

# Small Solar Electric Systems for Africa

MARK HANKINS

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Commonwealth Science Council

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## A Guide for Planning and Installing Solar Electric Lighting Systems in Rural Africa

By Mark Hankins

Illustrations by Francis Njeru

Published by:  
Commonwealth Science Council  
Marlborough House  
Pall Mall  
London SW1Y 5HX  
United Kingdom

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Motif Creative Arts, Ltd.  
Ragvhani Hse., Tom Mboya St.  
PO Box 22415  
Nairobi  
Kenya

May, 1991

CSC(91)ENP-30  
Technical Paper 288  
ISBN 0 85092 374 3

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# Foreword

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Since the 1981 UNCNRSE conference in Nairobi, a number of policy makers and NGO representatives have been calling for increased reliance on renewable energy. However, despite attempts by donors and policy makers to increase use of renewable energy technologies, there are very few renewable energy success stories in Africa. Part of the problem is that rural people are unaware of the technologies, and do not have the material or information resources to attempt projects, no matter how technically, environmentally or economically viable they may be. For too long the emphasis has been on 'turnkey' style transfer of technology, with limited involvement of local manpower and industry. In too many cases, this results in technology transfer that is donor-led rather than demand-led.

However, the Kenya experience provides a refreshing alternative to aid-led interventions. Since 1985, local Kenyan companies have installed thousands of lighting systems in schools and homes on a commercial basis. There are similar experiences with the PV technology in Zimbabwe, Botswana, and West Africa. The sale of solar electric systems has created jobs for installers in rural areas, and opportunity for urban and cottage industry. For example, solar batteries are now sold in Kenya, and low voltage lamps are being manufactured for solar electric systems in Zimbabwe and Botswana.

A key to the successful Kenyan experience has been commercial response to real demand. In rural Kenyan homes, institutions, and cottage industry, there is a very high demand for electricity to power, lights, televisions, radios, vaccine refrigerators, and small appliances such as sewing machines. For these requirements, solar electricity is a realistic alternative to costly extensions of grid power or generators.

Dissemination of renewable energy technologies can only occur if there is appropriate information available to potential end-users, installers, extension workers and policy makers. However, educational material prepared in Western countries may not be suitable to the needs of rural Africans. There is therefore a need for information suitable to regional needs. Like Mr. Hankins first book, *Renewable Energy in Kenya*, this book provides information in a form that is accessible to local people.

There are other effective methods by which information can and should be shared in the region. The technology is changing rapidly, and prices have come down for a number of solar electric system components; there is a need for this information to be passed along the dissemination chain. It is hoped that a number of organisations will take up roles in this chain.

Achoka Aworry  
Executive Director  
Kenya Energy and Environment  
Organizations

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# Acknowledgements

Thanks to all those committed to solar energy in Africa who contributed to this project. Without their efforts, the book would not have been possible.

Special thanks to Harold Burris for technical comments and long-distance telephone critiques (at his own expense). The book is based largely on the experience of his team of electricians who installed hundreds of systems in East Africa. Material in the text and appendices has been gratuitously adapted from material co-written by Burris for a 1985 solar electric training course.

Dr. Anne Wheldon of Reading University's "Alternative Energy Engineering for Developing Countries" Programme (UK) deserves a special vote of thanks for pointing out technical blunders, and for making extremely

useful comments on a draft copy of the book.

Thanks to the Commonwealth Science Council (CSC) who provided most of the financial support for this project. Thanks especially to Dr. Peter de Groot for his persistent encouragement, editorial advice and dedication to the project. Thanks also to Dr. Raul Vicencio for comments on the text.

Thanks to Energy for Sustainable Development, Ltd. who provided part of the funding and support for the work.

Thanks to Raphael Njuguna of Associated Battery Manufacturers, Dickson Muchuri of Alpa Nguvu, and Kennedy Masakhwe of AFREPREN for reading and commenting on sections of the text, and to Shadrack Amakoye for editing the manuscript.

Thanks to Muiruri Kimani (KENGO) for much-needed advice and encouragement and to Silas Kinyua of Chuka Solar Electric Agents for practical advice on wiring, switches, and fuses in East Africa.

Thanks to Martin Fisher, for allowing his house to become an office and communications centre during the 8 months of production. Thanks also to Maria Olson for editorial assistance, assorted helpful contributions and copious moral support.

Special thanks to the staff of Motif Creative Arts, Ltd. for extra hours worked to get out a high quality product. Michael Okendo and Clifford Ikenga Thongora did the layout. Francis Njeru produced the drawings and illustrations. Anthony Mwangi is responsible for the cover illustration.

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# Introduction

This manual is about making solar electricity available to rural Africans. It was developed from lesson notes produced for a 1985 training programme conducted in south Meru District, Kenya, by Harold Burris and myself. At the time, Harold Burris and a number of Kenyan electricians (their company was called *Solar Shamba*) were designing and installing solar electric systems tailored to the expectations of rural home owners. During the USAID-financed training programme, a dozen Meru-based electricians learned the *jua kali* (cottage industry) approach to solar electric technology pioneered by *Solar Shamba*. Five years later, these and other rural-based electricians have completed thousands of solar electric installations throughout East Africa.

Solar electricity is generated directly from sunshine using devices called solar cell modules. All over the world, people are taking up the technology to provide power for many remote and rural applications. Since 1984, small solar companies have installed hundreds of thousands of systems in developing countries, from Kenya to the Dominican Republic, and from Sri Lanka to the South Pacific Islands. While the prices of petroleum products have been unstable over the last decade, prices of solar electric equipment have been steadily declining. Today, more solar modules are being produced than ever before. Countries as diverse as Brazil, Germany, the United States, Japan, China, and India have solar cell production facilities. Installation and assembly of solar electric systems is fast becoming a village level technology.

The pages that follow describe how solar electricity can provide power for the small-scale applications found in East African rural homes, schools and industries. With the assistance of a

trained electrician, you should be able to follow this book's guidelines to design and install a solar electric system to power lights, appliances and small tools in a home, institution or business.

The success of any solar electric system depends on how well it is designed, installed, managed, and maintained. In order to design large systems, a full understanding of solar electric system theory is necessary. However, you do not need to be a highly trained engineer to design, install or service small solar electric systems. Only a few weeks' training provides skills sufficient to design and install effective small-scale systems.

First, you need to know a bit about electricity. You also need to know how much solar energy can be collected at what cost, how to store and distribute the energy, how to choose appliances and how to maintain the system. This book contains all the above information. Once you have mastered these basic principles, it is relatively simple to design and install a system that suits your needs.

Many good manuals have been written about solar electricity for the requirements of Western electricians and consumers (see References). But the energy consumption patterns, the appliances available and the budgets of East Africans are very different from those in developed countries.

Rural African schools, institutions and health centres require quality lighting to maintain acceptable levels of performance. Tea shops and kiosks demand electric power for radios, televisions and lights to attract customers. Cottage industries demand small amounts of electric power for sewing machines, small tools and work area lighting. Additionally,

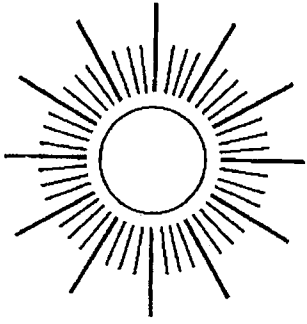
teachers, farmers and extension workers desire power for the radios, televisions and music systems that connect them with the rest of the world and make rural living more pleasant.

The following chapters answer questions that might be asked by rural teachers or businessmen, such as "What is the cheapest system that I could install to power two lights and a radio?" and "Do I really need a charge controller for my system?" It provides resources to rural solar electricians such as sizing worksheets, wiring guides and local meteorological information. For the extension agent or development worker, it gives a general idea of what solar electric equipment is available in East Africa and what is required to complete an installation.

Like improved stoves, biogas digesters, agroforestry systems or any other technology that benefits rural people, solar electricity relies on a wide network of people involved in its dissemination and development. No individual can take all credit for success that is the work of many. This book thus owes a great debt to rural solar practitioners such as Daniel Kithokoi of Solar Electric Systems (Meru), Dickson Muchuri of Alpa Nguvu (Nairobi), Silas Kinyua of Chuka Solar Agents (Chuka), and Charles Rioba of Solar World (Kisii and Nairobi). Their hard work has proven beyond doubt that solar energy is a practical technology for rural Africa. This book is dedicated to them, and to others like them seeking ways to solve the rural energy crisis in Africa.

Mark Hankins  
Nairobi  
February 1991

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# Chapter 1

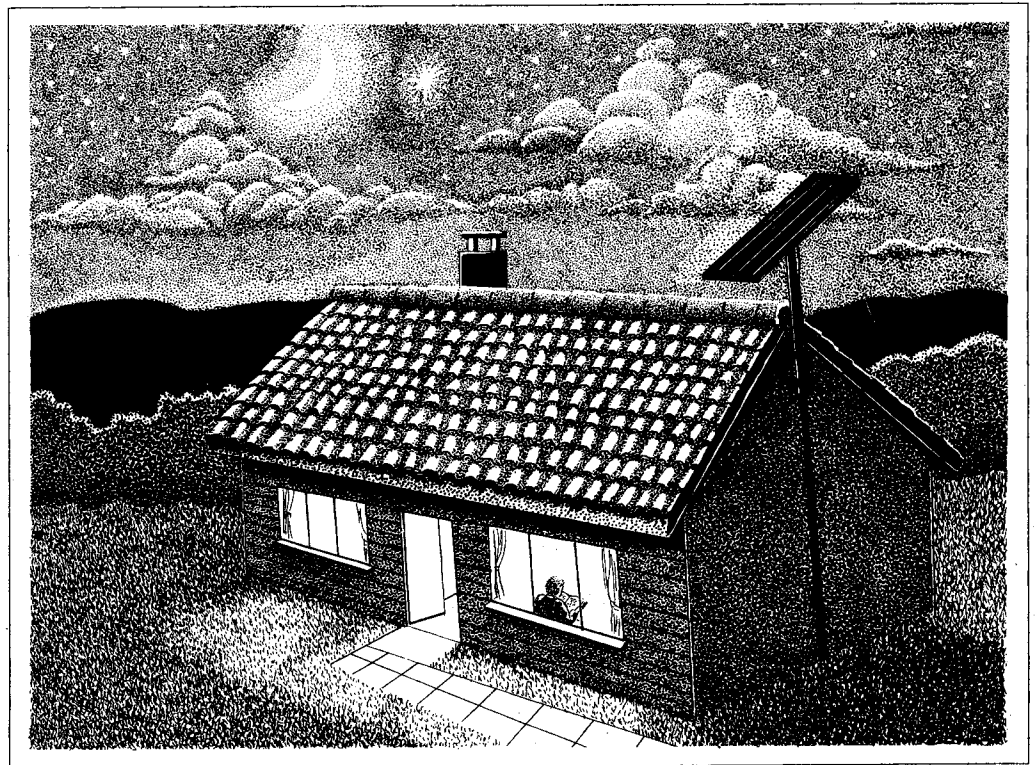
## Solar Electric System Fundamentals

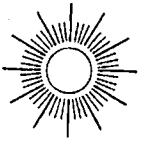
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*This chapter outlines the steps required to plan and install a solar electric lighting system. It summarises the applications, parts, advantages and disadvantages of solar electric systems, and directs readers seeking specific information to appropriate chapters.*

*Specifically, the chapter reviews:*

- *concepts and terms used throughout the book to describe energy and basic low voltage electricity;*
- *principles and components of solar electric systems, including the solar resource, solar modules, batteries, charge controllers, and appliances; and,*
- *estimating energy requirements, cost cutting, planning, installing and maintaining systems.*





## Solar Electric System Fundamentals

Solar electricity is electric power generated from sunlight using devices called solar cell modules.

### The Sun and Solar Electric Technology

The sun is the source of virtually all the energy we use each day. The energy we derive from woodfuel, petroleum, paraffin, hydroelectricity and even our food originates *indirectly* from the sun. Solar energy is captured and stored by plants. We use this energy when we burn firewood or eat food. The sun also powers the rainfall cycles that fill rivers from which we extract hydroelectricity. Petroleum is made up of fossilised remains of plants and animals that collected energy from the sun thousands of years ago.

It is also possible to collect energy from the sun *directly* for heating water, cooking, raising steam and generating electricity. There are a number of types of equipment which can be used to collect solar energy. These include collector panels, which harvest solar energy for heating water, and solar concentrators which focus the rays of the sun into high energy beams for raising heat.

Solar electricity is electric power generated from sunlight using devices called *solar cell modules*. The technology is gaining popularity in Africa as prices of other electric energy sources rise. Solar electricity can replace small applications of petroleum-fueled generators, grid power and even dry cell batteries. The technology is spreading rapidly to rural areas where there is great interest in its applications.

Solar electric theory is not difficult to master, but its principles differ from 220 V ac mains (or generator) wiring. The first part of this manual gives background information and explains the work of each part of a solar electric system.

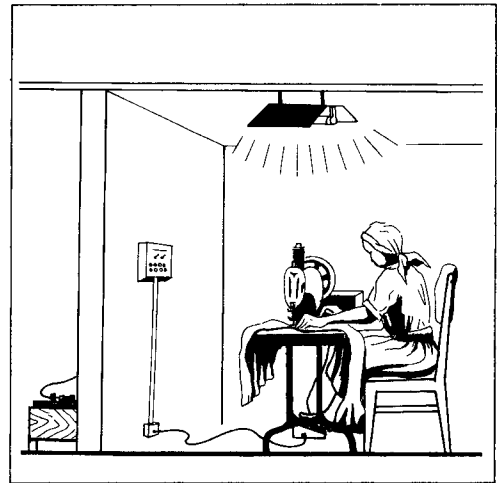
### Common Uses of Photovoltaics

In East Africa, the most common application of solar electricity is providing power for household lighting and appliances. By 1991, as many as 10,000 rural homes in Kenya were using solar electric power for household appliances. The list below describes some of the important applications for which solar electric power is being utilised.

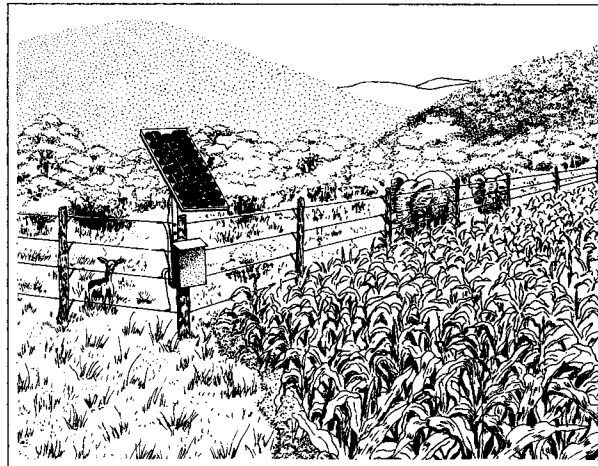
- *Household lights, televisions, cassette players, radios and small appliances.*

Night light is crucial for education, craft work and social activity, and televisions, radios and stereo systems are increasingly common in rural East Africa. Solar electric security systems are also popular among rural customers.

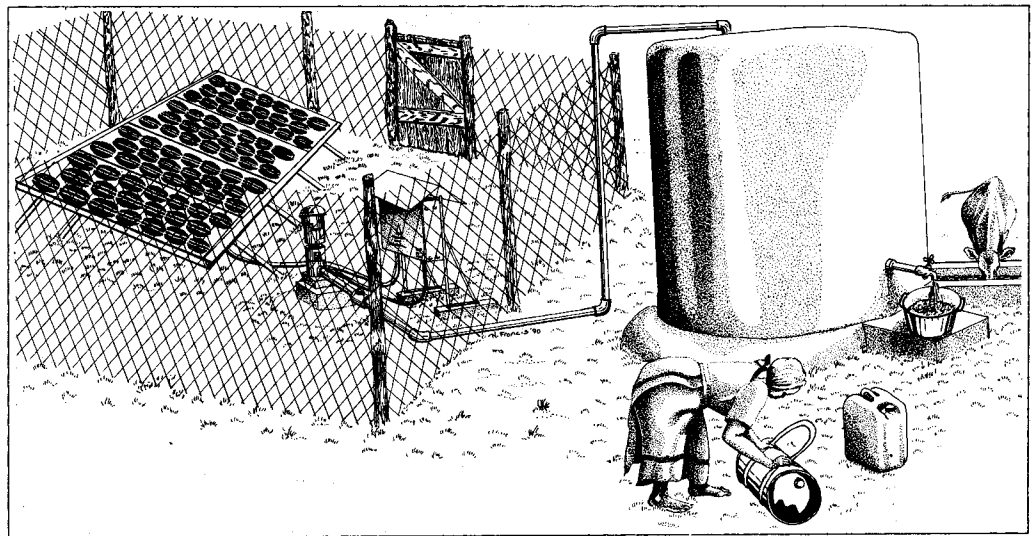
- *Small industries and institutions:* Schools and small businesses in rural areas use solar electricity to power lights, sewing machines, calculators, light tools, computers, typewriters, and security systems.



- *Telecommunications:* Because telecommunication systems are often installed in isolated places with no access to power, they often use stand-alone photovoltaic systems to power radios, remote repeaters, and even weather monitoring equipment.
- *Health centre vaccine refrigeration and lighting:* Solar electric systems are popular for vaccine refrigeration in rural health centres. Such solar refrigerators are also utilised to freeze ice packs and to keep blood plasma cool. The World Health Organisation supports programmes that install solar electric refrigerators and lighting in health centres throughout East Africa.
- *Electric fencing and other uses:* Electric fences, which keep wild animals inside game parks and out of farm land, are often powered by solar electricity. Other common uses of solar electric systems include street lighting, road sign illumination, security systems and protection of pipelines from corrosion.



- *Water pumping:* In a number of sites in East Africa, arrays of solar cell modules connected to electric pumps are used to pump water from wells or boreholes. This water is used for drinking, washing, other household purposes and for small irrigation projects. Solar electricity can also be used to purify drinking water.

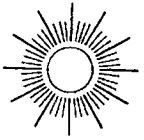


Solar electric systems consume no fuel, quietly converting sunlight directly into electricity.

### Advantages and Disadvantages of Solar Electricity

#### Advantages of solar electric power:

- Solar electric systems consume no fuel. Solar modules convert freely available sunlight directly into electricity without being used up.
- They produce electricity quietly, without giving off exhaust gases or other pollutants.
- Compared to conventional generators, solar electric systems require very little maintenance. Solar modules have no moving parts and last for over 20 years.
- Solar electric systems are economical for many small applications. While the price of oil has steadily risen over the past few years, the price of solar cells has been falling. In the long term, it is often cheaper to power lights, small tools, stereo systems and TV's with solar energy than it is to power them with dry cells, lead-acid batteries or generators.
- Solar electric systems can be tailored to the power needs of individual applications: from tiny electric calculators, to small radios, televisions and lights, to electric borehole pumps. Solar electric systems can be expanded easily by adding more modules and batteries.
- Properly installed solar electric systems are safe. Risk of electric shock is small because of the low system voltage. Fire risks are lower in homes and schools lit by solar electricity than in those lit with kerosene lanterns.

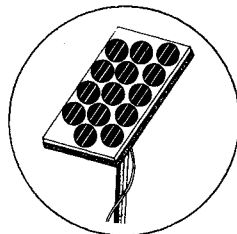


#### Disadvantages of solar electric power:

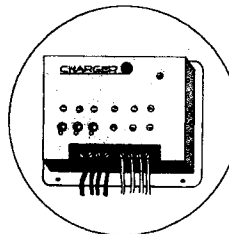
- The initial cost of solar electric systems is relatively high by rural standards. Even if a solar lighting system is more economical over its lifetime than kerosene or generators, it is still very difficult for many people to raise the cash to buy systems all at once.
- Solar electric systems require batteries for energy storage. Batteries must be carefully maintained. The performance of systems is dependent on the quality of batteries available on the local market or the availability of imported batteries.
- Appliances and lamps which run on low voltage are not as readily available as those that run on mains power. However, as more and more people install solar electric systems, the supply of 12 volt dc appliances is increasing.
- There is a lack of trained technicians to design and install solar electric systems. Because of this, poorly designed systems are sometimes installed by untrained individuals, reflecting badly on the solar electric technology.

### The Parts of a Solar Electric Lighting System

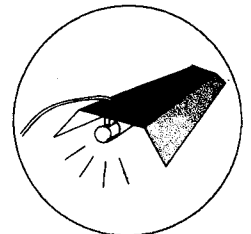
Before planning a system, make sure you are completely familiar with the various system parts as shown below:



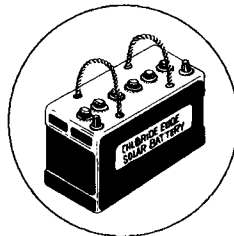
Solar Cell Module



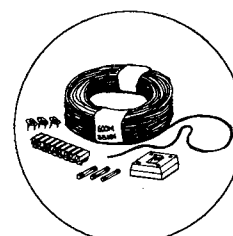
Charge Controller



The Load:  
Appliances and  
Lamps



Battery



Wiring and Fixtures

The rest of this chapter summarises the role of each part in a system, and directs the reader to the chapter in which that technology is explained in greater detail. Chapters 9, 10, 11 and 12 contain guide-lines for planning, installing, and maintaining systems.

A basic understanding of energy concepts is necessary before planning a solar energy project.

#### Basic Energy Concepts

A basic understanding of energy concepts is necessary before undertaking solar energy system installation and design. Appendix 1 (page 98) contains detailed information on these terms for readers unfamiliar with them.

*Energy* is referred to as the ability to work. It is measured in units called *joules (J)*, or (throughout this book), in *watt hours (Wh)*. *Amp hours (Ah)* are also used to indicate energy transfer in solar electric systems (particularly to measure battery capacity). Strictly speaking, amp hours do not measure energy — they must be multiplied by the voltage of the system to arrive at watt hours.

*Power* is the rate at which energy is supplied (or energy per unit time), and is measured in *watts (W)*.



When installing solar electric systems, make sure that all work is supervised and checked by a qualified electrician.

*Efficiency* is the ratio of output energy to input energy. In the case of solar electric systems, the input energy is the energy received from the sun by the modules and the output energy is the electricity available for lights and appliances. An energy-efficient device uses less energy to perform a given task. Efficiency is measured as a percentage; the higher the percentage, the more efficient the transfer is.

*Energy Example*

At noon on a sunny day, equatorial solar radiation arrives at a rate of about 1000 watts per square metre (this is *power*) (see Figure 2.3, page 11). If all of the solar radiation striking one square metre in one day in a typical East African location could be collected, then a total of about 6,000 watt hours, or 6 kilowatt hours, could be harvested per square meter of solar cell module per day (this is *energy*). However, we know that it is impossible to capture all of the solar energy because some energy is always lost in transformations (as heat or in reflection).

In fact, the best solar cell modules have an *efficiency* of only about 15%, which means that they can only transform about one sixth of the arriving radiation into electricity (at noon, they transform only 150 W/m<sup>2</sup> of the incoming 1000 W/m<sup>2</sup> into electric power). Over the course of a sunny East African day, the energy converted to electricity by a square meter of solar cells is about 900 watt hours, or enough to power four 15W globe lights for 15 hours.

### Basic Low Voltage Electric Concepts

Besides understanding energy concepts, you also need a basic knowledge of electricity to install and design solar electric lighting systems. Those who are used to working with 240V ac systems will find that low voltage dc systems are safe and easy to work with. For anyone who has not had experience with electricity, Appendix 2 (page 99) explains electrical concepts in more detail, and goes through several examples. Once you have mastered the terms and principles below, then the following chapters should be readily understandable.

*Current* is the rate of flow of electrons through a circuit. The symbol *I* represents current, which is measured in *amps* (*A*). *Direct current* (abbreviated *dc*) is a flow of electric charge which does not change direction with time. With dc current, the positive terminal always remains positive, and the negative terminal is always negative. Solar cells always produce direct current electric charge, as do batteries. *Alternating current* (*ac*) is electric current which first flows through the wire in one direction and then the other, and continues to switch back and forth over time. Mains electricity, and that produced by generators, is ac current.

*Potential difference* (or *voltage*), measured in *volts* (*V*), is the difference in potential energy between the ends of a conductor that governs the rate of flow of current. It may also be referred to as the electromotive 'pressure' of electrons in an electric circuit. If there is no potential difference, there is no flow of current.

A *circuit* is a system of conductors (i.e. wires and appliances) capable of providing a closed path for electrons. Current can flow when the circuit is *closed*. No current can flow when the circuit is *open*.

*Resistance* is the property of a conductor (i.e. a wire or appliance) which opposes the flow of current through it and converts electrical energy into heat. Resistance has the symbol *R*, and is measured in *ohms*,  $\Omega$ .

*Electric power*, measured in *watts* (*W*) or *kilowatts* (*kW*), is the rate at which energy is supplied from the power source.

The *load* is the set of equipment or appliances that use the electrical power from the generating source, battery or module. *Series* and *parallel* refers to the arrangement of the load and batteries within the circuit (see Appendix 2).

*Power Law*: The power law states that electric power (in watts) is equal to the voltage (*V*, in volts) multiplied by the current (*I*, in amps).

$$\text{Power (Watts)} = \text{Voltage (volts)} \times \text{Current (amps)}$$

*Ohm's Law*: Ohm's Law states that the voltage of a circuit is equal to the current (in amps) times the resistance (in ohms). This law is useful in determining how much voltage is lost on long wire runs.

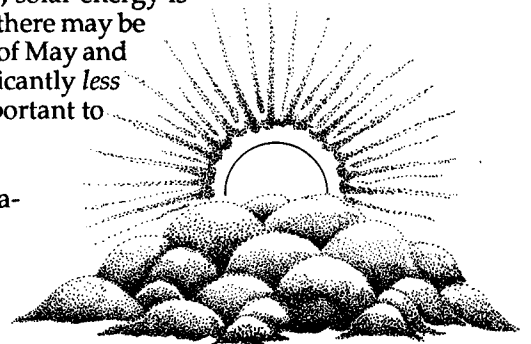
$$\text{Voltage (volts)} = \text{Current (amps)} \times \text{Resistance (ohms)}$$



## The Solar Energy Resource: How much energy is available?

When planning a solar electric system, the first question to ask is whether there is enough solar energy available. The output of a solar module depends on the amount of sun light falling on it. In most areas of East Africa, solar energy is plentiful, although at certain times of the year, there may be less energy. For example, between the months of May and August in Meru District, Kenya, there is significantly *less* solar radiation because of cloudiness. It is important to plan a system with weather patterns in mind.

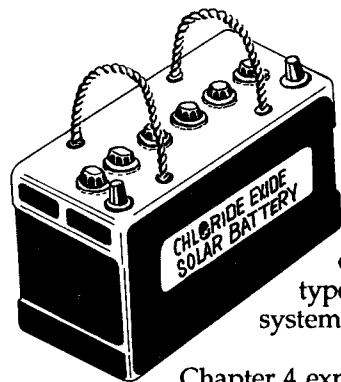
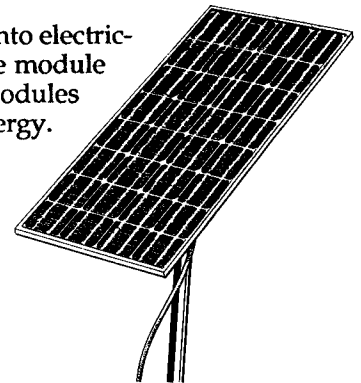
Chapter 2 explains the principles of solar radiation, and how to use meteorological records to estimate how much power will be available in a given area.



## Solar Cell Modules: Harvesting solar energy

Solar cell modules are devices used to convert sunlight into electricity. Because there are many types of solar modules, the module required for a given task should be chosen carefully. Modules should be mounted so that they can collect maximum energy.

Chapter 3 explains the principles of solar electricity, the types and behaviour of solar modules, how to size modules, and how to choose and maintain solar cell modules.



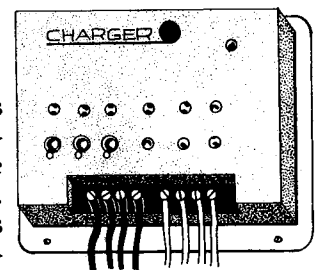
## Batteries: Storing solar energy

Lights, radios and other appliances are used at night when the sun has set; that is, when the solar modules are not producing electricity. Batteries store energy collected during sunny days for use at night and during cloudy days. Various types and sizes of batteries are available. The type of battery chosen depends on the energy requirements of a system and the budget of the user.

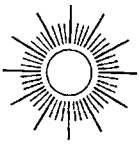
Chapter 4 explains operating principles of batteries, the different types that are available, how to size, choose and maintain them, and how to keep them charged during prolonged cloudy periods.

## Charge Controllers: Managing solar energy

Solar cell modules supply a *limited* amount of energy. For this reason, solar electric systems must be managed so that the energy collected by the solar cell modules nearly equals the amount of electricity used to power lights and appliances. Charge controllers are used to prevent damage to batteries and other parts of the system due to over-charging and deep-discharging. They may also alert the user when the battery or module is not functioning properly.

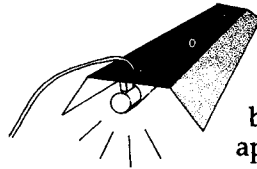


Chapter 5 explains the operation and features of charge controller, and explains how to manage energy in solar electric systems with or without a charge controller.

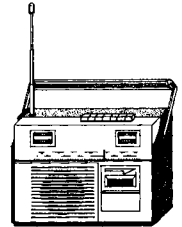


## Lamps and Appliances: The efficient application of solar energy

Unlike generators or mains (which supply electricity at 240 volts ac), solar electric systems operate on low voltage direct current. For this reason, special low voltage direct current lamps and appliances are usually installed in such systems. Furthermore, efficient fluorescent or halogen lamps are usually used in solar electric systems because they consume far less power than standard incandescent-type lamps.



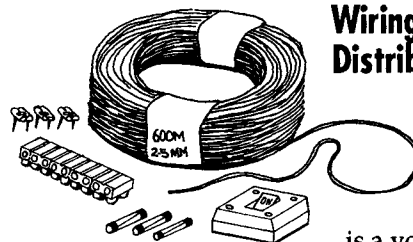
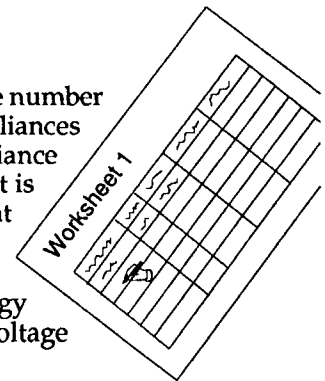
Chapter 6 explains the principles behind lamps, reflectors and ballast inverters (devices that power fluorescent lamps), and how to choose the best for a given job. It also discusses low voltage appliances, voltage converters and use of power conditioning units (i.e. inverters) to operate 240 volt ac appliances.



## The Load: Calculating your energy requirements

The electrical energy requirements of any site depend on the number of lights, radios, televisions, cassette players and other appliances used, and on the number of hours which each light or appliance operates. By adding up each appliance's energy demand, it is possible to calculate the total daily electric energy requirement of a home, school or institution.

Chapter 7 explains how to calculate the total electrical energy demand in a given system, and how to decide on the correct voltage for a system.



## Wiring and Fittings: Distributing energy

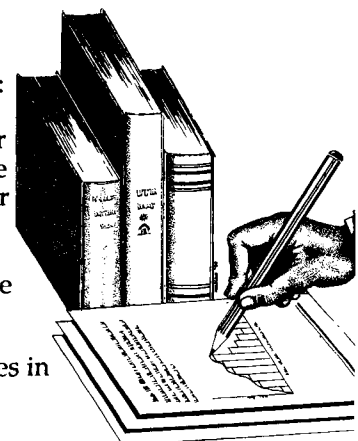
Wiring of solar electric systems is similar to the wiring of 240 V ac systems. However, low voltage solar electric systems often require thicker wires than those used in 240 V ac systems because there is a voltage drop associated with low voltage dc wires on long runs. When designing a system, consider all possible voltage drops and use the correct wire size.

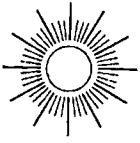
Chapter 8 explains how to choose proper cables and fittings for solar electric systems, how to calculate voltage drops in long cable runs, and how to earth systems against lightning and short circuit damage.

## Planning a System

In order to properly plan a solar electric system, you must:

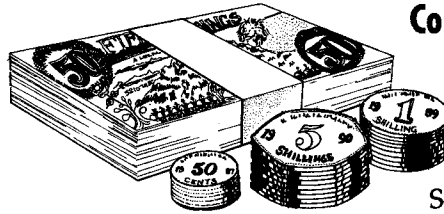
- determine how much energy is needed to power your lamps and appliances. This is done by adding up the number of lamps and appliances, tabulating their power demand, and their daily usage time;
- estimate how much solar energy is available at the site per day;
- estimate how much energy is lost due to inefficiencies in the system;





- determine the size of array, control and battery required.

Chapter 9 explains in detail the process of designing small solar electric systems, and explains how to use the planning worksheets contained at the end of this book. It also provides several examples which demonstrate their use.



### Cost Considerations: Getting the most from a solar electric system

Solar electric systems may be *expensive* investments for rural users. Before buying a system, you should compare its cost against other options.

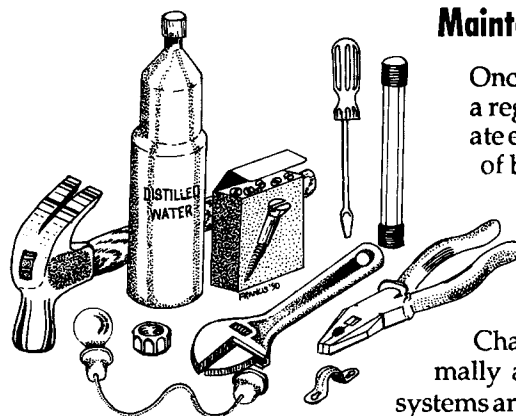
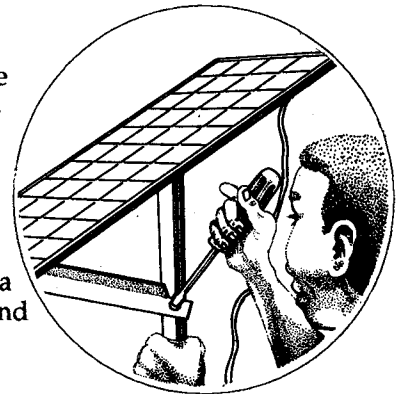
Solar electric systems are often economic over the long term, but the cost of purchasing and installing them is very high. Still, there are tactics you can use to minimize costs. An important strategy to cut costs is to collect and manage energy as efficiently as possible.

Chapter 10 explains how to compare the cost of solar electricity against alternatives. It also highlights practices and devices that reduce the cost of solar electric systems.

### Installation Steps

If a lighting system is planned properly, installing the components should proceed smoothly. Nevertheless, there is a correct order which you should follow, and there are electrical standards that need to be maintained for safety reasons and to ensure that the equipment is not damaged.

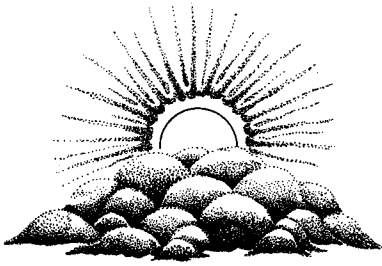
Chapter 11 explains the steps involved in installing a system, the safety precautions that should be taken and the tools necessary to do the job properly.



### Maintenance Practices

Once a system is installed, it must be serviced on a regular basis to ensure that it continues to operate efficiently. Tasks include regular maintenance of batteries and lamps, and cleaning of the solar cell modules. If you are installing a system for customers, then you must make sure that the customers are completely familiar with the maintenance practices.

Chapter 12 describes maintenance practices normally associated with small solar electric lighting systems and explains how to fix the system when it fails.



# Chapter 2

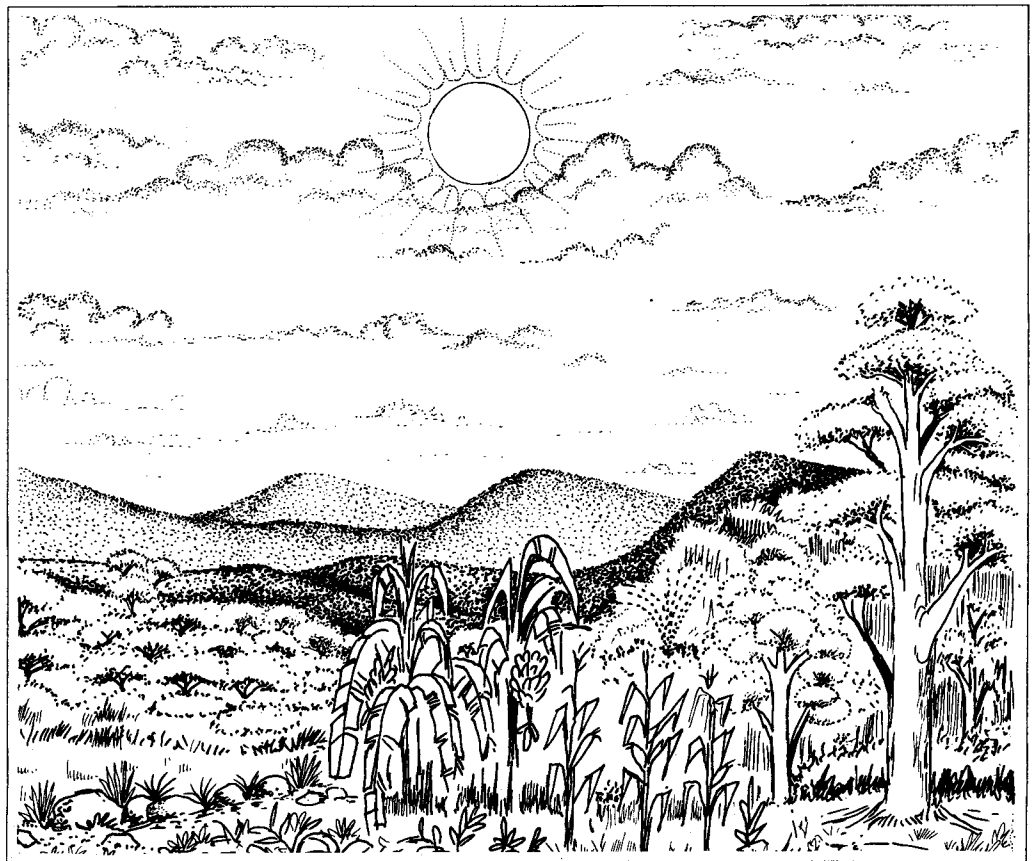
## The Solar Resource

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*This chapter explains applications and basic principles of solar energy. The theory of diffuse and direct solar radiation, irradiance, and insolation are discussed (as well as the terms kilowatt hours, peak sun hours and langleys). Estimation of energy available at a given site using meteorological records and local knowledge is outlined. Tracking the sun to increase energy output is examined.*

Solar cell modules harvest energy from the sun. Their output depends on the amount of sunlight (or *solar radiation*) falling on them. When planning or using a system, you should consider seasonal and daily solar radiation changes. The output

of a solar module changes as the sun moves across the sky during the day, and as the angle of the sun changes with seasons. The output also changes depending on how cloudy and how dusty the site is.





## Tapping Solar Energy

Solar energy is plentiful in Africa. Sunshine is useful for drying a variety of products including clothes, agricultural produce, cash crops, and bricks. Factories along the Indian Ocean coast have long made industrial use of energy from the sun in the production of salt.

However, solar energy's potential in Africa has not been fully tapped. This is because, unlike energy sources such as petrol or charcoal, solar energy arrives in a spread-out manner that is difficult to trap, convert and store for useful purposes. In order to collect it, solar energy-harnessing equipment must be utilised. Through the use of such equipment, solar energy can generate electricity, provide industrial process heat, cook food or heat water.

Solar energy has, until recently, been overlooked because of the high price of the equipment used to harvest it (in relation to

the low cost of other sources of energy). However, as the prices of fuel, wood, grid electricity and dry cells rise, solar energy equipment is fast becoming more economically attractive. In East Africa today, solar water heaters and solar electric systems are increasingly popular because they are powered by freely-available sunshine.

## Solar Radiation Principles

**Solar Spectrum and Solar Constant**  
Sunshine arrives on the earth as a type of energy called *radiation*. Radiation is composed of millions of high energy particles called *photons*. This energy is easily converted into heat energy (objects placed in direct sunshine gain energy and become hot). It can also be converted into stored chemical energy (as plants do through photosynthesis) or it can be converted into electricity using solar cells.

Each unit of solar radiation, or *photon*, carries a certain amount of energy. Depending on the amount of energy that it carries, solar radiation falls into different categories including infrared (i.e. heat), visible (radiation that we can see) and ultraviolet radiation (very high-energy radiation). The *solar spectrum* describes all of these groups of radiation energy which are

As the prices of fuelwood, petroleum, electricity and dry cell batteries rise, solar energy harvesting devices are becoming more economically attractive

Figure 2.1  
Solar water heaters

Solar water heaters, which should not be confused with solar electric devices, consist of glass-covered panels with dark-coloured pipes inside. Water flows through the pipes, is warmed by the sun, and then stored in insulated tanks for use in washing and bathing. Solar water heaters are used in hospitals, schools, hotels and homes throughout East Africa, saving considerable amounts of money that would otherwise have been spent on wood, oil, or electricity.

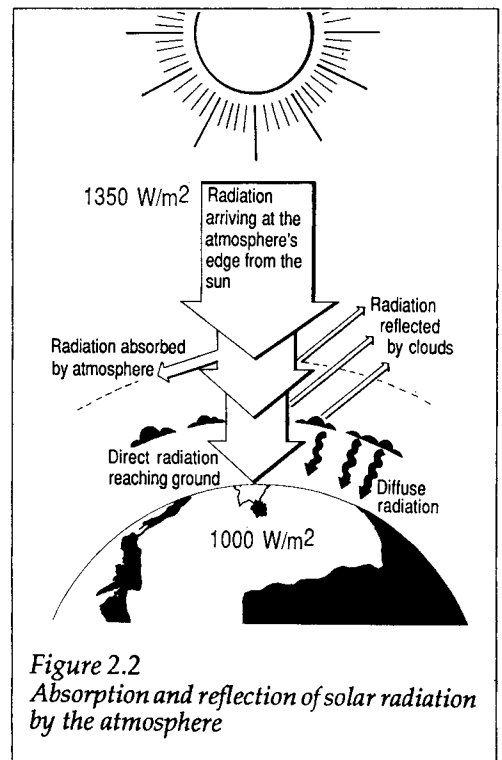
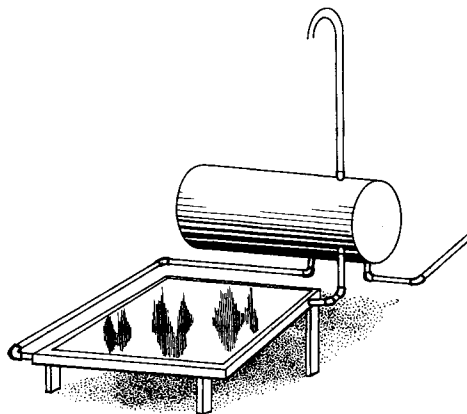
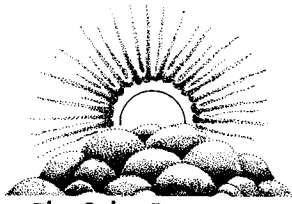


Figure 2.2  
Absorption and reflection of solar radiation by the atmosphere

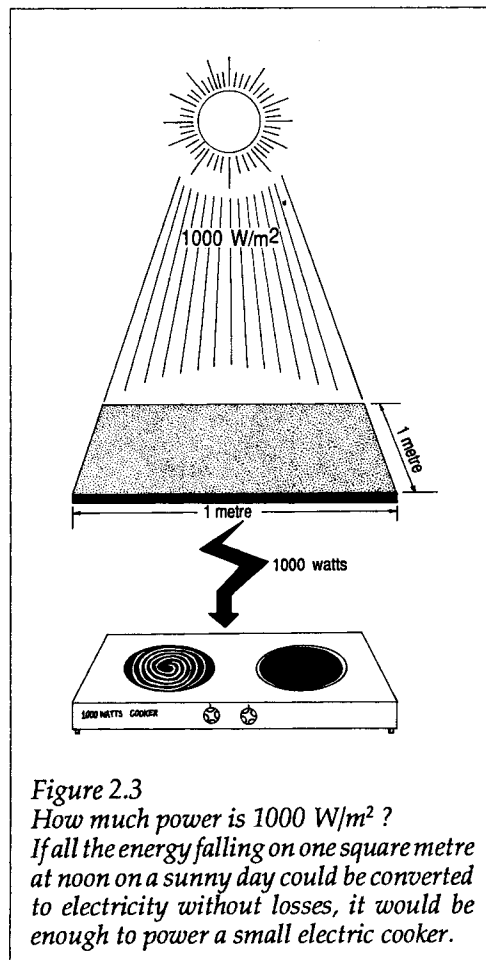


## The Solar Resource

constantly arriving from the sun, and categorises them according to their wavelength. However, solar cells can only convert part of the solar spectrum to electricity and if, for example, a photon from the infrared category strikes a solar cell, its energy will be converted as heat and not electricity.

Solar energy arrives at the edge of the earth's atmosphere at the rate of about 1350 watts per square meter. This does not change throughout the year and is referred to as the *solar constant*. However, not all this energy reaches the earth's surface. The atmosphere absorbs and reflects much of it, and by the time it reaches the earth's surface, it is reduced to a maximum of about 1000 W/m<sup>2</sup> in tropical countries (see Figure 2.2). This means that when the sun is directly overhead on a sunny East African day, solar radiation is arriving at the rate of about 1000 W/m<sup>2</sup>. Countries in high northern and southern latitudes receive much less radiation than countries located near the equator.

When the sun is directly overhead on a clear day in East Africa, solar radiation is arriving at the rate of about 1000 watts per square meter.



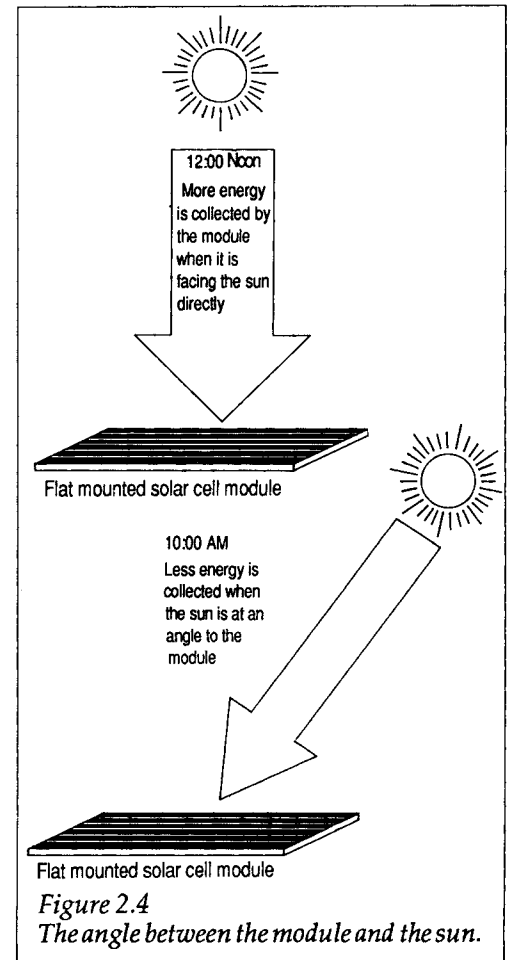
### Direct and Diffuse Radiation

Solar radiation can be divided into two types: *direct* and *diffuse*. *Direct radiation* comes in a straight beam and can be focused with a lens or mirrors. *Diffuse radiation* has been scattered by clouds or dust. Clouds and dust absorb and scatter radiation, reducing the amount that reaches the ground. On a sunny day, most of the radiation is direct, but on a cloudy day, up to 100% of the radiation is diffuse. Together, direct and diffuse radiation are known as *global radiation*.

Radiation received on a surface in cloudy weather is reduced to one third or less compared to the amount received on a sunny day. It is therefore necessary to design systems that guarantee enough power in cloudy months, or to economise use of energy when it is cloudy.

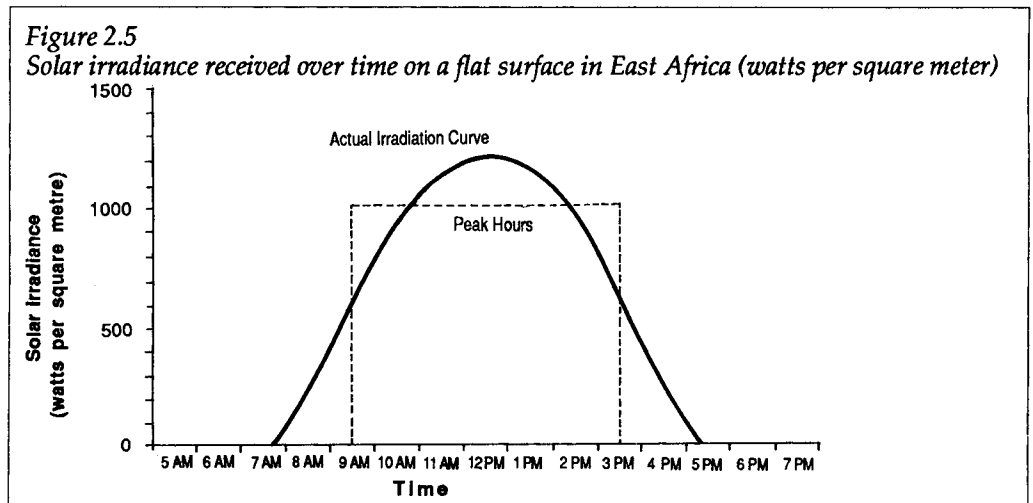
### Solar Irradiance

*Solar irradiance* refers to the solar radiation actually striking a surface, or the *power received per unit area* from the sun. This is





**The Solar Resource**



measured in *watts* or *kilowatts per square metre*. If a solar module is facing the sun directly (i.e. if the module is perpendicular to the sun's rays), *irradiance* will be much higher than if the module is at a large angle to the sun (see Figure 2.4).

Figure 2.5 shows the changes in the amount of power received on a flat surface during a clear day. In the morning and late afternoon, less power is received because the flat surface is not at an optimum angle to the sun and because there is less energy in the solar beam. At noon, the amount of power received is highest. The actual amount of power received at a given time varies with passing clouds and the amount of dust in the atmosphere.

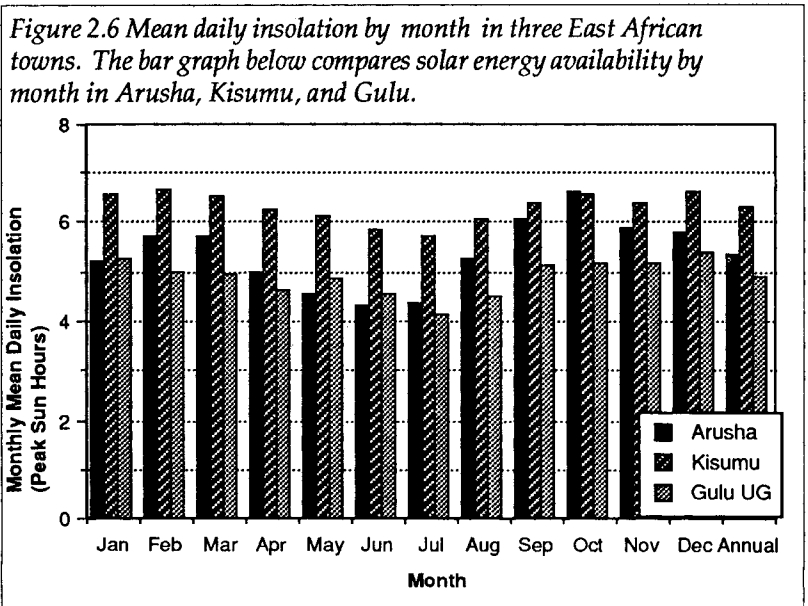
The angle at which the solar beam strikes the surface is called the *solar incident angle*. The closer the solar incident angle is to 90 degrees, the more energy is received on the surface. If a solar module is turned to face the sun throughout the day, its energy output increases. This practice is called *tracking* (see page 15).

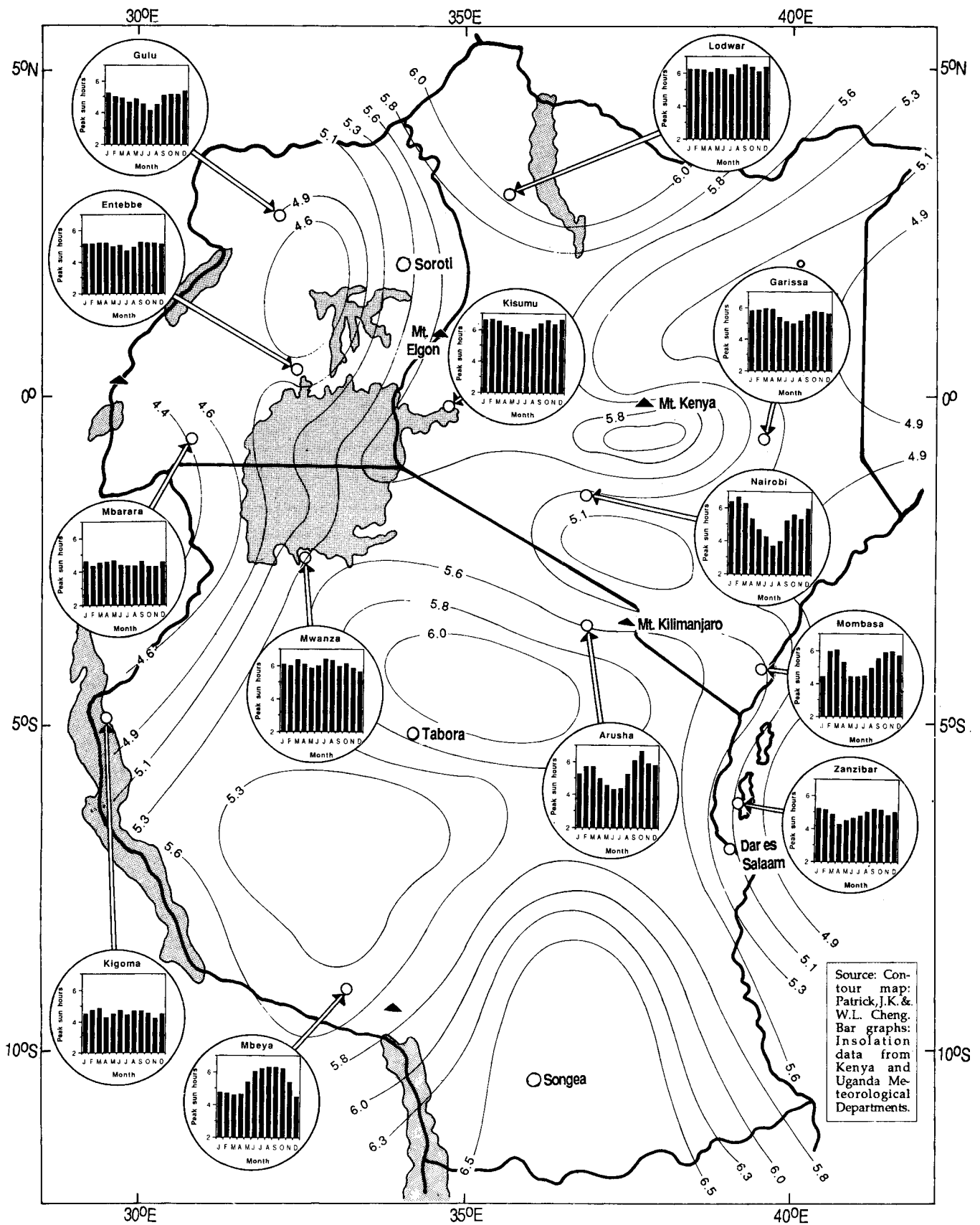
**Insolation**  
*Insolation* (incident solar radia-

tion) is a measure of the solar energy received on a specified area over a specified period of time. It is normally measured in *kilowatt hours per square metre per day (kWh/m<sup>2</sup> per day)*, *peak sun hours per day* or *langley's per day*. Meteorological stations throughout East Africa keep records of monthly solar insolation which are useful in planning systems.

*Kilowatt hours per square metre per day* measures the amount of radiant energy collected at a site. It corresponds closely to *peak sun hours*, or the number of hours per day during which solar irradiance averages 1000 W/m<sup>2</sup> at the site. A site that receives six peak sun hours a day receives the same amount of energy that would have been received if the sun had shone for six hours at 1000 W/m<sup>2</sup>. Actually, the

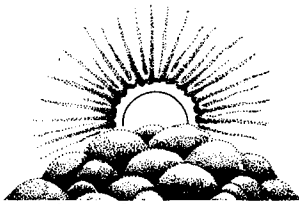
A site which receives six peak sun hours per day receives the same amount of energy that would have been received if the sun had shone for six hours with an intensity of 1000 watts per square metre.





**Figure 2.7**  
**Insolation Contour Map of East Africa**

This map is an overall depiction of the solar energy availability in East Africa. The contour lines give general indications of the annual mean daily insolation (in peak sun hours or  $\text{kWh}\cdot\text{m}^{-2}$ ) in various areas. To use the map, locate the place for which you need information and read the insolation value from the lines on either side. For example, the contours show that the southern areas of Tanzania have a very high annual mean daily insolation (above 6.5 peak sun hours), and that the southwestern parts of Uganda have comparatively low levels (below 4.4). Note that the map gives a rough indication of insolation, and that local geographical factors may change actual insolation considerably. The bar graphs inside the circles show monthly mean daily insolation values for selected sites in the region. These graphs are useful for determining seasonal insolation values, and for determining the design month (see page 59). Note, for example, that Lodwar has a constant high level of radiation throughout the year, but that insolation levels change considerably in Nairobi and Arusha.



## The Solar Resource

### Peak sun hours

- = the equivalent number of hours each day when solar irradiance averages 1000 watts per square metre.
- = kilowatt hours per square metre per day of solar insolation

To convert langleys into peak sun hours (or kilowatt hours), multiply by 0.0116.

Use Table 2.1 to estimate peak sun hour values from mean daily sunshine hours.

irradiance at such a site changes throughout the day. It is above  $1000 \text{ W/m}^2$  for about three hours, above  $800 \text{ W/m}^2$  (but below  $1000 \text{ W/m}^2$ ) for two hours, above  $600 \text{ W/m}^2$  for two hours and above  $400 \text{ W/m}^2$  for two hours and above  $200 \text{ W/m}^2$  for two hours. Still, the energy is equivalent to six hours of irradiance at  $1000 \text{ W/m}^2$  (see Figure 2.5). Peak sun hours are useful because they simplify calculations. They are commonly used when planning systems, and are used throughout this book as a measure of solar energy.

Figure 2.6 shows the mean daily insolation in peak sun hours for each month at three sites in East Africa. Note that the total amount of energy available per day changes considerably from month to month. On a sunny January day, Kisumu receives more than six peak sun hours of insolation. On a cloudy day in July, Arusha receives only 4 peak sun hours.

In East African meteorological stations, insolation is measured in *langleys per day* (calories per square centimetre per day). To convert *langleys* into *peak sun hours*, multiply langleys by 0.0116. For example, 430 langleys is about equal to 5 peak sun hours.

### Using Meteorological Records

Using records kept at meteorological stations, you can estimate the amount of solar energy available in a given location. This information may be kept at the station itself, or at a government meteorological agency in the capital. The most useful information is the monthly mean daily insolation, but the monthly mean daily sunshine hours will be useful if the former is not available (see Table 2.1). Many meteorological stations keep records of monthly average daily insolation and daily sunshine hours.

Locations in East Africa receive between three and seven peak sun hours per day. The exact amount of insolation depends on the location and time of year. Figure 2.6 shows how insolation changes each month in three East African locations. It is difficult to accurately estimate the number of peak sun hours a site will receive on any given day. However, on a monthly basis, it is possible to predict insolation. If it was sunny last December and the December before that, it will probably be sunny this December as well.

Figure 2.7 shows a contour map of East African annual mean daily insolation (in peak hours) prepared by meteorologists. It gives an overall indication of solar energy distribution per year in the region. The circles show mean daily insolation per month in regional cities. However, different seasons and altitudes cause large local variations. For example, insolation is actually much less than shown on the map in the high altitude towns of Arusha, Tanzania and Meru, Kenya because of cloud caused by nearby mountains. If possible, the nearest meteorological station should be consulted when planning a system.

*Monthly mean daily hours of sunshine.* If records on solar insolation are not kept at a meteorological station, then check for the *monthly mean daily sunshine hours* (which is not the same as peak sun hours). This measures the number of hours each day when the sun is not blocked by clouds. Sunshine hours can be roughly converted into kilowatt hours per square metre (or peak sun hours) (see Table 2.1).

If there are no insolation records at all, then insolation can be very roughly estimated for a day or month using Table 2.1. During a very sunny month near the equator, for example, there would be between six and seven peak sun hours of insolation per day.

Table 2.1: Approximate Peak Sun Hour Values

Site Weather Conditions	Mean Daily Sunshine Hours	Approximate Peak Sun Hours
Cloudy all day	4 or less hours of sunshine	4.5 or less peak sun hours
3-5 hours of cloud cover	4 - 6 hours	4.5 - 5.5 peak sun hours
1-3 hours of cloud cover	6 - 8 hours	5.5 - 6.5 peak sun hours
Completely clear all day	8 hours or more	6.0 or more peak sun hours



## Tracking the Sun

Although a module will collect the most energy when facing the sun directly, the sun is not always overhead. As Figure 2.8 shows, between morning and afternoon the sun's position relative to a fixed solar module changes from 90° on one side to 90° on the other side. During the year, the sun changes its angle with respect to a fixed solar module at the equator as well. In December the sun's path is 23.5° to the south, in March and September its path is directly overhead, and in June its path is 23.5° to the north.

More solar power can be tapped if solar modules are turned to face the sun directly throughout the day. Turning the modules to follow the sun's movements is called *tracking*.

Manually-operated tracking mounts are used in Kenya to gain an additional 20-30% more power over fixed mounts. The two designs shown in Figures 2.9 and 2.10 are locally-made tracking mounts for one-module home systems and multiple mod-

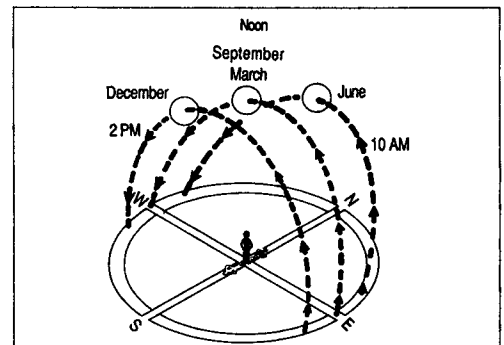


Figure 2.8  
Daily and seasonal path of the sun relative to fixed position on the ground. The sun is shown at its noon position.

ule systems. Both operate on the principle that a rotatable module tilted at 30° will optimally harvest sunshine at 10 AM and at 2 PM. They also effectively harvest sunshine during December and June. During cloudy weather, the module can be turned to face the sun when it appears from behind the clouds. Note that modules on tracking mounts will produce *less* energy than flat-mounted modules if the tracking mount is not properly operated.

A metal frame supported by a pipe holds solar cell modules at an angle of 30° from horizontal. The pipe is slipped inside a larger one which is cemented into a foundation. The frame holding the solar cell modules is free to rotate almost one full turn. With the cells at 30°, the frame can be rotated to make good use of the solar radiation any time of the day or any time of the year.

In practice, both mounts are rotated to face the 10 AM sun in the morning and again at noon to face the 2 PM sun in the afternoon. This simple operation increases the available energy in the system by more than 25% on a clear day. In addition, the rotatable mount can be used to harvest high value sunlight when the sun appears from behind the clouds on sunny days. This type of mount can significantly increase the amount of power available from a group of solar cell modules in locations within 15° to either side of the Equator.

Figure 2.9: Manually-operated solar cell module mount for arrays of 2-6 modules (designed by Harold Burris).

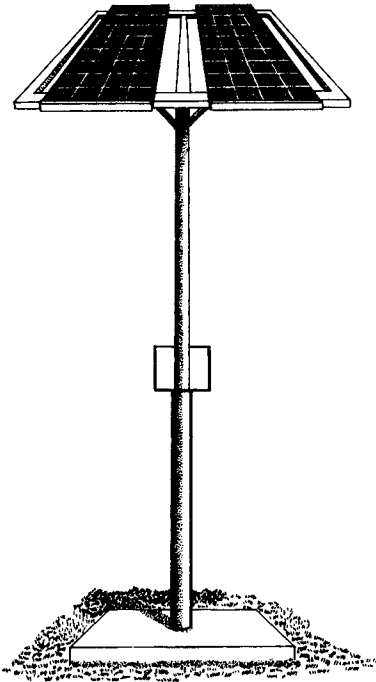
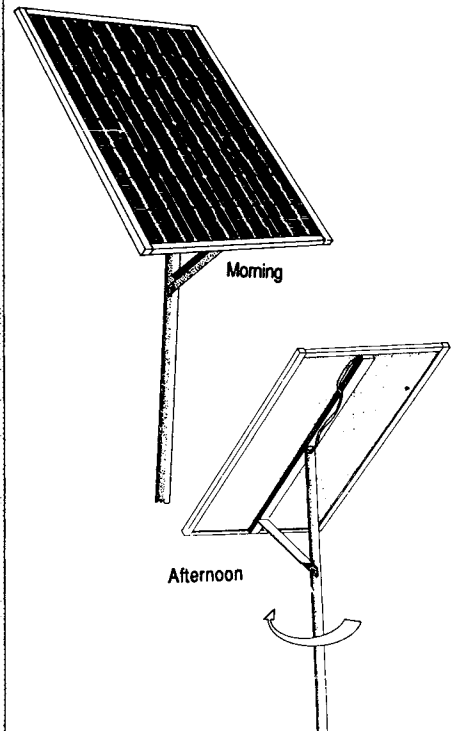
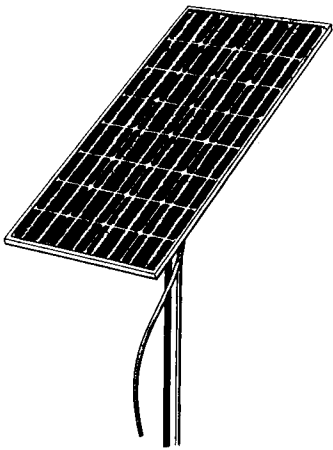


Fig 2.10 Rotatable pole mount for single modules

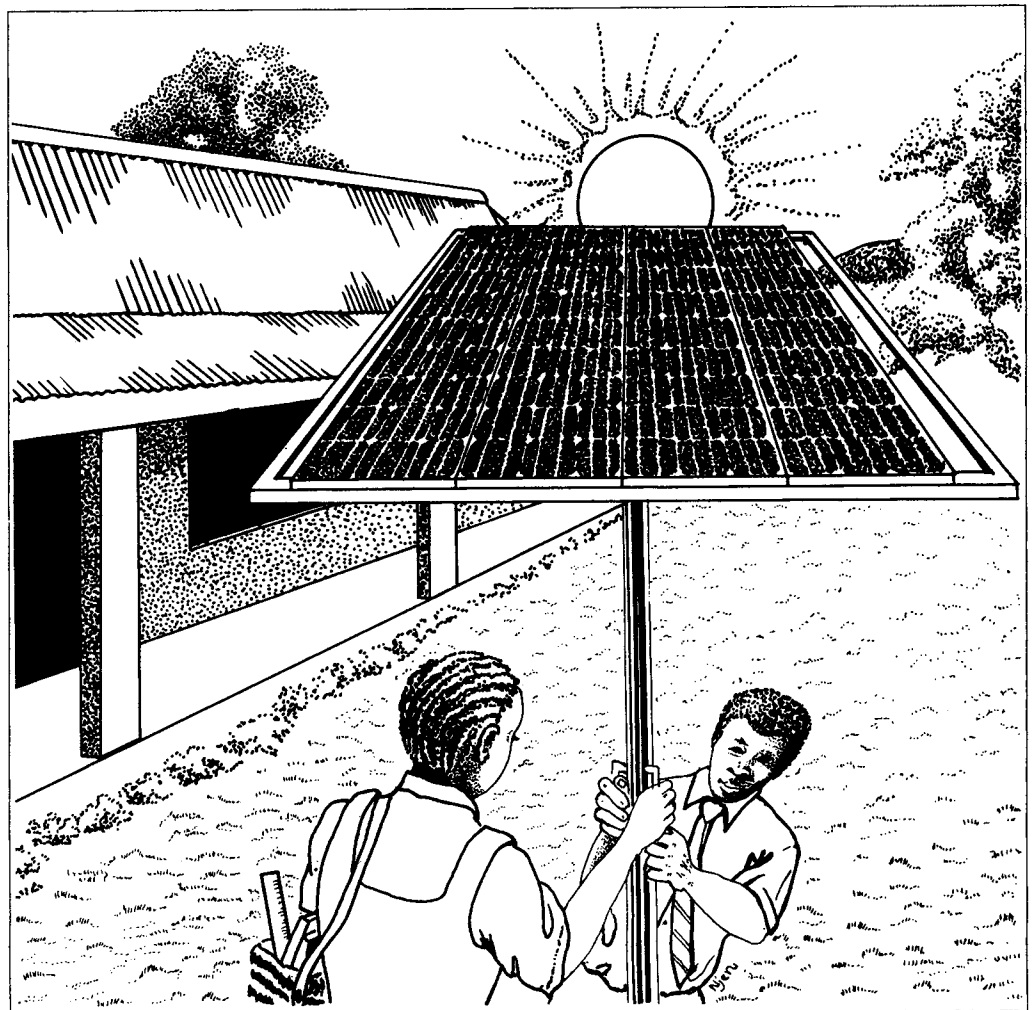


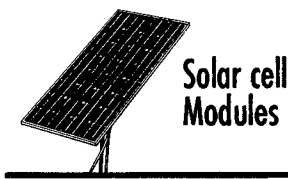


# Chapter 3

## Solar Cell Modules

*This chapter gives general details about solar cell modules. It describes basic principles by which solar cells operate, the types of solar cells and modules available (including monocrystalline, polycrystalline and amorphous), and the methods by which they are manufactured. Module parts are identified, and the system by which they are rated is introduced. The energy output and characteristics of modules under various temperature and weather conditions are explained. This information will help system designers to choose, install and estimate module energy output under nominal conditions.*





Solar cell Modules

The basic unit of solar electric production is the solar cell.

## Solar Cells and the Photo-electric Effect

### The Photo-electric Effect

Solar electricity is the direct conversion of sunlight to useful electricity. Whenever light strikes solar cells they convert *light energy into electric energy*. They do this according to a principle of physics called the *photo-electric effect*. Solar electric devices are also called *photovoltaic* or *PV* devices.

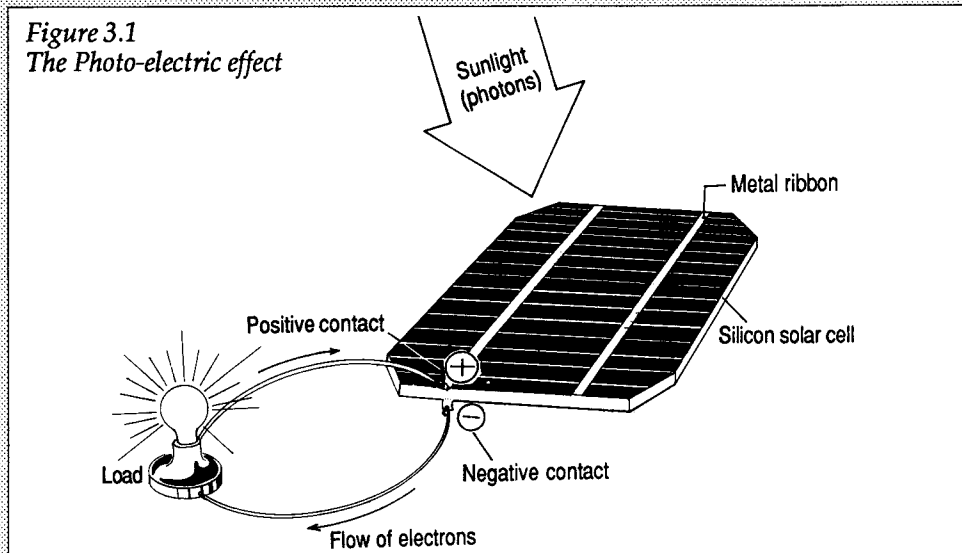
The photo-electric effect was first discovered about 100 years ago by a French physicist, Jacques Becquerel, but did not find a useful power-generating application until the 1950's, when the US space programme started using solar cells to provide electrical power for space ships.

Following the oil crisis in 1973, much research was put into improving the technology for applications on Earth. The first automated production of solar cells began in the USA in 1983. By 1991, the industry was well established and growing. Today solar cells are manufactured in many countries, including the USA, Germany, Spain, Italy, Japan, Brazil, China and India. The price of solar cells fell from about US\$ 100 per peak watt in 1974 to about US\$ 4 per peak watt by 1986. It is expected to fall even further in future.

### Solar Cells

The basic unit of solar electric production is the *solar cell*. Light striking solar cells creates a current powered by incoming light energy.

Figure 3.1  
The Photo-electric effect



### How solar cells work

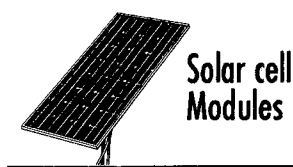
Whole books have been written about solar electricity and the *photoelectric effect*, and it is not the purpose of this book to go deeply into solar electric theory. The following is an extremely rough explanation of the operation of a solar cell; those interested in finding out more should consult the books listed in the reference section.

Solar radiation is composed of millions of tiny high-energy particles called *photons*. Each photon carries a quantity of energy; some have more than others. When a photon of sufficient energy strikes a silicon atom in a solar cell, it pushes the outermost silicon electron out of its orbit around the nucleus, freeing it to move across the cell's electric field.

Solar cells rely on the special electric properties of the element *silicon* (or other *semiconductor* materials) which enable it to act as both an insulator and a conductor. Specially-treated pieces of silicon "sort" electrons dislodged by solar energy in one direction to produce an electric current.

If a load is connected between the negative and positive side of the cell, the electrons flow as a current. Thus, solar energy (in the form of photons) continuously dislodges silicon electrons from their orbitals and "pushes" the electrons through the wires. More intense sunlight gives a stronger current. If the light stops striking the cell, the current stops flowing immediately.

Today solar cells are manufactured in many countries, including the USA, Germany, Spain, Italy, Japan, Brazil, China and India.



Solar cells produce electricity when placed in sunlight. They do not get used up or damaged while generating electric power. Their life is shortened only by breakage or exposure to the elements. If a cell is properly protected behind glass, it should last for more than 20 years.

### Solar Cell Technology

Several varieties of silicon-type solar cells and solar cell modules are available. These include modules with cells made from monocrystalline, polycrystalline and amorphous silicon. Monocrystalline refers to cells cut from a single *crystal* of silicon (a crystal is the regular geometric state taken up by elements in certain conditions; silicon crystals are specially grown through expensive processes). Polycrystalline refers to cells made from *many* crystals. Amorphous refers to silicon that is not in crystalline form and is therefore cheaper. When shopping for modules, it is important to consider the advantages and disadvantages of various types.

Several varieties of silicon-type solar cells are available, including ones made from monocrystalline, polycrystalline and amorphous silicon.

The most common type of solar cells are specially-treated silicon *wafers* (i.e. pieces of very thinly-sliced silicon). These cells are cut out of mono- or polycrystalline silicon crystals which are grown from very pure molten silicon (with trace amounts of boron). The wafers are chemically treated with phosphorus in furnaces, and then anti-reflective coating is applied to the cell surface to help it absorb radiation more effectively. After this, thin metal wires are applied to the front of the cell. These 'ribbons' of metal on the cell act as the positive contact, whereas a solid layer of metal on the back side of the cell acts as a negative contact (see Figure 3.1).

**Monocrystalline** cells have an efficiency of 12-15 %. This means that if solar radiation is striking the cells at a perpendicular angle with an intensity of 1000 W/m<sup>2</sup>, 120 to 150 Watts per m<sup>2</sup> of solar cell is produced as electricity. Monocrystalline cells are chemically stable, so they last for a very long time if properly protected.

Monocrystalline cells were the first to be developed for commercial purposes. They are made by using a special saw to slice thin pieces from a cylindrically-shaped crystal of pure silicon. In the process of slicing, almost as much of the expensive crystal is lost as dust as is cut into cells.

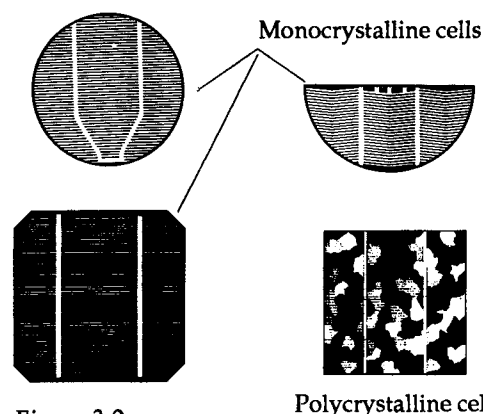


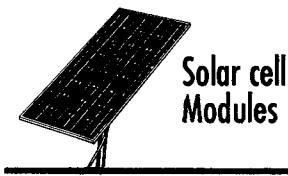
Figure 3.2  
Various types of crystalline solar cells

**Polycrystalline** (or multicrystalline) cells have a slightly lower efficiency than monocrystalline cells (i.e. 10-12 %). Like monocrystalline cells, they have a very long lifetime, and do not degrade over time.

Like monocrystalline cells, polycrystalline cells are sliced from crystals of silicon. However, they are made from cast ingots of polycrystalline silicon which is made by a different process than monocrystalline silicon. The cells have a different appearance than monocrystalline cells (see Figure 3,2). As of 1991, the price per watt of both types of crystalline cells was about the same.

**Amorphous** (or thin film) cells are the most recently developed solar electric technology. Amorphous-type cells do not use silicon in crystalline form, and hence cells can be manufactured much more cheaply than with poly- and monocrystalline cells. With amorphous modules, silicon material is deposited on the back of a glass or plastic surface in very thin layers. The surface is then scored to divide it into a number of cells, and electrical connections are added (see drawing page 23). In this process, very little silicon material is required. This enables mass production of modules at a low cost. The solar cells used in toys, calculators and watches are usually made from amorphous silicon.

Amorphous cells operate according to the same principles as crystalline modules, but have much lower efficiencies (between 4 and 6%). Because they operate at low efficiencies, amorphous modules must be three to four times the size of mono- or poly-crystalline modules to generate the same power.



Amorphous silicon *degrades* over time, meaning that as they get older amorphous cells produce less power. When first installed, new modules produce about 25% more power than their rating; after several months they degrade down to their rated power output and no longer degrade appreciably.

Because of their low cost, amorphous modules are often the most suitable modules for applications of 20 watts and under.

*Other types of cells:* More research is being conducted into the development of cheaper and more efficient solar cells, and these technologies are expected to become important in future. *Tandem* cells utilise two or more types of amorphous films to collect a higher portion of the solar radiation than a single thin film. *Gallium arsenide* cells, which capture a wider portion of the solar spectrum and which operate more efficiently at high temperatures than silicon cells, may become important if more cheaply manufactured.

### Solar Cell Modules and Arrays

Solar cells vary in size and can be used according to the task at hand. No matter the task, though, all silicon-type solar cells generate a potential difference of about 0.4 volts in normal operation. For this reason, solar cells are connected in series to bring the voltage up to a useful level. Five cells in series are enough to power a calculator

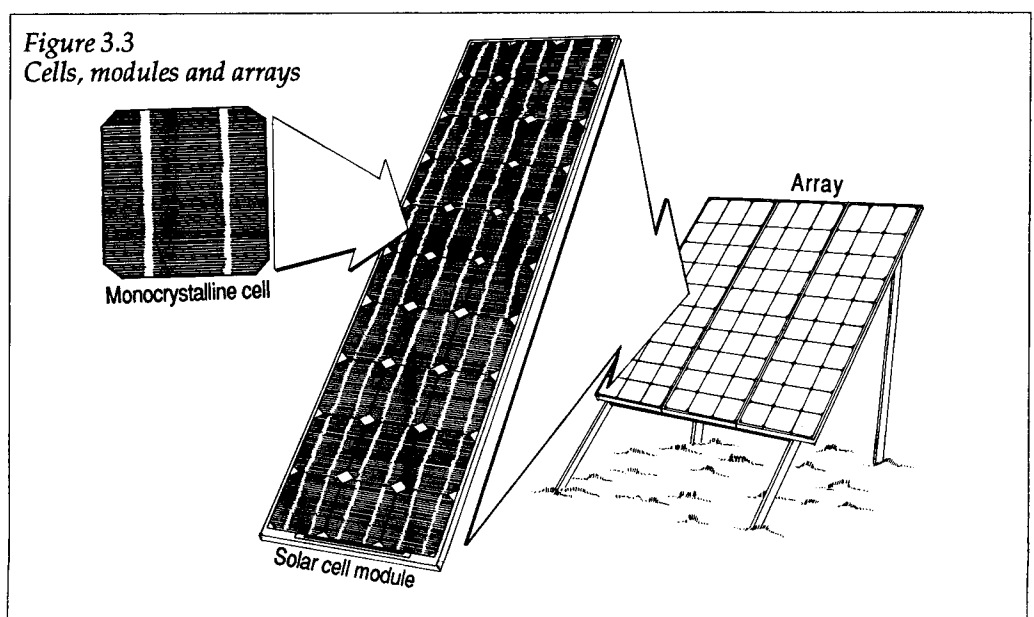
of two volts, and 30-36 cells are enough to charge a 12 volt battery.

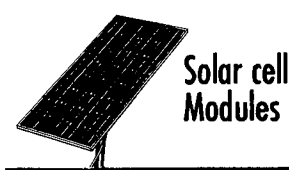
The current produced by a solar cell depends on its size and type. A 10 cm square monocrystalline cell produces a current of about 3.5 amps under *Standard Test Conditions (STC)* of 1000 W/m<sup>2</sup> solar irradiance at 25°C and an air mass of 1.5 (air mass tells how much radiation is absorbed by the atmosphere). Standard test conditions are a set of guidelines commonly used by manufacturers to compare solar cell modules of different types, but modules usually produce *less* power under actual working conditions.

As mentioned before, it is usually not convenient to use single solar cells because their output does not match the load demand. For example, one cell cannot power a radio if the radio requires current at three volts and the cell produces a voltage of only 0.4 V. Thus solar cells are arranged in series to increase voltage. Furthermore, solar cells are fragile, so they must be protected from breakage and corrosion. For these reasons, groups of solar cells are usually sold to consumers in framed glass and plastic units called *solar cell modules*.

**From Solar Cells to Solar Cell Modules**  
Arrangements of many solar cells wired in series, sealed between glass and plastic, and supported inside a metal frame are called *solar cell modules*.

Solar cells are connected in series to increase the voltage. Arrangements of many solar cells wired in series, sealed between glass and plastic, and supported inside a metal frame are called solar cell modules. Groups of modules mounted together are called arrays.





The process of making solar cell modules from mono and polycrystalline silicon cells involves several steps. Once properly prepared and treated with anti-reflection coatings, solar cells are soldered together in series (i.e. the front of one cell is connected to the back of the next) and then mounted between glass and plastic. The process by which mono- or polycrystalline solar cells are sealed between glass and plastic is called *encapsulation*.

During encapsulation, the cells are sealed at high temperature between layers of plastic (a special type called *EVA plastic*) and glass in such a manner that air or water cannot enter and corrode the cells. Modules are then cased in metal or plastic frames to protect their edges and to protect them from twisting. The frame may have holes drilled in it for easy mounting, and a connection point for earthing cables.

Electric contacts are fixed onto the back of the module. These will either be two terminal screws or two wires. With some modules, the terminals are enclosed in a junction box. The negative terminal, usually black in colour, is connected to the negative terminal on the charge controller or battery. Likewise, the positive terminal, usually red in colour, is fixed by a length of wire to the positive terminal on the control or battery. Some modules are wired so that their voltage can be adjusted to either 6 or 12 volts.

#### Module Ratings

All solar cell modules are rated according to their maximum output, or *peak power*. The *peak power*, abbreviated *Wp*, is defined as the amount of power a solar cell module can be expected to deliver at noon on a sunny day when it is facing directly towards the sun at STC (i.e. Standard Test Conditions, which are 1000 W/m<sup>2</sup> of solar irradiance, a temperature of 25°C, and an air mass of 1.5). The module's power rating in peak watts should be specified on the module by the manufacturer or dealer.

By counting the number of cells in a module, it is possible to estimate its voltage. Solar cell modules are available in several voltages and power ratings. For charging 12 volt car batteries, modules usually have between 30 and 36 solar cells wired in series. With good solar insolation, a 40 Wp module with between 33 and 36 cells can harvest enough electricity to power the

lights and small appliances (*but not cookers!*) in a typical East African rural household.

#### Arrays

Often, a number of modules are required to meet the power requirements at a site. When mounted together, groups of modules are referred to as *arrays* (see Figure 3.3). Solar water pumps and solar refrigerators typically require large arrays of modules for their operation.

#### Output of Solar Cell Modules

The power output of a module depends on the number of cells in the module, the type of cells, and the total surface area of the cells.

The output of a module changes depending on:

- the amount of solar radiation,
- the angle of the module with respect to the sun,
- the temperature of the module, and
- the voltage at which the load (or battery) is drawing power from the module.

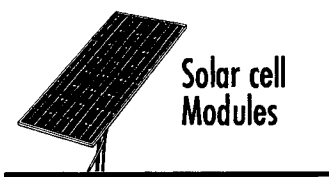
#### The I-V Curve

Each solar cell and module has its own particular set of operating characteristics. These properties can be described by the current - voltage curve, which is better known as the *I-V curve*. I-V curves are used to compare various solar cell modules, and to determine their performance at various levels of insolation and temperatures.

Figure 3.4 shows an I-V curve for a 42 Wp module. The left-hand side (I) gives the current of the module produced depending on voltage. The bottom side gives the voltage produced by the module at various currents. At each point along the line, it is possible to determine the power of the module for particular conditions. For example, imagine that a battery is being charged by a module, and that it has reached 12.0 volts (Point A). The current from the module is 3.2 amps at Point A and the power output is 38.4 watts (amps x volts = power, so 12.0 V x 3.2 A = 38.4 watts).

The shaded portion of Figure 3.4 shows the

The peak power rating of a module (Wp) is the amount of electric power it will produce at noon on a sunny day when it is facing directly towards the sun, under standard test conditions.

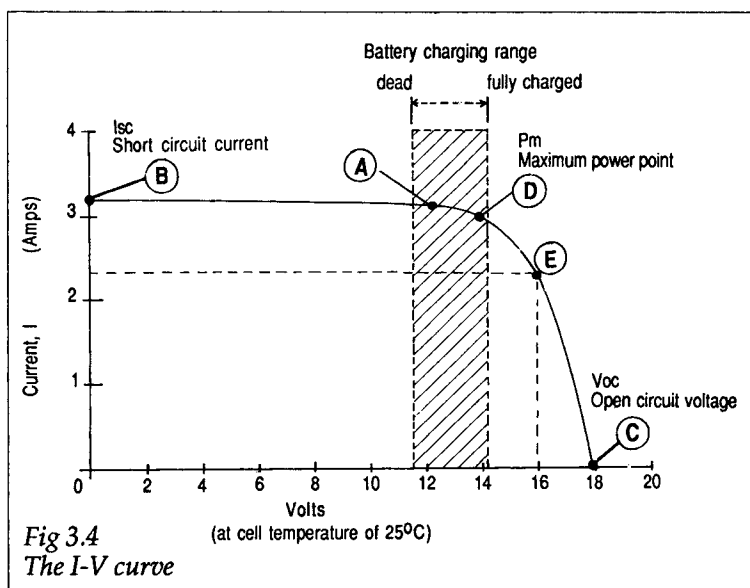


It is advisable to operate a module as near to the maximum power point as possible.

voltage boundaries within which a lead-acid battery is charged. Note that as the battery gets fully charged, the charging current begins to decrease.

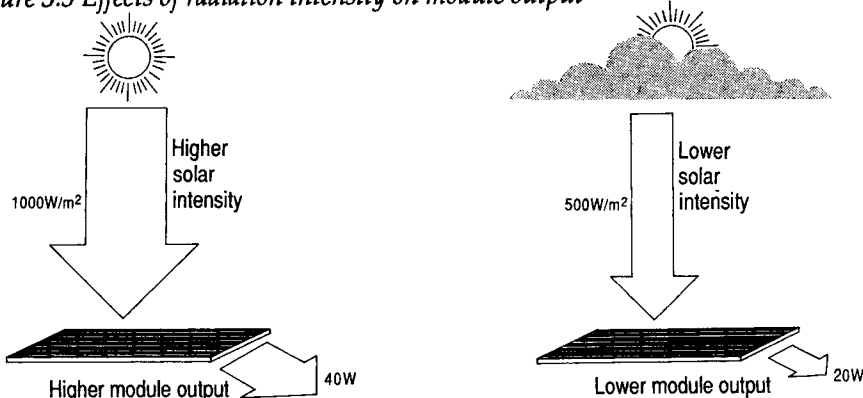
There are several points of interest about the I-V curve in Figure 3.4:

- $I_{sc}$ , the short circuit current, is the point where the curve crosses 0 volts (Point B). This is the maximum current that the module is capable of producing.
- $V_{oc}$ , the open circuit voltage, is the point where the curve crosses 0 amps (Point C). This is the maximum voltage that the module can produce on a sunny day.
- $P_m$ , the maximum power point, is the point on the I-V curve where the module produces the greatest power (its



rated maximum, in this case 42W). The maximum power point is always found at the place where the curve begins to bend steeply downward (i.e. at the knee, Point D). It is advisable to operate a module as near to the maximum power point as possible. If, for example, the module in Figure 3.4 is operating a load that demands 16 volts (Point E), power output (at 36 watts) is much less than that at the maximum power at Point D.

Figure 3.5 Effects of radiation intensity on module output



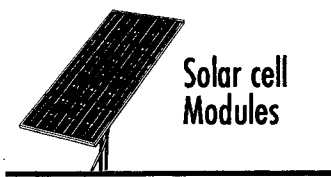
Solar cell module output is very much governed by the intensity of the solar radiation on a module. Figure 3.5 shows that module output is directly proportional to the solar irradiance; i.e. halving the intensity of solar radiation reduces the module output by half. Lower radiation also lowers the voltage at which current is produced.

Cloud cover reduces the output of a module to a third or less of its sunny weather output.

During cloudy weather, the voltage output of a module is also reduced, and modules for charging 12 volt batteries should thus be carefully chosen. Modules with 30 or fewer cells may not produce a voltage high enough to fully charge a 12 volt battery in hot, cloudy weather. If the intended installation site has long periods of cloudy weather, it is best to choose a module with 35 or 36 cells.

Continued

While operating, modules are typically 20°C warmer than the peak ambient temperature.



Solar cell Modules

Halving the intensity of the solar radiation reduces module power output by half.

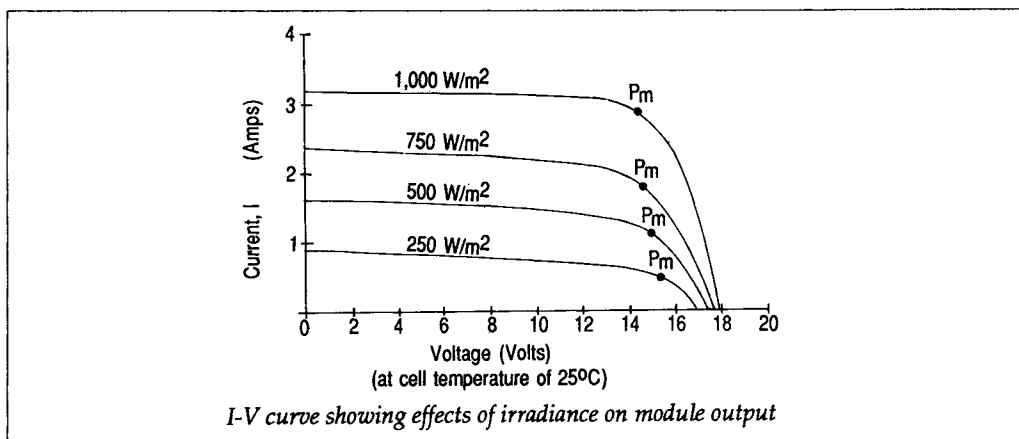
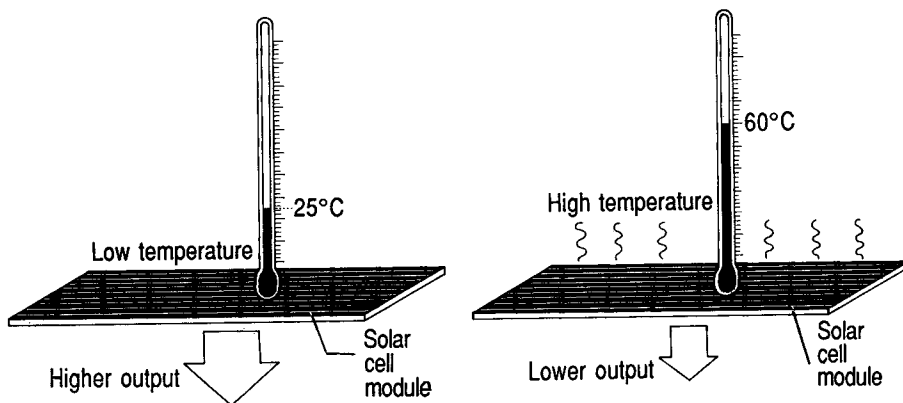


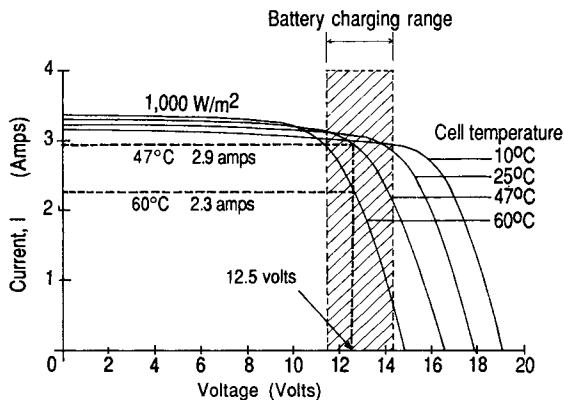
Figure 3.6 Effects of temperature on module output



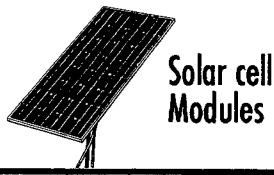
As mentioned previously, solar electric devices are quite different from solar heating devices. Whereas solar water heaters function well when hot, the output of solar cells decreases as they get hotter.

As the temperature increases, power output of monocrystalline solar cells falls by 0.5 % per degree centigrade (this is shown by the I-V curve in Figure 3.6). Thus, a 5 degree rise in temperature will cause a 2.5% drop in power output. In strong sunlight, solar cell

modules may be 20°C warmer than the thermometer temperature. Furthermore, the temperature on *mabati* roof tops may reach as high as 60°C, meaning that the output of the module placed directly on *mabati* may be 15% or more below its rated output. For this reason, installers are encouraged to mount modules on poles, on structures above the roof, or in places where they are cooled by wind so that their output remains as high as possible.



I-V curve showing effect of temperature on module output



Shading a single cell of a module will considerably lower its output.

### Effects of Shading on Module Output

Obviously, if a shadow falls across all or part of a module, its electric output will be reduced. In fact, even shading a *single cell* will considerably lower a module's output and possibly damage it. Damage occurs because the cells in a module are connected in series, and they each must

carry the same current. When one cell (or more) is shaded, it stops producing current and instead *consumes current*, converting it to heat. If a single cell is shaded for a long time, it may cause the entire module to fail. Even a single tree branch, a weed or a bird's nest could shade one cell and cause electrical production to fall dramatically.

### How Much Energy Does a Solar Module Produce?

The maximum amount of energy that a solar module produces per day in equatorial locations can be roughly estimated by multiplying the *peak power rating* of the module (in Wp, see page 20) by the number of peak sun hours received by the module over the course of the day (for details on peak sun hours see page 12). The actual energy output will be less, depending on how near to the peak power point the module is operated.

Maximum energy produced by a module (in watt hours per day)	≈	Peak power rating of module x peak sun hours at site (in Wp)
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*Example: Solar module output:  
Kisumu in January*

A Siemens M-55 module has a rated power of 53 Wp. Using meteorological records, the maximum daily energy output of such a module mounted flat in Kisumu can be

predicted. Figure 2.6 on page 12 shows that, in January, the expected daily insolation is about 6.5 kWh/m<sup>2</sup>. Following the above equation, the energy produced by the module can be calculated:

Maximum energy produced by module (in watt hours per day)	=	53 Wp x 6.5 peak sun hours
	=	345 watt hours

**Note:** A more accurate method of estimating power output is described on page 61.

This is enough energy to run a 15 watt television for 23 hours, or to run two 8 watt fluorescent tube lamps for about the same amount of time. However, this is not enough energy to run a 1500 watt cooker for more than a few minutes.

### Choosing Solar Cell Modules

Modules should be chosen according to the energy requirements of the system load. Information on calculating the system load and planning systems is given in Chapters 7 and 9. Table 3.1 gives details on three types of modules available in East Africa.

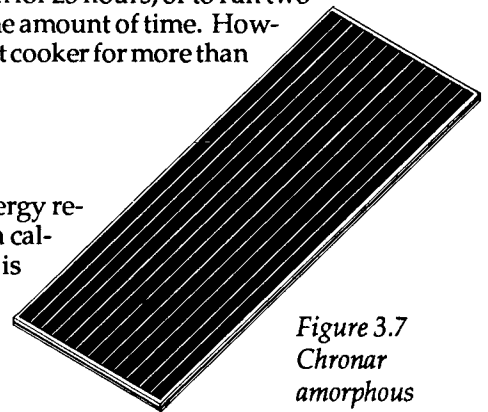
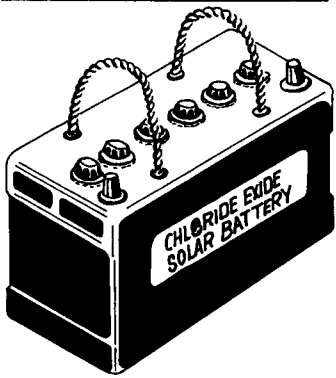


Figure 3.7  
Chronar  
amorphous  
module

Modules should be chosen according to the energy requirements of the system load.

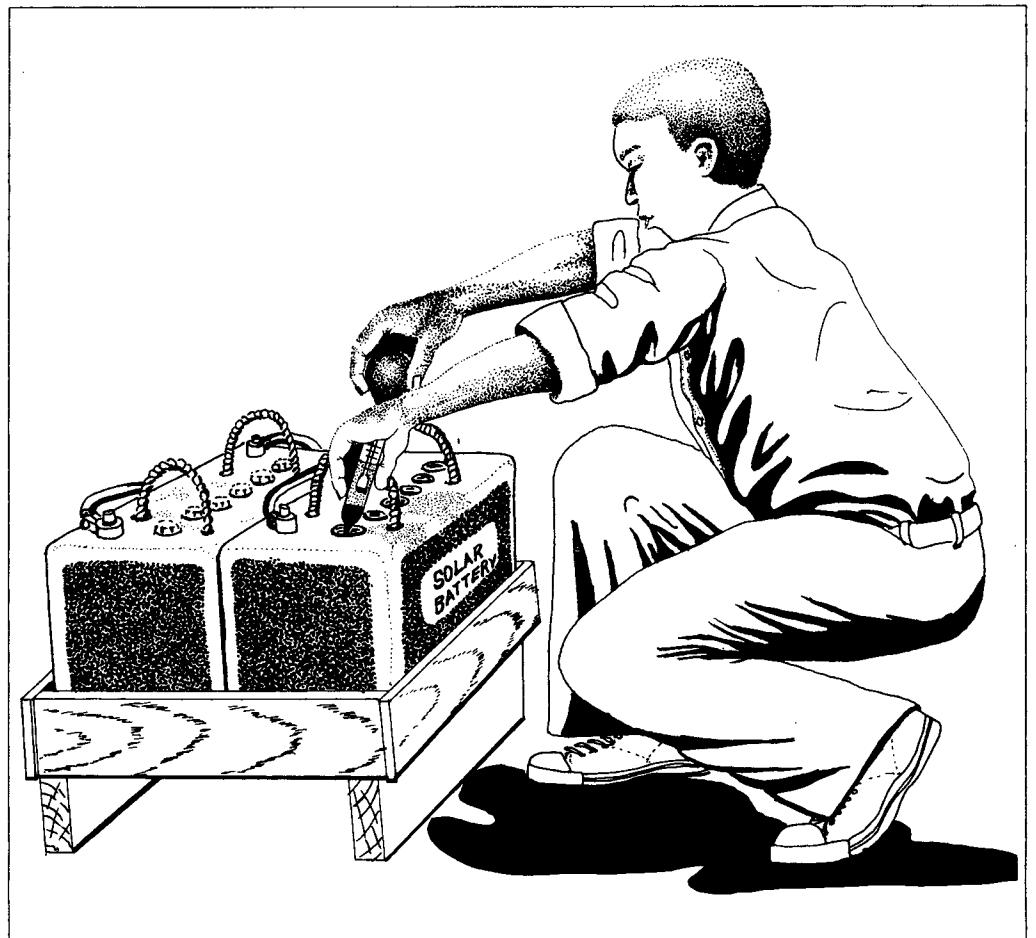
Table 3.1: Features of Three Modules Available in East Africa

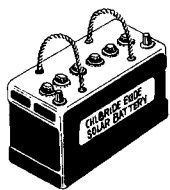
MODULE	CHRONAR CSA 13 E	SOLAREX MSX - 30	SIEMENS (ARCO) M-65
Peak Power (Wp)	12 Wp	30 Wp	42 Wp
Type of cells	Amorphous	Polycrystalline	Monocrystalline
Current at Peak Power (I <sub>p</sub> )	0.72 amps	1.75 amps	2.90 amps
Short Circuit Current (I <sub>sc</sub> )	1.08	n/a	3.3 amps
Open Circuit Voltage (V <sub>oc</sub> )	24.0	n/a	18.0 volts
Overall Module Efficiency	4%	10%	12%
Number of Cells	30	36	30



## Chapter 4 Batteries

*This chapter provides information about rechargeable batteries which are used for storing solar charge. Principles and operation of lead-acid and nickel-cadmium batteries are outlined. Battery concepts discussed include storage capacity in amp hours, charge and discharge, state of charge, cycle life, depth of discharge, and self discharge. The problems caused by deep discharge and overcharging of batteries are discussed in detail, and types of batteries available in East Africa are presented. The practice of battery management and maintenance is introduced (together with a description of the tools needed).*





Batteries

A battery is like a tank for electric energy. It is impossible to remove more energy from the battery than was put in by charging.

## Energy Storage Theory

Solar cell modules generate electricity *only when the sun is shining*. They do not store energy. If solar electric power is used to pump water into a storage tank, there is no need to store the energy from the modules because the pumped water is stored in a tank while the sun is shining. Unfortunately, this is not the case with solar electric lighting systems. Electric lights are required when the sun is *not* shining, so it is necessary to find a way to save the electric power generated during the day so that it is available at night.

The most obvious answer to this problem is to use *batteries*, which chemically store electric energy. Other proposed solutions to energy storage include flywheels (which store energy in rotating wheel-like masses), compressed air, and pumped water. Today these are neither practical nor economical for small systems. In fact, all of the stand-alone PV lighting and refrigeration systems installed in East Africa use some type of battery system to store their harvested solar energy.

Stated simply, a battery is like a tank for electric energy. The solar array collects solar energy, producing an electric charge as long as the sun is shining. The charge travels through wires into the battery where it is converted to stored chemical energy. Over the course of several days, a battery may 'fill' with stored energy like a water tank 'fills' with water collected from the roof top gutters.

Note that it is *impossible* to remove more energy from the battery than is put in by charging. As is the case with the tap of a water tank left open, if an appliance is left ON by accident, electricity will drain from the battery. Batteries operate like energy bank accounts. From the bank, as with batteries, you can never get something for nothing. You cannot take out more energy from a battery than was put in. Like a bank account as well, the long-term benefits from a battery are greatest when a large amount of energy is kept in the battery.

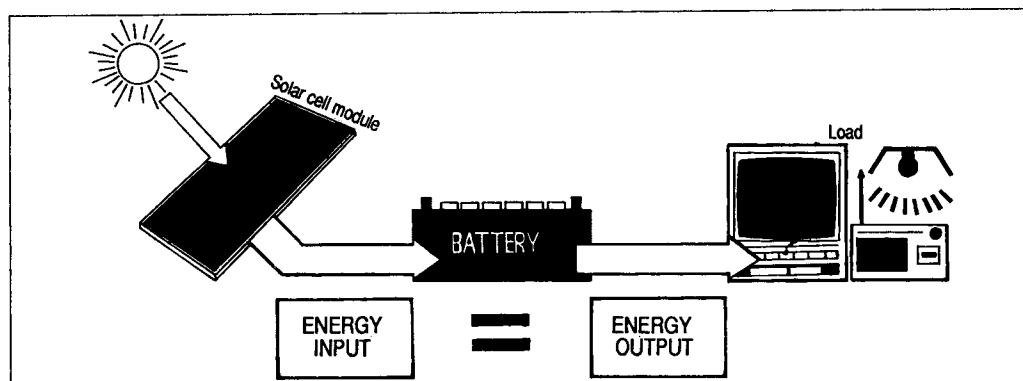


Figure 4.1 Energy input from the solar module must balance the energy output to the load.

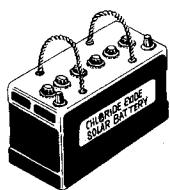
As a battery is charged, electric energy is stored as chemical energy within the battery cells.

## Battery Principles and Operation

Batteries are groups of *electrochemical cells* (devices that convert chemical energy into electrical energy) connected in series. Battery cells should not be confused with solar cells, which operate according to completely different principles. Battery cells are composed of two *electrodes* (also called plates) immersed in *electrolyte* solution which produce an electric current when a circuit is formed between them. The current is caused by reversible chemical reactions between the electrodes and the electrolyte within the cell.

Some cells can only be used once (i.e. dry cells) while others can be recharged over and over again (these are called *accumulators* or *secondary batteries*). Because dry cells available in shops cannot be recharged, this chapter is concerned with rechargeable secondary batteries only.

As a battery is charged, electric energy is stored as chemical energy within the cells. When the battery is being *discharged* (i.e. when it is connected in circuit with a load), stored chemical energy is being removed from the battery and converted to electrical energy.



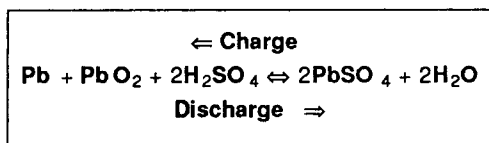
## Batteries

Nicad batteries have some advantages that should be considered when planning small systems.

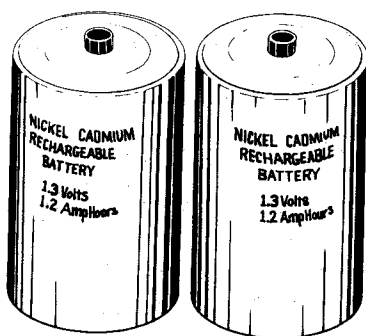
The two most common types of secondary battery systems on the world market today are *lead-acid* and *nickel-cadmium* batteries. In East Africa, lead-acid batteries are far more readily available than nickel-cadmium batteries (also called *nicad* batteries, for short), but nicads are used in a number of installations. Nicad and lead-acid batteries contain different types of electrodes and different electrolyte solutions.

As indicated by its name, the lead-acid battery operates on the basis of chemical reactions between a positive lead dioxide plate ( $PbO_2$ ), a negative lead plate ( $Pb$ ) and an electrolyte composed of sulphuric acid ( $H_2SO_4$ ) with water ( $H_2O$ ). When a battery is being charged, lead dioxide accumulates on the positive plate, spongy lead accumulates on the negative plate, and the relative amount of sulphuric acid in the electrolyte increases. When the battery is being discharged, lead sulphate ( $PbSO_4$ ) accumulates on the negative plate, and the relative amount of water in the electrolyte increases (see chemical equation below). Each cell in a lead-acid battery has a voltage of about 2.0 volts.

### Chemical Equation for Lead-Acid Battery Charge and Discharge:



Nicad batteries operate on the basis of similar chemical reactions between the positive nickel hydroxide electrode and the negative cadmium hydroxide electrode in a potassium hydroxide electrolyte. Each nicad cell has a voltage of about 1.3 volts.



### Nicad Batteries

Nicad batteries are more expensive per unit of storage than lead-acid batteries; for this reason most installations choose lead-acid batteries. However, nicads have some

advantages that should be considered, particularly by small system planners:

- Nicads are lighter and available in smaller sizes. Nicads, sized like dry cell batteries, can be used to power appliances such as radios, cassette players and torches.
- They can be completely *discharged* without damage to the cells, and they can be left for long periods in a low state of charge (see page 28). In very small systems without charge controllers, this is an important advantage.
- Nicads can be operated over a wider range of temperatures than lead-acid batteries.
- Nicad batteries require less maintenance than most lead-acid batteries, an important consideration at sites where the system maintenance is a problem.
- Finally, nicad batteries have a very long life compared to lead-acid types. Locally available 1.3 volt cells (packed like dry cells, see Figure 4.2) have a calendar lifetime of between 3-4 years when used in solar electric systems. Larger nicad batteries may last longer than 10 years.

Assembly of nickel cadmium batteries has been carried out on a limited basis in East Africa (i.e. for Kenya Railways by Associated Battery Manufacturers, Nairobi). However, at present the demand for such batteries is far too low to justify the high cost of production. Furthermore, cadmium is a very poisonous chemical, and the environmental problems posed by large-scale manufacture and use of such batteries must also be solved before production begins.

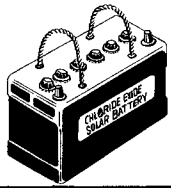
### Lead-acid Batteries

The discussions that follow in the next several sections concern lead-acid batteries. Where nicad batteries differ significantly from lead-acid batteries, the point is made.

#### Lead-acid Battery Hazards:

- Lead-acid batteries contain corrosive sulphuric acid. If spilled, sulphuric acid will burn the skin or eyes; it will burn holes through clothes and furniture, and it will damage cement floors.
- If acid is splashed into the eyes, rinse the eye continuously for 10 minutes with clean water. Then take the affected person to the hospital for further treatment.

Figure 4.2 Rechargeable nickel-cadmium cells. Such cells can be connected with solar modules and used to power radios and torches.



Batteries

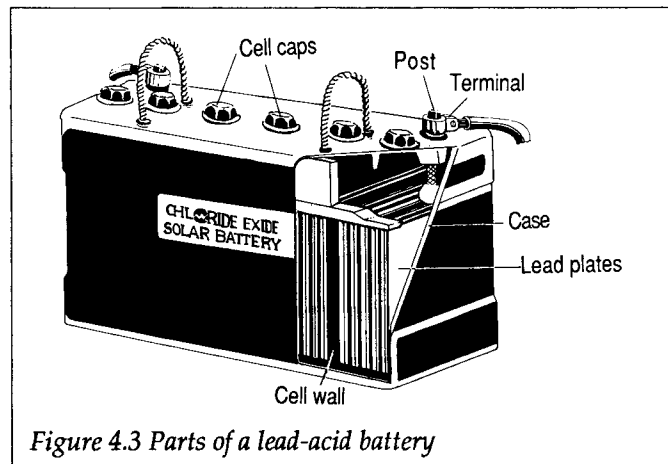


Figure 4.3 Parts of a lead-acid battery

The amount of energy that a battery can store is called its capacity, and is indicated in amp hours.

You should never use the full capacity of a lead-acid battery, as this will damage its plates.

- If acid gets splashed on skin wash immediately with plenty of water.
- If acid spills on the floor, rinse the floor with water, and pour "chapa mandazi" (bicarbonate of soda) on the acid.
- Batteries give off explosive hydrogen gas when they are being charged. This gas must be vented away from the battery to prevent explosions. Do not smoke or carry open flames in battery storage rooms.
- Batteries contain a large amount of energy. Make sure nothing can accidentally be placed across the terminals. If the terminals are shorted, they could cause a bad shock, or a fire.

There are many types of lead-acid batteries, which fall in two general categories: *deep discharge* and *shallow discharge*. Deep discharge batteries are preferred for solar electric systems because more energy can be taken out of deep discharge batteries than shallow discharge batteries without causing damage to the cells (these terms are explained on pages 28 and 29).

Shallow discharge batteries (i.e. automotive batteries) are designed to supply a large amount of power for a short duration; taking too much energy out of these batteries before recharging them is likely to damage the plates inside. If chosen for solar electric systems, shallow discharge batteries *must be managed very carefully*, or the results will be expensive and disastrous.

Shallow discharge automotive batteries are manufactured by Yuasa battery company in Dar es Salaam and by Uganda Bat-

teries in Kampala. Both shallow and deep discharge batteries are manufactured in Nairobi by Associated Battery Manufacturers.

### Rated Storage Capacity

The amount of energy that a battery can store is called its *capacity*. A water tank, for example, with a capacity of 8000 litres can hold at *most* 8000 litres. Similarly, a battery can only store a fixed amount of electrical energy, typically marked on the side

of the battery by the manufacturer.

The capacity of a battery is measured in *amp hours (Ah)*. This indicates the amount of energy that can be drawn from the battery before it is completely discharged (note that amp hours are *not* a measure of energy — to convert amp hours to energy in watt hours, multiply by the battery voltage). A battery of 100 Ah should ideally give a current of 2 amps for 50 hours (i.e. 2 amps times 50 hours equals 100 amp hours). The rated storage capacity, however, is a general guideline and not an exact measurement of the battery's size, as capacity changes with a battery's age and condition, and the rate at which power is drawn from it. If current is drawn from the battery at a high rate, its capacity is reduced.

### Charge, Discharge and State of Charge

*Charge current* is the electric current supplied to and stored in a battery. As a water tank will take more or less time to fill depending on the rate at which water enters it, the amount of time required to completely charge a battery depends upon the size of the *current* at which it is being charged. Batteries can be charged by solar cell modules, by mains-power connected to a battery charger, or by diesel, petrol or automobile engines attached to a properly-sized alternator or generator.

The amount of charge a battery has received ( $Q$ , in amp hours) can be approximately determined by multiplying the charging current ( $I$ , in amps) by the amount of time the current has been left on ( $T$ , in hours):



## Batteries

$$Q \text{ (amount of charge in amp hours)} = I \text{ (charging current in amps)} \times T \text{ (time in hours)}$$

If this figure (Q) is multiplied by the battery voltage, then the energy supplied to the battery will be given in watt hours.

Of course, some energy is always lost in the charging and discharging process as heat. Depending on the type of battery and its age, the energy lost is between 10 and 30% for lead-acid batteries.

Batteries should not be charged at a current that is higher than one tenth of their rated capacity. Thus a 70 Ah battery should not be charged at a current of more than 7 amps. When batteries are charged at too

high a current, the electrolyte level falls quickly because of gassing and the cells may be damaged. Low currents are more efficient than high currents for charging batteries.

Most solar cell modules are designed to charge 12 volt batteries. In a 12 volt system, the *solar charge* from a 40 Wp module does not get much higher than 3 amps, which is well-suited for charging a 100 Ah battery.

*Discharge* is the state a battery is in when its energy is being used by a load (i.e. lights, radio or television). The *discharge current* is the rate at which current is drawn from the battery. The amount of energy removed from a battery over a period of time can be calculated (as charging energy was determined above) by multiplying the discharge current by the amount of time the load is used. For example, a lamp drawing 1.2 amps for four hours uses 4.8 amp hours of energy from the battery (1.2 amps x 4 hours = 4.8 amp hours).

The *state of charge* is a measure of the energy remaining in the battery. It tells whether a battery is fully charged, half charged or completely discharged. With lead-acid batteries (but *not* with nicads) it is possible to measure state of charge using a hydrometer or voltmeter (see page 31). The cells of a fully charged battery have a state of charge of 100%, while those of a battery with one quarter of its capacity removed are at a 75% state of charge.

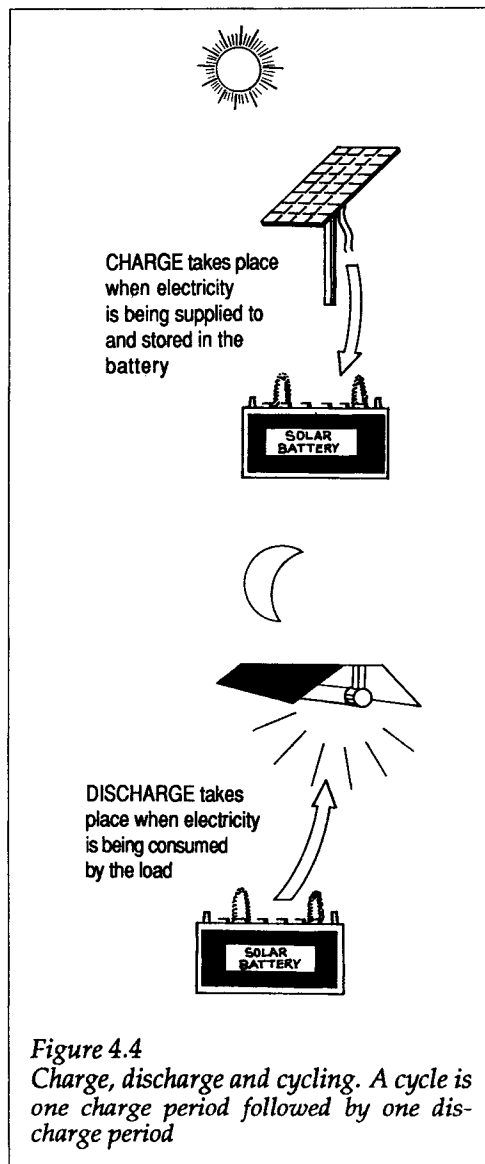
## Cycle, Cycle Life and Depth of Discharge

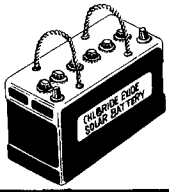
A battery in a solar electric lighting system is charged each day by the solar cell module and then discharged by the load each night. Each charge period together with the following discharge period is called a *cycle*. For example, in one *cycle* a 100 Ah battery might be charged up to 95% state of charge during the day, and then discharged by lights and television to 75% state of charge that evening.

The *cycle life* of a battery is the number of cycles it is expected to last. Most batteries have a cycle life of several thousand cycles; nicads usually have longer cycle lives than lead-acid batteries. The *rated cycle life* of a battery (this should be specified by the manufacturer) is the number of cycles a battery is expected to last before its capac-

Several deep discharges will ruin or drastically shorten the life of a lead-acid automotive battery.

State of charge is a measure of the energy remaining in the battery.





## Batteries

With small solar electric systems, deep discharging is a more common problem than overcharging.

Lead-acid batteries should not be left standing uncharged for long periods of time.

ity drops to 80% of its original rated capacity. The actual cycle life of a battery is shortened by deep discharges (see below), high temperature, and too much discharging at a high rate.

*Depth of discharge (DOD)* tells how much batteries are discharged in a cycle before they are charged again. Shallow cycle batteries should not be discharged below 80% state of charge on a regular basis. Deep cycle batteries should not regularly be discharged below 40% state of charge.

A *deep discharge* cycle is a cycle in which a battery is completely or almost completely discharged. This typically occurs during long cloudy periods, or when the load is much larger than the solar charge.

In East Africa, the most common cause of failure in solar lighting systems is abuse of batteries by deep discharge during cloudy weather. Small lighting systems often work well during sunny weather, but fail during the cloudy season. This is because there is not enough solar charge to meet the energy demands. If the battery is very low after a week or more of cloudy weather, it should immediately be charged by an alternative method. Meanwhile, the use of electricity should be reduced to protect the battery until the weather gets sunny again.

### Self-discharge

If they are left standing uncharged, all batteries lose charge slowly by a process called *self-discharge*. This occurs because of reactions within the cells of the battery. For example, cars that have not been used for several months often do not start due to self-discharged batteries.

The rate at which batteries lose their charge depends on the temperature, the type of batteries, their age and condition. As batteries get older, their rate of self-discharge goes up. As well, dirty batteries (i.e. those with a high accumulation of acid mist on their surface) tend to have higher self-discharge rates. Warmer weather increases the rate of self-discharge. Normally, new batteries do not discharge more than 5% per month. However, in hot weather, old automotive lead-acid batteries may lose up to 40% of their capacity per month if they are not charged regularly.

To avoid high self-discharge rates:

- store the battery off the floor in a wooden battery box or non-metallic tray (see page 88);
- keep the top surface of the battery clean;
- keep the terminals clean and greased.

Lead-acid batteries left in a low state of charge for long periods lose some of their capacity due to *permanent* chemical changes in the plates (i.e. *sulphatation* of the plates). If a battery is left in a low state of charge for over a month, it may not accept its rated charge capacity, or it may not accept charge at all. (Note that nicad batteries *can* be left discharged for long periods without damage).

### Overcharging and Charge Controllers

Batteries left on solar charge after they have been fully charged are said to be *overcharged*. If, for example, a 70 Ah battery at a 100% state of charge is still connected to a solar module on a sunny day, it will be *overcharged*. Small amounts of overcharging will not damage a battery (i.e. a 40 Wp module is unlikely to overcharge a 100 Ah battery), but continued overcharging of a battery causes a loss of electrolyte, damage to the plates, and a shortened life-span.

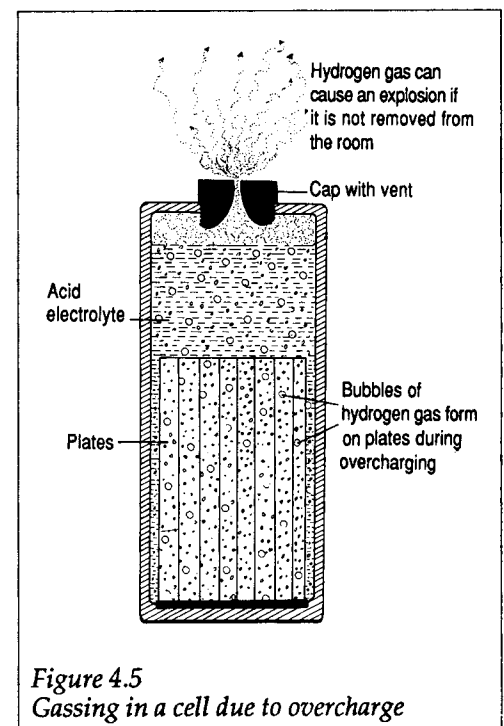
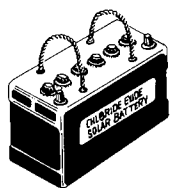


Figure 4.5  
Gassing in a cell due to overcharge



## Batteries

When a battery is being overcharged, it loses water by *gassing*. Since a fully charged battery can no longer hold solar charge from the module, the charge causes a chemical reaction which changes water in the electrolyte to hydrogen gas which escapes from the electrolyte as bubbles. Gassing causes two problems: First, the level of electrolyte in each cell goes down. Distilled water must be added to replace it. Secondly, explosive hydrogen gas is given off. To avoid the risk of explosion, this gas must be vented from the battery storage area.

In order to avoid damaging the battery by overcharging, several steps should be taken:

- a device called a *charge controller* may be connected between the battery and the solar module (see page 34). When the battery is fully charged, the charge regulator reduces the solar charge entering the battery to a *trickle*. This prevents water loss from the cells by gassing.
- the battery's state of charge should be checked regularly to determine whether it is being overcharged (see page 31).
- if a battery is being overcharged, the load should be left on longer, or, if there is no charge regulator, the solar charge should be disconnected when the battery is fully charged.

### Types of Lead-acid Batteries

#### Automotive Batteries

Automotive batteries (also called Starting, Lighting and Ignition or SLI batteries) are shallow discharge lead acid batteries used mainly for starting car engines. They have a low self-discharge rate (1-4% per month when new) and they have a long cycle life with shallow cycling (i.e. if the battery is not taken below 80% SoC).

They are *not* the best choice of energy storage for solar electric lighting systems. However, since they are locally-manufactured, cheap and widely available in East Africa, many people do use automotive batteries for powering lights and televisions in rural areas. For those installing systems on limited budgets, 40 - 100 amp hour automotive batteries may be practical options.

If automotive batteries are chosen, special care should be taken to ensure they last as long as possible. They should not be used below 80% state of charge (i.e. only 20% of their capacity should be removed per cycle). Furthermore, during cloudy weather, they should be carefully maintained and taken for charging in town if necessary.

#### Lead Antimony (Motive) Batteries

Lead antimony batteries are deep discharge batteries which were originally designed to power electric vehicles. Antimony is added to the positive plate, enabling the battery to withstand deep discharges of between 50 and 80%. Lead antimony batteries have higher self discharge rates, however, and require more frequent additions of distilled water.

#### Example: ABM Solar Battery

Associated Battery Manufacturers, Kenya Ltd., (ABM) in Nairobi manufactures 12 volt lead antimony batteries for use in small solar electric systems. The batteries, available in 70 and 100 amp hour capacities, have been specially developed for solar electric uses. Their features include the following:

- A good cycle life. Cycle life should be between 1000 to 2000 cycles (i.e. between 3-6 years) if the batteries are not deep discharged too often.
- A low self-discharge rate of between 2 and 4% per month.
- A large electrolyte reservoir to prevent damage from excess gassing and to minimise the need to add de-ionised water.
- Much better tolerance of deep discharge than automotive batteries. The battery will last long under daily discharge of 40%. Still, a daily discharge of 10% gives the longest life.

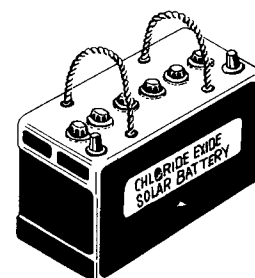
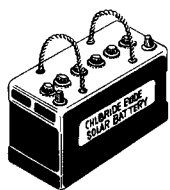


Figure 4.6 ABM solar battery



## Batteries

**Beware of battery acid when measuring the state of charge. Wear old clothes, and keep plenty of water nearby to rinse spilled acid.**

### Captive Electrolyte (Gel) Batteries

Captive electrolyte batteries use a non-liquid electrolyte to eliminate the problems of water loss through gassing. Sealed at the factory, they do not leak or spill, so they are easily transported and require less maintenance. They can withstand deep discharges, and have a good cycle life (i.e. 2 years when cycled to 50% SoC and 3 years when cycled to 25% SoC at 25°C). They have a low self discharge rate.

Captive electrolyte have poor performance characteristics at high temperatures, so they should not be used in hot sites. They are among the most expensive type of battery.

### Measuring State of Charge

The state of charge is checked to determine whether the battery is being discharged too much, and to determine whether there are any bad cells. Each battery in a solar electric system should have its state of charge checked at least once a month. Heavily used small systems should have battery state of charge checked once per week during cloudy weather.

When measuring state of charge, check the electrolyte level in each cell to make sure that it has not fallen too low due to gassing.

As mentioned above, it is possible to measure the state of charge (SoC) of a lead-acid battery using either a *hydrometer* (a tool which measures the thickness of sulphuric acid) or a *voltmeter*.

Hydrometers are more accurate than voltmeters. They measure the *density*, or the weight per unit volume of the sulphuric acid electrolyte in a cell (this is also called the *specific gravity*), which is directly related to the state of charge of the battery. As lead-acid batteries are discharged, the sulphuric acid within each cell is converted to water, which has a lower density than sulphuric acid. As the cell is discharged, the electrolyte becomes less dense and the battery's state of charge decreases.

#### Hydrometers

Typical hydrometers contain a floating scale with specific gravity readings. Use the hydrometer as follows:

1. Draw sulphuric acid up into the hydrometer from the battery cell by

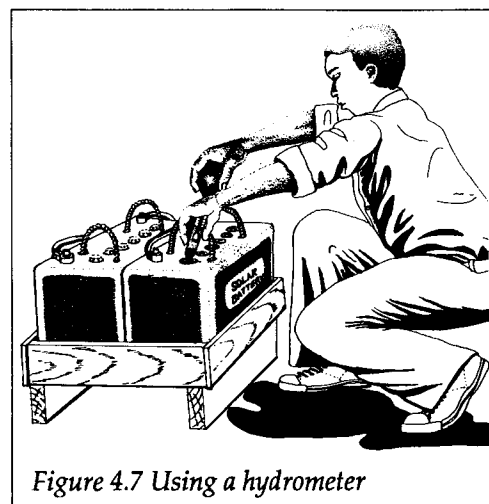


Figure 4.7 Using a hydrometer

squeezing the bulb while the nozzle of the hydrometer is placed in the cell (see Figure 4.7).

2. The scale floats at a level that varies according to the density of the acid, and the state of charge of the cell.
3. Read the specific gravity of the cell from the scale floating in the acid (see Figure 4.8). Sometimes the hydrometer scale does not give the specific gravity, but only tells whether the battery is in a low, medium or high state of charge.
4. Consult a state of charge vs. specific gravity table or graph to determine the SoC (i.e. for ABM solar batteries, see below).

The arrow and dotted lines in Figure 4.9 show that if the specific gravity reading is 1205 with an ABM solar battery, the state of charge is about 80%.

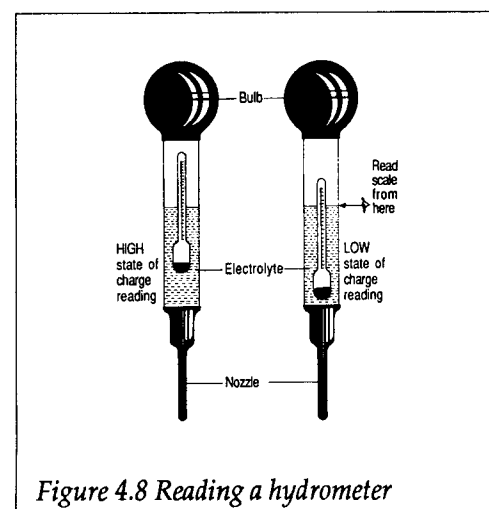
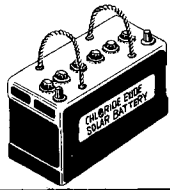


Figure 4.8 Reading a hydrometer



Batteries

Table 4.1 What the Hydrometer Readings Mean with ABM Battery

Specific Gravity (grams/litre)	Stage of Charge	Action to be taken
1210 and above	Good	None. Battery cell is fully charged.
1160 - 1210	Fair	The cell needs charging. Reduce use of lights and appliance
1110 - 1160	Poor	The cell is almost flat. Do not use load until battery is charged.
Below 1110	Flat	The cell is flat. Take for recharging at a petrol station.

Figure 4.9 Using specific gravity to measure the ABM "Solar" battery's SoC

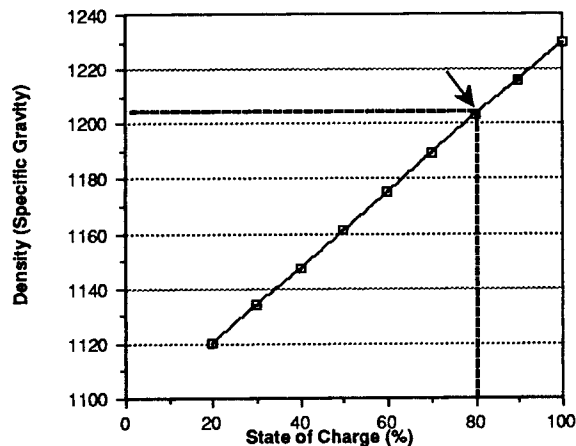


Table 4.2 State of Charge for ABM Solar Battery

State of charge (%)	Specific Gravity (grams/litre, 25°C)	Open circuit voltage (volts)
100	1230	12.74
90	1216	12.62
80	1203	12.50
70	1189	12.36
60	1175	12.25
50	1161	12.13
40	1147	12.00
30	1134	11.87
20	1120	11.75
10	n/a	11.64
0	n/a	11.51

Battery state of charge can be measured with voltmeters or hydrometers.

#### Voltmeters

Voltmeters are also used to measure a battery's state of charge. As the state of charge of a lead-acid battery decreases, its voltage also decreases. An ABM solar battery at 100% state of charge, for example, has a voltage of about 12.7 volts; when discharged to 50% SoC its voltage will be about 12.1 volts (see Table 4.2). The actual reading varies with the type of battery and the temperature.

To measure a battery's state of charge with a voltmeter:

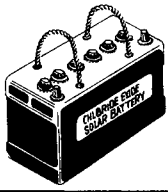
1. Disconnect the battery from the load and solar charge. If the battery was being charged (or discharged), wait 20 minutes to allow the cell voltages to stabilise *before taking a measurement*. If you measure right away, the reading will be inaccurate.
2. Connect the voltmeter's leads to the positive and negative terminals of the battery. Read the voltage on the voltmeter and compare it to the reading on a state of charge table that is appropriate to your battery (i.e. Table 4.2).

#### Bad Cells

Sometimes, a battery may have a *bad cell*. This means that, although the other cells in the battery are still working, one cell has stopped functioning properly (possibly due to a short circuit in the plates). When a battery's voltage is low (i.e. about 10.5 volts or less), but the state of charge in most of its cells is high, the battery probably has a bad cell. To check for a bad cell, measure the state of charge of each of the cells in the battery individually using a hydrometer.

If a hydrometer is not available, you can still check a battery in a *low* state of charge for bad cells. To do this, remove the caps of all the cells and short the terminals with an insulated wire. If a cell is bad, it will bubble furiously and produce a disagreeable smell.

It is possible to rebuild bad cells; certain *fundis* have set up businesses charging batteries and repairing bad cells. However, you should first check the work of such *fundis* before paying money to have a battery repaired. Quite often with old batteries, the repair job will only last several weeks before another cell goes bad in the battery. It is often more economical to



## Batteries

Never put an old second hand battery in parallel with a new one.

Do not add tap water, sulphuric acid, battery tonics or any other impure solutions to the cells.

purchase a new battery rather than repair a single bad cell.

### Replacing Batteries

Depending on its type and the way it is treated, a battery in a solar lighting system should last between two and ten years. When the battery is dead, it needs to be replaced. When they finish their cycle life, batteries no longer hold a charge. At this time, the cells may have different state of charge readings.

Typically, one or more cells will fail before the others, so it is a good idea to occasionally check for bad cells in old batteries. Repairing very old batteries is usually futile, because they are likely to fail again. Battery manufacturers buy the cases of old batteries for recycling.

If a system has more than one battery in parallel, the batteries should be of the same age and condition. Putting a new battery in parallel together with an old battery will prevent the new battery from getting fully charged.

### Maintaining Batteries

Batteries will last for a long time (from 2-10 years depending on the type) if they are properly installed, maintained and managed. They should be located in well-ventilated rooms (i.e. where air can circulate).

Tasks involved in maintaining and managing batteries include:

- Regular checking of state of charge to ensure that the battery is performing well. Keeping state of charge records may help to detect when a battery is getting too old to use, or when a cell has gone bad.
- Checking electrolyte levels in each cell. Replacing water lost during gassing with *de-ionised* water. The plates should always be below the level of the electrolyte to avoid damage to the battery. De-ionised water, which is available at battery shops, is used instead of tap water because it does not contain any impurities which could damage the cells. Rainwater or home-made distilled water may be added to replace lost electrolyte (see page 93).
- Cleaning the top of the battery. This avoids high rates of self-discharge caused by electrical conduction through acid mist accumulating on

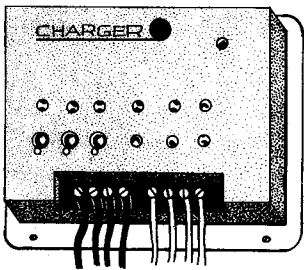
top of the battery.

- Cleaning terminals and contacts. Cleaning the terminals ensures a good electrical contact with the solar array and load. Application of petroleum jelly or grease to the terminals prevents them from becoming corroded.
- Giving the battery occasional *equalizing charges* to mix up the electrolyte. Equalising charges are charges well above the normal "full" charge which cause the electrolyte in the cells to bubble and get mixed up. These charges can be done in town, preferably in the cloudy season when the solar radiation is low.

### Alternatives to Solar Charging

Systems should be designed so that the module is large enough to keep batteries in a high state of charge *even in cloudy weather*. However, because of the high expense of modules, and because of the lengthy cloudy periods in some areas, small lighting systems sometimes do not receive enough solar charge to meet the load requirements. In such cases, the users should protect the battery from deep discharge by charging it with an alternative method:

- *Charging with a battery charger:* The battery can be taken to town for charging. In many small towns, petrol stations or *jua kali* industries operate battery chargers from mains, and top batteries up for a small fee.
- *Charging from a car's alternator:* Batteries can also be charged from the alternator of a car. This is done by replacing the battery in the car with the solar battery and, *either* running the engine when the car is stationary for enough time to bring the battery to a high state of charge, *or* driving the car on a journey with the solar battery in the place of the other battery.
- *Charging with a bicycle generator:* Nicad cells can be charged with a bicycle generator. The generators available for bicycles produce a current of less than one amp at about four volts, and an hour or two of easy pedalling should bring a pair of nicad cells to full charge. In cloudy weather, a bicycle can thus be used to charge nicads as a supplement to small modules. Using a transformer, small (below 50 Ah) 6 and 12 volt batteries can also be charged.



# Chapter 5

## Charge Controllers and Load Management

*This chapter discusses charge controllers, devices which are used to manage the energy flow in solar electric systems. The work of charge controllers is described, and controller components are introduced, including fuses, main switches, blocking diodes, LED indicators, low voltage disconnects, and charge regulators. The choice of charge controllers in East Africa is briefly described. Management of small systems without charge controllers is also considered.*

As explained in Chapter 4, the success of a solar electric lighting system depends, to a large extent, on the performance of the batteries. For a system to operate well and have a long lifetime, the batteries must be kept in as high a state of charge as possible. The energy entering the batteries during the day (i.e. the solar charge), must be roughly equivalent to the energy being discharged from the batteries at night by the load.

Any solar electric lighting system must be managed so that the energy flow from the batteries to the load is not too great, and so that the energy flow into the batteries from the modules is not too great. Most solar electric systems use a charge controller to manage the electrical power produced by

the modules, and to act as a connection point for all the system components. To save money, some designers of small lighting systems do not include charge controllers in the system, and instead rely on the user to manage the energy flow.

### The Charge Controller

The charge controller, or control panel (as it is sometimes called), has two primary functions. First, it provides a central point for connecting the load, the module and the battery. Secondly, it manages the system so that the harvested electricity is effectively used, and so that components are protected from damage due to changing voltage levels.

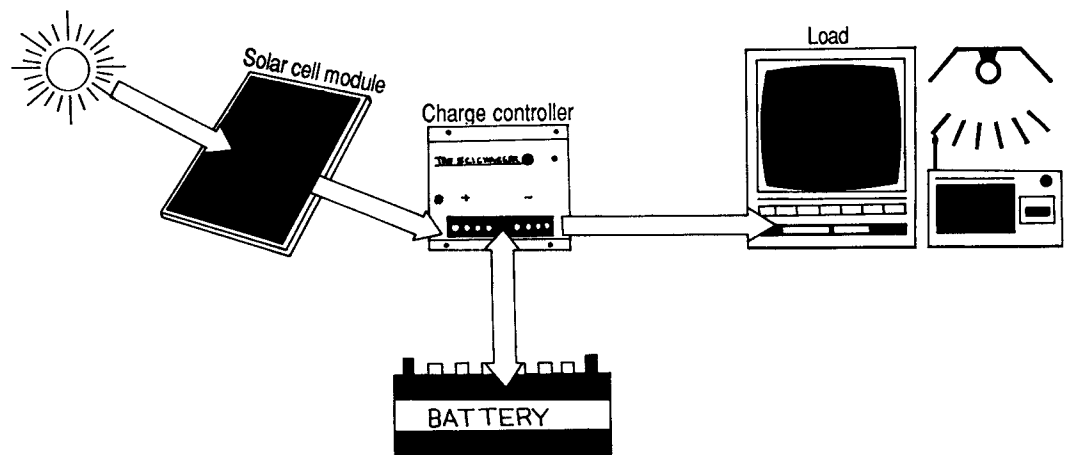
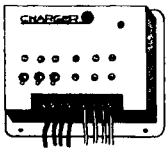


Figure 5.1: Role of a charge controller in energy management



## Charge Controllers and Load Management

The charge controller provides a central point for connecting the load, module, and battery. It also manages the system so that harvested electricity is effectively used.

### System Connections

The control panel, at the very least, should act as a *junction box*. Here, the battery, solar module and load are fastened together by means of connector strips, and fuses are incorporated to protect the equipment from damage by *short circuits*.

**Fuses and circuit breakers.** The controller should contain the system *fuses* or *miniature circuit breakers (MCB's)*. Fuses and circuit breakers protect the major circuits in the system from short circuits. Simple automotive-type fuses or fuse wires are readily available in East Africa. Five amp fuses are sufficient for very small systems, while 20 amp fuses (or larger) are necessary for larger systems. MCB's are small switches that automatically break the circuit when there is a short circuit. They can be switched back ON when the wiring problem is corrected. Both the charge wire from the solar cell and the load wires (to the lights and to other loads) should be fused or protected by an MCB.

### Main circuit switches.

It may be necessary to control certain loads from the centrally-located control panel using *main circuit switches*. For example, in a school, classroom lights may be switched ON from the charge controller located in the office. This prevents misuse of lights by students in the classrooms. In a home, the lights can be turned OFF from the main circuit switch during the day to prevent draining of the battery by lights accidentally left ON.

### Power Management

Charge controllers perform services that protect the system and notify the user as to whether the system is functioning properly.

Charge controllers often contain a *blocking diode*. Blocking diodes prevent current from flowing from the batteries to the solar cell module when the battery voltage is higher than the module voltage (see Figure 5.3). When the modules are not

producing current at night, the battery voltage is higher than that of the modules, and current will flow *backwards* to the modules. This loses energy in the system. A blocking diode is like a one-way gate that allows current to enter the battery from the module but does not allow it to flow back. Instead of using a blocking diode, some charge controllers automatically disconnect the solar modules from the battery when no current is flowing from the module. Blocking diodes may also be installed inside the junction box of the module by the solar electric agent.

Part of the work of charge controllers is to inform the user whether the system is properly working. Usually, light-emitting diodes (LEDs), beepers or alarms are used for such purposes:

- The *solar charge light* indicates whether a current is flowing from the solar array to the battery. It lights up when the array is charging the battery. If the solar charge light

does *not* come ON when the sun is out, the cause could be any of the following problems:

- a loose connection on the charge wire
- bad fuse or disconnected circuit breaker
- loose battery terminal
- bad battery or cell
- broken solar cell module

- The *low battery light* notifies the user that the battery is in a low state of charge. If this light comes ON, the user should completely stop, or reduce *as much as possible*, the use of electrical lights and appliances until the battery is in a higher state of charge. Some controllers use an alarm or beeper instead of an LED light. The low bat-

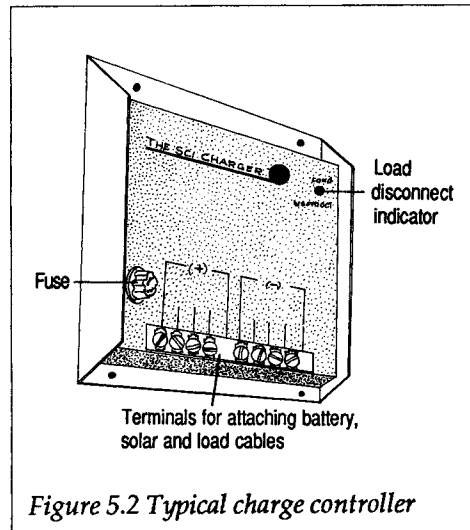
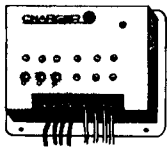


Figure 5.2 Typical charge controller

Blocking diodes prevent current draining from the batteries to the solar cell modules at night.



## Charge Controllers and Load Management

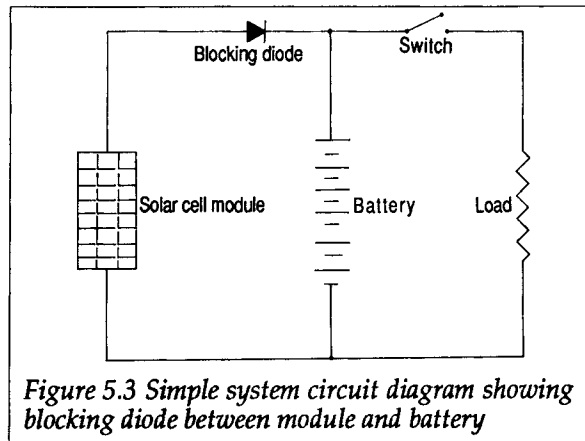


Figure 5.3 Simple system circuit diagram showing blocking diode between module and battery

tery light avoids the need to continually use a hydrometer to check the battery state of charge.

- The *battery full light* tells the user that the battery is fully charged, and, with some controllers, that the controller has reduced the battery charging current to a trickle charge.

Charge controllers often manage the system by automatically disconnecting the load or array from the battery.

- The *low battery disconnect* continuously measures the state of charge of the battery. If the state of charge drops to a level that is too low (for example, 40% SoC), the charge controller disconnects the load from the battery. This might happen during the cloudy season when the television is being used too much, and when there is not enough charge to bring the battery state of charge up. With some charge control-

lers, the level at which the controller cuts off the load can be adjusted.

- The *charge regulator* prevents the array from overcharging the battery. Like the low battery disconnect, it also monitors the battery's state of charge. When it gets above 90% SoC, the controller reduces the current from the module to a *trickle charge*, which is a very small current that fills the battery slowly without causing gassing. Such

a charge regulator is not required when the battery is properly matched to the solar cell module (i.e. a 40 Wp module attached to a 100 Ah battery does not normally require a charge regulator).

The controller may include other features to enhance the system's performance.

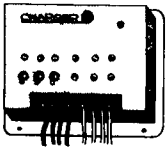
- *Load timers* are switches that connect and disconnect loads after a certain amount of time. They automatically turn loads ON, limit the amount of time that the loads are kept ON, and prevent abuse of the battery. For example, in a school, a load timer might switch classroom lights so that they come ON at sunset, stay ON for three hours before automatically being turned OFF.
- *Ammeters* and/or *voltmeters* measure the current and potential difference of the load, batteries and modules. On large systems, they are sometimes in-

Charge controllers often manage the system by automatically disconnecting the load or array from the battery.

Table 5.1: Comparison of Three 12 volt Charge Controllers

These three charge controllers are available on the market in East Africa (see Figures 5.2 and 5.4).

Feature	Sollatek SPCC 05	Sollatek SPCC 20	SCI Charger
<b>Installation Size</b>	up to 40 Wp	40 to 200 Wp	up to 200 Wp
<b>Voltages available</b>	12, 24, 48	12, 24, 48	12, 24
<b>Maximum current</b>	5 amps	20 amps	20 amps
<b>Blocking diode</b>	Yes	Yes	Relay disconnect
<b>Low Voltage Disconnect</b>	10.0 volts (adjustable)	10.0 V (adjustable)	11.0 V
<b>Reconnect voltage</b>	11.7 V	12.5 V	13.0 V
<b>Indicator lamps</b>	Green: load connected Red: Battery low, load disconnected	Green: Fully charged, module disconnected Yellow: Charge ON Red: Battery low, load disconnected	Red: Battery low, load disconnected



## Charge Controllers and Load Management

Load timers automatically turn loads ON, limit the amount of time that the loads are kept ON, and prevent abuse of the battery.

stalled in the control panel to allow users to monitor their system's performance. If a voltmeter is installed in the controller, the battery voltage (and hence state of charge) can be checked by looking at the control panel. Similarly, output of the solar modules and the current of the load can be carefully monitored by users.

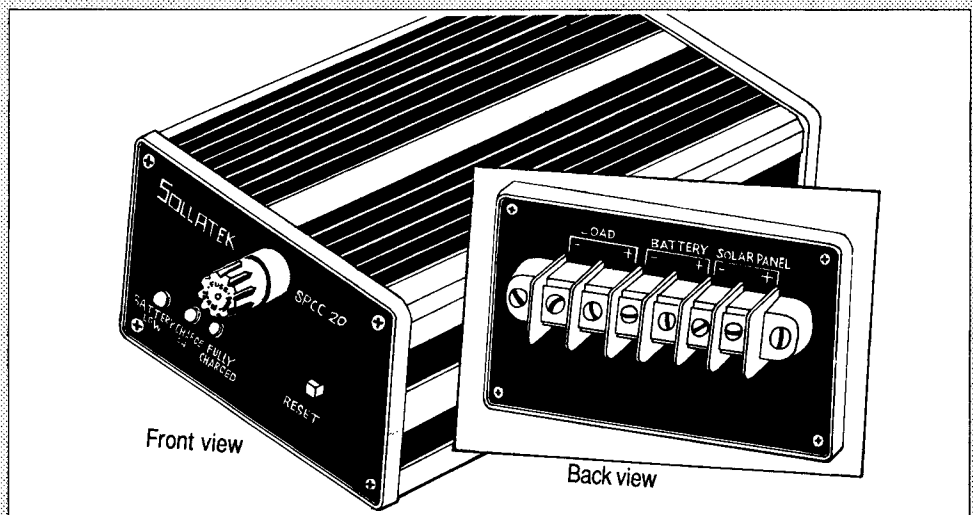
- *Surge protectors* protect the system components and appliances against the rapid power increases expected when lightning strikes nearby. A module (and the other solar equipment) will probably not survive a direct lightning strike but, if lightning strikes nearby, a surge protector would prevent damage to the system. Surge protectors operate by disconnecting

the system when a very high current moves through the wire.

## Choosing Charge Controllers

Charge controllers are rated according to the current they can manage. The smallest available controllers are rated at 5 amps; they best serve systems with a few lamps and a radio. A home with a television, four or five lamps, a cassette player and a sewing machine would require a 20 amp controller. As of 1991, not many charge controllers were available separately in East Africa, but it is hoped that as the industry develops more will become available at lower prices. Table 5.1 compares some of the charge controllers that are available on the local market.

Figure 5.4: The Sollatec SPCC 20 Charge Controller

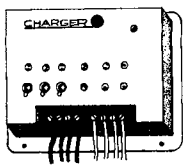


The Sollatec SPCC 20 is an example of a locally-available charge controller. It contains a 20 amp fuse, and is suitable for larger 12 volt home lighting systems (i.e. five or more lights with a television). The controller features a *low voltage lamp* and a *low voltage disconnect* (this is set at 10 volts, which is extremely low, but the manufacturer claims it can be set higher; i.e. 11 volts). When the battery reaches a low state of charge (10 volts), the load is automatically disconnected and a red LED warning lamp comes on. Once the battery has been disconnected, users cannot turn ON lights or television until the battery has reached a higher state of charge and the controller has been reset.

The controller has a green *battery full* indicator lamp which turns ON when the battery is fully charged. When this lamp comes ON,

the charge from the module to the battery is disconnected by a *charge regulator*. There is also a *solar charge lamp* which turns ON when batteries are being charged by the solar modules. If the low voltage disconnect turns OFF the load, then the user must wait until the batteries have been charged up again. After some charging, press the *reset button*. If the state of charge and voltage has gone up sufficiently, the load will be re-connected.

The diagram shows where the cables to the battery, module and load are connected on the back of the controller. Note that the positive and negative terminals are clearly marked. When installing and connecting the controller, the positive and negative leads *must* be connected to the correct terminal (see Chapter 11).



## Charge Controllers and Load Management

If you chose not to use a charge controller, take special care to manage the energy so that the battery is not ruined.

## Local Production of Charge Controllers

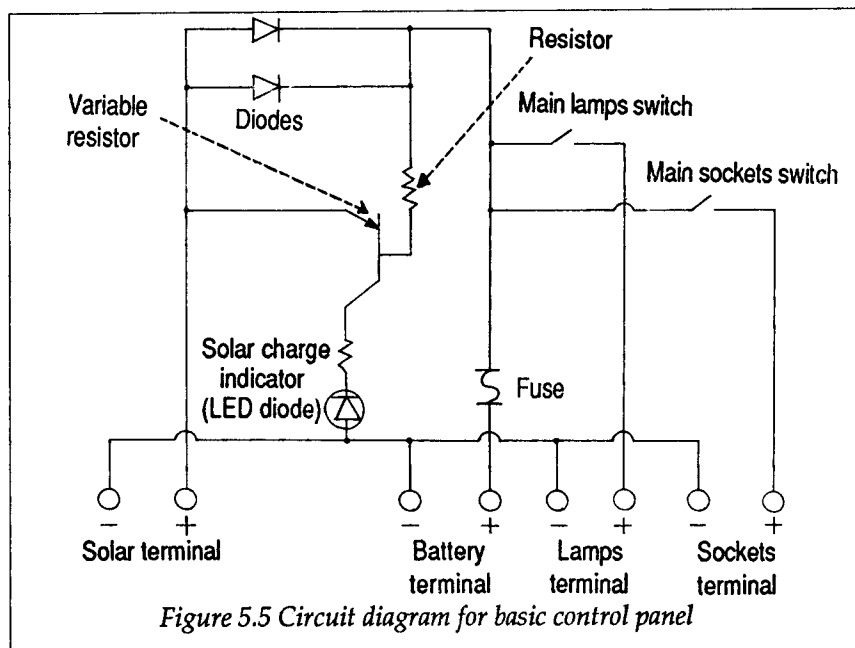
Charge controllers are manufactured from various electrical components (i.e. relays, diodes, resistors and circuit boards). Most charge controllers used in East Africa today are imported. However, they can be assembled from locally-available components. By 1990, at least one East African company had begun assembling charge controllers. Cottage industries in Kenya have successfully designed, assembled and sold their own controllers.

Figure 5.5 shows a circuit diagram which can be used to build a very simple charge controller with locally available electrical spares. The controller has an LED solar charge indicator lamp, a fuse and switches for the sockets and lights. It does not have

must take special care to manage the energy so that the battery is not ruined.

At times there is not enough solar power to fully recharge the batteries, especially in the case of 20 Wp or smaller systems. Take, for example, the cases of Meru, Kenya, Arusha, Tanzania or Mbarara, Uganda which have less than 4.5 peak hours of insolation per day during certain months. As the cloudy days go by, users in such places are likely to take more energy out of the battery each night than was put in by the solar charge, while the battery steadily loses its charge. Within two weeks, the battery may be completely discharged and permanently damaged.

The guidelines below suggest ways by which a system can be effectively managed without a controller. Chapter 10 discusses further techniques of effective energy management (see page 75).



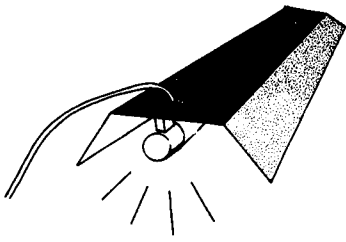
a low voltage warning light or disconnect, however, so the user would still have to manage the energy flow of the system.

## Managing Systems without Controllers

Because of the high cost of charge controllers, many small system buyers choose not to install one in their system. Without a controller, however, the battery is not protected by a low voltage disconnect from deep discharging. In such cases, the user

screen, and the motors in cassette players and other machines run slowly.

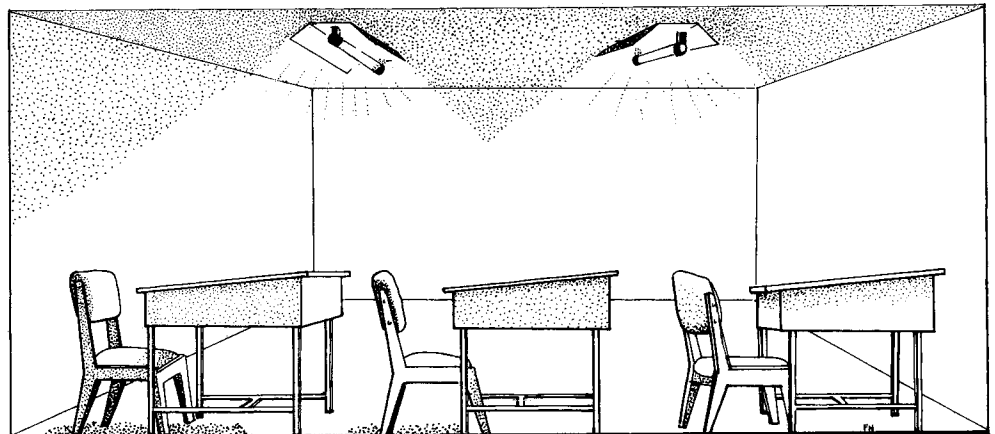
- Calculate the approximate energy harvest of the module (see page 23), and adjust energy use so that it is approximately the same as energy harvest.
- When the battery state of charge is low, limit the use of appliances.
- Charge the battery by other means if necessary (see page 33).



# Chapter 6

## Lamps and Appliances

*This chapter explains how to choose the best lamps and appliances for solar electric systems. Principles of efficient lighting are explained, including lumen output, efficacy, and reflection. Information about incandescent, halogen, and fluorescent lamps (and their associated fixtures) is provided. Choice of lamp, depending on the purpose intended, is outlined. Important aspects of low voltage tools and appliances likely to be used in solar electric systems are presented. Finally, voltage converters and inverters (power conditioning units) are briefly explained.*



Normal 240 V ac light fixtures and appliances cannot be directly connected in 12 or 24 volt solar electric systems. Instead, special types of lamps and appliances must be chosen. Efficient low voltage dc fluorescent or halogen-type lamps are normally used in solar lighting systems. Incandescent lamps (globes) consume much more energy to produce the same light, and should be used only in places where light is not required for long periods of time.

### Lighting Principles

Electric lamps convert electric energy into *light energy*, which is also called *visible radiation*. Visible radiation is the part of the

radiation spectrum that our eyes can detect. We can see visible radiation, but we cannot see heat radiation or ultraviolet radiation. Efficient lamps give off a maximum of visible light while producing only a small amount of wasted heat.

There are three important points to consider when choosing and installing lamps:

- The *amount of visible light* the lamp produces;
- the *amount of electric power* required by the lamp; and
- the *direction* in which the light shines.

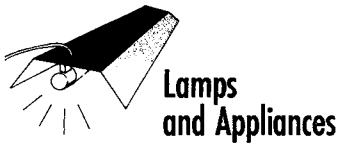


Figure 6.1 shows that when a lamp is in use, it produces both heat and light energy. Visible light produced by a lamp is called the *luminous flux*; the amount of visible light a source produces is measured in *lumens (lm)*. For example, a hurricane lantern produces about 100 lumens. A flashlight bulb produces a luminous flux of about 30-40 lumens. A 40 watt incandescent globe lamp produces about 400 lumens. An 8 watt fluorescent lamp produces 240 lumens.

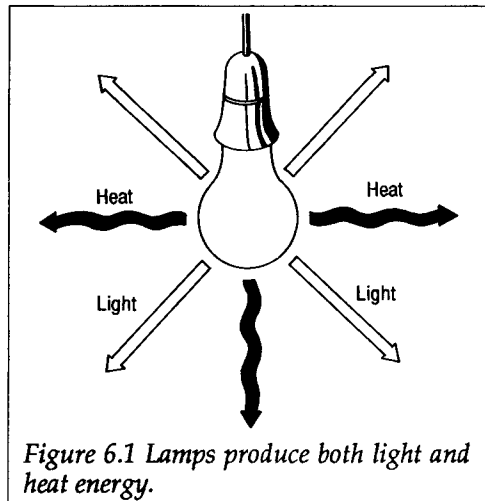


Figure 6.1 Lamps produce both light and heat energy.

**Efficacy** describes how much light is produced per watt of electric power.

The rating of an electric lamp is always given in watts. An 8 watt fluorescent lamp draws 8 watts of electric power, and a 40 watt globe lamp draws 40 watts. *Efficacy* is a special term which tells how much light (in lumens) is produced per watt of electric power. Lamps with a high efficacy produce more light energy per watt of power than lamps with a low efficacy, and are thus more desirable. For example, the 8 watt fluorescent lamp described above has an efficacy of 30 lumens per watt ( $240 \text{ lm} \div 8 \text{ W} = 30 \text{ lm/W}$ ). The globe lamp has an efficacy of only about 10 lumens per watt ( $400 \text{ lm} \div 40 \text{ W} = 10 \text{ lm/W}$ ). Note that if you touch a globe lamp, it is hotter than a fluorescent lamp because the globe lamp is losing much more energy as heat.

The direction in which light from a bulb travels is also important. Light moves from a bulb in all directions, but it may only be needed in one direction. For example, if you are trying to read a book, then the light should shine on the pages of the book, and not on the ceiling. Light can be directed where it is needed using *reflectors*. Even a small amount of visible radi-

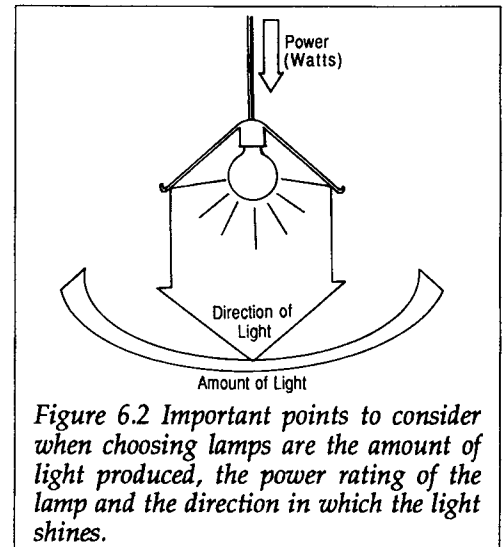


Figure 6.2 Important points to consider when choosing lamps are the amount of light produced, the power rating of the lamp and the direction in which the light shines.

tion may be useful if it is directed onto the place where it is required. Use of reflectors to maximise usage of a lamp's output is discussed on page 42 and 43.

### Incandescent and Halogen Lamps

*Incandescent lamps*, or globe lamps, are made up of a thin tungsten wire (called a *filament*) inside a glass globe which contains an inert gas. When electricity passes through the tungsten filament, the filament offers resistance to the current, and heats up to a very high temperature. At such a high temperature ( $3000^{\circ}\text{C}$ ), the filament glows brightly, giving off both light and heat.

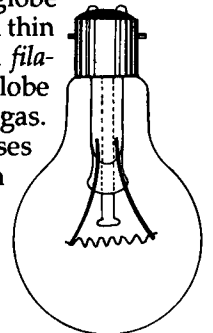
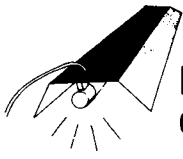


Figure 6.3 Incandescent lamp

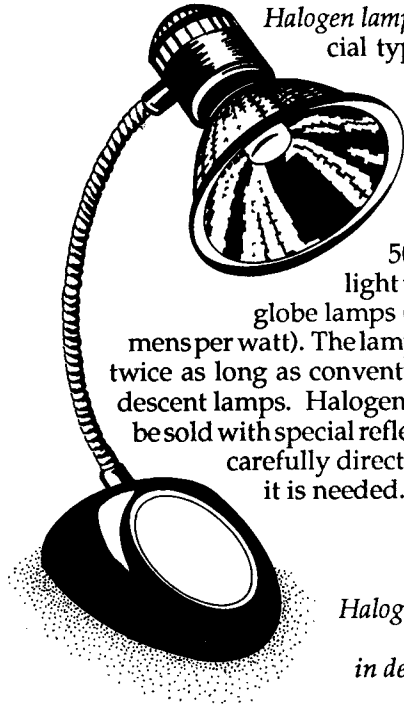
Globe lamps have very low efficacies of between 9 and 16 lumens per watt (compared to fluorescent lamps which are three to four times more efficient). They also have a rather short life of between 500 to 1000 hours. However, globe lamps are much cheaper than fluorescent lamps, and they do not require ballast inverters to work (see page 41). Also, globe lamps are not damaged when the battery voltage gets low (though their lives are shortened when the lamp is operated above its rated voltage).

Kenyan home lighting systems frequently use 15 watt auto globe lamps in places



## Lamps and Appliances

Do not stare directly into the bulb of a halogen lamp, as it may damage your eyes.



Halogen lamps are a special type of incandescent lamp with filaments that produce a 40 to 50% brighter light than regular globe lamps (up to 30 lumens per watt). The lamps last about twice as long as conventional incandescent lamps. Halogen lamps may be sold with special reflectors which carefully direct light where it is needed.

Figure 6.4  
Halogen lamp with reflector in desk top fitting

## Fluorescent Lamps and Ballast Inverters

Fluorescent lamps (also called *tube lamps*) use current flowing through mercury vapour to produce light radiation. A fluorescent lamp is a glass tube containing mercury vapour and argon gas, with electrodes at either end of the tube. When the lamp is turned ON, an electric current flows from the electrodes through the mercury vapour in the tube. The current causes the mercury vapour to give off ultraviolet radiation. This invisible ultraviolet radiation strikes the inside of the glass tube which is coated with a thin layer of phosphor. The phosphor glows with a bright white light when it is struck by ultraviolet radiation.

Fluorescent lamps have

where light is only needed occasionally or for short periods. Such places include stores, bathrooms, hall ways and little used rooms. Weather-proof globe lamps are also sometimes used outside the house as security lights.

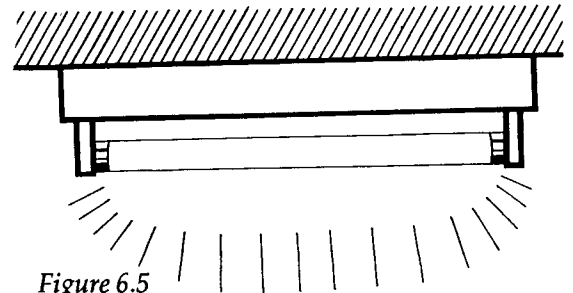


Figure 6.5  
Fluorescent lamp fitting

high efficacies of between 30 to 75 lumens per watt. For example, an 8W tube lamp has an efficacy of between 30-40 lumens per watt, while a 13W lamp has an efficacy of between 50-60 lumens per watt. Tube lamps have long lifetimes of between 2000 and 5000 hours.

Most solar electric lighting systems choose fluorescent lamps in places where light is required for lengthy periods of time. For example, dining rooms and living rooms (in homes), classrooms (in schools), and examination rooms (in clinics) are best served by tube lamps. However, the price of fluorescent lamps is high compared to the price of incandescent lamps. When operated on direct current, all fluorescent lamps require a *ballast inverter* to modify the power. This device may be damaged if the battery voltage falls to a low level.

*Ballast inverters.* Fluorescent lamps operate at high voltage alternating current (between 70-100 V ac), and, as such, they cannot be powered directly by 12 volt dc current from batteries. Low voltage dc fluorescent fixtures contain a special device called a *ballast inverter*, which converts low voltage direct current to the type of current

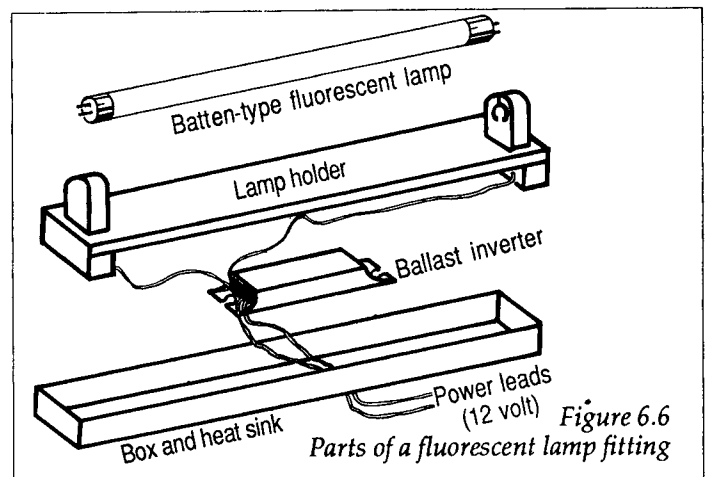
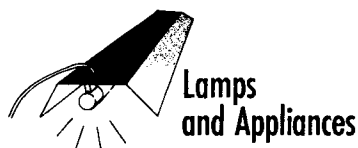


Figure 6.6  
Parts of a fluorescent lamp fitting



**Table 6.1: Performance of Typical 12 Volt Lamps**

Lamp Type	Watts W	Light Output lumens (lm)	Efficacy lm/W	Lifetime hours
Incandescent Globe	15	135	9	1000
Incandescent Globe	25	225	9	1000
Halogen Globe	10	140	14	2000
Halogen Globe	20	350	18	2000
Batten-type Fluorescent (with ballast)	6	240	40	5,000
Batten-type Fluorescent (with ballast)	8	340	42	5,000
Batten-type Fluorescent (with ballast)	13	715	55	5,000
PL-type Fluorescent (with ballast)	7	315	45	10,000

Source: Manufacturers' Data

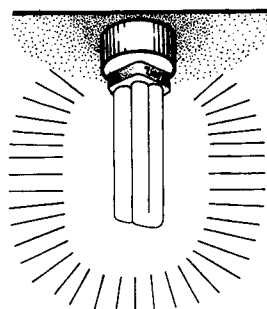


Figure 6.7  
'PL'-type fluorescent lamp fitting

required by the lamp. The ballast converts direct current into alternating current, it transforms the battery voltage from 12 or 24 to 70-100 volts. Similarly, ballast inverters raise the frequency of the current, and they may contain a special circuit which helps the lamp start (see Figure 6.6).

Several types of tube lamps are available. The most common type, the batten lamp, is a straight tube fastened to a fixture in which the ballast is contained (Figures 6.5 and 6.6). Another type that is available from some suppliers is the 'compact' fluorescent. This lamp, made by Philips and called 'PL' fluorescent, is more efficient than the batten-type fluorescent lamp (see Figure 6.7 and Table 6.1).

Several types of tube lamps are available. The most common type, the batten lamp, is a straight tube fastened to a fixture in which the ballast is contained (Figures 6.5 and 6.6). Another type that is available from some suppliers is the 'compact' fluorescent. This lamp, made by Philips and called 'PL' fluorescent, is more efficient than the batten-type fluorescent lamp (see Figure 6.7 and Table 6.1).

### Reflection

Lamps give off light in all directions. As Figure 6.8 shows, some light from a lamp source travels up, some travels down, and some travels sideways. If a light fixture is placed on the ceiling, the light rays travelling upwards and sideways are wasted. Reading, sewing, crafts and other work is done *below* the lamp—those light rays that travel upward do not reach the place where they are needed. In other words, energy is being used to produce light, and much of that light is wasted.

However, using the principles of *reflection* it is possible to make use of the light rays

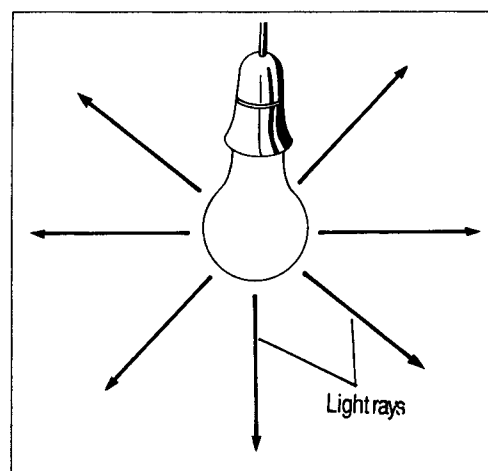


Figure 6.8  
Light travels in all directions from bulb source

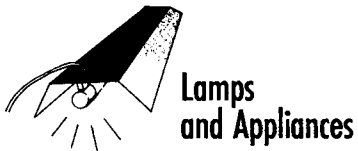
that are otherwise lost. A shiny surface causes light rays to bounce off it and return in the opposite direction from which they came. Figure 6.9 shows how a reflector placed around a lamp directs the light rays from the lamp in one direction. For example, reflectors found in torches (flashlights) direct the relatively small amount of light from the bulb in a beam to the place where it is wanted.

There are two simple ways to make better use of light by reflection in work places and classrooms: *reflectors* and *white paint*.

### Reflector Fittings

Reflector fittings are shiny materials used to reflect light to the areas where it is needed. They are placed above and on the sides of lamps to reflect light that would otherwise be lost down onto the reading area. Reflectors can be made from mirrors, from polished stainless steel sheets, or from polished aluminium. Reflectors are especially cost effective in schools and workshops where large areas must be lit.

Using the principles of reflection it is possible to make much more effective use of light sources.



### White Paint

While dark surfaces absorb light, white surfaces reflect it. White paint reflects light from walls and ceilings of the room back into the work area. Rooms freshly painted with white paint are much brighter than rooms with dark or unpainted walls. School and workshop walls should be repainted with white paint every few years to keep the walls bright for easier reading.

### Choosing the Type and Size of Lamp

The most important factor in the choice of lamps is efficacy. Lamps that use more power require more solar cell modules to provide them with enough energy. As mentioned above, fluorescent lamps have efficacies that are four to five times higher than globe lamps, and they last much longer. However, there are other factors that influence the lamps chosen, including price and intended use.

Fluorescent lamps are between 10 and 20 times as expensive as incandescent lamps. For this reason, rural home system design-

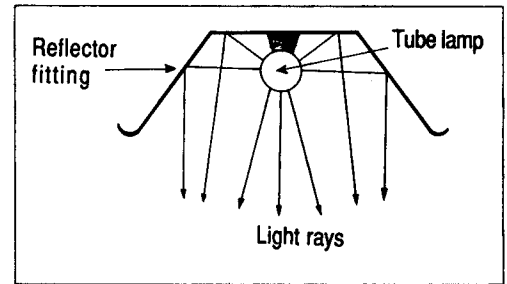


Figure 6.9 Reflectors direct light to the place where it is needed.

ers often include only two or three fluorescent fixtures in the house (i.e. in one bedroom, in the sitting room and in the kitchen). Rooms where light is needed for shorter amounts of time are fitted with globe lamps.

Size and choice of lamp also depend on the intended purpose of the light. The amount of light required differs depending on the particular situation for which the light is needed. Whether the light is required for craft work, to light a shop, for security, for study or for social purposes (i.e. *ambient lighting*) will have a great bearing on the size of lamp chosen. The distance from the

Rooms freshly painted with white paint are much brighter than rooms with dark or unpainted walls.

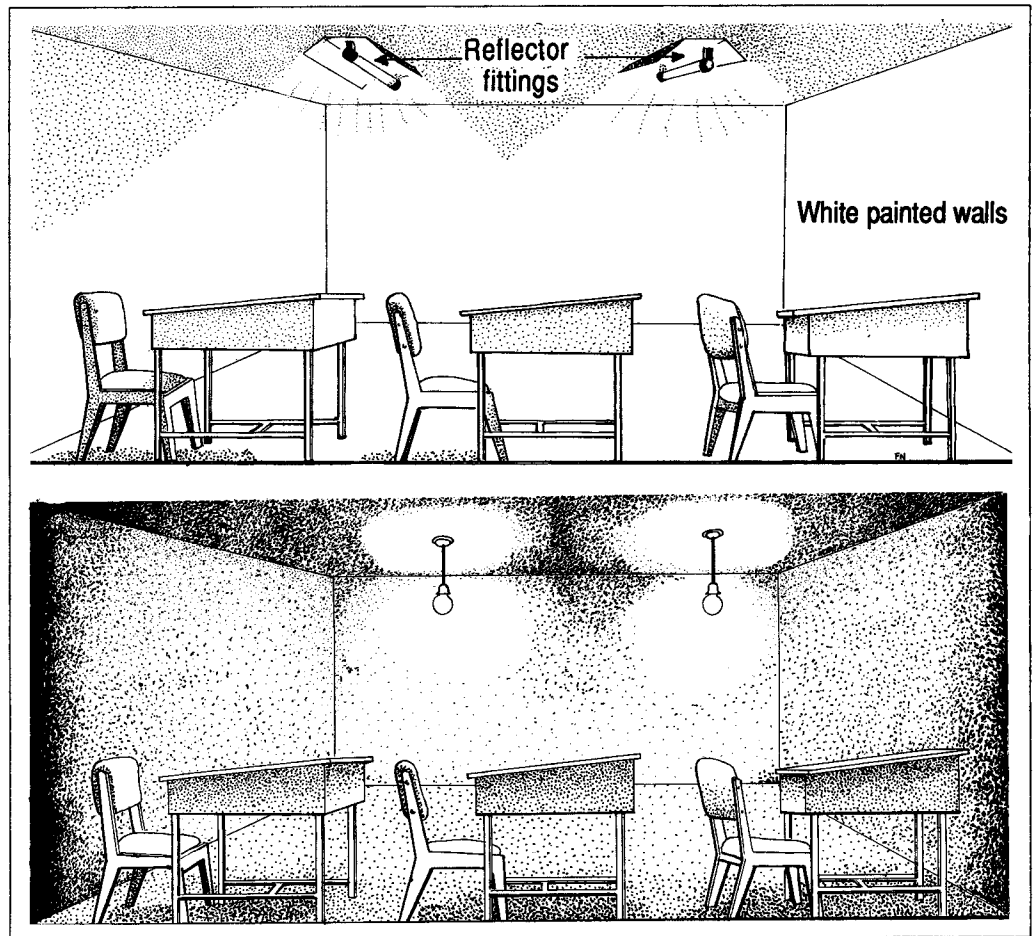


Figure 6.10 Classroom lighting. Fluorescent lamps fitted with reflectors provide a much brighter light for study than incandescent lamps.



When choosing appliances, always select the most energy-efficient.

lamp to the work area is also important because light scatters quickly with distance. The closer a lamp is to the work surface, the less light lost due to scattering.

When choosing lamps for a particular room, the most important factor is the size of the room. Larger rooms, and rooms with high ceilings, require larger lamps. There are no absolute standards to use since people prefer different levels and types of lighting. Many people in East Africa have reached university studying under the inadequate light of paraffin lamps. There is a simple test to determine if the light is enough: If a book can be easily read anywhere in the room, most people agree that the light level is sufficient. Consider the following cases:

- *Health clinic examination rooms* require a very strong light so that the doctor can observe the patient properly. Even a small room requires a 13W fluorescent tube light or a 20W halogen with a reflector. If the doctor needs to perform operations, an even brighter light is required.
- *Craft work* such as sewing, electrical soldering or beadwork require more light than *ambient* lighting. If light is to be used for such purposes, the system should be designed with lamps that are adequately sized (i.e. 13 watt fluorescent tube lamps instead of 8W lamps).
- *Classrooms.* The large areas of classrooms must be provided with enough light for reading. Experience in Kenya indicates that students can read well in the typical 8m x 10m classrooms under two 15W fluorescent lamps fitted with stainless steel reflectors (see Figure 6.10).
- *Sitting rooms.* In East Africa, owners of home solar electric systems are usually satisfied with 8 watt fluorescent lamps placed on low ceilings above the dining table. This allows those working at the table to read, and those sitting in the far corners of the room to see well. One 8 watt tube gives off enough light for a room of up to 4m x 5m. Larger rooms can be lit with two or more 8W lamps with separate switches.

## Appliances

Most home solar electric systems supply energy for small appliances as well as lights. These include televisions, radios, cassette players, record players, sewing machines, fans, workshop tools and computers. In order to work in a home system, the appliance must operate at 12 *volt direct current* (or 24 *V dc* if the systems is wired at 24 volts). 12 volt appliances are available in East Africa. For example, 12 volt televisions that operate from car batteries are readily available.

In order that they do not drain the battery, appliances should be energy-efficient. When choosing appliances, check the labels to find the unit with the lowest power consumption. For example, old 100W televisions should be avoided, and instead efficient 13-15 watt units should be chosen.

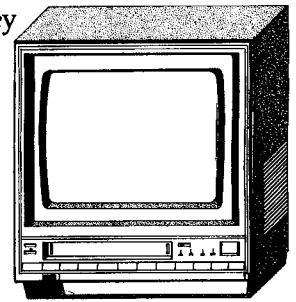
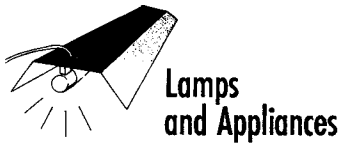


Figure 6.11  
Note that energy consumption for televisions depends on the screen size, the model and whether it is colour or B & W.

## Voltage Converters and Power Conditioning Units

**Voltage Converters.** If an appliance operates at a different voltage than the battery (i.e. if a radio draws 6 volts dc when the storage battery is at 12 volts dc), then a *voltage converter* is required to step the current down to the proper voltage. This will avoid damage to the radio (or other appliance). Voltage converters are often available in electric appliance stores (see Figure 7.2, page 48).

**Power Conditioning Units** (also called *inverters*). Especially with large systems, it may be necessary to run appliances that require 240 *volts alternating current* (i.e. colour televisions, refrigerators or videos). *Power conditioning units* (PCU's) convert dc power into a form suitable for high voltage ac loads. Changing dc power into ac power is also called *inverting* dc to ac, which is why PCU's and low voltage lamp ballasts



**Table 6.2: Approximate Power and Energy Requirements of Appliances for Household Use**

Appliance (Daily Usage Time)	Power Rating (watts)	Daily Energy Use (watt hours)	Notes
Sewing Machine (2 hours)	80	50	Motor is engaged only 25% of time
14" Colour Television (2 hours)	80	160	
12" B & W Television (2 hours)	13	26	
14" B & W Television (2 hours)	33	66	
20" B & W Television (2 hours)	60	120	
Radio (3 hours)	5-30	15 - 90	Power draw depends on volume setting
Cassette player (2 hours)	20-60	40-120	Power draw depends on volume setting
Small Iron (30 minutes)	300	100	
Soldering Iron (10 minutes)	200	45	
Electric drill (5 minutes)	300	60	
Computer (2 hours)	100-200	200-400	
Fan (continuous)	60	1,440	
Water Pump (3 hours)	450	1,000	
Refrigerator (continuous)	300	1,500	Compressor motor engaged 40% of time

Use this table when estimating the daily energy demand of your appliances.

Power conditioning units (PCU's) convert 12 or 24 volt dc power to 240 volt ac power.

are called inverters. Unlike ballast inverters in lamps (which change up to 50 watts of dc power to ac), PCU's invert hundreds or thousands of watts from dc to ac.

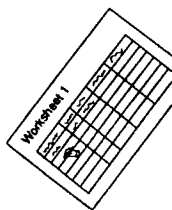
In the process of converting dc to ac, inverters use up energy. They are typically about 80% or less efficient in converting power. When planning large systems this energy loss must be calculated.

If power conditioning units are used in a system, they must be properly sized to handle the highest current possible, or the *peak energy demand* (i.e. when all the appliances are turned ON). Important factors to consider when buying inverters include:

- *Efficiency:* Usually they are between 60-90% efficient. Efficiency varies greatly depending on the load, and most inverters do not perform up to their efficiency rating all the time.

- *Cost:* As one would expect, better quality inverters cost more.
- *Wave form:* This is a measure of how "clean" the 240 V ac current output is. Inverters are classified by their three types of output: sine wave, modified sine wave and square wave. Square wave inverters are cheap but cannot power some appliances (such as fluorescent lamps or videos). Sine wave inverter output is closest to grid power, but these inverters are most expensive.
- *Surge capability:* This is how the inverter reacts to sudden changes in power demand. For example, when a motor or refrigerator compressor turns ON, it draws a large amount of power for a short time, and the PCU must be able to react to this surge.





## Calculating Daily Energy Demand

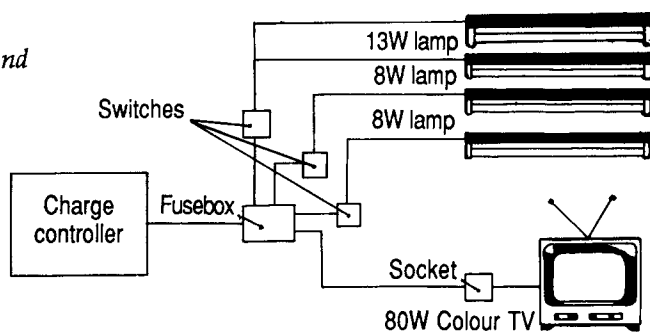
### How to Calculate the Total Daily Load Energy Demand

To calculate the total daily energy demand of the load, add up the energy in watt hours required by each lamp and appliance per day. Table 7.1 provides a step by step method of carrying out this calculation. It is identical to the table found in Worksheet 1, page 107. The instructions below explain how to fill in the table:

- Individual load description:** List all the lamps and appliances to be powered by the system in Column A.
- Individual lamp and appliance voltage:** List the voltage of each of the appliances and lamps in Column B.
- Individual lamp and appliance power:** List the power in watts of each appliance and lamp in Column C. Usually, the manufacturer indicates the power rating on the appliance itself. Radios and cassette players are rated according to their maximum power, but they normally operate at much less than half the indicated power (i.e. if a radio is rated at 30W, write down 15 watts in Column C).
- Individual lamp and appliance use (in number of hours per day):** List the estimated amount of hours per day that each lamp and appliance will use in Column D. If the appliance is only to be used a few times per week (i.e. a sewing machine might only be used on weekends), estimate the number of hours it is used per week, divide by 7 and write the number of hours per day in Column D.
- Individual lamp and appliance energy use (in watt hours per day):** Multiply the power of each load (Column C) by the number of hours it is used per day (Column D). Write this figure in Column E. This is the energy use in watt hours per day of each appliance.
- Total daily energy demand of load:** Add all the numbers in Column E, and write the total in Box F. This is the total daily load energy demand in watt hours. At a later stage (see Chapter 9), this number will be used to calculate the total daily system energy requirement.

To calculate the total daily energy demand of the load, add up the energy in watt hours required by each lamp and appliance per day.

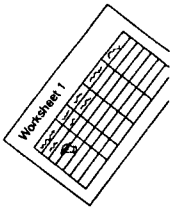
Figure 7.1  
Total daily load energy demand calculation: example



Column A Lamp or appliance (list below)	Column B Voltage (volts)	Column C Power (watts)	Column D Daily use (hours)	Column E Daily Energy Use (watt hours)
Fluorescent lamp	12 V	13 W	3 hours	39 Wh
Fluorescent lamp	12 V	13 W	2 hours	26 Wh
Fluorescent lamp	12 V	8 W	2 hours	16 Wh
Fluorescent lamp	12 V	8 W	1 hour	8 Wh
14" Colour TV	12 V	80 W	2 hours	160 Wh

Total Daily Load  
Energy Demand

Box F  
249 Wh



## Calculating Daily Energy Demand

### Watt Hours and Amp Hours

For planning purposes, energy consumption is indicated in *watt hours* or *amp hours*. Watt hours (or kilowatt hours) is a common measure of electric energy. However, because battery capacity is generally measured in amp hours, solar electric system planners often use amp hours to indicate energy instead of watt hours (strictly speaking, though, amp hours are not a measure of energy, but a measure of total charge). A twelve volt, 100 amp hour battery contains approximately 1200 watt hours of energy.

To calculate amp hours, divide the energy in watt hours by the system voltage.

$$\boxed{\text{Total charge (amp hours)}} = \frac{\text{energy (watt hours)}}{\text{system voltage (volts)}}$$

*Example:*

A 12 volt system in a house with four lamps and an 80 watt television has an energy demand of 250 watt hours per day (see Figure 7.1). How many amp hours does the system consume per day?

*Answer:*

$$\boxed{\text{Total charge (amp hours)}} = \frac{250 \text{ Wh}}{12 \text{ V}} = 20.8 \text{ Ah per day}$$

### Choosing the System Voltage

*System voltage* is the voltage at which the appliances in the system operate. It is normally the voltage of the largest load in the system. This book is written mainly for those using 12 or 24 volt (or smaller) dc systems. Small home systems can operate at 12 volts quite reliably, and 12 volt appliances are available in East Africa (including televisions, sewing machines, electric

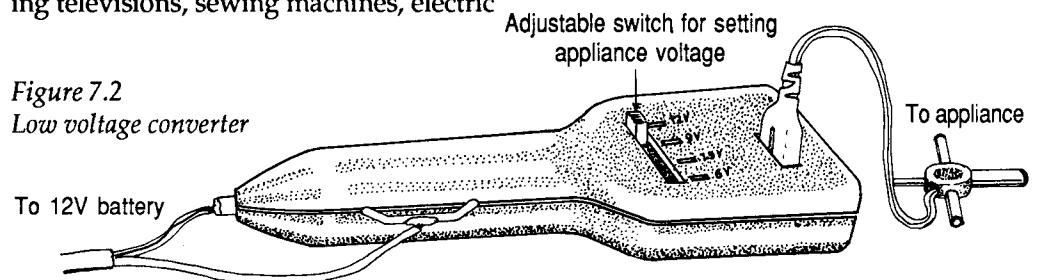
drills, radios and lamps). If appliances of different voltages than the system voltage are to be used in the system, then *voltage converters* (Figure 7.2) or *power conditioning units* will be required (see page 44).

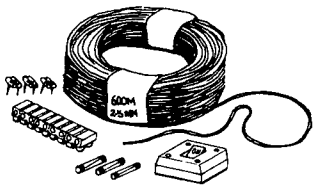
For systems that use nicad cells to power radios or cassette players *only*, the system voltage can be set at the voltage of the radio. If, for example, a radio operates at 6 V, then five 1.3 volt nicad batteries could be placed inside the radio and charged with a small solar cell module at a system voltage of 6 volts (see Figure 10.1, page 73 ).

In systems where there are long cable runs, system voltage is often set at 24 volts or higher because the higher voltage reduces energy loss caused by voltage drop in the cables (see page 53). School systems are often 24 volts because of the long runs between classrooms and buildings. However, finding appliances that operate at 24 volts may be a problem in some areas. If more power is required in a 24 volt system, batteries and modules must be added *two at a time* (the 12 volt batteries and modules are in parallel and cannot be added one at a time).

System voltage above 24 volts is beyond the scope of this book. It is quite possible to design systems that operate at 36 volts, 48 volts or more, but these systems become increasingly complex. Otherwise, large systems can be designed to include a power conditioning unit (PCU, or inverter) which converts low voltage dc to 240 V ac. A properly sized PCU can operate 240 V ac appliances such as videos and refrigerators (see page 44). However, the price of an inverter may be more than that of the colour television. Systems that include PCU's should be designed by qualified solar electricians.

Figure 7.2  
Low voltage converter

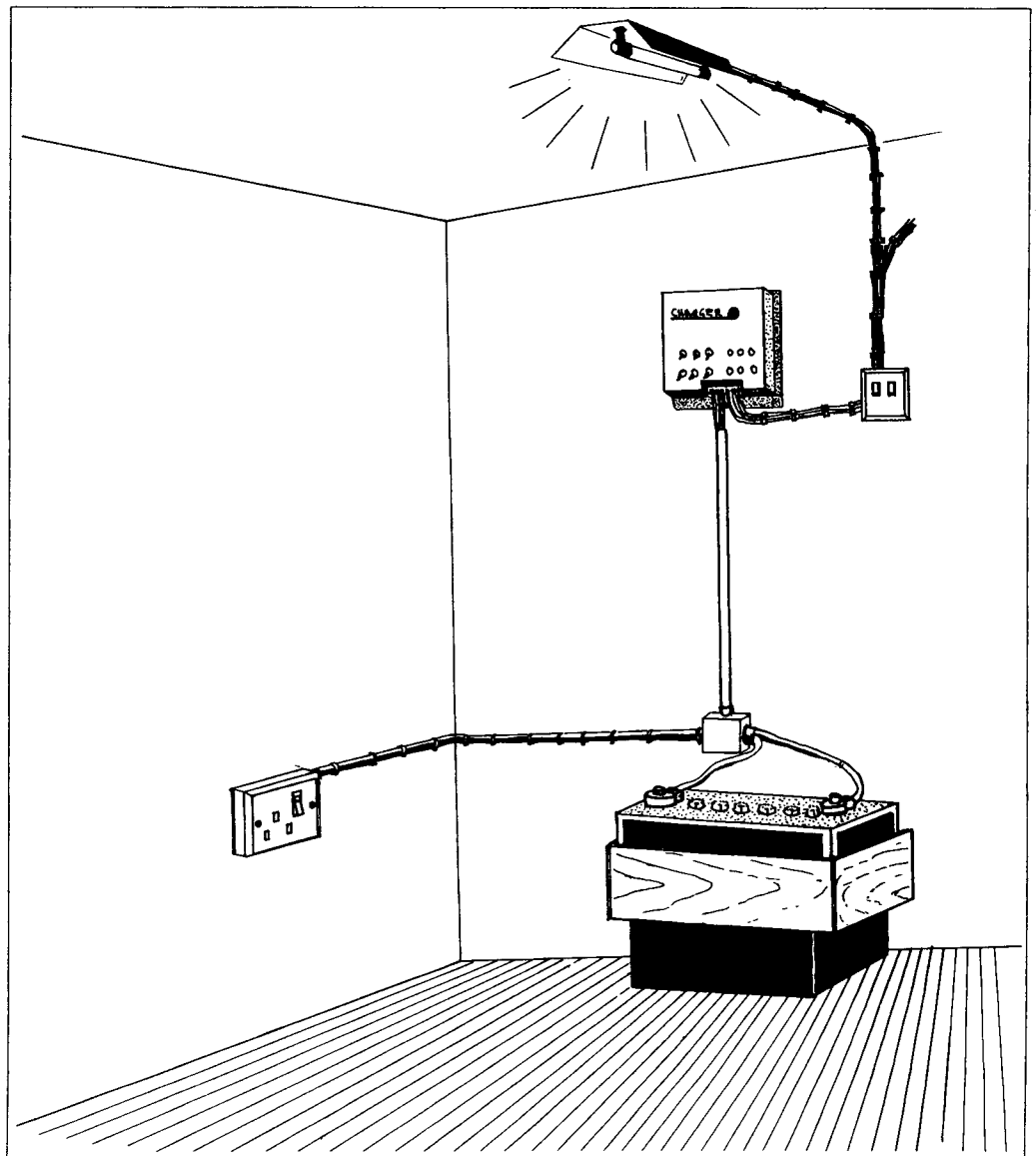




# Chapter 8

## Wiring and Fittings

*This chapter describes low voltage dc cables and fittings for solar electric systems. Topics covered in the first sections include choosing cable size and type, choosing fittings (switches, fuses, connector strips, etc.) and the method of earthing the system. Tips on connecting cables are given. The theory of voltage drop is explained in some detail. Two methods of choosing proper cable size are presented with examples.*





## Wiring and Fittings

When installing solar electric systems, follow established wiring codes for local areas.

A qualified electrician should supervise the planning and installation of any electric system.

Previous chapters discuss the parts of solar electric systems. Harvested energy is distributed between these parts using electric cables and fittings. To make efficient use of the energy collected by the modules and stored in batteries, you must choose cables and fittings carefully. Wiring procedures are much the same in low voltage dc systems as with 240 V ac systems, but there are some important differences, as explained below. Houses that have previously been wired for mains or generator power can easily be adapted to use solar electric power.

### House Wiring Cable

Make sure you choose the proper cable size when planning your system. Wiring cable manufactured in East Africa is available in 1.0 mm<sup>2</sup>, 1.5 mm<sup>2</sup>, 2.5 mm<sup>2</sup>, 4.0 mm<sup>2</sup>, 6.0 mm<sup>2</sup>, and 10 mm<sup>2</sup> (this number refers to the cross-sectional area of the wire). 240 volt ac systems normally distribute power using wiring cable with a cross-sectional area of 1.0 or 1.5 mm<sup>2</sup>, but this wire is too small for solar electric systems. Low voltage dc systems in small households normally use 2.5 mm<sup>2</sup> cable (without a separate earth wire) which is also known as 2.5 mm<sup>2</sup> twin flat. The black wire serves as the negative 'earth', and the red wire is the positive 'live' wire.

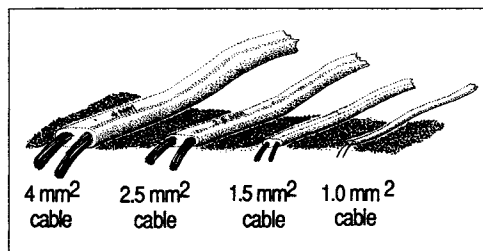


Figure 8.1  
Wiring cable

In solar electric systems, multi-stranded wire should be used instead of single-stranded wire. Those cables laid where they will be exposed to the sun should be *sunlight resistant*. The insulation of 2.5 mm<sup>2</sup> twin flat is somewhat resistant to sunlight (it should last about 5 years before shredding), but common single insulated strands of wire are not sunlight resis-

tant. When wires pass underground or up outside walls, they should be run through *conduit*, a special type of plastic pipe used for enclosing electric wire.

### Switches, Sockets and Fuses

**Switches.** Switches are used to turn lamps, appliances and other loads ON and OFF. They also serve the important purpose of disconnecting modules, batteries and loads during servicing and emergencies.

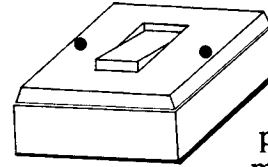


Figure 8.2  
Standard switch

*DC-type switches* are preferred for low voltage solar electric systems. However, because they are not readily available in East Africa, installers commonly use *standard* 240 V ac switches. Standard light switches are sized at 3 and 5 amps, and can safely be used for lamps of up to 36 and 60 watts respectively in 12 volt dc systems.

**Sockets.** Sockets (or power outlets) are devices into which the plug is inserted to access power for an appliance. Low voltage, high current dc sockets are recommended for solar electric systems. As with switches, however, low voltage sockets are not readily available in East Africa. For this reason, standard 240 V ac sockets with switches are commonly used in small solar electric systems. These sockets, usually rated at 13 amps, are capable of providing current for loads up to about 150 W. If a larger load (i.e. a colour TV) is to be used in a solar electric system, ask an electrician or the appliance dealer to help locate a suitably sized socket.

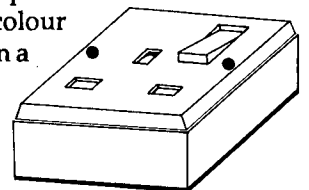


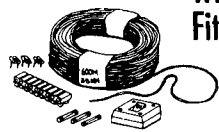
Figure 8.3  
Socket

**Fuses and Miniature Circuit Breakers (MCB's).** Fuses are devices placed in the circuit between the battery and the load to prevent damage from high current to appliances, modules and charge controller circuitry. Because batteries are capable of delivering a very high current, there is a risk of a fire or damage to the system in the

### Warning:

Never plug 240 V ac appliances into sockets wired with 12 V dc current. If standard 240 V ac sockets are used in a solar electric system, tell everyone who uses the system not to plug in any equipment without checking its voltage. Accidental connection of ac appliances into dc power will destroy the ac appliance and may cause a shock to the unlucky user.

## Wiring and Fittings



Fuses are devices placed in the circuit between the battery and the load to prevent damage from high current to appliances, modules and charge controller circuitry.

More system problems are caused by bad connections than by failures of the equipment itself.

event of a short circuit. When a short occurs, the fuse "blows" (i.e. a strip of wire inside melts) and opens the circuit so that current cannot flow. Once a fuse has blown, the cause of the high current should be investigated and repaired before replacing the fuse with a new one of the same size.

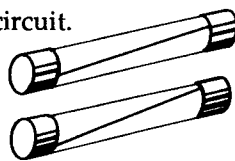


Figure 8.4  
Cartridge-type fuses

Miniature circuit breakers are small switches that automatically break the circuit when there is a short circuit. They can be switched back ON once the wiring problem has been corrected.

If the solar electric system contains a charge controller, a fuse is usually positioned inside the control itself. If there is no control, or if there are loads that need to be protected independently, then fuses should be included in the circuit. Small systems usually require only one fuse to protect the load. Larger systems should have a fuse to protect each major circuit.

**Sizing Fuses.** Fuses are rated in amps according to the current demand of the circuit they are protecting. They are sized to 'blow' when the current is 20% greater than the maximum expected current in the circuit. If, for example, there is a short circuit in one of the appliances, the circuit draws much more than the rated current (i.e. more than 20% higher), and the fuse rapidly heats up, 'blows' and opens the circuit.

In East Africa, radio dealers and electronic equipment shops stock fuses of various sizes, ranging from 0.25 amps to 30 amps or larger. For circuits 5 amps and above, cartridge-type fuses are commonly used. Below 5 amps, simple wire fuses or glass 'automotive' type fuses are used.

To calculate the required fuse size for each major circuit, follow the following steps (see also Worksheet 4, page 110):

- 1) List the circuits that need to be protected. Determine the maximum possible power required by adding the

power in watts of all loads (Column B on Worksheet). This is the power drawn when all appliances and lamps are turned ON.

- 2) Change the power to current in amps by dividing it by the system voltage. This is the maximum rated current in the circuit (Column C).
- 3) Increase this figure by 20% of its value (i.e. multiply this figure by 1.2, see Column D).

This is the size of the fuse required.

*Example:* If a twelve volt system circuit includes a 15W television and three 8 watt lamps, then the maximum power is 39 watts.

$$15W + 8W + 8W + 8W = 39 \text{ watts}$$

Divide the power by the system voltage (12 volt):

$$39 \text{ watts} \div 12 \text{ volts} = 3.25 \text{ amps}$$

Increase this figure by 20%:

$$3.25 \text{ amps} \times 1.2 = 3.9 \text{ amps}$$

In the above circuit example, a 4 amp fuse should be used.

## Making Connections

Wires in solar electric systems should be connected securely, safely and carefully. More system problems are caused by *bad connections* than by failures of the equipment itself. The following tips are given to help make sure that the initial connections last a long time.

*Use connector strips.* Never connect wires by twisting. Connector strips are insulated screw-down wire clamps used to connect wires together in solar electric systems. They are used instead of junction boxes because the largest size cable that junction boxes can fit is only 1.5mm<sup>2</sup>. Connector strips are available in several sizes to fit 2.5mm<sup>2</sup> or larger wire.

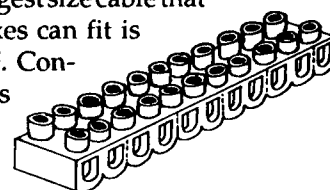


Figure 8.5  
Connector strips



## Wiring and Fittings

Neat wiring not only looks better, it is easier to service and less likely to get tangled, or crossed and shorted.

*Prepare wire ends carefully.* Strip 1/2 to 1 centimetre of insulation from the end of the wire. Make sure the wire is clean. Then, before fixing the wire to a terminal or connector, twist the end.

*Use weatherproof boxes and conduit when connecting wires outdoors.* If connected outdoors, wires should be enclosed in junction boxes. Make sure there is extra wire for entry and exit from junction boxes.

*Avoid twisting wires around terminals.* Use a crimp tool (see Figure 11.1, page 83) if one is available, to fix ring-type or spade-type ends to the wire. These are less likely to be pulled off or to be affected by corrosion. If the installation site is near the ocean, solder terminal connections so that they do not corrode.

*Inspect all connections after installing.* Make sure no wires are loose. Check for places where bare wire might overlap and cause a short circuit.

*Be neat in wiring.* Neat wiring not only looks better, it is easier to service and less likely to get tangled, or crossed and shorted. Align wires coming from terminal strips so that they are straight.

## Earthing the System

*Earth wires* protect against electric shocks to people and against damage to the system from lightning. Earth wires (called 'ground wires' by Americans) provide an easy path for electricity to travel through if a live wire accidentally touches the casing of an appliance, control box or module. They are commonly attached from the metal casings of appliances or modules to a rod driven into the ground. In ac systems, one of the three wires in the plug is an earth wire.

Low voltage dc systems are earthed by connecting the negative (black) wire to earth. This is accomplished by connecting the negative battery terminal to an earthing rod.

It is also desirable to earth the frames and negative terminals of all modules in a system, as well as any valuable appliances that you do not want to risk destroying. In reality, most small solar electric systems are not earthed. This has not been a serious problem, because the small loads of solar electric systems are low voltage and do not carry high enough currents to necessitate earthing (although large loads should *always* be earthed).

However, in areas where lightning storms are common, earth wires are advisable on arrays of two or more modules to guard against lightning damage (one dealer in Kenya reports that at least four of his systems have been struck by lightning). Earthing wires allow the electrical energy from lightning to pass into the ground without damaging the module, controller, or loads.

Solar modules are earthed by running thick gauge earth wires from the frame and negative terminal of each module to an earthing rod driven into the ground. If there are several modules in a system, earthing wires from each module should be connected to one cable which runs to the

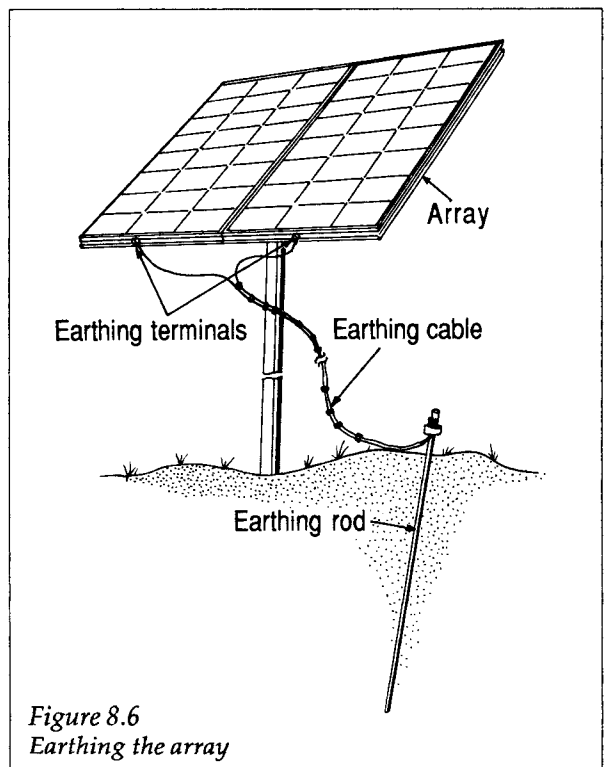


Figure 8.6  
Earthing the array

It is desirable to earth the frames and negative terminals of all modules in a system, as well as any valuable appliances that you do not want to risk destroying.

## Wiring and Fittings



As with water pipes, cables with large cross-sectional area allow more current to flow.

earthing rod. Some 40 Wp or larger modules have a terminal for the attachment of earthing wires. For example, Arco (Siemens) modules include a self-tapping screw to which the earth wire is fixed (see Figure 8.6). This screw is inserted into a designated hole in the side of the module, and the earth wire is wrapped around it before it is tightened (Note that the wire should be connected to the negative terminal, as well). An earth wire should also be attached to the mounting structure itself.

### Wire Size, Voltage Drop and Maximum Wire Runs

As with water pipes, cables with a large cross sectional area allow more current to flow than those with small cross sections (see Figure 8.7). The size of a wire thus determines the amount of current that can pass through it. Unfortunately, low voltage systems require a *higher current* to carry the same power as high voltage systems. In long cable runs, energy is lost as heat through the resistance of the wire to the flow of electricity. If the wire cross section is not large enough to support the current, a voltage drop will occur over the length of the cable. This may damage or cause poor performance in lamps and appliances

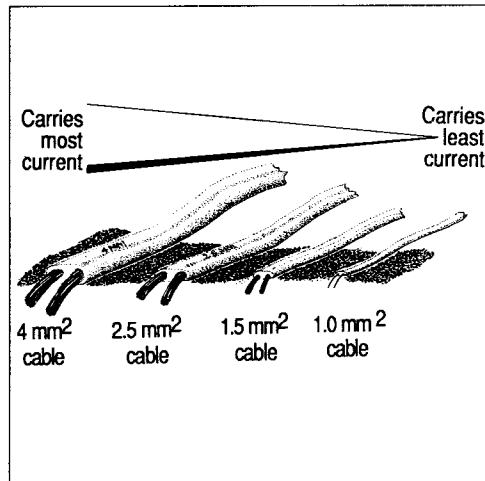


Figure 8.7  
Larger wire sizes carry more current

The example below considers the difference in current flow between wires that connect separate 24 watt lamps to a 12 V battery and 240 V ac grid power (see Figure 8.8).

*Example:*

The Power Law (see Appendix 2) is used to determine the current flowing in each wire.

$$\boxed{\text{Power (watts)}} = \boxed{\text{Voltage (volts)}} \times \boxed{\text{Current (amps)}}$$

A 24 watt globe lamp consumes 24 watts of power regardless of whether it is designed to work with a 240 V ac or 12 V dc power supply. However, to produce the same power as high voltage ac, more current must flow in the low voltage lamp. Figure 8.8 shows the current draw of high and low voltage lamps. Note that the current drawn by the high voltage lamp, 0.1 amps, is 20 times less than the low voltage lamp's current of 2.0 amps.

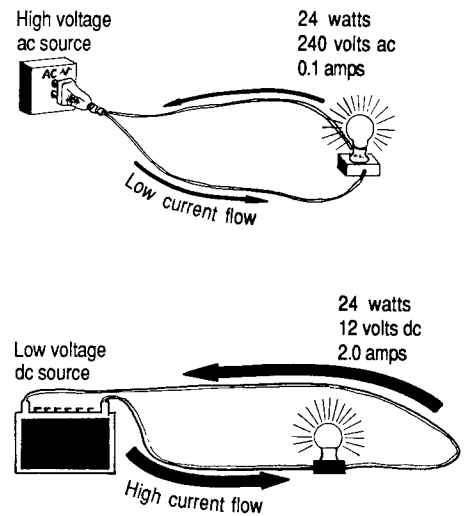


Figure 8.8  
Current flow in high and low voltage systems

The above discussion makes it clear that low voltage systems use a much higher current than high voltage systems. Cables for low voltage systems must be large enough in diameter to carry this high current. In small home systems, 2.5 mm<sup>2</sup> wire is usually sufficient for all short cable runs; however, it is still good practice to calculate the voltage drop for all cables, especially those that connect solar modules and batteries.

## Wiring and Fittings



Voltage drop is a loss of voltage (and hence power) due to resistance in long runs of cable.

### What is Voltage Drop?

As mentioned above, voltage drop is a loss of voltage (and hence power) due to resistance in long runs of cable. It occurs in all wire runs, but is only a serious problem in low voltage systems with long cable runs.

Suppose that the 24W lamp operated from a battery in the above example is located in a kitchen 50 metres from the battery (see Figure 8.10, page 56). How much of a voltage drop will there be if a 1.5 mm<sup>2</sup> cable carries the power to the lamp? Will the voltage drop affect the performance of the lamp? If so, what wire size should be used?

These questions need to be answered before installing the lamp. Whether voltage drop will affect an appliance depends on the appliance (fluorescent lamps may be ruined when run at a voltage below the recommended level). It is good practice not to allow voltage drops of more than 5% on a cable, but in most cases equipment in small systems can tolerate up to 10% voltage drops.

If the conditions in the box to the right hold true for your system, you do not need to go through the wire sizing process. Use 2.5 mm<sup>2</sup> cable through out.

#### Note:

In very small systems, all connections can safely be made using 2.5 mm<sup>2</sup> wiring cable. In such cases, calculations do not need to be made. Use 2.5 mm<sup>2</sup> for all connections if all three of the following conditions are true for the system:

- no wire run is more than 16 metres long;
- the module is rated at 40 Wp or below; and,
- no wire carries a current greater than 4 amps.

Whether the wire size chosen in a cable run is large enough can be determined in either of two ways: By using Maximum Wire Run tables or by calculating the voltage drop. Both methods are described in the following sections.

For either method, first follow the instructions below (see Worksheet 4, page 110):

- 1) List each wire run together with its one way distance. Write them in Columns A and B in the worksheet.
- 2) Find the current passing through each wire. To do this, add the power in watts of all the lamps and appliances on each wire run, and divide by the voltage. Write this on the worksheet in Column C.
- 3) Use the Maximum Wire Run tables (see page 55) to determine the maximum length that can be used with a given type of wire. Alternatively, follow the instructions for calculating the exact voltage drop for each run on page 55.

### Using Maximum Wire Run Tables

Tables 8.2 and 8.3 give the maximum run of cable that can be used between modules, batteries, and loads in 12 and 24 volt systems under various currents. They should be used as described below:

- First, calculate the current in amps that the wire will carry (as entered in column C of the worksheet). If in a 12 volt system, for example, there are two 8 watt lamps at the end of a wire, the current being carried by the wire is 1.3 amps (8W x 2 lamps + 12 volts = 1.3 amps).

Voltage Drop Table						
Column A Cable run (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/ No)

Figure 8.9  
Voltage drop table



## Wiring and Fittings

**Table 8.2: 12 Volt System Maximum Wire Length in Metres (0.6 V max voltage drop, or 5%)**

Wire Size (mm <sup>2</sup> )	Load Current			
	2 amps	4 amps	6 amps	10 amps
1.5	11 metres	6 metres	4 metres	2 metres
2.5	19	9	6	4
4.0	30	15	10	6
6.0	44	22	15	9
10.0	75	38	25	15

**Table 8.3: 24 Volt System Maximum Wire Length in Metres (2.0 V max voltage drop)**

Wire Size (mm <sup>2</sup> )	Load Current			
	2 amps	4 amps	6 amps	10 amps
1.5	37 metres	19 metres	12 metres	7 metres
2.5	63	31	21	13
4.0	100	50	33	20
6.0	147	74	49	29
10.0	250	125	83	50

Increasing system voltage decreases voltage drops in long runs.

- Next, read from the table the load current in amps that is closest to this figure. If the current is not listed in the tables, read the next higher figure. (For example, in Table 8.2, if the current to be carried is 3 amps, read down the 4 amp column).
- Read across the row for the corresponding wire size. In a 12V system, for example, if the current to be carried by the cable is 4 amps, and the wire size is 2.5 mm<sup>2</sup>, then the maximum distance that the appliance can be placed from the source is 9 metres.

### Example 1

The 24W lamp mentioned on page 53 draws 2.0 amps at 12 volts. Reading down the 2.0 amp column, the maximum distance that a 1.5 mm<sup>2</sup> cable carrying 2 amps could support without a 5% voltage drop (i.e. 0.6 volts) is 11 metres. The maximum distance a 2.5 mm<sup>2</sup> wire could run without significant losses is 19 metres. A 4 mm<sup>2</sup> cable would safely be able to carry 2 amps up to 30 metres.

Note from Table 8.3, that if the lamp was

run on 24 volts dc, the voltage drop is much less, and that even a 1.5 mm<sup>2</sup> wire could be used to transmit the current 37 metres at that voltage. Increasing system voltage decreases voltage drops in long runs.

### Calculating Voltage Drop

Instead of using the above tables, it is possible to calculate the voltage drop on a cable run using simple electric principles. Ohm's Law states that voltage is equal to the current in amps multiplied by the resistance in ohms (see Appendix 2). This can be used to calculate the voltage drop in a circuit as follows:

$$\boxed{\text{Voltage drop (volts)}} = \boxed{\text{Current, I (amps)}} \times \boxed{\text{Resistance, R (Ohms)}}$$

To calculate voltage drop, one must first know three values:

- the current flow through the wire in amps (I);
- the distance of the cable run in metres; and,



## Wiring and Fittings

- the resistance factor,  $K$ , of the intended cable in ohms per metre (see Table 8.4). Multiplying the distance of the wire by the resistance factor gives the total resistance,  $R$ .

The voltage drop in each wire is calculated, using Worksheet 4 (see pages 71 & 110), as follows:

- Identify each cable run and note its one-way length in Columns A & B.
- Determine the maximum current that each cable will carry as described on page 54. Write this down in column C.
- Determine the *resistance factor*,  $K$ , of the intended cable using Table 8.4. Note this value in Column D. For example, a 1.5 mm<sup>2</sup> copper wire has a  $K$  value of 0.027 ohms per metre.
- Calculate the *total resistance* of the cable by multiplying the resistance factor (Column D) by the distance of the wire (Column B):

$$\boxed{\text{Total Resistance (ohms)}} = \boxed{\text{Resistance Factor, K (ohms/metre)}} \times \boxed{\text{Length of Cable (metres)}}$$

Write this value in Column E.

- Using Ohm's Law, calculate the voltage drop through each cable. The voltage drop will be equal to the *total resistance* (Column E) multiplied by the maximum current carried in the wire (Column C). If the voltage drop

**Ohms Law:**  
voltage drop =  
current x resistance

**Table 8.4: Resistance Factors for Copper Cables**

Wire Area (mm <sup>2</sup> )	Resistance Factor, $K$ (ohms/metre)
1.0	0.040
1.5	0.027
2.5	0.016
4.0	0.010
6.0	0.0068
10.0	0.0040
16.0	0.0026

is greater than 5%, consider using a larger diameter cable. If the voltage drop is greater than 10%, use a larger cable.

$$V_{\text{drop}} = \text{maximum current (Column C)} \times \text{total resistance (Column E)}$$

Example 2 shows how to use the worksheet to calculate voltage drop in a systematic manner.

### Example 2:

Suppose electricity is provided for a 24 watt lamp in a kitchen 50 metres from the power source using 1.5 mm<sup>2</sup> cable. Using Ohm's Law, it is possible to compare the voltage drop of a 240 V ac system with a 12 V dc system (see Figure 8.10 & 8.11).

- The current passing through and the length of each wire is given in Table 8.5. For a 12 volt system this is 2 amps.
- The resistance factor of the 1.5 mm<sup>2</sup> cable, from Table 8.4, is 0.027 ohms/metre.

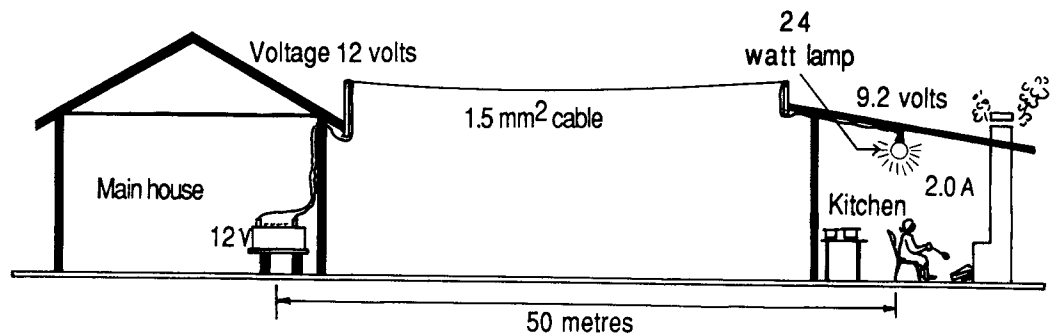


Figure 8.10  
Voltage drop in a 12 volt dc system



## Wiring and Fittings

**Table 8.5: Example Calculation of Voltage Drop in High and Low Voltage Systems**

	240 volt ac globe lamp	12 volt dc globe lamp
Current (amps)	0.1 amp	2.0 amps
Length of Wire (m)	50m	50m
Resistance Factor, K (1.5 mm <sup>2</sup> cable)	0.027 ohms/m	0.027 ohms/m
Total Resistance (K x 50 metres)	1.35 ohms	1.35 ohms
Voltage drop	0.12 volts	2.8 volts
Voltage at Lamp	240 volts	9.2
Percent Voltage Drop (%)	< 0.1%	23.3%

- The total resistance of the wire is calculated by multiplying the resistance factor by the length of the wire. Note that the number is equal for both 240 V ac and 12 V dc because the wire is the same in each case.
- Next, as per Ohm's Law, the total resistance is multiplied by the current carried in the wire. This gives the voltage drop.

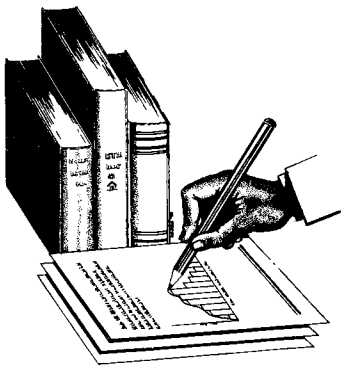
For the 240 V cable, there is little voltage drop over 50 metres. This shows the advantage of high voltage ac power for trans-

mitting electricity over long distances.

However, for the 12 volt lamp, the voltage drop is 23%. This drop is too high, and a larger diameter wire size needs to be used. Voltage drops over 5% are not recommended; but, because of the high cost of thicker cable, drops of up to 10% may be allowed in small systems to save money. In the example above, a 4.0 mm<sup>2</sup> cable gives a voltage drop of less than 10%. Note that 50 metre cable runs in small solar electric systems are not appropriate because of the large voltage drop and the high cost of the cable.

Voltage Drop Table						
Column A Cable run (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/No)
Main House to Kitchen	50 M	2 A	0.027 Ω/m	1.35 Ω	2.8 V	Yes

Figure 8.11 Filled voltage drop table for example 2



# Chapter 9

## Planning a Small System

*This chapter is a guide to designing small solar electric systems. It combines the information presented in the preceding chapters, enabling you to tailor a solar electric system to your own particular requirements and resources. Worksheets 1 to 4 (attached at the end of the book) guide the reader through four design steps, including:*

This planning method is for basic systems only. Systems above 200 peak watts should be designed with the assistance of a qualified solar electric engineer.

1. Calculation of the load and system voltage;
2. Survey of solar energy resource and selection of module(s);
3. Sizing and selection of battery and charge controller;
4. Sizing and selection of cables, fuses and switches.

### Total Daily System Energy Requirement and System Voltage

The *total daily system energy requirement* is the amount of energy the modules must generate to meet the daily energy load *plus* the extra energy required to overcome system losses. The steps below explain how to use Worksheet 1 (see page 107) to calculate this figure, and how to decide on the system voltage.

1. Determine the total daily energy load demand in watt hours (as explained in Chapter 7, page 46). Write this number in Box F of Worksheet 1.
2. Next, estimate system losses to the battery, wires and inverters. Not all energy produced by the modules is available for use in the system, as some is lost as heat in conversions. For small systems, it is reasonable to assume that losses will be about 20% of the total daily load, but losses increase if the system has long wire runs, old batteries, or inverters. Write the estimated energy losses in Box G.

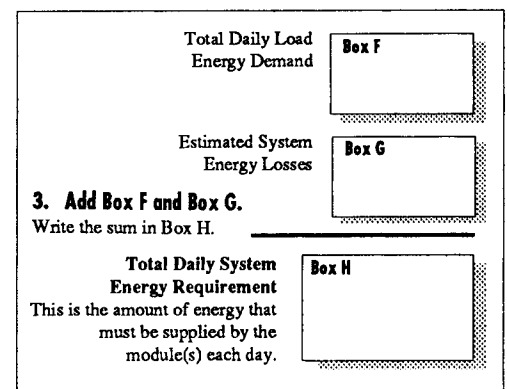


Figure 9.1 Determining daily system energy requirement

3. Add Box F to Box G. This sum is the daily total system energy requirement in watt hours. Enter this number in Box H of the worksheet.
4. Decide on the system voltage. This will be 12 volts in a majority of home systems in East Africa. Systems with long wire runs (i.e. schools) should operate at 24 volts or higher. Very small loads (i.e. radios or lanterns) may be run at 6 volts or lower with nicad battery storage (see page 48). Write the system voltage in Box I.

The worksheets referred to in the text are found on pages 107 to 110 at the end of the book. Whenever the text refers to a table or box (for example, Box F), it is referring to a box within a worksheet.



## Planning a Small System

### Resource Survey: Estimate the energy harvest

Before selecting your module, you need to estimate the solar energy available at the site (i.e. mean daily insolation in peak sun hours). Worksheet 2 (see page 108) will help you do this. Records from a nearby meteorological station should be used if they are available (see Chapter 2). If there is no met station nearby, you will have to estimate the amount of power available at your location, as explained below.

#### Using Meteorological Records

If *monthly mean daily insolation* data is available from a station nearby, enter the monthly data in the table in Box A, Worksheet 2. (Data may be in langleys: to convert langleys into peak sun hours, multiply by 0.0116). If only *sunshine hours* data is available, convert it to peak hours using Table 2.1, page 14 (note this conversion is an estimate only).

Mean insolation data. Enter insolation data from nearest met station. Convert from sunshine hours or langleys to peak sun hours.

Box A			
Month	Langleys	Sunshine hours	Peak sun hours
J			
F			
M			
A			
M			
J			
J			
A			
S			
O			
N			
D			
Annual			

Figure 9.2  
Enter records in Box A of Worksheet 2.

Check which month has the *lowest* mean daily insolation. This is called the *design month* because its low mean daily insolation value is often used to size the array (for example July is the design month for Arusha, see Figure 9.3). If solar charge is the source of *all* your electric power, and

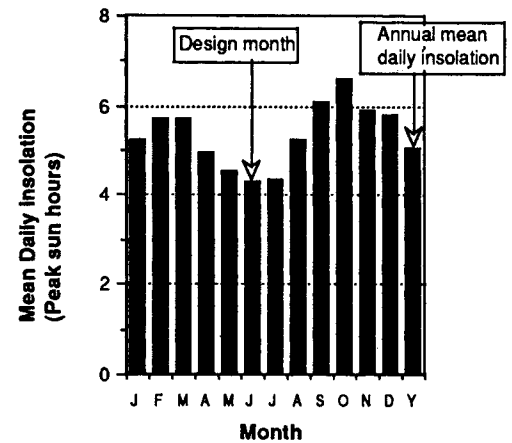


Figure 9.3  
Monthly mean daily insolation for Arusha

you cannot reduce power consumption during cloudy weather, then you must design the system so that the modules produce enough power during the cloudiest, or *design month*. For example, in a rural health centre that *cannot* function without a minimum supply of energy for lights and vaccine refrigerators, the system should provide enough energy even during the cloudiest weather.

However, if you base the size of your array and battery on the design month, then your array may be too expensive, and it may produce excess energy in the sunny months (in Nairobi, the mean daily insolation varies between 4 peak sun hours in the cloudiest month and 6 peak hours in the sunniest). To reduce the size and expense of the array required, the *annual mean daily insolation* value may be used as a planning figure instead of the design month value (see Figure 9.3). This is the *average* energy available per day over the whole year (add all monthly values together and divide by 12). Note that a shortage of energy during cloudy parts of the year is likely if you use this value when designing, so you will have to reduce use of lights and appliances (or charge the battery by an alternative method) during those months.

Decide whether you will use the *design month* mean daily insolation value or the *annual* mean daily insolation value when planning your system. Enter this value in Box B.

The month with the lowest mean daily insolation value is called the design month.



## Planning a Small System

If no meteorological station is nearby, it will be necessary to make an estimate (or educated guess) of the insolation received at your site.

### Estimating Insolation without Records

If no meteorological station is nearby, it will be necessary to make an estimate (or educated guess) of the insolation received at your site. Consult the contour map of East Africa's annual mean daily insolation to get a rough estimate of your site's *annual mean daily insolation* (Figure 2.7, page 13). In Figure 2.7, for example, Dar es Salaam is located between the 5.1 and 5.3 peak sun hour contours on the map. Therefore Dar has an *estimated* annual mean daily insolation value of about 5.2 peak sun hours. Write this value in Box C1.

Next, use Table 2.1 on page 14 to refine the above value based on the seasonal changes at the site that you have observed. Compare your site's monthly weather variations with the monthly variations of sites near yours on the map in Figure 2.7. Which month is the cloudiest, and how much more cloudy is it? This value corresponds to the *design month*. It may be as much as half the annual mean daily insolation figure in Box C1. Write it down in Box C2.

Choose whether to use the design month value in Box C2 or the annual average value in Box C1. Enter this value in Box B. Remember, most sites in East Africa have mean daily insolation levels of between four and seven peak sun hours, so the number you enter in Box B should be between four and seven.

### Extra Energy from Tracking

Modules attached to tracking mounts like the one described on page 15 will collect about 25% extra energy (if properly operated). For modules mounted on such trackers, calculate 25% of the value in Box B and write it in Box D. If the module is *fixed* (not tracking), write '0' in Box D. Now, add Box B and D together, and write the sum in Box E of the worksheet.

This is the number of peak sun hours (or the total amount of energy in kilowatt hours per square metre) expected per design day, from which the array and battery size will be determined.

## Sizing and Selection of the Array

The module(s) in a system must be chosen so that their energy output matches the energy requirements of the load as closely as possible. For a solar electric system to succeed over the long term, average daily energy output must equal the average daily energy requirements:

$$\begin{array}{l} \text{Energy Produced by} \\ \text{Module per day} \\ \text{(in watt hours)} \end{array} = \begin{array}{l} \text{Total Daily System} \\ \text{Energy Requirement} \\ \text{(in watt hours)} \end{array}$$

As discussed in Chapter 3, the power output of any module depends primarily on:

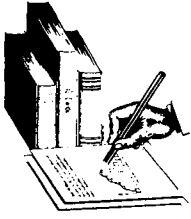
- the level of insolation (i.e. the number of peak sun hours received by the module, as calculated in the previous section). Insolation is determined by weather conditions and by the angle of the module to the sun;
- the temperature of the module (the hotter the module, the less the power output);
- the voltage at which it is operating (the closer the voltage is to the maximum power point, the higher the power output).

### Choosing the Size of your Module

Chapter 3 explains how to roughly estimate any module's maximum output:

$$\begin{array}{l} \text{Maximum energy} \\ \text{output of module} \\ \text{in watt hours} \end{array} = \begin{array}{l} \text{Peak power} \\ \text{rating of module} \\ \text{in Wp} \end{array} \times \begin{array}{l} \text{Insolation} \\ \text{in} \\ \text{peak sun hours} \end{array}$$

Note that modules will always produce less energy under field conditions. This is because module peak power ratings (Wp) are measured under *ideal* conditions, and in the field, conditions are *not ideal* (i.e. it is hotter or the load voltage may be poorly matched to the module). This calculation, however, conveniently allows planners to make a rough estimate of module output using only the *module's rating* and *insolation data*. Module output can be estimated more accurately using manufacturer's I-V curves (see next page).



## Planning a Small System

$$\boxed{\text{Rated size of module required in Wp}} = \boxed{\text{Total daily system energy requirements in Watt hours}} \div \boxed{\text{Insolation in peak sun hours}} \times \boxed{\text{Adjustment Factor}}$$

The rated size of the module(s) required in your system can be calculated from the total daily system energy requirements, the daily insolation in peak sun hours and an adjustment factor.

Insert each of these numbers into their respective boxes in Worksheet 2, and complete the calculation as follows:

1. Enter the total daily system energy requirement (from Box H in Worksheet 1) in Box F.
2. Enter the design insolation value from (Worksheet 2, Box E) in Box G.
3. Enter an adjustment factor in Box H. This figure accounts for the lower actual field output of the module. In most cases, use the value 1.1 as the adjustment factor. If the module is mounted directly on tin, or if the average ambient temperature is above 40°C, use the value 1.2.
4. Complete the maths, double check your answer, and write it in Box I. This is the size of the module you need.

Depending on your budget, and the module sizes available, you can choose a slightly larger or smaller module. A larger module will produce extra energy for appliances. A smaller module will require that less energy is used during cloudy weather.

Table 9.1 shows the maximum daily energy output of variously-sized modules at several levels of insolation. The table also

shows that modules attached to tracking mounts collect significantly more energy each day.

### A More Accurate Method of Estimating Module Output

The method described above for sizing your module is not accurate for several reasons:

- First, the peak power rating is based on module output at 25°C with a solar irradiance value of 1000 W/m<sup>2</sup>. In reality, your module will probably operate at a higher temperature, and have a lower output.
- Secondly, the actual module power output depends on the voltage at which it operates (see I-V curves, page 21). Modules are rated at their peak power output, which occurs at a specific voltage (the maximum power point, P<sub>m</sub>). Unless the load is exactly matched to the maximum power point voltage, modules will produce less than the rated peak power.

The I-V curve supplied with your new module can be used to make a more accurate estimate of energy output. You need to find the current (in amps) at which the module operates, which depends on the voltage, temperature and irradiance. Fig-

Use this table to roughly estimate the energy output of a particular module size under different levels of insolation.

**Table 9.1: Maximum Daily Module Energy Output per Day (in Watt Hours) at 3 Insolation Levels**

Module Size (Wp)	4 peak hours		5 peak hours		6 peak hours	
	Fixed	Tracking	Fixed	Tracking	Fixed	Tracking
2.5	10Wh	12Wh	12Wh	16Wh	15Wh	19Wh
5	20	25	25	31	30	37
10	40	50	50	62	60	75
20	80	100	100	125	120	150
40	160	200	200	250	240	300
60	240	300	300	375	360	450



## Planning a Small System

If you have I-V curves for your module, you can calculate its output much more accurately.

The operating voltage of a module charging a battery in sunny weather will be slightly higher than the normal voltage of the battery.

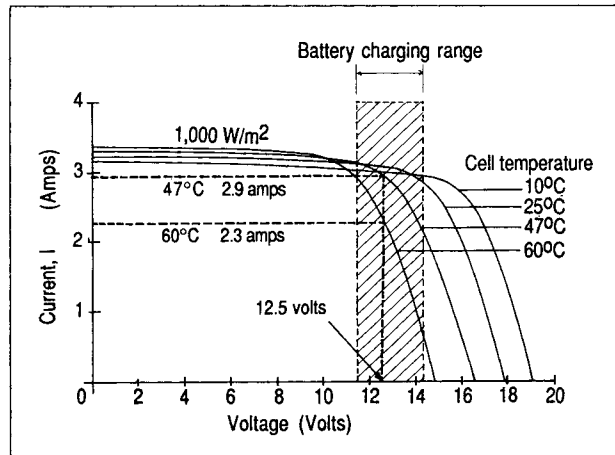


Figure 9.4  
Using I-V curves to calculate module current output. Note that this curve is for a given irradiance.

Figure 9.4 shows I-V curves for a typical 32 cell module at a fixed solar irradiance. Note that there are different curves for different temperatures (i.e. 10°, 25°, 47°, and 60°C). Note also the shaded area which shows the battery charging range between about 11.5 and 14 volts. If you know the charging voltage and the operating temperature, you can use your module's I-V curve to calculate the operating current of the module at a given solar irradiance.

For example, using the I-V curve, we can estimate the operating current of a module at a temperature of 47°C charging a 12.5 volt battery (remember, modules are typically 20° warmer than the ambient temperature). Follow the dotted line up from 12.5 volts until it touches the 47°C curve, and then follow the dotted line across to the current reading (about 2.9 amps). If the module's temperature was 60°C, you would use the 60° curve to calculate the current output (i.e. 2.3 amps).

Now, multiply the operating current (in amps) by the daily insolation figure (in peak sun hours) to get the amp hour output of the module per day:

$$\boxed{\text{Output of module (in amp hours)}} = \boxed{\text{Operating current (in amps)}} \times \boxed{\text{Insolation in peak sun hours}}$$

Multiply this amp hour figure by the system voltage to convert to energy in watt hours.

## Sizing and Choosing the Battery

As mentioned in Chapter 4, the battery is the part of the system most likely to experience problems, so it must be carefully selected. Worksheet 3 guides you through battery sizing calculations (see page 109).

Choice of battery will be limited by what is on the market and how much you have to spend. A new, deep-discharge solar battery is the best option, but many 40 Wp systems successfully utilise automotive or second-hand batteries. When choosing second-hand batteries, remember that their capacity may be greatly reduced by age and previous cycling. Very small systems (i.e. 20 Wp and below) should consider utilising nicad batteries (see Chapter 4).

Battery voltage is determined by the system voltage. Most systems use 12 volt batteries, but six volt (or smaller) batteries are available. Larger systems use 12 volt batteries arranged in series.

Battery capacity for any system depends upon:

- 1) the total daily system energy requirement (obviously, the larger the system, the more battery capacity required). This number was calculated in Box H of Worksheet 1, and should be entered in Box A of Worksheet 3. Convert this figure to amp hours (see page 48) and enter the new figure in Box B.
- 2) the number of storage days required. This is the maximum expected consecutive days of cloudy weather when the battery will supply most system power. In sunny areas, this number may be as low as two or three days only. In places with long cloudy seasons, this number may be much larger (i.e. 7 days or more). Write your estimate in Box C of the worksheet.
- 3) the maximum daily depth of discharge.



## Planning a Small System

Shallow cycle automotive batteries, for example, should not be cycled below 75% state of charge, so only 25% of their capacity is available for system energy requirements (see Chapter 4). Write this number in Box D as a decimal (i.e. 25% is 0.25 as a decimal).

The required system battery capacity can now be calculated by relating the three variables in the following equation:

$$\begin{array}{c}
 \boxed{\text{Total Daily System Energy Requirement (Ah)}} \times \boxed{\text{Number of Storage Days Required (Days)}} \\
 \div \boxed{\text{Maximum Daily Depth of Discharge}} = \boxed{\text{Required System Battery Capacity (Ah)}}
 \end{array}$$

### Example Calculation:

Calculate the battery capacity of a system that has four lamps and a television, or a daily energy requirement of 274 watt hours (see Figure 9.9, page 67).

In Box A, write the total daily system energy requirement in watt hours. Convert 274 watt hours into amp hours by dividing by the system voltage, 12 volts:

$$274 \text{ watt hours} \div 12 \text{ volts} = 22.8 \text{ amp hours}$$

The total daily system energy requirement (in amp hours) is entered in Box B of the worksheet as 22.8 amp hours.

Next, calculate the number of days of storage. In Box C, write the number of consecutive days of complete cloud cover that would ordinarily be expected at the site. For this example, the site experiences a cloudy season during which there are likely to be about 3 days of completely cloudy weather in a row, so the number 4 is entered in the Box C of the worksheet.

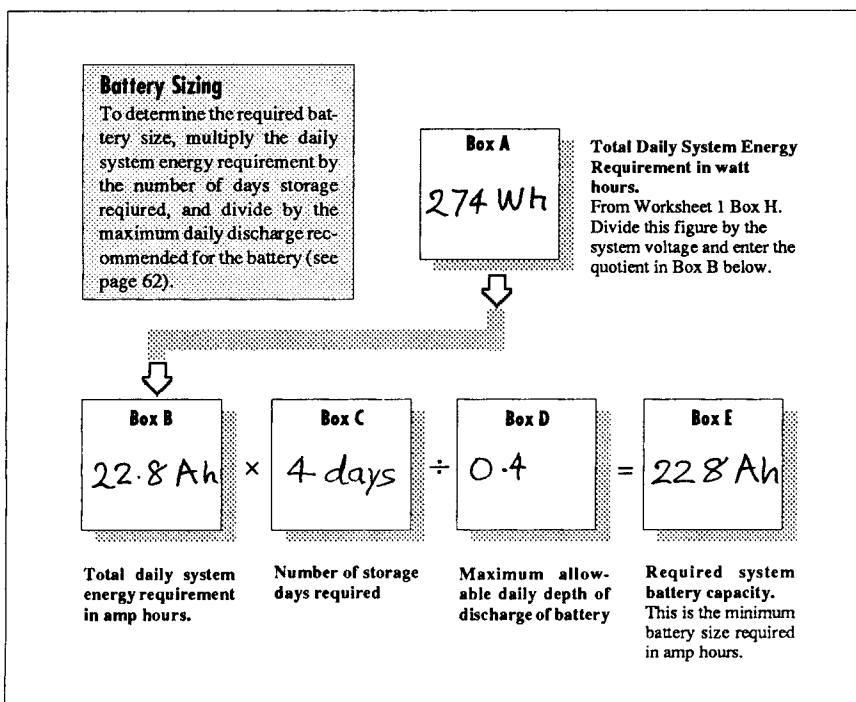
Finally, the maximum depth of discharge of the battery must be entered in Box D. The battery type is an ABM solar battery which can accept a 40% discharge regularly (see page 28 & 30). Enter the value 0.4 (in decimal, 40% is expressed as 0.4) in Box D of the worksheet.

Now complete the calculation and write the result in Box E:

$$22.8 \text{ Ah} \times 4 \text{ days} \div 0.4 = 228 \text{ Ah}$$

It is always better to oversize the battery slightly. However, in this case, two 12 volt 100 amp hour 'solar' batteries are chosen. They provide 200 amp hours of storage, which is reasonably close to the required value.

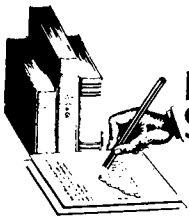
Figure 9.5  
Example battery sizing calculation



## Choosing the Charge Controller

Before choosing a charge controller, the planner must: 1) decide if a charge controller is necessary; 2) decide what controller size is needed; and 3) decide what controller features are required. Worksheet 3 provides space to answer these questions.

*Is a control needed?* This is the first question to ask. Of course, any system should have a junction box where the main switches, blocking diode and fuses are located, but the extra cost of a charge control unit may not be justified. Those installing small systems may be reluctant to pay for a control that costs more than the battery itself. But this means that the users must actively manage energy consumption so that the battery and appliances are not damaged.



## Planning a Small System

**Controller sizing.** Systems with modules larger than 40 Wp should invest in some type of charge control. Controllers are sized according to the current load of the system; those available in East Africa come in sizes between 5 and 20 amps (or larger). Home lighting systems with arrays below 100 Wp will not ordinarily require a controller larger than 20 amps. Make sure the control purchased is rated at the system voltage (i.e. 12 volts, *not* 24 volts).

**Controller features.** Depending on the size of the system, the appliances used, and the solar insolation at the site, a controller may be required to perform different functions. Chapter 5 discusses the features of charge controllers, and Table 5.1 (page 36) shows the features of three locally available controllers. Important features to consider include: high voltage cut-out, low voltage cut-out, solar charge and low voltage warning lamps, voltage and current meters, and load timers.

### Choosing Cables and Fixtures

Chapter 8 explains how to choose cables and fixtures. Use Worksheet 4 (page 110) to determine the size of the cables and fuses required in your system. This section does not go into detail, as the process of selecting proper sized cables is carefully explained (with an example) on pages 53 to 57 in the previous chapter. Remember, in small systems, you can use 2.5 mm<sup>2</sup> cable for most runs.

Draw a floor plan of the house or institution in the space provided, and mark where the lamps, appliances, batteries, modules and appliances will be located. This scale drawing of the system should indicate cable lengths, and the number of lamps, sockets and switches required.

Important tasks in sizing and selecting cables and fixtures include:

- 1) Determining the proper length and sizes of cables between the loads and battery, and between the battery and the module. Make sure that there is not too much voltage drop in any wire.

- 2) Determining the type and quantity of sockets, fuses, switches, connector strips and mounting material required (i.e. clips, tacks, etc.). Make a list of the materials required before going to purchase them.
- 3) Making sure that the system is safely earthed.

### Some Planning Considerations

- Before starting, draw a scale diagram of the floor plan where the system is to be installed. It will help to estimate the amount of cables and wiring material required, and to decide where to locate the battery, modules, control, sockets and appliances (as discussed in Chapter 11).
- A major barrier which prevents people from obtaining a solar electric system is the high initial cost. Systems large enough to supply enough power *all of the time* are much more expensive than those that will supply electric energy requirements *most of the time*. For example, to obtain the same amount of energy during the cloudy season as is produced during sunny months, the solar array and battery may have to be sized twice as large. A cheap alternative to 'over-sizing' systems is to charge batteries by other means and to limit the use of appliances during cloudy weather.
- When planning, remember that the electric energy demand will probably grow. For example, in a school, classrooms may be added, or in a small home system, a television might be added. Adding more appliances will increase the load and will often require additional solar modules and/or batteries.
- Consider and compare the costs of alternatives carefully. Solar electricity is often the cheapest alternative for those who require power for a few lamps and appliances. There are some situations when grid connection or use of a diesel generator is cheaper than solar

Remember, in small systems, you can use 2.5 mm<sup>2</sup> cable for most runs. It is good practice to use 4.0 mm<sup>2</sup> cable between the module and battery.

Keep your system simple. The more complex you make it, the more likely it is to fail.



Visit another system before installing your own. This will enable you to learn from the experience of other system users.

electricity. If possible, investigate the possibilities of other renewable energies, including biogas, micro-hydro and wind-generated electricity (see Appendix 5, page 105).

- Visit another system before installing your own. There may be other solar electric systems in your area. If so, it is advisable to find out what type of problems the users have experienced and to learn from their mistakes.
- Keep your system simple. The more complex you make it, the more likely it is to fail.
- Shop around for different equipment. Do not believe any dealer who claims to have the best equipment unless you have looked at what others are selling. Check the prices of equipment available, and decide carefully which is the most practical.
- Estimate the load carefully. Over-estimation of the load will increase the cost of the system significantly. Underestimating the size of the load may result in continual battery problems.

### Two Planning Case Studies

The two case studies below are modelled

on systems actually installed in Kenya. The entire planning process of the first system is presented; the other one is briefly described with worksheets showing how they were planned. Any system designer should review these cases before planning his or her own system.

#### Example 1: A Small Lighting System in Meru, Kenya

A farmer wants to buy the cheapest possible solar electric system to light his children's study area and his wife's separate hut. He also wants to use solar charge to power his radio. He discusses his needs with a solar technician and they plan the system by calculating his energy requirements and estimating the available solar radiation. They then choose the proper solar module, battery and associated equipment for the system.

#### Worksheet 1: The Total Daily System Energy Requirement

First, using the worksheet (see Figure 9.6), they calculate the daily load energy demand in watt hours. Assuming that 20% of the power will be lost through inefficiencies in the batteries and wires, they estimate that the actual energy demand will be about 50 watt hours, or about 4.2 amp hours per day.

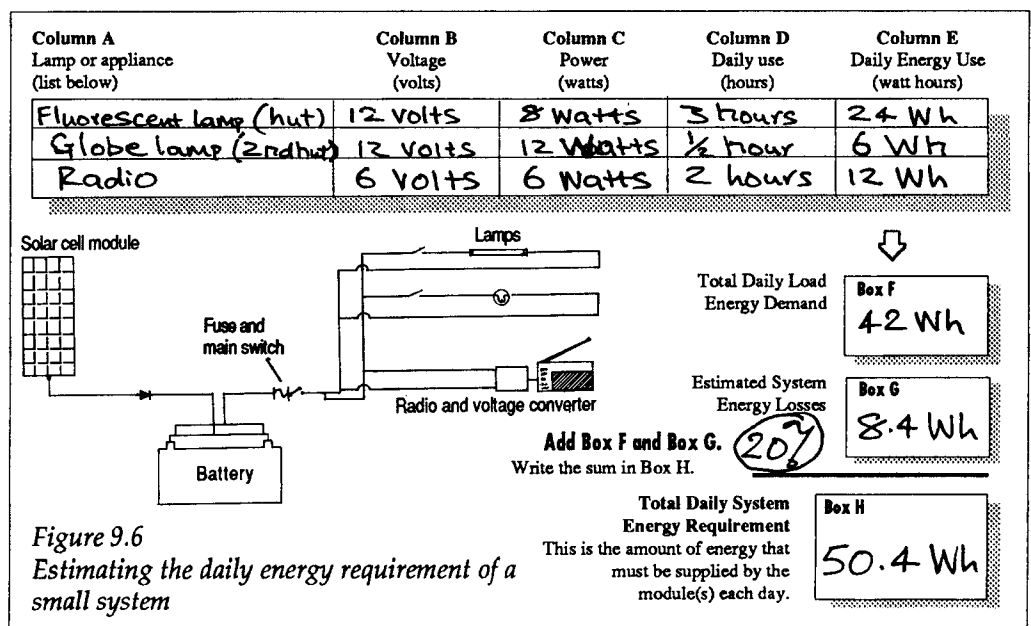


Figure 9.6  
Estimating the daily energy requirement of a small system



## Planning a Small System

### Worksheet 2: Sizing the Module

#### Estimating the solar resource

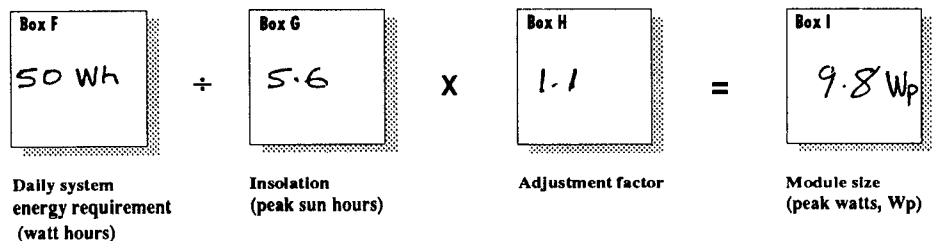
Now, the farmer and electrician estimate their location's solar resource. The nearest meteorological station is in Meru town, about 20 kilometres away, so they visit the Meru Station and collect the data. This information is entered in Box A of Worksheet 2, as shown in Figure 9.7. Daily insolation varies between a low of 3.6 peak sun hours in July (July is the *design month*) and a high of 5.0 peak hours in February. The *mean annual daily insolation* in Meru is about 4.5 peak hours.

Month	Langleys	Peak Sun Hours
J	379	4.4
F	432	5.0
M	429	5.0
A	384	4.5
M	382	4.4
J	365	4.2
J	315	3.7
A	366	4.3
S	431	5.0
O	426	4.9
N	361	4.9
D	335	3.9
Annual	384	4.5

Figure 9.7  
Meru insolation data entered in Worksheet 2

The farmer wants to save money, and to buy the least expensive module possible. Therefore, he does not use the design month insolation value in his planning. Instead he uses the annual mean daily insolation value, and decides that during long cloudy periods he will economize use of his radio, and, if necessary, charge the battery in town. In Box B, he enters the

Figure 9.8  
Example module sizing calculation



*mean annual daily insolation* value, 4.5 peak sun hours.

Since he plans to mount the module on a tracker, he calculates 25% of the value in Box B, and writes it in Box D (1.1 peak sun hours). He then adds Box B and Box D as shown, and writes the number 5.6 peak sun hours in Box E.

$$4.5 \text{ peak sun hours} + 1.1 \text{ extra peak sun hours (from tracking)} = 5.6 \text{ peak sun hours}$$

This is the estimated daily energy collectable at the site in peak sun hours.

#### Calculating module size

Now they calculate the required module size. They enter the total daily system energy requirement (50 watt hours, from Worksheet 1, Box H) in Worksheet 2, Box F. They divide this figure by the peak sun hour figure (Box G) to calculate the base module rating in peak watts. They then multiply this number by 1.1, the adjustment factor. As shown in Figure 9.8, the calculated module size is 9.8 Wp.

#### Peak power rating of module required (Wp)

$$= 50 \text{ watt hours} \div 5.6 \text{ peak sun hours} \times 1.1$$

$$= 9.8 \text{ peak watts (Wp)}$$

Note that a 10 Wp module would work well in this system.

### Worksheet 3: Battery and Control Selection

**Batteries.** Using Worksheet 3, the farmer calculates the battery capacity required. He compares automotive lead-acid battery with nicad batteries, and notes that, because of their different recommended

Meteorological information is available for sites throughout East Africa.



## Planning a Small System

**Nicad batteries can be completely discharged on a daily basis.**

daily discharge (25% for lead acid, 90% for nicad), different capacities would be required for nicad and lead-acid batteries.

He enters the total daily system energy requirement of 50 watt hours in Box A (from Worksheet 1). He converts this figure to amp hours, dividing it by the system voltage, 12 volts, and enters the result in Box B, 4.2 Ah. The number of storage days (Box C) is entered as 5 days because they estimate the longest period of completely cloudy weather to be 4 days.

The maximum allowable daily depth of discharge figure (Box D) is different for the two types of batteries that the farmer is considering. This means he will have to make two calculations, one for nicad and one for lead-acid batteries. Nicad batteries can be almost completely discharged on a daily basis, so the figure of 0.9 (i.e. 90%, see page 26) is entered in Box D. Automotive lead-acid batteries can only be discharged by 25%, so 0.25 is entered in Box D.

The calculation for nicad batteries is:

$$4.2 \text{ amp hours} \times 5 \text{ days} \div 0.9 = 23.3 \text{ amp hours of storage capacity}$$

(This would require about 18 nicad cells of 1.3 Ah each)

For lead acid batteries, calculation is as follows:

$$4.2 \text{ amp hours} \times 5 \text{ days} \div 0.25 = 84 \text{ amp hours of storage capacity}$$

Although nicads require less capacity, the farmer decides to buy an 84 amp hour automotive battery because he can not afford nicad batteries. He fills in the data about the battery in the space provided.

### Control:

Following the guide-lines in the worksheet, the farmer notes that his system is small enough to avoid the extra cost of a control. Instead, he installs a blocking diode, a fuse to protect the load and a master switch. He is aware that he will have to manage the system carefully to make sure that the battery was not ruined. His electrician advises him, however, that if the system is expanded he will need to add a charge controller.

### Worksheet 4: Sizing Cables and Fuses

#### Choosing Fuses and Wiring:

Worksheet 4 (see page 110) states that some small systems can use 2.5 mm<sup>2</sup> cable without the need to go through worksheet calculations. These cases include systems where no wire carries more than 4 amps, where the module's rating is less than 40 Wp, and where no wire is longer than 16 metres. These conditions hold true for this system. Therefore, the farmer knows immediately that he can use 2.5 mm<sup>2</sup> cable for his whole system.

Because the largest current draw from the battery at any time would be about 2.5 amps, the electrician advises the farmer that he should use a 3 amp fuse, and consult him if he increases the load.

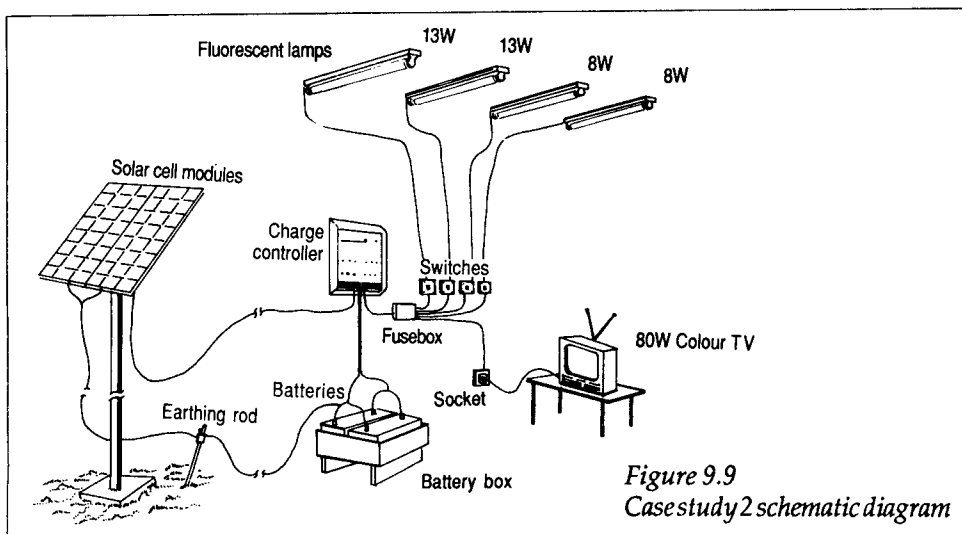


Figure 9.9  
Case study 2 schematic diagram

### Example 2: Planning a Larger System

The system shown on the left is developed in the following four worksheets. It contains four fluorescent lamps and a colour television, and the owner plans to add more appliances after installing it, so he prefers to size it a bit large. To see how it was planned, follow the stages described on pages 68 to 71.

First, he needs to calculate the daily system energy requirement as shown in example Worksheet 1.



## Planning a Small System

### WORKSHEET 1: DAILY SYSTEM ENERGY REQUIREMENT

Use this worksheet to calculate the energy which must be supplied by the module(s) each day to power all the lamps and appliances in your system.

#### 1. Calculate the total daily load energy demand using the table below (see page 46-48).

Column A Lamp or appliance (list below)	Column B Voltage (volts)	Column C Power (watts)	Column D Daily use (hours)	Column E Daily Energy Use (watt hours)
Fluorescent lamp	12	13 W	2 hrs	26 Wh
Fluorescent lamp	12	13 W	1.5 hrs	20 Wh
Fluorescent lamp	12	8 W	2 hrs	16 Wh
Fluorescent lamp	12	8 W	2 hrs	16 Wh
Colour TV (14")	12	80 W	2 hrs	160 Wh

#### 2. Estimate system energy losses

Energy is always lost due to inefficiencies in wires, batteries and inverters. This extra amount should be added to the total daily load energy demand. It is difficult to measure energy losses exactly.

Very general estimates of energy losses can be made as follows:

• If the system components are new and properly sized, estimate energy losses to be:	15% of Box F
• If there are a number of long wire runs (over 10 metres), and the equipment is new, estimate energy losses to be:	20% of Box F
• If the battery is secondhand, estimate energy losses to be at least:	25% or more of Box F
• If the system uses a power conditioning unit (see page 44-45), estimate system losses to be:	30% of Box F

Write your estimate of energy losses in Box G above.

Total Daily Load Energy Demand

Box F  
238 Wh

Estimated System Energy Losses

Box G  
36 Wh

#### 3. Add Box F and Box G.

Write the sum in Box H.

Total Daily System Energy Requirement

This is the amount of energy that must be supplied by the module(s) each day.

Box H  
274 Wh

#### 4. Choose System Voltage

- Running from a 12 volt battery? 12 volts
- Running from nicad cells? Add up voltage at 1.3 volts per cell. Run at voltage of appliance or module. variable
- Long cable runs? Large system? Check voltage drops. 24 or more volts

System Voltage

Box I  
12 V

#### Example Worksheet 1 (see page 107)

- Note that the lamps and television have all been written in the space in Column A, with their respective voltages and power in the following columns. Note also that the daily use will differ with each site. The figures in Column E are added up to get the total daily load energy demand in Box F (238 Wh).
- Energy losses are estimated at 15% because the system and batteries are new (15% of 238 Wh is 36 Wh).
- The Total Daily System Energy Requirement is totalled in Box H (274 Wh).
- System voltage is chosen as 12 volts because all of the appliances operate at 12 volts (see Column B).



## Planning a Small System

### WORKSHEET 2: SIZING AND CHOOSING THE MODULE

#### SOLAR INSOLATION ASSESSMENT (See page 59)

1. Do you have meteorological information?

No

If there is no met station for the site, solar insolation must be estimated roughly. Follow instructions on page 60.

Yes

2. Mean insolation data. Enter insolation data from nearest met station. Convert from sunshine hours or langleys to peak sun hours.

Box A			
Month	Langleys	Sunshine hours	Peak sun hours
J	379		4.4
F	432		5.0
M	429		5.0
A	384		4.5
M	382		4.4
J	365		4.2
J	315		3.7
A	366		4.3
S	431		5.0
O	426		4.9
N	361		4.9
D	335		3.9
Annual	384		4.5

Box C

Estimated Annual Mean Daily Insolation

Box C1

Estimated Design Month Mean Daily Insolation

Box C2

3. Insolation value. Choose design month or annual mean daily insolation (see page 59-60). Enter in Box B.

Box B  
3.7

4. Tracking/fix? If tracking calculate, 25% of Box B. Write in Box D. If not tracking write 0 in Box D.

Box D  
0.9

Design solar insolation value

Add Box B and Box D together. This sum is the value to be used when sizing the module. Enter in Box E below.

Box E  
4.6

#### Example Worksheet 2 (see page 108)

1 Note that there is monthly mean daily insolation data from the Meru Meteorological Station. The table has been filled with this information. The figures, provided by the station in langleys, are multiplied by 0.0116 to convert them to peak sun hours, and entered in the second column.

2 The peak sun hour figure from the design month, July, is entered in Box B (3.7 peak sun hours). The person purchasing the system wants it to work even in the cloudiest month. Note that in the sunny months there will be extra energy for longer use of the television or extra lamps.

3 Note in Box D that the module will be mounted on a tracker as described on page 15. This means the system will gain an extra 25% energy from the module selected (0.9 peak sun hours).

#### CALCULATE THE SIZE OF THE MODULE (See pages 60-62)

To determine the required module size divide the daily system energy requirement by the peak sun hours of the site's design month.

Details of solar module chosen  
When you choose your module, write its details in the table to the right.

Company	ARCO Modules
Model	M-65 (TWO)
Peak Watts	43
Rated Voltage	14.6 V
Rated Current	2.95 A

Box F  
274 Wh

Box G  
4.6

Box H  
1.1

Box I  
66 Wp

Daily system energy requirement (watt hours)

This number tells how much energy is required per day to power the system (see Worksheet 1, Box H).

Insolation (peak sun hours)

This number tells how much energy is available from the sun per day during the design month (see Box E above).

Adjustment factor

This number adjusts the calculation to account for actual field performance of the module. Use 1.1 for most installations.

Module size (peak watts, Wp)

This is the size of the module required to power your system. You have finished the module sizing calculation.

4 Box B and D are added together (4.6 peak sun hours).

5 The total daily system energy requirement is brought to Box F from Worksheet 1 Box H (274 Wh). The peak sun hour figure from Box E is brought down to Box G. An adjustment factor

of 1.1 is entered in Box H. The result of the calculation is entered in Box I. A module size of 66 Wp is required.

6 Details of the modules eventually chosen are entered in the Table. In this case, two Arco M-65 modules (43 Wp each) are chosen.



## Planning a Small System

### WORKSHEET 3: BATTERY AND CONTROL SELECTION

#### Battery Sizing

To determine the required battery size, multiply the daily system energy requirement by the number of days storage required, and divide by the maximum daily discharge recommended for the battery (see page 62).

Box A

274 Wh

Total Daily System Energy Requirement in watt hours. From Worksheet 1 Box H. Divide this figure by the system voltage and enter the quotient in Box B below.

Box B

22.8 Ah

Box C

4 days

Box D

0.4

Box E

= 228 Ah

Total daily system energy requirement in amp hours.

Number of storage days required

Maximum allowable daily depth of discharge of battery

Required system battery capacity. This is the minimum battery size required in amp hours.

#### Battery Information

Before buying your batteries, collect this information along with the price of each type available.

Company & Model	ABM Solar
Capacity (Ah)	100 Ah
Volts	12 V
Number required	2
Number in Series	—
Number in Parallel	2
Estimated Lifetime	3-5 yrs.

#### Example Worksheet 3 (see page 109)

- The total daily system energy requirement is entered from Worksheet 1 (274 Wh). This is divided by the system voltage (12V) and the quotient is entered in Box B as amp hours (22.8 Ah).
- The number of storage days required is entered in Box C (4 days). In Meru, the system designers expect 3 or more days of completely cloudy weather. In sunnier sites, the number would be less.
- The maximum allowable daily depth of discharge for the battery is entered in Box D as 0.4. This is the recommended figure from the battery manufacturer. Now the calculation is carried out, and the required system battery capacity is 228 amp hours.
- When the battery is purchased, information about it is entered in the table. Note that the estimated life of the battery has been entered as 2-4 years, so that the system owner knows how long to expect the battery to last.

#### Control Selection

First decide if a charge controller is actually necessary. With small systems, there is no need to pay more for a control than for the battery it is supposed to protect. If a control is required, decide on the size of the controller and the required features (see page 63).

##### 1. Is a control needed?

- Is the battery worth protecting? Yes  No
- Does the system use nicad batteries? Yes  No
- Is the system above 20 Wp Yes  No
- Will the system be well managed? Yes  No

- Protect expensive batteries using a control with low voltage cut out.
- If the system is above 40 Wp, consider using a charge controller.
- If the system is small and uses nicad batteries for storage, no control is needed.
- If the system is below 20 watts and well managed, then there may be no need for control.

Is a charge controller required? Yes  No

##### 2. Size of controller required

Controllers are commonly available in 5 amp and 20 amp sizes (see page 36). If there are only one or two lamps and no TV in the system, a 5 amp control can be used. Most systems, however, should use a 20 amp controller. Check the rated size of the controller before buying it.

##### 3. Features desired in controller

- High voltage cut out Yes  No
- Low voltage cut out Yes  No
- Low voltage warning Yes  No
- Reverse current protection Yes  No
- Solar charge indicator Yes  No
- Ammeter/volmeter Yes  No
- Timer Yes  No

#### Charge Controller Information

Company and Model	SPCC-20
Size in amps	20 Amps
Features	high voltage cut-out, low voltage cut-out
Low voltage cut-out at	11.0 volts

- The questions in section 1 are answered, and it is decided that a control is needed.
- In section 2 and 3, the size of the control (20 amps) and the features required are selected. A high voltage cut-out is required because, in this system, the modules have a high possibility of over-charging the batteries.
- When the controller is selected, its features are filled in the Charge Controller Information table. Note that the low voltage cut-out is adjusted by the factory from 10.0V to 11.0V (the supplied SPCC-20 controller's low voltage cut-out is set at 10.0V, which will damage the batteries).



## Planning a Small System

### Example Worksheet 4 (see page 110)

- A map is drawn of the site, and the lengths of all the wire runs are estimated. The location of each lamp and appliance is marked. The wire runs are then listed in the Voltage Drop Table (Column A) with the size wire expected (in  $\text{mm}^2$ ).
- The system is not small enough to assume that all wiring can be made with 2.5  $\text{mm}^2$  cable. Note that the module size is above 40Wp, some runs are over 16 metres, and some wires carry a current over 4 amps.
- Six cable runs are listed in the table and each cable distance is written in Column B. Next the maximum expected current of each cable is determined by dividing its load in watts by the system voltage (12V). This is entered in Column C. The K value, obtained from Table 10.4, of each wire is written in Column D. (Note that the wire between the module and the battery is 4.0  $\text{mm}^2$  and the rest are 2.5  $\text{mm}^2$ ).
- The total resistance of each cable is calculated by multiplying the length of each cable (Column B) by the K value (Column D). This is entered in Column E.
- The voltage drop is calculated for each wire run by multiplying the total resistance (Column E) by the maximum cur-

## WORKSHEET 4: WIRING, VOLTAGE DROP AND FUSES

### 1. Determine the lengths of all cable runs

Draw a scale map of the site and estimate the distance of all the major cable runs, including from the module to the control, from the control to the battery, and runs connecting buildings. Estimate the required lengths of branch cables (these use 2.5  $\text{mm}^2$ ) and conduit required. Note the locations of lamps, sockets, switches, connector strips and fuses. Estimate the amount of mounting materials required.

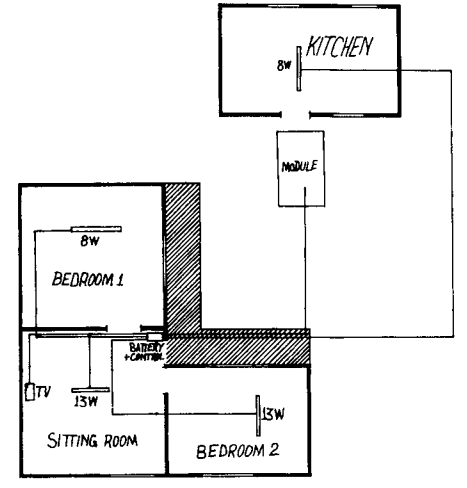
### 2. Work out voltage drops on major cable runs

**Note:**  
In very small systems, all connections can be safely made using 2.5  $\text{mm}^2$  wiring cable. Voltage drop calculations do not need to be made if:

- no run is longer than 16 metres.
- the module is rated at 40 Wp or below; and
- no wire carries a current of more than 4 amps.

Follow the instructions on pages 54-56 to fill out the voltage drop table below:

Draw a scale map of house or site in this box.



Voltage Drop Table

Column A Cable run (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/No)
Module to Control	8 M	7.2 A	4.0-0.010	0.08 $\Omega$	0.58 V	2.5? No
Battery to Bedroom 1	7 M	0.7 A	0.016	0.112 $\Omega$	0.08 V	1? No
Battery to Sitting room	3 M	7.8 A	0.016	0.048 $\Omega$	0.37 V	3? No
Battery to Bedroom 2	7 M	1.1 A	0.016	0.112 $\Omega$	0.12 V	1? No
Battery to Kitchen	20 M	0.7 A	0.016	0.32 $\Omega$	0.22 V	2? No

### 3. Sizing Fuses (see page 50 & 51)

- List circuits to be protected. Write in Column A.
- Determine the maximum power draw in watts of each circuit to be protected. Write in Column B.
- Change the figure in Column B to amps by dividing by the system voltage. Write in Column C.
- Increase the figure in C by 20%. This is the fuse required.

Column A Circuits (list each)	Column B Max rated power (watts)	Column C Max rated current (amps)	Column D Fuse size (amps)
To all loads	122 W	10.2	12 A
To TV socket	80 W	6.7	8 A

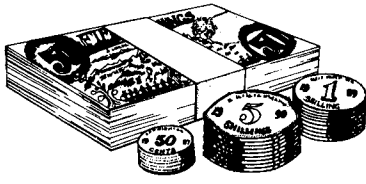
### 4. List all electrical connection equipment required

Fill in the table below to estimate the amount of electrical accessories to be bought. Use it when purchasing equipment.

Item and Type	Size	Amount
Cable	4 $\text{MM}^2$	10 M
Cable	2.5 $\text{MM}^2$	50 M
Cable	—	—
Conduit		6 M
Switches	Standard	4
Sockets (fused)	Standard	1
Fuses	12 Amps	1
Connector strips		2 boxes
Junction boxes		2

rent (Column C). Enter this figure in Column F. To calculate the percentage voltage drop in each wire, divide the voltage drop by the system voltage (12V). If the voltage drop is greater than 5%, try the calculation again with a larger wire size. Note that the voltage drop between the module and the battery would be almost 8% if a 2.5  $\text{mm}^2$  cable was used in that run. To reduce energy loss, a 4.0  $\text{mm}^2$  wire was used.

- Fuse sizes are estimated in section 3. Note that there is one fuse for all the loads, sized at 12 amps. The television has a separate 8 amp fuse in its socket.
- Finally, all electrical equipment required is listed in the table in section 4. This will help when buying the required equipment. Note that two different wire sizes are listed.



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# Chapter 10

## Cost Considerations

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*This chapter discusses how to compare the cost of solar electricity against alternatives. Simple cost comparisons of solar electric systems are presented for kerosene lighting systems, dry cell powered cassette players, and conventional generators. Practices and devices that reduce the cost of systems are introduced, including modular approaches to system planning, methods of collecting and storing more power, and improvements to energy management.*

### Deciding on Solar Electricity

Buying a solar electric system is like buying anything else. Often the difference between the thing you want and the thing that you can afford is quite a few shillings. Perhaps you want to buy a new motorcycle but, because of a tight budget, you can only afford a bicycle. Such *economic considerations* dictate what is practical.

In East Africa, economic considerations are crucial because solar electric systems are large investments. It is difficult for most rural people to save the money required to buy a solar electric system all at once. Although credit could help them buy systems, solar lighting systems are seldom available on a hire-purchase basis. It is therefore important that you carefully consider whether it will be economical to buy a solar electric system.

The demand for electric energy in rural areas is high, as electricity is the most efficient and safe way to power lamps, tools and amenities. Radios, televisions and other appliances must be run from electricity. In cases where the electric energy requirement per day is below one kilowatt hour (i.e. 1000 watt hours), solar electric systems have several economic advantages over other electricity sources:

- In many cases, the *initial cost* of a solar electric system is cheaper than a generator or grid electricity.

- Solar cells use no fuel. Because there are no recurring fuel expenses, solar electric systems are often cheaper than kerosene, dry cell, and centrally recharged lead-acid battery alternatives when costed over time.
- Solar electric systems are *modular*. This means that they can be built up a piece at a time if necessary. A school without enough money to install power throughout the compound can first install lights in one block of classrooms. When more money becomes available, the system can be expanded to other classrooms, laboratories, workshops and teachers' houses. Cash-starved farmers can also buy systems a piece at a time.

### Comparing the Costs

You should decide whether it is economic to install a solar electric system for your purposes. Compare the costs and benefits of the practical alternatives. When making a simple economic comparison between a solar electric system and, for example, a generator, you should consider the following costs of each:

- *Initial cost of the device*: the money paid to install the device, including the price of the device and the money paid for labour and transport.
- *Annual recurrent costs*: the money that



## Cost Considerations

Benefits and disadvantages of alternatives which cannot be listed in monetary terms should be considered when selecting power sources.

must be spent to operate, provide fuel, maintain and repair the device per year.

- *Investment costs:* the interest that must be repaid for any loans (i.e. if the device was bought by hire purchase or with a bank loan).

More detailed cost comparisons, such as life-cycle cost analysis, are beyond the scope of this book, but can be found in some of the references.

Benefits and disadvantages which cannot be listed in monetary terms should also be considered. For example, a diesel generator makes noise, a drawback (especially for school and homes) which cannot be considered in a strict cost comparison. Electric lights are much more convenient than kerosene lamps, and are preferred over paraffin lamps by most people. But the advantages of electric lamps (less smoke and maintenance, ease of operation) cannot be given a value in shillings.

### Example 1:

#### Power for a 6 volt Cassette Player

Initial and annual costs are illustrated simply by comparing costs involved in powering a cassette player with solar electricity versus the cost of powering it with dry cell batteries (in this case, there is no investment cost because the equipment is bought with cash).

**Table 10.1: The Cost of Powering a 6 Volt Cassette Player: Dry Cell Batteries vs. Solar Electricity**

Energy Source	Dry cells	Solar electricity
Equipment Required	5 dry cell batteries per week	10 Wp solar module, 5 nicad batteries, mount and cables
First Cost*	None	Ksh. 3600: buying equipment
Annual Recurrent Costs	Ksh.1820 /year: 260 batteries per year	Ksh. 200 /year: replace nicads after 2 years

\*1991 Kenya Shillings

Table 10.1 illustrates one of the most important points about the cost of solar electric systems relative to alternatives. The initial cost of the solar electric system is high, but the *recurrent costs* are low. Once the rechargeable nicad cells have been purchased, they will last for 2 or more years, and the module is likely to last as long as the cassette player. On the other hand, you will have to buy 5 dry cells per week if you power the player with dry cells. This does not seem to be a heavy cost, but it adds up until, at the end of the year, you find that you have bought 260 or more batteries. Within 2 years, the solar electric system will have paid for itself in battery savings.

The solar electric system has other advantages. When there are shortages of dry cells the solar electric system will continue to provide power for the cassette player. For cassette player operation, a 10 Wp module will provide more total energy over one year than 260 dry cell batteries in most East African sites (but during cloudy weather cassette player use may have to be reduced). Furthermore, the pollution caused by throwing away 260 dry cell batteries is an issue that must not be overlooked.

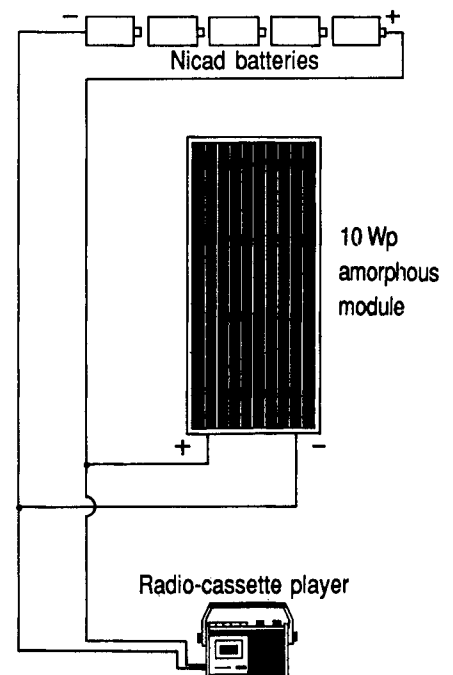


Figure 10.1

Six volt system for powering a radio cassette



## Cost Considerations

**Table 10.2: The Cost of Lighting a Single Room: Kerosine (Paraffin) vs. Solar Electricity**

Energy Source	Kerosine	Solar electricity
<b>Equipment Required</b>	Pressure lamp, mantles & fuel	10 Wp module, lead acid battery, 13 watt lamp, mount, wiring & switches
<b>First Cost*</b>	Ksh. 600: Pressure lamp	Ksh. 4600 buying equipment
<b>Annual Recurrent Costs</b>	Ksh. 1400/year Fuel and mantle costs	Ksh. 500/year Battery/tube replacements

\*1991 Kenya Shillings

Although it may take as long as four years for a solar electric lighting system to pay for itself when costed against a kerosene lamp, the solar system has attractive benefits.

### Example 2: Power for Kiosk Lighting

The costs of lighting a kiosk with solar electric power and kerosene can also be compared. Table 10.2 shows typical costs associated with solar electric and kerosene pressure lamp lighting systems. Both systems provide two and a half hours of light for one room.

As the table shows, this comparison is not as favourable for solar electric power as the first example. It takes about 4 years for the solar electric system to save enough money on fuel costs to pay for itself. The obvious drawback to the solar electric system is the high initial cost.

However, the solar electric system has attractive benefits. First, it has a longer life than the pressure lamp. Secondly, in the event of kerosene price rises or shortages,

the solar electric system will not be affected. Thirdly, the fluorescent tube lamp does not produce soot, smoke, or glare, as does a pressure lamp. The electric lamp can be turned ON with the flick of a switch, instead of the more tedious process of lighting a pressure lamp. Finally, the electric energy which the solar electric system produces can be used for other purposes such as powering a radio.

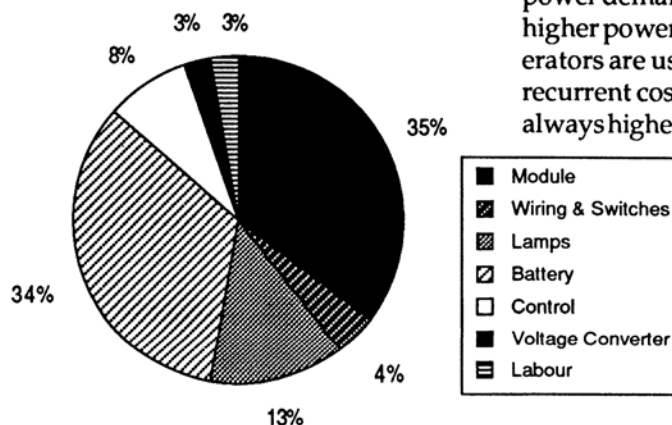
### Example 3:

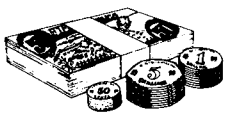
#### Solar Electricity versus Generator Power

Table 10.3 presents basic elements that must be considered when comparing the cost of powering a home or school with solar electricity versus a generator. It does not go into detail because space does not permit a comprehensive analysis, and conditions are different for each site.

There are benefits and drawbacks to diesel and solar powered systems. The *initial* solar electric system cost is often lower for power demand of up to one kilowatt. With higher power demands, *initial* costs of generators are usually less. However, annual recurrent costs (fuel and maintenance) are always higher with diesel systems, the exact amount depending on daily usage rate of the generator. Investment costs depend on the amount of money that must be borrowed to purchase the system, and thus increase with higher initial costs.

**Figure 10.2**  
Cost breakdown of small solar lighting system





## Cost Considerations

Table 10.4 presents a number of points that may help you choose between generators and solar electricity.

Note that it is possible to combine diesel and solar electric (or other renewable energy) systems when there is a high power demand. In such cases (these are called *hybrid systems*), solar modules or wind generators are used to charge batteries and supply daily power requirements. The generator is used to charge batteries when there is not enough sunshine, and to power occasional large loads. Hybrid systems are popular in remote locations with constant loads (for more information, see References).

**Table 10.3: Electrifying a Home, Health Centre or School: Diesel Generator vs. Solar Electricity**

Energy Source	Diesel	Solar electricity
<b>Equipment Required</b>	Diesel generator electrical equipment	Solar modules, batteries, controller, electrical equipment
<b>First Cost</b>	Equipment, labour, transport	Equipment, labour, transport
<b>Annual Recurrent Costs</b>	Fuel, transport, spare parts, maintenance	Spare parts, maintenance
<b>Investment Costs</b>	Loan/Hire purchase charges	Loan/Hire purchase charges

**Table 10.4 Comparing Generators and Solar Electricity**

Situations which favour generators	Situations which favour solar electricity
<p><b>Sites where:</b></p> <ul style="list-style-type: none"> <li>• Power requirements are above 1-2 kW</li> <li>• Fuel supply is stable</li> <li>• The fuel depot is nearby</li> <li>• Fuel and maintenance costs are low</li> <li>• Cloudy weather is common</li> <li>• Low voltage lamps and appliances are not available</li> <li>• Deep discharge batteries not available</li> <li>• Lights and appliances are required for a short time only each day</li> </ul>	<p><b>Sites where:</b></p> <ul style="list-style-type: none"> <li>• Power requirements are below 500 watts</li> <li>• There are frequent shortages of fuel</li> <li>• Fuel depots are far away</li> <li>• Fuel and maintenance costs are high</li> <li>• There is high solar radiation (5 or more peak sun hours throughout the year)</li> <li>• The equipment is expected to last a long time with little maintenance</li> <li>• Noise and exhaust must be avoided</li> <li>• Lights and appliances are in constant use</li> </ul>

## Practices and Devices that Reduce the Cost of Solar Electric Systems

To be economically practical, solar electric systems must be well-planned and managed. During planning, you may find that there is a shortfall between your equipment needs and the cash available to meet these needs. When modules are sized too small, or batteries are not up to standard, the system performs poorly.

However, with careful management even those on limited budgets can put together successful solar electric systems. The following sections present tactics for reducing high initial costs, for collecting and storing more energy, and for avoiding abuse of solar electric systems.

### Methods of Reducing Initial System Costs

*Use modular approaches to develop the system*  
Solar cell modules are available in sizes ranging from less than five peak watts to 60 Wp or higher. By choosing a module of the size you need, you can tailor a system to your own requirements. It is possible to meet one requirement at a time instead of trying to meet them all at once.

For example, in a rural home, a teacher on a fixed income may require electric energy to power a television, 4 lights, a radio and a sewing machine. Upon completing the calculations as described in Chapter 9, the teacher might decide that the cost of such a system is too expensive. Meanwhile, he or she might continue to buy paraffin for lamps and batteries for the radio, and to pay for occasional charging of the second-hand battery that powers the television. These costs add up.

However, the teacher could build a solar electric system *modularly* (i.e. a piece at a time). He or she could buy an amorphous 10 Wp module, and use it to charge the battery for the television and radio. Later on, the teacher could buy another module and several fluorescent lamps. The module would be wired in parallel with the first one to charge the battery; and at this stage, the system would power lamps, the television and the radio. When more



## Cost Considerations

Any boarding school administrator is aware of the high cost of fuelling and maintaining several pressure lamps for evening studies.

money becomes available, the teacher could add another module, a control and a solar battery for more appliances.

Such a modular approach can also be used for lighting rural schools. Any boarding school administrator is aware of the high costs of keeping pressure lamps in operation for evening studies. However, he or she is probably discouraged by the high costs of buying, installing and maintaining a generator to light classrooms. Solar electricity may provide an effective method of avoiding high generator costs. A 100 Wp system could initially be installed to light several classrooms, and more modules could be added later to meet the lighting requirements of dormitories, dining halls, teachers' houses and other classrooms. There is already some success with this approach in rural Africa.

*Decide which energy requirements are most important.*

Modular planning of a system is only effective when you decide what energy requirements are most important. The question "What is desired, and what is required?" must be answered (i.e. Do you want to power the TV or the lights?). The priority energy need should be met first, and the others should wait until more energy is available.

For example, consider the case of a health clinic on a limited budget that requires power for a vaccine refrigerator, operating and examination room lighting, some small electrical appliances and a staff colour television. If the clinic cannot examine people at night because of lack of lighting, and it considers lighting a priority need, then it should install a solar lighting system first. When the lighting system is installed, however, the system manager should not power the television from the lighting system power sup-

ply unless the system has been designed to include it.

*Know the prices of solar electric systems.*

A major problem facing rural people who want to install solar electricity is that there is little information available about the prices of solar electric equipment. Because of this, it is easy for solar electric agents to overcharge customers, which discourages others from taking up the technology. It is always a good idea to visit as many companies as possible to get information on prices and equipment. Equipment prices often differ significantly among different companies.

### How to Collect and Store More Power

*Tracking: Getting the most energy from solar modules*

Tracking is changing the position of the solar array to face the sun as it moves across the sky from morning to evening (see Chapter 2). This management practice helps to get the most power from the sun as it changes its path with different seasons. In East Africa, depending on the season, the sun may be in the northern sky (i.e. between April and August), directly overhead (March and September), or in the southern portion of the sky (between October and February).

Even small system users should consider tracking the sun, as simple manually-operated rotatable mounts (see page 15) cost much less than the price of a module and produce up to 25% more solar charge.

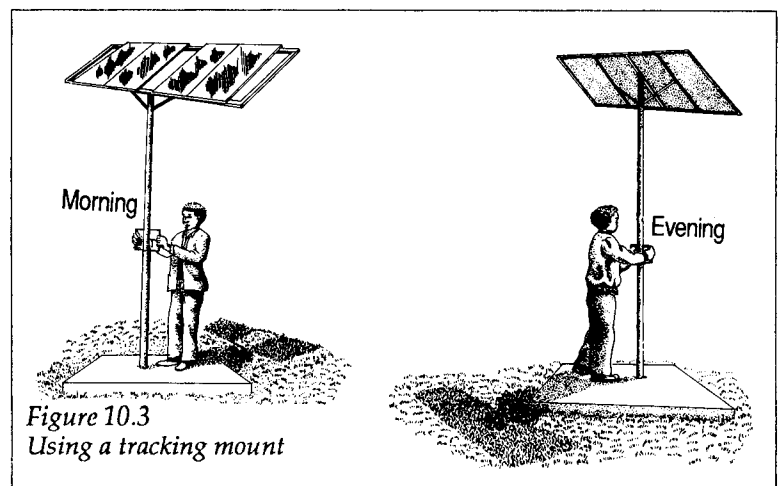
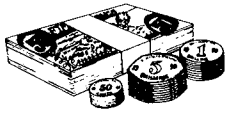


Figure 10.3  
Using a tracking mount



## Cost Considerations

A well educated system manager is far cheaper, and, in the long run, more effective than a control device.

*Keep batteries charged and clean*  
Well-charged batteries have longer life spans, and do not have to be replaced as frequently. Batteries kept clean lose less energy due to self-discharge.

*Keep modules clean*  
Dust-covered modules produce less electric charge. Regular cleaning of the module (i.e. every two weeks) in dusty locations will pay off in terms of extra energy collected. Always mount modules where they can be easily reached for cleaning.

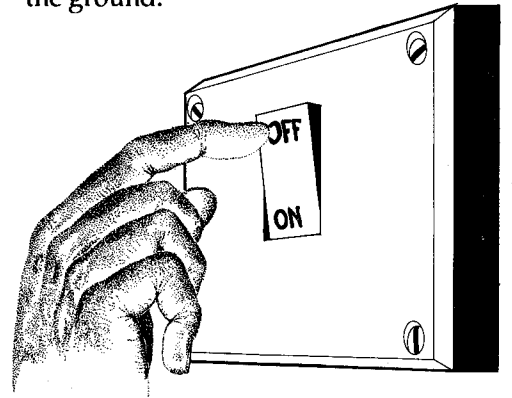
*Ensure proper connections and cable choice*  
Choose correct cable sizes during planning to make sure power is not lost due to small sized wires. Make sure that connections are tight, especially at the control, module and battery terminals. Poor contacts can reduce the flow of electric power considerably.

### How to Effectively Manage Collected Energy

*Consider how much energy is collected and how much is being used.*  
Charge controllers with low voltage warnings and/or cut-outs are extremely useful for protecting the battery during cloudy weather. However, an educated system manager is far cheaper, and, in the long run, far more effective than any control device. If you know how much energy your module is collecting, and how much

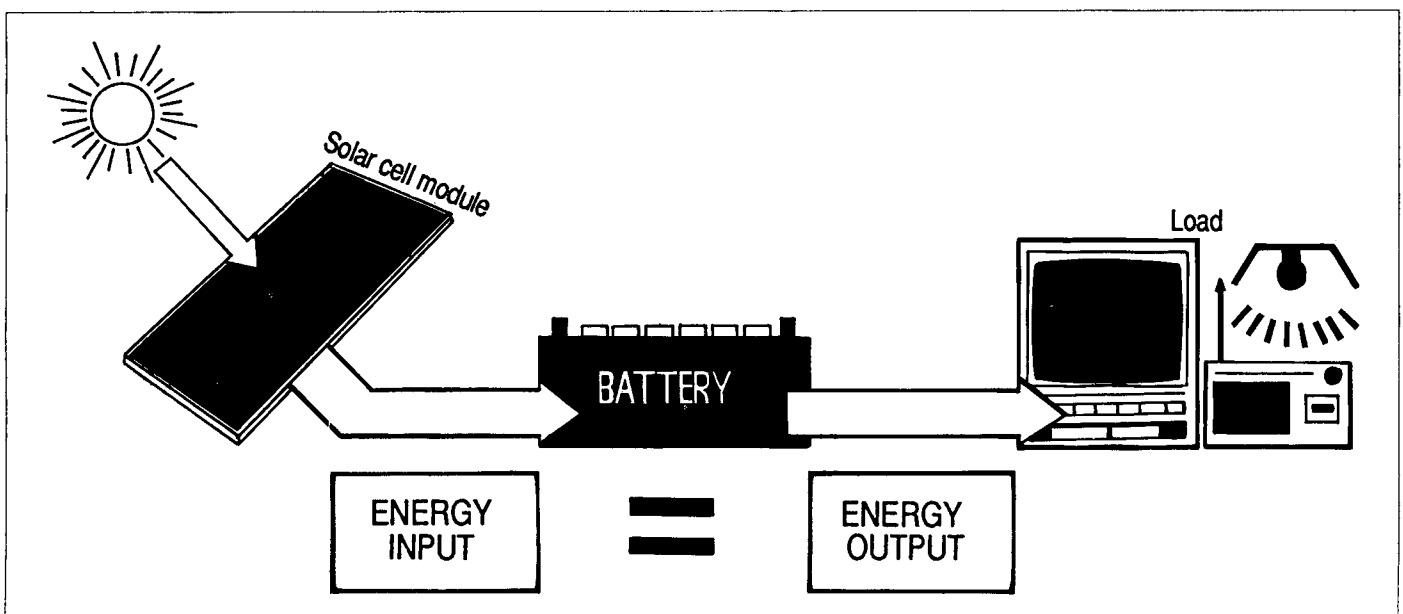
energy your equipment is using, then the task of balancing the input with the output is far easier. If you think that a 10 Wp module can power an electric cooker you are likely to ruin your battery very quickly!!!

*Limit the use of loads*  
Turn OFF loads that are not in use. A 15W light bulb accidentally left ON overnight in a grid-connected house is not a problem. In a small solar electric system, on the other hand, one 15W bulb left ON accidentally for a few nights *can* be a major drain to the system. Leaving unused lights and appliances ON is like pouring paraffin on the ground.



*Use efficient appliances and lamps.*  
Fluorescent tube lamps, though more expensive, are always preferable to globe type lamps. Where globe lamps are installed, try to limit their use to just a few minutes per day if possible, and choose the

Figure 10.4  
Remember, the energy output to the loads must be balanced by the energy input from the module





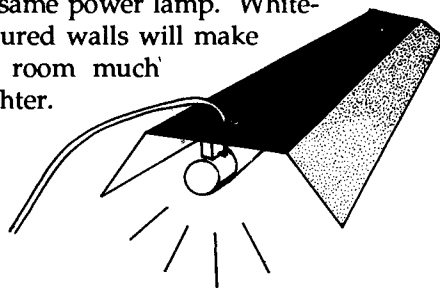
## Cost Considerations

Reflectors direct light to the place it is needed most.

lowest power to do the job needed. When buying appliances such as radios, televisions or sewing machines, choose the one which uses the least amount of power but still meets your requirements.

*Put reflectors on lamps, and paint walls with a light colour.*

In schools, clinics or workshops where solar power is primarily used for lighting, place reflectors on work area lamps. With reflectors, 40% more light is easily provided to the desks or work benches with the same power lamp. White-coloured walls will make any room much brighter.



*Use timer switches on lamps and/or loads if possible.*

Timer switches turn lights ON and OFF automatically so that energy is not wasted by accidental or purposeful over use of lamps. There are two types of timer switches:

The first type is located in the control system, and it turns major circuits ON and OFF at times set by the system manager. This is particularly useful in schools or workshops where loads accidentally left ON overnight or over a weekend could drain the batteries. For example, in a school, study lights in Form I to IV can be set to turn ON at 6 PM and OFF at 9 PM. This prevents students from leaving the lights ON. Such a timer switch can be provided with a manual "override" so that, if desired, the system manager can occasionally leave lights or loads ON for a few extra hours.

The second type is simply a switch with a timing device inside it which automati-

cally turns the light OFF after a preset amount of time (i.e. 5 minutes). Such switches are commonly used in European bathrooms and hallways to save energy lost from lights carelessly left ON.

*Switch to alternative power sources during cloudy weather.*

During cloudy months the module output is likely to be reduced by one third or more. The load must therefore be reduced by the same amount to protect the batteries. Consider which loads need to be reduced. If the television is the most important load, then reduce use of the lights by switching to paraffin lamps until the weather turns sunny again. If the lights are the most important loads, then reduce, or cut out use of all other appliances.

Take batteries for charging when solar charge is not enough. It is much cheaper to charge them up when they are under stress than to replace ruined batteries with new ones.

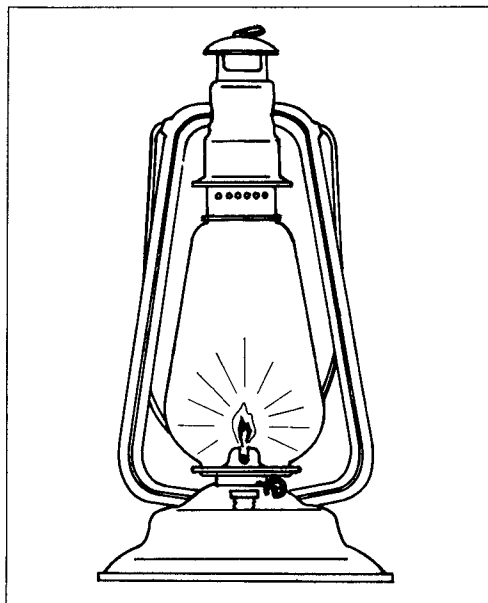
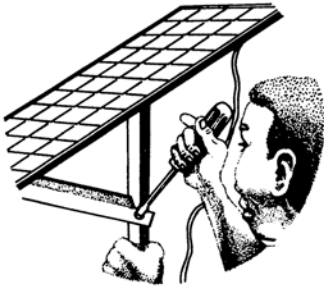


Figure 10.5

*Remember, if there is not enough solar power, you can revert to paraffin lamps for a few weeks to protect your battery.*



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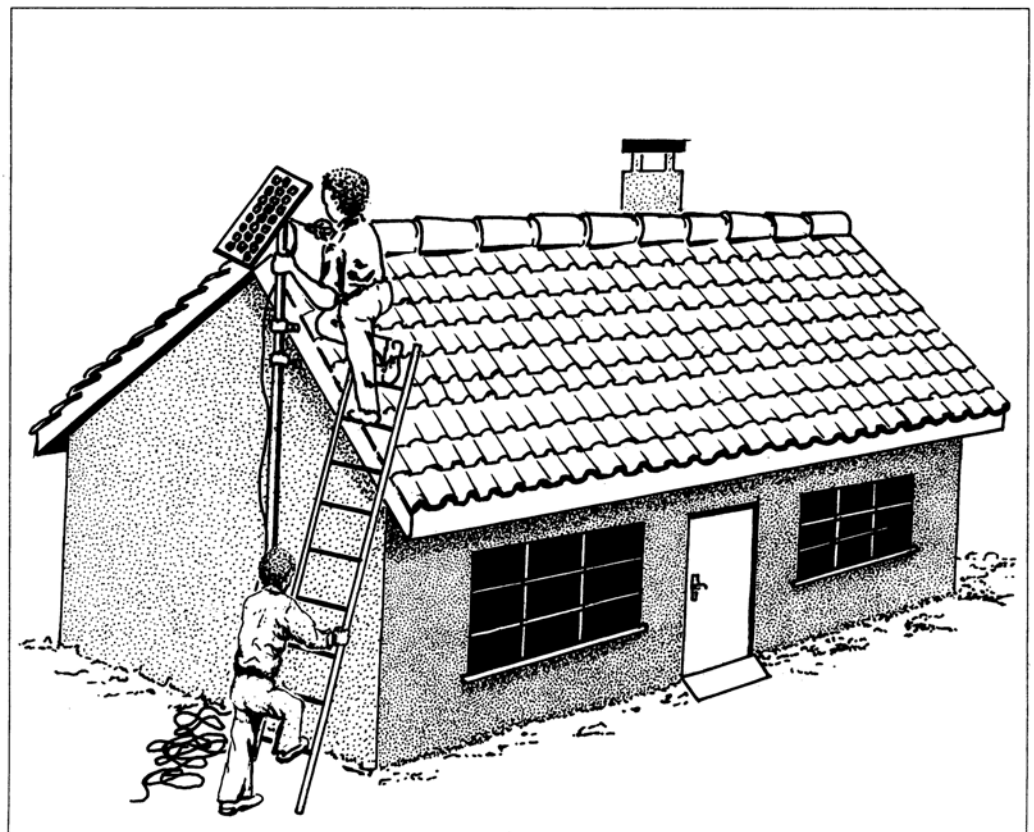
# Chapter 11

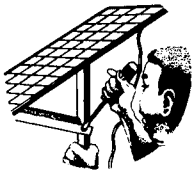
## Installing a System

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*This chapter describes the actual process of installing a solar electric system. It guides the reader through the following tasks:*

- *Preparation of tools and materials necessary to complete an installation;*
- *Positioning, mounting and wiring solar cell modules;*
- *Positioning and wiring the control and batteries;*
- *Laying the cables;*
- *Making and inspecting the final connections before commissioning the system; and*
- *Training the system managers.*





## Installing a System

**Warning:**  
Installation should be performed by qualified personnel only.

**Warning:**  
Do not connect cables to the modules, controller or batteries until the final connection sequence.

## Foreword to Installation

Once a system has been planned and the necessary equipment obtained, installation can begin. In all cases, a qualified electrician should supervise work to ensure that the system is installed according to the local electric safety codes, and so that no person is injured or equipment damaged during installation.

The installation methods presented in this text are based on techniques used by several companies in rural East Africa. The effectiveness of these methods is demonstrated by the fact that thousands of small systems have been installed using these techniques since 1984. The methods are, in general, similar to wiring practice already familiar to East African electricians although they are adapted to low voltage dc principles.

### Recommended Installation Procedure

1. Check to make sure that all equipment is on site.
2. Lay cables to loads. Attach lamps and sockets.
3. Locate site for solar modules, lay cables and install array.
4. Locate site for battery, lay cables and install.
5. Locate site for controller, lay cables and install.
6. Complete the final connection sequence and commission system.

### Installation Tips

- Before beginning an installation, make sure that all equipment is at hand. This includes tools, materials, necessary spares and information resources. Solar electric installations are often conducted in remote areas where equipment and spares are not available. Installations have been delayed (at great cost to the electric agent) because there

were not enough connector strips carried to site, or because a certain special screw was missing!

- Follow the recommended sequence of installation. Do not connect appliances, lamps, batteries or solar cell modules to the control until the last step. Follow the final connection sequence carefully (see pages 89 - 90).
- Complete the installation with help from an electrician.
- Always try to use proper tools for each task (see next section).
- Maintain high work standards. Work standards refer to the way the wires are laid, the consistency of switch placement, the method with which fixtures are attached to walls and the general neatness of the work. High standards will make the system look more attractive and last longer, and will add to the system safety.

## Tools and Materials

It may be difficult to obtain tools, extra parts and equipment on site. For this reason, make check lists of all the materials and tools needed during installation before departing for the installation site. This list should be carefully cross-checked during trip preparations. Use the information gathered during the planning stages (i.e. the map of the site, the worksheets and the circuit diagram, see Chapter 9) together with Tables 11.1 & 12.1 to make the check lists.

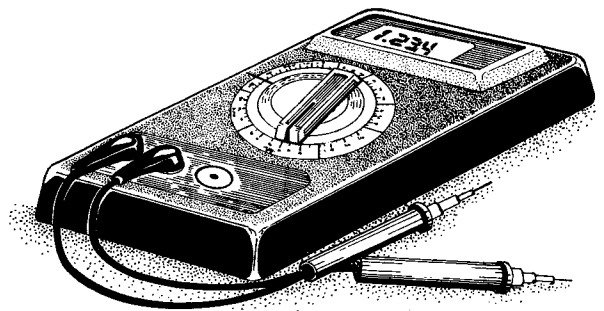


Figure 11.1  
Digital volt meters are extremely useful when installing and repairing solar electric systems



## Installing a System

**Table 11.1: Recommended Tools for a Solar Electric Installation**

Tool	Purpose of Tool
Crimp tool	Attaching ring and spade terminals to wires
12V dc Soldering iron	Connecting wires to terminals, fixing electrical parts
Voltmeter	Testing connections, measuring voltage
Screw drivers (star & flat-bladed)	Tightening screws and terminals
Hydrometer	Measuring battery state of charge
12V drill & drill bits	Drilling holes for various purposes
Tape measure	Measuring distances and marking wire clip placement
Pencil & paper	Taking notes on measurements
Hack saw	Cutting metal frames
Utility knife	Various cutting jobs
Wire cutter & stripper	Preparing cables
Torch	Laying wires in dark places (ceiling)
Pliers	Holding bolts and nuts during tightening
Adjustable spanner	Tightening battery terminals
Hammer	Various construction tasks
Shovel	Digging trenches
Level	Checking grade of mount, laid wire and foundations
File	Smoothing rough surfaces after cutting
Extension cord	Running power from batteries to tools
Inclinometer & compass	Fixing the angle of solar modules
Product literature for system components	Source of reference information

Unless you have a portable generator, there won't be 240 volt power for tools. Thus, all power tools must be rated at 12 volts dc to be powered by the batteries or solar modules. Upon arrival at site, the batteries should be filled (see page 88) and connected to the modules for charging so that there is power for tools and lights during the installation work.

The installation, maintenance, and troubleshooting work described in Chapters 11 and 12 requires that installers use a voltmeter, preferably a digital voltmeter (DVM). Voltmeters are useful when checking for broken wires (continuity), polarity, and when measuring voltage of modules and batteries. Many digital voltmeters also allow measurement of current. Make sure you are familiar with the use of the

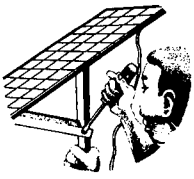
voltmeter, as a mistake could damage the meter or cause injury (consult the manual if necessary).

### Safety

Solar electric systems have a good record for safety. Nevertheless, installers should be aware that the equipment they are working with has potential to cause serious injury if safety standards are not observed. In the remote areas where many systems are installed, there are few doctors or hospitals, so it is especially important to use care to avoid accidents.

*In general*, to avoid shock risks when working with electricity you should:

- always remove rings and jewelry;



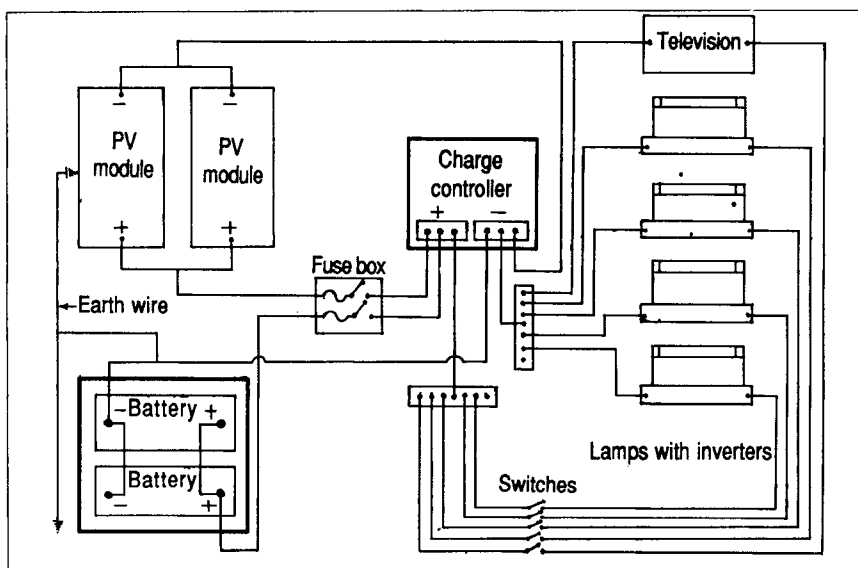
## Installing a System

- use insulated tools;
- keep loose cables and metal tools away from the control, batteries and arrays so that they do not accidentally come into contact with live terminals or leads;
- always be aware of possible shocks from modules and batteries, and take steps to avoid them.

*Batteries* need to be handled with special care.

- Battery acid is extremely corrosive. It can destroy clothes, burn skin or cause blindness if it comes in contact with the eyes. Wear protective clothing and glasses, and use a funnel to avoid splashing when filling cells. *Always* keep fresh water available to rinse spilled acid off clothes, hands and eyes. Baking powder (*chapa mandasi*) neutralizes acid spilled on clothes and on the floor.
- Batteries are heavy. Carry them upright, from the bottom, or by the handles provided. *Never* lift batteries by the terminals.
- Make sure that batteries are located in a ventilated space. Do not smoke near batteries.
- Beware of electrical current in a battery. If the terminals of the battery are accidentally shorted, someone could get a bad shock.

Figure 11.2  
Circuit diagrams are used by electricians to plan wire layout. This circuit diagram is for the system described on page 67.



*Modules* are expensive and potentially breakable, so:

- Transport with care. Beware of the back side of the module which is especially fragile.
- Beware of shocks when wiring and installing modules. One 40 Wp cannot easily cause a lethal shock. However, several modules in series or parallel are more dangerous. Disconnect or cover the array with a blanket when wiring to avoid shocks.

*Ladders/Roof Mounting.* A high percentage of the injuries from solar electric installations are caused by falls from the roof. When on the roof:

- Use stable ladders, and position them correctly. Have somebody hold the bottom part of the ladder.
- Use ladders or planks while walking on the roof to prevent the tin (*mabati*) from ripping.

*First Aid* kits should be on the site during any installation.

- Keep the kit well-stocked and ready.
- Make sure someone knows how to use it.

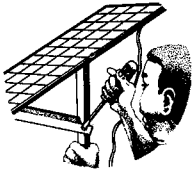
## Wiring the Load

Wiring of the house or building is usually the first task during a solar electric installation. This is especially useful if the installers need a place to work, because the installed lamps and tools can be temporarily connected to the battery in one room, providing a convenient place to organise and conduct assembly work even after sunset.

### Wiring Guide-lines

During wiring of the load (and the other system components, as well) the following guide-lines should be followed:

1. *Use a circuit diagram.* Keep a copy of the diagram near the control box. The more complex a system is, the more useful a circuit diagram will be for electricians who want to repair the system in the future. If, for example, a



## Installing a System

A labelled cable can be easily identified if it gets disconnected.

school lighting system is to be expanded later, a circuit diagram will enable electricians to quickly understand how the system is wired.

2. *Follow established cabling colour codes.* Electrical cable is insulated with colour-coded covering which specifies its function. Systems that do not use proper wire colouring are both illegal and dangerous. The established East African wire colouring codes are given in Appendix 4.
3. *Label cables.* Pieces of labelled electrical tape fixed onto cable from connector strips, batteries and/or charge controllers enables quick identification of the cable without the need to waste time following it. For example, a positive cable from a control panel to the array should be labelled 'ARRAY +'. With a label, the wire will still be identified even if it accidentally gets disconnected.
4. *Always double check polarity when wiring.* It is easy to fix the wrong cable to the wrong terminal. If this is done with a load wire, then an expensive fluorescent lamp or appliance could get ruined by reversed polarity. Modules will be damaged by reversed polarity.
5. *Earth module frames and loads.* It is always good practice to earth systems for safety and for protection from lightning (see page 52). The larger the system and array, the more important earthing is.

### Low Voltage Wiring Practice

Because of the voltage drop that occurs in the case of poor connections, all connections should be as tight and secure as possible. Always use stranded wire in low voltage applications.

When preparing cables:

- Cut the exact amount of insulation required from the end of the wire;
- Avoid cutting the small strands in the wire;
- Twist the wire strands before inserting them into connector strips.

When laying cables:

- Use correctly-sized connector strips for joining cables.
- Never allow 'twist' connections between cables as they are likely to come apart or cause a voltage drop.
- When tightening screws in connector strips and terminals, turn the screw until it is tight enough for a secure connection, but not so tight that it cuts the wire.
- Locate all connections so that they are accessible.

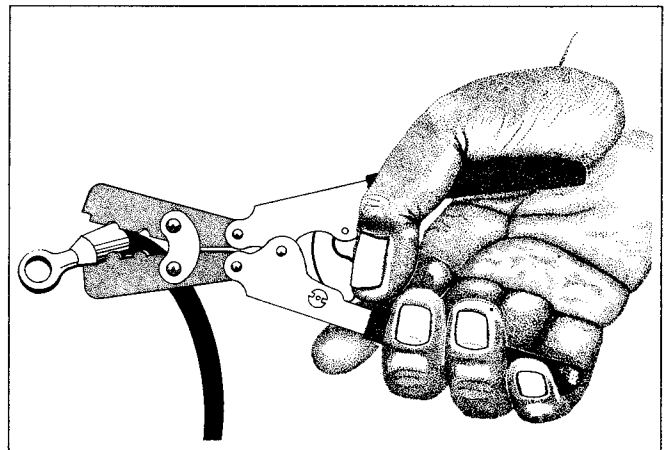
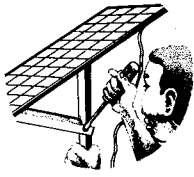


Figure 11.3

*Crimping tools are special types of pliers used for making electrical connections. They securely attach 'ring' and 'spade'-type connectors to the end of wiring cable, by pinching (i.e. crimping) the metal connector collar tightly around the end of the wire. Ring or spade-type connectors attach more securely to terminals than bare wire.*

- Use a crimping tool if one is available. Crimping tools and connectors make secure electrical contacts and enable work to be done quickly (See Figure 11.3).
- Clip cables neatly to the wall, spacing



## Installing a System

Solar cell modules should be mounted in a place where they can receive a maximum of solar radiation, but where they will not be shadowed, overheated, or covered with dust.

the clips at regular intervals, or run cables in conduit that is properly fixed to the wall;

- Make sure all wire runs are clipped so they run exactly horizontal or vertical (use a levelling tool);
- Place light switches and power sockets in wall-mounted pattress boxes.
- When positioning switches and sockets, consider needs of users.
- Use standard OFF and ON positions throughout the installation (OFF is up in East Africa).
- When laying conduit outdoors, make sure it is supported every three metres, and within six cm of the electrical box.
- Make sure controller and junction boxes are sealed, as spiders and wasps like to use such boxes as homes.

### Mounting Solar Modules

Before installation begins, the mounting location and the method of mounting should be chosen. Solar cell modules should be mounted in a place where they can receive a maximum of solar radiation, but where they will not be shadowed, overheated, or covered with dust. They should be located as close as possible to the batteries and control, and in a place that is safe from vandalism and theft.

#### Handling Solar Cell Modules

Solar cell modules, like any other pieces of glass, can be broken. However, the glass used to make modules is a very strong type designed to withstand the impact of falling hailstones. Modules can be broken by thrown rocks, and they may break if they are dropped. Once broken, it is likely that a new module will have to be bought, as modules are almost impossible to repair.

Care must be taken when transporting modules. The back side of modules especially should be protected

during travel or work. Hard, sharp objects (such as screw drivers) which strike the back of the module can break a cell from behind. Even if only one cell is broken, the module will be ruined. Modules should never be twisted, as this could break the cells inside.

If holes must be drilled in the frame for mounting purposes, take care not to punch through the frame into a cell. Use a piece of wood behind the frame to prevent such an accident. Better still, use the holes that were drilled in the frame at the factory.

#### Choosing The Mounting Site

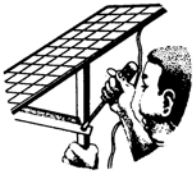
The most important consideration in the search for a mounting place for the module is that it gets as much sunlight as possible. When choosing the place to fix the module (or array), the following points should be taken into consideration.

Modules should be located:

- off the ground, if possible, so that they are out of the dust and out of the way of humans and animals. Do not locate modules near chimneys or kitchens lest they be covered with soot and smoke.
- in a place where they will not be covered by shadows. Check the position of the sun during different times of the day (and during different seasons) to determine whether shadows from trees or other objects will fall on the intended module location. Even if one cell is shaded, the output of a module will fall considerably.



Figure 11.4  
Module site. Do not place module where it might be shaded by trees or obstructions.



## Installing a System

Between the module and the battery or control, use a cable with a great enough diameter to ensure that the voltage drop is less than 5%.

- in a place where they will not get too hot. If fixed on a tin roof, modules should be at least 10 centimetres off the tin roof top. If possible, the module should be located where it will be cooled by the wind.
- in a secure place. Do not place modules where they might be stolen. Do not locate them where they might be vandalized or hit by stones.
- in a place that is as near as possible to the batteries and control. If the modules are located too far from the control and batteries, there will be a voltage drop and power loss. Use a wire with a thickness great enough to ensure that the voltage drop is less than 5% between the modules and battery (see Chapter 8).

### Method of Mounting

Once the site has been chosen, it is necessary to decide whether the array will be mounted in a *fixed* or *tracking* position. Solar electric suppliers supply mounts (or plans for mounts), and will be able to help decide which mount is the best for a given installation.

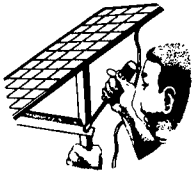
Tracking equipment, however, adds extra cost and complications to the system, and increases system management work. In East Africa, a cheap, easily-operated tracker that increases module output by 25% has been developed (see page 15).

If the module is to be mounted in a *fixed position*, then the decision should be made as to whether it will be mounted on the roof, on a pole or on the ground. Fixed mounts must be rigid, flat and well-ventilated. They must also be strong enough to withstand the strongest expected winds in the location without bending or breaking.

- Roof top mounts use racks or brackets to fix the array to the roof structure. Their advantage is that they are safe and secure, although it may be difficult to clean modules mounted high on the roof. Brackets may be constructed so that they pivot downward for easy cleaning (see Figure 11.5), or so that their angle can be adjusted seasonally.
- Pole mounts are popular with systems that have up to four modules. They keep the modules well off the ground in secure highly visible places. Pole mounts are more expensive than roof top mounts, as they require metal pipes (6 cm steel poles) and, sometimes, a foundation. Note that small pole mounts are easily converted into trackers for one module systems.
- Ground mounts are used for arrays of four or more modules (i.e. for water pumps, refrigeration or large home systems with no other suitable place to locate the modules). They secure modules to racks fixed in concrete found-

Figure 11.5  
Two fixed roof top  
mount designs





## Installing a System

Check with solar dealers to find what tilt and direction fixed modules are commonly mounted at in your area.

dations and may be fenced off to protect the array from animals and curious people. Under normal circumstances, a one or two module system would not be ground mounted.

Fixed mounts must be aligned so that rain-water runs off the modules (i.e. they must have at least a 5° tilt), and so that the modules face the direction where they are likely to get the best sun. In Kenya, modules are usually mount with a tilt of 10° to the north. This is because the cloudiest season in Kenya is between April and July when the sun is in the northern hemisphere, and the tilt enables the system to make best use of the sun when it does appear in the cloudy season. Check with local solar dealers to find what tilt and direction fixed modules are commonly mounted at in your area.

### Construction of Mounts

Once the type of module mount design has been chosen and the required materials obtained, the mount can be assembled. Most solar electricians are familiar with mounting methods, and can help in the assembly and installation process.

When constructing all types of mounts (both fixed and tracking) corrosion-resistant, weather-proof parts should be used. Stainless steel and anodized aluminium angle irons are commonly used to make mounts in East Africa. If the steel used to make the frame is not weather-proof, then it should be coated with a layer of red oxide paint to prevent corrosion. Wood can also be used to build mounts inexpensively, but wooden mounts do not last as long as metal ones. Note that bolts, nuts and washers should also be weather-proof and corrosion-resistant.

When mounting modules on the roof, use ladders and walk boards to protect roofs from the weight of installers. Minimize the number of people on roof. Bolt the mount securely to roof timbers, or to the "facia board" at the peak of the roof (see Figure 11.5). Avoid tears in tin which cause rain leakage.

When installing an array with several modules, attach the modules to the frame

on the ground, and then attach the frame to the fixtures on the roof or pole.

### Wiring the Modules

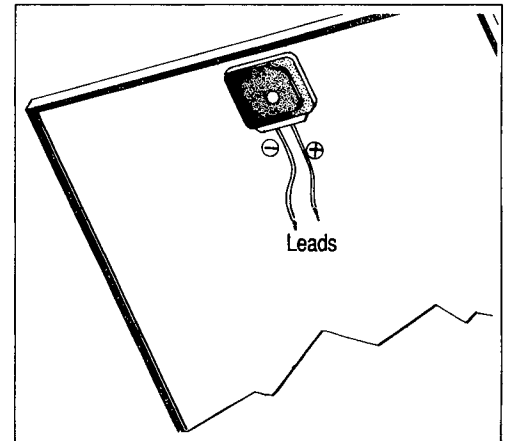


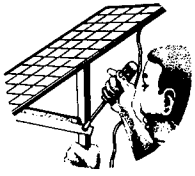
Figure 11.6  
Backside of module showing leads from junction box.

Unless the batteries are being charged to power equipment during installation, *do not* attach the module leads to the battery or control until the *final connection sequence*. The following practices are advisable during wiring:

- Use properly sized cable.
- Earth the entire array (as described in Chapter 8) by connecting the frame and negative terminal of each module to an earthing cable.
- Wire the junction boxes carefully. Use a soldering iron or crimp tool to make sure that the connections are good. Make sure that the junction boxes are well-sealed to prevent possible corrosion.

If there is *more than one module* in the array, then the modules must be wired in a configuration that matches the system voltage. Two questions should be answered before attempting to wire modules together:

- How many modules should be wired in series?
- How many modules should be wired in parallel?



## Installing a System

(The principles of series and parallel circuits are discussed in Appendix 2)

Most small systems in East Africa have a voltage of 12 volts. Likewise, most modules commercially available in East Africa produce current that approximately matches the charging characteristics of 12 volt batteries. Such modules are always wired in parallel in 12 volt systems. Figure 11.7(a) shows two 10 Wp amorphous modules wired in parallel to charge a 12 volt battery.

If the system voltage is 24 volts, then two standard modules must be wired *in series* to charge two 12 volt batteries *in series*. Figure 11.7(b) shows 2 modules in series charging two batteries wired in series.

Always consult a qualified electrician to make sure that the series and parallel wiring of modules and batteries has been properly done.

The battery should be located in a cool, vented room where there is little traffic.

## Battery and Controller Installation

After installing the module, the battery and controller should be installed in the most appropriate room or building.

### Choosing the Battery Location

The battery should be located in a cool, vented room where there is little traffic. The following recommendations should be followed when locating and installing the battery:

- *Nearness to array.* The battery should

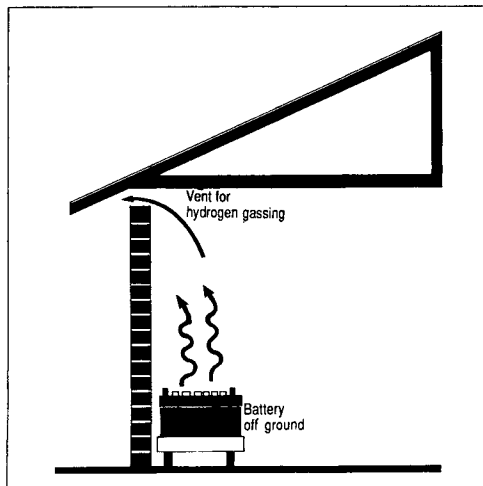


Figure 11.8  
The battery should be located in a place that is well-ventilated.

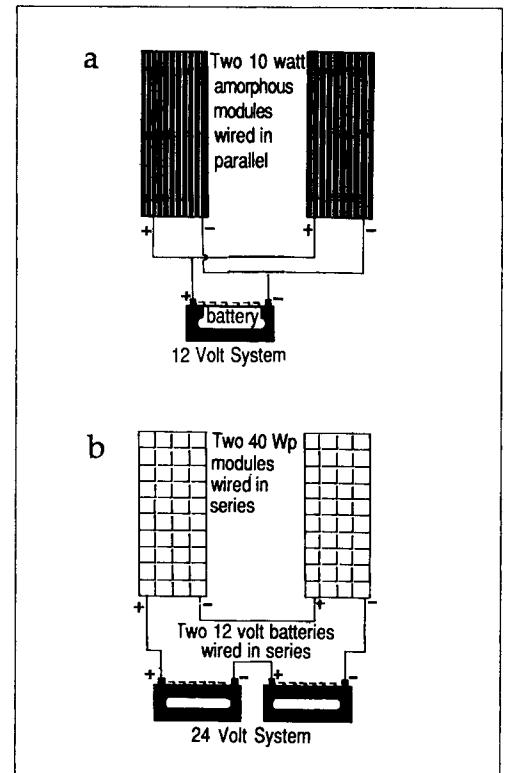
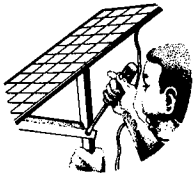


Figure 11.7 Modules charging batteries in parallel and series.

be located as close as possible to the array to reduce voltage drop. Check that the size of the cable is large enough to carry the charge current from the module without more than 5% voltage drop.

- *Ventilation.* The battery room *must* have some sort of opening for air to enter and leave. Batteries emit explosive gases when charging and this must be allowed to escape. Place a "NOSMOKING" sign in the room where the batteries are located.
- *Temperature.* The battery should be located in a place where the temperature does not get too high. If the battery temperature gets above 40°C, the battery's lifetime and performance will be reduced. *Never* place the battery where it will be exposed to the sun.
- *Battery boxes.* Batteries should not be kept on the floor, as this will increase their self-discharge rates. Batteries should be kept in a vented wooden box to reduce self-discharge, to prevent children and animals from injur-



## Installing a System

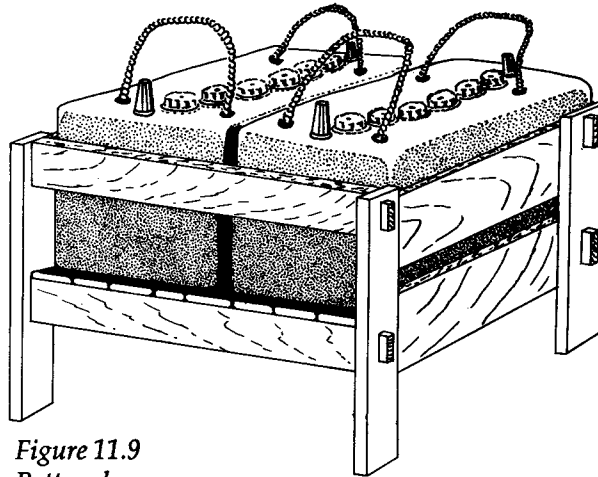


Figure 11.9  
Battery box

Do not put the battery in a closet and forget it! Batteries must be maintained.

ing themselves accidentally and to prevent objects from falling on them, (see Figure 11.9). If it is not possible to construct a box, keep the batteries off the ground on a plastic or wooden tray (but not metallic).

- *Security and safety.* The battery should be located where it is secure and not likely to be stolen. Ideally, it should be in a closet or room where children and animals cannot tamper with it. However, the place should be accessible for easy state of charge measurement and cleaning. In an institution, the room where the battery is kept should be locked.

### Transporting and Filling the Battery

Locally-made lead acid batteries are usually supplied *dry* for solar electric applications. This means that when they are sold, sulphuric acid electrolyte has not yet been added to the cells. The acid is supplied in plastic jerry cans (i.e. *mutungis*) which can be safely sealed for transport to remote areas. Because batteries are likely to tip and spill during transport on the rough roads, it is recommended that they always be transported dry, and acid carried separately in sealed jerry cans.

After arrival at the site, acid should be carefully poured into the batteries until they are almost full, either by using a plastic tube, or by using a funnel. Wait ten minutes for the acid to settle and then top them up. Afterwards, wipe the top of the batteries, and rinse the funnel, plastic tubes, clothes and hands that have come into contact with acid.

- Keep plenty of water around when filling the battery so that any spills can be quickly rinsed. Be aware that sulphuric acid is dangerous, and take care when pouring it.
- Wear old clothes and goggles when filling batteries. Fill them outside if possible.

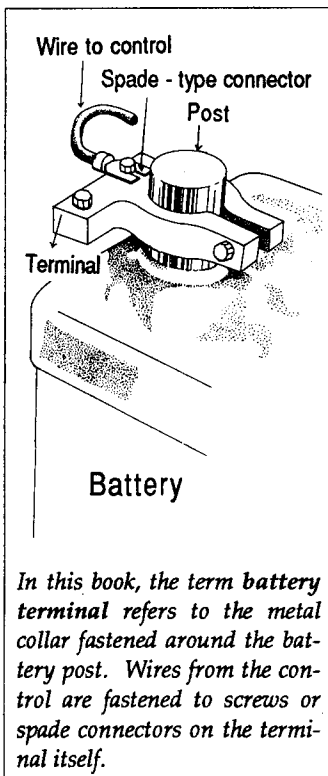
Once the batteries have been filled, they are charged and can produce a very high current. Keep tools and cables clear of the terminals and posts, as accidental short circuits are both expensive and dangerous.

### Battery Wiring

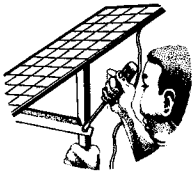
As stated previously, the cable run from the modules to the control and batteries should be as short as possible. If the modules are on the roof, run the cable through the roof space down an *inside* wall. If the modules are on a separate pole or ground mount, protect the underground cable run with conduit, and mark the place where the cable is.

If there is only one 12 volt battery, attach the cables to the battery terminals (when the terminals are *not* attached to the battery), tighten the screws and secure them. It is always better to use ring or spade-type connections on terminals than to simply wind the wire around the terminal screws. Unless the battery is being used to power tools and lights, leave one terminal disconnected from the battery until the final connection sequence. Coat the outside of the terminals with a thin layer of petroleum jelly. Check the electrolyte level in each cell. Check the state of charge of each cell to make sure that no cell is bad.

If there is more than one 12 volt battery, *make sure* that they are arranged properly in series or parallel. Twelve volt batteries in 12 volt systems are arranged in *parallel*. If there are two 12 volt batteries in a 24 volt system, they should be arranged in series. If there are four 12 volt batteries in a 24 volt system, two should be in series and two should be in parallel.



When wiring, have an electrician check series and parallel connections.



## Installing a System

### Final Connections

For final connections in small systems, the guide-lines below represent a method of safely commissioning the system. These guide-lines are designed for systems that use charge controllers, but the order can be adapted for systems that do not use controllers.

- AN ELECTRICAL TECHNICIAN PROPERLY TRAINED AND EXPERIENCED WITH SOLAR ELECTRIC SYSTEMS SHOULD MAKE THE FINAL CONNECTIONS. This supervisor should conduct commissioning tests of the array, the junction boxes, the support structure, the solar modules, the control unit and the battery.
- Follow the manufacturer's instructions for controls and inverters.
- If the installation is for an institution, there should be an official handover to the operator/client with some type of receipt/record of transaction to mark the occasion.

#### Caution:

Solar electric equipment is expensive. Damage to the equipment can be prevented by following the four steps slowly and carefully.

Before commencing with the final connection sequence, the wires should have been installed without being connected to the control terminals. Before beginning this process, disconnect fluorescent tube lamps to allow a polarity check to be made.

#### 1 Connect the Wires from the Battery to the Charge Controller

Make sure that the wires are securely connected to the battery terminals, and that the inside surface of both terminals is clean and shiny. Make sure the battery posts are clean. After checking to make sure that the wires are *not* touching the control terminals, place both terminals on the battery posts without tightening the clamping bolts (this will enable them to be removed quickly if there is a problem). The black wire should be connected to the negative (-) and red wire should be connected to positive (+).

Connect the black negative wire to the indicated negative terminal on the controller (i.e. BATTERY -), and tighten. Touch the red power wire to the positive BATTERY terminal on the control very briefly. If there is a spark, the controller may be defective, or there may be some other mistake; so re-check the connections. If there is no spark, connect the positive red battery cable to the terminal and tighten.

#### 2 Connect and Check the Load

Since the battery is connected, power is now available to check the wiring of lamps and sockets in the load. Before beginning, all dc globe lamps should be removed from their lamp holders and no fluores-

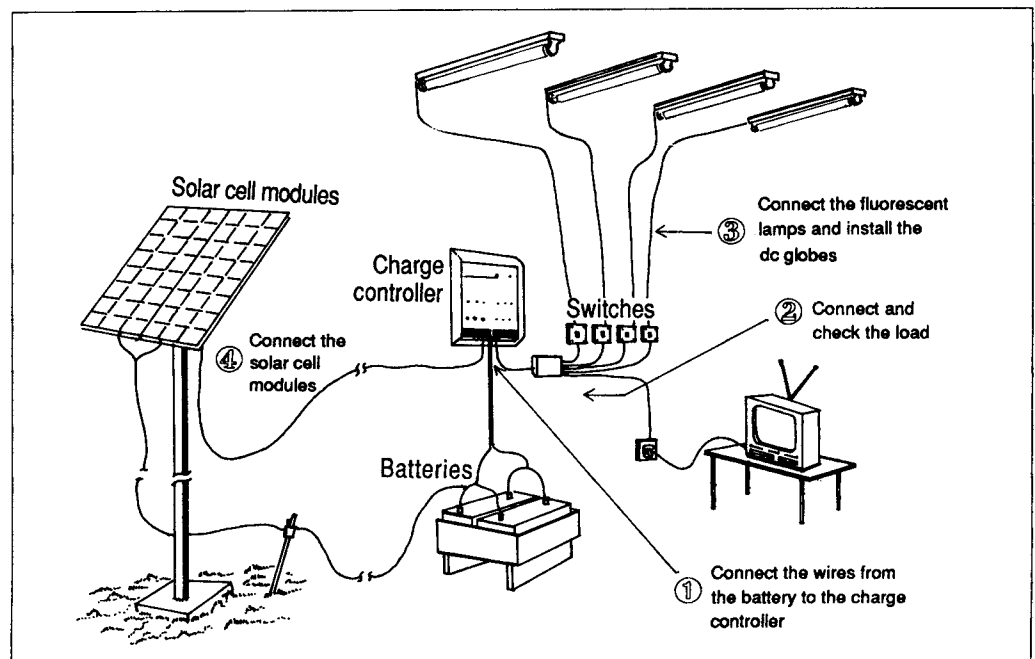
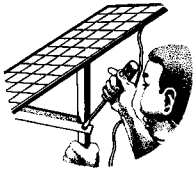
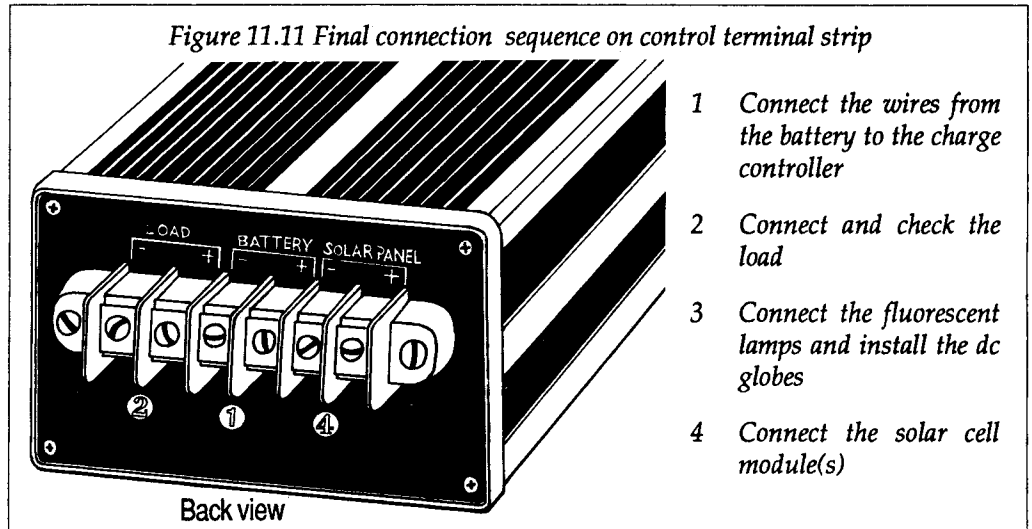


Figure 11.10  
Installation sequence in a solar electric home system



## Installing a System

Figure 11.11 Final connection sequence on control terminal strip



cent tube lamp should be connected (if sockets are on the same load circuit as the lamps, disconnect the positive wire from each socket). First, connect the negative wire from the lamps circuit (or *load circuit* if there is not a separate lamps and socket circuit in the system) to the negative load terminal on the controller, and turn the main switch ON. Touch the positive wire to the positive load terminal and check for sparks. There should be no spark since all of the lamps (and sockets) have been disconnected. If there is a large spark and/or a fuse has been blown, then there must be a short circuit somewhere. Find it and fix before proceeding. If there is no spark, then the wires can be fixed to the control terminals.

Polarity of the fluorescent tube lamp wires should now be checked using a voltmeter. If the polarity is wrong, fluorescent tube fixtures will be damaged. Set the voltmeter at the DC VOLTS scale, and connect the red voltmeter wire to the red fixture wire (from the battery) and the black voltmeter wire to the black fixture wire. Have someone switch the lamp ON and read the voltage on the voltmeter. If the voltmeter displays the system voltage, then the polarity is proper. Repeat this test for each fluorescent lamp (polarity does not matter with globe lamps).

Now check the socket circuits (if there is a separate outlet circuit on the control and load). Connect the black wire from the

sockets to the proper terminal on the control, and touch the red wire briefly to the positive terminal with the "sockets" main switch turned ON. If there is no spark, secure the wires to the terminals.

Polarity of each socket should be checked with a voltmeter. Reversed polarity in sockets will damage some dc appliances such as televisions. An easy way to check outlets is to use a three pin plug with the cover removed. Insert the plug into the socket, and check the polarity by touching the red meter wire to the 'L' (+) terminal and the black meter wire to the 'N' (-) terminal.

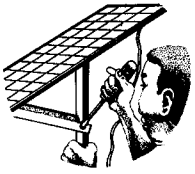
### 3 Connect the Fluorescent Lamps and Install the dc Globes

Now that the polarity has been checked, the tube lights can be connected and put into service. After connecting each lamp, turn it ON to see if it lights properly, and to check if the switch is properly installed (OFF is up). When connecting the fluorescent lamp leads, note that in some wire coding systems, white lamp leads are *negative* and black lamp leads are *positive* (read the label for details). At this point, the dc globe lamps can also be inserted into lamp holders, and checked for proper operation and switch placement.

### 4 Connect the Solar Cell Module(s)

First, turn all the lamps and sockets OFF using the main switches in the control (if there is none, turn them OFF at the room

**Polarity of the fluorescent tube lamp wires should be checked using a voltmeter.**



## Installing a System

switches). If there the array is above 60 Wp, cover it with a blanket before wiring. Connect the cable leading from the control to the module leads (or terminals), observing proper polarity. Some types of modules have terminal boxes, while others have long cables (leads) attached to the back of the module. A junction box should be used to make the connection with the wire to the control. Use connector strips inside the box; seal and fix it to the mount when finished. Once the connections are complete, you can remove the blanket from the array if necessary.

Now, connect the black charge wire leading to the module to the negative SOLAR terminal of the controller. Meanwhile, attach the voltmeter to the battery terminals. Write down the battery voltage. Touch the red charge wire to the control terminal briefly. If there is a charge indicator light it should come ON, and the battery voltage should jump between 0.3 and 0.4 volts (depending on the time of day).

If no problems have been encountered, secure these wires. The system wiring is complete, and it can now be safely commissioned and used.

### User-Training

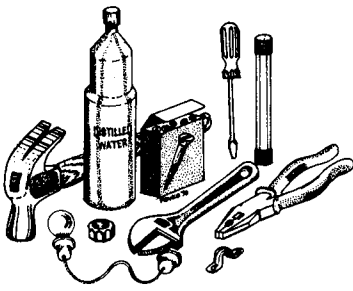
As explained in the next chapter, not much is required in the management of a solar electric system, but it *does need to be managed*. The person who installs a system is usually not the person who operates and maintains it. It is crucial to the success of the system that the users learn how to manage

and maintain the system. This means that during the installation process, someone must teach the person responsible for managing the system what he or she needs to do.

The system manager needs to learn the following:

- *Maintenance routine.* What tasks need to be completed and how often (i.e. on a daily, weekly or seasonal basis)? Which tools are required and how are they used?
- *Expected service operations and schedule.* Which parts wear out and how are they replaced? Where are they available? The system manager should be given a schedule of the service contract (if there is any).
- *What records need to be kept?* In some systems, particularly institutions, records should be kept regarding the age and condition of the batteries (they will have to be replaced), the place of purchase of system components, and the electrical details of the system (i.e. circuit diagrams). The manager needs to be shown how to keep these records.
- *What to do in case of breakdown.* The manager should know who to contact in the case of a problem that cannot be solved on the site. There should be some kind of regular contact (at least annually) between the operator and the sales agent or installer.

It is crucial to the success of the system that the users learn how to manage and maintain it.

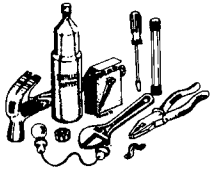


# Chapter 12

## Maintaining and Servicing Solar Electric Systems

*This chapter explains how to take care of a solar electric system, and how to fix it if there is a problem. It explains routine maintenance tasks involved in the care of the battery, modules, wiring and control, and loads. The section on troubleshooting explains how to identify the causes of problems and how to solve them when the system fails to work.*





## Maintaining and Servicing

### Routine Maintenance

A properly installed solar electric system requires very little maintenance. In fact, the work involved in maintaining a solar electric system is much less than that needed to maintain a diesel or petrol-powered generator. The best maintenance practice is to make regular inspections of the equipment (especially batteries and modules), to make sure things are kept clean, and to make sure all electrical contacts are tight.

The following section describes most of the tasks that need to be done when managing a system. You do not have to go out and check each wire in the system every two weeks. However, you should follow the suggested procedures below, and you should at least make an annual system check to look for problems not covered below. These include checks for tree growth that has shaded your modules, birds' nests in your module junction boxes, *shambas* above buried wires, and other unexpected problems.

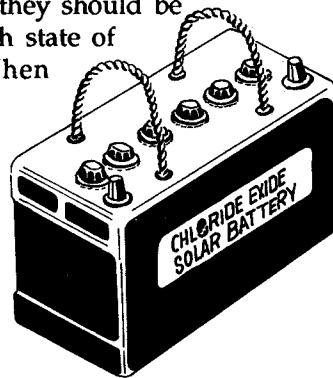
**Table 12.1**  
**Useful Tools and Materials for Maintenance of Solar Electric Systems**

Hydrometer	Measuring battery and cell state of charge
Voltmeter	Measuring state of charge, checking wiring
Adjustable spanners	Tightening loose connections
Distilled water (or rainwater)	Replenishing battery electrolyte
Petroleum jelly	Protecting battery terminals
<i>Chapa cha mandazi</i> (Baking soda)	Neutralising spilled battery acid
Spare switches	Replacing broken switches
Spare tubes and globes	Replacing burned out lamps
Spare fuses (of the proper size)	Replacing blown fuses
Extra screws and wires	Replacing stripped or worn screws and wires

Give your battery an equalizing charge once every few months, preferably during cloudy weather.

### BATTERY MAINTENANCE

Batteries require careful maintenance. For long life, they should be cleaned monthly, they should have their electrolyte level checked and they should be kept in a high state of charge. When cleaning batteries, beware of the battery acid and do not short the terminals.



#### Cleaning

(do this once a month)

Carry the battery outside when cleaning it to avoid spilling acid. Keep plenty of water nearby to rinse spills.

1. Turn OFF or disconnect the solar charge
2. Disconnect the battery from the leads, and remove the terminals from the posts.

3. Clean the top and outside of the battery with water (do not allow water to enter the cells).
4. Clean the terminals and posts until they are shiny. If the terminals are corroded (i.e. if they are covered with white powder), clean them carefully using a solution of baking soda (*chapa mandasi*) and water. If the terminal has been badly corroded buy a new one at an auto supply store.
5. Replace the clean terminals and tighten bolts. Apply petroleum jelly or grease to connected terminals.

#### Checking and topping up electrolyte level (do this once a month)

1. Remove the caps of each cell one at a time and check the level of the electrolyte. Acid should be within two cm of the top of the battery. If you can look inside the batteries, check the plates to see their condition.



## Maintaining and Servicing

Do not add acid, tap water, or tonics to batteries.

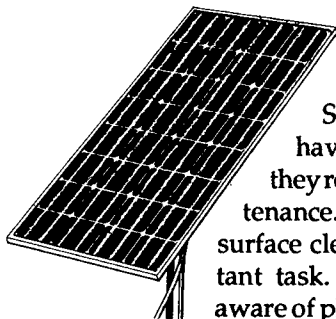
2. If the electrolyte level is down, add de-ionised or distilled water until the level is about two cm below the cap opening. Distilled water can be bought at petrol stations (It can also be made in most secondary school labs using glass beakers). Rain water collected in glass or plastic (but not metal) containers can also be used to replace distilled water.

### Checking state of charge (do this once a month or as required)

- For information on checking battery state of charge, see page 31. If the battery is in a low state of charge reduce use of the load, allow the battery to be charged up by the module, or have it charged at a petrol station.
- With large systems (i.e. in schools and institutions), keep records of battery state of charge, age and performance. This allows users to judge more easily whether a battery needs replacement; if a new headmaster comes the records will enable him to budget for new batteries.

### Equalizing charge (once every 4 months)

- An equalizing charge is a 'hard' charge from a grid or generator powered battery charger that takes the battery a bit above its normal full state. It causes bubbling which mixes up the acid inside the battery, and also helps remove accumulated sulphate from the battery plates. Give your battery an equalizing charge during the cloudiest month of the year.



### MODULE MAINTENANCE

Since modules do not have any moving parts, they require minimum maintenance. Keeping the glass surface clean is the most important task. You should also be aware of plants or trees that grow up around the module and shade it. Check occasionally for loose nuts in the mounting hardware.

### Inspecting for dust and cleaning the modules (do this once a month).

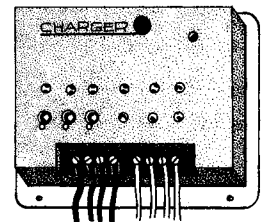
1. Solar modules must be kept clean to produce maximum power. If dust is allowed to collect on top of the module, its electric output will be reduced. During the dry season, inspect the module every two weeks to see if dust has collected on top of it. Run a finger along the top of the module to check for dust.
2. Clean modules with water and, if necessary, a mild soap. Wipe the glass with your hands, a sponge, or a soft cloth. Hands or soft cloth are used to avoid scratching the glass (if the glass is wiped with a rough cloth, it will be scratched, and its output will be reduced).

### Checking connections (do this every few months)

- Inspect the junction box on the back of each module to make sure that the wiring is tight. Make sure that the wires have not been chewed by rodents and that there are no spiders living in the junction boxes.

### WIRING AND CONTROL

If wiring is installed properly, there should be no wiring problems for the life of the system. However, it is useful to check the wiring of a system at least once a year, especially in places where it might be chewed by rodents, tampered with or accidentally pulled.



### Inspecting wiring, fuses, indicator lamps and switches (do this once a year)

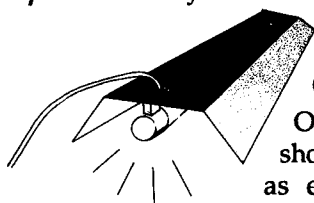
1. Check the tightness of all connector strips. Make sure that no bare wire is visible.
2. Inspect system wire runs for breaks, cracks in the insulation or places where it has been chewed. This is especially important for old or exposed wire.



## Maintaining and Servicing

You should operate the loads as efficiently as possible on a daily basis.

3. Inspect junction boxes to make sure they have not become homes for insects, and, if they are in an exposed location, to make sure they are still watertight.
4. Check switches to make sure they are operating properly.
5. Check fuses to find if any has blown. If so, find the cause and repair it or replace it with a new one of the same size.
6. Check the indicator lamps on the control. The solar charge indicator should come ON when the sun is up. If it is not ON, check to see if batteries are being charged. Check whether the other LED indicator lamps are working (i.e. battery full and low voltage).
7. Check grounding wires to make sure they are still intact.



### LAMPS AND OTHER LOADS

On a daily basis, you should operate the loads as efficiently as possible. Maintenance of loads includes turning lights and appliances OFF when not in use.

1. Clean lamps, reflectors and fixtures once every few months. Dust and dirt will reduce lamp output as much as 20%.
2. Check for blackening tubes in fluorescent fixtures. If tubes blacken at one end, this is an indication that they are approaching the end of their lives, and that their output is reduced. Replace blackened or blinking tubes.
3. Replace burnt out globes.

### System Records and Manuals

Keep all information about the system in a safe place, preferably under lock and key, where it can be referred to when necessary. Update it periodically. Most of the important information can be kept in one ledger or file. Large institutional systems work better when someone is given the job of maintaining the system and keeping

records up to date. This information includes:

- Circuit diagrams and maps showing the location of batteries, loads, wire runs, junction boxes, and buried cables.
- Manuals, warranties, and manufacturers' specifications for system components.
- Records of battery state of charge & history, installation dates, repairs, equipment replacement and system maintenance.

### Trouble Shooting

Trouble-shooting means fixing problems as they occur. Although the equipment in properly installed systems is unlikely to fail, problems that need attending to sometimes rise up. This section explains how to tackle problems in solar electric systems when they do occur.

The first thing to do is not to panic. Most problems have very simple causes, and can be discovered simply by checking in a few key places. The battery, for example, is the most likely source of problem in a small solar electric system.

It is especially useful to have a voltmeter when trouble-shooting, as you can use it to quickly measure the battery's state of charge, check for broken wires and shorts, check the output of the module and measure voltage drops. If you do not have a voltmeter, make sure you have a hydrometer (see page 31) for checking the battery's state of charge. Learn how to tell whether a fuse is blown where you buy your fuses and electrical equipment.

There are two sections below. The first provides basic questions you should first ask about the system to identify the source of the problem. The second section is a detailed table that should help you identify specific problems. If you are not confident with dc electric principles, then you should try to answer the questions in the first section, and, if you cannot identify the problem or solve it with them, consult an electrician familiar with solar electricity.



## Maintaining and Servicing

If a system failure occurs, check for basic problems first, then consult the detailed trouble shooting guide on the next page.

### Check for Basic Problems First

- What was the weather like for the weeks before the problem? Has the weather been cloudy? Is it likely that the load has been using more energy than the solar modules produce?

If this is the case, then the problem may be due to mis-use of the system, and not due to the failure of any part of the system.

- Is the system new? Do the owners know how to use and maintain it properly?

If the system is only a few weeks old or less, then the problem may be due to failure of one of the parts (due to faults in the components) or improper installation. On the other hand, if the owners do not know how to use the system, you should question them carefully (Have they been trying to run six lights with a 10 Wp module?).

- What is the type, condition and age of the battery? Can it still hold a charge?

If the battery is corroded and looks like it has not been cleaned in months,

then you should immediately begin to suspect it. Similarly, if the system uses an eight year old automotive battery, there is reason to suspect that the problem is the battery. If, however, the battery is new, clean and well-charged, then you should look elsewhere.

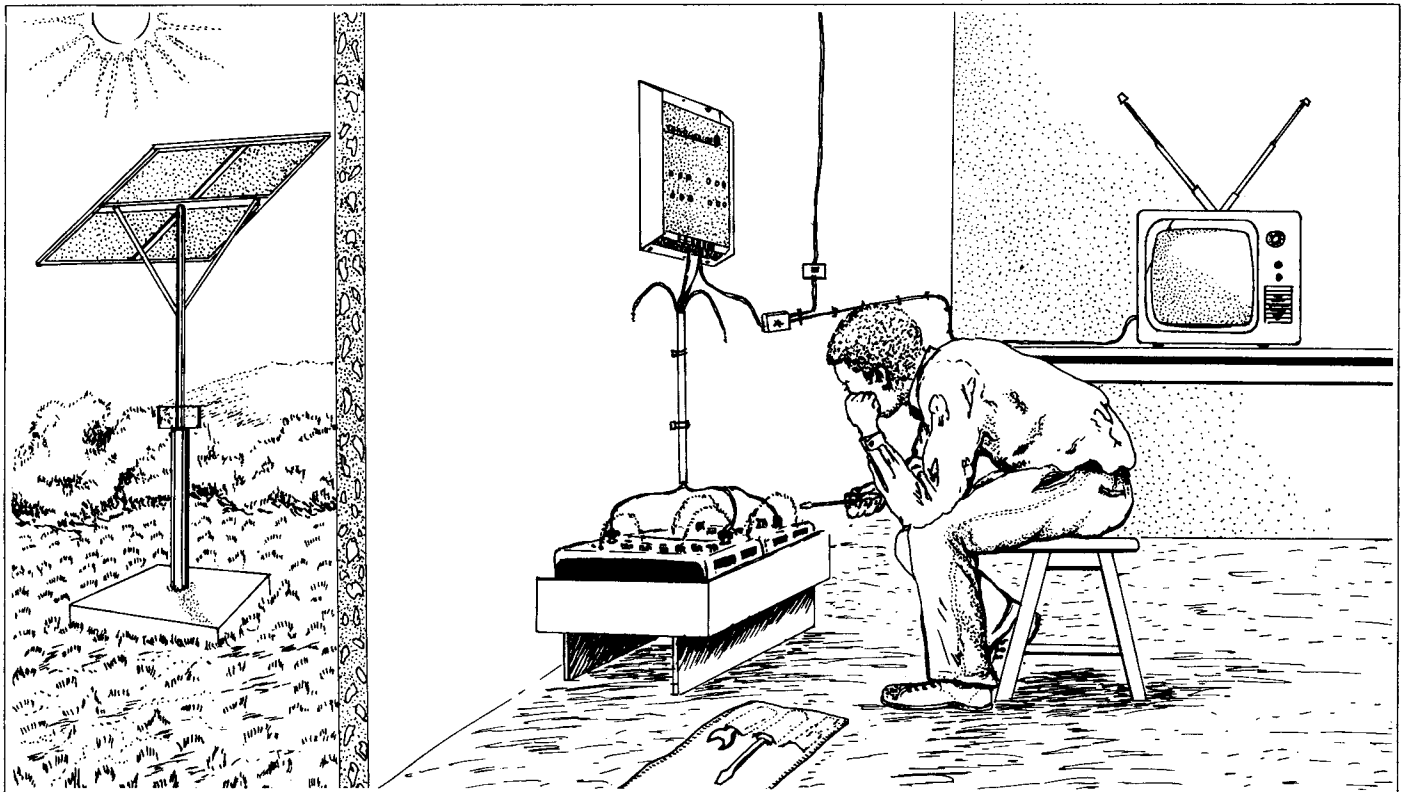
- Are all the fuses and circuit breakers okay?

Locate all the fuses in the system and see if any have blown. Check to see what caused the fuse to blow (i.e. overload, short circuit) before replacing it.

- Are all the wires connected securely? Are any corroded? Is there any place where a wire is likely to have broken?
- Are the modules dusty? Are they shaded?

### Detailed Trouble-Shooting Guide

If you cannot find the problem with your system after using the above basic check, then you may have to do a bit more exploring to find what is wrong, with the help of an electrician if possible.

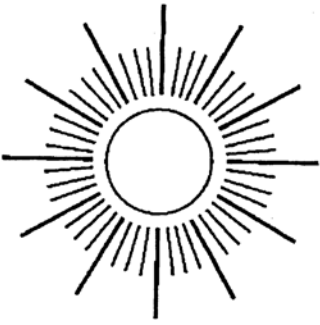




## Maintaining and Servicing

Table 12.1: Trouble-Shooting Guide

Problem	Cause	How to Fix
<p><b>Battery state of charge is low</b></p> <p>"Battery low" indicator comes on, low voltage disconnect turns OFF load, or battery state of charge is constantly below 11.5 volts</p>	<ul style="list-style-type: none"> <li>• There is no solar charge</li> <li>• Battery acid low</li> <li>• Bad connection to control terminal</li> <li>• Defective (bad) battery or cell</li> <li>• Loose or corroded battery terminal</li> <li>• Dusty modules</li> <li>• Blown fuse</li> <li>• Overuse of system</li> <li>• Battery will not accept charge</li> <li>• Voltage drop between module and battery too high</li> <li>• Defective controller</li> </ul>	<ul style="list-style-type: none"> <li>• Check and fix connection to module</li> <li>• Add distilled water to cells</li> <li>• Check for broken wire or loose connection</li> <li>• Check state of charge of each cell. If there is a significant difference between cells, replace or repair</li> <li>• Clean and tighten battery terminals</li> <li>• Clean modules</li> <li>• See 'blown fuse' section, below</li> <li>• Leave appliances and lamps OFF for a week to allow recharging or recharge battery by other means</li> <li>• Find out age and history of battery. Replace if old, or if ruined by careless use</li> <li>• Check voltage drop. Replace cable with larger diameter if required</li> <li>• Check operation of controller with dealer. Replace or repair if necessary</li> </ul>
<p><b>No solar charge</b></p> <p>Solar charge indicator does not light up during the day. There is no current in wires from module.</p>	<ul style="list-style-type: none"> <li>• Short circuit along wires to modules</li> <li>• Loose connection in wires connecting battery to the control</li> <li>• Blown fuse</li> <li>• Thick coating of soot or dust on module</li> <li>• Broken module</li> </ul>	<ul style="list-style-type: none"> <li>• Locate and repair short circuit</li> <li>• Locate and repair loose connection</li> <li>• See "Blown fuse" below</li> <li>• Clean module with water and soft cloth</li> <li>• Check for broken cells, broken glass, or poor connection inside module. Replace solar cell module</li> </ul>
<p><b>Appliances or lamps do not work</b></p> <p>One or more lamp or appliance fails to come ON when connected.</p>	<p><b>Lamps</b></p> <ul style="list-style-type: none"> <li>• Bad tube or globe</li> <li>• Bad ballast inverter</li> <li>• Bad connection in wire</li> <li>• Switch is "OFF"</li> <li>• Tubes or globes have very short lifetimes</li> </ul> <p><b>Appliances</b></p> <ul style="list-style-type: none"> <li>• Bad connection in wire</li> <li>• Switch is "OFF"</li> <li>• Bad socket</li> <li>• Broken appliance</li> </ul>	<p><b>Lamps</b></p> <ul style="list-style-type: none"> <li>• Replace with new tube or globe</li> <li>• Replace ballast inverter with new one</li> <li>• Locate broken or loose wire and repair</li> <li>• Turn switch "ON"</li> <li>• Check voltage of system: too low or too high? (Voltage is always lower when load is ON).</li> </ul> <p><b>Appliances</b></p> <ul style="list-style-type: none"> <li>• Locate broken or loose wire and repair</li> <li>• Turn switch "ON"</li> <li>• Check socket. If bad, replace</li> <li>• Try appliance where there is a good power supply. Replace or repair.</li> </ul>
<p><b>Blown fuse</b></p> <p>When the fuse is removed, the wire inside is broken</p>	<ul style="list-style-type: none"> <li>• Short circuit along wire to solar cell module</li> <li>• Fuse was too small</li> <li>• Lightning or power surge</li> </ul>	<ul style="list-style-type: none"> <li>• Locate and repair short circuit</li> <li>• Use fuse 20% larger than combined power of loads</li> <li>• Replace fuse</li> </ul>



# Appendices

## Appendix 1 Energy, Power, and Efficiency

The following section is a review of the energy concepts which must be understood to install and design solar energy systems.

### Energy

Energy is referred to as the ability to do work. For example, energy is required to boil tea, to move a vehicle between two points or to make a radio work. When boiling tea in a *jiko*, the energy source is chemical energy stored in firewood. When driving a car, the source is chemical energy stored in petrol. When operating a radio, the energy source is chemical energy stored in dry cells.

Energy is measured in units called *joules, J*, or in *watt hours*, as below. Because one joule is such a small amount of energy, words that name large numbers of joules are commonly used. One *kilojoule, kJ*, is equal to a thousand joules, and one *megajoule, MJ*, is equal to a million joules. Charcoal, for example, contains about 32 kJ of energy (or 32,000 J) per gram, and petrol contains about 45 kJ per gram. During the course of a clear day at the Equator, about 23 MJ of solar radiation energy falls upon an area of one square metre.

*Watt hours (Wh)* are a convenient way of measuring electrical energy. One watt hour is equal to a constant one watt supply of power supplied over one hour (3600 seconds). If a bulb is rated at 40 watts, in one hour it will use 40 Wh, and in 8 hours it will use 240 Wh of energy. Electric power companies measure the amount of energy supplied to customers in *kilowatt hours, kWh* (or thousands of watt-hours). In this book, energy is always referred to in watt or kilowatt hours. Note that one kilowatt hour is equal to 3.6 megajoules.

### Power

Power is the rate at which energy is supplied (or energy per unit time). Energy can be supplied at a high rate or at a low rate. For example, it takes roughly the same amount of energy to travel ten kilometres walking as it does to travel ten kilometres running. The difference is that, when running, more energy

is being used per unit time than walking. Similarly, the amount of energy required to boil a pot of water is constant; the time it takes to boil the water depends on the power, or the rate at which the energy is supplied. More power is required to boil a pot of water in two minutes than is required to boil the same pot in ten minutes.

Power is measured in *watts*. One watt is equal to one joule supplied per second. As in the case above, large amounts of power are given the name *kilowatts, kW* (thousands of watts), and *megawatts, MW*, (millions of watts). As an example, an incandescent light bulb might use 40 watts, while a radio uses about 5 watts, and an electric cooker might use 2000 W. A human being riding a bicycle produces about 200 watts of power, while a typical automobile engine produce about 25 kilowatts. On a clear day, solar power arrives upon a flat surface at a rate of about 1000 watts (one kilowatt) per square metre. Jinja Dam in Uganda supplies hundreds of megawatts of power.

### Efficiency

*Efficiency* is the ratio of output energy to input energy expressed as a percentage. Mathematically, it is expressed as follows:

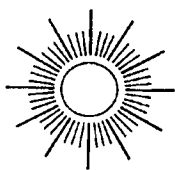
$$\text{Efficiency (\%)} = \frac{\text{output energy}}{\text{input energy}} \times 100$$

Energy-efficient devices use less energy to perform a given task than energy-wasting ones. For example, some types of stoves use less charcoal to cook a pot of tea than others. Similarly, some types of cars use petrol more efficiently than others. Tube-type lamps consume less energy than globe lamps to produce the same amount of light.

In the case of solar electricity, input energy is the radiation received from the sun by the solar cell modules, and output energy is the electrical output. The best solar cell modules are only 15% efficient. This means that, when the equatorial sun is shining at about 1000 W/m<sup>2</sup>, only about 150 watts per square meter of solar cells are produced.

The higher the percent efficient a device is, the

One kilowatt hour is equal to 3.6 megajoules.



## Appendices

more effectively it converts energy. Solar cells that convert solar energy to electricity with an efficiency of 15% are therefore much more efficient than solar cells which convert solar energy with an efficiency of only 5%.

Other solar energy devices, including solar cookers and concentrators, are able to transform solar energy much more efficiently than solar cells (i.e. up to 60%) The problem is that, for small applications, *only* solar cells are able to convert solar energy directly to electricity. Solar water heaters convert solar energy to heat, which is useful for producing hot water, but not very useful for running television sets or electric lamps. You should therefore consider using solar cookers if you want to use solar energy for cooking or heating. Using solar cells for cooking or heating is wasteful because you first convert solar energy at only 15% efficiency to electricity, before distributing the energy through wires. With solar collectors, the energy is collected as heat in one step only.

### Appendix 2: Introduction to Basic Low Voltage Electricity

This section reviews some terms used in to describe basic electric principles. If you are just beginning to learn about electricity, you should check a secondary school text such as *Principles of Physics* by M Nelkon (see References) for a good introduction to the subject.

Electricity is power provided by the flow of very small charged particles called electrons through metal wires. Because electrons are so small, it takes millions of them moving together in the same direction to develop an detectable electric current. Wires carrying electricity do not appear any different from wires not carrying electricity (although they may get a bit hot), so electricity is invisible to the human eye when travelling through wires.

**Conductors and Insulators.** Not all substances can carry electricity. Those that can carry electricity are called *conductors* and those that

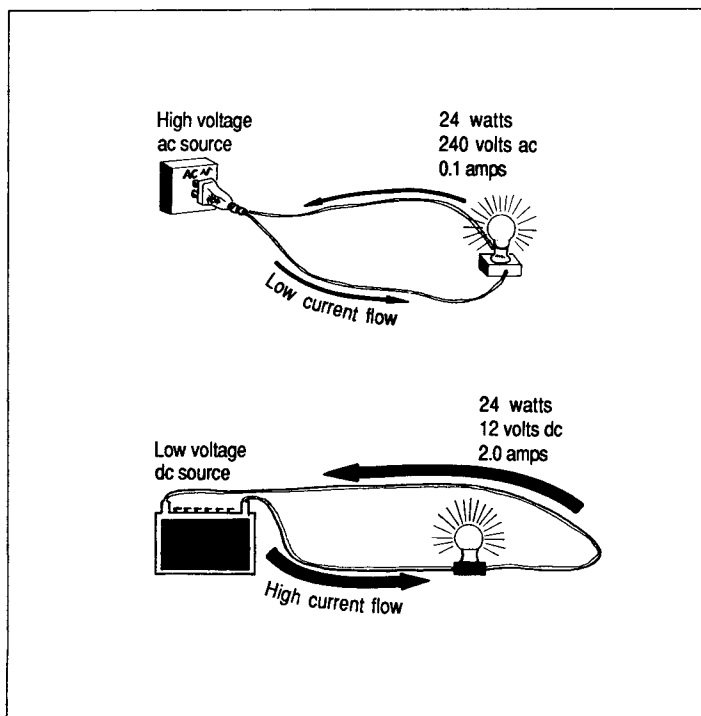
cannot are called *insulators*. Metals such as copper and aluminium are good conductors of electricity, as are salty liquid solutions called *electrolytes*. Wood, plastic and rubber cannot carry electricity and are thus called insulators. Note that wire cables are wrapped with plastic insulators to prevent the electricity from deviating from its pathway.

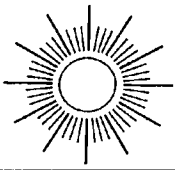
#### The Flow of Electric Current.

Although wires are actually very different from water pipes, electricity flowing through wire can be compared to water flowing through pipes. When electricity is flowing, there is said to be *electric current*.

*Current (I)* is the rate of flow of electrons through the wires. It is measured in *amperes* (called *amps*, *A*) which is a measure of the number of electrons passing through a given length of wire. This is similar to the rate of flow of water through pipes (i.e. litres per second). Current flowing in one direction is called direct current (dc), while current which changes direction of flow is called alternating current (ac). In a 12 volt dc system, a 13 watt lamp draws about one ampere of current.

*Potential difference, or voltage*, is the difference in potential energy between the ends of a conductor (i.e. a wire) that governs the rate of flow of current through it. Voltage is measured in *volts* (*V*). In basic terms, it is the amount of energy each electron has to move about, and is similar





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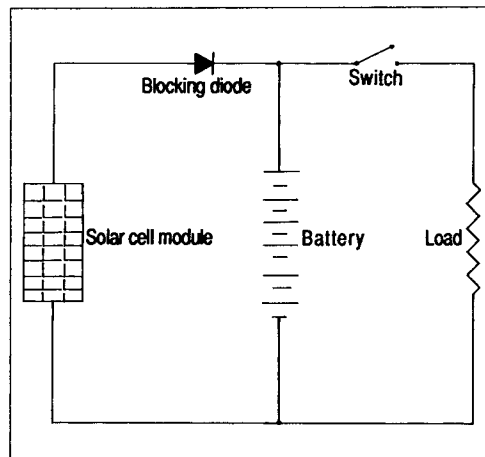
to the pressure pushing water through a pipe. Grid electricity is supplied at 240 volts ac, while the electricity from automotive batteries is at about 12 volts dc.

**Circuits.** A pathway which electricity flows through (i.e. the wires, batteries, lamps, switches, etc.) is called a *circuit*. Current flows from a source of electricity (a battery, generator or solar cell) through wires to loads (lamps, motors, electric coils) and back. When there is an uninterrupted pathway for electricity to flow, the circuit is said to be *closed*. When there is a point where electricity cannot pass (i.e. switch turned OFF), the circuit is said to be *open*. Thus, when you turn ON a light, you close the circuit, and when you turn OFF a light, you open the circuit. Current cannot flow through an open circuit. *Circuit diagrams* are pictures of electric circuits with special symbols for switches, batteries, resistive loads, diodes and other electric equipment that help electricians to understand and plan circuits.

### Series and Parallel Circuits.

When a number of electrical components are wired up end to end in a continuous chain, they are joined in *series*. If lamps are joined in series, and one of them fails, then the circuit will be broken and all the lamps will fail. If batteries or solar cells are joined in series, the voltage increases according to the number of units joined. For example, three 1.5 volt dry cells joined in series will produce a voltage of 4.5 volts.

When components are wired so that one path can be broken without affecting the flow of electricity through the others in the circuit, the components are said to be wired *in parallel*. The lamps in a mains-wired house are in parallel, and you can turn one OFF without turning the rest of the lights in the circuit OFF. When batteries or solar cells are wired in parallel, the available current increases but the voltage stays the same. For example, if the above three 1.5 volt dry cells were wired in parallel, the voltage would remain at 1.5 volts, but the amount of current available would increase.



### Basic Electric Laws:

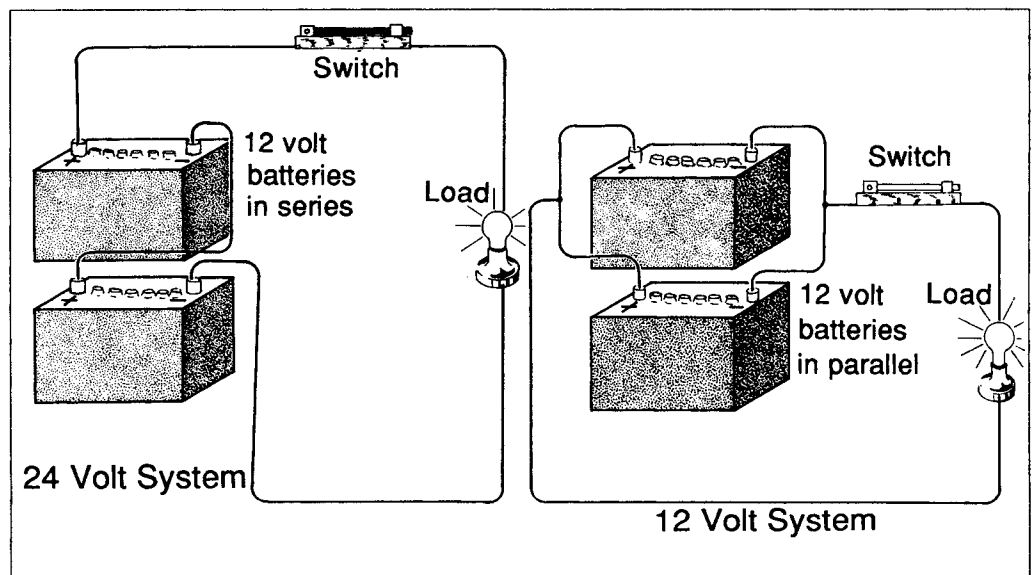
In all basic electrical work, the understanding of two formulae are required. Once they are understood, most electrical problems encountered in low voltage systems can be easily solved. These formulae are simple:

#### Power Law:

$$\text{Watts (w)} = \text{volts (v)} \times \text{amps (A)}$$

#### Ohm's Law:

$$\text{volts (V)} = \text{amps (A)} \times \text{ohms (\Omega)}$$





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## The Power Law

Power (P) is the amount of work the electricity is doing at a given instant. It is measured in watts. The power rating in watts of a light fixture, for example, is a measure of the power it will consume to produce light. Power is calculated by multiplying the voltage (V) by the current (I):

$$\text{Power (P)} = \text{Voltage (V)} \times \text{Current (I)}$$

or

$$\text{watts} = \text{volts} \times \text{amps}$$

or, (if you divide by voltage),

$$I = P \div V = \text{watts} \div \text{volts}$$

*Example:*

a) A globe lamp is connected to a 12 volt battery. When it is turned ON, 3 amps of current flowing through the wire. What is the power of the lamp?

b) A 24 watt dc globe lamp is connected in a 24 volt dc system. When the globe is turned ON, what current will be flowing?

*Solutions:*

a) Example (a) is asking for the power of the globe lamp.

$$\begin{aligned} \text{Power (P)} &= \text{Voltage (V)} \times \text{Current (I)} \\ &= 12 \text{ volts} \times 3 \text{ amps} \\ &= 36 \text{ watts} \end{aligned}$$

b) Example (b) is asking for the current flowing through the 24 volt wire.

$$\begin{aligned} \text{Current (I)} &= \text{Power (P)} \div \text{Volts (V)} \\ &= 24 \text{ watts} \div 24 \text{ volts} \\ &= 1 \text{ amp} \end{aligned}$$

## Ohm's Law

Resistance (R) is the property of a conductor (i.e. a wire or appliance) which opposes the flow of current through it and converts electrical energy into heat. It determines the amount of current that can flow for a certain voltage. Resistance is measured in units called *ohms*, which are given the symbol  $\Omega$ .

The formula that relates these three electrical measures is called Ohm's Law:

$$\text{Voltage (V)} = \text{Current (I)} \times \text{Resistance (R)}$$

or

$$\text{volts} = \text{amps} \times \text{ohms}$$

or

$$V = I \times R.$$

## Ohm's Law Example

In a circuit, a long wire with a resistance of 0.5 ohms connects a 12 watt lamp to a 12 volt battery. What is the voltage drop in the wires between the battery and the lamp?

*Answer:*

From the power rating of the lamp (watts), we can determine the current (amps):

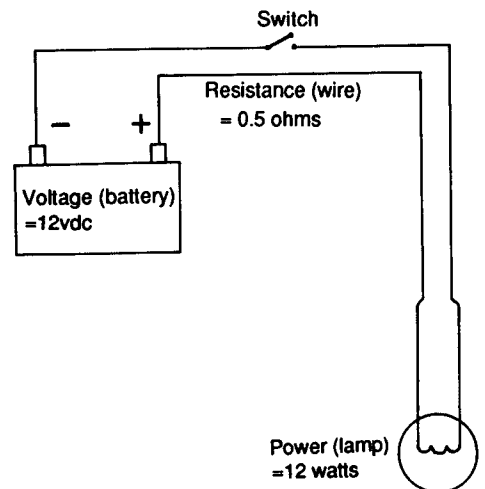
$$\begin{aligned} I \text{ (amps)} &= \text{watts} \div \text{volts} \\ &= 12 \text{ watts} \div 12 \text{ volts (voltage of battery)} \\ &\approx 1 \text{ amp} \end{aligned}$$

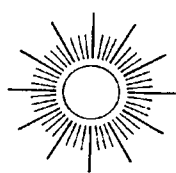
Actually, when the resistance of the lamp is added to that of the wire, the current is calculated to be about 0.96 amps.

Because the wire is long we need to know if the voltage loss due to the resistance of the wire will make the voltage for the lamp too low. Ohm's Law tells us that the voltage drop is the current times the resistance:

$$\begin{aligned} \text{Voltage drop in wire} &= \text{current (amps)} \times \\ &\quad \text{resistance (ohms)} \\ &= I \times R \\ &= 0.96 \text{ amps} \times 0.5 \text{ ohms} \\ &= 0.48 \text{ volts.} \end{aligned}$$

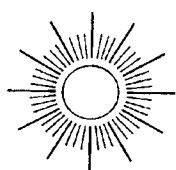
The voltage drop will be 0.96 amps multiplied by the current of 0.5 ohms, or 0.48 volts. This means that, at the lamp, the voltage will be about 11.52 volts (12 volts from the battery less 0.48 volts from the voltage drop). This is less than a 5% voltage drop, and is acceptable for a solar electric system.





### Appendix 3: Glossary

- alternating current (ac):** electric current in which the direction of flow changes at frequent, regular intervals.
- amorphous silicon:** a type of thin film PV silicon cell having no crystalline structure.
- ampere (amp)(A):** unit of electric current which measures the flow of electrons per unit time.
- ampere hour (amp hour) (Ah):** a measure of total charge commonly used to indicate energy capacity of batteries. One amp hour is equal to the quantity of charge in the flow of one ampere over one hour.
- annual mean daily insolation:** the *average* solar energy per square meter available per day over the whole year.
- appliance:** a tool or other device such as radio or television which consumes electricity.
- array:** an assembly of several modules on a support structure together with associated wiring.
- ballast inverter:** a device which converts low voltage direct current to the type of high voltage ac current required by fluorescent lamps.
- battery:** a device that converts chemical energy contained in its active materials directly into electrical energy by means of an electrochemical reaction.
- battery capacity:** the total number of amp hours that can be removed from a fully-charged battery or cell at a specified discharge rate.
- blocking diode:** a solid-state electrical device placed in circuit between the module and the battery to prevent discharge of the battery when the voltage of the battery is higher than that of the module (i.e. at night).
- by-pass diode:** a solid-state electrical device installed in parallel with modules of an array which allows current to by-pass a shaded or damaged module.
- cell (battery):** the smallest unit or section of a battery that can store electrical energy and is capable of providing a current to an external load.
- cell (photovoltaic):** see solar cell
- charge controller:** a device which protects the battery, load and array from voltage fluctuations, alerts the users to system problems and performs other management functions.
- charge current:** electric current supplied to and stored in a battery.
- circuit:** a system of conductors (i.e. wires and appliances) capable of providing a closed path for electric current.
- circuit diagram:** a special type of drawing used by electricians to represent electric circuits.
- connector strips:** insulated screw-down wire clamps used to fasten wires together in solar electric systems.
- converter:** a device that converts a dc voltage source to a higher or lower dc voltage.
- crystalline silicon:** a type of PV cell made from a single crystal or polycrystalline slice of silicon.
- current (amps, amperes) (A):** the rate of flow of electrons through a circuit.
- cycle:** one discharge and charge period of a battery.
- cycle life:** of a battery, the number of cycles it is expected to last before being reduced to 80% of its rated capacity.
- days of storage:** the number of consecutive days a stand-alone system will meet a defined load without solar energy input.
- deep discharge battery:** a type of battery that is not damaged when a large portion of its energy capacity is repeatedly removed (i.e. motive batteries).
- depth of discharge:** a measure in percentage of the amount of energy removed from the battery during a cycle
- design month:** the month has the *lowest* mean daily insolation value, around which many stand alone systems are planned.
- diffuse radiation:** solar radiation that reaches the earth indirectly due to reflection and scattering.
- direct current (dc):** electric current flowing in one direction.
- direct radiation:** radiation coming in a beam from the sun which can be focussed.
- discharge:** the removal of electric energy from a battery.
- efficacy:** special term which refers to the efficiency by which lamps convert electricity to visible radiation. Measured in lumens per watt.
- efficiency:** the ratio of output power (or energy) to input power (or energy) expressed as a percentage.
- electric power:** the rate at which energy is supplied from an electricity generating source. It is measured in *watts (W)*.
- electrolyte:** a conducting medium in which the flow of electric current takes place by migration of ions. Lead-acid batteries use a sulphuric acid electrolyte.
- equalising charge:** a charge well above the normal "full" charge of a battery which causes the electrolyte inside the cells to bubble and get mixed up.



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- fuse:** a device which protects circuits and appliances in the system from damage by short circuits.
- global radiation:** term which refers to the combined diffuse and direct solar radiation arriving on a surface.
- hydrometer:** a tool which indicates the state of charge of lead-acid batteries by measuring the thickness of the acid inside its cells.
- I-V curve:** the plot of current versus voltage characteristics of a solar cell, module or array. I-V curves are used to compare various solar cell modules, and to determine their performance at various levels of insolation and temperatures.
- insolation:** incident solar radiation. A measure of the solar energy incident on a given area over a specified period of time. Usually expressed in *kilowatt-hours per square metre per day* or indicated in *peak sun hours*.
- inverter:** a solid state device which changes a dc input current into an ac output current.
- irradiance:** the solar radiation incident on a surface per unit time. Expressed in watts or kilowatts per square metre.
- kilowatt (kW):** one thousand watts. Standard method of measuring electrical power.
- kilowatt hour (kWh):** energy equivalent to one thousand watts delivered over the period of one hour. Standard method of measuring electrical energy.
- langley (L):** unit of solar insolation ( $1L = 85.93 \text{ kWh/m}^2$ ).
- light-emitting diode (LED):** a type of diode which lights up when current is flowing through it. Commonly used as an indicator in charge controllers.
- load:** the set of equipment or appliances that use the electrical power from the generating source, battery or module.
- low voltage cut-out:** a feature of some charge controllers that cuts off power to the load when the battery reaches a low state of charge.
- maximum power point:** the specific point, or voltage, where, under given conditions, the module produces the greatest power. This can be identified on an I-V curve.
- monthly mean daily insolation:** the *average* solar energy per square meter available per day of a given month.
- ohm ( $\Omega$ ):** a unit of electrical resistance.
- open circuit voltage ( $V_{oc}$ ):** the maximum possible voltage across a solar module or array. Open circuit voltage occurs in sunlight when no current is flowing.
- overcharging:** leaving batteries on charge after they have reached their full (100%) state of charge.
- peak power (Wp):** the amount of power a solar cell module can be expected to deliver at noon on a sunny day (i.e. at Standard Test Conditions) when it is facing directly towards the sun.
- peak sun hours:** the number of hours per day during which solar irradiance averages  $1000 \text{ W/m}^2$  at the site. A site that receives six peak sun hours a day receives the same amount of energy that would have been received if the sun had shone for six hours at an irradiance of  $1000 \text{ W/m}^2$ .
- photovoltaic (PV) device:** a device which converts light energy into electric energy.
- potential difference (voltage)(V):** the difference in potential energy between the ends of a conductor that governs the rate of flow of current. Measured in volts (V).
- power conditioning unit (PCU):** electrical equipment used to convert dc power from a PV array or battery into a form suitable for standard ac loads (240 Vac or 110 Vac). PCU's are used to operate high voltage appliances such as videos and refrigerators.
- resistance:** the property of a conductor (i.e. a wire or appliance) which opposes the flow of current through it and converts electrical energy into heat. Resistance has the symbol R, and is measured in *ohms*,  $\Omega$ .
- self-discharge:** charge lost from batteries left standing due to reactions within the cells.
- shallow discharge batteries:** batteries designed to supply high power for a short duration; taking too much energy out of these batteries before recharging them is likely to damage the plates inside (eg. automotive batteries).
- short circuit current ( $I_{sc}$ ):** current across the terminals when a solar cell or module in strong sunlight is not connected to a load (measured with ammeter).
- silicon:** a semi-conductor material commonly used to make photovoltaic cells.
- solar cell:** a specially-made semiconductor material (i.e. silicon) which converts light energy into electric energy.
- solar cell module:** groups of encapsulated solar cells framed in glass or plastic units, usually the smallest unit of solar electric equipment available to the consumer.
- solar constant:** an amount referring to radiation arriving from the sun at the edge of the earth's atmosphere. The accepted value is about 1350 watts per square meter.
- solar incident angle:** the angle at which the incoming solar beam strikes a surface.
- specific gravity:** the ratio of the weight of a solution (i.e. battery acid) to an equal volume of water at a specified temperature. Used as an indicator of battery state of charge.



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**standard test conditions:** a set of accepted testing conditions commonly used by manufacturers to compare solar cell modules of different types. The conditions are 1000 W/m<sup>2</sup> solar irradiance at 25°C with an air mass of 1.5

**stand-alone solar electric system:** a solar electric system that receives all of its energy from solar electric charge, and which is not connected to the grid or any other source of power.

**state of charge:** the amount of charge in a battery expressed as a percent of its rated charge capacity.

**system voltage:** the voltage at which the charge controller, lamps and appliances in a system operate, and at which the module(s) and battery are configured.

**total daily system energy requirement:** the amount of energy required to meet the daily electrical load *plus* the extra energy required to overcome system energy losses.

**tracking:** the practice of changing the position (i.e. angle) of the array at various times during the day so that it faces the sun and so harvests a larger amount of solar charge.

**trickle charge:** a low current charge. When the

batteries are fully charged, some charge controllers reduce the energy from the module to the battery to a trickle charge so that the batteries are not overcharged, but so that they still get enough current to overcome self-discharge.

**volt (V):** a unit of measurement of the force given to electrons in an electric circuit; see potential difference.

**voltage drop:** loss of voltage and power due to resistance of the wire to the flow of electricity in long runs of cable.

**watt (W):** the internationally accepted measurement of power. One thousand watts are a kilowatt, and a million watts are a megawatt.

**watt hour (Wh):** a common energy measure arrived at by multiplying the power times the amount of time used. Grid power is ordinarily sold and measured in kilowatt hours.

## Appendix 4: Conversions and Electric Wiring Code

### ENERGY CONVERSIONS

watt hours x 1000	= kilowatt hours
kilowatt hours x 1000	= megawatt hours
megajoules ÷ 3.6	= peak sun hours
	= kilowatt hours
kilowatt hours x 3.6	= megajoules
langleys x 0.0116	= kilowatt hours
	= peak sun hours
langleys x 0.0418	= megajoules
watt hours ÷ system voltage	= amp hours

### POWER CONVERSIONS

watts ÷ 746	= horsepower
watts x 1000	= kilowatts
kilowatts x 1000	= megawatts

### ELECTRICAL WIRE CODING

#### East African/British Colour Coding System

##### Direct Current

Black	-	negative
Red	+	positive

##### Alternating Current

Blue	neutral
Brown	line ('hot')
Yellow/green	earth

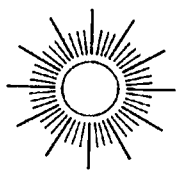
#### American Colour Coding System

##### Direct Current

Black	-	negative
Red	+	positive
Green/bare	0	ground

##### Alternating Current

White	neutral
Black	line ('hot')
Green or bare	earth
Red or any other	'hot'



## Appendices

### Appendix 5: References

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- Derrick, Anthony, Catherine Francis, and Varis Bokalders, *SOLAR PHOTOVOLTAIC PRODUCTS: A Guide for Development Workers*. Intermediate Technology Publications, London, 1989. 127 pages.

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103/105 Southampton Row  
London, WC1B 4HH, UK.

A general introduction to solar electricity for water pumping, refrigeration and lighting. Contains addresses and information about where to get equipment internationally. There is a 2nd updated edition.

- Hankins, Mark, *Renewable Energy in Kenya*. Motif Creative Arts, Ltd. Nairobi, Kenya, 1989 (second printing).

Basic introduction to the subject of renewable energy for the African reader.

- Hansen, Richard and Martin Jose, *Photovoltaics for Rural Electrification in the Dominican Republic*, August 1987. Enersol Associates, Inc. Somerville, Massachusetts, USA.

- Kenya Meteorological Department, *Climatological Statistics for Kenya*, Kenya Met. Dept., PO Box 30259, Nairobi, 1984.

This volume contains solar energy statistics from a number of stations all over Kenya. Similar publications are available with climatological statistics from the Meteorological Departments of other East African countries including Tanzania and Uganda.

- Nelkon, M., *Principles of Physics*

This is a standard O-level physics text used in secondary schools in Kenya. It contains a good introduction to electricity.

- McCarney, Steve, Ken Olson, and Johnny Weiss, *Photovoltaics: A Manual for Design and Installation of Stand-Alone Photovoltaic Systems*. Appropriate Technology Associates, Carbondale, Colorado, USA, 1987. 302 pages.

A basic, practical manual aimed at those installing and designing small systems in the USA. Enables readers to understand solar electric system operating principles, evaluate potential stand-alone system applications, understand capabilities and limitations of systems, and to design and install small systems.

- Patrick, J.K. & W.L. Cheng, *Solar Radiation and its Relation to Surface Glare*, Proceedings of the First Technical Conference on Meteorological Research in Eastern and Southern Africa, Kenya Met. Dept., Nairobi, Jan, 1987.

Information from this paper was used to make the contour map on page 13.

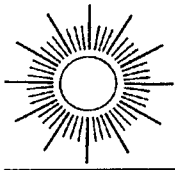
- Photovoltaic Design Assistance Centre, Sandia National Laboratories, *Stand-Alone Photovoltaic System: A Handbook of Recommended Design Practices*. Sandia National Laboratories, Albuquerque, New Mexico, USA, revised edition 1990. 300 pages.

Available from:  
National Technical Information Service  
US Department of Commerce  
5285 Port Royal Road  
Springfield, VA 22161

Practical design manual for planning PV-powered lighting, refrigeration, remote monitoring, communications, residential, cathodic protection and water pumping systems. Contains worksheets for each of the above applications, and for economic analysis of systems.

- Strong, Steven, *The Solar Electric Home*. Rodale Press, Emmaus, Pennsylvania, USA, 1987. 276 pages.

A very thorough book on solar electric homes. Practical guide to installing and planning large systems (i.e. one kilowatt or more), with excellent sections on inverters, back-up generators, grid-interfaced systems, and all system components.



## Appendices

### Other Publications in this Series:

Renewable Energy Development in Africa, Volume 1: Proceedings of the African Energy Programme Conference 25-29 March 1985, Mauritius, 1986, vi + 261 pp., ISBN 0-85092-291-7. Price 25 GBP/42.50 USD in UNESCO coupons (or 40 GBP/68 USD in UNESCO coupons for 2 vols).

Renewable Energy Development in Africa, Volume 2: Proceedings of the African Energy Programme Conference 25-29 March 1985, Mauritius, 1986, vi + 384 pp., ISBN 0-85092-292-5. Price 25 GBP/42.50 USD in UNESCO coupons (or 40 GBP/68 USD in UNESCO coupons for 2 vols).

Solar Dryers: their role in post-harvest processing, by B Brenndorfer, L Kennedy, C O Oswin Bateman, D S Trim, G C Mrema & C Wereko-Brobby. 1987 (second edition), x + 298 pp., ISBN 0-85092-282-8. Price 7.50 GBP or 12.75 USD in UNESCO coupons.

International Conference on Research & Development of Renewable Energy Technologies in Africa, University of Mauritius, Reduit, Mauritius, 25 March - 1 April 1985 - Summary Report. CSC(85)ENP-6—Order No. 172. Free.

Solar and Wind Power Technologies for Remote Applications: Proceedings of a Training Workshop held at the University of Melbourne, Australia, 8-17 December 1985 (Edited by W W S Charters & C Y Wereko-Brobby) CSC(86)ENP-9. Order No. 187. Free.

Assessment of Biomass Resources in Developing Countries. CSC(86)ENP-10. Order No. 188. Free.

Resources and Energy Potentials in Rural Bangladesh: A Case study of four villages (June 1982). June 1986 vi + 143 pp. CSC(86)ENP-11. Order No. 188. Free.

Common Accounting Procedures for Biomass Resources Assessment in Developing Countries: Proceedings of the inaugural workshop of the Technical Working Groups, Imperial College, London 14-18 April 1986. July 1986, 67 pp. CSC(86)ENP-13. Order No. 195. Free.

Potential use and performance studies of solar crop driers in Mauritius. CSC(87)ENP-18. Order No. 238. Free.

Natural Convection Solar Crop Driers in Kenya: Theory and Practical Application (by Herick Othieno, Kenyatta University, Nairobi, Kenya) CSC (87) ENP-20. Order No. 241. Free.

Biogas Technology for Rural Development in Zimbabwe (by G Marawanyika, M Mapako & McGarry S J AEP Report series No 5) CSC(87)ENP-21. Order No. 242. Free.

African Energy Programme - A Perspective of a Regional Project Network, by R W'O Okot-Uma. July 1989, vii + 77 pp., CSC(89)ENP-28 Order No. 272.

Development of Solar Driers for Pyrethrum in Tanzania, by T. E. Simalenga and G C Mkema. February 1991, viii + 56 pp. CSC(91)ENP-29. Order No. 285. Free.

*Titles available from: Executive Officer (Information), Commonwealth Science Council, Commonwealth Secretariat, Marlborough House, Pall Mall, London SW1Y 5HX, United Kingdom.*



# WORKSHEET 2: SIZING AND CHOOSING THE MODULE

## SOLAR INSOLATION ASSESSMENT (See page 59)

**1. Do you have meteorological information?**

**No** → If there is no met station for the site, solar insolation must be estimated roughly. Follow instructions on page 60.

**Yes** ↓

**2. Mean insolation data.** Enter insolation data from nearest met station. Convert from sunshine hours or langley's to peak sun hours.

Box A			
Month	Langley's	Sunshine hours	Peak sun hours
J			
F			
M			
A			
M			
J			
J			
A			
S			
O			
N			
D			
Annual			

**3. Insolation value.** Choose design month or annual mean daily insolation (see page 59-60). Enter in Box B.

**4. Tracking/fixed?** If tracking calculate, 25% of Box B. Write in Box D. If not tracking write 0 in Box D.

**Design solar insolation value**  
Add Box B and Box D together. This sum is the value to be used when sizing the module. Enter in Box G below.

**Box C**  
Estimated Annual Mean Daily Insolation (Box C1)  
Estimated Design Month Mean Daily Insolation (Box C2)

**Box B**

**Box D**

**Box E**

## CALCULATE THE SIZE OF THE MODULE (See pages 60-62)

To determine the required module size divide the daily system energy requirement by the peak sun hours of the site's design month.

**Details of solar module chosen**  
When you choose your module, write its details in the table to the right.

Company	
Model	
Peak Watts	
Rated Voltage	
Rated Current	

Box F ÷ Box G × Box H = Box I

**Daily system energy requirement (watt hours)**

This number tells how much energy is required per day to power the system (see Worksheet 1, Box H).

**Insolation (peak sun hours)**

This number tells how much energy is available from the sun per day during the design month (see Box E above).

**Adjustment factor**

This number adjusts the calculation to account for actual field performance of the module. Use 1.1 for most installations.

**Module size (peak watts, Wp)**

This is the size of the module required to power your system. You have finished the module sizing calculation.

# WORKSHEET 3: BATTERY AND CONTROL SELECTION

## Battery Sizing

To determine the required battery size, multiply the daily system energy requirement by the number of days storage required, and divide by the maximum daily discharge recommended for the battery (see page 62).

**Box A**

**Total Daily System Energy Requirement in watt hours.**

From Worksheet 1 Box H. Divide this figure by the system voltage and enter the quotient in Box B below.

**Box B**

×

**Box C**

÷

**Box D**

=

**Box E**

Total daily system energy requirement in amp hours.

Number of storage days required

Maximum allowable daily depth of discharge of battery

Required system battery capacity. This is the minimum battery size required in amp hours.

## Battery Information

Before buying your batteries, collect this information along with the price of each type available.

Company & Model	
Capacity (Ah)	
Volts	
Number required	
Number in Series	
Number in Parallel	
Estimated Lifetime	

## Control Selection

First decide if a charge controller is actually necessary. With small systems, there is no need to pay more for a control than for the battery it is supposed to protect. If a control is required, decide on the size of the controller and the required features (see page 63).

### 1. Is a control needed ?

- Is the battery worth protecting?      Yes  No
- Does the system use nicad batteries?      Yes  No
- Is the system above 20 Wp      Yes  No
- Will the system be well managed?      Yes  No

- Protect expensive batteries using a control with low voltage cut out.
- If the system is above 40 Wp, consider using a charge controller.
- If the system is small and uses nicad batteries for storage, no control is needed.
- If the system is below 20 watts and well managed, then there may be no need for control

Is a charge controller required?      Yes  No

### 2. Size of controller required

Controllers are commonly available in 5 amp and 20 amp sizes (see page 36). If there are only one or two lamps and no TV in the system, a 5 amp control can be used. Most systems, however, should use a 20 amp controller. Check the rated size of the controller before buying it.

### 3. Features desired in controller

- High voltage cut out      Yes  No
- Low voltage cut out      Yes  No
- Low voltage warning      Yes  No
- Reverse current protection      Yes  No
- Solar charge indicator      Yes  No
- Ammeter/voltmeter      Yes  No
- Timer      Yes  No

## Charge Controller Information

Company and Model
Size in amps
Features
Low voltage cut-out at      volts

# WORKSHEET 4: WIRING, VOLTAGE DROP AND FUSES

## 1. Determine the lengths of all cable runs

Draw a scale map of the site and estimate the distance of all the major cable runs, including from the module to the control, from the control to the battery, and runs connecting buildings. Estimate the required lengths of branch cables (these use 2.5mm<sup>2</sup>) and conduit required. Note the locations of lamps, sockets, switches, connector strips and fuses. Estimate the amount of mounting materials required.

Draw a scale map of house or site in this box.

## 2. Work out voltage drops on major cable runs

**Note:**  
In very small systems, all connections can be safely made using 2.5mm<sup>2</sup> wiring cable. Voltage drop calculations do not need to be made if:

- no run is longer than 16 meters.
- the module is rated at 40 Wp or below; **and**
- no wire carries a current of more than 4 amps.

Follow the instructions on pages 54-56 to fill out the voltage drop table below:

Column A Cable run  (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/ No)

## 3. Sizing Fuses (see page 50 & 51)

- List circuits to be protected. Write in Column A.
- Determine the maximum power draw in watts of each circuit to be protected. Write in Column B.
- Change the figure in Column B to amps by dividing by the system voltage. Write in Column C.
- Increase the figure in C by 20%. This is the fuse required.

Column A Circuits (list each)	Column B Max rated power (watts)	Column C Max rated current (amps)	Column D Fuse size (amps)

## 4. List all electrical connection equipment required

Fill in the table below to estimate the amount of electrical accessories to be bought. Use it when purchasing equipment.

Item and Type	Size	Amount
Cable		
Cable		
Cable		
Conduit		
Switches		
Sockets		
Fuses		
Connector strips		
Junction boxes		

## About this book

This book is about making solar electricity available to people in rural Africa. It describes how, with guidance from an electrician, anyone can adapt a small solar electric system to their own needs. Twelve chapters cover the following essential solar electric topics:

- estimating local solar resources;
- solar electric, battery, and charge controller choice and technology;
- choosing lamps, appliances and small tools;
- low voltage wiring principles and practice; and,
- planning, installing and maintaining a system.

For aspiring African solar electricians, the book is a rich source of information, including planning worksheets, wiring guides, meteorological information and well-illustrated examples. For the extension agent, development worker or layman without previous solar electric experience, the book is a careful planning guide towards the completion of a small installation.

The author has worked with renewable energies in East Africa since 1984. As a volunteer, he taught science in a Kenyan secondary school, organised solar electric and biogas training courses, and later wrote the book *Renewable Energy in Kenya*. He was awarded a Master of Science degree in Alternative Energy for Developing Countries from Reading University, UK in 1990.

The artwork, layout and printing of this book was completed in Nairobi, Kenya, by Motif Creative Arts, Ltd. Writing and production of the book was made possible by a grant from the Commonwealth Science Council (UK) with additional support from Energy for Sustainable Development, Ltd. (UK).



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ISBN 978-1-84859-481-4

