

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.

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.

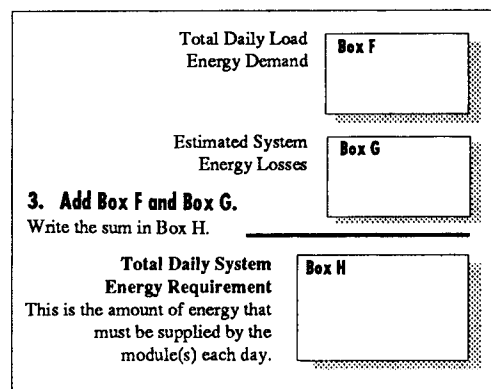


Figure 9.1 Determining daily system energy requirement

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.



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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

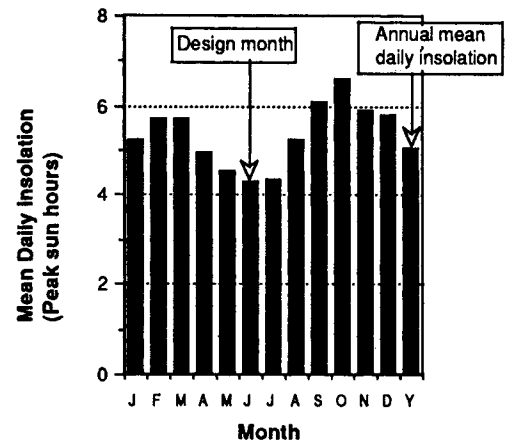


Figure 9.3
Monthly mean daily insolation for Arusha

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.



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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).



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

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/m². 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_m). 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



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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.

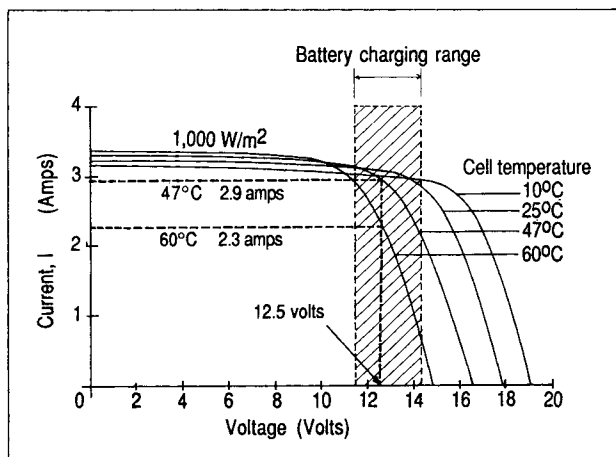


Figure 9.4
Using I-V curves to calculate module current output. Note that this curve is for a given irradiance.

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.



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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.

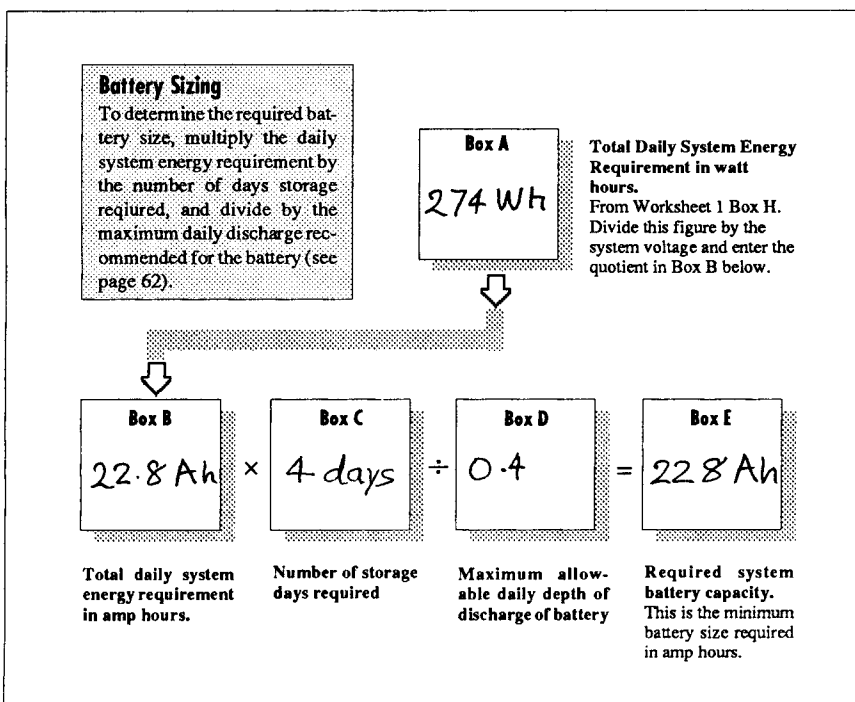
Finally, the maximum depth of discharge of the battery must be entered in Box D. The battery type is an ABM solar battery which can accept a 40% discharge regularly (see page 28 & 30). Enter the value 0.4 (in decimal, 40% is expressed as 0.4) in Box D of the worksheet.

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.

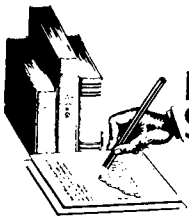
Figure 9.5
Example battery sizing calculation



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.



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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 mm² 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 mm² cable for most runs. It is good practice to use 4.0 mm² 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.

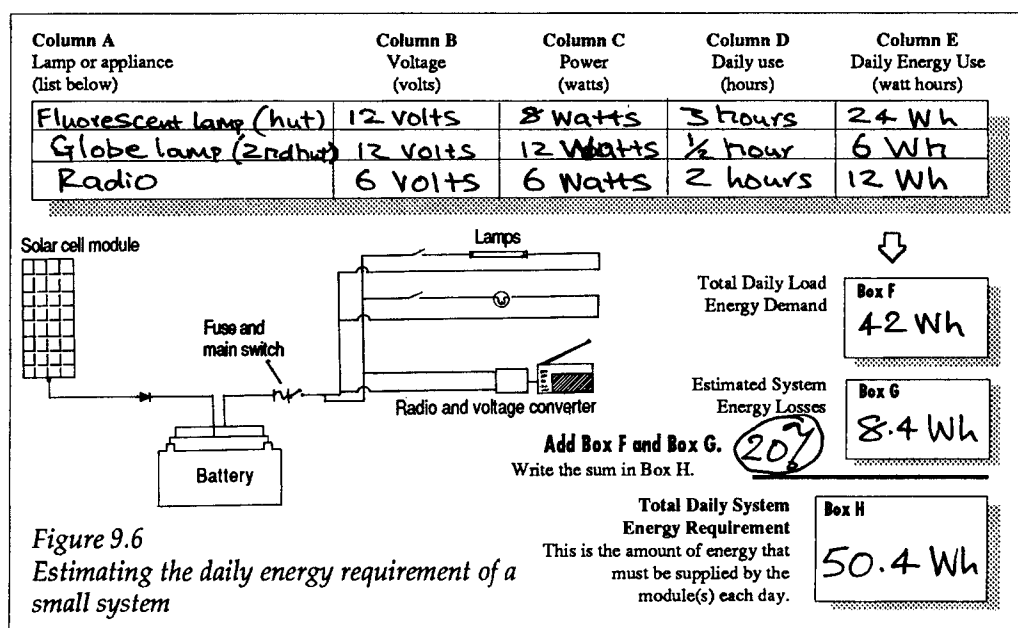


Figure 9.6
Estimating the daily energy requirement of a small system



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Worksheet 2: Sizing the Module

Estimating the solar resource

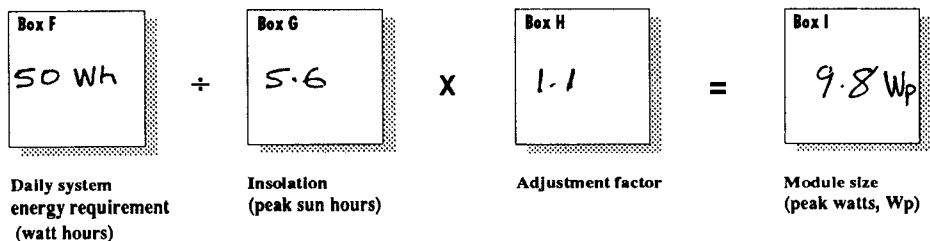
Now, the farmer and electrician estimate their location's solar resource. The nearest meteorological station is in Meru town, about 20 kilometres away, so they visit the Meru Station and collect the data. This information is entered in Box A of Worksheet 2, as shown in Figure 9.7. Daily insolation varies 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.

Box A MERU Insolation Data		
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.



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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:

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

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

For lead acid batteries, calculation is as follows:

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

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 mm² 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 mm² 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.

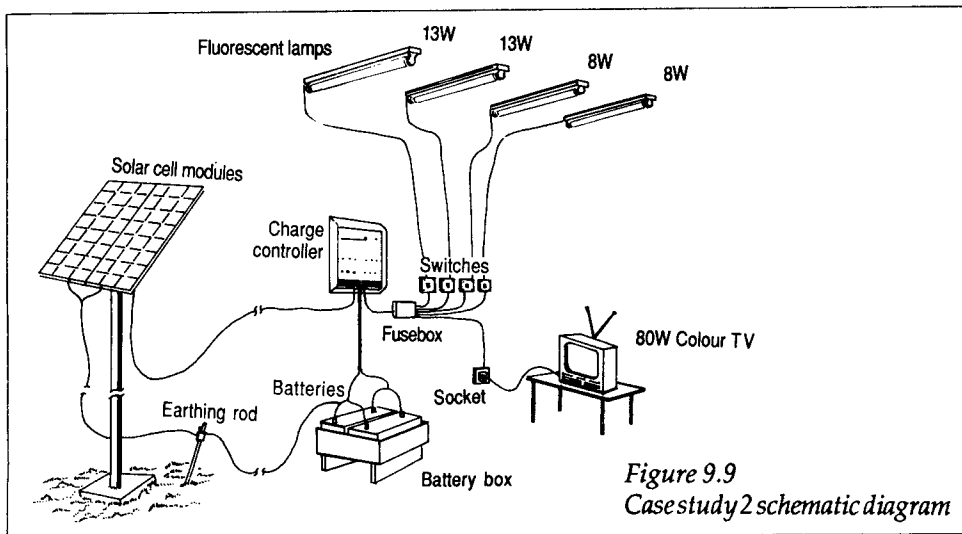


Figure 9.9
Case study 2 schematic diagram

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).



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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	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 langley's, 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.



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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/voltmeter 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).



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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 mm^2).
- The system is not small enough to assume that all wiring can be made with 2.5 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 mm^2 and the rest are 2.5 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 mm^2) and conduit required. Note the locations of lamps, sockets, switches, connector strips and fuses. Estimate the amount of mounting materials required.

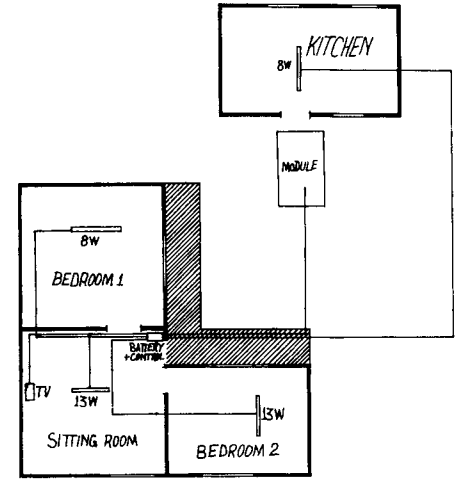
2. Work out voltage drops on major cable runs

Note:
In very small systems, all connections can be safely made using 2.5 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 Ω	0.58 V	2.5? No
Battery to Bedroom 1	7 M	0.7 A	0.016	0.112 Ω	0.08 V	1? No
Battery to Sitting room	3 M	7.8 A	0.016	0.048 Ω	0.37 V	3? No
Battery to Bedroom 2	7 M	1.1 A	0.016	0.112 Ω	0.12 V	1? No
Battery to Kitchen	20 M	0.7 A	0.016	0.32 Ω	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 MM^2	10 M
Cable	2.5 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 mm^2 cable was used in that run. To reduce energy loss, a 4.0 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.