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.

One kilowatt hour is equal to 3.6 megajoules.

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^2, only about 150 watts per square meter of solar cells are produced.

The higher the percent efficient a device is, the 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%.

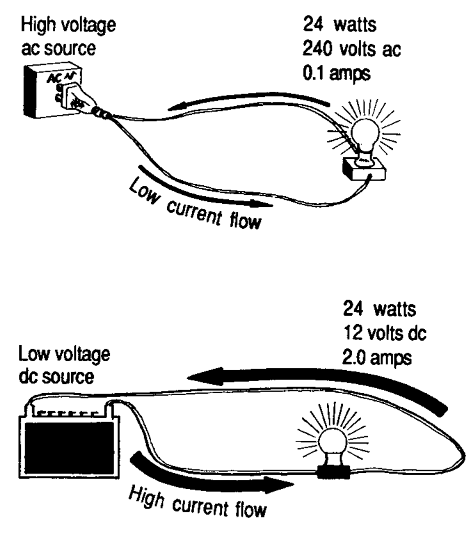
Other solar energy devices, including solar cookers and concentrators, are able to transform solar energy much more efficiently than solar cells (i.e. up to 60%) The problem is that, for small applications, *only* solar cells are able to convert solar energy directly to electricity. Solar water heaters 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.

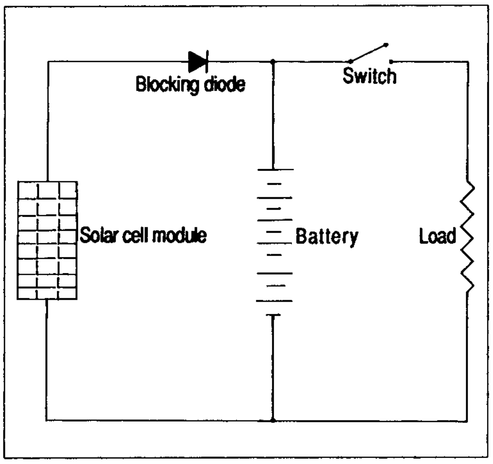


The Flow of Electric Current.
Although wires are actually very different from water pipes, electricity flowing through wire can be compared to water flowing through pipes. When electricity is flowing, there is said to be *electric current*.

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 though 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 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.

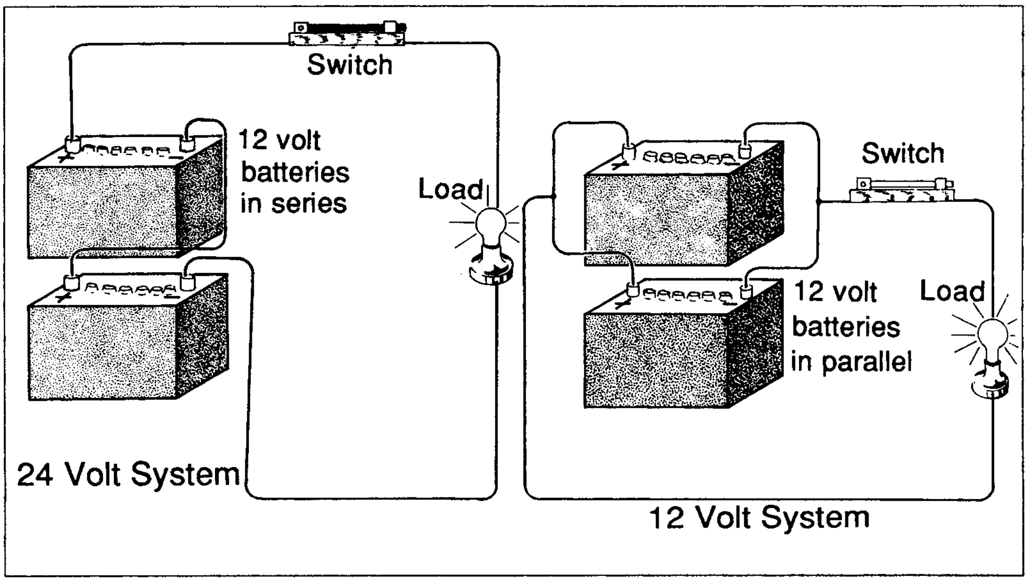
Basic Electric Laws:
In all basic electrical work, the understanding of two formulae are required. Once they are understood, most electrical problems encountered in low voltage systems can be easily solved. These formulae are simple:

Power Law:

Watts (w)	=	volts (v)	x	amps (A)

Ohm's Law:

volts (V)	=	amps (A)	x	ohms (Ω)



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):

Power (P) = Voltage (V) x Current (I)
or
watts = volts x amps

or, (if you divide by voltage),
I = P ÷ V = watts ÷ 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.

Power (P)	= Voltage (V) x Current (I)
	= 12 volts x 3 amps
	= 36 watts

b) Example (b) is asking for the current flowing through the 24 volt wire.

Current (I)	= Power (P) ÷ Volts (V)
	= 24 watts ÷ 24 volts
	= 1 amp

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 Ω.

The formula that relates these three electrical measures is called Ohm's Law:

Voltage (V) = Current (I) x Resistance (R)
or
volts = amps x ohms
or
V = I x 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):

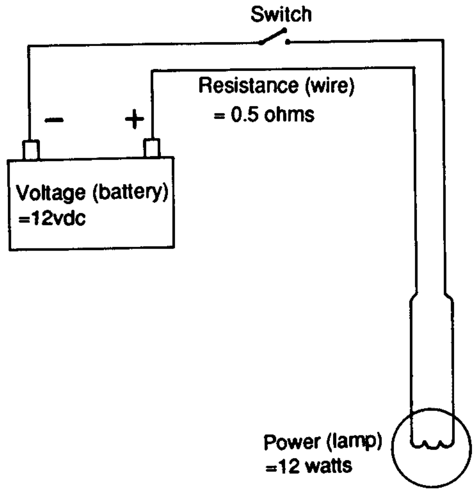
I (amps)	= watts ÷ volts
	= 12 watts ÷ 12 volts (voltage of battery)
	≈ 1 amp

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:

Voltage drop in wire	= current (amps) x resistance (ohms)
	= I x R
	= 0.96 amps x 0.5 ohms
	= 0.48 volts.

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.

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 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 (Ω): 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 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 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, Ω.*

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.

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^2 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 is 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'

Appendix 5: References

- Burris, Harold and Mark Hankins, *Solar Electric Lighting Systems, A Sourcebook for Kenya.* Unpublished training manual for US Peace Corps South Meru Solar Electric Lighting Project, 1985.

- Derrick, Anthony, Catherine Francis, and Varis Bokalders, *SOLAR PHOTOVOLTAIC PRODUCTS: A Guide for Development Workers.* Intermediate Technology Publications, London, 1989. 127 pages.

  Available from:
  IT Publications Ltd.
  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.

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. Prioe 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. 0rder 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 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)

Total Daily Load Energy Demand — **Box F**

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.

Estimated System Energy Losses — **Box G**

3. Add Box F and Box G.

Write the sum in Box H.

Total Daily System Energy Requirement — **Box H**
This is the amount of energy that must be supplied by the module(s) each day.

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**

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. ⇨

Box C

Estimated Annual Mean Daily Insolation	Estimated Design Month Mean Daily Insolation
Box C1	**Box C2**

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			
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.

Box B

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

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 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** X **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 2.5mm²) 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 2.5mm² 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; <u>and</u>
- 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:

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 resisitance (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		