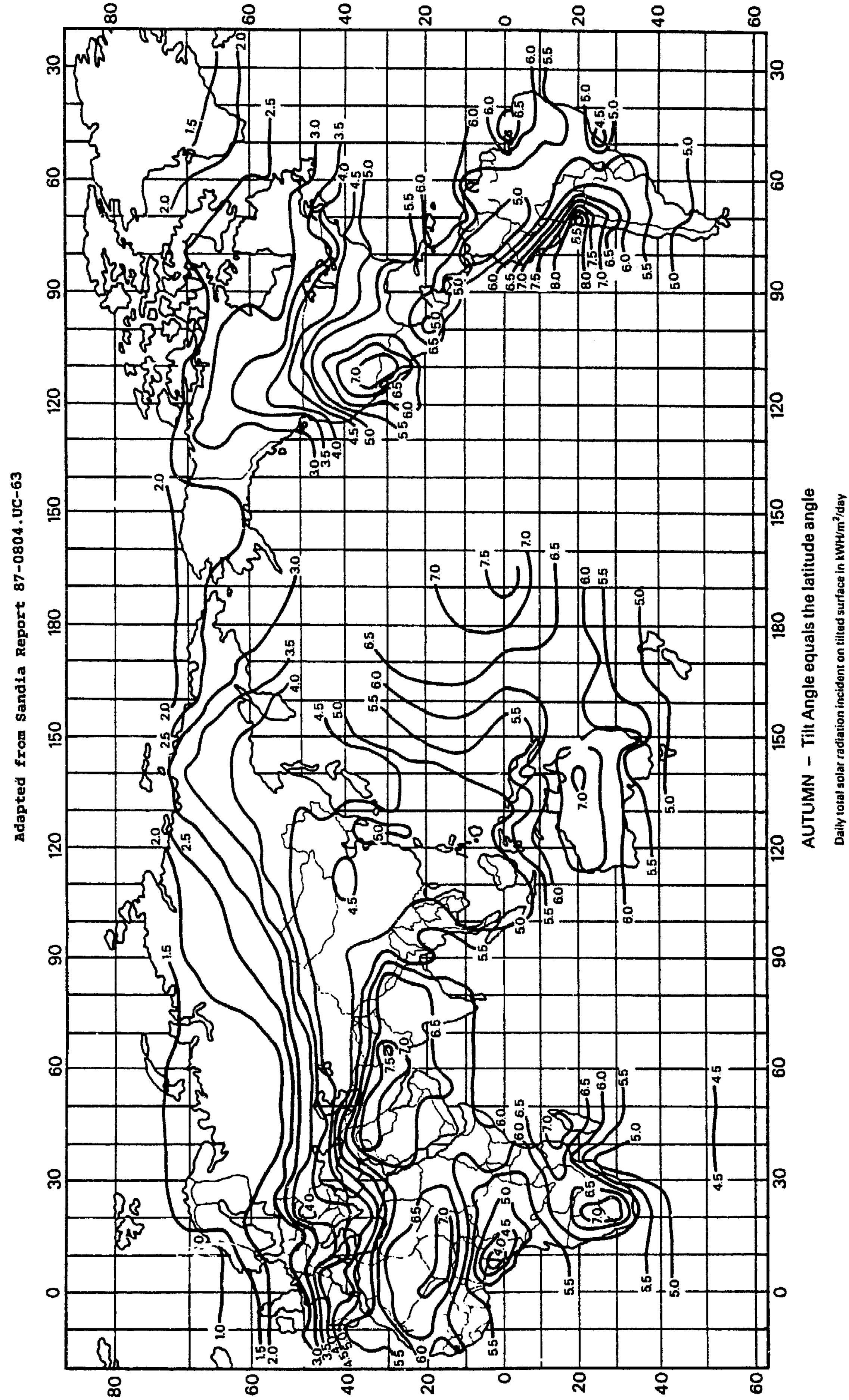



**Figure 3.3 Solar Energy Distribution in Autumn (September to November)**

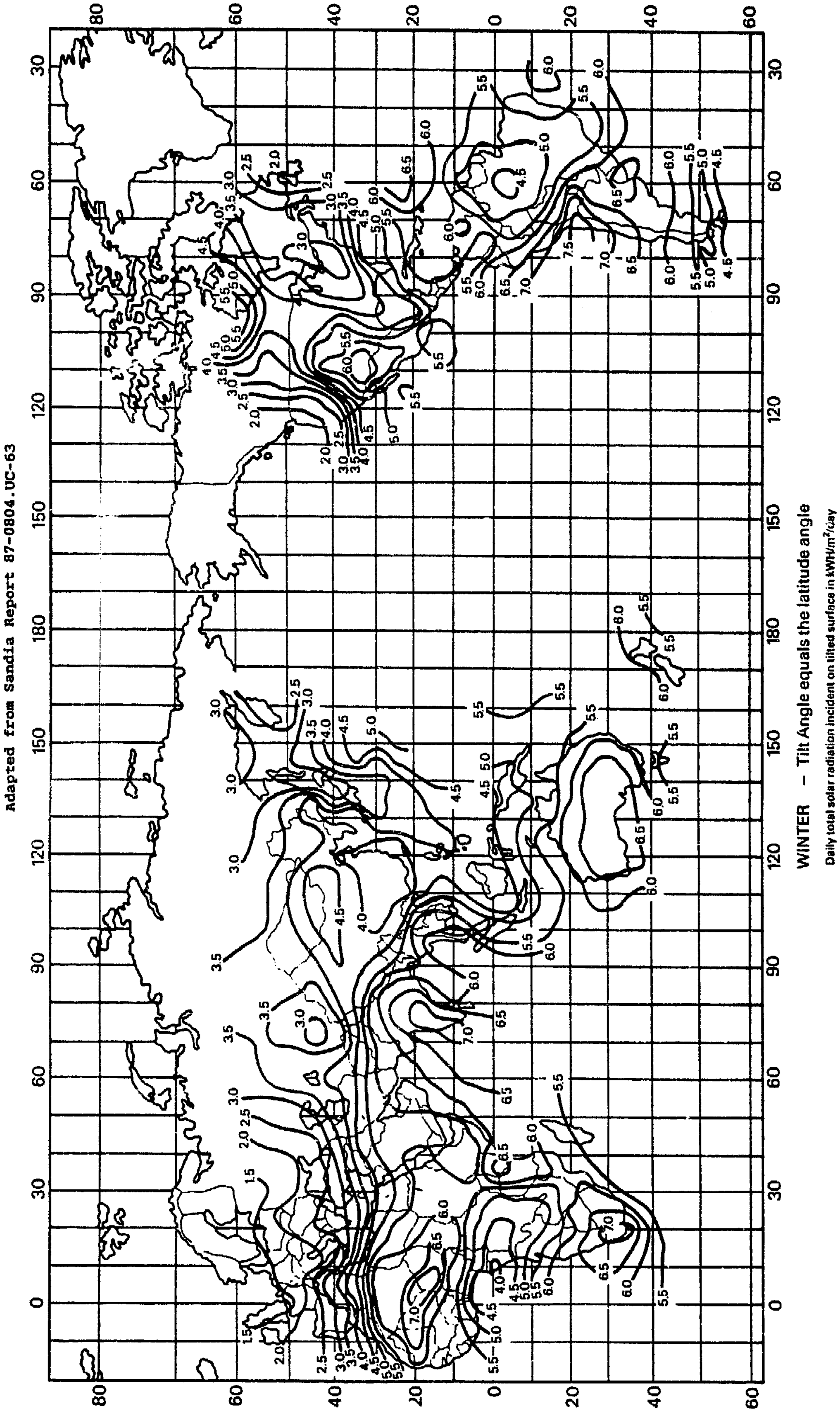



**Figure 3.5 Solar Energy Distribution in Winter (December to February)**

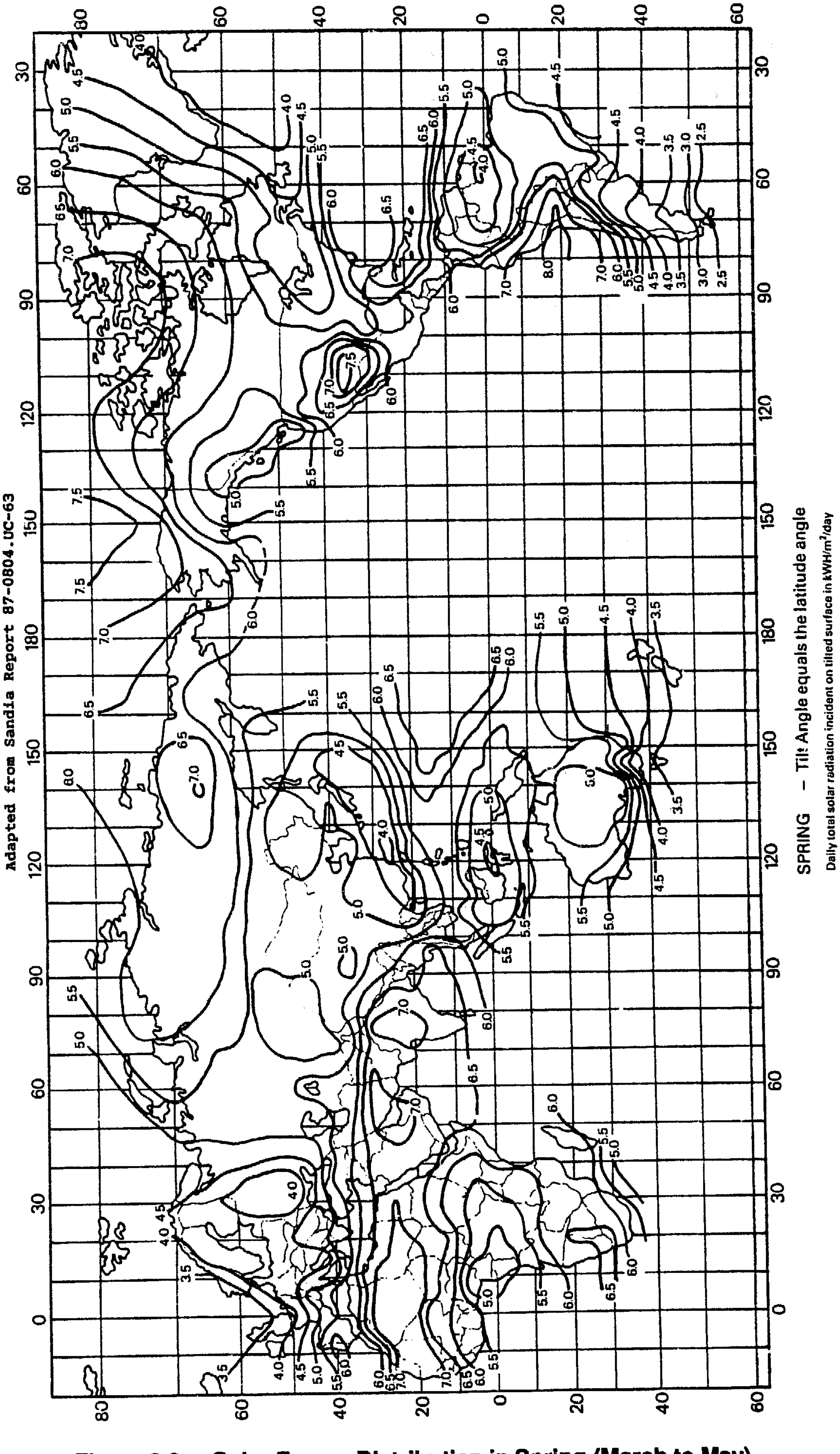



**Figure 3.6 Solar Energy Distribution in Spring (March to May)**

## 3.2 SYSTEM SIZING

### 3.2.1 How Big a PV Solar Array do I Need?

**Normally when you buy a PV system the supplier will determine the size and power of PV array you require using a computer based model. This is a service which should be taken advantage of.**

You will be asked to supply information regarding the intended location of the equipment and user's needs, eg quantity of water or hours of light required per day. Satisfactory performance of the final system will depend on it being correctly sized at this stage. It is therefore important to provide as full and accurate details as possible regarding the proposed site and use of the required systems.

An appreciation of system sizing is valuable in order to check supplier's recommendations. It is also useful to obtain recommended sizes from several suppliers for comparison. Suggestion by any one supplier that the load can be met with a small PV array would indicate that their sizing assumptions may be too optimistic.

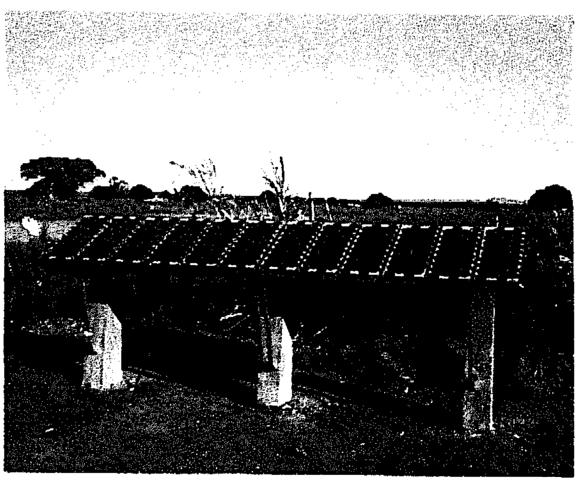


**Figure 3.6 420 Wp Array for a PV Pump in Brazil (Heliodinamica)**

A general nomogram for estimating the array size required for a given daily load energy demand is shown in Figure 3.7.

To use the nomogram:

a) determine the average daily energy demand for the month being assessed and locate it on the axis OB

b) trace a line horizontally from the point on OB to intercept with the line which corresponds to the average daily efficiency of your load equipment

c) move from this point vertically upwards to intercept the average daily insolation in the month

d) move from this point horizontally to intercept the line OA from which the approximate PV array size in watts peak is derived.

e) repeat the procedure for each month. The array size required is the highest value derived from the twelve monthly assessments.

The nomogram can be used in the reverse mode to determine the monthly system output if the array size, insolation and sub-system efficiency are known.

Note also that the nomogram can be used for large or small values of daily energy demand by factoring by 10 on axis OB and then factoring the array size indicated also.

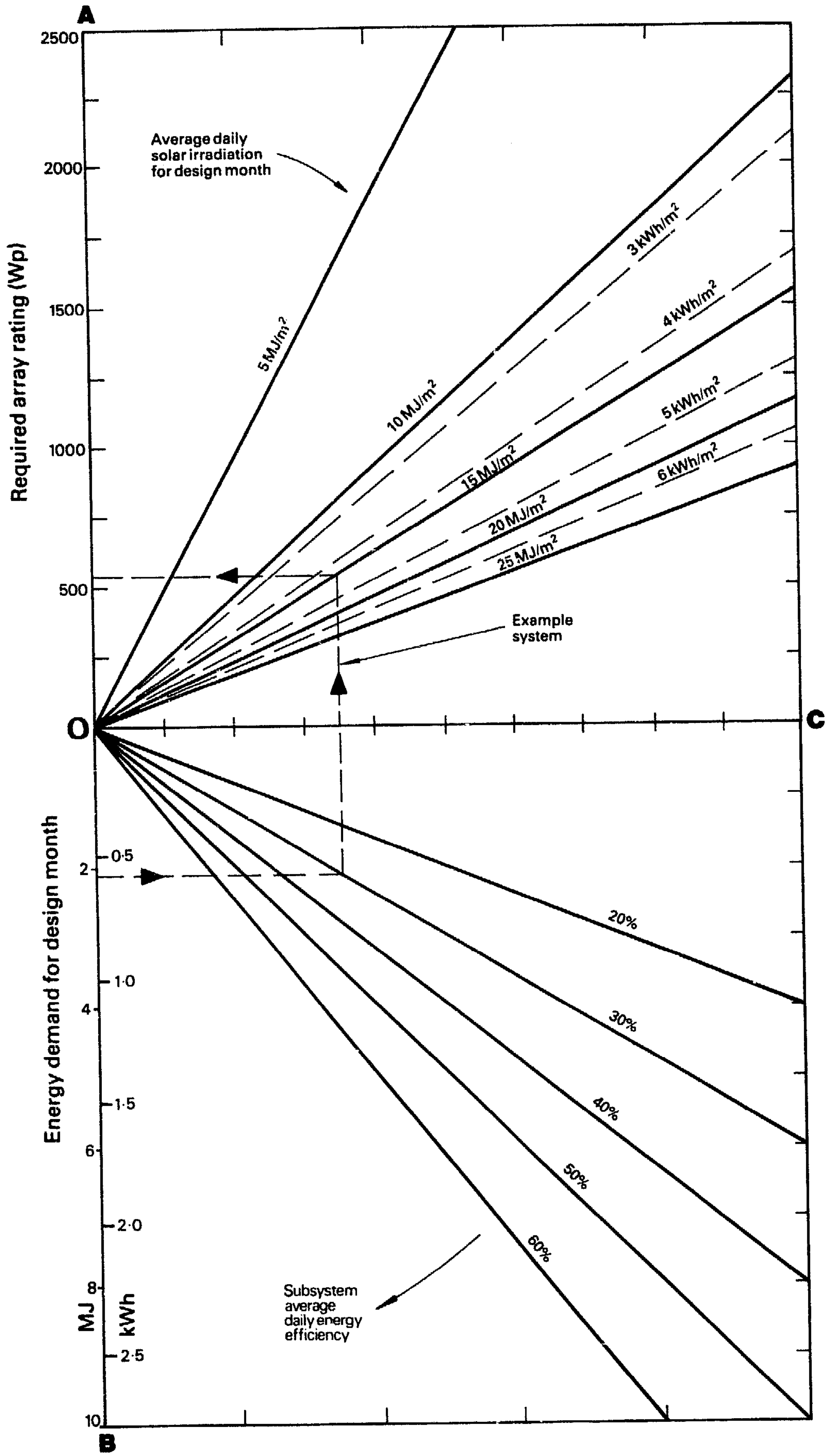



**Figure 3.7 Nomogram for System Sizing**

### 3.2.2 Assessing the End Use Requirements

In general, to size arrays it is necessary to determine the daily energy demand in kWh/day to fulfill the requirements of the user(s). This will have to take account of the power rating of the equipment to be used and estimated daily hours of operation. Where there are seasonal variations in demand the period with the highest ratio of energy demand to solar energy availability should be used.

| IF YOUR REQUIRE | YOU NEED TO KNOW |
|---|---|
| A SOLAR PUMP | ● WATER SOURCE TYPE (well, river, canal, borehole)<br>● WELL/BOREHOLE CHARACTERISTICS (diameter, yield)<br>● HEAD (total static lift in metres)<br>● WATER DEMAND (month by month average daily demand and peak requirements).<br>● WATER STORAGE AND DISTRIBUTION SYSTEM |
| A SOLAR REFRIGERATOR | ● INTERNAL VOLUME REQUIRED<br>● MAXIMUM AMOUNT OF ICE OR GOODS TO BE FROZEN PER DAY<br>● THE NORMAL AMBIENT TEMPERATURE |
| LIGHT (S) | ● NUMBER OF LIGHTS REQUIRED<br>● WATTAGE OF EACH LIGHT<br>● AVERAGE HOURLY USAGE OF EACH LAMP |
| TELECOMMUNICATIONS | ● CONTINUOUS STANDBY POWER FOR THE EQUIPMENT.<br>● TRANSMITTING/RECEIVING POWER<br>● NUMBER OF HOURS OF TRANSMITTING/ RECEIVING. |

**Table 3.1 Load Parameters Needed to Determine System Size**

A summary of the load parameters to be specified when ordering PV systems is given in Table 3.1. The appropriate application chapters have more detailed information on assessing the load requirements for each application.

## 3.3 PROCUREMENT

### 3.3.1 Where to Obtain Photovoltaic Systems - (see Appendix II)

Solar photovoltaic systems are commercially available from many companies throughout the world. There are some indigineous companies manufacturing or assembling PV systems in Brazil, China, India, Indonesia, Senegal, Thailand, Vietnam and Zimbabwe though the majority are based in Europe, USA, Japan and Australia. Many of the latter group have agents and representatives in the Developing World.. A summary of the areas of particular experience for some leading companies is given in Table 3.2.

### 3.3.2 Selecting Equipment

**Equipment should be selected on the basis of technical viability, cost, experience of the manufacturer and supplier and ease of implementation.**

**Technical viability** - the system should have the capability to perform the required function in the specified location. Field experience has shown the actual load (ie, kilowatt-hours consumed) is often greater than anticipated. A safety margin of 20% should be added to allow for this. Ensure it is clear exactly which components are included in the system, and which necessary components are not included and hence are assumed to be readily available locally (eg, pipework in a solar pumping system). Check these components are available locally.

**Simplicity of the system** is often a major factor in obtaining reliable and effective performance in the field. This is particularly so in rural areas of developing countries.

**A cost comparison** of all systems which fulfill the technical requirements should be made taking account of initial purchase, transport to site, installation, operation and maintenance of the system.

**The experience of the manufacturer** and supplier should be considered. Much information can be gained by an examination of other units already operating in a similar situation.

**Practical considerations** of procurement, transportation and installation should be made. Determine if after sales service is available locally for spares supply and repair. Enquire if training courses in the operation and maintenance of the equipment are available.

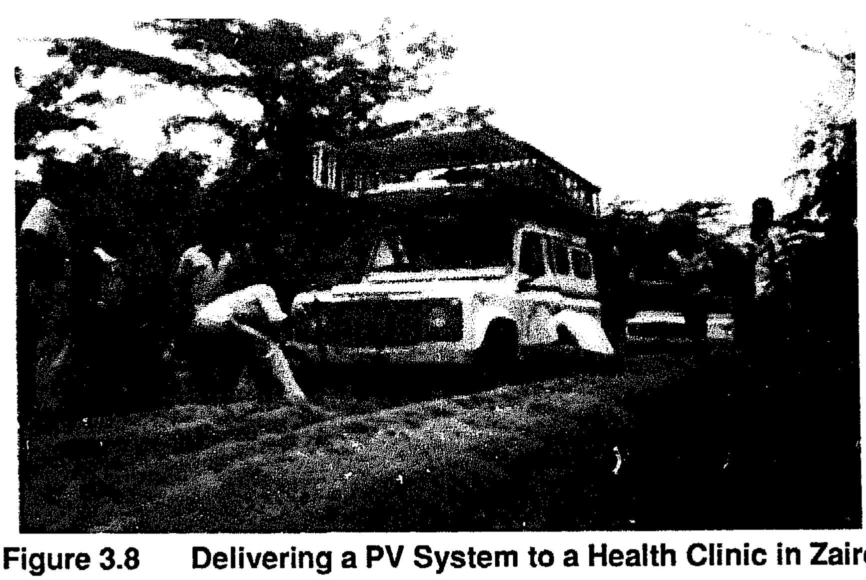


Figure 3.8 Delivering a PV System to a Health Clinic in Zaire

| Company | Country | Modules | Pumping | Refrigeration | Battery Charging and Lighting | Village Telecoms | Water Treatment and Desalination | Other CT = Commercial Telecomms (CP = Cathodic Protection) |
|---|---|---|---|---|---|---|---|---|
| BP Solar | UK, Australia Spain, Thailand | ● ● | ● ● | ● ● | ● ● | ● ● | ● ● | Nav-Aids, CP, CT |
| BHEL | India | ● | | | ● | | | |
| CEL | India | ● | ● | | ● | ● | | |
| Chloride Solar | UK | | | ● | ● | ● | | |
| Chronar | UK, France | ● ● | ● | | ● ● | | | Home Power Kits, Fencing |
| Dinh Co | USA | | ● | | | | | |
| Dulas Eng. | UK | | | ● | | | | |
| FNMA | Zaire | | | ● ● | ● ● | | | |
| Grundfos | Denmark | | ● ● | | | | | |
| Heliodinamica | Brazil | ● ● | ● ● | ● ● | ● | ● | | Nav-Aids, CT |
| Hiltec | UK | | | | | | | Educational Kits |
| Hitachi | Japan | ● | | | | | ● | |
| Hoxan | Japan | ● ● | | | ● | ● | | CT, Fans |
| Hydrasol | USA | | ● ● | | ● | ● | | |
| Intersolar/Solarpak | UK | | ● | ● | ● | ● | ● | Nav-Aids, CP, Fans, CT |
| IPC | USA | | | | | | | Mobile Power, Towable Arrays |
| Isofoton | Spain | ● | | | ● | | | CT, Home Power Kits |
| Italsolar | Italy | ● | ● | ● ● | ● | ● | | CT, Nav-Aids |
| K.S.B. | Germany | | ● ● | | | | | |
| Kyocera | Japan | ● ● | ● ● | ● | ● | ● | ● | Nav-Aids, CP, CT |
| MBB | Germany | ● | | | | | | |
| McDonald A.Y, CO | USA | | ● ● | | | | | |
| Mitsubishi Elec. | Japan | ● | | | ● | | | Tunnel Lighting, TV |
| Mobes | Germany | | | | | | | Fencing |
| Mono Pumps | UK, Australia | | ● ● | | | | | |
| Neste | Finland/Sweden | | ● | ● ● | ● ● | ● ● | ● | Nav-Aids, CT |
| Noack Solar | Norway | | | ● ● | ● | ● | | |
| Photocomm | USA | | | | | | | Air cooler |
| Photowatt | France | ● | ● | | ● | ● | | |
| Polar Products | USA | | | ● ● | ● | | | Fans, Sterilizers |
| Portsol | Portugal | | | | ● | | | Home Power Kits, Fencing |
| R&S | Netherlands | ● | ● | ● | ● ● | ● | | Nav-Aids, Home Power Kits |
| Rade Koncar | Yugoslavia | ● | | | ● | | | Home Power Kits |
| S.E. I. | Italy | | | | ● | | | |
| S.E. T. | Germany | | ● | ● ● | ● | | | TV, Fans |
| Siemens | Germany | ● | ● | ● | ● | ● | | TV, Nav-Aids, CT |
| Solarex | USA/Australia | ● ● | ● ● | ● ● | ● ● | ● ● | ● | Nav-Aids, CT |
| Solarwatt | Australia | | ● | | ● ● | ● | | Home Power Kits |
| Solems | France | ● | | | ● | | | |
| Soltech | Belgium | ● | ● | | ● | | | |
| Sovonics | USA | ● | | | ● | | | Home Power Kits |
| Sun Frost | USA | | | ● ● | | | | |
| Suryovonics | India | ● | ● | ● | ● | | | |
| Suntron | Australia | | ● ● | | | | | Home Power Kits |
| Telefunken | Germany | ● ● | ● ● | ● ● | ● ● | ● ● | ● | |
| Total Energie | France | | ● ● | ● ● | ● | ● | | |
| Transcoast | Belgium | | | | | | ● | |

**Table 3.2 Principal Suppliers of Photovoltaic Systems**

### 3.3.3 Tender Procedure and Evaluation

Here are some things you should think of during the tender procedure.

- **Assess the viability of using PV with** regard to technical, social, institutional, cost and practical considerations. If PV appears to be sensible then:

- **Prepare site details** including location, factors which may affect installation and if available, local meteorological data.

- **Prepare details of load requirements** for each month. These should be expressed as monthly average daily values with any specific peak demands noted.

- **Prepare a tender document** to send to potential suppliers. Allow adequate time for suppliers to respond (4 weeks typically).

- **Undertake preliminary assessment** of tenders for

  - completeness of tender including spares, tools, manuals
  - delivery period
  - warranty

- **Undertake a detailed assessment** for

  - compliance with the specification and estimate of the safety margin in the array size over the worst case daily load
  - the extent and credibility of the information supplied
  - suppliers credibility and availability of back-up services
  - cost competitiveness

- **Select the preferred supplier** and ensure you have answers to all queries on the equipment before ordering.

Figure 3.9 Carrying a PV Array onto a Roof

Figure 3.10 Installing a Roof Mounted Array

## 3.4 SAFETY

**Although photovoltaics modules and systems are no more dangerous than any other small-scale power source, users must always take the following precautions:**

### Solar Array

**Photovoltaic modules have a glass cover;** always carry and transport them carefully.

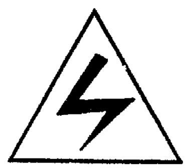
**There is a risk of receiving an electric shock from a solar array.** Although most modules have output voltages of less than 20 volts, if several modules are connected together such that the voltage is greater an electric shock risk is present.

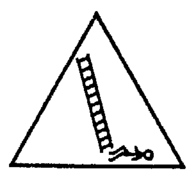
Always take the following precautions when undertaking servicing or repair work on PV systems:

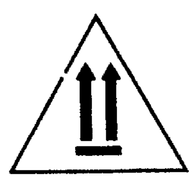
- cover the solar array with a sheet or cloth
- disconnect the array from the load
- use insulated tools.

Solar arrays may need regular cleaning. With roof mounted arrays there is a risk of falling off a roof or ladder.

- make sure that the user has easy and safe access to clean the array.
- always use good ladders and position them firmly.
- use crawling boards when walking on roofs.





### Batteries

**Batteries contain acid** which can cause acid burns on skin or blindness if in contact with the eye. The acid will also damage clothes.

- avoid spilling or splashing battery acid especially in transport.
- always keep the batteries upright.
- carry batteries carefully (do not carry them on your head).
- always use a funnel or plastic bottle with a spout to add distilled water.
- do not let children near batteries and keep batteries in locked, ventilated containers.

**Batteries also give off gases which are explosive**

- make sure that the battery containers provided are well ventilated and that they are placed in a well ventilated room.
- keep naked flames and lighted cigarettes well away from batteries.
- use insulated tools to prevent sparks.

## 4.1 BATTERIES

### 4.1.1 The Case for Batteries

**The amount of electricity produced by a photovoltaic array will vary throughout the day and be zero at night. Some applications need an electric supply at times when no electricity is being produced by the module, for example night lighting. In these instances, batteries are used to store the electricity for use at a later time.**

For some applications, batteries are not important. For example, if water is being pumped into a storage tank it is not critical when it happens only that sufficient water is pumped to meet the day's demand. Batteries are thus not needed in this type of system.

In other cases the supply of electricity needs to be constantly available, for example, for refrigerator or telecommunications loads.

In many countries, particularly in Asia, batteries are routinely used in rural areas to power lights, fans and radios. PV systems may be used to recharge these systems which otherwise have to be undertaken by transporting the batteries to urban areas.

Battery charging is a source of employment and economic activity in many rural areas and is being promoted as a source of income for health centres, for example.

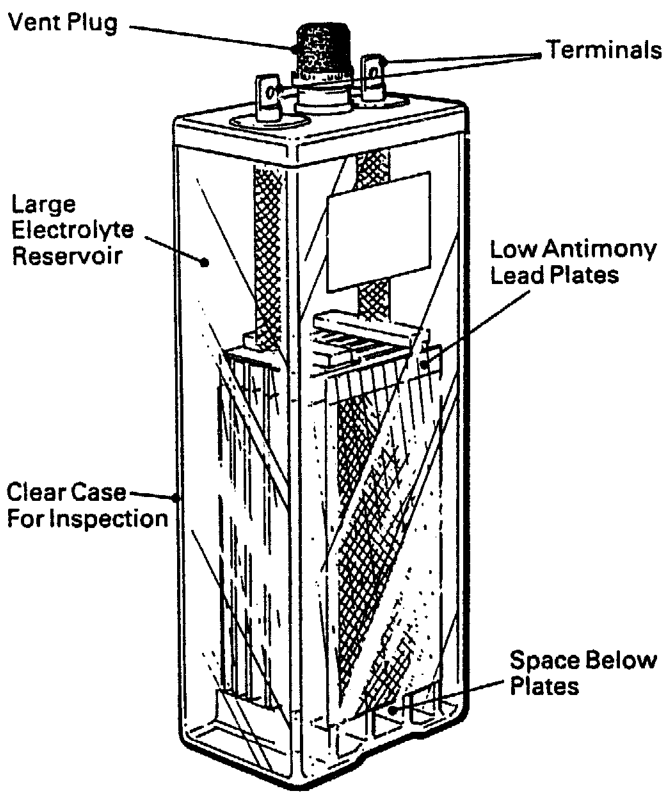



**Figure 4.1 Desirable Features of a Battery for Photovoltaic Use**

### 4.1.2 Batteries for Photovoltaic Systems

Batteries come in all shapes and sizes, each designed to suit a particular use. The characteristics of most importance for use with PV are: ability to be repeatedly charged and discharged without damage, the storage capacity of the battery, the ability to hold charge when not in use, a need to be charged and discharged with minimum loss of electrical energy and a requirement to operate for long periods with little or no maintenance.

These characteristics, (described in terms used by manufacturers), are discussed below. Actual data should be requested from the suppliers.

- **Cycle Life** - is the number of times a battery can be discharged and recharged. This is happening continuously in a PV system so it is essential that the battery has a high cycle life. Some types of batteries are designed with a longer cycle life than others.

  The cycle life for any particular type of battery will depend on the extent to which it is discharged. If only a small amount of power is taken from the battery before recharging, the cycle life will be much longer (see Figure 4.2).

- **Rated Storage Capacity** - a battery's size is expressed by the amount of charge it can hold and is measured in terms of Ampere-hours (Ah). A battery of 100 Ah used to run a light which consumes a 2A current will operate for 50 hours.

  The actual, or available, storage capacity can be significantly less than rated and depends on battery type, manufacture and operating conditions.

- **Depth of Discharge** (DOD) - is the extent to which a battery should be allowed to discharge in normal operation. Beyond the maximum permissible DOD permanent damage will be caused to the battery.

DOD is expressed as a percentage of the rated battery capacity, and typically varies from 50 to 100% depending upon type of battery. Those with a high DOD are called deep-cycle batteries and are most suitable for use with PV systems.

For any type of battery, the DOD is affected by operating temperature. In low ambient temperatures, the allowable DOD will be significantly reduced.

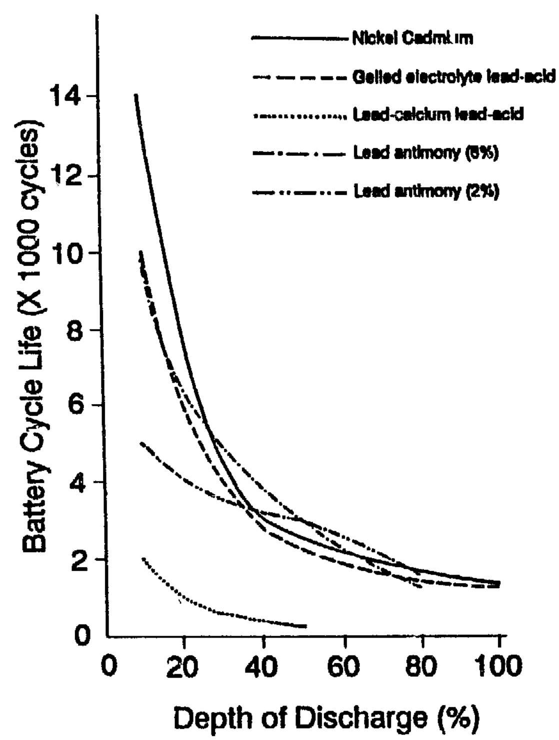



**Figure 4.2 Variation in Battery Cycle Life with Depth of Discharge**

- **Self-Discharge Rate** - if left unused, all batteries will slowly lose their charge but some types self-discharge faster than others, as shown in Figure 4.3. A loss of 0.1 to 0.3% of capacity per day is typical. This can be greater at high ambient temperatures.

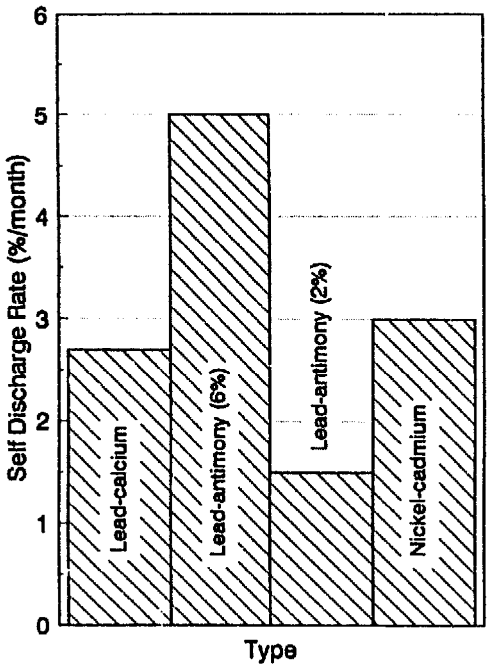



**Figure 4.3 Self Discharge Rate by Battery Type**

- **Discharge Rate** is the period of time in which a battery is designed to deliver its full storage capacity. A 100Ah battery with a discharge rate of 50 hours is designed to deliver a current of 2A. The available storage capacity of a battery will be greater if it is discharged over a longer period or less if the discharge rate is increased.

- **Charge Rate** - charging a battery with a high current causes excessive heat to build up and can cause damage. Normally a battery can be safely charged with a current equal to one tenth of its amp hour capacity or less. The lower the charge current, the greater the efficiency of recharging.

- **Temperature** - a battery's capacity is usually quoted at 25°C. Above this the available capacity will be greater but beyond 40°C the capacity will decrease again. Temperature below 25°C will also increasingly reduce battery capacity to 75-90% of rated capacity. At 0°C freezing of electrolyte particularly in lead-acid batteries can casue permanent damage. Temperature also affects battery cycle life. Continuous operation above 25°C will cause a significant reduction in life.

- **Maintenance** - the battery is often the component of a PV system with highest maintenance requirements. If sited at remote locations or without frequent maintenance services, a low maintenance battery should be chosen. Maintenance requirements vary with the battery type and operating conditions.

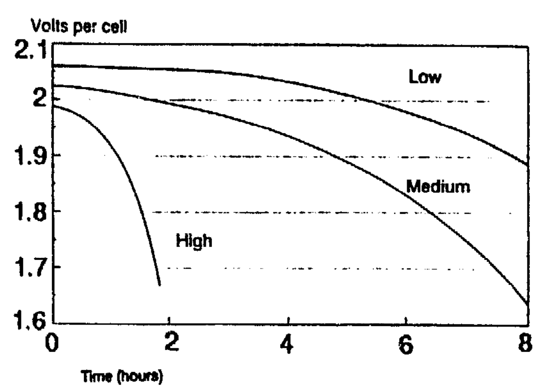



**Figure 4.4 Effect of Discharge Rate on Battery Voltage**

### 4.1.3 Commercially Available Batteries

**Two principal battery types are used with PV systems. These are lead acid batteries and nickel-cadmium batteries.**

**LEAD ACID BATTERIES** can be further divided into:

**Lead Calcium** - they are most commonly used for automotive applications. Calcium is added to the lead plates to increase their strength. The result is a battery able to deliver a high current, but with a poor cycle life. Self-discharge rate and water loss is low.

**Lead Antimony** - these have a small amount of antimony in the lead plates to improve the deep cycle characteristics. They can tolerate repeated discharging to 50-80% of rated capacity. The presence of antimony in the battery increases both its rate of water loss and self-discharge rate. The extent of these effects are proportional to the amount of antimony used. High water loss can be counteracted by a large electrolyte reserve. These batteries are commonly used as traction batteries for electric vehicles.

**Lead-alloy** with gelled electrolyte - have been developed to provide a sealed, spill-proof battery. The internal design minimises gassing and eliminates water loss. They require no topping up and hence maintenance requirements are minimal. Cycle life is variable depending on the design. Certain types have no antimony in the plate alloy in which case, cycle life can be poor.

Those with a medium to long cycle life are suited to use in PV systems, however, their cost is high and will limit their widespread use. Similarly, the number of manufacturers producing this type of battery is very small.

**Sealed Batteries** - both lead antimony and lead calcium are available in sealed casings. They require no topping up throughout their life so maintenance requirements are low. This is achieved by a large electrolyte reserve and a catalytic recombination plug which reabsorbs the gasses back into the battery as water.

**NICKEL CADMIUM BATTERIES** have very different characteristics. They are not liable to sudden failure because plates are not "used up" in chemical reactions. They can be fully discharged without damage and they have a high tolerance to being overcharged. Nickel cadmium batteries can operate for long periods without replenishment of electrolyte and they have a long cycle life, if shallow discharged.

This gives nickel cadmium (ni-cd) batteries advantages for use with PV systems because the depth of discharge is maximised. A battery with a smaller rated capacity than that necessary with a lead-acid type may be chosen whereby easing storage and transportation requirements. They can operate successfully without sophisticated voltage regulation units.

However, nickel cadmium batteries have not been as widely used in PV systems as lead acid types because of higher initial cost and poor availability in developing countries. When greater depth-of-discharge and longer life expectancy are taken into account, their life cycle costs are however often comparable with lead-acid batteries.

| PLATE TYPE | LEAD CALCIUM | LEAD-CALCIUM ANTIMONY (6%) | LEAD-CALCIUM ANTIMONY (<2%) | NICKEL CADMIUM |
|---|---|---|---|---|
| ELECTROLYTE | Liquid | Liquid | Liquid | Liquid |
| TYPICAL DOD | 50% | 80% | 80% | 100% |
| DESIGN USE | Automotive | Traction | Emergency Power supplies and PV | Low Maintenance Needs, PV |
| SELF-DISCH RATE | Low | Medium | Low | Low |
| CYCLE LIFE | Low | Medium-Long | Long | Long |
| SEAL | Vented | Vented | Vented | Vented |
| TOPPING-UP REQUIRED | Infrequent | Frequently | Infrequently | Minimal |
| CAPITAL COST | Low | Mid-range | Mid-range | Very High |
| SUITABILITY TO PV USE | Not Recommended | Recommended Recommended | Highly Recommended | Highly |

**Table 4.1 Comparison of Battery Types Commonly Used with PV Systems**

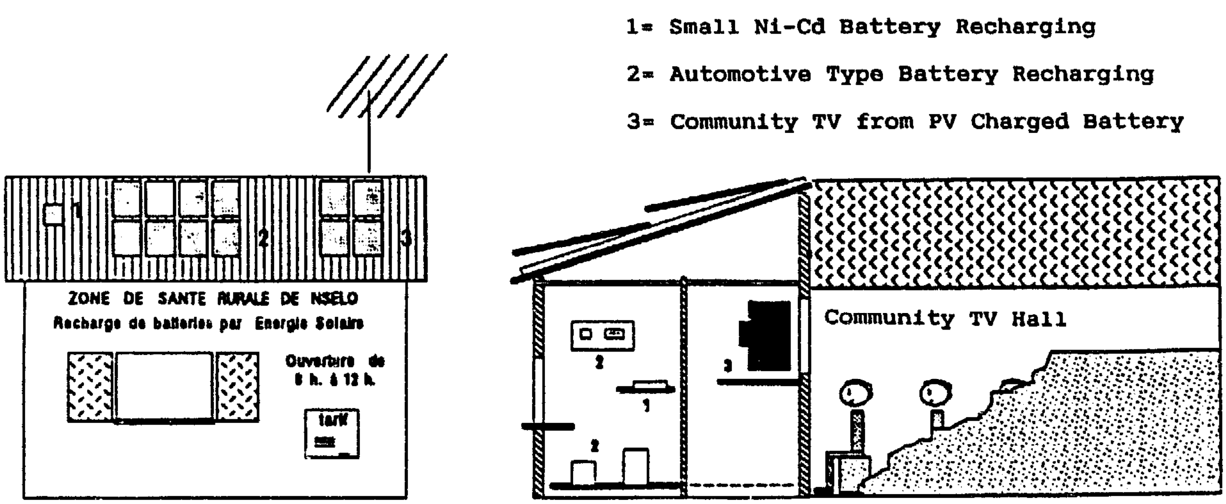



**Figure 4.5 Commercial Battery Charging in Zaire**

### 4.1.4 Battery Sizing

**A storage battery is the balancing factor between the pattern of energy production from the array and the pattern of energy used by the consumer. If too small, the battery will be completely discharged at times and overcharged at others. (A lead acid battery will suffer permanent damage if used in this way.)**

Determining the correct size of battery to use can be complex due to the range of factors which should be considered. The two methods commonly used are by deciding either:

- **the number of days or hours of autonomous operation** required, ie the length of time the energy stored in the battery will operate the load when no power is produced by the array.

- **the required availability of the power supply** (expressed as a percentage of time when there is low probability of a power failure). For high value loads, such as vaccine refrigerators or commercial telecommunication equipment, very high availability is required. For non-essential services such as lighting or household electrification, a lower availability can be tolerated. Lower availability will result in a smaller array and battery size along with lower cost. Typical battery sizes for equatorial regions have 3-5 days storage capacity for low status loads and 5 to 10 days where high reliability is required.

Lead acid batteries are made up of 2 volt cells connected in series to create 6, 12 or 24 volt units. Ni-Cd batteries contain 1.2 volt cells connected together. They may be connected in series or parallel configurations to achieve the required operating voltage and current conditions. Figure 4.6 illustrates typical wiring configurations.

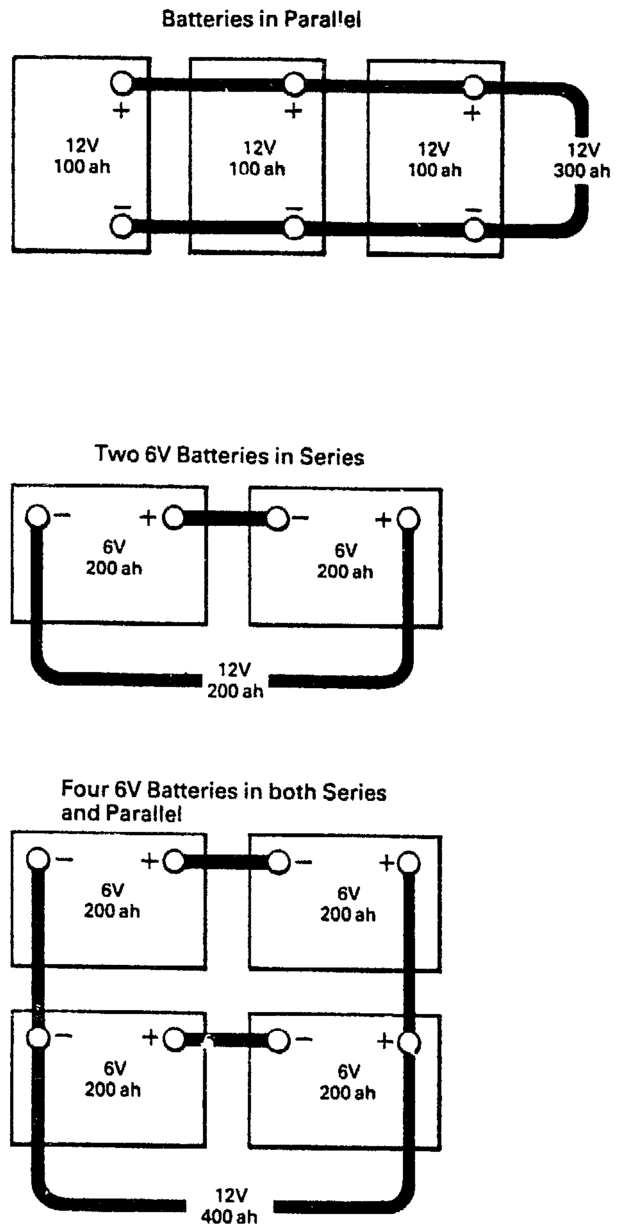



**Figure 4.6 Wiring of Batteries**

## 4.2 POWER CONTROL UNITS (PCU)

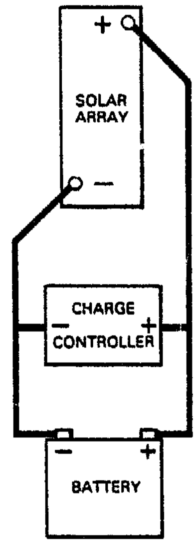
**As already said, the power produced by a PV array is continually varying. Most electrical equipment will only tolerate small variations inthe voltage and requency of the electrical supply. Power control units essentially manage and refine the system to enable smooth and efficient operation.**

The principal functions of a PCU will depend on the type of system. Commonly used PCUs are:

**Charge Regulators** - are required for battery charging systems, particularly those using lead acid batteries. Their main purpose is to prevent damage to the battery by over charging or discharging. Initially the regulator will allow all the power from the PV array to be used to charge the batteries. As the battery voltage approaches a fully charged level the charge from the array will be cut to a float or 'top-up' charge level. This is just sufficient to maintain full charge, but will prevent gassing and subsequent loss of water. If a battery is near the fully discharged voltage the regulator will cut the supply to the equipment - or warning lights are illuminated to indicate the low state of charge of the battery.

These regulators operate on the voltage level of the battery. However, the available capacity of a battery depends on its operating temperature. In low temperatures, the battery voltage can be relatively high yet the available charge will be substantially reduced. Similarly, battery voltage can be temporarily reduced if a large current is being drawn to power equipment.

Good quality charge regulators will therefore include temperature and current "compensation" features. It should be noted that the better the quality of regulator, the longer the batteries are likely to last.



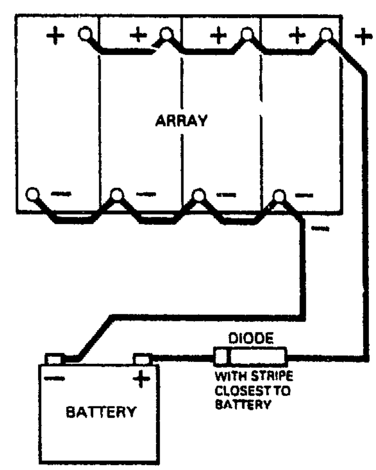




Figure 4.7 **Charge Regulator and Blocking Diode Positions**

**Blocking Diodes** - are used in battery charging systems. They are connected in line between the array and the battery to prevent discharge of the battery through the array. This would otherwise occur when the battery voltage is greater than that produced by the array (such as night).

**Inverters** - are necessary only when a.c. electrical appliances - eg, normal domestic appliances and some pump types. They convert the direct current (d.c.) electricity produced by the array, or stored in the battery, into alternating (a.c.) current. Inverters are expensive and introduce power losses, so where possible the use of d.c. appliances is preferred, eg, d.c. lights, fan units, etc.

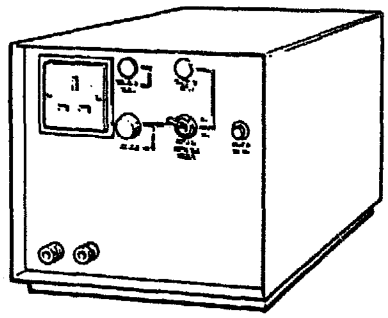


**Figure 4.8 Typical 400 W Inverter**

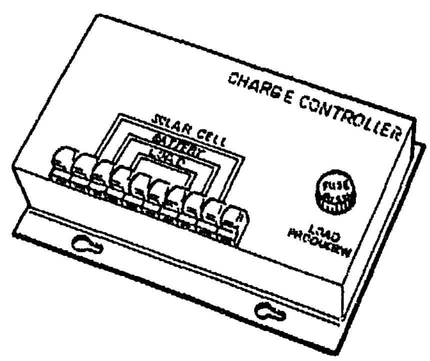



**Figure 4.9 A Charge Controller**

**System Indicators** - display how the system is functioning. This may be a light to show power is being produced in the array, or state of charge of the batteries. It may include a voltmeter to show battery voltage and an ammeter to indicate the array output.

**Junction Box** - the control unit can provide a useful point to join cables at installation of the system. A terminal block is usually provided.

**Maximum Power Point Trackers** - are quite sophisticated controllers used to maximize the amount of power produced by the array by optimising the impedance match between the array and the load. They usually employ a micro-processor which looks at the array power output (typically every 30 milliseconds) and steps up the array output voltage by means of impedance adjustment. If the power output has increased since the last sample, the array voltage is increased again. If the array power has decreased, the controller will decrease the voltage. Hence the controller hunts for a point of maximum power output.

MPPT'S are sometimes used in PV pumping systems. The controller itself consumes power and has an associated cost so only in a few systems are they cost-effective. In general, power control units should be used with discretion. Sophisticated electronic controllers can be self-defeating if their unreliability disrupts the system to the extent of outweighting th benefits of improved efficiency. This is particularly relevant in areas where regular maintenance or electronic repair services are not readily available.

The choice of PCU will usually be dictated by the system supplier. Whilst their advice should not be ignored, the information given in this chapter should enable a qualitative evaluation of the types available and their appropriateness for the intended application.

## 4.3 BATTERY CHARGING SYSTEMS

**In many remote locations or countries where the extent of grid electricity supply is very limited, batteries are used as a source of power. PV systems are now being increasingly considered as a means of recharging batteries, either at battery charging stations or in dedicated systems. In Zaire the income from PV battery charging stations is used to maintain health centres.**

The conventional methods of battery charging in rural areas are periodically transporting the batteries to a mains supply or by using diesel or gasolene generators.

The use of PV for battery charging has the advantage that local charging points can be established remote from the grid network, there are no inherent fuel costs or fuel supply problems, and unattended operation of equipment at remote sites is possible.

It can be considered suitable in areas of medium to high levels of insolation (above about 3.0 kWh/m²/day). When assessing economic viability of PV battery charging compared to its alternatives, associated operational and maintenance factors should be considered as well as capital cost and relative output. These will vary considerably for each site and application.

When comparing systems from alternative suppliers, it is necessary to look at array size, battery size and type, charge rate specified for a given level of insolation and which components are supplied with the system. Some suppliers include batteries in their systems, others leave this for local purchase.

The inclusion of a power control unit will depend on supplier and type of battery used. Reliability is an important factor as electronic controls have proved the least reliable part of many PV systems. For unattended operation, particularly with lead acid batteries, a control unit with voltage regulation is essential. Simple units from suppliers with proven experience and reliable back-up services are the safest choice.

Typical system costs range from US$10-20 per Wp of array rating.

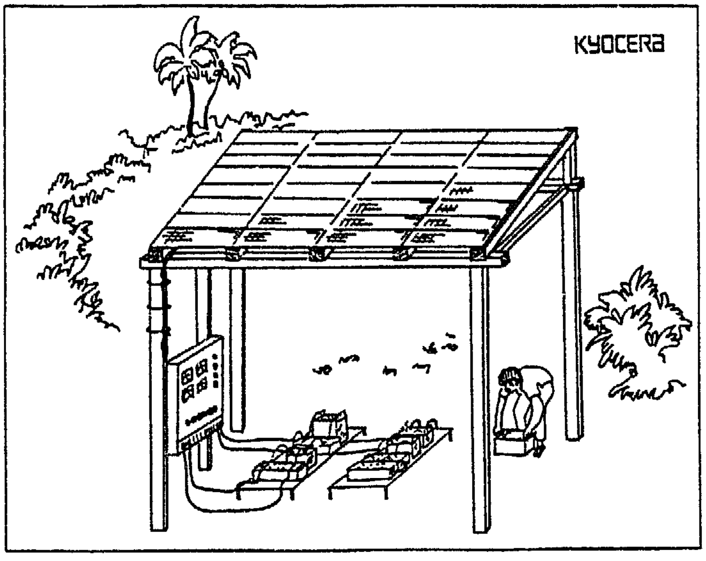



**Figure 4.10 A 1400 Wp Battery Charging Station**

## 4.4 IMPLEMENTATION CONSIDERATIONS

### 4.4.1 Procurement

You will need to specify to the supplier:

- the site location (country, nearest town, latitude and longitude)
- your month by month daily charge required in Ampere hours
- full details of the load on the battery
- the type of batteries you intend to charge
- which type of batteries you prefer to buy with the PV battery charger and your preference for either high quality (and high cost), long life batteries and controllers or for lower cost equipment which will require more frequent maintenance and replacement.

### 4.4.2 Transportation

If batteries are being transported over long distances and/or kept in storage before use, this should be done in a "dry" condition (without electrolyte). It is then important to ensure the supplier provides both acid and distilled water to fill the batteries prior to use.

### 4.4.3 Siting

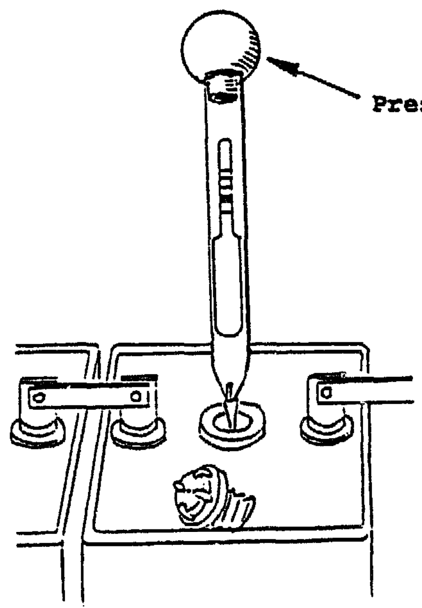
Batteries should be sited in a dry, well-ventilated position. This should not be in a living area. They should be protected from unwanted interference especially from children and animals. Always keep them upright.

### 4.4.4 Maintenance

Regular checks are necessary to ensure that:

- the electrolyte level is sufficient to cover the internal plates
- batteries are clean and dry to prevent losses from the terminals
- there is no build up of corrosion around the terminals
- casing is sound without cracks or leakage

The amount of charge in each cell of a battery can be checked by measuring the specific gravity of the electrolyte with a hydrometer (see Figure 4.12). It is important that the battery cell is kept at a good state of charge. Any discrepancy can be rectified by boost charging the battery - ie, maintaining a high charge rate until full charge level is reached in all cells.



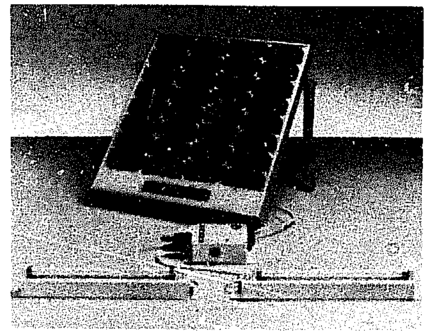

| Specific Gravity at 15°C | | Temperature Correction from 15°C | |
|---|---|---|---|
| State of Charge % | Specific Gravity | Electrolyte Temperature °C | Correction to Specific Gravity |
| 100 | 1.225 | 55 | +0.028 |
| 90 | 1.216 | 50 | +0.024 |
| 80 | 1.207 | 45 | +0.021 |
| 70 | 1.198 | 40 | +0.017 |
| 60 | 1.189 | 35 | +0.014 |
| 50 | 1.180 | 30 | +0.010 |
| 40 | 1.171 | 25 | +0.007 |
| 30 | 1.162 | 20 | +0.003 |
| 20 | 1.153 | 15 | 0.000 |
| 10 | 1.144 | 10 | -0.003 |
| 0 | 1.135 | 5 | -0.007 |

STATE OF CHARGE VS SPECEFIC GRAVITY TABLE

**Figure 4.11 Checking the Battery State of Charge**

Product: BATTERY CHARGING SYSTEM

Includes: Self regulating module, support structure, wiring and connectors

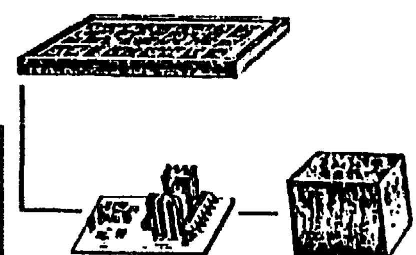


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| BP 320 CH | 20 | 90 @ 5 kWh/m² /d | 425 |

## Company: CURRIN CORPORATION — PO Box 1192, Midland MI 48641, USA

Product: BATTERY CHARGING KIT AND POWER SUPPLY

Includes: PV module, charge controller, discharge controller, warning light circuit breaker, connectors and manual.

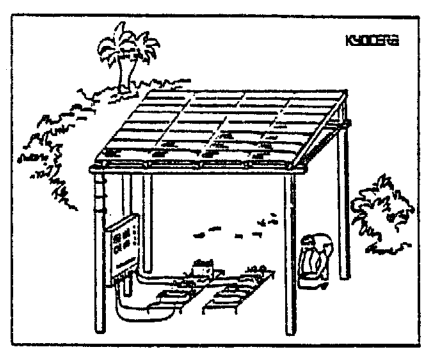


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| SPC 15 | 5 | 15 | 180 |
| SPC 60 | 18 | 60 | 370 |
| SPC 120 | 36 | 120 | 630 |
| SPC 180 | 60 | 180 | 860 |

## Company: KYOCERA — Chiba Sakura, Ohsaku, Chome Sakura - shi, Chiba-Pref, 285, Japan

Product: BATTERY CHARGING STATION

Includes: PV array & support structure, charge controller and multiple battery charging facility for 6, 12, or 24V batteries



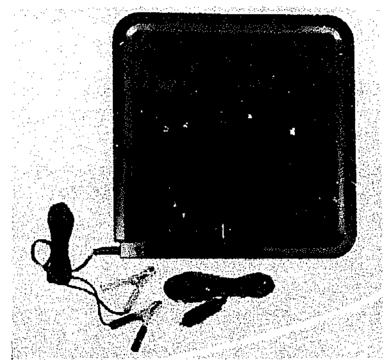

| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| charge station | 1440 | charge rate: ten 100Ah 12v batteries in 3 days | refer to supplier |

## EXAMPLES OF PRODUCTS AVAILABLE - BATTERY CHARGERS

**Company: RADE KONCAR** Fallerovo Setaliste 22, 4100 Zagreb, Yugoslavia

Product: VEHICLE BATTERY CHARGING SYSTEM

Includes: PV Module and Connectors

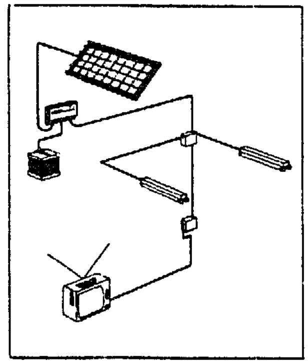


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| RK-PV | 4 | 15Wh/day at 5kWh/m²/day | Refer to supplier |

**Company: R & S RENEWABLE ENERGY SYSTEMS** P.O. Box 45, 5600 AA Eindhoven, The Netherlands

Product: BATTERY CHARGING SYSTEM

Includes: Module & mounting bracket, battery charge regulator with overcharge protection, manual, all necessary tools & installation materials. Does not include battery. optional low battery voltage protection

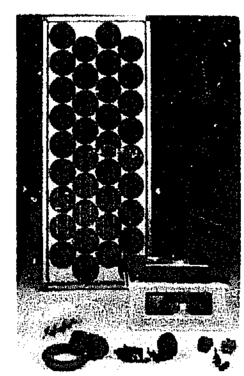


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| SOLARC I | 45 | 180 @ 5 kWh/m²/d | 340 |

**Company: SIEMENS** Buchenallee 3, D-5060, Bergisch Gladbach, W. Germany

Product: DOMESTIC BATTERY CHARGING STATION

Includes: PV module, 100Ah battery, charge controller, cable junction box, instruction manual and optional array support and battery box.



| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| | | approx @5kWh/ m²/d | |
| SG1 | 35 | 140 | 550 |
| SG2 | 70 | 280 | 1,270 |
| SG3 | 105 | 420 | 1,590 |
| SG4 | 140 | 560 | 2,050 |
| SG6 | 210 | 820 | 3,100 |

**Company: SOLAPAK LTD** Factory 3, Cock Lane, High Wycombe, Bucks, HP13 7DE, UK

Product: PORTABLE BATTERY CHARGING SYSTEMS

Includes: PV modules, carrying case and charge regulator

| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| | | | approx |
| HDS Portapak | 106 | 250 - 350 | 1,700 |
| Chargeabout | 10.8 | 30 - 50 | 800 |

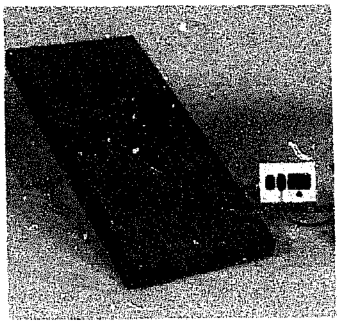
The most versatile of **solapak**'s portable power range, the solar **Chargeabout** is supplied in a folding canvas pouch which may be carried on a belt or a back pack.

# EXAMPLES OF PRODUCTS AVAILABLE - BATTERY CHARGERS

**Company: SOLAR ENERGIE TECHNIK** Postfach 1180, D-6822, Altlussheim, W Germany

Product: BATTERY CHARGING SYSTEM

Includes: PV Modules and support structure, battery and charge controller

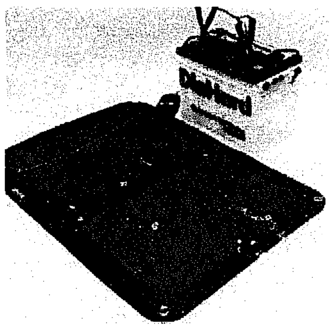


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| 1SM55/12V | 53 | 265 | 554 |
| 4SM55/12V | 212 | 1060 | 1,760 |
| 8SM55/24V | 424 | 2120 | 3,376 |

**Company: SOVONICS** 1100 West Maple Road, Troy, Michigan 48084, USA

Product: BATTERY CHARGING SYSTEMS

Includes: FET switching, battery charge controllers for PV applications

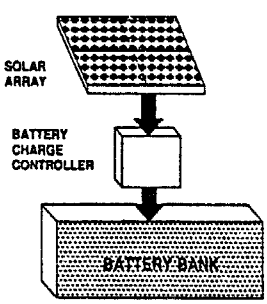


| MODEL NO. | ARRAY Wp | OUTPUT Wh/day | PRICE U.S. $ |
|---|---|---|---|
| SP 102 | 2 | 10 | refer to supplier |
| SP 105 | 6 | 25 | |
| SP 110 | 12 | 50 | |

**Company: SUNTRON** 2/861 Doncaster Road, Doncaster East, Vic 3109, Australia

Product: BATTERY CHARGING SYSTEMS

Includes: FET switching, battery charge controllers for PV applications

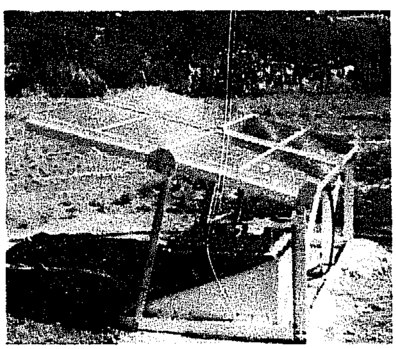



| MODEL NO. | OUTPUT | PRICE U.S. $ |
|---|---|---|
| BCC1203 | 12 volt, 3 Amp | refer to supplier |
| BCC1230 | 12 volt 30 Amp | |
| BCC2424 | 24 volt 24 Amp | |

**Company: TOTAL ENERGIE** 7 Chemin du Plateau, ZI. Le Tronchon, 69570 Dardilly France

Product: BATTERY CHARGING SYSTEMS

Includes: Module and support structure, battery box charge controller with battery overcharge & discharge protection. Optional kit form s upport structure. (TGK series).



| MODEL NO | ARRAY Wp | OUTPUT Wh/day @6kWh/m2/d | PRICE U.S. $ |
|---|---|---|---|
| TGP 45 | 45 | 170 Wh/day | 1,690 |
| TGP 180 | 180 | 700 Wh/day | 4,900 |
| TGP 270 | 270 | 1000/ Wh/day | 7,200 |
| TGP 360 | 360 | 1400 Wh/day | 9,200 |
| TGP 540 | 540 | 2100 Wh/day | 11,800 |

## 5.1 EXPERIENCES

More than 10,000 PV pumps are known to be operating throughout the world and experiences have been good. Solar pumps are used to pump from boreholes, open wells, rivers and canals to provide rural water and irrigation supplies. Less common applications include de-watering drainage pumping and water circulation for fish farms.

With technical problems now largely resolved, experience suggests that reports of poor performance are largely caused by incorrectly specified solar, water resource and water demand data. Proper consideration must be given to these parameter and also the well characteristics (yield and draw down) to ensure correct system operation.

A comprehensive UNDP and world Bank study, completed in 1983 included testing of systems in Egypt, Mali, Philippines and the Sudan. This did much to demonstrate that solar pumps are technically and economically viable and ready tomeet the pumping needs of rural areas.

Particular project experience includes:

**Mali:** provides a good example of solar pumping experience. Over the past 11 years more than 150 PV pumping systems have been installed, mainly under the auspices of Mali Aqua Viva, a charitable organisation. A high degree of local involvement has been insisted upon, especially with construction work on water tanks, foundations, access, etc. This has provided up to 25% of the initial cost of any one project and generated a high level of enthusiasm within the locality.

Borehole centrifugal pumps have been the type most widely used in Mali, originally coupled to surface mounted d.c. motors. More recent installations have changed to using pumps with submerged a.c. motor/pump sets because of their lower maintenance costs. Reliability of the equipment in the harsh Sahelian environment has been good with the solar pumping systems operating for more than 99% of the time. Most recent installations have operated faultlessly and effectively since being commissioned. Monitoring of over 70 pumps for 8 years showed mean time between failures of greater than 12 years.

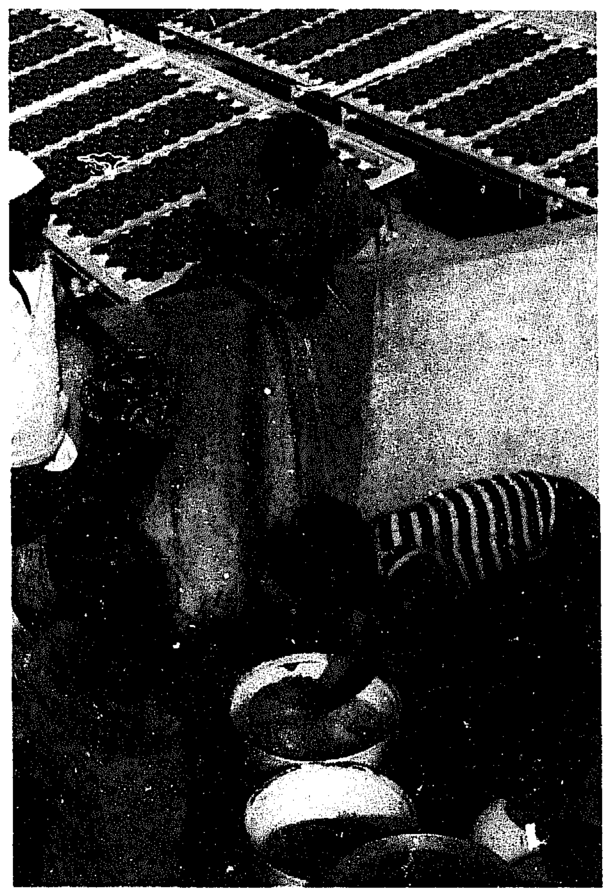
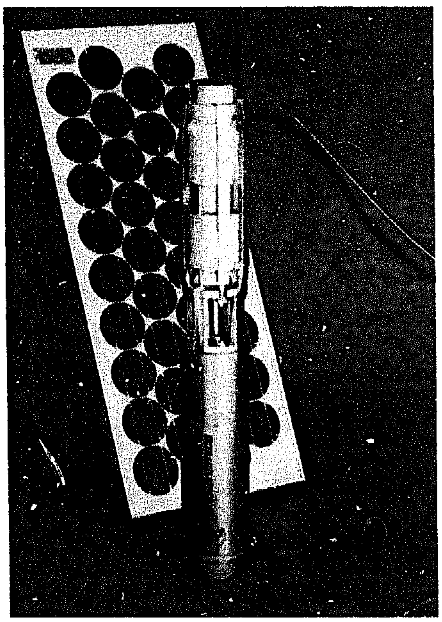


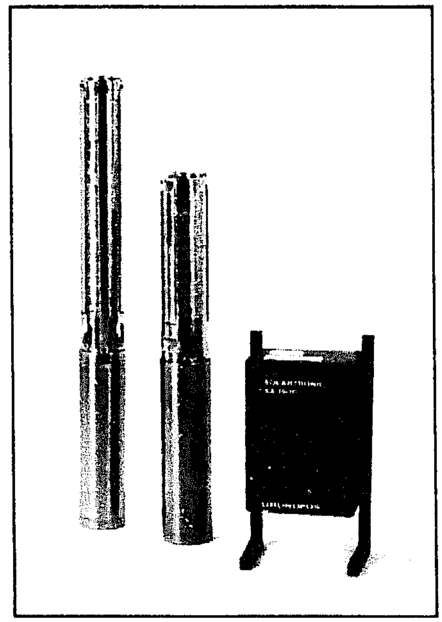
**Figure 5.1 A Solar Pump in Mali**

**Bolivia:** in co-operation with the World Bank and the Government of Bolivia, the US Department of Energy has installed three pumping systems in the altiplano region of Bolivia near Lake Titicaca. The systems have operated flawlessly in providing a potable water supply, since installation in 1986. A submerged centrifugal pump/motor combination is used with photovoltaic arrays ranging from 160 to 320 Watts. Acceptance by the users was immediate, resulting in a higher usage than that originally anticipated and considerable interest for further system in the area.

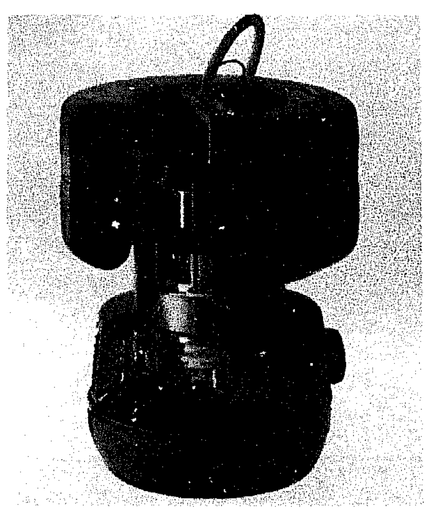
**India:** the largest number of solar pumps in one country is in India, where more than 500 systems have been installed for village water supplies. Good responses have been reported along with wide user acceptance. The modules and systems have been manufactured by Central Electronics Limited (CEL) in India. The potential of PV in India is so great that other companies have started PV production including Bharat Heavy Electricals Limited (BHEL), Rajasthan Electronics and Instruments Limited (REIL), Tata-BP Solar and Suryovonics.



**Heliodinamica (Brazil)**



**Grundfos (Denmark)**



**KSB (Germany)**

**Typical Commercially Available Products**

## 5.2 RELATIVE MERITS

Water pumping has a long history so many methods have been developed to pump water with a minimum of effort. These have utilised a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fossil fuels (diesel and gasoline) for small generators.

The relative merits of these are laid out in Table 5.1.

| | Advantages | Disadvantages |
|---|---|---|
| Hand pumps | • local manufacture is possible<br>• easy to maintain<br>• low capital cost<br>• no fuel costs | • loss of human productivity<br>• often an inefficient use of boreholes<br>• only low flow rates are achievable |
| Animal driven pumps | • more powerful than humans<br>• lower wages than human power<br>• dung may be used for cooking fuel | • animals require feeding all year round<br>• often diverted to other activities at crucial irrigation periods |
| Hydraulic pumps (eg. rams) | • unattended operation<br>• easy to maintain<br>• low cost<br>• long life<br>• high reliability | • require specific site conditions<br>• low output |
| Wind pumps | • unattended operation<br>• easy maintenance<br>• long life<br>• suited to local manufacture<br>• no fuel requirements | • water storage is required for low wind periods<br>• high system design and project planning needs<br>• not easy to install |
| Solar PV | • Unattended operation<br>• low maintenance<br>• easy installation<br>• long life | • high capital costs<br>• water storage is required for cloudy periods<br>• repairs often require skilled technicians |
| Diesel and Gasoline Pumps | • quick and easy to install<br>• low capital costs<br>• widely used<br>• can be portable | • fuel supplies erratic and expensive<br>• high maintenance costs<br>• short life expectancy<br>• noise and pollution |

**Table 5.1 Comparison of Pumping Techniques**

The wind, solar and water powered stand-alone systems will operate without input from other resources. This makes them most applicable to very remote or inaccessible sites - BUT they involve the introduction of a new technology so time is required for:

- assessing the availability of the resource
- acquiring the equipment
- familiarisation and training in operation and maintenance.

- **Handpumps** - are the most common type of water pumping device because of their low cost and relative simplicity. They are appropriate for low lifts (<20m) and where the demand is small. Handpumps do have hidden costs, namely the time spent by people queuing and pumping water and the limitation on the output of a borehole they impose.

- **Animal powered pumps** - Some 200 million draft animals are in use in developing countries mainly in South East Asia. Many of these are used for powering Persian wheels, Mohtes, Sakias and other animal driven pump designs. In many countries these devices are gradually being replaced by diesel pumps.

- **Water powered pumps** - can be used in one of two forms, to drive small hydro-electric plant which can then be used to power electric pumps or for water driven pumps - hydraulic rams or river current turbines. The use of water power is also very site specific - there has to be a sufficient amount of water in the right place and with reasonable access. Generally, if these conditions are fulfilled, the use of hydraulic powered pumps is often very appropriate.

- **Windpumps** are considered appropriate in relatively windy locations where average wind speeds are over 2.5m/s in the least windy month. Windpump performance is very site specific. The output is dependent upon the wind availability and often the windy areas are not where the water resources are, ie wind is generally more available on hills while water is in the valleys. Windpumps almost always utilize reciprocating positive displacement pumps and can pump from boreholes and wells and lift water more than 200 metres.

- **Photovoltaic pumping** systems should be considered in sunny locations (where worst month insolation exceeds 2.8 kWh/m$^2$/day and in areas where supply of other fuels is difficult. Solar pumps are not normally economic for very large pumping needs (where a 3 kWp or more PV array is required).

- **If diesel or gasoline engine** pump sets are to be considered (ie, if the wind or solar resource is poor) then it is essential that fuel and spare parts supplies are reliable.

  A decision chart to assist in identifying the appropriate water pumping option is shown in Figure 5.2.

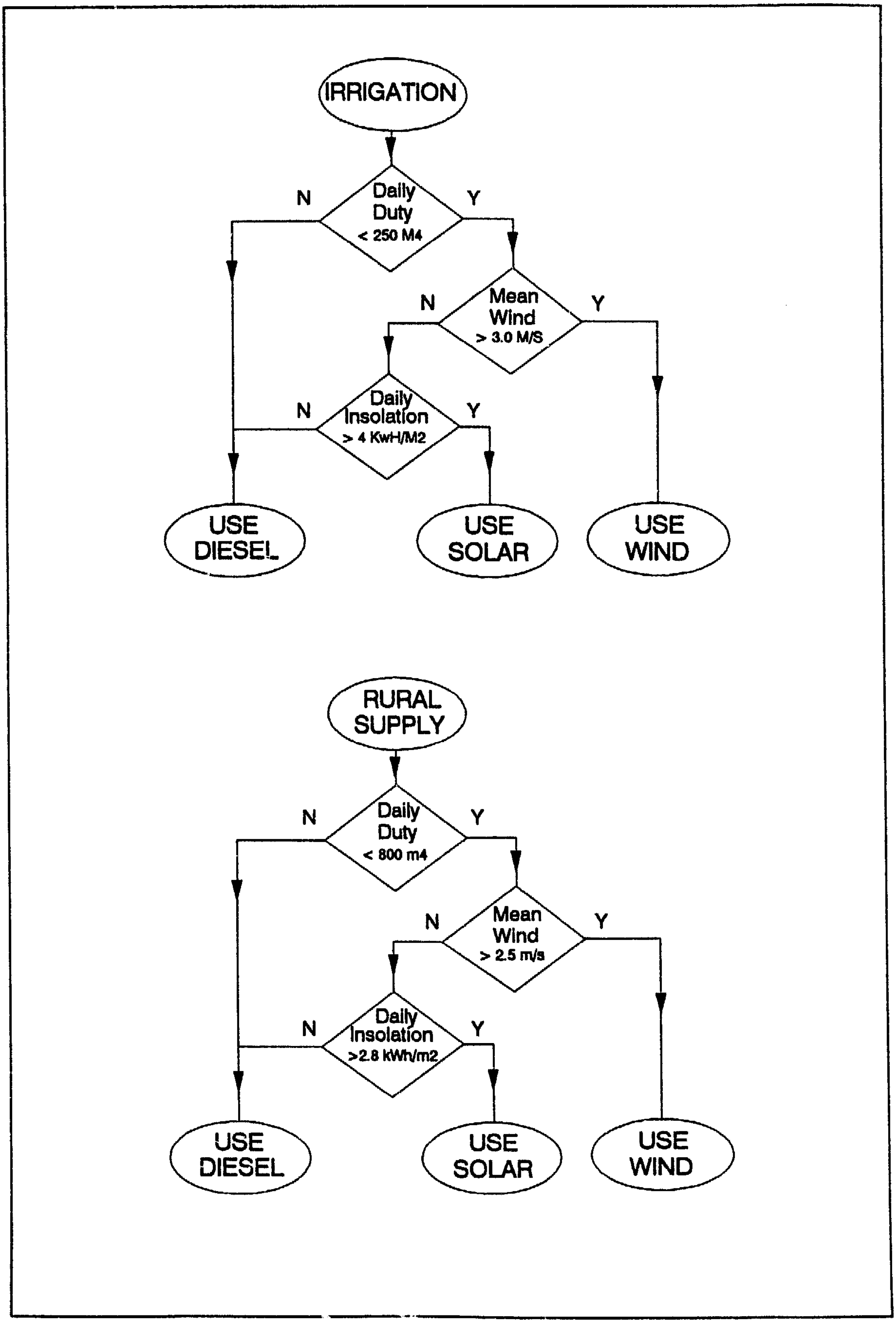



**Figure 5.2 Decision Charts for an Appraisal of Solar Pump Appropriateness**

## 5.3 COMMERCIALLY AVAILABLE EQUIPMENT

### 5.3.1 Applications

**Solar pumps are used principally for two applications, Village Water Supply (including livestock water supply) and Irrigation.**

A solar pump for village water supply is shown schematically in Figure 5.3. With village water supply a constant water demand throughout the year occurs although there is need to store water for periods of low insolation. Typically in Sahelian Africa the storage would be 3 to 5 days of water demand. In environments where rainy seasons occur the reduced output of the solar pump during this period can be offset by rain water harvesting. The majority of solar pumping systems installed to date are for village water supply or livestock watering. Systems typically have arrays of less than 3 kWp and pump at heads of 20 - 60m.

A solar irrigation system needs to take account of the fact that demand for irrigation water will vary throughout the year. Peak demand during the irrigation seasons is often more than twice the average demand. This means that solar pumps for irrigation are underutilized for most of the year. Attention should be paid to the system of water distribution and application to the crops. The system should minimize water losses without imposing significant additional head on the pumping system, and be of low cost.

The suitability of major irrigation systems for use with solar pumps is shown in Table 5.1.

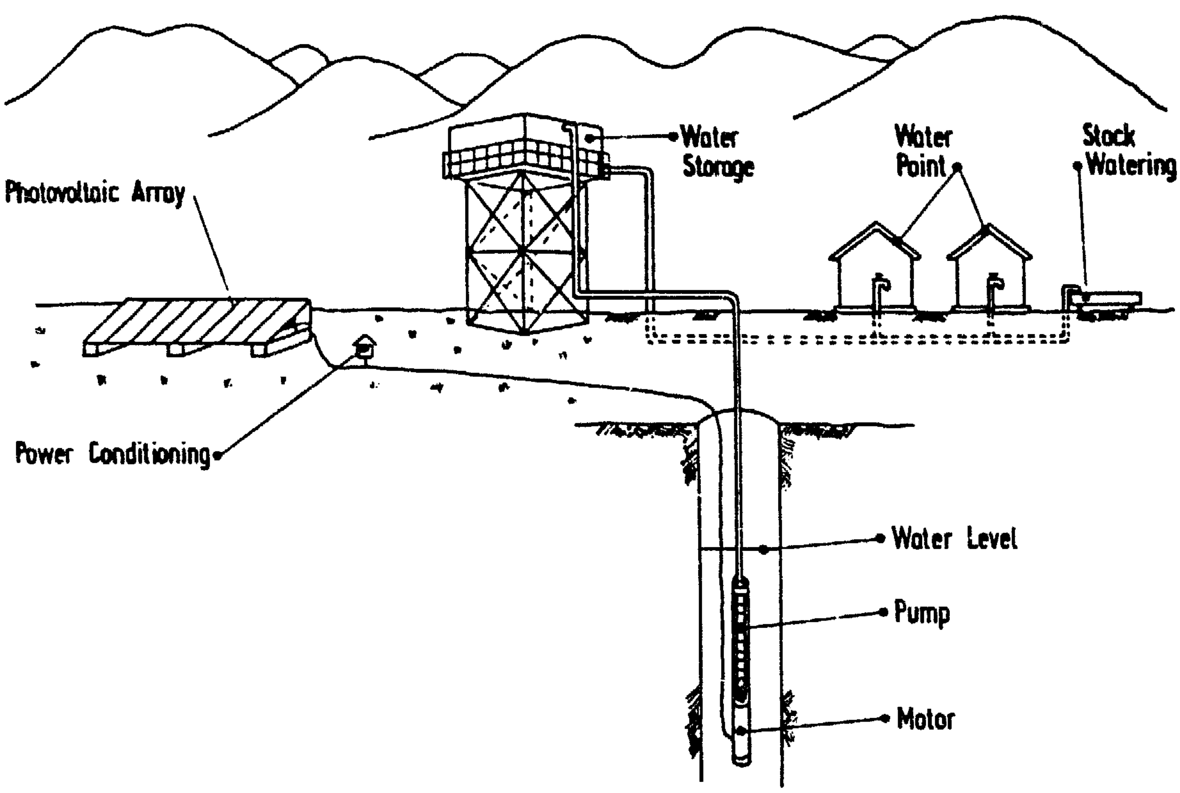



**Figure 5.3 Schematic of A Solar Powered Village Water Supply System**

| Distribution Method | Typical Application Efficiency | Typical Head | Suitability for use with Solar Pumps? |
|---|---|---|---|
| Open channels | 50 - 60% | 0.5 - 1m | Yes |
| Sprinkler | 70% | 10 - 20 m | No |
| Trickle | 85% | 1 - 2 m | Yes |
| Flood | 40 - 50% | 0.5m | No |

**Table 5.2 Suitability of Major Irrigation Methods for use with Solar Pumps**

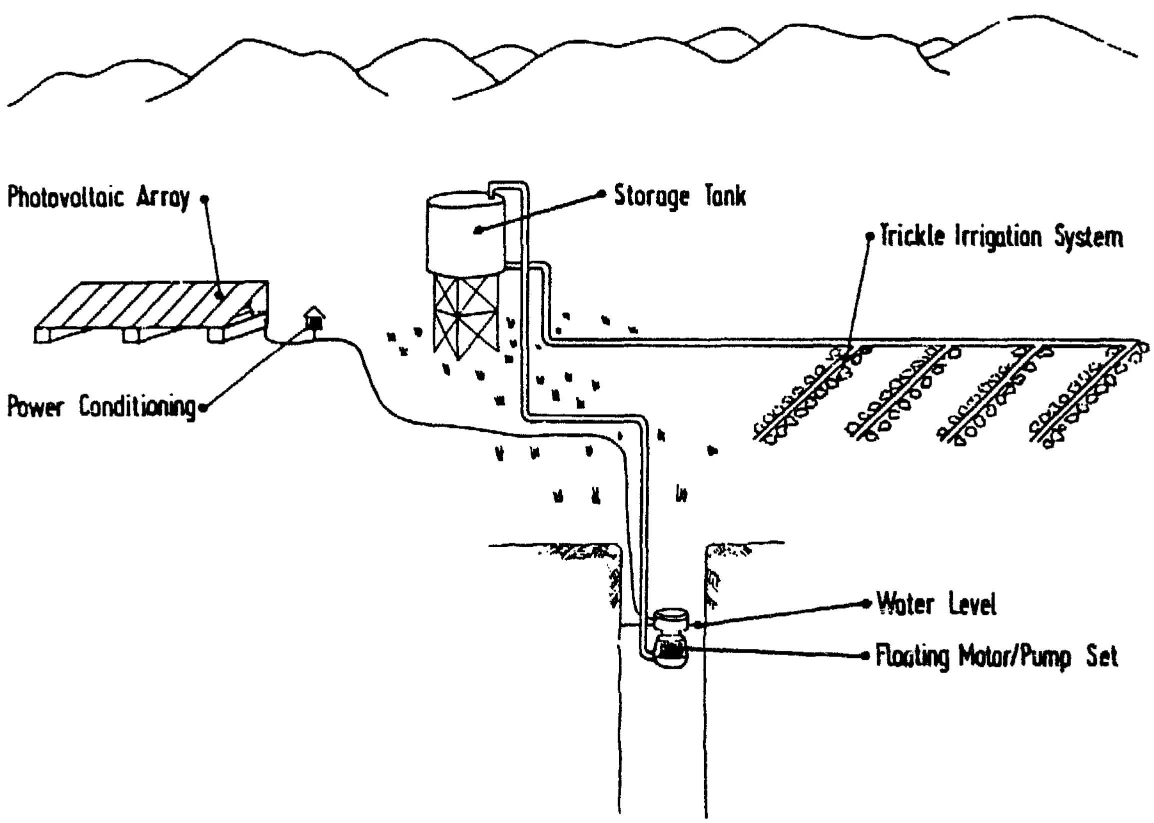



**Figure 5.4 Schematic of A Solar Irrigation Pumping System**

### 5.3.2 The Technology

Systems are broadly configured into 5 types as described below:

**Submerged multistage centrifugal motor pumpset (Figure 5.5).**

This type is probably the most common type of solar pump used for village water supply. The advantages of this configuration are that it is easy to install often with lay-flat flexible pipework and the motor pumpset is submerged away from potential damage.

Either a.c. or d.c. motors can be incorporated into the pumpset although an inverter would be needed for a.c. systems. If a brushed d.c. motor is used then the equipment will need to be pulled up from the well (approximately every 2 years) to replace brushes. If brushless d.c. motors are incorporated then electronic commutation will be required. The most commonly employed system consists of an a.c. pump and inverter with a PV array of less than 1500 Wp.

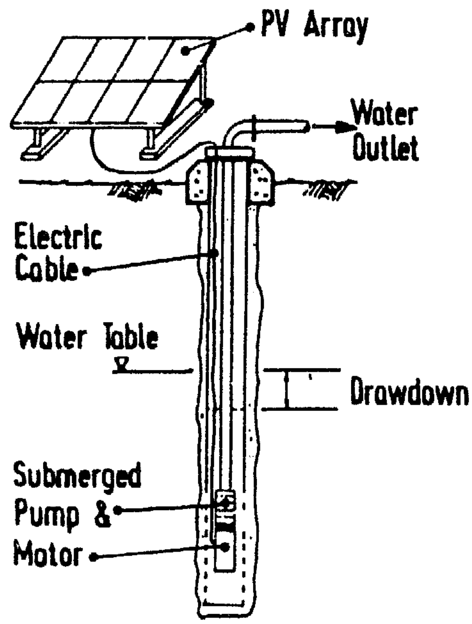



**Figure 5.5 Submerged Centrifugal Pumpset Configuration**

**Submerged pump with surface mounted motor (Figure 5.6).**

This configuration was widely installed with turbine pumps in the Sahelian West Africa during the 1970s. It gives easy access to the motor for brush changing and other maintenance.

The low efficiency from power losses in the shaft bearings and the high cost of installation have been disadvantages.

In general, this configuration is largely being replaced by the submersible motor and pumpset.

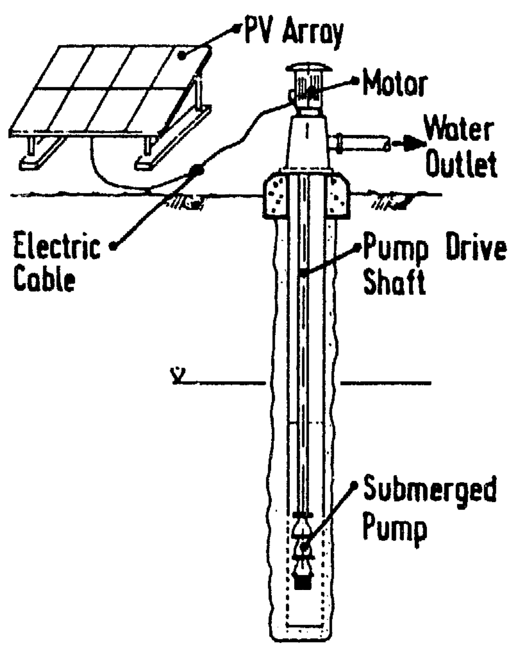



**Figure 5.6 Surface Motor-Submerged Pump Configuration**

**Reciprocating positive displacement pump (Figure 5.7).**

The reciprocating positive displacement pump (often known as the jack or nodding donkey) is very suitable for high head. low flow applications.

The output is proportional to the speed of the pump. At high heads the frictional forces are low compared to the hydrostatic forces, often making positive displacement pumps more efficient than centrifugal pumps for this situation. Reciprocating positive displacement pumps create a cyclic load on the motor which, for efficient operation, needs to be balanced. Hence the above ground components of the solar pump are often heavy and robust and power Controllers for impedance matching often used.

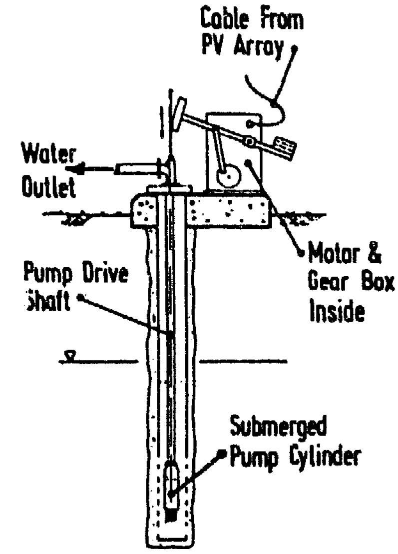



**Figure 5.7 Positive Displacement 'Jack' pump**

**Floating motor-pump sets (Figure 5.8).**

The versatility of the floating unit set makes it ideal for irrigation pumping from canals and open wells. The pumpset is easily portable and there is a negligible chance of the pump running dry.

Most of these types use a single stage submersed centrigual pump. The most common type utilize a brushless (electronically commutated) d.c. motor. Often the solar array support incorporates a handle or 'wheel barrow' type trolley to enable transportation.

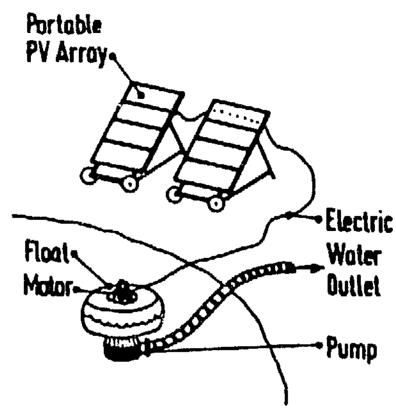



**Figure 5.8 Floating Motor-pump Configuration**

**Surface suction pumpsets (Figure 5.9)**

This type of pumpset is not recommended except where an operator will always be in attendance. Although the use of priming chambers and non-return valves can prevent loss of prime, in practice self start and priming problems are experienced. It is impractical to have suction heads of more than 8 metres.

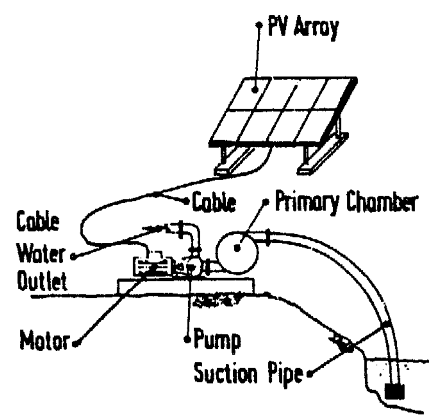



**Figure 5.9 Surface Suction Configuration**

### 5.3.3 Performance

**The performance of some commercially available products is shown in Figure 5.10 It can be seen that solar pumps are available to pump from anywhere in the range of 1.5m to 200m head and with outputs of up to 250m³/day.**

Solar pumping technology continues to improve. In the early 1980s the typical solar energy to hydraulic (pumped water) energy efficiency was around two per cent with the photovoltaic array being six to eight per cent efficient and the motor pumpset typically 25 per cent efficient. Today, an efficient solar pump has an average daily solar energy to hydraulic efficiency of more than four per cent.

Photovoltaic modules of the monocrystalline type now have efficiencies in excess of 15 per cent and more efficient motor and pumpsets are available. A good sub-system (that is the motor, pump and any power conditioning) should have an average daily energy throughput efficiency of at least 30% or ideally more than 40%.

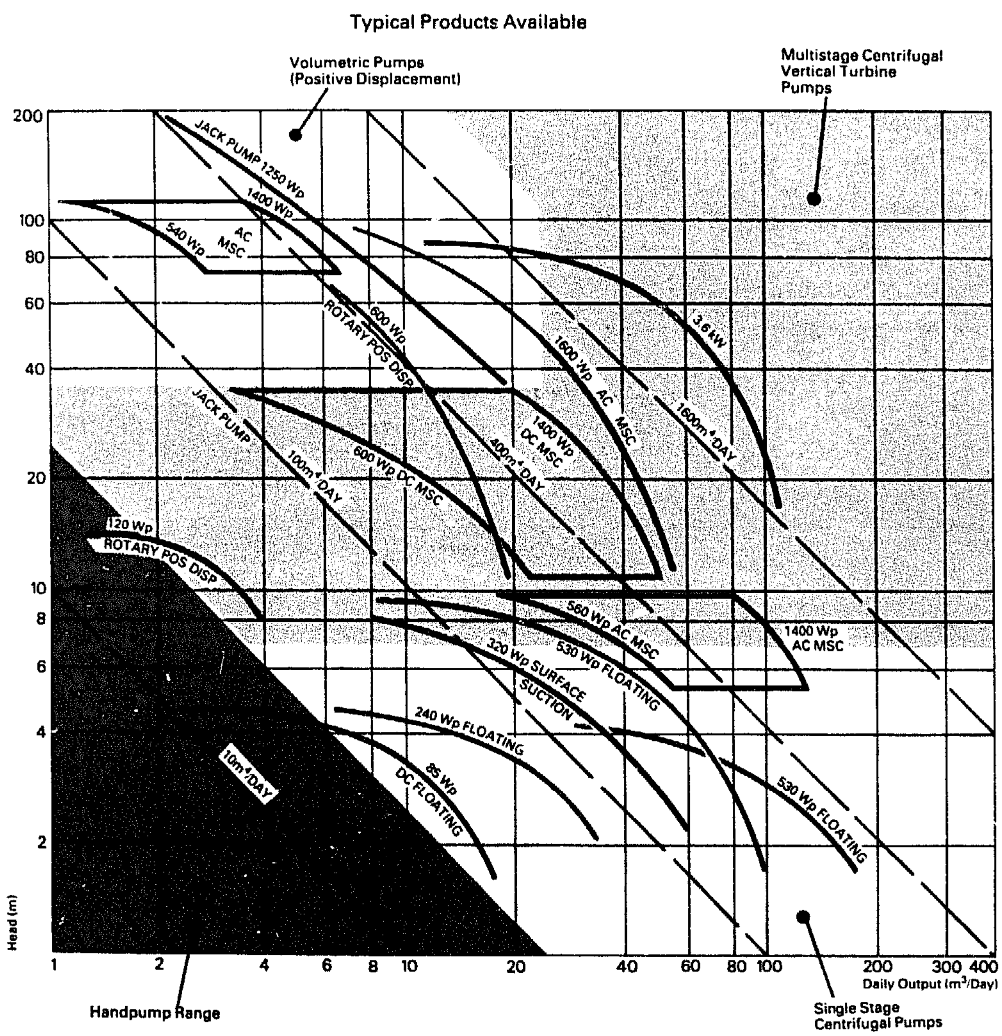



**Figure 5.10 Performance of Commercially Available Solar Pumping Systems**

### 5.3.4 Costs

A PV pumping system to pump 25m³/day through 20m head requires a solar array of approximately 800 Wp in the Sahelian regions. Such a pump would cost approximately $9,000 FOB. Other example costs are shown in Table 5.2.

A range of prices is to be expected, since the total system comprises the cost of modules, pump, motor, pipework, wiring, control system, array support structure and packaging. Systems with larger array sizes generally have a lower cost/Wp. The cost of the motor pumpsets varies according to application and duties; a low lift suction pump may cost less than $800 whereas a submersible borehole pumpset costs $1500 or more.

| Motor Pump/configuration | Output ($m^3$/ day) @ 5kWhm²/day Insolation | Head (m) | Solar Array (Wp) | System Price US$ FOB |
|---|---|---|---|---|
| a) Submerged borehole motor pump | 40<br>25 | 20<br>20 | 1200<br>800 | 12,000 - 15,000<br>9,000 - 10,000 |
| b) Surface motor / submerged pump | 60 | 7 | 840 | 8,000 - 9,000 |
| c) Reciprocating positive displacement pump | 6 | 100 | 1200 | 9,500 - 11,000 |
| d) Floating motor/pumpset | 100<br>10 | 3<br>3 | 530<br>85 | 5,500 - 7,500<br>2,000 - 2,500 |
| e) Surface suction pump | 40 | 4 | 350 | 3,500 - 4,500 |

**Table 5.2 Typical PV Pumping Systems**

A life cycle cost analysis of a solar pumping system is shown in Table 5.3

| System | | Life cost Analysis | |
|---|---|---|---|
| Location | : Sahel | Period of Analysis | : 15 years |
| Array Size | : 1400Wp | Discount Rate | : 10% |
| Head | : 10m | | |
| Annual Output | : 27,200m³ | Replacement Costs (2 spare pumps) | : $3,500 |
| System Cost | : $16,500 | - present worth (bought wih system) | : $3,500 |
| Transportion and Installation | : $8,300 | Recurrent Costs (Maintenance) | : $250 / yr |
| | | - present worth | : $1,902 |
| Total Installed: | : ——— | Total Present worth of life cyc;le cpsts | : $30,202 |
| Cost | : $24,800 | Annualised Life Cycle Costs | : $3,960 |
| | | Unit Water Cost | : |
| | | If 100% of Output utilised | : $0.15 per m³ |
| | | If 50% of Output utilised | : $0.29 per m³ |

**Table 5.3 Life Cycle Cost Analysis for Solar Pumps**

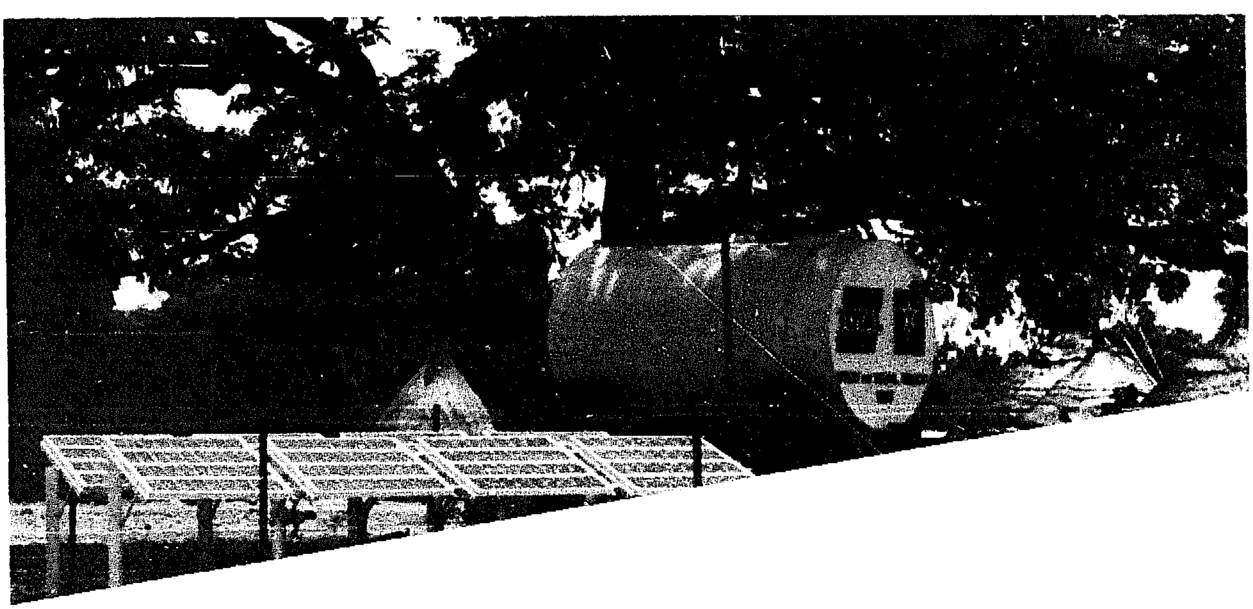
## 5.4 PROCUREMENT

### 5.4.1 Assessing Requirements

The output of a solar pumping system is very dependent on good system design derived from accurate site and demand data. It is therefore essential that accurate assumptions are made regarding water demand and pattern of use and water availability including well yield and expected drawdown.

Domestic water use per capita tends to vary greatly depending on availability. The long term aim is to provide people with water in sufficient quantities to meet all requirements for drinking, washing and sanitation. Present short term goals aim for a per capita provision of 40 litres per day, thus a village of 500 people has a requirement of 20 cubic metres per day. Most villages have a need for combined domestic and livestock watering.

Irrigation requirements depend upon crop water requirements, effective rainfall, groundwater contributions and efficiency of the distribution and field application system. Irrigation requirements can be determined by consultation with local experts and agronomists or by reference to FAO document "Cropwater requirements" (J Doorenbos, W O Pruitt, FAO, Rome, 1977). Typical figures are given in Table 5.4.



Generally accepted water requirements for community water supply, livestock and irrigation are given in Table 5.4.

| **COMMUNITY litres/day/person** | | **LIVESTOCK litres/day/animal** | | **IRRIGATION $m^3$/day/hectare cultivated** | |
|---|---|---|---|---|---|
| To survive | 8 | goats/sheep | 8 | potatoes | 30 |
| Subsistence level | 20 | pigs | 15 | vegetables | 50 |
| | | donkeys/camels | 20 | coffee | 55 |
| Present aims | 40 | cattle/horses | 45 | rice | 100 |

**Table 5.4 Typical Daily Water Requirements**

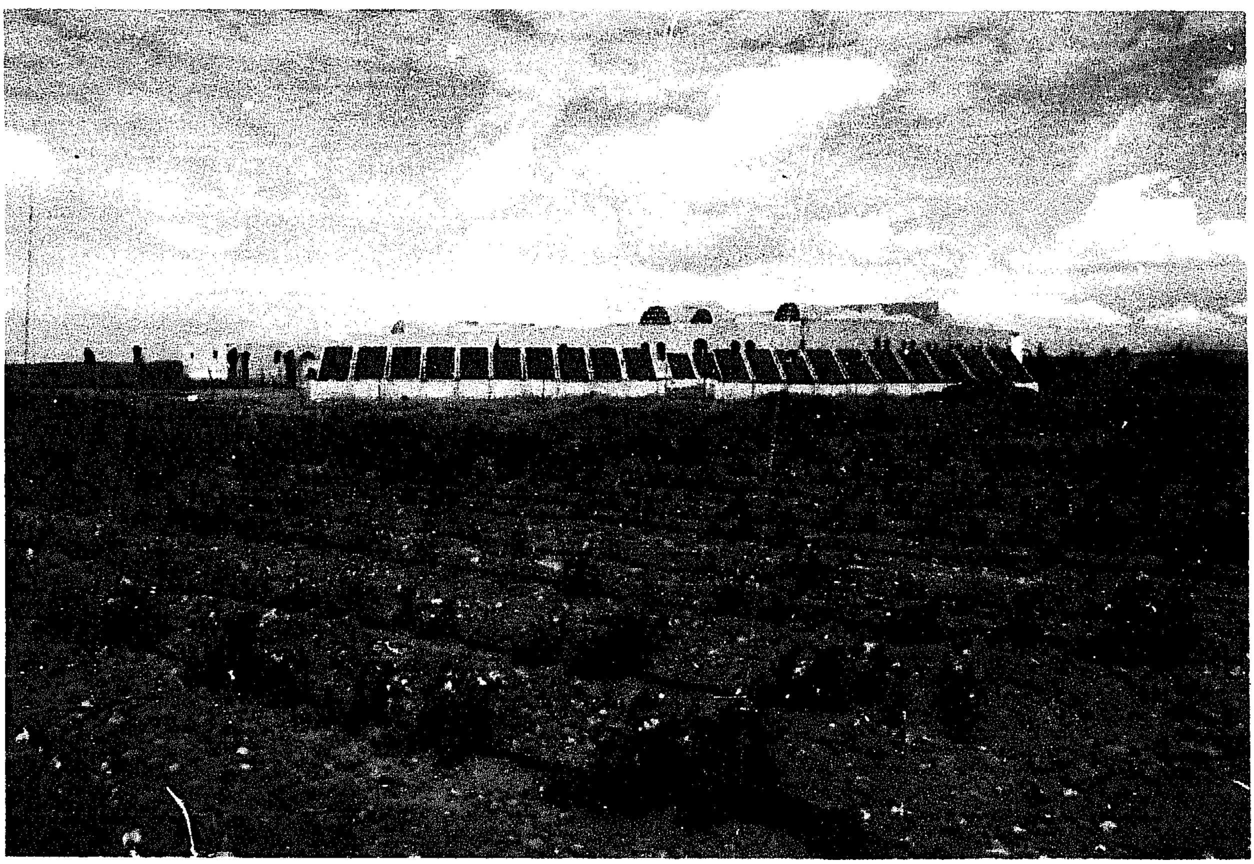
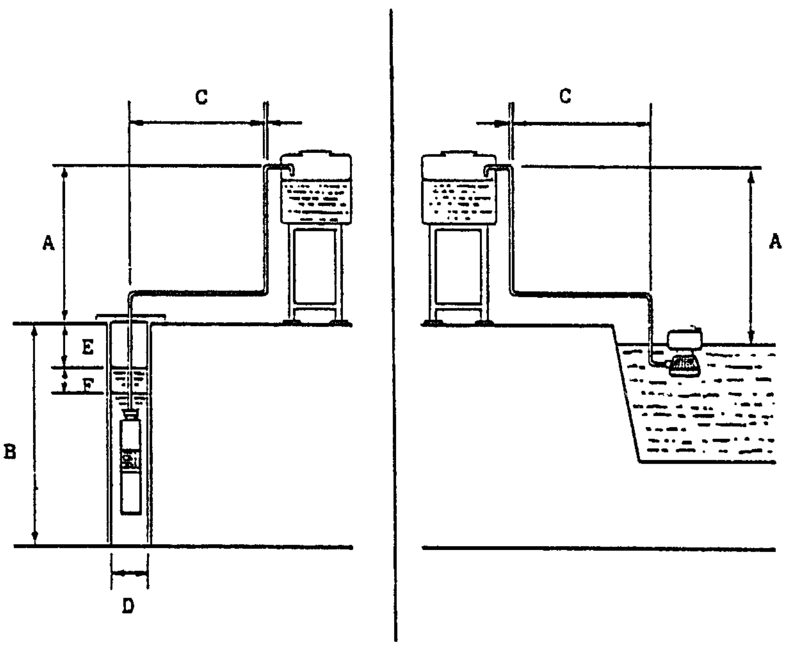


**Figure 5.12 PV Irrigation System in Egypt**

### 5.4.2 Assessing Water Availability

Several water source parameters need to be taken into account and where possible measured. These are the depth of the water source below ground level, height of the storage tank or water outlet point above ground level and seasonal variations in water level. The draw-down or (drop in water level after pumping has commenced) also needs to be considered for well and borehole supplies. This will depend on the ratio between pumping rate and the rate of refill of the water source. It is useful to present site details to the supplier in the format laid out in Figure 5.13. The pattern of water use should also be considered in relation to system design and storage requirements. Water supply systems should include sufficient covered water storage to provide for daily water requirements and short periods of cloudy weather. Generally two to five days water demand is stored.

| Ground Water Supply | Surface Water Supply |
|---|---|




| Ground Water Supply | Surface Water Supply |
|---|---|
| Height of storage tank ............ A: ............ | Height of storage tank ............ A: ............ |
| Depth of well ............ B: ............ | Suction elevation ...... B: ............ (surface mounted pump only) |
| Distance of tank from pump ............ C: ............ | Distance of tank from pump ............ C: ............ |
| Diameter of well or borehole ............ D: ............ | Pipe diameter ............ |
| Depth of water level E: ............ | Seasonal variation of A or B (+ or −) : ............ |
| Drawdown ............ F: ............ | |
| Pipe diameter ............ | |

**Figure 5.13 Pro-forma Specification for PV Pumping System Layout**

### 5.4.3 Selection of Equipment

1. **Determine the Viability of Solar Pumps**

   Using the decision chart on page 46, determine if, on economic grounds, solar pumps are appropriate. Consideration should then be given to associated social and institutional factors, such as the present systems being used for water pumping in the vicinity and compliance with national standardisation plans. Different systems will affect existing patterns of water supply and use. How these fit in with the local skill levels and experience should be considered.

2. **Prepare Pro-forma Specification Sheets**

   Complete the site layout and water demand pro-forma sheets (Figures 5.13 and 5.14 respectively).

3. **Issue Request for Tender**

   By reviewing the product information sheets listed at the end of this chapter, select five or so companies to send a request for tender. Also take into consideration companies that are known to have representation in the region where the equipment is to be installed (see Appendix 2).

   A general tender document is given in Annex 3. This can be modified to suit particular applications and specifications. Figure 5.15 shows a performance sheet which should be completed by the supplier. Forward the tender document, the two pro-forma specification sheets you have prepared, plus a blank performance sheet to each company selected.

4. **Compare the Costs with Alternative Pumping Systems**

   When quotations have been received from the manufacturers, it is necessary to check that buying a solar pump will be a sensible use for development funds. In almost all cases, a solar pump will cost more on an initial capital cost basis, but will have lower running costs than a diesel pumpset. Ideally, life cycle costing should be undertaken using present worth analysis of future costs and benefits. This is described in Appendix III. An example shown in Table 5.5 compares life cycle costs for a solar and a diesel pump. It can be seen that although the solar pump costs more to buy, over its life the unit cost of pumping water is less expensive than if a diesel pump is used.

5. **Place the Order**

   Select the most appropriate solar pump to meet your requirements and budget. Ensure you are satisfied that solar pumping is the most aprorpriate use of funds available, that satisfactory answers have been received from the manufacturers on all queries relating to the equipment, that all the necessary components, special tools and accessories necessary to complete the installation have been ordered and that spare parts sufficient for 5 years' operation have been ordered.

Pro Forma Specification Sheet – To be completed by user

Location: Latitude: Longitude:

Water source:

Application
water supply or irrigation:

no. of users or area to irrigate:

Site Details: (Complete layout information on next page also):

| Month: | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Daily Water Need ($m^3$) | | | | | | | | | | | | |
| Static Head (m) | | | | | | | | | | | | |

**Figure 5.14 Water Demand Pro-Forma Sheet: To be Completed by User**

System Details and Performance – To Be Completed By Supplier

System specification

Arrav Wp: .................... Pipe diameter: .................... mm

Tilt angle: .................... Pipe lengths supplied: .................... m

Motor Voltage: .................... Volts... Motor Type: ....................

Pump Type: ....................

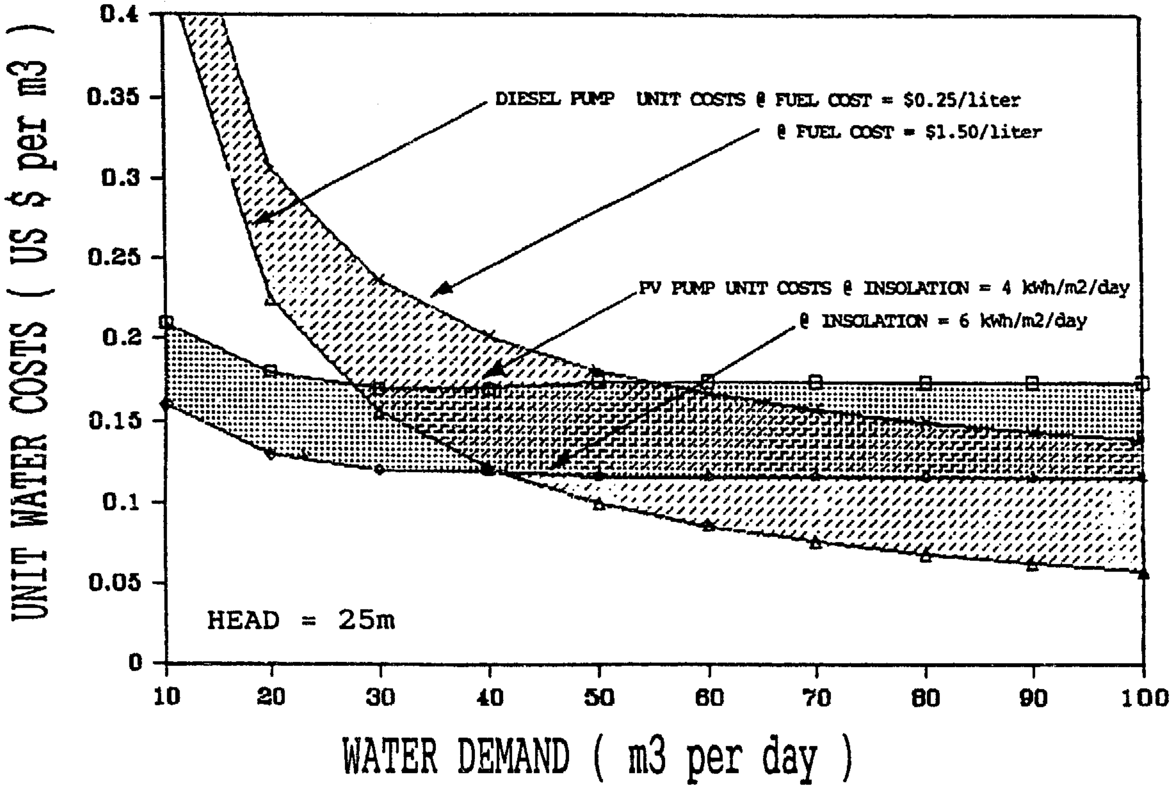
Water Store: .................... $m^3$ ... Type: ....................

Distribution System Details and Type: ....................

....................

| Month: | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dynamic Head (m) | | | | | | | | | | | | |
| Insolation Assumed $MJ/m^2/d$ | | | | | | | | | | | | |
| Average Daily Water Output ($m^3$) | | | | | | | | | | | | |

**Figure 5.15 Performance Specification Sheet: To be Completed by Supplier**




| | |
|---|---|
| **PV PUMP SYSTEM CHARACTERISTICS** | |
| Depth of Water Supply, Head | 25m |
| Annual Average Daily Water Demand | 20 $m^3$ /day |
| Annual Max Daily Water Demand | 30 $m^3$ /day |
| Insolation | 5.0 kWh/m $^2$/day |
| PV Array Peak Power | 1.11 kWp |
| PV Pumping System Capital Cost | 12.00$/Wp |
| PV Pumping System Availability | 95% |
| PV Array Life | 20 yrs |
| Pump Life | 5 yrs |
| Normal Discount Rate | 10 % |
| Inflation Rate | 5% |
| PV Annualised Life Cycle Cost | $0.14/$m^3$ |
| **DIESEL PUMP CHARACTERISTICS** | |
| Depth of Water Supply, Head | 25m |
| Annual Average Daily Water Demand | 20 $m^3$/day |
| Annual Max Daily Water Demand | 30 $m^3$ /day |
| Diesel Generator Power Rating | 3.0 kW |
| Average Load Factor | 45.4% |
| Diesel Fuel Cost | $0.75 /litre |
| Diesel Gen-Set pump Capital Cost | $1.59/W |
| Diesel Pump Availability | 90% |
| Diesel Gen-Set Life | 6 yrs |
| Pump Life | 5 yrs |
| Diesel Annualised Life Cycle Cost | $0.26 /$m^3$ |

**Table 5.5 Example of Comparative Life Cycle Costs of Solar and Diesel Pumps**

## 5.5 IMPLEMENTATION CONSIDERATIONS

### 5.5.1 Installation

When installing the equipment, ensure:

- manufacturers' instructions are followed accurately
- the array is kept covered throughout installation of the system
- the solar array faces towards the equator and is tilted at the angle of latitude plus 10 degree or as recommended by the supplier
- the solar array cannot be shaded by trees or buildings during the day except before 0730 or after 1630
- there is safe access to the array for cleaning
- all cable lengths are kept to a minimum in order to reduce power losses
- power controllers and junction boxes are shaded and protected from rain penetration
- you position the motor-pumpset in the well to allow for drawdown and possible long term water table drop
- pipe lengths and number of bends and restrictions in the pipework are kept to a minimum to reduce head losses
- water storage tank and stand pipe configurations do not impose high static lifts (or shade the array)
- pipe diameters are sufficiently large so as not to impose additional head losses
- any paint or sealants used are safe and do not contain harmful additives.

### 5.5.2 Maintenance

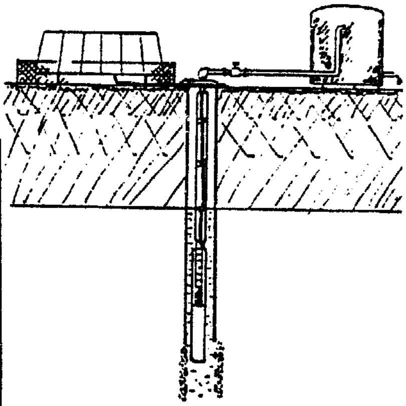
Regular maintenance will help ensure maximum performance is obtained from a solar pump. The following should be undertaken as often as possible:

- clean the solar array with water and a cloth
- clear the pump inlet filter and strainer of leaves and other particles that may impede the flow into the pump
- check cables for evidence of damage or loose connections
- commutator brushes of d.c. motors may need changing every 2-5 years
- Routine maintenance as specified by the supplier must be undertaken.

Product: SUBMERSIBLE BOREHOLE PUMPING SYSTEM - TYPE SPTP

Includes: PV array and support structure. MPPT control unit, inverter, flexible riser pipe, submersible a.c. motor pumpset, cable and necessary fittings

Applications: Boreholes and rivers. Head range 10-120m



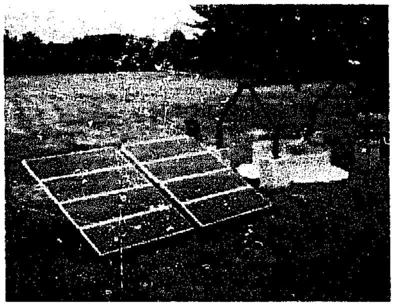
| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m²/day | | | PRICE U.S.$ |
|---|---|---|---|---|---|
| | | HEAD RANGE m | HEAD m | m³/day | |
| BP SP1 | 1225 | 80 - 120 | 100 | 5 | P.O.A. |
| BP SP2 | 1225 | 30 - 80 | 50 | 15 | 18,000 |
| BP SP3 | 1225 | 5 - 35 | 20 | 36 | 15,300 |
| BP SP4 | 1225 | 8 - 20 | 15 | 52 | 12,000 |
| BP SP5 | 1225 | 5 - 11 | 8 | 86 | 9,500 |
| BP SP6 | 1225 | 5 - 80 | 6 | 130 | 6,700 |

## Company: CHRONAR FRANCE - 3 Allee Edme, Lheureu, 94340 Joinville - Le Pont, France

Product: SUBMERSIBLE SOLAR PUMPING SYSTEM

Includes: 8 PV modules, support structure, cables, pumpset and instruction manual

Applications: Boreholes and rivers. Head range 10 - 80m

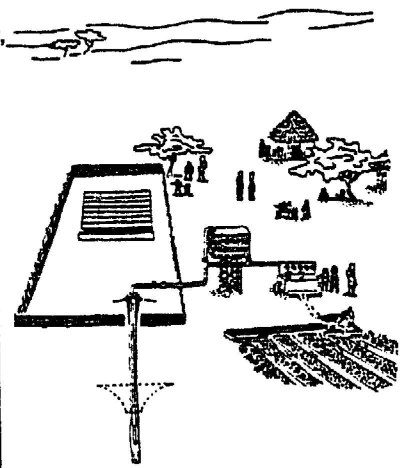


| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m²/day | | | | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| | | HEAD | m³/day | HEAD m | m³/day | |
| ESPOIR | 88 | 10 | 1.8 | 6.0 | 0.7 | 2,300 |

Product: SUBMERSIBLE SOLAR PUMPING SYSTEM

Includes: Subsystems for submersible water pumping, submersible pump/motor, DC-AC inverter and accessories.

Applications: Boreholes and rivers. Heads up to 120 m, flow up to 250 m3/day



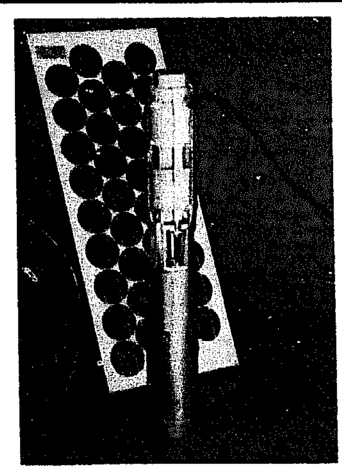
| MODEL NO | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m2/day | | PRICE U.S.$ |
|---|---|---|---|---|
| | | HEAD m | Watts Peak | |
| SP 1 - 28 | | 80 - 120 | 750 - 1500 | Refer to Supplier |
| SP 2 - 18 | | 30 - 80 | 500 - 1500 | |
| SP 4 - 8 | | 5 - 40 | 250 - 1500 | |
| SP 8 - 4 | | 8 - 20 | 500 - 150 | |
| SP 27 - 1 | | 5 - 8 | 750 - 1500 | |
| (ex.) | | ---------- examples | ---------- | |
| SP 2 - 18 | 1484 | 60 | 14.5m³/day | |
| SP 4 - 8 | 1484 | 20 | 46,7m³/day | |
| SP16 - 2 | 1484 | 10 | 99,2m³/day | |

**Company: HELIODINAMICA** Caixa Postal III, 06730 Vargem Grande Paulsita, SP, Brazil

Product: SUBMERSIBLE SOLAR PUMPING SYSTEM

Includes: PV array with support structure and DC submersible pumpset

Applications: Boreholes, wells and rivers



| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m²/day | | | | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| | | HEAD | m³/day | HEAD | m³/day | |
| SB 37 | 735 | 14 | 39 | 38 | 13 | 11,600 |
| SB 46 | 840 | 14 | 42 | 54 | 10 | 13,400 |
| SB 47 | 980 | 14 | 45 | 58 | 10 | 15,000 |
| SB 56 | 1050 | 15 | 45 | 63 | 10 | 15,800 |

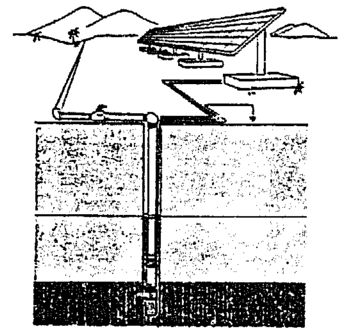
# EXAMPLES OF PRODUCTS AVAILABLE - BOREHOLE PUMPING SYSTEMS

**Company: SOLAR ENERGIE TECHNIK** Postfach 1180, D-6822, Altlussheim, W. Germany

**Product:** SUBMERSIBLE SOLAR PUMPING SYSTEM

**Includes:** PV array, support structure, cable submersible motor pumpset

**Applications:** Boreholes small volume - high head



| MODEL NO. | WATTS PEAK | PERFORMANCE Low head | | PERFORMANCE high head | | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| | | HEAD m | $m^3$/day | HEAD m | $m^3$day | |
| SDS | 106 | 20 | 0.3 | 65 | 0.13 | 1,300 |

**Company: TELEFUNKEN SYSTEMTECHNIK** Industriestrasse 23, 2000 Wedel, Holstein, Germany

**Product:** SUBMERSIBLE BOREHOLE PUMPING SYSTEM

**Includes:** PV array, steel support structure, inverter submersible a.c pumpset, dry run protection

**Applications:** Boreholes, wells and rivers

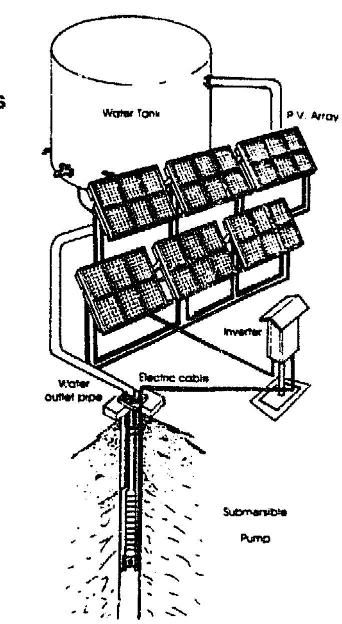
| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m2/day | | | | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| | | HEAD | $m^3$/day | HEAD | $m^3$/day | |
| 21 - 3/61-28 | 1050 | 80 | 4.5 | 120 | 1.5 | Refer to Supplier |
| 21 - 3/26-28 | 1050 | 30 | 18 | 80 | 3 | |
| 21 - 3/46-18 | 1050 | 10 | 47 | 40 | 11 | |
| 28 - 4/2-18 | 1400 | 30 | 24 | 80 | 7 | |
| 56 - 4/4-15 | 2800 | 40 | 32 | 75 | 14 | |
| 70 - 5/4-19 | 3500 | 50 | 32 | 95 | 12 | |

**Company: TOTAL ENERGIE** 7 Chemin du Plateau, Z.I LeTronchon, 69570 Dardilly France

**Product:** SUBMERSIBLE BOREHOLE PUMPING SYSTEMS - TYPE TSP

**Includes:** PV array, anodised aluminium support structures, control box, with inverter, centrifugal submersible a.c. pumpset and fitting accessories

**Applications:** Wells or boreholes, heads from 10 - 120m, output from 10 to 150 $m^3$/day




| MODEL NO. | WATTS PEAK | PERFORMANCE Low head | | PERFORMANCE High head | | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| | | HEAD m | $m^3$/day | HEAD m | $m^3$day | |
| TSP 720 | 720 | 10 | 36 | 25 | 15 | 17,400 |
| TSP 1080 | 1080 | 10 | 60 | 45 | 12 | 23,000 |
| TSP 1440 | 1440 | 10 | 75 | 60 | 16 | 28,000 |
| TSP 1800 | 1800 | 10 | 115 | 60 | 20 | 31,400 |
| TSP 2160 | 2160 | 10 | 133 | 100 | 11 | 42,300 |
| TSP 2520 | 2520 | 10 | 148 | 120 | 8 | 46,800 |
| TSP 2880 | 2880 | 10 | 162 | 120 | 11 | 51,000 |
| TSP 3240 | 3240 | 20 | 99 | 120 | 15 | 55,500 |
| TSP 3600 | 3600 | 20 | 107 | 120 | 18 | 60,500 |
| TSP 3960 | 3960 | 20 | 113 | 120 | 21 | 63,000 |

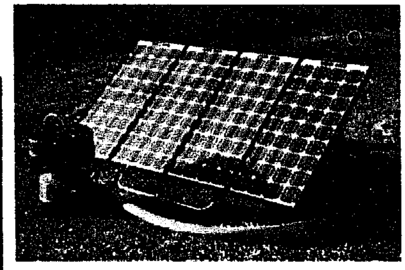
# EXAMPLES OF PRODUCTS AVAILABLE
# FLOATING AND SUBMERSIBLE SYSTEMS FOR OPEN WELLS/RIVERS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8BZ U.K.

Product: FLOATING PUMP SYSTEM

Includes: PV array, on mobile support structure, floating motor pumpset with centrifugal pump and integral brushless DC motor

Applications: Open channels or wells, low lift, irrigation



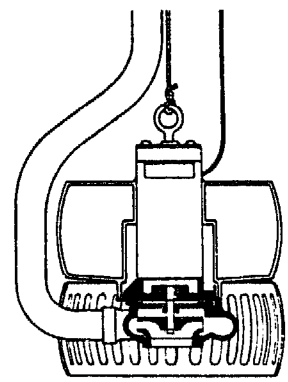
| MODEL NO. | WATTS PEAK | PERFORMANCE Low head HEAD m | Low head m³/day | High head HEAD m | High head m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| BP FM | 312 | 4 | 45 | 8 | 10 | 6,000 |
| | 418 | 4 | 75 | 8 | 35 | 8,300 |
| BP FL | 312 | 1 | 210 | 3 | 90 | 6,000 |
| | 418 | 1 | 260 | 3 | 120 | 8,400 |

**Company: HYDRASOL CORPORATION** — 1001 Alt AIA, Jupiter, Florida 33477, USA

Product: FLOATING PUMPING SYSTEM

Includes: Floating pumpset, PV array and support structure 20m of cable and connectors

Applications: Open wells or rivers, low lift irrigation



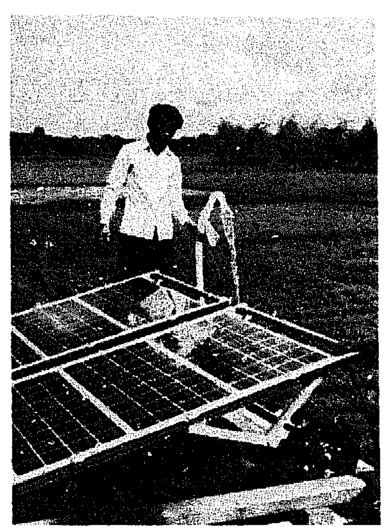
| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5.0 kWh/m²/day HEAD m | m³/day | HEAD m | m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| HF450 - 100 | 450 | 3 | 130 | 4.2 | 93 | 5,848 |
| HF450 - 110 | 450 | 3 | 138 | 5 | 83 | 5,848 |
| HF - 800 | 800 | 5 | 164 | 7.5 | 109 | 9,446 |
| HF - 1000 | 1000 | 5 | 158 | 9 | 103 | 11,524 |

**Company: KYOCERA** — Chiba Sakura, Ohsaku, Chome Sakura, Chiba - Pref. 285, Japan

Product: SUBMERSIBLE DC SOLAR PUMPING SYSTEM

Includes: PV array, support structure, cable submersible pump

Applications: Open wells or rivers, low lift irrigation



| MODEL NO. | WATTS PEAK | PERFORMANCE @ 6kWh/m²/day HEAD m | m³/day | HEAD m | m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| SMB - 50 | 96 | 6 | 5 | 10 | 2 | Refer to supplier |
| SMB - 200 | 384 | 3 | 50 | 6 | 30 | |
| SMD - 750 | 864 | 9 | 40 | 32 | 10 | |
| SMD - 750 | 1344 | 12 | 50 | 35 | 20 | |

# EXAMPLES OF PRODUCTS AVAILABLE
## SURFACE MOUNTED SYSTEMS

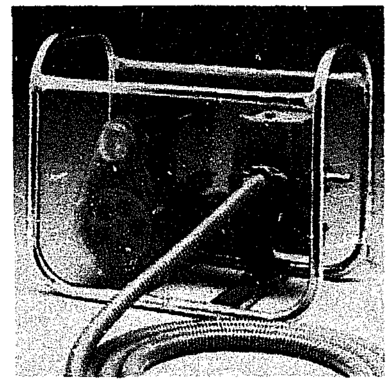
Company: BP SOLAR — 36 Bridge Street, Leatherhead, KT22 8BZ U.K

Product: SURFACE MOUNTED PORTABLE PUMP SYSTEM

Includes: PDI: Surface mounted double-acting posive displacement pump, PV array mounted on mobile trolley, pre-wired with plug and socket connections, d.c. electgnic control unit, riser pipe and intake filter.

Utility: Module, support, pumpset and hose.

Applications: Open channels, wells, mobile applications, low volume requirements, low-medium head



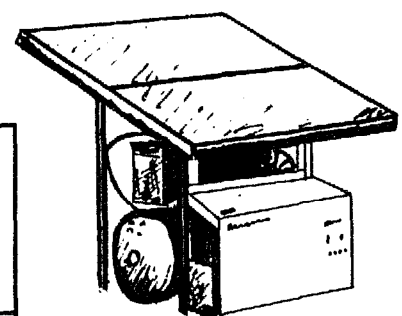
| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5 kWh/m²/day Low head HEAD m | Low head m³/day | High head HEAD m | High head m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| BP PD1 | 175 | 5 | 3.5 | 30 | 2.5 | 4,000 |
| Utility | 40 | 5 | 2.5 | 15 | 1.0 | 900 |

Company: DINH CO. INC. — Box 999, Alachua, Florida 32615, USA.

Product: SURFACE MOUNTED PISTON PUMP

Includes: Surafce mounted piston pump, permanent magnet d.c. motor, PV array with concentrating reflectors mounted on tracking support structure, MPPT control unit

Applications: Low head, irrigation medium output



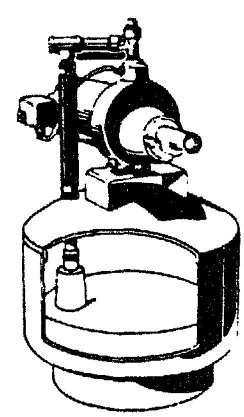
| MODEL NO. | WATTS PEAK | PERFORMANCE @ 5 kWh/m²/day Low head HEAD m | Low head m³/day | High head HEAD m | High head m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| HP 500 | 80 | 9 | 5.7 | 24 | 1.9 | 1,788 |
| HP 900 | 120 | 9 | 10 | 24 | 3.4 | 2,340 |

Company: A.Y. McDONALD MANUFACTURING CO — 4800 Chavenelle Rd, Dubuque, IA 52001, USA

Product: SURFACE MOUNTED PRESSURISED PUMPING SYSTEM

Includes: PV array, surface mounted pump with permanent magnet d.c. motor and 100Ah battery, Jet ejector provides pressurised water supply

Applications: Open wells rivers and boreholes with water source within 7m of ground level



| MODEL NO. | WATTS PEAK | PERFORMANCE @ 6 kWh/m²/day Low head HEAD m | Low head m³/day | High head HEAD m | High head m³/day | PRICE U.S.$ |
|---|---|---|---|---|---|---|
| 810103DS | 40 | 2 | 0.76 | 20 | 0.3 | 1000 |
| 810203DS | 80 | 2 | 1.66 | 20 | 0.8 | 1500 |

## 6.1 EXPERIENCES

### 6.1.1. Why PV Refrigerators?

**Extensive immunization programmes are in progress throughout the developing world in the fight against the six common communicable diseases. To be effective, these programmes must provide immunization services to rural areas.**

Solar power for refrigerators has great potential for lower running costs, greater reliability and longer working life than kerosene refrigerators or diesel generators. Over the past five years, at least 3000 photovoltaic medical refrigerators have been installed.

All vaccines used have to be kept within a limited temperature range throughout transportation and storage. The provision of refrigeration for this, known as the Vaccine "Cold Chain", is a major logistical undertaking in areas where electricity supplies are non-existent or erratic. The performance of refrigerators fuelled by kerosene and bottled gas is often inadequate. Diesel powered systems frequently suffer fuel supply problems. Solar power is therefore of great importance to health care.

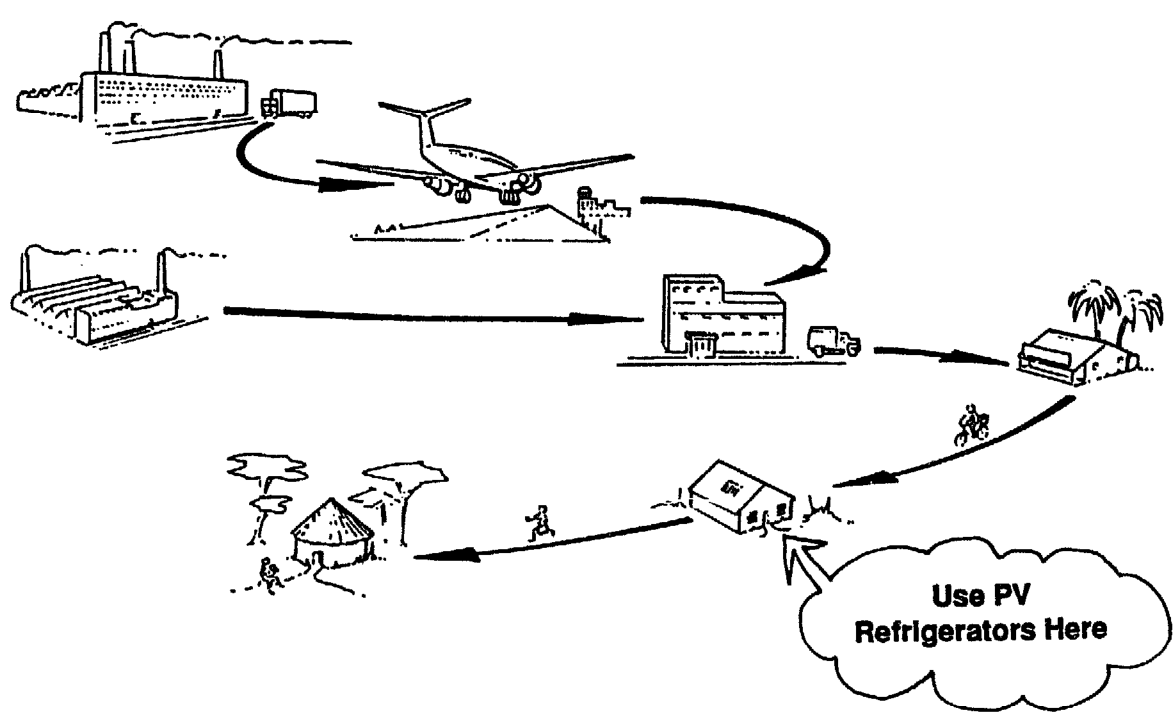



Figure 6.1 The Vaccine "Cold Chain"

### 6.1.2 International Field Testing and Evaluation Programmes

Much work has been carried out on the field testing and evaluation of PV refrigerators, the most significant being under the World Health Organization's Expanded Programme on Immunization and USAID/NASA/CDC Programmes. These have involved field testing of over 50 systems in more than 30 countries - the first systems being installed in 1981.

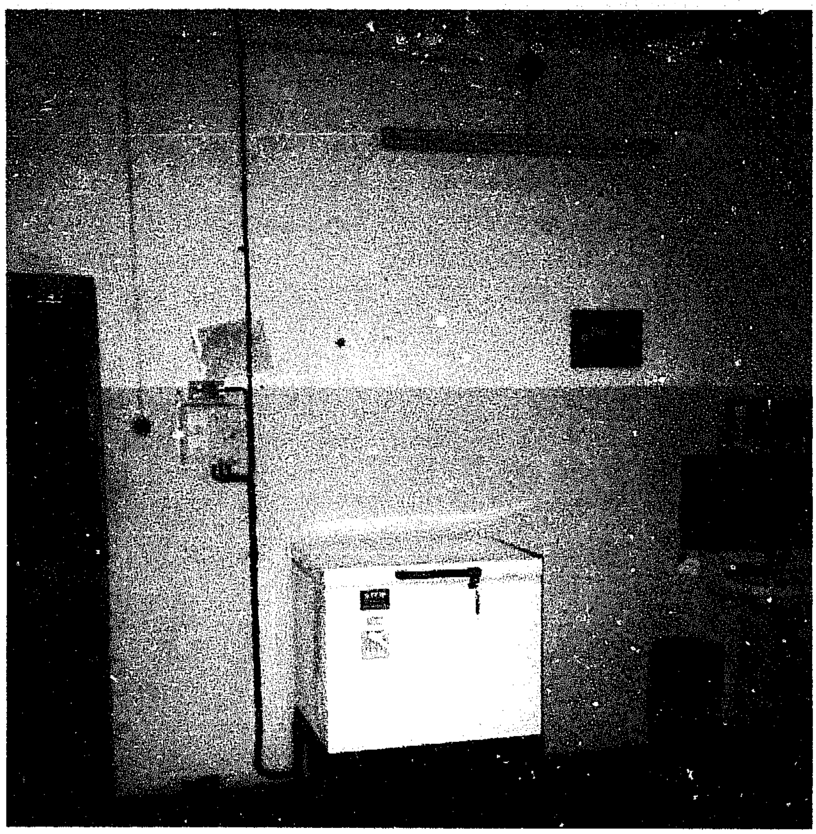


**Figure 6.2 One of more than 850 PV Refrigeration and / or Lighting Systems being Manufactured and Installed in Zaire**

Field trials organised by the NASA Lewis Research Centre in the USA reported favourable user reaction and that correct operating temperature was achieved for at least 83% of the time. Reasons cited for temperature deviating outside the specified limits were:

- defective components - temperature controls, voltage regulators.
- excessive amounts of warm material being placed in the unit at one time.
- incorrect setting of the thermostat.
- shadowing of the array.

The performance of these early units exceeded the reliability of kerosene refrigerators but was poor in comparison to recently installed systems. Correct operation for over 98% of the time is now routine.

### 6.1.3 Project Experience

Major programmes to utilize solar refrigerators are underway notably in:

**Zaire** - The Department of Public Health and Social Affairs in Zaire, with the technical and financial assistance of the European Economic Community (EEC), is carrying out a programme of installing 100 photovoltaic refrigerators (and 750 lighting systems) in rural hospitals and health centres. This operation will equip roughly 400 health establishments spread out over more than 20% of Zaire's territory. A Zairian firm FNMA designed and now produces the refrigerator utilizing imported compressors and batteries.

User reaction has been good, and the systems have demonstrated greater reliability than kerosene fridges. In 1986, the World Health Organization undertook an evaluation of the installations. Their conclusions were very supportive.

**Indonesia** : More than 100 solar refrigerators are being installed in Sudan as part of a world bank health programme

**Mali** - over six years of trials have taken place in Mali leading to the conclusion by the Laborataire de l'Energie Solare that with periodic maintenance checks, the rate of equipment failure is negligible.

**Uganda** - a project to install initially 100 solar refrigerators and eventually more than 400 systems in Uganda is underway.

**Africa** - Projects involving significant numbers of solar refrigerators are also now underway in Chad, Ghana, Kenya, Mozambique and Sudan.

**Pakistan** - In the desert town of Diplo in the Thar desert region of Sind province, a solar refrigerator was installed by UNICEF in 1987. With the enthusiastic support of the health centre staff, the total installation time was less than 5 hours. In addition to UNICEF, other agencies such as the Aga Khan Foundation are using solar refrigerators in Pakistan.

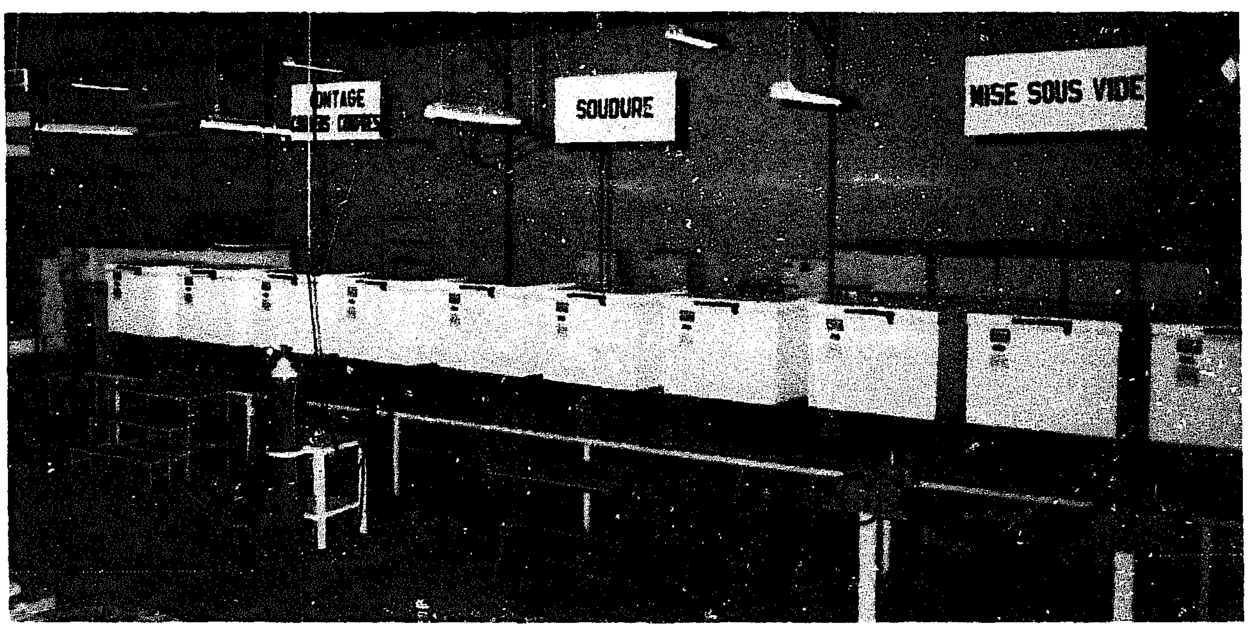



**Figure 6.3 PV Refrigerator Assembly in Zaire (FNMA)**

## 6.2 RELATIVE MERITS OF USING PV REFRIGERATORS

### 6.2.1 Advantages of PV Refrigerators

Compared to kerosene or bottled gas fuelled refrigerators, PV systems have the following advantages:

**Improved vaccine storage facilities as a result of:**

- elimination of fuel supply problems
- elimination of fuel quality problems
- greater refrigerator reliability
- better refrigerator performance (and temperature control).

**Reduced running costs as a result of:**

- elimination of kerosene fuel costs
- elimination of kerosene transportation costs
- reduced vaccine losses
- lower refrigerator maintenance costs
- reduced need for back-up refrigerators where there are fuel supply or repair problems.

**Cold chain management benefits due to:**

- longer equipment life (PV array 15 years, battery 5 years, refrigerator 10 years)

- reduced logistical problems arising from non-availability of working refrigerators and associated vaccine losses.

The above operational advantages of introducing solar refrigerators into the cold chain indicate that solar refrigerators can provide a more sustainable vaccine cold chain.

### 6.2.2 Disadvantages of PV refrigerators

Failure of a main component, such as the compressor control unit, requires repair or replacement by skilled technicians.

As each system is site specific, more time is necessary for planning and implementing a project with solar refrigerators.

User training deman
overloa

### 6.2.3 Comparative Costs

A true comparison of solar refrigerators and comparable kerosene and bottled gas fuelled refrigerators can only be made through a life cycle cost analysis. A solar photovoltaic refrigerator is likely to cost around $3000 to $6000 and will cost more to install than a kerosene unit.

A kerosene refrigerator will cost only $600-$800 but will use 0.5 to 1.0 litres of fuel per day, require frequent maintenance and have a shorter life. In general life cycle costs are approximately the same for solar and kerosene refrigerators, but because of their greater reliability and resultant savings in wasted vaccine solar refrigerators are the preferred option. Table 6.1 shows the relative costs of utilizing a PV or kerosene refrigerator in a health centre in Pakistan, serving a population of 12,000 with a crude birth rate of 4.5%. It can be seen that a PV refrigerator is the most economic option.

| | KEROSENE Rs | PHOTOVOLTAIC Rs |
|---|---|---|
| Array (125 Wp - 15 yr life) | - | 13,047 |
| Battery (2400 Wh - 5 yr life) | - | 5,107 |
| Refrigerator | 10,400 | 22,409 |
| Installation Costs | 2,880 | 7,219 |
| Total Installed Cost | 13,280 | 47,864 |
| Annual Maintenance Costs | 1,400 | 479 |
| Annual Fuel Costs (3.08 Rs/Litre) | 675 | - |
| Annualised Refrigerator Life Cycle Cost (ALCC) | 5,579 | 8,894 |
| Refrigerator Reliability/Availability | 60% | 97% |
| Potent Vaccine Doses Available | 3,600 | 5,820 |
| ALCC per potent vaccine dose | 1.55 | 1.53 |
| EPI Programme Cost per outlet | 21,300 | 21,300 |
| Programme Cost per Potent Vaccine Dose | 5.92 | 3.66 |
| **Total Cost per Effective Dose (Rs)** | **7.47** | **5.19** |

**Table 6.1 Costs of Photovoltaics vs Kerosene Refrigerators for Vaccine Storage in Pakistan (6,000 Doses/year required at a Health Centre)**

## 6.3 COMMERCIALLY AVAILABLE EQUIPMENT

### 6.3.1 The Technology

**The Refrigerator** - Photovoltaic refrigerators operate on the same principle as normal compression refrigerators but incorporate low voltage (12 or 24 v) d.c. compressors and motors, rather than mains voltage a.c. types. A PV refrigerator has higher levels of insulation around the storage compartments to maximise energy efficiency, a battery bank for electricity storage, a battery charge controller and a compressor controller which converts the power from the battery to a form required by the compressor motor.

Typical refrigerator components are shown in Figure 6.6. Most refrigerators include a freezer compartment for ice pack freezing. Other systems have separate units to provide solely for refrigeration or freezing. Sizes available range between 10 and 200 litres of vaccine storage capacity with ice production rates of up to 5 kg per 24 hours.

**Batteries** - The type most commonly used are lead acid batteries. Long life, deep cycle batteries are preferred. A capacity to run the refrigerator for 5 days without sun is recommended.

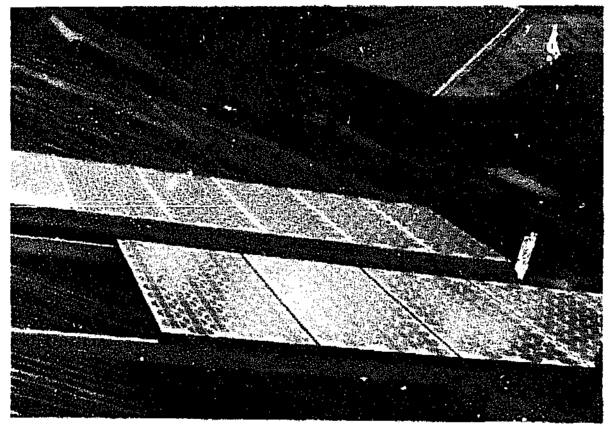


**Figure 6.5 PV Array on Rural Health Clinic**

Charge Regulator - The regulator maintains the power supply within the current and voltage range tolerated by the refrigerator and prevents overcharge of the battery. Some models include an audible alarm or warning light to signal when battery voltage becomes low. Lightning surge protection must be provided for tropical areas.

**Array and Support Structure** - The solar array can be for roof (Figure 6.5) or ground mounting. The array size for a refrigeration system is calculated to meet the power requirements for the proposed site. The typical requirement is 150 to 200 Wp of photovoltaic modules.

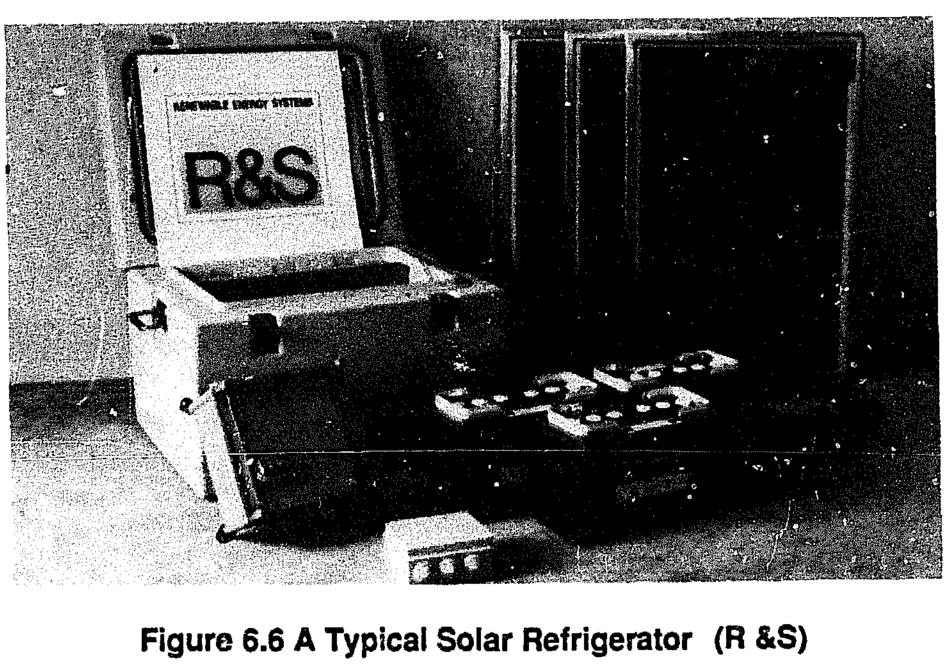



**Figure 6.6 A Typical Solar Refrigerator (R &S)**

### 6.3.2 Performance

**Vaccine refrigerators are required to maintain vaccine between +0°C and +8°C at all times. In addition, there is normally a requirement for a separate freezer compartment to freeze ice packs which are used for transporting vaccines in cold boxes.**

The performance of a refrigerator or freezer is dependent on the ambient temperature, therefore specifications are usually defined at 32°C and/or 43°C. The following criteria are used to assess performance:

- internal temperature distribution and variation within the permissible range of +0°C to +8°C.
- the rate of icepack freezing in kilograms per 24 hours.
- holdover time during loss of power. This is the length of time for which the internal temperature of the refrigerator will remain below 8°C when the power supply has been disconnected.

For system sizing, the energy consumption per 24 hours in kilowatt hours, whilst freezing icepacks and/or without icepack freezing is required.

The energy consumption of a PV vaccine refrigerator is typically 300 to 500 Watt hours per 24 hours for a 100 litre refrigerator without icepack freezing and at +32°C ambient temperature. At +43°C ambient tmperature and freezing 2 kg of icepacks per 24 hours, the energy consumption of the same refrigerator would rise to about 600 to 1200 Watt hours per 24 hours. It is very important not to overload a solar refrigerator as this increases energy consumption considerably.

A good (well insulated) vaccine refrigerator should be able to maintain correct internal temperatures for at least ten hours in the event of it being disconnected from the battery and solar array.

### 6.3.3 Costs

The output of a PV array will vary according to the location at which it is to be installed and the refrigerator energy consumption will depend on local climate. Therefore the size of the solar array, the battery storage capacity and hence system cost will vary depending on location. Typical system costs are in the range of US $3000-$6000 excluding transport and installation.

### 6.3.4 Products Available

At the end of this chapter, product information sheets are listed presenting brief details of some commercially available products. The World Health Organization, in its EPI Technical Series, publishes a document entitled "The Cold Chain Product Information Sheets". This catalogues equipment which have undergone tests to verify the performance is of a standard acceptable to the WHO and UNICEF. The document may be obtained from:

The Cold Chain Unit, Expanded Programme on Immunization, World Health Organization, 1211 Geneva 27, Switzerland.

## 6.4 PROCUREMENT

### 6.4.1 Assessing Requirements

The points below should be considered when estimating the required refrigerator capacity. Full details are given in the WHO document EPI/CCIS/86.3 - "A Guide to Estimating Capacity of Equipment for Storing and Transporting EPI Vaccines".

It is necessary to delineate the functions required of the system to fulfill the immunization programme. This should take account of:

- the type of vaccine to be used and its required storage temperature
- the population figure targeted for immunization in the area allowing approximately 4 litres storage capacity to fully immunize 150 infants and their mothers
- the frequency at which vaccines are likely to be delivered
- the requirements for icepack freezing (for use in cold boxes)
- storage space required for other medical supplies, eg blood bags
- likely future requirements for approximately 10 years.

From these can be determined:

- vaccine storage capacity required
- ice pack freezing capability required

### 6.4.2 Selection of Equipment

Selection of the model of solar refrigerator should be made with regard to:

- required vaccine storage capacity and ice production capability
- cost competitiveness
- operating experience of local health sector personnel with the type of equipment being considered
- the local availability of backup services for spares and repairs.

Some technical points to look for are:

- thermostat position (this may be better concealed to prevent unauthorised tampering) and indicators supplied
- batteries - are they sealed? If not, will distilled water be available? do they come with a lockable ventilated battery box or do they fit within the refrigerator cabinet?

### 6.4.3 Placing the Order

When placing the order, the type of number of spare parts should be specified. The recommended spare parts (per 10 systems) are given below.

| SPARE PARTS REQUIRED | QUANTITY / 10 SYSTEMS |
|---|---|
| 1. Photovoltaic modules | 2 |
| 2. Battery charge regulators | 2 |
| 3. Battery sets | 1 |
| 4. Array cables | 1 |
| 5. Compressor or complete cooling unit, as recommended by the manufacturer | 1 |
| 6. Spare electronic control cards | 3 |
| 7. Thermostat or temperature control cards | 3 |
| 8. Condenser fans (if used) | 2 |

Ensure also that instruction manuals for the user and technician are ordered for the correct language for the country of use.

**Purchase of complete system from WHO approved suppliers given in the WHO/ UNICEF Cold Chain Product Information Sheets is recommended.**

## 6.5 IMPLEMENTATION

Documents are available from WHO, Geneva, which are of direct use in implementing a solar refrigeration project. They include:

(a) "A User's Handbook for PV Refrigerators"
(b) "Fault Finding and Repair of PV Refrigerators"
(c) "Installation of PV Refrigerators"
(d) "Instructor's Notes for PV Refrigerators" (for training courses).
(e) "Guide to Infrastructure requirements for PV Refrigerators"

Training courses for solar refrigerator technicians are periodically organised by WHO. For information on these contact your local WHO office or WHO, Geneva.

### 6.5.1 Installation

Ensure:

- the solar array is not likely to be shaded
- the solar array can be easily and safely cleaned
- cable lengths are reduced to a minimum
- the refrigerator is located in the coolest room of the clinic
- there is good air circulation around the refrigerator
- the sun does not shine on the refrigerator
- the batteries are mounted in a well ventilated protective case away from the reach of children.

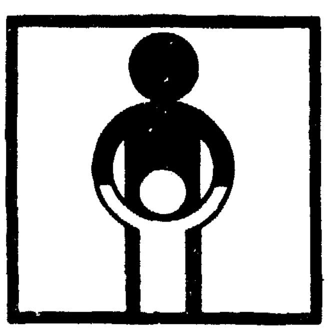
**QUALIFIED REFRIGERATORS**

| Model | Country | Net Vaccine Capacity (litres) | Gross Freezer Volume (litres) |
|---|---|---|---|
| BP Solar VR50 | U.K. | 38 | 5 |
| Dulas V50 | U.K. | 37 | - |
| Dulas I50 | U.K. | - | 54 |
| Electrolux RCW42 | Luxembourg | 14 | - |
| Electrolux RCW42 | Luxembourg | - | 27 |
| FNMA 75 | Zaire | 27 | 13 |
| NESTE - NAPS | Norway | 30 | 2 |
| Polar Products | USA | 80 | 27 |
| SASA 60 | Australia | 26 | 11 |
| SET KT180/24 | Germany | 56 | 55 |
| Sunfrost RFV - 4 | USA | 17.5 | 34 |
| UM Tropic | Germany | 30 | 20 |

**APPROVED SYSTEM SUPPLIERS**

| | | | |
|---|---|---|---|
| Ansaldo | Italy | Noack Solar | Norway |
| Budimex/FNMA | Belguim | Polar Products | USA |
| BP Solar | U.K. | Rand S | Netherlands |
| Chloride Solar | U.K. | Solapak | U.K. |
| FNMA | Zaire | Solarex | USA |
| Italsolar | Italy | Telefunken | Germany |
| Neste - NAPS | Norway | Soltech | Belgium |

**Table 6.2 WHO Qualified Refrigerators and System Suppliers**



### 6.5.2 Maintenance

Each day:

- record the temperature in a log book each morning and afternoon
- check the indicator lights for correct operation
- check the ventilation grill is not obstructed.

Each week:

- check the freezer evaporator for build up of ice - defrost if more than 5 mm thick
- clean the solar array.

Each month:

- clean the condenser and compressor with a soft brush
- check for shadowing of array early in the morning and afternoon.

Six monthly:

- check the level of acid electrolyte mixture in the batteries and top up with distilled water if necessary
- check all mountings, fixtures and cables for loose connections
- check the lid seal - if there is a gap between the seal and lid or refrigerator, replace it or glue it back on.

### 6.5.3 Fault Finding and Repair

It is outside the scope of this handbook to give detailed fault-finding procedures but:

**If the refrigerator will not run:**

- check the fuse in the compressor controller
- check the array cables

**If the refrigerator is too warm but does run:**

- adjust the thermostat setting
- check battery state of charge with a voltmeter or hydrometer
- check the refrigerator is not overloaded or that there has been an exceptional persistance of cloud
- check the array is not shaded at times.

**If the refrigerator is too cold:**

- adjust the thermostat
- check the freezer/refrigerator thermal barrier is not damaged or missing.

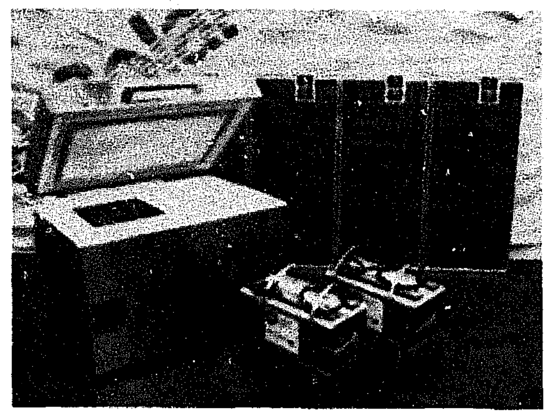
# EXAMPLES OF PRODUCTS AVAILABLE

## VACCINE REFRIGERATORS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8BZ U.K.

**Product:** REFRIGERATOR/ICEPACK FREEZER SYSTEM

**Includes:** PV array and support structure, cable battery, charge regulator, BP VR50 refrigerator/freezer unit, controller and alarms, instruction manual, tools and spares kit.



**Peformance:** @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.6 | kg/10 hrs |
| Internal temp. range | 2-7 | deg. C |
| Holdover time | 4 | hours |

**Vaccine Storage Capacity:**

| | | |
|---|---|---|
| Refrigerator | 38 | litres |
| Freezer | 5 | litres |

**Price: US$** - depending on insolation and ice needs

$3,500 - $6,000

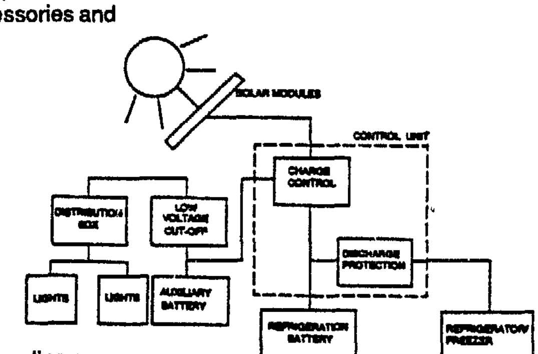
**Company: CHLORIDE SOLAR** — The Lansbury Est. Knaphill, Woking, Surrey. GU21 2EW. U.K.

**Product:** MS3: COMBINED VACCINE REFRIGERATION AND LIGHTING SYSTEM

**Includes:** PV array (288Wp), support structure, FNMA 75 refrigerator /freezer unit, minimum-maintenance (300Ah + 120Ah) batteries, control unit. 8 x 8 Watt fluorescent lights, cables, accessories and installation handbook

**Performance:**@ 5kWh/m2/Day, and 32°C. ambient temperature:

| | |
|---|---|
| Ice pack freezing | 2.7kg/24hrs |
| Internal temp range | 1 - 7 C. |
| Holdover time | 5.6 hrs |




**Vaccine Storage Capacity:**

| | |
|---|---|
| Refrigerator | 27 litres |
| Freezer | 13 litres (gross) |

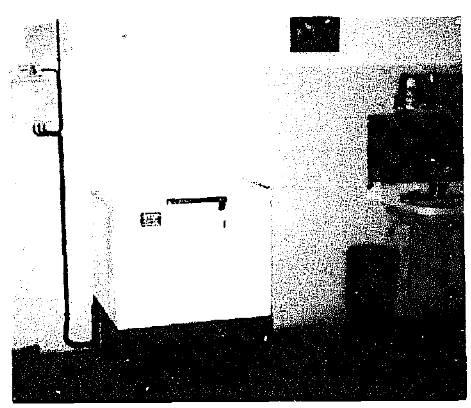
**Lighting:** Up to 3 hrs per night from each of the eight lights depending on the refrigerator usage

**Price:** US$ 5,740.00

**Company: FNMA** — 14 Rue Limete, BP 1967, Kinshasa 1, Zaire

**Product:** REFRIGERATOR/ICEPACK FREEZER SYSTEM

**Includes:** PV array (120 - 160 Wp) and support structure, cable, batttery, charge regulator, FNMA 75 refrigerator/freezer unit and instruction manual



**Peformance:** @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.7 | kg/24 hrs |
| Internal temp. range | 1-7 | deg. C |
| Holdover time | 5.6 | hours |

**Vaccine Storage Capacity:**

| | | |
|---|---|---|
| Refrigerator | 27 | litres |
| Freezer | 13 | litres (gross) |

**Price: US$** - depending on insolation and ice needs

$3,500 - $5,000

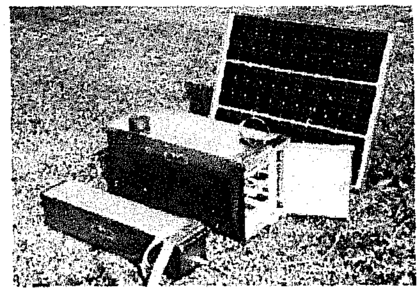
## EXAMPLES OF PRODUCTS AVAILABLE

## VACCINE REFRIGERATORS

**Company: NESTE Advanced Power Systems — Ralssitie, SF - 01510 Vantaa, Finland.**

Product: MOBILE PV VACCINE REFRIGERATOR SYSTEM

Includes: PV array (3 x 48Wp), special array structure for mobile use. Sealed batteries in a special box, which includes charge controller Mobile refrigerator CFM49, 49 litre gross internal volume



Peformance: @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.4 | kg/12 hrs |
| Internal temp. range | 1 - 8 | deg. C (max) |
| Holdover time | 6 - 8 | hours |

With std solar day of 5kWh/m2/day, it can operate continously at ambient temperatures of upto 41 deg C (no or occasional icemaking), or up to 25 Deg C with 2.4kg icemaking every day

Vaccine Storage Capacity:

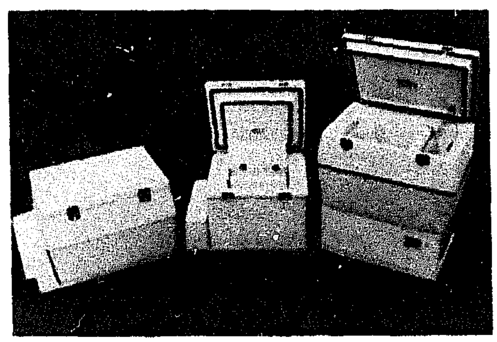
| | | |
|---|---|---|
| Refrigerator | 20 | litres |
| Freezer | 7 | litres (gross) |

Price: US$ $4,720 (3 module system as above)

**Company: POLAR PRODUCTS — 2808 Oregon Court, Bldg. 4, Torrance, California, USA**

Product: REFRIGERATOR/FREEZER SYSTEM

Includes: PV array (235 - 282 Wp) and support structure, cable, battery, charge regulator, Polar Products refrigerator freezer unit, manuals and thermometer



Performance: @ 32 deg. C ambient temperature:

| | | |
|---|---|---|
| Ice pack freezing | 2.1 | Kg/ 24hrs |
| Internal temp range | 4 - 7 | deg. C |
| Holdover time | 4 | hrs |

Vaccine Storage Capacity:

| | | |
|---|---|---|
| Refrigerator | 80 | litres |
| Freezer | 20 | litres |

Price: US$ depending on insolation and ice needs. Refer to supplier

**Company: R & S RENEWABLE ENERGY SYSTEMS BV — PO Box 45, 5600 AA Eindhoven, Netherlands**

Product: REFRIGERATION SYSTEM

Includes: PV array (135 - 180 Wp) and support structure, cable, batttery, charge regulator, with low battery alarm and Electrolux RCW42DC refrigerator.

Peformance: @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.1 | kg/24 hrs |
| Internal temp. range | 3 - 6 | deg. C |
| Holdover time | 4 | hours |

Vaccine Storage Capacity:

| | | |
|---|---|---|
| Refrigerator | 14 | litres |
| Freezer | 7 | litres (gross) |

Price: US$ $3,200 - $4,200

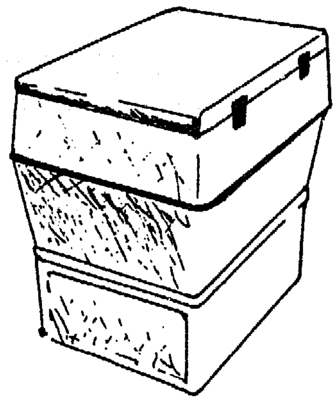
## EXAMPLES OF PRODUCTS AVAILABLE

## VACCINE REFRIGERATORS

**Company: SOLAREX** — 135 Piccard Dr., PO Box 6008, Rockville, Maryland 20850, USA

**Product:** REFRIGERATOR/FREEZER SYSTEM

**Includes:** PV array (168 - 208 Wp) and support struture, cable, battery, charge regulator, Polar Products refrigerator unit, manual, and alarms



**Peformance:** @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.1 | kg/12 hrs |
| Internal temp. range | 4 - 7 | deg. C (max) |
| Holdover time | 4 | hours |

**Vaccine Storage Capacity:**

| | | |
|---|---|---|
| Refrigerator | 80 | litres |
| Freezer | 20+ | litres (gross) |

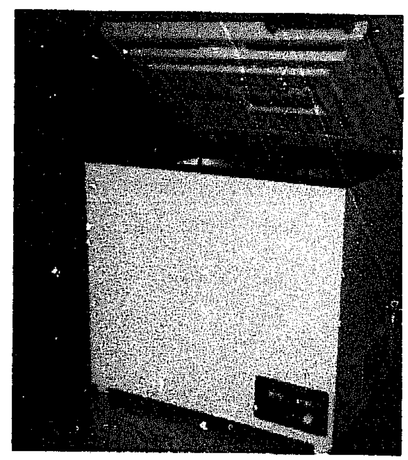
**Price: US$** Depending on insolation and ice needs

Refer to suppler

**Company: SOLAR ENERGIE TECHNIK** — Postfach 1180, D-6822, Altlussheim, Germany

**Product:** REFRIGERATOR/FREEZER SYSTEM

**Includes:** PV array cable, battery, charge regulator, SET KT 180 (24V) refrigerator/freezer unit two 100Ah batteries, array support and instruction manual



**Performance:** @ 32 deg. C ambient temperature:

| | | |
|---|---|---|
| Ice pack freezing | 2.4 | kg/ 24hrs |
| Internal temp range | 1-8 | deg. C |
| Holdover time | 3.9 | hrs |

**Vaccine Storage Capacity:**

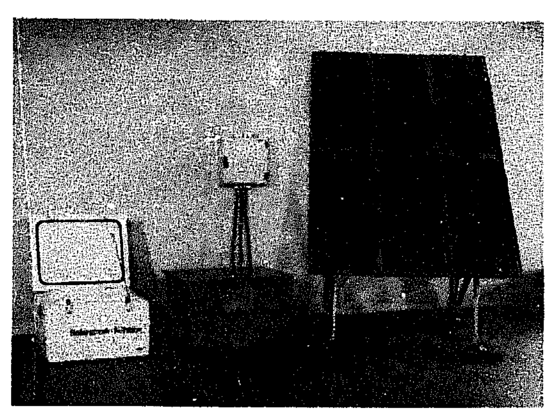
| | | |
|---|---|---|
| Refrigerator | 56 | litres |
| Freezer | 35 | litres (gross) |

**Price: US$** Depending on insolation and ice needs.
$2,600 - $3,400

**Company: TELEFUNKEN SYS. TECHNIK GMBH** — Industriestr. 23 - 33, 2000 Wedel, Holstein, Germany.

**Product:** VACCINE REFRIGERATOR SCS 200

**Includes:** PV array (180 - 400Wp) incl. support structure and cabling, refrigerator/freezer, electronic temperature regulator, lead acid battery, charge regulator



**Peformance:** @ 32 deg.C ambient temp.:

| | | |
|---|---|---|
| Ice pack freezing | 2.4 | kg/24 hrs |
| Internal temp. range | 2 - 7 | deg. C |
| Holdover time | 3 | hours |

**Vaccine Storage Capacity:**

| | | |
|---|---|---|
| Refrigerator | 56 | litres |
| Freezer | 55 | litres (gross) |

**Price: US$** Refer to supplier

# 7. LIGHTING

## 7.1 EXPERIENCE

**In terms of number of installations, lighting is presently the biggest application of photovoltaics with tens of thousands of units installed worldwide. They are mainly used to provide lighting for domestic or community buildings, such as schools or health centres. PV lighting is also being increasingly used for security, street and tunnel lighting.**

User experiences have been excellent with increasing demand for more systems in the locality where a PV light is installed. Specific examples of lighting experience include:

**French Polynesia** - Where more than 1000 homes on the islands have been PV powered with anything from 2 to 20 roof mounted modules. The scheme had a 25% grant from the government with the remainder coming from private resources or loans. As a commercial project, the extent of uptake has been high with favourable responses. The users reported PV to be less expensive than diesel.

**Dominican Republic** - Approximately 70% of the rural population have no access to the utility grid in the Dominican Republic. In 1984, a PV based rural electrification project was set up, using USAID seed money to install PV lighting systems. The income from charging for these systems has allowed further equipment to be bought and the project is now self-financing, with more than 1000 systems now installed.

**Thailand** - In many villages in Thailand, lighting is achieved by sending automotive batteries into towns for charging and then running 12 volt lamps from the batteries. With Japanese seed funding, the ministry of Rural Electrifications has installed 500 Wp PV battery charging stations. Due to savings on replacement battery, and transportation costs, a PV system will pay for itself in three years or less.

**Zaire** - Here the Departement de la Sante Publique has been installing 850 PV lighting systems in health centres and clinics, in conjunction with 100 refrigerators. One side effect of the project is that the provision of lighting has given medical staff a significant incentive to work or to continue to work in rural areas, thereby contributing to improved health care services.

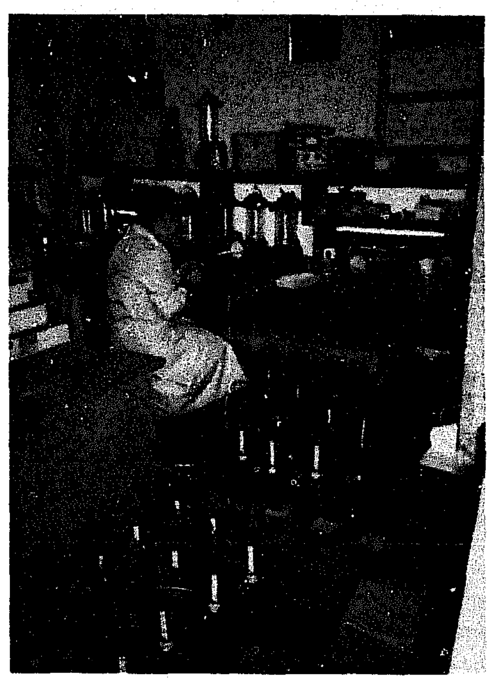


**Figure 7.1 PV Light Assembly in Mongolia**

Lighting is taken for granted in the industrial countries and in most of the urban areas of developing countries. In areas without access to mains electricity, lighting is restricted to candles or kerosene lamps. Torches (or flash-lights) powered by expensive, throw-away dry-cells are used intermittently as a portable source of light.

## 7.2 RELATIVE MERITS

Common means of lighting where mains electricity does not exist, or is impractical, include:

- candle
- kerosene lamp
- kerosene hurrican lamp
- diesel generator for electric lamps
- automotive batteries for electric lamps

Kerosene lamps and candles have the obvious drawback of producing only a low light output and being a fire hazard. They do, however, have the lowest purchase price, but are expensive and inefficient to run. In comparison the convenience, relative safety and brightness of the electric light is generally accepted as preferable. The use of fluorescent lamps rather than filament lamps is necessary for efficient use of the electricity.

**Figure 7.2 PV Lighting Kit**

The output and power use efficiency of lamps are summarised in Table 7.1.

| TYPE OF LIGHT | | ENERGY SOURCE | INTENSITY (LUMENS) | POWER USE EFFICIENCY (LUMEN/WATT) | USE PV? |
|---|---|---|---|---|---|
| candle | | parraffin wax | 1 | .01 | NO |
| kerosene lamp (wick) | | kerosene | 10 | .1 | NO |
| hurricane lamp (wick) | | kerosene | 100 | .2 | NO |
| oil lamp (mantle) | | Kerosene | 1000 | 1 | NO |
| gas lamp (mantle) | | butane | 1000 | 1 | NO |
| filament lamp | 3W | dry batteries | 10 | 3 | NO |
| filament lamp | 40W | electricity | 400 | 10 | NO |
| flourescent | 15W | electricity | 600 | 40 | YES |
| | 20W | electricity | 1000 | 50 | YES |
| mercury | 80W | electricity | 3200 | 40 | YES |
| sodium SOX | 35W | electricity | 4500 | 128 | YES |

**Table 7.1 Lamps: Power and Efficiency**

The relative merits of providing light by diesel generators, battery recharging and photovoltaics is given in Table 7.2.

| System | Advantages | Disadvantages |
|---|---|---|
| Diesel Generators | • widespread operating and maintenance experience | • creates noise and fume pollution pollution |
| | • moderate capital cost | • require a reliable fuel supply |
| | • easy to install | • high running costs |
| | • can be combined power supply for additional uses | • high maintenance costs |
| | | • low operating efficiency often achieved |
| Automotive Battery Recharging | • low capital cost | • relies on transporting to charging stations |
| | • easy to install | • high charging fees often apply |
| | • batteries locally available | • short battery lifetimes |
| Photovoltaics | • high reliability | • involves the introduction of a new and often poorly understood technology |
| | • low maintenance requirements | • high capital cost |
| | • low running costs | • spares not widely available |
| | • suited to most locations | • not physically robust so vulnerable to damage |
| | • long life expectancy for main components | • specialised batteries not widely available |

**Table 7.2 Comparison of Power Sources for Electric Lighting**

Even though individual PV lamps may be more expensive to buy initially, in general they are cost-effective on a life-cycle cost basis, compared to kerosene lighting and in addition provide a better quality light. The relative economics of PV versus kerosene lighting is shown in Table 7.3.

| CONVENTIONAL | | PHOTOVOLTAIC | |
|---|---|---|---|
| Weekly Fuel Requirements: | | Weekly Energy Requirements: | |
| Kerosene Pressure Lamp | = 2.8 litres | Fluorescent Lamps | 2 x 8 W |
| Hurricane lamp | = 1.2 litres | | = 64 Wh |
| | | But battery charging efficiency is only 80%, hence requirements | = 80 Wh |
| Weekly Energy Costs: | | | |
| Kerosene at $0.3 Litre | $ 1.20 | Average Daily Insolation 5 kWh/m$^2$ | |
| | | Required Array Size 18 Wp | |
| Annual Total | $ 62.40 | Capital Costs: PV Array | $150.00 |
| Capital costs: | | Battery (100 Ah x 12 v) | $140.00 |
| Pressure lamp | $ 20.00 | Flourescent Lights (2) | $ 34.00 |
| Hurricane Lamp | $ 5.00 | Voltage Regulator | $ 50.00 |
| Total | $ 25.00 | Total | $374.00 |
| Recurrent Costs: | | Recurrent Costs: | |
| Present Worth of Fuel Discounted at 10% over 15 yrs = $62.4 x 7.61 | = $475.00 | Battery (replace 5 years) PW | = $141.00 |
| | | Tubes (replace 2 yrs) PW | = $ 28.00 |
| | | Voltage Regulator (replace 8 yrs) PW | = $ 24.00 |
| | | Total | $193.00 |
| Lamps are replaced every 2 years. Present Worth Of Replacements | = $ 95.00 | | |
| Total Life Cycle Costs (15 years) = $25.00 + $475.00 + $95.00 | = $595.00 | Total Life Cycle Costs (15 years) = $374.00 + $193.00 | = $567.00 |
| Annualised LC Cost | = $ 7 8.00 | Annualised LC Cost | = $ 74.00 |

**Table 7.3 Life Cycle Cost Comparison of Conventional and PV System**

The use of photovoltaic systems for lighting should therefore be considered where:

- kerosene fuel supplies are erratic or expensive;
- good quality lighting is required (eg, in schools and home industries - such as needlework)
- solar irradiation levels are moderate to high (>3 kWh/m$^2$/day).

## 7.3 COMMERCIALLY AVAILABLE EQUIPMENT

### 7.3.1 Applications

PV lighting systems can broadly be categorised as suitable for use in one of the following applications:

- domestic or community building lighting (homes, schools, community centres, mosques, churches)
- street, area or security lighting (car parks, industrial areas, warehouses)
- portable light units.

Specialised commercial lighting such as terrain avoidance lighting for aircraft and other navigational aids are briefly described in Chapter 9.

### 7.3.2 The Technology

**The main difference between photovoltaic and other electric lighting systems is that a d.c. supply is produced, thus the use of d.c. lights is preferred. A.c. lights may be used by incorporating an inverter into the system, but this will introduce significant additional electrical losses, hence a larger array will be needed.**

Many d.c. lights are now commercially produced, but the most efficient in terms of light output (lumens) per watt of power consumed are low voltage fluorescent tubes. If these are not available, conversion of a.c. tubes is possible by changing the a.c. starter and ballast components to produce a d.c. version. Figure 7.3 shows common types of d.c. lights for use with PV systems.

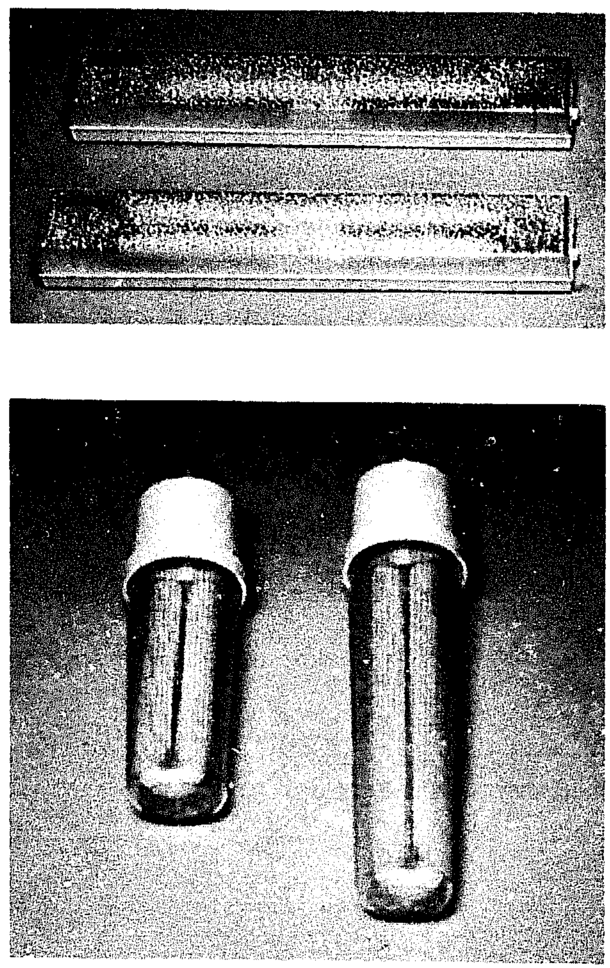


**Figure 7.3 12 Volt Fluorescent lamps**

Domestic or Community Building Lighting

Usually systems are dedicated for use in one building, normally providing one or two lights, but often up to about eight lights. Complete system packages are available, comprising of:

- PV array including one or two modules and mounting structure;
- fluorescent lights usually 8 W, 13 W, 16 W or 20 W;
- battery
- charge control regulator;
- cabling, installation tools.

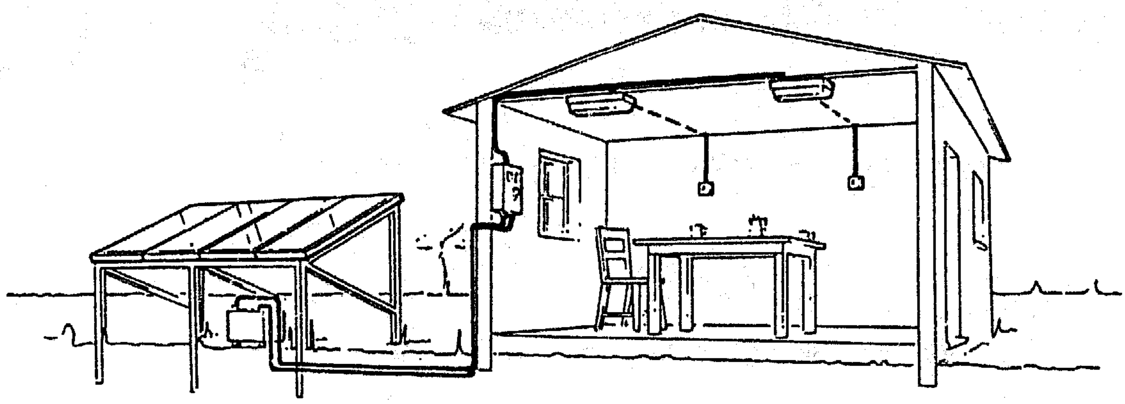


Figure 7.4 Typical PV Lighting System

**Street, Area or Security Lighting**

Specific systems, usually pole mounted, have been developed for this purpose and typically include:

- PV modules; (typically 40 - 120 Wp)
- support structure - (usually pole-mounted);
- battery;
- lamp - generally d.c. fluorescent tubes, low pressure sodium or mercury vapour lamps;
- controller - including charge regulation and optional automatic on/off switching (set by timer or light sensitive switch).

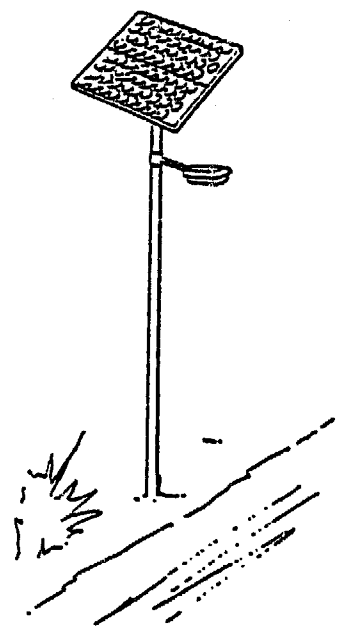


Figure 7.5 Area or Security Light

**Portable Lighting Systems**

Small systems have been designed to be easily carried by hand. One model developed with user acceptability in mind has a hand lamp based on the conventional kerosene lamp design, but fitted internally with a fluorescent tube. Many systems combine PV module, battery and lamp in an integral unit, whilst others have a detachable PV module.

**Typical specifications:**

| | |
|---|---|
| array size: | 4-10 Wp |
| lamp: | 4-8 Watts |
| performance: | 3-5 hours/day |

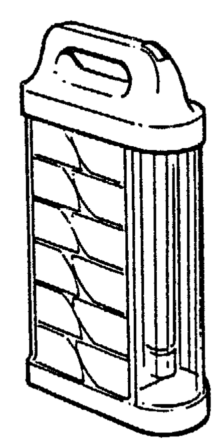


Figure 7.6 Portable Light with Integral PV Cells

### 7.3.3 Costs

Typical costs for the three applications of lighting considered are shown below. It should be noted that in all cases, although the PV option is higher capital cost, the life cycle cost is lower than in comparison to kerosene systems.

| APPLICATIONS | SYSTEM | INITIAL CAPITAL COST $ |
|---|---|---|
| Home or Community Building | 1 x 20 Wp PV Module<br>2 x 8 Wp fluor. lamps | 430 |
| Security Light | 2 x 40 Wp PV module<br>2 x 20 Wp fluor. lamps<br>pole mounting<br>battery & regulator | 1600 |
| Portable Light | 5 Wp of PV module<br>6 W fluor lamp<br>15 Wh sealed battery | 150 |

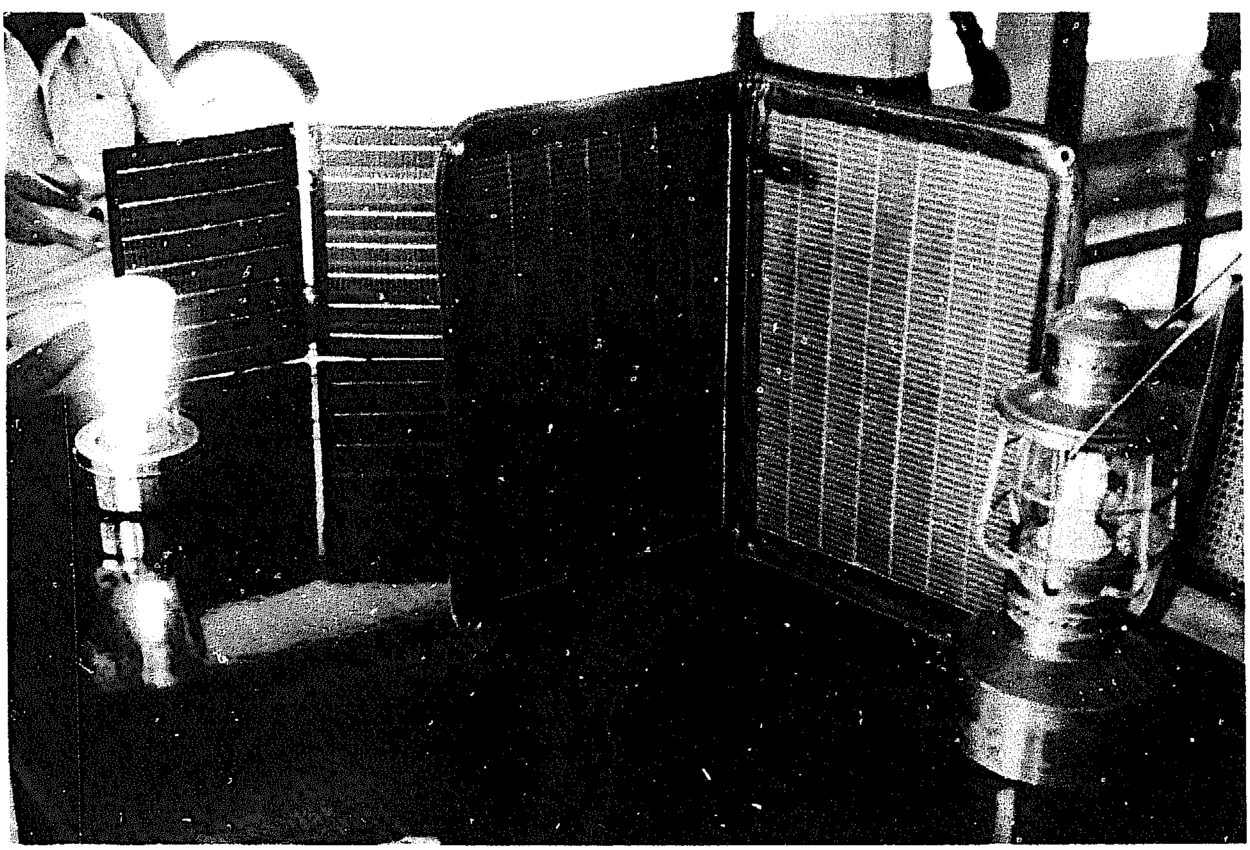


Figure 7.7 Portable PV Lighting Systems (Suryovonics, India)

### 7.3.4 Products Available

There are many types of PV lighting products available. Details of some typical products are given at the end for this section. In fact, almost all the suppliers listed in this book are able to supply lighting systems.

## 7.4 PROCUREMENT

### 7.4.1 Assessing Requirements

The requirements of a lighting system should be appraised in terms of:

- quality and intensity of light required
- number of lights and their proposed location
- daily hours of operation
- the anticipated pattern of use of the lighting system
- how requirements may change and future demands.

It is preferable to over-estimate demand but financial resources often prove to be the limiting factor. It is important to look at the overall system and operating procedure when designing the system configuration, eg:

- if several lights are required in dispersed locations, it may be better to use
- several small systems rather than one large;
- portability of lights may be a requirement;
- automatic switching of outside lighting or timers may be required.

A pro-forma sheet for determining the approximate system sizing required is given in Table 7.6. An example is shown below in Table 7.5. If specific component efficiencies are not available, battery and regulator efficiencies of 0.8 and 0.9 respectively should be used.

| | | |
|---|---|---|
| Requirements: | = | one 8 W lamp plus one 20 W lamp for 4 hours per day |
| Insolation level: | = | 4 kWh/m² /day |
| System nominal voltage: | = | 12V |
| Maximum Battery Discharge | = | 20% |
| Energy consumption | = | (8W x 4h) + (20 W x 4h) |
| | = | 112 Wh/day |
| Array Load | = | 112 / (battery and regulator efficiency) |
| | = | 112 / (0.8 x 0.9) |
| | = | 155 Wh/day |
| Array Size | = | Array Load/(Insolation x mismatch factor) |
| | = | 155 / (4 x 0.85) |
| | = | 46 Wp |
| Battery Size | = | Daily lamp consumption / Max. discharge x nominal voltage |
| | = | 112/ (0.20 x 12) |
| | = | 47 Ah |

**Table 7.5 Example of Simple System Sizing**

1. How many and what size of lights are required? ........................

2.. How many hours of lighting are required each day? .........................

3. Calculate daily energy consumption:

a) ............ lamps at ........... Watts, for ........... hours = ......... Wh
b) ............ lamps at ........... Watts, for ........... hours = ......... Wh
c) ............ lamps at ........... Watts, for ........... hours = ......... Wh

Total daily energy consumption = ..... Wh

4. Calculate PV array daily energy load:

$$\text{Array load} = \frac{\text{daily energy consumption}}{\text{battery effic.} \times \text{charge regulator effic.}}$$

= ................ Wh

5. What is the average daily insolation in the lease sunny month?

6. Calculate PV array size required from:

$$\text{array size} = \frac{\text{Array load}}{\text{insolation} \times \text{mismatch factor (mismatch factor} = 0.85)}$$

7. Calculate minimum battery capacity

$$\text{Battery Capacity} = \frac{\text{daily energy consumption}}{\text{max. allowable discharge (\%)} \times \text{nominal voltage}}$$

= .......... Ah

**Table 7.6 Pro Forma for PV Lighting Systems**

### 7.4.2 Equipment Selection

Unless there is good reason for doing otherwise, equipment should be purchased as a complete package from one supplier. The components included in the package will vary from supplier to supplier. Points to look for when comparing systems include:

- array size in Wp;
- number of lights provided;
- the output (in lumens) of the lights per Watt of energy consumption and estimated hours of use per day;
- if switching for the lights is included;
- type of support structure, if included, and its suitability for proposed site;
- ease of installation with tools and facilities available;
- battery capacity in ampere hours;
- maximum permissible depth of discharge of the battery;
- controller functions (automatic load disconnection at low battery voltage is recommended and lighting protection is essential for tropical regions);
- sufficient cable lengths and wall fixings.

## 7.5 IMPLEMENTATION

### 7.5.1 Installation

PV lighting systems are generally easy to install because normally they only require one or two modules, which may be roof mounted, pole mounted, or, for small systems, hung on walls or porches. The module should face the equator and be tilted at an angle recommended by the supplier (approximately latitude plus 10 degrees).

This ease of installation presents one major problem in that they are easy to remove and hence vulnerable to theft (if not integral in a lantern). Except for portable systems, a secure roof mounting fixture is thus preferred.

The battery should be located in a ventilated locked battery box. It should be out of the reach of children. This is very important in a domestic installation.

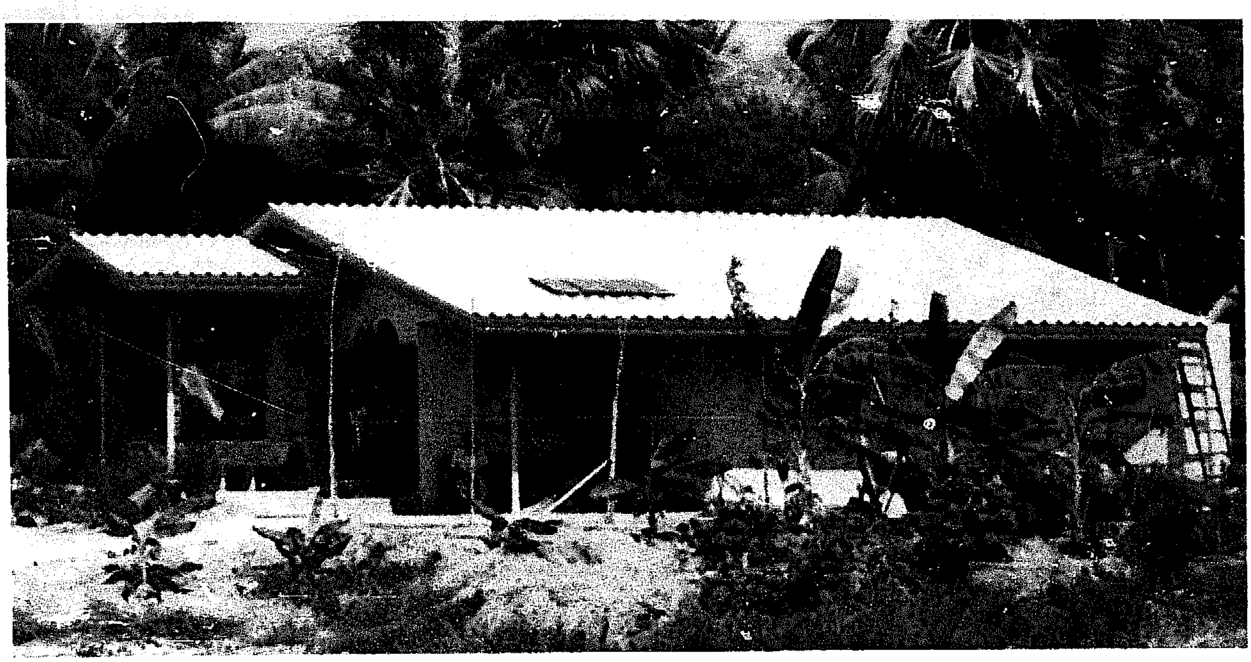


Figure 7.8 Lighting in a Rural Health Clinic

### 7.5.2 Maintenance

The principal maintenance requirements will be to:

- clean the PV module(s) each week (if accessible)
- check cables and connections weekly
- check the battery electrolyte level monthly.

If the battery electrolyte requires topping up, it is essential to use distilled water.

### 7.5.3 Fault Finding and Repair

If the light does not work at all:

- check the fluorescent tube on another 12 volt battery.

If the light comes on but for fewer hours than expected:

- check the battery state of charge
- check for loose connections.

If the battery is completely discharged, check the fuse in the charge regulator (if fitted). The battery may be recharged by disconnecting the lamp for a few days (to allow the battery to be recharged by the modules). Alternately, the battery can be taken to the nearest town for commercial recharging.

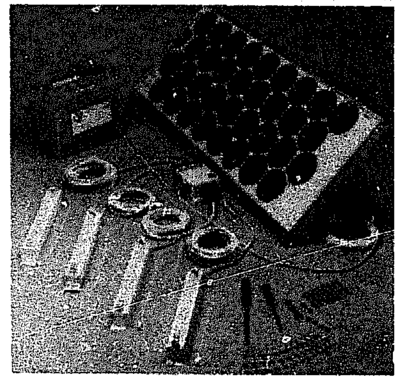
## EXAMPLES OF PRODUCTS AVAILABLE

## DOMESTIC AND COMMUNITY LIGHTING SYSTEMS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8BZ, UK

**Product:** DOMESTIC OR COMMUNITY LIGHTING

**Includes:** A complete kit with self regulating 40Wp PV module, support structure for roof or ground mounting, 4 x 8W fluorescent lights with 10m of cable, pre-wired plug and socket connections, distribution box, installation fastenings and instruction manual

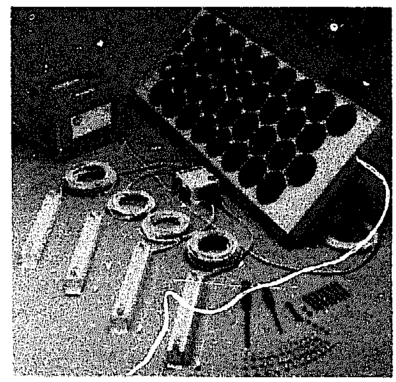


| MODEL NO. | ARRAY Wp | LIGHT HOURS/DAY | PRICE U.S. $ |
|---|---|---|---|
| Lighting kit | 40 | 16hr @ 5kWh/m²/d | 580 |

**Company: BP SOLAR ESPANA** — Calle Primera Valportillo 5, Alcobendas, Madrid, Spain

**Product:** DOMESTIC OR COMMUNITY LIGHTING

**Includes:** A complete package with 45W module, support structure for roof or ground munting, 3 x 15W and 1 x 9W lights, 10m of cable, accessories and manual

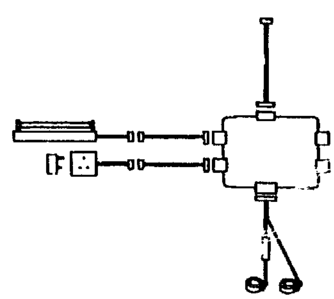


| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| L-PAK | 45 | 4.5 hrs @ 5kWh /m²/day<br>6.0 hrs @ 7kWh/m²/day<br>insolation | 720 |

**Company: CHLORIDE SOLAR,** The Lansbury Estate, Knaphill, Woking, Surrey, GU21 2EW U.K.

**Product:** DOMESTIC AND COMMUNITY LIGHTING SYSTEM

**Includes:** Self regulating 43 Wp PV module, support structure, 105Ah battery and home lighting kit comprising 3 x 8W fluorescent lights, distribution box with three light switches and low voltage cut our, plugs, connectors, 2 x 5m cables, 3 x 10m cables, 1.5m battery cable, fuse, terminals, clips and screws

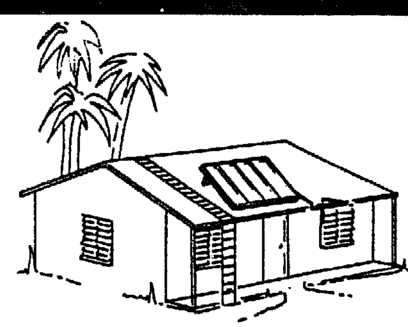


| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| LK1 | 43 | 7 hrs @ 5kWh /m²/day | 594 |

**Company: HELIOS TECHNOLOGY** — 1 - 35015 Galliera Veneta, (PD), Via PO, 8, Italy

**Product:** DOMESTIC OR COMMUNITY LIGHTING SYSTEM

**Includes:** One PV module, control unit, 4 x fluorescent lamps, 100Ah battery, installation fittings and handbook



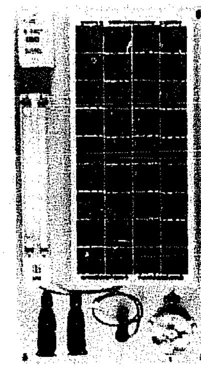
| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| M 40 | 40 | 6 hrs @ 5 kWh/m²/day | Refer to supplier |

# EXAMPLES OF PRODUCTS AVAILABLE
# DOMESTIC AND COMMUNITY LIGHTING SYSTEMS

**Company: IBC** — Am Kreuzberg 5, PO Box 1107, D- 8628 Staffelstein, Germany

**Product:** DOMESTIC LIGHTING SYSTEM

**Includes:** Complete kit with PV module, support structure, 2 x 8 W fluorescent lights, 15m cables, 12v, 50Ah battery, switch, junction box, fittings and manual

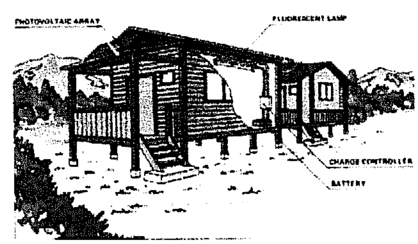


| MODEL NO | ARRAY Wp | LIGHT HOURS/DAY | PRICE U.S. $ |
|---|---|---|---|
| 4050 | 11 | 3 hrs | 395 |
| 4055 | 24 | 8.5 hrs | 450 |

**Company: KYOCERA** — Chiba Sakura, 4-3 Ohsaku 1- Chome Sukura Shi, Chiba 285 Japan

**Product:** COMMUNITY BUILDING LIGHTING SYSTEM

**Includes:** PV Module, structure, battery, controller 2 x 20W fluorescent lamps and manual

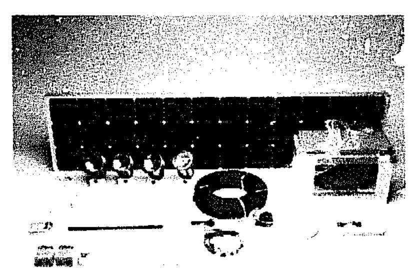


| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| KLK 41 | 96 | 4 hrs @ 4kWh/m2/day<br>7 hrs @ 5kWh/m2/day<br>8 hrs @ 6kWh/m2/day | 2,500 |

**Company: NESTE Advanced Power Systems** — Ralssitie, SF-01510 Vantaa, Finland

**Product:** LIGHTING SYSTEMS

**Includes:** PV module s mounting brackets, control unit, battery, switches and cables plus 4 x 13W fluorescent lamps and one 10W spotlamp per module

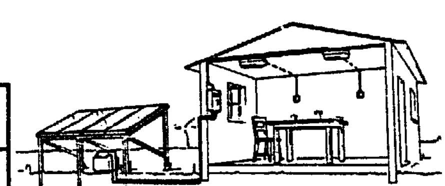


| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| LK 1<br>1 module | 48 | 180 Wh available per day | 630 |
| LK 2<br>2 modules | 96 | 360 Wh available per day | 1050 |
| LK 3<br>3 modules | 144 | 540 Wh available per day | 1475 |

**Company: SOLAPAK LTD** — Factory 3, Cock Lane, High Wycombe, Bucks HP13 7DE U.K.

**Product:** DOMESTIC OR COMMUNITY LIGHTING SYSTEM

**Includes:** Modules, support structure, regulator, 60Ah battery and enclosure, 1050 Lumen fluorescent lamp (s)



| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| | | @ 5 kWh/m2/d insolation | |
| A53-1 lamp | 53 | 4 hrs | 800 |
| A106-1 lamp | 106 | 8 hrs | 1,300 |
| B106-2 lamps | 106 | 4 hrs | 1,400 |

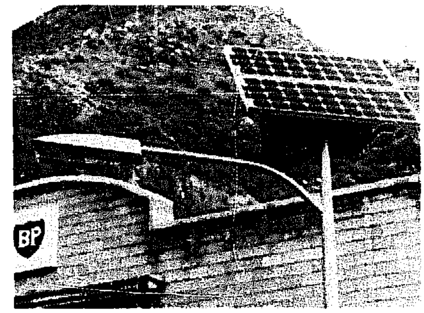
# EXAMPLES OF PRODUCTS AVAILABLE
# STREET AND AREA LIGHTS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8BZ, U.K.

**Product:** STREET LIGHTING SYSTEM

**Includes:** 2 PV modules, 4.5m pole, 200 Ah battery, electronic control unit, 8W or 35W sodium lamps

| MODEL NO. | ARRAY Wp | LIGHT HOURS/DAY | PRICE U.S. $ |
|---|---|---|---|
| SL 90<br>SL 110 | 90<br>110 | 10 hrs @ 4kWh/m²/d<br>10 hrs @ 4kWh/m²/d | 2,765<br>3,250 |

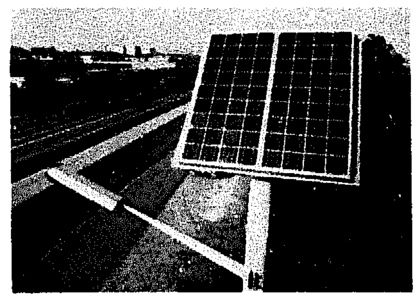


**Company: IBC** — Am Kreuzberg 5, PO Box 1107, D-8623 Staffelstein, Germany

**Product:** STREET LIGHTING SYSTEM

**Includes:** 2 PV modules, 5 m pole, 100 Ah battery, electronic control unit, 18W sodium lamp.

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| 4080 | 96 | 12 hrs @ 5kWh/m²/day | 2,280 |

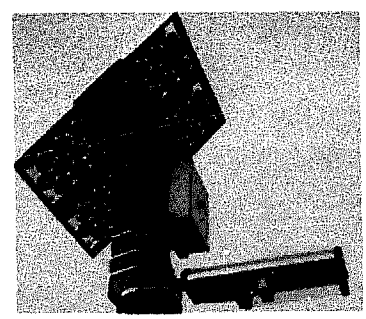


**Company: SOLTECH** — Boekterheide 30 - 3550 Zolder, Belgium

**Product:** STREET LIGHTING SYSTEM

**Includes:** PV modules, pole, battery, charge and load controller, 18W fluorescent lamp

| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| SL 80 | 80 | 12 hrs @ 5kWh/m²/day | from 1,600 |



**Company: TOTAL ENERGIE** — 7 Chemin du Plateau, ZI Le Tronchon, 69570, Dardilly, France

**Product:** SOLAR LAMP POST

**Includes:** 2 PV modules, 3.5m aluminium pole, 200Ah battery electronic control unit, 11W fluorescent lamp or 18W sodium on LP 90-s)

| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| LP45<br>LP90<br>LP90-S | 45<br>90<br>90 | 6 hrs @ 5kWh/m²day<br>12 hrs @ 5kWh/m²/day<br>12 hrs @ 5kWh/m²day | 2,000<br>2,600<br>3,000 |

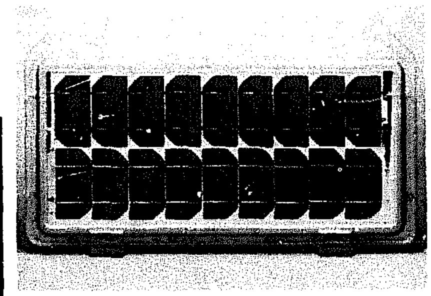
# EXAMPLES OF PRODUCTS AVAILABLE
## PORTABLE LAMPS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8 BZ U.K.

Product: PORTABLE LANTERN

Includes: 10 Wp PV panel, nickel-cadmium battery and 8W fluorescent light all in a moulded plastic case. The total weight is 4 kg

| MODEL NO. | ARRAY | LIGHT HOURS / DAY | PRICE U.S. $ |
|---|---|---|---|
| SL48 | 10 | 5.0 @ 7kWh/m²/d | 300 |



**Company: CHRONAR FRANCE** — 3 alle E. L'heureux, 94340 Joinville - Le Pont, France

Product: PORTABLE LANTERN

Includes: 9W PV moldule, 9w fluorescent lamp and battery in conventionally styled lantern with rugged case

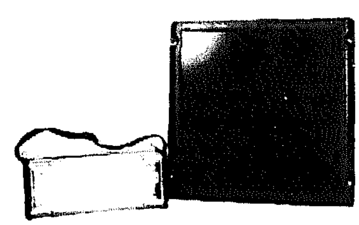
| MODEL NO. | ARRAY Wp | LIGHT HOURS/DAY | PRICE U.S. $ |
|---|---|---|---|
| AFRICA | 9 | 5 hours @ 5kWh/m²/day | 130 |

**Company: NESTE Advanced Power Systems** — Ralssitie, SF - 01510 Vantaa, Finland

Product: PORTABLE LANTERN

Includes: Detachable 5W PV module, light and battery in robust container with 12V output socket for other devices

| MODEL NO. | ARRAY Wp | LIGHT HOURS DAY | PRICE U.S. $ |
|---|---|---|---|
| BEDOUIN | 5 | 5hrs @ 3.3 kWh/m²/d | 170 |

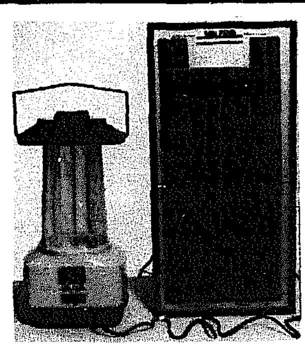


**Company: SOLTECH** — Boekterheide 30, 3550 Zolder, Belgium

Product: PORTABLE LAMP

Includes: 10 Wp PV module, 6Ah battery with charge controller and two flourescent lamps in a conventinally styled lantern

| MODEL NO. | ARRAY Wp | LIGHT HOURS / DAY | PRICE U.S. $ |
|---|---|---|---|
| Lantern | 10 | 4 - 8 Hours | 300 |



## 8.1 EXPERIENCE

**Small scale communications systems can play an important role in rural development, those of most relevance are radio transceivers, radio telephone links, radio receivers, community television and public address systems. To operate they need a small, but reliable power supply. Photovoltaics is an ideal power supply for these applications. A significant number of systems have already been installed almost always with good user responses. In fact, the level of use of the equipment has often far exceeded expectations.**

Specific examples include:-

**The Jungle Aviation and Radio Service** (JARS): USA has shipped more than 1000 PV systems to development workers throughout the developing world.

**Panama:** At Boca del Monte, a radio station is powered by a 180 Wpk array. The cost of the PV modules, transmitter, studio equipment, fan and lights was less than $3000.

**Liberia:** At ELRB radio station in Monrovia, a 360 Wp PV array provides power for lighting, ventilation and standby transmitters.

**India:** More than 250 community television systms have been installed in India, under the National Solar PV Energy Demonstration Programme. Many of the systems were combined with community lighting to provide a range of educational activities.

**Gambia:** In the Gambia, VHF transceivers are being used to provide communication of urgent information between health centres.

**Pan Africa:** The Panaftel telecommunications network has seen increased availability since the introduction of PV on key repeators.

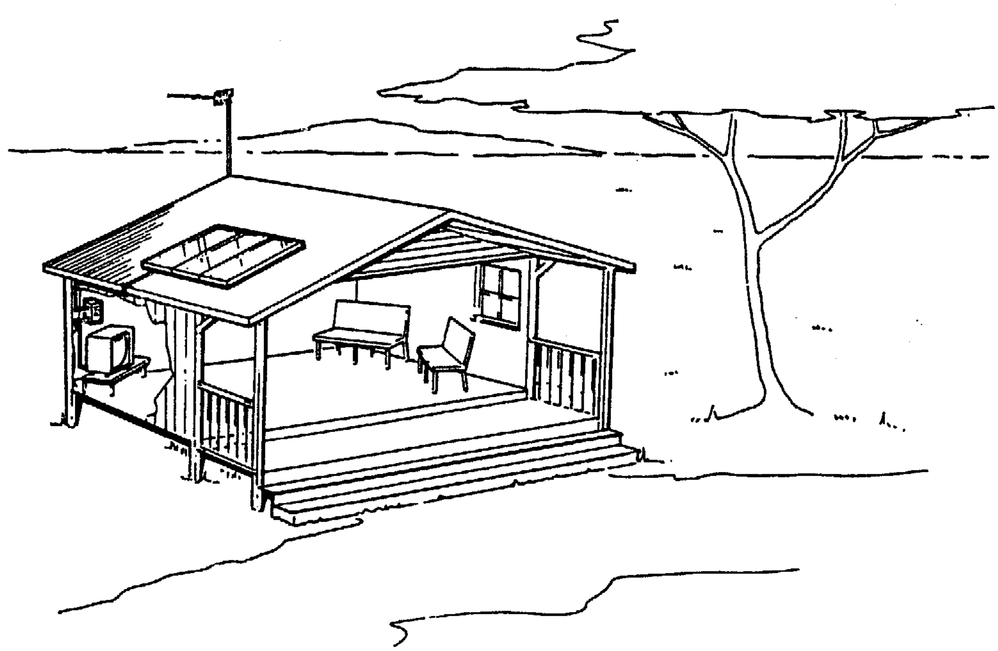


**Figure 8.1 Community Centre with PV Operated Television**

## 8.2 RELATIVE MERITS

PV has several attributes which make it particularly suited to telecommunications applications. They include:

- reliability - PV systems are the most reliable power source;
- size - PV systems can be sized to provide the relatively small amounts required for transmission and receipt of signals;
- unattended operation - PV systems will operate for long periods with little or no maintenance;

## 8.3 COMMERCIALLY AVAILABLE SYSTEMS

### 8.3.1 The Technology

Suppliers are packaging systems for use in a range of applications, namely:

Radio receivers - radios of 1.5 to 20 Watts output are available. The solar module typically 1-2 Wp may be incorporated into the side of the radio or more commonly a separate module is used with connection via an extendible lead. The battery and charge regulator are integrated into the radio.

Television receivers - comprising array, batteries, charge regulator and TV.

Public address loud speaker systems - pole mounted array and loud speaker with battery, charge controller, amplifier and microphone.

Radio Transceivers - typical systems incorporate a 100 W transmitter, 30-50 Wp PV array, 105 Ah 12 volt battery and transceiver equipment. The solar array is sometimes pole mounted on the antennae of the transmitter.

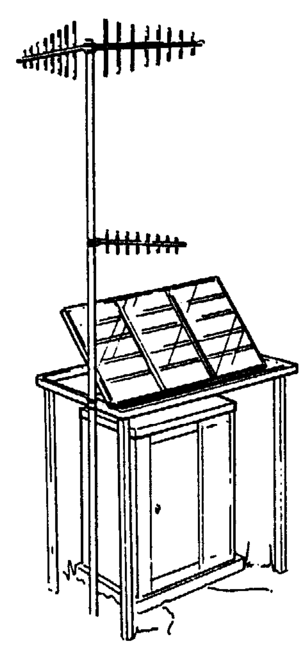


**Figure 8.2 PV Powered Radio Telephone System**

Due to the wide range of different receivers and transmitters available or specified by users, it is common for PV companies to offer solar powered battery charging systems suitable for 12 Volt telecommunication equipment.

### 8.3.2 Costs

Typical complete system costs are given in Table 8.1.

| System | Performance | Price $ |
|---|---|---|
| Radio: | 1.5 Watts output | 75 |
| | 20 Watts output | 500 |
| Transceiver: | 100 Watts | 3000 |
| TV System: | | 2000 |
| Public Address System: | 100 Watts | 3000 |

**Table 8.1 Typical Costs of Small PV Telecommunications Systems**

## 8.4 PROCUREMENT

### 8.4.1 Assessing Requirements

This should principally cover two areas, the telecommunication functions required of the equipment, taking account of likely changes in future needs and the daily usage levels in operating hours per day and number of users.

It should be noted that some equipment will have different power consumption levels when receiving, transmitting and on standby. Hence, if it is necessary to source the telecommunications equipment separately from the photovoltaic power supply, careful consideration of daily energy consumption should be made.

Having determined the average daily energy load in watt-hours, the PV array and battery sizes can be determined in the same manner as for a lighting load (steps 6 and 7 on Table 7.6).

## 8.5 IMPLEMENTATION

### 8.5 Installation

The principal considerations to be given which are specific to the installation of PV powered telecommunication equipment are:

- adequate lightning protection for the telecommunications equipment;
- ensure the antennae of the transmitter (or anything else) does not shade the array.

## Maintenance

The recommended maintenance of PV powered telecommunications equipment includes:

- clean the solar array weekly (if accessible)
- check battery electrolyte level monthly and top up with distilled water, if necessary.

## Fault Finding and Repair

The suggested fault finding and repair of the PV array and battery power supply is the same as that described for lighting systems in Section 7.5 of this guide.

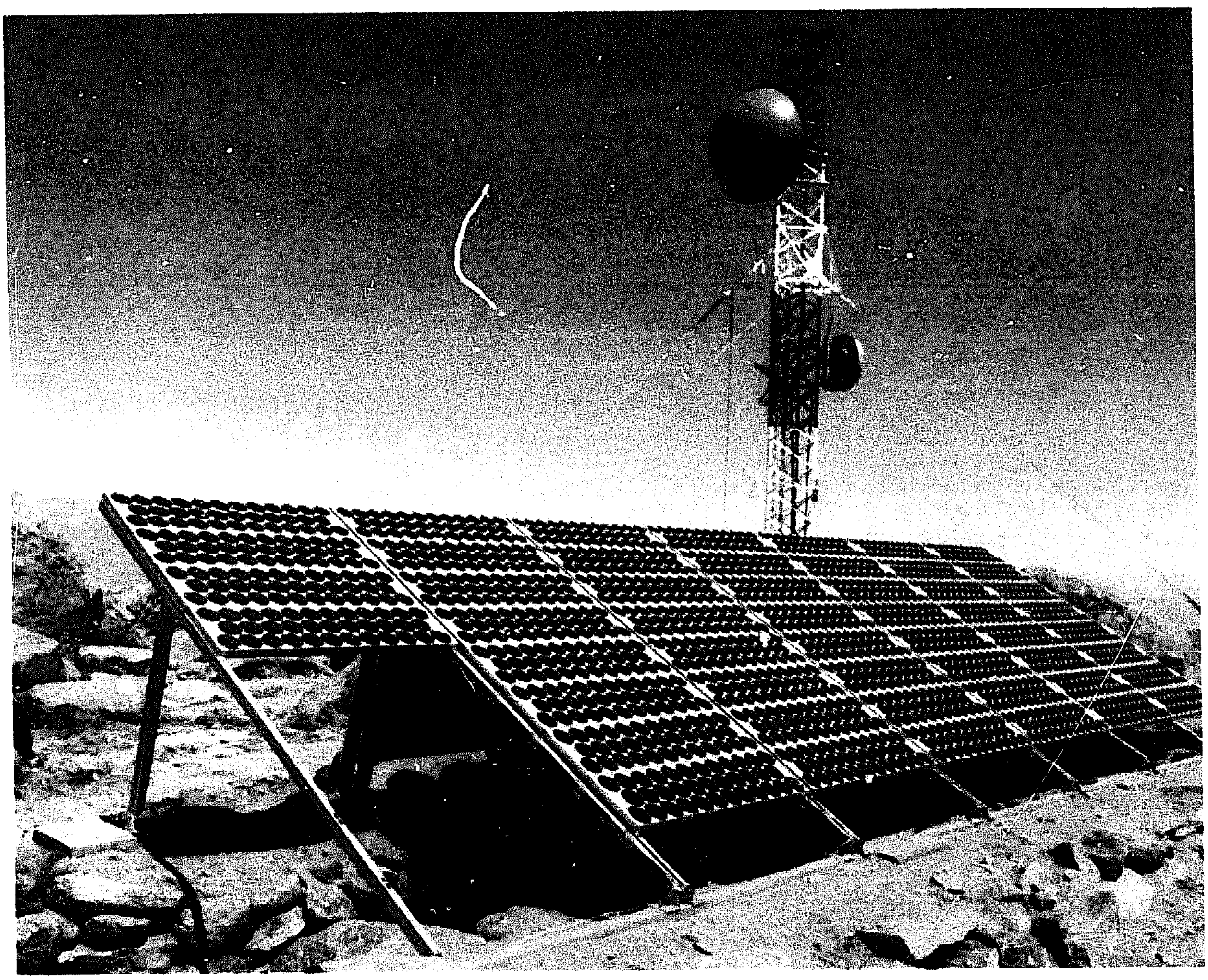


**Figure 8.3 PV Telecommunications Repeater (NAPS - Sweden)**

# EXAMPLES OF PRODUCTS AVAILABLE
## T.V. VIDEO AND BROADCASTERS

**Company: CODAN** — 6 Grove Park, Mill Lane, Alton, GU34 2QG, U.K.

Product: SOLAR POWERED TRANSCEIVER

Includes: 30 W SSB transmitter and receiver, 2 channels, steel case, microphone and 10Wp PV module for 6Ah battery pack.

Applications: Health centres, schools and outposts

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| 6924B | 10 | 30W SSB TRANSMITTER | 3,500 |

**Company: KYOCERA** — Ohsakui 1 - Chome - shi, Chiba Pref - 285, Japan

Product: LOUD SPEAKER SYSTEM

Includes: PV module, control unit with charge regulator battery, amplifier (20W), microphone, cassette player and two 15W speakers

Applications: Schools, parks, mosques and campsites

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| SP-152PT | 48 | 2 hrs/day | 4,070 |

**Company: NESTE Advanced Power Systems** — Ralssitie, SF - 01510 Vantaa Finland

Product: EDUCATION SYSTEM

Includes: PV modules, control unit, 3 fluorescent lights, TV receiver, video recorder, inverter and cabling, battery (150 Ah)

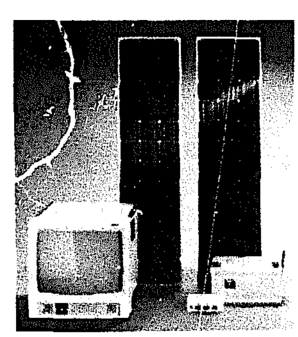
Applications: Remote educational viewing

| MODEL NO. | Array Wp | PERFORMANCE | PRICE (USD) |
|---|---|---|---|
| EC-2 | 96 | 360 Wh/day available | 2,160 |

**Company: SIEMENS SOLAR Gmb H** — Bu chenallee 3, D - 5060, Burgish Gladbach, Germany

Product: TV SYSTEM

Includes: PV array, charge regulator, television, battery, module support and aerial.



| MODEL NO. | ARRAY Wp | LIGHT HOURS /DAY | PRICE U.S. $ |
|---|---|---|---|
| SM 36-18 A2<br>FC 918 | 70<br>100 | 51cm colour T.V.<br>40cm colour T.V. | Refer to Supplier |

# 9. OTHER APPLICATIONS

## 9.1 INTRODUCTION

Photovoltaics can be used as a power source whenever small amounts of energy are required in a rural or remote location. The range of applications are thus numerous. Those of principal interest to development workers are described here.

## 9.2 WATER TREATMENT

### Water Purification

In many parts of the world, drinking water is taken from polluted water sources. In fact, it is estimated that more than half the illnesses in the developing world are attributable to water related infection.

Solar powered water treatment plants are in operation in Kenya, Nigeria, Indonesia and several other countries. Although chemical dosing and ultraviolet sterilization are technically feasible practices, a simpler approach is to combine a solar-powered water pump with slow-sand filtration where many of the components, particularly the storage and settlement tanks, can be obtained and assembled locally. Such installations are found in Indonesia, Kenya and Nigeria

### Desalination

PV Desalination equipment to remove the salt from water is available commercially, but costs are very high due to the high energy consumption of the desalination process.

Desalination is of particular interest to island communities with no fresh water sources. Thus demonstrations have been set up in the Asia and Pacific regions. In Japan a 25 kWp system is installed on Ohshima Island where approximately 5 cubic metres per day of clean water is produced, from the sea water. The salt content is reduced from 35,000 mg/litre to 400 mg/litre.

Other installations of PV desalination can be found in Austrialia, Indonesia and the Middle East.

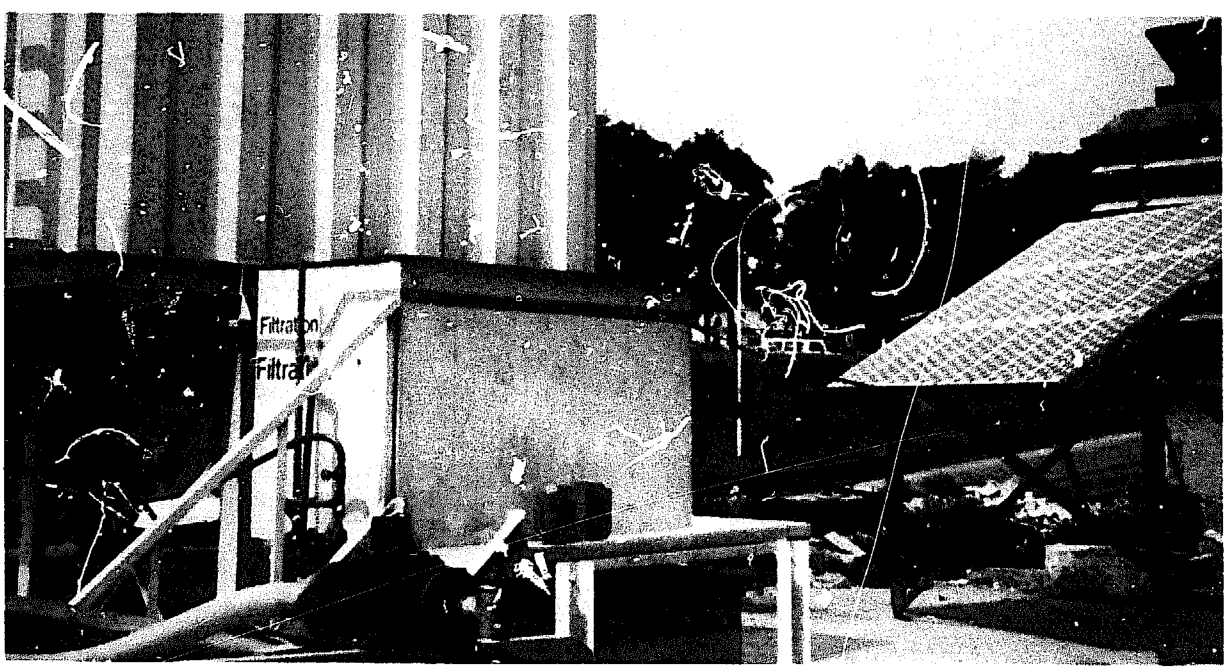


**Figure 9.1 PV Water Purification Plant in Nigeria (Satec)**

## 9.3 AGRICULTURAL APPLICATIONS

In addition to irrigation pumping covered in Chapter 5, PV can be used for:

- electrified cattle fencing
- grain milling
- produce cooling.
- freeze protection in stock tanks

PV powered electric fence systems are in widespread use with several thousand systems installed. A small PV array of 10 Wp with battery can electrify several kilometres of fence.

A PV powered grain mill has been operating successfully for eight years in Tangaye, Burkina Faso. It forms part of a 3.6 kWp PV system which also includes a water pump. The overall availability has been reported as over 90%. A similar unit is operating successfully in Tanfa, Mali. PV powered grain mills are not a commercially available "off-the-shelf" product.

PV powered cold stores are a rarity with only a few demonstration units operating such as the 45 kWp 275 m³ cold store on Giglio Islano, Italy. Generally, these units are also not "off-the-shelf" items and are very expensive because of the high energy consumption.

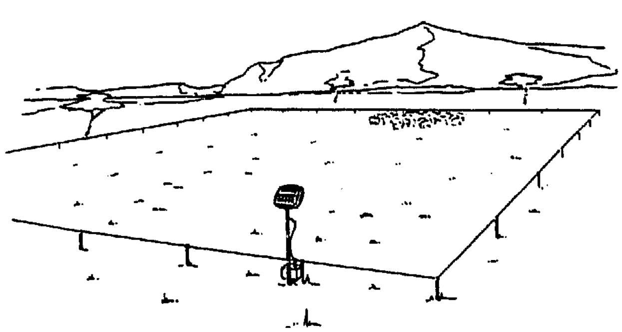


**Figure 9.2 PV Powered Electrical Fencing**

## 9.4 FISHERIES APPLICATIONS

Within the fisheries industries, the principal applications for PV are:

- shore-based navigational aids for fishing boats;
- lights on fishing boats;
- aeration and circulation pumps at fish farms;
- ice production for transporting fish;
- insect traps.

The main products being sold for the fisheries industry are lights and circulation pumps which can be used in fish farms. Suspended lights are used to attract insects thereby providing a concentration of insects for the fish to catch.

Ice production requires large amounts of energy and hence few photovoltaic products are available commercially. A PV-diesel hybrid system has been installed on the Red Sea Coast in Egypt for demonstration purposes.

## 9.5 TRANSPORT AIDS

Photovoltaics has become well established for powering transport aids particularly in:

- railway crossings and signalling
- obstacle lights
- terrain avoidance lights
- navigational buoys
- navigational lights on coasts
- runway lights
- highway signalling
- tunnel lighting
- navigational lights
- emergency phones

In Zambia and Zimbabwe, photovoltaics are used for railway signalling and communications. The Sudan Civil Aviation Authortity uses PV power navigation aid equipment in Sudan.

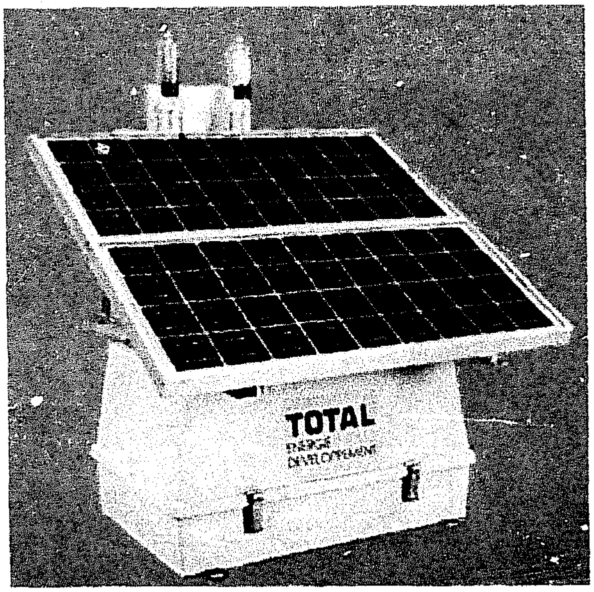



Figure 9.3 Rural Airfield Lighting (Total Energie)

Of particular relevance to development workers are the new range of runway lighting and airfield equipment such as illuminated windsocks for use at small airfields.

Solar power is recognised as the best option for off-shore navigational aids because the need to make refuelling visits is thus eliminated. Not only are these devices used in the equatorial countries, but also throughout the coast of Europe and North America, even at high latitudes. Some 3000 systems are installed in Canada.

## 9.6 SECURITY SYSTEMS

Photovoltaics is used to power both lighting and also remote alarm systems using infra-red detectors. In Pakistan, a PV alarm system in use at a rural agricultural engineering training centre successfully alerted a night watchman that an intruder had entered the area where expensive agricultural equipment was stored (including PV pumps!).

## 9.7 CORROSION PROTECTION SYSTEMS

Photovoltaics has been utilised in many developing countries to protect steelwork from corrosion. In Pakistan, PV protects pipelines in the Badin gas fields. In China, lock gates are protected by PV and in India PV is used for off-shore platform protection. Photovoltaics is also being used to protected well-heads in many oil and gas fields and has recently been applied to the protection of bridge structures.

## 9.8 DOMESTIC APPLIANCES

Several domestic appliances can now be obtained to operate from a 12 volt power supply and thus are suitable for a solar-powered battery charging system. In addition to lighting covered in chapter 7, these include:

- circulation pumps for solar water heating systems
- domestic refrigerators
- PV fan powered evaporative coolers
- fans and ventilation systems
- television, radios and video machines
- air compressors
- chain saws, drills, soldering irons and other tools.

It is important, when selecting any of these appliances, to consider its rated power consumption. Equipment with the lowest power consumption is preferred to minimise the load on the PV system.

As described in Chapter 7, the total daily load of all appliances should be calculated in watt-hours to determine the PV array and battery size required. Alternatively, for a given PV array and battery combination, it is possible to calculate the maximum time available to operate the appliances for a particular location and season.

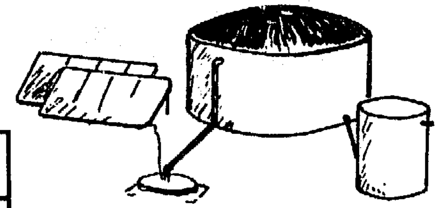
# EXAMPLES OF PRODUCTS AVAILABLE
## WATER TREATMENT SYSTEMS

**Company: BP SOLAR** — 36 Bridge Street, Leatherhead, KT22 8BZ, U.K.

**Product:** SAND FILTRATION WATER TREATMENT SYSTEM

**Description:** A PV pump lifts water which feeds through a slow sand filter plant providing clean water to W.H.O standards. System supplied ready to assemble

**Includes:** PV pumping unit, raw water storage tank, filtration tank, clean water tank, control unit



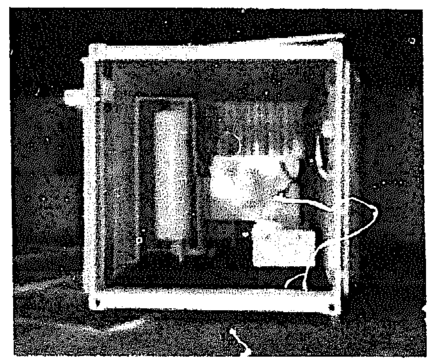
| MODEL NO. | WATER OUTPUT m³/day | PRICE U.S. $ |
|---|---|---|
| BPP 250 | 12.5 | Refer to Supplier |
| BPP 500 | 25 | |
| BPP 1000 | 50 | |

**Company: TRANSCOAST LTD** — Ave de Gaulle 28, 1050 Brussels, Belgium

**Product:** WATER TREATMENT SYSTEM

**Description:** A containerised (Wasol) water treatment system of sand filtration and ultra-violet light sterilisation

**Includes:** PV pumping unit, sand and carbon filters, U.V. sterilizer, clean water storage tank, batteries, controller, distribution system



| MODEL NO. | ARRAY Wp | WATER OUTPUT m³/day | PRICE U.S. $ |
|---|---|---|---|
| Ref 100 | 840 | 6 - 20 (100 - 30m) | 59,600 |

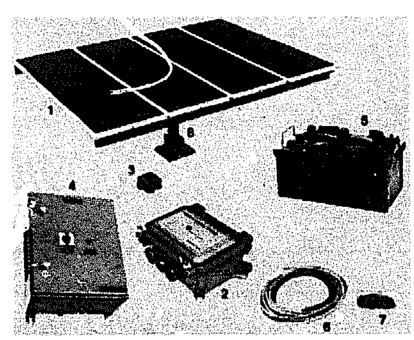
## HOME POWER (A.C.) SYSTEMS

**Company: RADE KONCAR** — Tezački put bb, 5800 Split, Yugoslavia

**Product:** HOME UTILITY KIT (220V, 50Hz)

**Includes:** 4PV modules, charge controller, 300 VA inverter, 78 Ah battery, support structures and wiring.

**Applications:** Where a.c power is required



| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| Utility Kit | 48 | 200 Wh/day typical | Refer to supplier |

# EXAMPLES OF PRODUCTS AVAILABLE
# AGRICULTURAL SYSTEMS

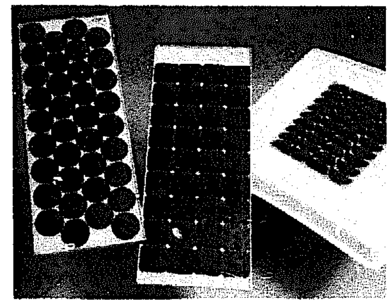
**Company: HELIODINAMICA · Caixa Postal 911 - 06730 Vagem Grande Paulista, S.P., Brazil**

Product: ELECTRIC FENCE

Includes: PV module, battery, fence electrifer support structure, cables

Applications: Livestock fencing

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| EF | 9 | for 10km fence | 380 |



**Company: MOBES GMBH** Bergiusstrasse 40-44, Berlin 44, Germany

Product: ELECTRIC FENCING UNIT

Description: A range of electric fencing systems for use in a variety of locations

Includes: Pole Mounted PV module, fence energiser sealed battery and voltmeter display

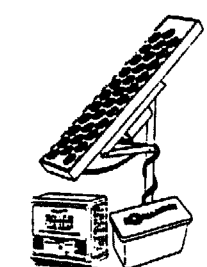
| MODEL NO. | PERFORMANCE | PRICE U.S. $ |
|---|---|---|
| W4000 GNi | For medium - high sunshine areas, larger fences. | refer to supplier |
| W4000 CNI | For abundent sunshine areas smaller fences. | |

**Company: SOUTHERN CROSS** PO, Box 155 Darra, Qld 4076, Australia

Product: ELECTRIC FENCE

Includes: PV module, battery, fence electrifier for (30W) support structure, cables

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| 346 | 30 | for 40km of fence | 990 |



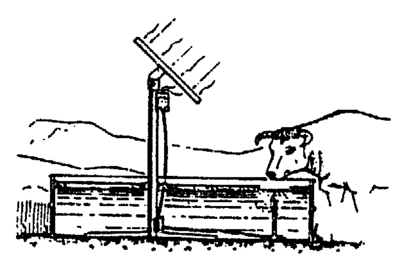
**Company: ZOME WORKS PO Box 25805, 1011A Sawmill Rd, Albuquerque NM 87125, USA**

Product: STOCK TANK ICE BREAKER

Includes: PV module, module mount, pipe, pole air lift pump, nozzle, enclosure.

Applications: Stock tank and trough ice breaking

| MODEL NO. | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| De-icer | 18 | up to 50 cms ice prevented | 550 |

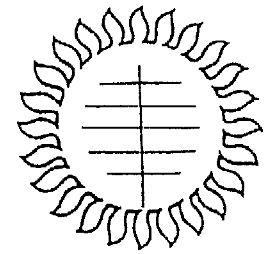


# EXAMPLES OF PRODUCTS AVAILABLE
## MISCELLANEOUS

**Company:** HILTEC SOLAR Unit 24D North Tyne Ind. Est. Whitley Road, Newcastle-U-Tyne, NE 12 U.K.

**Product:** EDUCATIONAL PRODUCTS

**Includes:** Ranges of kits, cells, small motors, fans, battery chargers, clock, etc for school projects

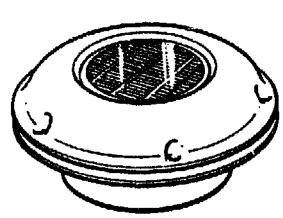


| MODEL NO. | WATTS PEAK | Performance | PRICE U.S. $ |
|---|---|---|---|
| SK01 | - | cells, motor etc | 22 |
| SK03 | - | Water pumping kit | 50 |
| SK04 | - | Battery charging Kit | 22 |

**Company:** INTERSOLAR LTD Cock Lane, High Wycombe, Bucks, HP13 7DE 1DQ, U.K.

**Product:** EXTRACTOR FANS

**Description:** An extractor fan unit with integral PV cell for surface mounting in glass or wall structure. Complete unit ready for installation Automatic or manual operation. Optional battery for night time use.



| MODEL NO. | output air changes/day | PRICE U.S. $ |
|---|---|---|
| Type 21 | 20 - 40 | 50 |
| Type 22 | 15 - 30 | 64 |
| Type 25 | 40 - 80 | 60 |
| Type 26 | 20 - 50 | 76 |

**Company:** KOMATSU ELECTRONICS 2612 Shinomiya, Hiratsuka, Kamagova, Japan

**Product:** SOLAR VENTILATOR

**Description:** A free-standing ventilation fan with PV module for direct operation during daylight hours

**Includes:** PV module, ventilator fan and motor unit

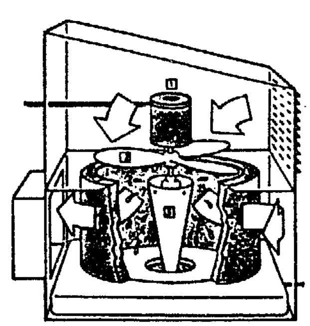
| MODEL NO. | ARRAY Wp | OUTPUT | PRICE U.S. $ |
|---|---|---|---|
| KB - 1802 | 9 | 12W Fan | refer to supplier |

**Company:** PHOTOCOMM INC. 930 Idaho - Maryland Road, CA 95945, USA

**Product:** AIR CONDITIONING UNIT

**Description:** Evaporative cooler with PV powered fan

**Includes:** PV module, support structure, 12V evaporitive cooler unit with fan and pump. Battery optional for night time cooling



| MODEL NO | ARRAY Wp | PERFORMANCE | PRICE U.S. $ |
|---|---|---|---|
| New Breeze | 30 - 40 | suitable for areas with relative humidity <75% | refer to supplier |

1. **How long will a PV system last?**

PV modules will last twenty years or more and many suppliers will give a five to ten year warranty. Generally, the component with the shortest life will be the battery which may have to be replaced each three to five years.

2. **Is there enough sun in my area - I often have cloudy days?**

In general, PV can be economically applied to all regions between the latitudes of 40° N and 40° S. Having cloudy days or rain is not necessarily a problems because batteries can store electricity for these days. In the case of solar pumps water can be stored in storage tanks. With many applications, there is good correlation between supply and demand. For example, a solar irrigation pump is not needed if it is raining!

3. **Is the application I'm considering likely to be economic for PV power?**

If the average daily energy consumption of your application equipment (motor/pump, refrigerator, lights, etc) is less than 50 kWh per day, PV is likely to be economic.

4. **Should PV be used only where there is no electric grid?**

In general - yes. If you have access to grid electricity it is more economic to connect to the grid. If the grid electricity is unreliable it may be less expensive to buy a mains battery charger and batteries for the power cut periods rather than buy PV.

5. **Can I get an electric shock from a PV array?**

Yes, treat PV arrays as potentially dangerous as any other electricity supply.

6. **I cannot run my lights and other appliances as often as I want to. What can I do?**

Most PV systems are modular. You can add more PV modules to increase the energy available and add additional battery capacity if necessary. Seek advice from your supplier before doing this.

7. **Is PV an "appropriate technology" for countries?**

Yes, Just because it's considered advanced technology dosn't make it inappropriate. PV is reliable, has a long life, is environmentally clean and economic for small scale applications. PV systems are now being manufactured in Brazil, China, India, Mongolia, Tunisia, Vietnam, Zimbabwe and other developing countries.

**Alternating current** (A.C.) - Electric current in which the direction of flow is reversed at frequent intervals. Opposite of direct current (D.C.).

**Amorphous** - The condition of a solid in which the atoms are not arranged in an orderly pattern; not crystalline.

**Annual equivalent life cycle cost (ALCC)** - The total life time costs of a system expressed as a sum of annual payments.

**Balance of system (BOS)** - Parts of a photovoltaic system other than the array.

**Cathodic protection** - A method of preventing oxidation (rusting) of exposed metal structures such as bridges by imposing between the structure and ground a small electrical voltage that opposes the flow of electrons, and is greater than the voltage that is present during oxidation.

**Clearness index** - The ratio of global solar irradiation to extraterrestrial solar irradiation.

**Concentrator** - A photovoltaic array which includes an optical component such as a lens or focusing mirror to direct incident sunlight onto a solar cell of small area.

**Conversion efficiency (cell).** The ratio of the electric energy produced by a solar cell (under full sun conditions) to the energy from sunlight incident upon the cell.

**Czochralski process** - Method of growing a perfect crystal of large size by slowly lifting a seed crystal from a molten bath of the material under careful conditions of cooling.

**Deep discharge** - Discharging a battery to 20 per cent or less of its full charge.

**Design month** - For the purpose of sizing a solar photovoltaic system, it is necessary to choose a 'worst month' in relation to the solar resource for which the system must meet the load requirements. This month is termed the design month.

**Diffuse radiation** - Solar radiation scattered by the atmosphere.

**Direct radiation** - Solar radiation transmitted directly through the atmosphere.

**Direct current (D.C.)** - Electric current in which electrons are flowing in one direction. Opposite of alternating current (A.C.).

**Dynamic head** - The head loss in pipes caused by the flow of water through the pipes.

**Extra-terrestrial irradiation** - The solar energy received outside the earth's atmosphere.

**Fill factor** - The ratio of maximum output of a PV cell under reference conditions to the product of open circuit voltage and short circuit current/under the same conditions.

**Flat plate (module or array)** - An arrangement of solar cells in which the cells are exposed directly to normal incident sunlight. Opposite of concentrator.

**Global irradiance** - The sum of diffuse and direct solar irradiance incident on a horizontal surface.

**Hydraulic energy** - The energy necessary to lift water.

**Impedance matching** - The process of matching the output of one device to the input of another device such that there is a maximum transfer of power between the two.

**Insolation** - Sunlight, direct or diffuse (not to be confused with insulation).

**Inverter** - Device that converts D.C. to A.C.

**I-V curve** - A graphical presentation of the current versus the voltage from a photovoltaic cell as the load is increased from the short circuit (no load) condition to the open circuit (maximum voltage) condition. The shape of the curve characterises cell or module performance.

**Kilowatt (kW)** - 1,000 Watts.

**Kilowatt hour (kWh)** - 1,000 Watt hours.

**Life Cycle Costs (LCC)** - The lifetime costs associated with a pumping system expressed in terms of today's money.

**Load** - Any device or appliance that is using power.

**Maximum Power Point Tracker (MPPT)** - Impedance matching electronics used to hold the output of the PV array at its maximum value.

**Parallel connection** - A method of interconnecting two or more electricity-producing devices, or power-using devices, such that the voltage produced, or required, is not increased, but the current is additive. Opposite of series connection.

**Peak Watt or Watt peak** - The approximate amount of power a photovoltaic device will produce at noon on a clear day (insolation at 1000 Watts per square metre) when the cell is faced directly toward the sun.

**Photovoltaic** - Pertaining to the direct conversion of light into electricity.

**Photovoltaic array** - An interconnected system of photovoltaic modules that functions as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting.

**Photovoltaic cell** - A device that converts light directly into electricity. A solar photovoltaic cell, or solar cell, is designed for use in sunlight. All photovoltaic cells produce direct current (D.C.).

**Photovoltaic collector** - A photovoltaic module or array which receives sunlight and converts it into electricity.

**Photovoltaic module** - A number of photovoltaic cells electrically interconnected and mounted together, usually in a common sealed unit or panel of convenient size for shipping, handling and assembling into arrays.

**Photovoltaic system** - A complete set of components for converting sunlight into electricity by the photovoltaic process, including array and balance-of-system components.

**Polycrystalline silicon;** polysilicon - Silicon which has solidified at such a rate that many small crystals have formed. The atoms within a single crystal are symmetrically arrayed, whereas in polysilicon crystals they are jumbled together.

**Power conditioner** - The electrical equipment used to convert power from a photovoltaic array into a form suitable for subsequent use, as in supplying a household. Loosely, a collective term for inverter, transformer, voltage regulator, meters, switches and controls.

**Present worth** - The value of a future cost or benefit expressed in present day money.

**Prime mover** - The power source for a system.

**PV** - Abbreviation for photovoltaic.

**Series connection** - A method of interconnecting devices that generate or use electricity so that the voltage, but not the current, is additive one to the other. Opposite of parallel connection.

**Short circuit current** - Of a PV cell, module or array is the current that flows when the output terminals of the device are joined together.

**Solar irradiance** - The power received per unit area from the sun.

**Solar irradiation or insolation** - The energy received per unit area from the sun in a specified time period. In this handbook, the time period is generally taken to be a day and the solar irradiation is expressed in MJ per $m^2$ per day or kWh per $m^2$ per day (1 kWh = 3.6 MJ).

**Stand alone** - An isolated photovoltaic system not connected to a grid; may or may not have storage, but most stand-alone applications require a battery or other form of storage.

**Tilt factor** - The ratio of solar irradiation incident on a tilted PV array to global irradiation.

**Watt, wattage** - A measure of electric power, or amount of work done in a unit of time. One amp of current flowing at a potential of one volt produces one Watt of power.

**Watt hour (Wh, Whr)** - A quantity of electrical energy (electricity). One Watt hour is consumed when one Watt of power is used for a period of one hour.

## 1. Introduction

Economic considerations are important when comparing Photovoltaics with other power sources. PV systems are technically viable but where alternatives exist the evaluation of the alternatives must include economic and technical and environmental considerations.

When economic viability is considered, a distinction should be made between economic and financial assessment. The economic approach seeks to make a true comparison of the value to siciety as a whole, and as such must use costs and benefits that are free from taxes, subsidies, interest payments, etc. Conversely, a financial assessment is an evaluation from the purchaser's viewpoint; so taxes, subsidies and the effect of spreading the capital cost over several years by means of a loan, are all taken into account.

## 2. Methodology

The most complete approach to economic appraisal is to use life cycle costing because all future expenses are than taken into account. In this method, all the future costs and benefits are discounted to "present day" values. The underlying concept in this approach is that investors would be indifferent as to whether they had $100 now or $110 in a years time if the $100 could be invested at an interest rate of 10%. Hence the Present Worth (PW) of an expenditure of $110 in one years time would be $100 when discounted at a rate of 10%.

The calculation of PW involves the use of a discount rate which reflects the opportunity cost of capital. Values of discount rate that are used for other projects in the country concerned can usually be taken as a guide, typical values are 10-12%. High discount rates mean that a low value is placed on future costs and benefits. For example, at a discount rate of 50%, an expenditure of $100 in one years time has a PW of only $66.67.

However it should be noted that such economic analysis doesn,t take into consideration such factors as environmental benefits (PV doesn't add to Global Warming like diesel engines) nor the benefits of superior service (e.g. higher reliability of PV).

## 3. Calculation of Present Worth

For a future cost or benefit (Cr), payable in N years, which is inflating at a fixed percentage "i" each year and discounted at a rate "d", the Present Worth is given by:

$$PW = Cr.Pr$$

with

$$Pr = \left[\frac{(1 + i)}{(1 + d)}\right]^N$$

For a payment or benefit Ca ($) occurring annually for a period of N years which is inflating at a rate "i" per year and discounted at a rate d, the Present Worth is

$$PW = Ca.Pa$$

$$\text{with} \quad Pa = \frac{\frac{(1+i)}{(1+d)}\left[\left|\frac{(1+i)}{(1+d)}\right|^{N} - 1\right]}{\frac{(1+i)}{(1+d)} - 1}$$

Tables 1 and 2 give the factor Pr and Pa respectively for selected values of N, i and d.

## 4. Examples

(a) To find the PW of a single cost of $10,000 occurring in 5 years time at an inflation rate of 5% per annum and discounted at a rate of 10% per annum. The factor Pr from Table 1 for d = 0.1, i = 0.05 and N = 5 is found to be 0.79. Hence the PW = (10,000 x 0.79) = $7900.

(b) To find the PW of an annual benefit of $2000 occurring for a period of 10 years which has an annual inflation rate of 5% per annum and is discounted at a rate of 15% per annum. The factor Pa from Table 2 for d = 15%, i = 5%, N = 10 is found to be 6.27. Hence the PW = $2,000 x 6.27 = $12,540

It is usual to carry out economic evaluations in real terms; the interest rates and discount rates used should be relative to general inflation. Hence costs are only assumed to inflate or deflate if their prices are changing relative to all other prices. However, as long as both discount and inflation rates are expressed in the same way (ie, both excluding general inflation or both including general inflation) the resulting Present Worth will be the same. Hence, normally inflation rates in Table 1 and 2 are assumed to be zero (general inflation excluded).

## 5. Considerations

When undertaking an economic comparison of different technologies it is important to consider if, some costs have subsidies, taxes or duties included. For example if diesel fuel is subsidised in a country then a solar photovoltaic pump may not appear to be competitive to the user on a life cycle cost basis compared to a diesel pump (if the subsidised diesel fuel price is used). However if the unsubsidised cost of the fuel is used the use of solar pumps may be found to be economic for the country.

| Discount Rate (d) | Inflation Rate (i) | Factor Pa for given number of years 5 | 10 | 15 | 20 | 30 |
|---|---|---|---|---|---|---|
| | 0.00 | 5.00 | 10.00 | 15.00 | 20.00 | 30.00 |
| | 0.05 | 5.80 | 13.21 | 22.66 | 34.72 | 69.76 |
| 0.00 | 0.10 | 6.72 | 17.53 | 34.95 | 63.00 | 180.94 |
| | 0.15 | 7.75 | 23.35 | 54.72 | 117.81 | 499.96 |
| | 0.20 | 8.93 | 31.15 | 86.44 | 224.03 | 1418.26 |
| | 0.00 | 4.33 | 7.72 | 10.38 | 12.46 | 15.37 |
| | 0.05 | 5.00 | 10.00 | 15.00 | 20.00 | 30.00 |
| 0.05 | 0.10 | 5.76 | 13.03 | 22.21 | 33.78 | 66.82 |
| | 0.15 | 6.62 | 17.06 | 33.51 | 59.44 | 164.68 |
| | 0.20 | 7.60 | 22.41 | 51.29 | 107.59 | 431.39 |
| | 0.00 | 3.79 | 6.14 | 7.61 | 8.51 | 9.43 |
| | 0.05 | 4.36 | 7.81 | 10.55 | 12.72 | 15.80 |
| 0.10 | 0.10 | 5.00 | 10.00 | 15.00 | 20.00 | 30.00 |
| | 0.15 | 5.72 | 12.87 | 21.80 | 32.95 | 64.27 |
| | 0.20 | 6.54 | 16.65 | 32.26 | 56.38 | 151.24 |
| | 0.00 | 3.35 | 5.02 | 5.85 | 6.26 | 6.57 |
| | 0.05 | 3.84 | 6.27 | 7.82 | 8.80 | 9.81 |
| 0.15 | 0.10 | 4.38 | 7.90 | 10.71 | 12.96 | 16.20 |
| | 0.15 | 5.00 | 10.00 | 15.00 | 20.00 | 30.00 |
| | 0.20 | 5.69 | 12.73 | 21.44 | 32.22 | 62.04 |
| | 0.00 | 2.99 | 4.19 | 4.68 | 4.87 | 4.98 |
| | 0.05 | 3.41 | 5.16 | 6.06 | 6.52 | 6.87 |
| 0.20 | 0.10 | 3.88 | 6.39 | 8.02 | 9.07 | 10.19 |
| | 0.15 | 4.41 | 7.97 | 10.85 | 13.18 | 16.58 |
| | 0.20 | 5.00 | 10.00 | 15.00 | 20.00 | 30.00 |

**Table 2 Selected Values of Present Worth Factors Pa for an Annually Recurring Cost**

| Discount Rate (d) | Inflation Rate (i) | Factor Pr for given number of years | | | | |
|---|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 20 | 30 |
| | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | 0.05 | 1.28 | 1.63 | 2.08 | 2.65 | 4.32 |
| 0.00 | 0.10 | 1.61 | 2.59 | 4.18 | 6.73 | 17.45 |
| | 0.15 | 2.01 | 4.05 | 8.14 | 16.37 | 66.21 |
| | 0.20 | 2.49 | 6.19 | 15.41 | 38.34 | 237.38 |
| | 0.00 | 0.78 | 0.61 | 0.48 | 0.38 | 0.23 |
| | 0.05 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 0.05 | 0.10 | 1.26 | 1.59 | 2.01 | 2.54 | 4.04 |
| | 0.15 | 1.58 | 2.48 | 3.91 | 6.17 | 15.32 |
| | 0.20 | 1.95 | 3.80 | 7.41 | 14.45 | 54.92 |
| | 0.00 | 0.62 | 0.39 | 0.24 | 0.15 | 0.06 |
| | 0.05 | 0.79 | 0.63 | 0.50 | 0.39 | 0.25 |
| 0.10 | 0.10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | 0.15 | 1.25 | 1.56 | 1.95 | 2.43 | 3.79 |
| | 0.20 | 1.55 | 2.39 | 3.69 | 5.70 | 13.60 |
| | 0.00 | 0.50 | 0.25 | 0.12 | 0.06 | 0.02 |
| | 0.05 | 0.63 | 0.40 | 0.26 | 0.16 | 0.07 |
| 0.15 | 0.10 | 0.80 | 0.64 | 0.51 | 0.41 | 0.26 |
| | 0.15 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | 0.20 | 1.24 | 1.53 | 1.89 | 2.34 | 3.59 |
| | 0.00 | 0.40 | 0.16 | 0.06 | 0.03 | 0.00 |
| | 0.05 | 0.51 | 0.26 | 0.13 | 0.07 | 0.02 |
| 0.20 | 0.10 | 0.65 | 0.42 | 0.27 | 0.18 | 0.07 |
| | 0.15 | 0.81 | 0.65 | 0.53 | 0.43 | 0.28 |
| | 0.20 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table 1 Selected Values of Present Worth Factor Pr for a Cost in N Years Time.**

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Tlx: 60731 GFOS DK
Fax: +45 - 86.68 4472

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Fax: +39 - 59 58255

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Fax: +44 - 91.2818430

Hydrasol
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GERMANY
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Fax: +49 6223 48159

IDEA
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40138 Bologna
ITALY
Tel: +39 - 51.393639
Fax: +39 - 51.394839

IBC
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D-8623 Staffelstein
GERMANY
Tel: +49 - 9573 3066
Fax: +49 - 9573.3832

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Tlx: 010486

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Tlx: 837383
Fax: +44 - 494 - 437045

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## 1. INSTRUCTIONS TO TENDER

### 1.1 Tender Procedure

Tenders are required for a complete solar photovoltaic system as described in the specification.
The Schedule for the purchase of system is as follows:

Tender forms issued by ............(day)............(month)............(year)

Completed tenders to be returned by ...........(day)............(month)............(year)

Tenders awarded by ............(day)............(month)............(year)

Systems to be delivered by ............(day)............(month)............(year)

The original tender shall be in the .................... language and shall be filled out in ink or typewritten and will be made a part of the awarded contract.

### 1.2 Adjudication Process

Tenders will be primarily considered for:

- Performance
- Durability
- Cost effectiveness
- Experience of the tender

The purchaser will not be bound to award a contract to the lowest, or any Tender.

## 2. SPECIFICATION

### 2.1 Scope

This specification is for the design, manufacture, supply and delivery of:

The system to be supplied shall include:

- Photovoltaic modules and array support structure
- Load equipment to be specified
- All control equipment and wiring
- All fixings and ancillaries necessary for complete construction and commissioning
- Tools needed for assembly and maintenance
- Spare parts
- Documentation

### 2.2 Design

The complete system shall be robust, and capable of withstanding hard usage in a harsh environment. It shall be resistant to damage from accidental misuse and reasonably resistant to vandalism and the attentions of animals, wild or domestic.

The system shall be designed for assembly, operation and servicing by unskilled personnel under the guidance of a trained technician. The requirement for special tools or instruments to install and maintain the system shall be minimised and all tools needed for installation shall be supplied with the system. Foundations or other preparatory work shall be as simple as practicable.

The system shall be designed for assembly from units which can be packed in containers small enough to be easily man-handled and transported on small vehicles. The maximum permitted dimensions for any one unit are:

The systems shall be designed to operate for a long lifetime with minimum deterioration of performance. The design life of the whole system shall be a least ten years with a minimal need for replacement of components. Routine maintenance shall be minimised and maintenance work necessary shall be a simple as possible, requiring only a few basic tools for its execution.

## 2.3 Environmental Conditions

The system shall be designed to meet the requirements of this Specification under the following environmental conditions:

- (i) Ambient air temperature between ...... and ...... (eg: 5°C and 45°C).
- (ii) Relative humidity up to .... at an ambient temperature of .... (eg: 90% and 45°C).
- (iii) Wind speed up to ..... km/hr (eg: 150 km/hr) (for fixed installations).
- (iv) A maximum altitude above sea level of ..... m (eg: 2000m).

The system should also be resistant to the following extremes of environment eg:

- (i) Sand storms
- (ii) Typhoon or hurricane winds
- (iii) Overnight freezing temperatures

The Contractor shall state the limits of environmental conditions under which the system is designed to operate.

## 2.4 Standards

Photovoltaic modules shall comply with the test requirements of the current Photovoltaic Module Control Test Specifications of the Commission of the European Communities Joint Research Centre (Ispra Establishment).

## 2.5 Performance Requirement

### 2.5.1 Location

The system to be supplied is to be located as detailed below:

- Name of nearest village/town:
- Country:
- Latitude:
- Longitude:

### 2.5.2 Required Performance

The required performance of the system is summarized in Table 1, along with the typical environmental conditions for the locations. The system should provide average daily output as specified in Table 1 for each month, provided that the specified monthly mean average daily solar irradiation for the month is met or exceeded. The tenderer shall state the output of the system expected for each month of the year. (The user should supply Table 1).

### 2.5.3 Installation Details

The sketch of the site is shown in Figure 1. (The user should add this).

### 2.6 Spare Parts

The Contractor shall supply with the system sufficient consumable items (such as motor brushes and fuses) which may need replacement to last for 2 years of operation. Space nuts, bolts, washers etc, likely to be lost during shipment and erection shall also be supplied at the time of shipment.

### 2.7 Packing for Shipment

All equipment shall be carefully and suitably packed for the specific means of transportation to be used, so that it is protected against all weather and other conditions to which it may become subject.

Complete assembly and operating instructions are to be included in packing.

### 2.8 Documentation

Prior to shipment of the equipment, the Contractor shall submit to the Purchaser the following documents: (Copies also should be shipped with system).

(i) A list of components and assemblies to be shipped including all spare parts andtools

(ii) The size, weight and packing list for each package in the shipment

(iii) Assembly instructions

(iv) Operating instructions

(v) Instructions for all maintenance operations and the schedule for any routine maintenance requirements

(vi) Sufficient descriptions of spare parts and components to permit identifications for ordering replacement

(vii) Revised drawings of the equipment as built if different from the approved proposals

All documents shall be in the .................. language.

### 2.9 Tools

The Contractor shall provide two sets of any special tools and other equipment that are required for erecting, operating, maintaining and repairing the equipment. Special tools shall include such items as Allen or socket keys, box spanners, feeler gauges, grease guns etc. A single set of all other tools required for erection shall also be supplied.

### 2.10 Insurance

The contractor shall arrange for the equipment to be comprehensively insured for its full value from the time it leaves his premises until clearance from customs at the point of entry into the country of installation.

### 2.11 Warranty

The contractor shall specify the period of the warranty together with a list of items covered under the warranty.

## 3. QUESTIONNAIRE FOR TENDERS

Tenders are asked to supply the following information to demonstrate their ability to meet the requirements of the project. All information will remain confidential.

### 3.1 General Information

Name of Company:

Individual Contract:

Address:

Tel: Telex: Fax:

Legal status (eg: limited company)

Country in which registered:

Total number of employees:

### 3.2 Experience of Tenderer

Number of years of experience with photovoltaic (PV) system:

Product Experience (list number in use of each main product type eg: pumps, lights, refrigerators etc):

-
-
-
-
-

### 3.3 Sources of Supply for Equipment Tendered

Items manufactured by Contractor:

Items bought in from Suppliers:

### 3.4 Maintenance Requirements (detail and frequency)

-
-
-
-
-

### 3.5 After Sales Service

Tenderers to list names, addresses, telex and telephone number of persons and organisation who may be contacted for advice during the period of installation and operation of the equipment.

## 4. PRICE AND DELIVERY

Terms of payment ............ % on order

............ % on delivery

............ % on satisfactory operation

| Item | Description | Currency | Price |
|---|---|---|---|
| 1. | Equipment | | |
| 2. | Transportation (from place of manufacture to point of entry) of complete pumping system, including insurance by air/ship | | |
| 3. | Other | | ___________ |
| | **Total Contract Price** | **Total:** | |

4. Spare parts (list prices of spare parts:

- 
- 
- 
- 
- 
- 

Delivery of complete system to be ............ weeks from receipt of order.

Small solar-electric (photovoltaic) powered devices are gradually being introduced into developing countries for water pumping, vaccine refrigeration, lighting, battery charging and other important development applications. Most of these have been purchased in small numbers by individuals, private voluntary organizations and donor agencies. The number of systems currently in use (although numbering tens of thousands) is extremely small compared to the potential demand. A major reason for this is a lack of awareness of how to go about purchasing and using these devices and a scarcity of information on products available in a form suitable for development workers. Recognizing this lack of information, the Swedish Missionary Council, IT Power and the Stockholm Environment Institute produced this guide.

The authors of this book are photovoltaic applications specialists with IT Power and the Stockholm Environment Institute. IT Power is an international firm of engineering energy consultants which specializes in the implementation of new and renewable energy technologies for rural development. For further information contact IT Power Ltd., The Warren, Bramshill Road, Eversley, Hants RG27 0PR, UK.

The Stockholm Environment Institute (SEI) is an international research organization specializing in environmental technology and management. The main themes of activities are at present global energy futures, climate change, biotechnology in agriculture, and the areas of economics, ethics and environmental value. A major component of SEI's energy programme is related to Third World energy utilization and technologies. The Institute's headquarters are in Stockholm, with branch offices in Boston (USA) and York (UK).

The Swedish Missionary Council is an organization dedicated to sustainable progress in less developed countries through missionary work and project support.

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