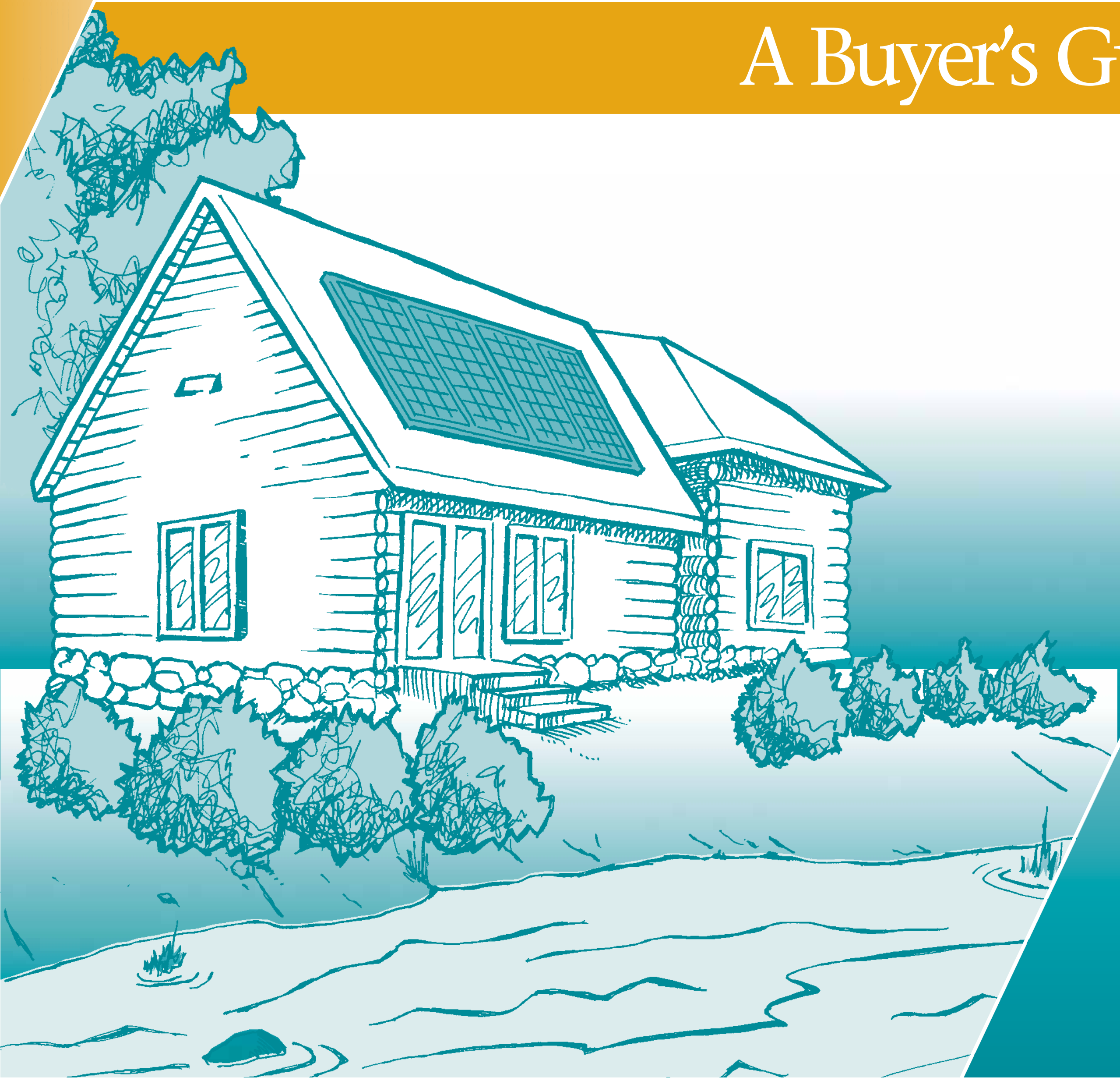
Photovoltaic Systems

A Buyer's Guide



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About this Guide

The information in the following pages is for prospective buyers of photovoltaic (PV) systems for use in the following:

- remote cottages and residences;
- recreational and mobile applications;
- agricultural applications;
- remote lodges; and
- remote lighting applications.

The purpose of this guide is to help you determine whether a PV system is a suitable option for you in providing electrical power for one or more of the above uses. It describes typical and innovative PV systems, provides examples of successful Canadian installations and answers some of the questions you should ask yourself before approaching a PV dealer (as well as questions a dealer should be able to answer).

Each section of this guide is divided into short, easy-to-read subsections. This format allows you to browse by topic or read the guide from cover to cover. Several forms are included to help you estimate your power and energy needs.

Once you have read this guide, you should know enough about PV systems to consult dealers and, with them, evaluate the best PV configuration to meet your needs – now and for the future. This guide provides only estimates and is not intended to replace the technical expertise required for the detailed design and installation of a PV system. Nowhere should you construe that this guide recommends or promotes any specific products.

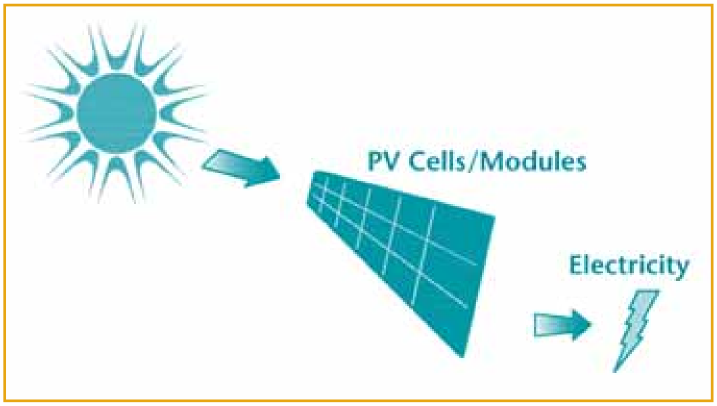
1. What Is a Solar Electric or Photovoltaic (PV) System?

What Is PV?

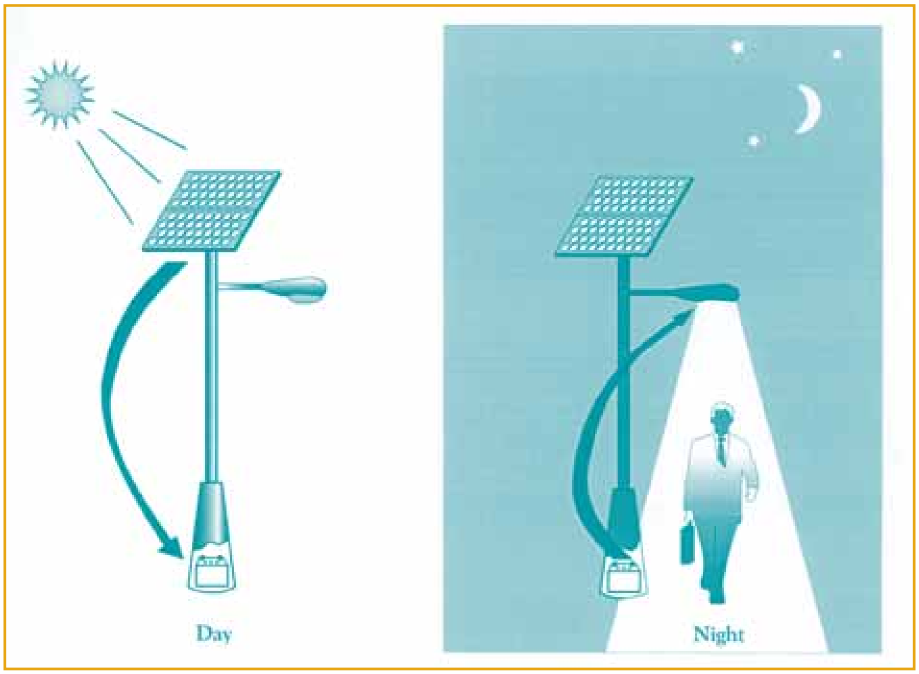
The term "photovoltaic," commonly referred to as PV, is derived from a combination of "photo," the Greek word for light, and "Volta," the name of the Italian physicist, Alessandro Volta, who invented the chemical battery in 1800. The PV effect is the direct conversion of solar energy into electricity. This process does not generate heat like solar domestic hot water or solar pool heating systems do. It also differs from the process used in solar thermal power plants, where concentrated solar energy is used to produce steam that activates a turbine connected to an electric generator. PV power systems do not have any moving parts. They are reliable, require little maintenance and generate no noise or pollutants. PV systems are modular – the building blocks (modules) come in a wide range of power capabilities, from a fraction of a watt (e.g. solar watches and pocket calculators) to more that 300 W. Modules can be connected to achieve the power that your application requires. Some demonstration PV power plants have several megawatts of power, although most installed PV systems are much smaller.

How Does It Work?

PV cells are normally fabricated using special semiconductor materials that allow electrons, which are energized when the material is exposed to sunlight, to be freed from their atoms. Once freed, they can move through the material and carry an electric current. The current flows in one direction (like a battery), and thus the electricity generated is termed direct current (DC).



S *A PV module converts sunlight directly into electricity.*



S *For applications that require electricity during overcast periods, batteries ensure that*

The energy generated by PV modules can be used immediately or stored in batteries for later use. Normally, the excess energy generated in autonomous PV systems during sunny periods is stored in batteries. The batteries then provide electricity at night or when there is not enough solar radiation. For these applications, the number of watts in the array and the capacity of the batteries are carefully sized to give optimum performance.

Some autonomous applications, such as water pumping, often have no need for batteries. Water is pumped when the sun shines and is stored directly in a reservoir or a tank that is installed at a higher level for later use by gravity feed.

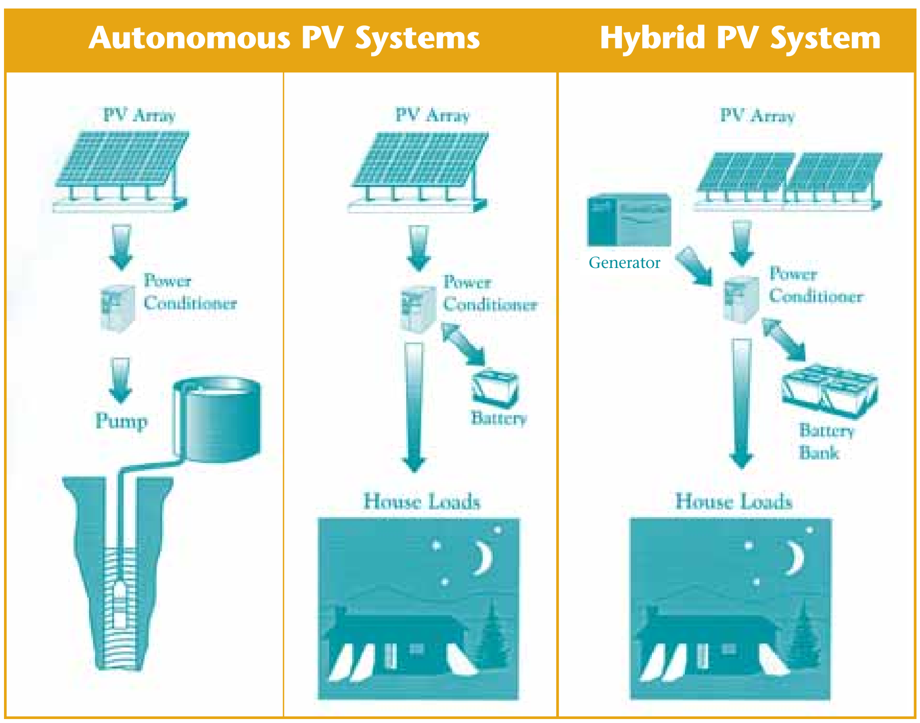
Other PV systems convert the electricity into alternating current (AC), feed excess electricity into the grid and draw out electricity at night or when the solar radiation is low. These systems are referred to as grid-connected, grid-tied or net-metered.

The Three Types of PV Power Systems

The three typical configurations of PV power systems are autonomous, hybrid and grid-connected. Autonomous and hybrid power systems are used in stand-alone applications. They are not connected to the main utility grid and are often used in remote areas.

Autonomous

Autonomous systems rely exclusively on solar energy to meet a need for electricity. As mentioned in the preceding, they may incorporate batteries – which store energy from the PV modules during the day – for use at night or in periods of low solar radiation. Alternatively, they may power the application entirely, with no need for batteries (e.g. water pumping). In general, autonomous PV systems are the most cost-effective source of electrical power. You may, however, decide to choose a hybrid PV system because of the environment in which it will operate or because you need a system that operates independently and reliably.



S *Autonomous PV system without batteries.*

S *Autonomous PV system with batteries.*

S *Hybrid PV system.*

Hybrid

Hybrid systems, also used in stand-alone systems, consist of PV modules and a wind and/or fuel-fired generator. A hybrid system is a good option for larger systems that need a steady power supply, when there is not enough sun at certain times of the year, or if you want to lower your capital investment in PV modules and storage batteries.

Grid-Connected

Grid-connected PV power systems are part of the movement toward a decentralized electrical network. Power is generated closer to where it is needed – not solely by central power stations and major hydro stations. Over time, such systems will reduce the need to increase the capacity of transportation and distribution lines.

A "grid-connected" system generates its own electricity and feeds its excess power into the utility grid for later use. This does away with buying and maintaining a battery bank. You can still use battery banks to provide backup power when the grid goes down, but they are not required.

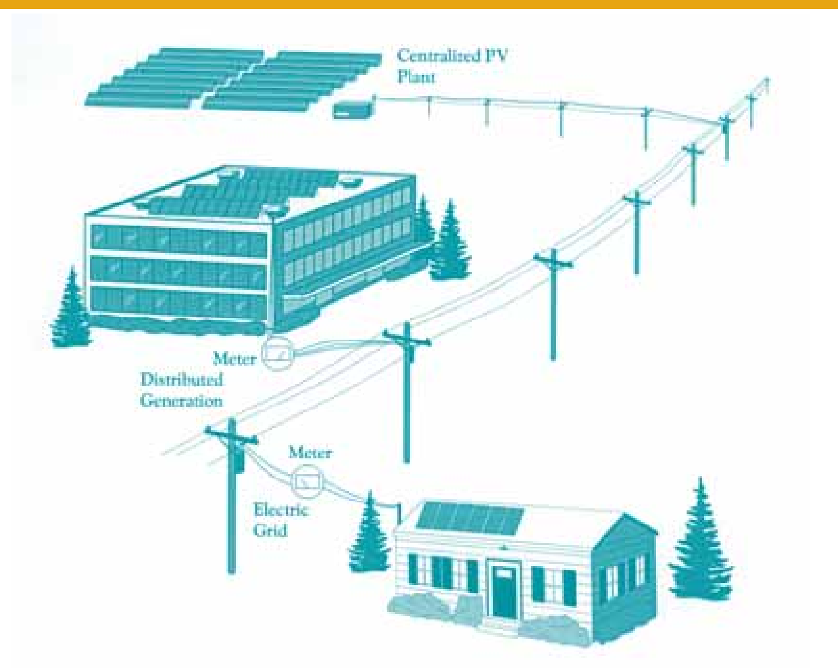
Smaller systems have a box – a small grid synchronous inverter – mounted on the back of each panel. Larger systems have one large inverter, which can handle many panels (as in a stand-alone system). Both types convert DC power output into AC power. Then they synchronize this output with the grid to slow down the electrical meter. They can even turn the meter backward. If the PV output is less than the load consumption, the meter slows down.

S *Water oxygenation compressors and water pumps are examples of PV systems that function without batteries. Photo courtesy of*

S *Remote residences or cottages can have access to electricity without extending the grid. Photo courtesy of Solener Inc.*

If PV output exceeds the load consumption, the meter turns backward, and a credit is accumulated. This credit can be drawn out of the utility when the sun is not shining. In essence, the grid acts like a limitless battery bank. In most parts of Canada, permission from the local utility is required in order to back feed power into the grid.

Grid-Connected PV Systems



S *Centralized and distributed grid-connected PV systems.*

A large portion of the cost of a grid-connected PV system is manufacturing the PV modules themselves. Significant decreases in manufacturing costs have occurred in recent years, with further decreases expected in the future. This kind of PV system is thus becoming more affordable. In some urban areas in warm climates, the cost per kilowatt-hour of electricity from grid-connected PV systems is competitive with that of other electricity-generating systems. In areas with less solar radiation, the cost-effectiveness of this type of PV system is still marginal. But there is a potential for peak power savings in areas where air conditioning causes a power peak in the summer. There are also system savings where the PV modules can replace the traditional roofing materials for buildings or the cladding material that is normally used in building façades. These material savings are making the costs per kilowatt-hour from grid-connected PV systems increasingly competitive.

Decentralized small home systems also hold some potential for grid-connected PV systems, but the costs will have to be reduced further in order to compete with the low electricity rates now available in most parts of Canada. Note, however, that PV electricity is “green” energy and, as such, is worth a premium. Even though this value is subjective, it should be expressed in numbers by the PV system’s designer. For example, how much is the avoided pollution of conventional sources worth and how much is the avoided distribution cost worth?

S *This house in Edmonton, Alberta, is equipped with a 2.3-kW system that is connected to the local power utility. About 2500 kWh are produced each year. The investment cost in 1995 was $28,000.*

To install a PV system, you must pay the capital cost of the system and amortize this cost over time. In contrast, where there is a utility grid, you pay for the electricity used and not a lump sum for the generating facility. The costs of the PV system may appear to be a burden because the electricity that the system generates may cost more per kilowatt-hour than what a utility charges. But using a PV system may also be considered a lifestyle choice, similar to choosing between a fuel-efficient car or a gas-guzzling sport utility vehicle.

2. What Photovoltaics Can Do for You

Perhaps you need reliable power in a location that is not connected to an electrical grid. In this case, photovoltaics may be the best and most cost-effective solution. Many locations in Canada that have a dry continental climate have the same number of daylight hours as some Mediterranean countries. A photovoltaic (PV) system used during the summer in Canada can take advantage of substantial daily amounts of solar energy. Contrary to what many people think, PV systems convert sunlight into electricity more efficiently at lower temperatures. However, the winter months in Canada provide half the hours of sunlight as in summer. Much of Canada experiences high winds in the winter, which can make a wind generator a logical addition to the system. Fuel-fired generators are then used only for backup.

Among other things, you can use PV energy to:

- supply power for lights, radios, televisions, pumps and other appliances in cottages and residences;
- power electric fences, water pumps and other devices in agricultural operations;
- run water-pumping and circulation systems in game fishing and aquaculture facilities;
- provide reliable electric power for wilderness lodges and hunting and fishing camps;
- recharge or maintain charge of batteries for recreational applications such as recreational vehicles and sailboats;
- power portable devices such as laptop computers;
- power exterior lighting;
- provide reliable power for many commercial applications; and
- lower your monthly utility bills.

The Advantages of PV Power Systems

Users of PV power systems appreciate their quiet, low-maintenance, pollution-free, safe and reliable operation, as well as the degree of independence they provide. Why else should you consider buying a PV system? If you are some distance from an electrical grid, it may be cheaper to generate your own power rather than pay to extend transmission lines from the grid. Diesel, gasoline or propane generators are the conventional alternatives, but many people find them noisy, polluting and costly to run and maintain. It also makes little sense to turn on a 5-kW generator to power a few 100-W light bulbs. PV systems reduce the negative aspects of generators by using them only as a backup.

When capital cost is an issue, or when photovoltaics alone are not enough to replace an existing generator, you can use a wind generator as part of a hybrid PV system, thus reducing the use of the generator. Such an intermittent charge system is more efficient than a generator running continuously at low load. In addition to saving fuel and lowering maintenance costs, you will increase the generator's life span. Also, since the PV panels and battery banks are modular, you can expand the PV system gradually as your budget or needs increase.

The Limitations of PV Power Systems

It is important to realize that PV power systems are capital intensive from the buyer's perspective and are expensive when compared with the low price of utility power in Canada. You should therefore reserve the electric power produced by PV modules, an inverter and a storage system for your most energy-efficient appliances, tools, lights, etc.

Although it is technically possible, heating with photovoltaics is generally not recommended. You can easily and more efficiently collect heat with a solar thermal system. A solar water heater generates more hot water with less initial cost than any PV-powered heater.[1] Also, for cooking, it is generally more cost-effective and convenient to use a stove that operates on propane or natural gas rather than solar electricity. Autonomous PV-powered homes and cottages often rely on wood cookstoves for cooking and space heating. Refrigerators are becoming more energy efficient, so the cost of operating them with PV power is now feasible. Extremely energy-efficient refrigerators and freezers are, unfortunately, still expensive, however, they can be had through PV dealers.

From an economic point of view, first consider investing in energy-efficient electric appliances, and then size your PV system based on actual consumption. For example, using compact fluorescent lights will reduce your electrical consumption for lighting by 80 percent.

[1] *For more information, obtain a free copy of* Solar Water Heating Systems: A Buyer's Guide *from Natural Resources Canada. Call 1 800 387-2000 toll-free, or visit the Web site at http://www.canren.gc.ca.*

3. Photovoltaics at Work in Canada

The use of photovoltaic (PV) technology is increasing rapidly in developed and developing countries. Although the Canadian PV industry has also expanded significantly over the past decade, the use of photovoltaics in Canada is still relatively limited. This is partly because of Canada's low utility rates, but the following commonly held myths are also responsible:

Myth: "There is not enough sunlight in Canada."

Myth: "Solar electric technology is not efficient in a cold climate."

Myth: "Photovoltaics is not a proven technology."

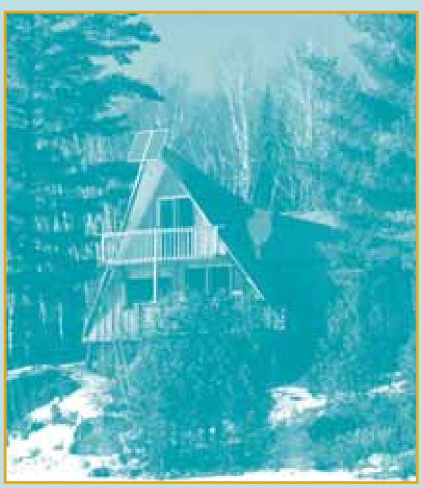
Myth: "PV systems are too expensive."

Thousands of PV systems in myriad applications throughout Canada and millions throughout the world today have debunked these myths. Although conditions in Canada pose a special challenge to the use of photovoltaics, an appropriately designed PV system can give you reliable power to most remote sites. In the following pages, examples of actual, cost-effective PV installations across the country will demonstrate what photovoltaics can do for you.

Cottages and Residences

Increasingly, Canadian homeowners are using PV systems to power lights and appliances in remote cottages and residences that are not connected to a utility grid. Like these homeowners, you'll appreciate the quiet, low-maintenance, safe and pollution-free operation of a PV system, as well as its versatility and reliability. In general, PV systems are cost-competitive for cottages and residences that are more than several hundred metres from the electricity grid. But they are not yet a cost-competitive alternative in locations that have direct access to power from the grid.

Example 1. A Typical Autonomous PV Application for a Remote Cottage



S *Photo courtesy of Cimat enr.*

A cottage, located away from the power grid, uses photovoltaics to power several fluorescent direct current (DC) lights, some halogen lights and a DC water pump, which supplies water to the residents. A stove and a refrigerator run on propane fuel. No inverter is needed, but one can be included any time if alternating current (AC) loads are added.

The cottage is equipped with a PV system that consists of the following:

- two 75-W solar modules (150 W of photovoltaics);
- a 20-A (ampere) regulator;
- a load/fuse panel;
- a bank of batteries; and
- a second PV system that powers a small, exterior DC light with an 8-W panel and an independent battery.

The cottage is used primarily on weekends and during vacations, which explains the large battery capacity compared with the total area of PV modules. This allows more energy to be available during two days of occupancy, and the PV modules recharge the batteries over the remaining five days of the week. This system has been functioning maintenance-free since 1997.

Example 2. An Autonomous PV System Powers a Summer Residence on an Island on the St. Lawrence River near Montréal, Quebec

Major power-line damages in Quebec have occurred twice in five years, the most recent being the severe ice storm of 1998. For one of its customers that has an island summer cottage, Hydro-Québec decided to provide a stand-alone PV system instead of maintaining a 200-m power line between the island and the mainland.

The average amount of electricity needed to run this cottage is 5.5 kWh/d (very low by Canadian standards), mainly during the summer. The load consists of lights, household appliances, power tools, water and pool pumps, an alarm system, etc. This load is expected to be 75 percent less during the winter, when only exterior lighting and the alarm system are active.

Three possible solutions were analysed: the replacement of the overhead power line, a submerged cable and renewable energy. Due to Canadian Coast Guard regulations, the new overhead line would have to be at least 10–15 m higher than the one previously installed. And it would have been expensive for Hydro-Québec to install a submerged cable, given the high levels of polychlorinated biphenyls (PCBs) in sediments of the St. Lawrence River. In November 1997, Hydro-Québec decided to evaluate alternative options. A PV stand-alone system was preferred to a wind generator, due to the potential for low winds in the Montréal region in the summer.

Finally, a solar-only PV system was chosen because the electricity needs in the winter were about a quarter of those in the summer. This would avoid the trouble of maintaining a fuel-fired generator. The solar-only PV system consists of the following:

- twelve 90-W PV modules, with a total capacity of just over 1 kW in 12 VDC (volt direct current);
- the existing Hydro-Québec pole used for the support structure;
- a separate, ventilated outbuilding provided by the owner for the batteries and system components (not always necessary);
- a 40-A solar controller;
- a 2.5-kW, 120-VAC (volt alternating current) pure sine-wave inverter with a surge capacity of 8 kW; and
- a 1595-Ah (ampere-hour), 12-VDC battery bank.

The batteries offer seven-day autonomy when the sun is not shining, based on the expected daily load. However, the homeowner knows about the need to monitor the use of electricity when overcast or rainy conditions are forecast. Therefore, a meter was installed to provide instant information on the reserve capacity remaining in the battery bank (based on current load consumption) and on the charge rate from the PV array.

Hydro-Québec financed the installation of the PV system, even though the cost of solar electricity produced was more than 10 times the regular cost charged by the utility (about 60¢ per kWh versus 6¢ per kWh). The savings on electric-line maintenance justify the cost. Hydro-Québec also planned funds for replacing system components after their lifetime (e.g. 25 years for the PV modules).

After two seasons of use, both Hydro-Québec and the homeowner are satisfied with the performance of the PV system. It can handle the heavy use of a washing machine, a toaster, lights, pumps, etc., during weekends when all five bedrooms are filled by up to all 16 members of the family.

Power for Remote Lodges

Owners of remote fishing lodges may find that a properly designed PV hybrid system is economically attractive, be it PV-diesel, PV-wind or a combination of the two. The high cost of diesel generation at remote sites often prompts the owners to look for alternatives, namely, renewable energy technologies. In many instances, a PV-diesel hybrid system proves attractive because it is cost-effective, simple and reliable. During periods of little sunshine, the use of the diesel generator can be reduced by drawing power from a bank of batteries and by running the generator only when the batteries are low.

Example 3. A Solar-Diesel Hybrid System at Tarryall Resort, Catherine Lake (Near Keewatin), Ontario

Tarryall Resort operates from April to October. The resort consists of seven cottages and a main house that can accommodate up to a dozen people. The cottages are equipped with propane-powered appliances and lighting. Electricity is used year-round in the main lodge to power a full range of appliances, including a clothes washer, a large freezer, a water pump, televisions, lights and power tools.

The resort is located six kilometres from the electrical grid. In 1980 the owners considered connecting to the utility grid, but the cost was estimated at more than $80,000.

The owners instead decided to improve the resort's energy efficiency. They switched to more efficient 12-V fluorescent lights, put a smaller motor in the water pump, installed timers on the exterior lights and moved their freezer outdoors in the winter. Using more efficient lights, in particular, has had a significant impact on daily energy consumption.

The resort's electrical generating system consisted of two diesel generators (a 7.5-kW main generator running 24 hours a day and a 3.0-kW backup generator). The high cost of diesel prompted the owners to investigate a solar-diesel hybrid system.

In 1986 the owners installed a hybrid system that included the following:

- a 564-W PV array;
- a bank of 24 two-volt, deep-cycle batteries; and
- the existing 7.5-kW diesel generator.

The resort's diesel consumption has been considerably reduced since the PV-diesel hybrid system was installed. The generator is used once every three or four days for about 10 hours to recharge the batteries. Previously, it had consumed fuel continuously, while supplying only about one quarter of its nominal capacity. The PV panels contribute about 15 percent of the lodge's energy requirements. They also permit a gentle trickle charge of the batteries at the end of the charging cycle, thereby extending battery life and increasing the system's efficiency. Because the diesel generator is used more efficiently in the hybrid system configuration than it would be on its own, it needs fewer oil changes and less frequent major overhauls and repairs. Also, the life span of the generator is extended. During its first year alone, savings in fuel and maintenance charges totalled about $7,000.

Despite the high up-front cost ($36,000 in 1986), the hybrid system paid for itself within six years. Tarryall's owners are pleased with their PV system and particularly enjoy the quiet, clean operation – a major improvement over the constant noise of a diesel generator. They have since added four PV modules, increasing the capacity to 752 W. This further reduced the need for diesel-generated electricity. The original lead-acid batteries were still being used in 2000, after 14 years of service. Tarryall's owners were so satisfied with photovoltaics that they also equipped each of the seven cottages with an autonomous PV lighting kit (one module with one deep-cycle battery).

Example 4. A Hybrid PV System at the Warden Station on Huxley Island, Gwaii Haanas Marine Conservation Area National Park Reserve

Located in the Moresby Island archipelago in British Columbia, Huxley Island serves as a registration office for visitors to Gwaii Haanas Marine Conservation Area National Park Reserve. These include scientists visiting the area, which is dedicated to environmental conservation. The camp has a 75-m^2 building with a full kitchen, bunks for four people and an office equipped with a satellite telephone, VHF radios and computers. To meet these electricity needs, park administrators chose a hybrid stand-alone PV system. Its advantages over a continuously operated generator include less engine maintenance, a lower need for refuelling and reduced noise.

A power system installed in 1996 consists of the following:

- a 600-W solar array using eight 75-W modules;
- a 4.0-kW sine-wave inverter;
- a 38-kWh lead-acid battery bank; and
- a 5.0-kW gasoline generator.

S *Photo courtesy of Soltek Solar Energy Ltd.*

To make installation easier, all electrical components were pre-assembled and wired on a 1.3-m^2 board before shipment. The distributor also provided a waterproof aluminum outdoor cabinet for the batteries and power equipment. It was installed directly behind the living quarters. A state-of-charge battery display and a remote control for the inverter and generator were installed on an interior wall of the building for the convenience of park staff.

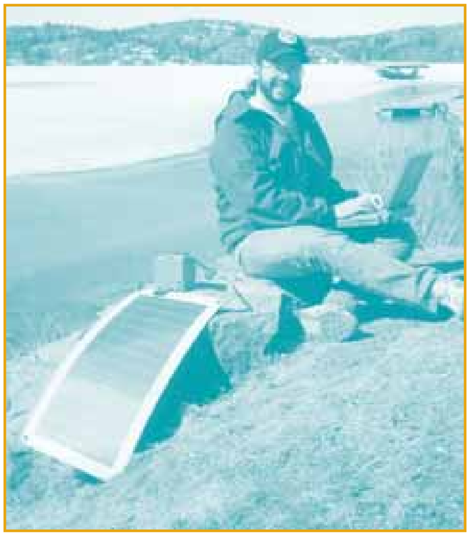
The integrated power system is completely automated. The system provides the bulk of the power to the loads, with the generator available for backup. In the event of poor weather or excessive loads, the generator is programmed to start when the battery bank reaches 50 percent of its nominal capacity. This way, the batteries are charged before a potentially damaging low-battery condition is reached.

Mobile and Recreational Applications

Chances are that you are already relying on PV technology to help you keep track of time, balance your budget or enliven your leisure hours. Many products such as watches, calculators and toys have been PV-powered in an inexpensive, reliable and convenient way for many years. Equipped with tiny PV cells that produce power even in dim lighting, these consumer products eliminate the need for costly batteries that need to be frequently replaced.

Nowadays, versatile PV power packs are also used to power larger consumer products. They are available in a range of sizes, from fractions of a watt to over 100 W. Power packs can also be hooked up in series or parallel connections to serve various power needs. They can be used as either a direct power source or as a battery recharger. These convenient PV systems power everything from radios, cassette recorders and cameras to lawn ornaments, walkway lights and batteries for sailboats and gliders. The clean and noiseless operation of PV systems for many recreational applications is a significant benefit.

In recreational vehicles and electric-powered boats, PV panels can help recharge batteries. The main advantage of a PV system is that it will, at the least, maintain the state of charge of batteries on board – even during extended periods of time when you are not using the equipment.



People working in the field with portable computers appreciate the autonomy that PV offers. Photo courtesy of Midnight Sun Energy Ltd.

Many owners of recreational vehicles are already using PV technology. Photo courtesy of Rozon Batteries Inc.

Example 5. Photovoltaics for a South Pole Expedition

Photo courtesy of Bernard Voyer Explorateur Inc.

Explorers Bernard Voyer and Thierry Petry were the first North Americans to reach the South Pole by ski unassisted. Each had to pull a 170-kg pulka (a toboggan-like sled) over an uneven surface of stratified ice swells. Sunlight was available 24 hours a day during their expedition; however, the usable sunlight hours per day was between two and nine hours (or 5.5 hours per day on average).

Electricity Need

The explorers used a PV system to power a satellite telephone under the extreme climatic conditions. This system also served as a backup for the lithium batteries for a video camera. The PV system was designed to power the following equipment:

		Converted to Wh per day	
• satellite telephone:	60 W (8 min/d)	60 W x 8/60	8 Wh/d
• portable computer:	42 W (15 min/d)	42 W x 15/60	10.5 Wh/d
• positioning system:	0.5 W (24 h/d)	0.5 W x 24	12 Wh/d
• video camera:	20 W (12 min/d)	20 W x 12/60	4 Wh/d
		Average total daily demand:	**34.5 Wh/d**

As mentioned above, sunshine was usable for 5.5 hours a day on average, so the team needed 6.3-W worth of PV modules (34.5 Wh/d ÷ 5.5 h/d) daily.

The Power System

As 5.5-W panels are common, the team needed at least two panels, which provided extra power to compensate for bad weather or additional loads. The PV system had the following characteristics:

- installed PV power: 2 x 5.5 W
- storage capacity: Lead-acid 12 V, 9 Ah; Nickel-cadmium 12 V, 5 Ah
- total weight: 5 kg

The conditions of operation were as follows:

- average temperature: -15°C to -33°C (December/January)

The system cost $600.

Main Advantages of the PV System

Primary lithium batteries are generally used for this kind of expedition. An estimated twenty 10-Ah lithium batteries would have been needed, for a total cost of $6,000 and a weight of 12.5 kg. This alternative was rejected due to its cost and weight.

Another alternative would have been to carry a small gasoline generator. The smallest, lightest generator available was a 300-W generator that weighed 18 kg. Apart from its weight, fuel would have had to be carried and handled. Also, fumes and noise from the generator would be unpleasant, and starting the engine in a cold environment would be difficult. The team rejected this alternative as impractical.

PV energy represented the most economical, reliable, practical and environmentally friendly way to generate electricity for such an expedition – not to mention the lightest.

Photovoltaics in Agriculture

PV systems are particularly well suited where a small amount of energy in remote locations is needed for agricultural applications, such as electric fencing, water pumping for irrigation or stock watering, pond aeration, etc.

Electric Fencing

PV-powered electric fencing is popular in Canada's western provinces, chiefly in northern pastures where land is open for cattle. Several cattle ranchers in northern Alberta and British Columbia have installed PV modules to charge the batteries of standard electric fencing. These batteries will never run down. PV-powered electric fencing not only eliminates the cost and inconvenience of regular visits to check batteries, but also costs less than barbed wire fencing, which is the other alternative to conventionally powered electric fencing. More and more ranchers and

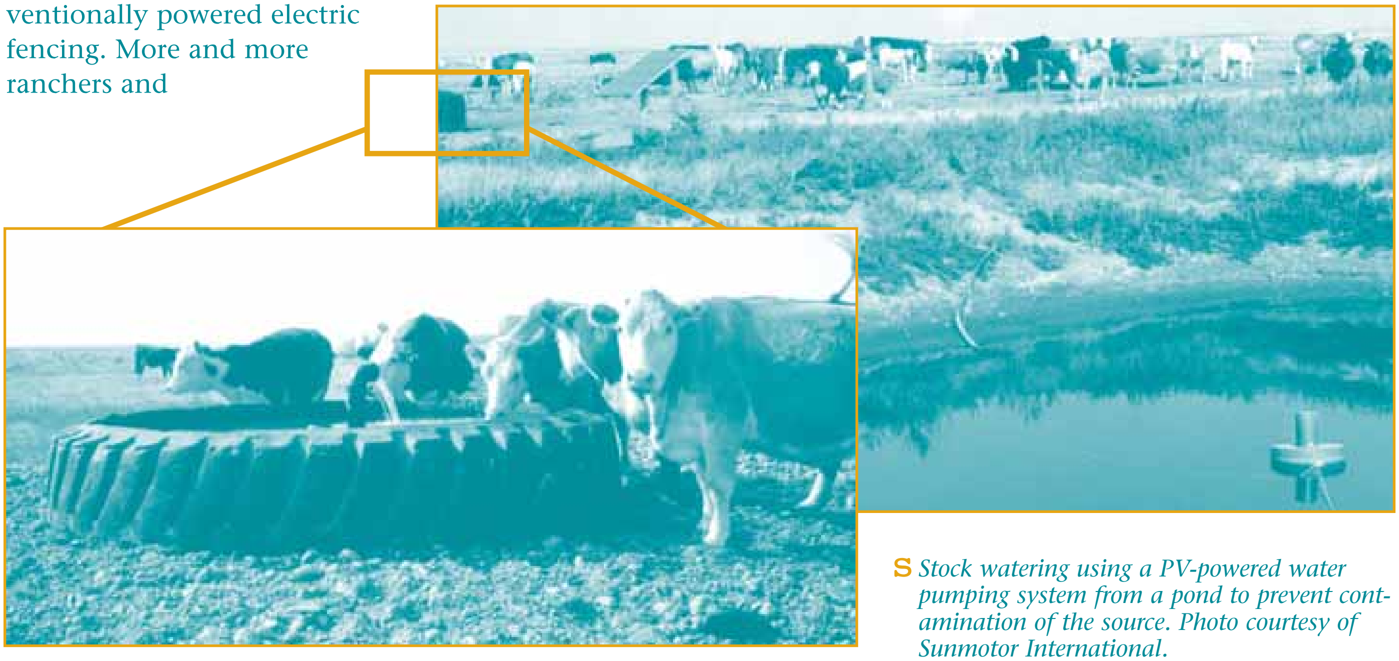
PV-powered electric fencing saves both time and money for ranchers and farmers. Photo courtesy of the Agricultural Technology Centre (formerly the Alberta Farm Machinery Research Centre).

farmers in Canada are finding that PV systems, which can run all summer with no need for servicing, are a practical alternative for their remote fencing needs.

Water Pumping for Stock Watering and Irrigation

Water pumping is one of the most attractive uses for PV systems. In agriculture, the demand for water is greatest when the weather is hot and dry, precisely when the most solar energy is available. Simple non-storage types of PV systems are ideal for many irrigation applications where crops can do without water when the sun is not shining. In situations where irrigation is needed independent of weather, power stored in the form of pumped water, rather than in costly storage batteries, makes PV-powered irrigation systems economically attractive.

Today, several million hectares of remote grazing land in Canada are not being used because the costs of pumping water for stock watering by conventional methods outweigh the grazing benefits. For many Canadian ranchers and farmers, PV-powered pumping systems offer a cost-effective solution.



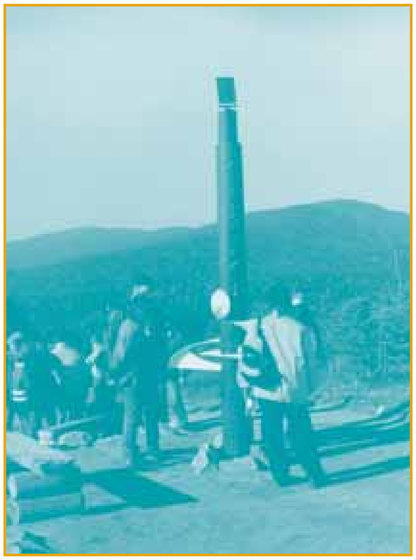
Stock watering using a PV-powered water pumping system from a pond to prevent contamination of the source. Photo courtesy of Sunmotor International.

A PV System to Suit Your Particular Power Requirements

Standardized PV systems are becoming more and more common. However, many PV systems in Canada are custom-designed to take into account the particular needs of the user and the characteristics of the site. Therefore, you should not necessarily expect to buy such a system "off the shelf" as you would a diesel or gasoline generator. Rather, you will probably have to consult PV equipment suppliers for a system that is right for your needs.

The telecommunications industry and the Canadian Coast Guard used PV power systems early on for remote telecommunications repeater stations, beacons and navigational aid systems. Their expectations for reliability helped the PV industry develop quality products and improve design tools.

Small PV lighting packages are available from dealers. For ski hills, lighthouses, isolated stretches of highway and off-grid communities and businesses, PV-powered lighting provides a practical, affordable solution to remote lighting problems.



A small PV module is used to power a trail indicator at night at Mont-Tremblant, Quebec. Photo courtesy of TN conseil inc.

This PV-powered aquaculture facility is on an island off Canada's west coast.

Early Uses for PV in Commercial Applications

The Canadian Coast Guard has been using thousands of PV-powered buoys along coasts for many years.

Due to the remoteness of repeater stations, telecommunications has been one of the first – and remains one of the most popular – applications for PV systems. Photo courtesy of Northwestel Inc.

The limited power needs of remote monitoring systems are easily met by small PV systems. This example shows a gas wellhead.

4. Buying Your Photovoltaic System

Be Prepared

Before approaching a dealer, you should consider your power requirements and the type of photovoltaic (PV) system that will suit your needs and your budget.

The following are typical questions that you should ask yourself. Be prepared to supply the following information as precisely and clearly as possible:

- What is the application?
- What needs to be powered?
- Are my loads as efficient as possible?
- How much power (wattage) and/or energy (watt-hours per day) is required?
- What is the energy-usage pattern (e.g. hour per day, days per week, seasonal use)?
- Do I need battery storage?
- Do I want an autonomous, hybrid or grid-connected system?
- Do I want to start small and add modules in the future?

A first step in any design or cost evaluation is to assess your load: i.e. what do you expect the PV system to power? Section 6, "Estimating Your Needs" (page 24) is intended to help you evaluate the options. A worksheet is provided in Appendix A (page 40) to help you estimate and choose a suitable PV system. This worksheet is intended to guide you in estimating your power and energy needs, evaluating the PV array size and estimating the battery capacity that you require.

Note that this exercise is optional. However, you should at least prepare a list of all appliances and other electrical equipment that the PV system might power and estimate their time of use (see Step 1 in the worksheet provided in Appendix A). The more detailed and accurate the list, the easier the sizing of your PV system will be for you or your dealer.

Where to Find PV Systems

Apart from some specific consumer products or special sales, PV power systems are just beginning to be widely available in hardware or department store chains. Dealers of recreational vehicles, boats and electric fences may sometimes offer PV solutions adapted to their products. However, for most custom applications, you will need to find a PV dealer. Generally, this gives you the advantage of better service, since such dealers should have a good understanding of the technology and can help you select, size and design the system that best suits your needs. There are many distributors and dealers of PV systems in Canada, and the industry network is growing. Some of these companies specialize in different types of systems, e.g. communications, home energy systems, consumer products, agricultural and unique design.

To find PV distributors or dealers, contact the Canadian Solar Industries Association, Natural Resources Canada (see "Learn More About Solar Energy" on page 46) or consult the Yellow Pages™. You may also wish to obtain a referral from a satisfied customer.

Choosing a Dealer

A PV system should be designed for the best efficiency and cost-effectiveness. It is wise to consult a professional at the design stage. Most dealers offer design and consultation services as well as PV modules and "balance of system" components such as batteries and inverters. Some companies concentrate on industrial applications; others specialize in residential and commercial systems. Make certain that the dealer you select has proven experience in designing and installing the type of system you want. Ask to see some systems that have already been installed, or talk to someone who has bought a system that is similar to what you want.

A responsible dealer will ask you questions about your power consumption, lifestyle and needs before designing your PV system. If you cannot afford as many PV modules as you would like but intend to add to the system later, make sure that the system designer knows this.

The PV dealer should offer a warranty on parts and labour. The warranty for PV modules can now be as much as 25 years, depending on the type of modules and manufacturers' policies. Most modules will perform reliably for a longer period. Check which warranties the dealer offers on the other components (electrical and mechanical) and on the labour. Moreover, check on follow-up service available from the dealer. In general, take the same sort of precautions when buying a PV system that you would when buying a new appliance.

Following is a list of items to consider in evaluating a dealer's product and service. Use it when choosing a dealer.

- design/sales experience
- knowledge of energy efficiency
- area of expertise
- product quality
- product warranty
- installation service
- follow-up service
- price

Making a Decision

Of course, cost is always important in any purchase decision. The economics of PV systems are often quite site-specific. In general, conventional energy sources tend to have low initial capital costs but have high operating and maintenance costs. In comparison, PV systems have higher initial capital costs but have lower maintenance and operating costs. Thus, to evaluate the economics of a PV system, you must consider the total costs of competing alternatives – including capital costs, fuel costs and maintenance and operating costs over the life of the system.

For off-grid commercial operations that have labour and maintenance costs, PV systems can often be economical. For individual homeowners, who usually do not count their own labour for operation and maintenance as a cost of running a generator, the initial cost of a PV system may appear to be high. However, for many home and cottage owners, the non-economic benefits of PV systems – in particular, their reliability and quiet, non-polluting operation – far outweigh the extra costs. Especially in summer, owners of PV systems appreciate that they can enjoy the sounds and smells of nature without interference from their power system.

Of course, the cost of a PV system depends on what it includes. A simple autonomous system for a cottage or cabin, suitable for powering a few lights, a water pump and radios (e.g. 40–100 W) can cost from $700 to $2,000. Larger, hybrid systems that are suitable for year-round residences or lodges (200–1500 W) can cost from $5,000 to $30,000.

In considering the economics of PV systems, it is important to realize that the costs of these systems are steadily declining. The PV industry, like the computer industry, is continually evolving. Improvements in PV cells, batteries and other system components and in system design are resulting in lower prices for PV systems.

One of the most attractive features of PV systems is that they come in modules. The PV component of a hybrid system can be sized to suit your budget: as prices decline and/or your savings increase, you can add more PV panels and decrease your reliance on the backup generator. If you do not already have a generator and are considering a solar-only system for a cottage or sailboat, you can start with a small system to power a few essential appliances and upgrade it as your finances allow. Because PV systems last 25 years or more, they represent a solid investment. By the way, the price for used panels is not much less than that for new panels because they remain in perfect condition for years.

The following form will help you compare the advantages and disadvantages of an autonomous or hybrid PV system with conventional diesel, gasoline or propane alternatives.

PV System – Purchase Decision Factors

Decision Factors	**Option A: Autonomous PV System**	**Option B: Hybrid PV System**	**Option C: Conventional System** (diesel, gasoline or propane generator)
Capital Costs			
Operating Costs			
Maintenance Costs			
Other Factors (e.g. noise, pollution, reliability, flexibility for expansion, refuelling needs, your time)			

5. Installing and Maintaining Your Photovoltaic System

One major advantage of photovoltaic (PV) systems is that they are relatively simple to install and maintain. For large or complex systems, PV companies usually help with installation and maintenance.

Installation

Your supplier should give you any relevant system documents. Carefully read all of the manufacturer's recommendations. As with any electrical system, safety is important. You must obtain any necessary building and electrical permits and ensure that the system is installed according to code. Qualified people should install the system. If you have a grid-connected system, installation will involve the local utility.

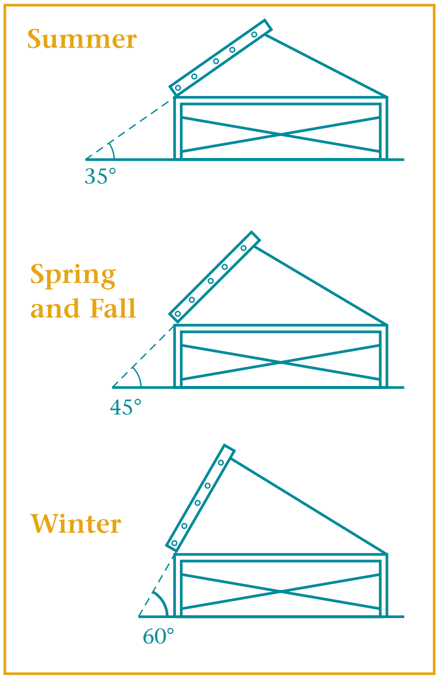
Wiring must be properly installed to avoid shocks, fires and other hazards. The main consideration is the type and size of wire. For example, the array wiring must be suited for outdoor use and be sized properly in order to carry the peak current. As a result, you will normally need larger wires for low-voltage systems (12 V compared with 120 V) to prevent overheating and voltage loss in the wires. Consult a professional designer or installer to select the proper wires. You will also need the services of a professional installer to:

- properly fuse the system for protection against short circuits in the wiring or appliances;
- ensure that the system is properly grounded and protected against lightning; and
- include switches between all components of the system that need to be isolated for any reason.

Mounting the PV Array

PV modules are designed to be installed outdoors without additional protection. A mounting structure must be constructed to support the modules in all weather conditions. Many manufacturers sell support frames designed to hold their modules; you may decide to build your own.

Factors to be considered in mounting the array include orientation, safety, structural integrity and local codes. The PV array should be mounted so as to take full advantage of the sunlight. In the northern hemisphere, it should face south; true south is best, but a deviation of 15 degrees east or west will not affect performance very much. Very large installations can be mounted to track the sun either automatically or manually (see "Technical Information on Photovoltaic System Components" on page 35). In most cases, the mounting is fixed at one angle (a right angle to the sun at noon), but can be adjusted according to the season.



S *Array orientations showing suggested tilt angles for summer, spring and fall and winter use in southern Canada.*

Select a site where the array will not be shaded at any point during the day. A shadow on the array can substantially cut power output. If possible, ask your neighbours if they plan to add trees or buildings adjacent to your property. Easements and restrictive covenants (for definitions, see the glossary on page 44) are two types of legal instruments. When used for solar applications, they provide certain guarantees to property owners about their access to sunlight. If access to sunlight concerns you, such a written agreement may be worthwhile.

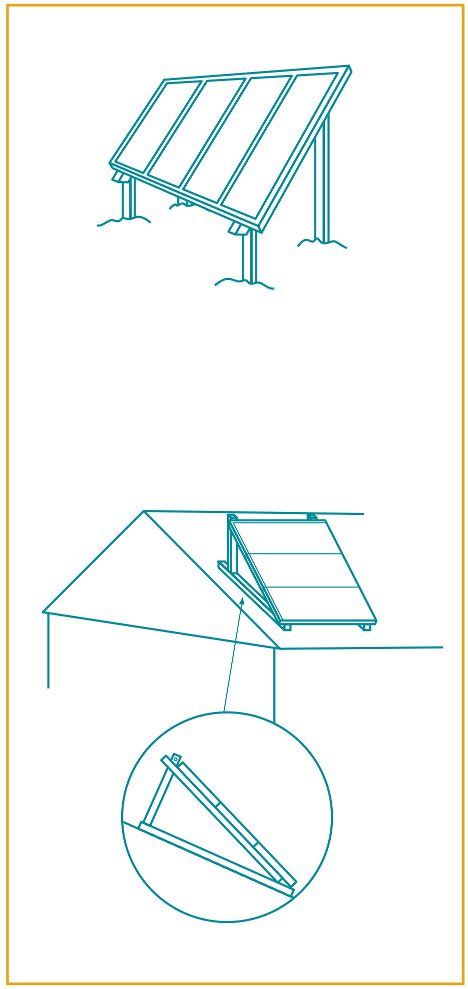
Depending on the array size and the particulars of the site, the PV array can be mounted on a roof, a pole or the ground. In general, the large surface areas of the modules create high wind loads on the mounting structure, so the structure must be designed accordingly. Due to these high wind loads, ground-mounted installations require proper foundations. For small, ground-mounted installations, foundations can be posts sunk into the ground to anchor the array support frame. The support frame itself may be made of metal or wood. Modules are mounted so that the bottom of the array is above the highest depth of snow likely to fall. Make sure that there is no bottom lip on the array so that snow can slide off freely.

S *Ensure that your PV array will not be shaded by neighbouring trees or other sources of shade.*

You can use pole mounting for small systems (one to 12 modules) to ensure proper orientation or to lift them above potential sources of shade, such as buildings or trees. The main advantages are no snow buildup to shade the array and the potential to track the sun.

For many residences and cottages, roof mounting is an attractive option, particularly if the building is under construction. The modules should be mounted a short distance above the pitched roof and tilted to the optimum angle. Since PV modules work better when the ambient air temperature is lower, the free circulation of air around them will improve their performance. Elevating the array will also prevent the buildup of moisture and debris behind the modules. This buildup could rot the roof and deteriorate the electrical connections. For residences and cottages with a chimney, the array should be mounted in such a way that shading from the smoke is avoided.

Wherever you choose to mount the array, unless shading is a concern, try to locate it as close as possible to the battery bank or to the load (if there are no batteries). This will lower wiring distances and resultant power losses.



S *Ground- and roof-mounted PV arrays.*

Is Magnetic South Truly South?

Using a compass to help you orient your PV array so that it faces south means that you will be relying on magnetic south instead of true south. It is better to use true south. In some parts of Canada, the deviation of true south from magnetic south can be large enough to affect the performance of your PV array. If your array is fixed (i.e. it will not be tracking the sun) and you are unfamiliar with the deviation of the compass needle from true south at your location, ask an experienced local dealer or installer for assistance.

Housing the Batteries

Your choice of battery location should comply with the *Canadian Electrical Code*, whether you install the batteries inside or outside. The location should also be designed to keep the batteries warm (25°C is best), because their capacity decreases at temperatures below 25°C. This means that if you choose to locate your batteries in an unheated space, you will need to insulate the area properly. You will also need greater battery capacity to compensate for the losses at lower temperatures. Make sure that your supplier knows about the planned location of your batteries.

The batteries and other equipment should be accessible for maintenance and inspection, but safety must also be considered. Batteries may give off hydrogen gas during charging and can be a source of electric shock, so the room or area where they are housed should be properly vented to the outside and kept locked.

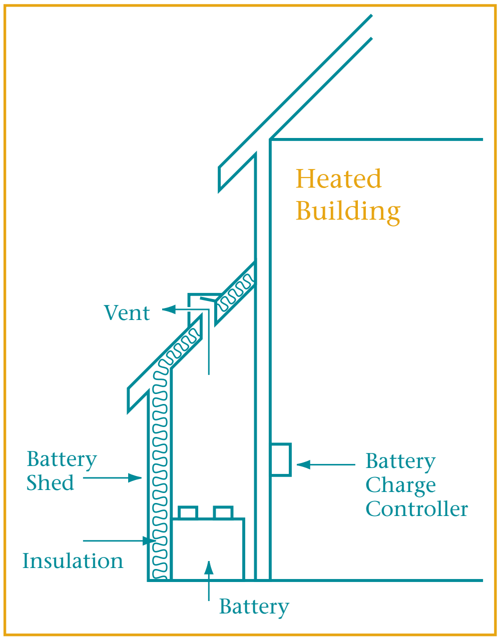
In addition, other electrical components, which can also be a source of spark, should be kept separately from the battery housing. Do not locate batteries near sources of heat or possible sources of open flame or spark. Finally, read all of the manufacturer's recommendations and warnings about the safe and proper use and handling of batteries.

Inside Locations

Batteries located inside the living space should be properly vented to the outside. For small cottage systems with, for example, two 12-VDC (volt direct current) batteries, you need a vent that is at least 2.5 cm (1 in.) in diameter. Keep batteries separate from the living space by housing them in special battery cases (with ventilation to the outside). For summer cottages, keep batteries full of charge to prevent freezing in the off-season.

Outside Locations

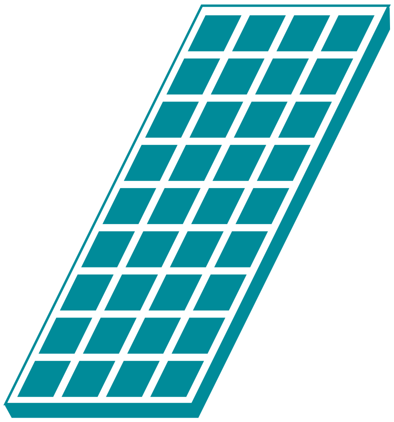
Batteries located outside of the living space should be housed in a box or shed. In a very cold location, you can house the batteries in a buried container for better temperature control. In all cases, batteries should be well protected from the elements and be well vented to the outside.



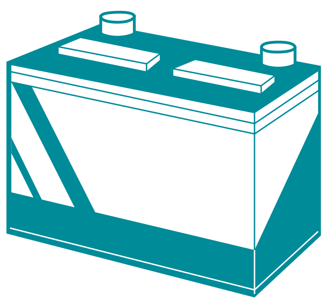
S *Battery housed in a shed.*

Maintenance

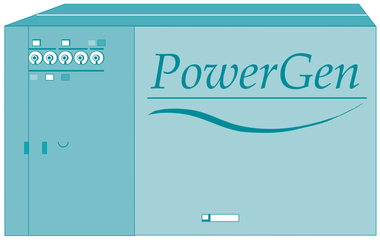
An important advantage of PV systems is that they require little maintenance. The arrays themselves are durable and reliable and need little attention. The following summarizes the principal maintenance that your system will need, but you may wish to ask your dealer for a maintenance schedule that is adapted to your particular system and location.



- *Unless you live in an extremely dusty area or have severe problems with ice storms, you need to inspect the wiring and general panel appearance only occasionally. If your system has an adjustable mounting, you can carry out this routine maintenance check at the same time as you adjust the tilt angle of the array. When you adjust the angle of the array for winter operation, snow loading is not a problem because the array is tilted steeply. If the array becomes dusty, clean it with a mild soap or plain water and a soft cloth. Do not use solvents or strong detergents.*



- *Battery maintenance varies with the type used. Basic maintenance includes visually checking the electrolyte levels and regularly verifying the specific gravity of your batteries with a hydrometer. Add distilled water as necessary, and clean and tighten battery posts (only the latter are required for maintenance-free batteries). Also, check for any leaks or physical damage to batteries. Follow battery and charge regulator instructions for annual equalization charges that help cure the batteries from plate fouling due to corrosion.*



- *Generator maintenance for hybrid systems is simpler and easier than using a generator to produce all your power. Change the oil as recommended (which will be less frequently than for a continuously operating generator).*

- *Keep track of any maintenance or modification made to the system (date and action). This will help you remember when your last maintenance routine was carried out and may ease troubleshooting should a problem occur.*

6. Estimating Your Needs

To further investigate which kind of system will meet your power needs, this section will help you estimate your energy requirements and then estimate the system size that your application will require (a blank worksheet is provided in Appendix A, page 40). Two examples have also been worked out in the next section. Once you have followed this process, you should be more comfortable discussing different options with a dealer.

If you are involved in the design of power systems, a more detailed sizing and design guide called *Photovoltaic Systems Design Manual* is available from Natural Resources Canada (see "Learn More About Solar Energy" on page 46).

Step 1. Estimate Your Power and Energy Needs

To work out how much power and energy you need, you must know what loads you want to power, how much power they use (including stand-by consumption) and how often they are used. For single-purpose applications, such as powering a water pump, this is fairly simple to calculate. However, if you want a system that will run several appliances in your home or business, you must estimate the usage pattern of each load.

The more energy you need, the larger and more expensive the system – especially if you want an autonomous one. Therefore, decrease your energy requirements as much as possible. This includes using energy-efficient appliances and using electricity only for appliances that really require it. For example, it is not practical to use a PV system to power an electric range or heating system. Rather, meet your heating and cooking needs with a more fitting energy source, such as wood or propane. A solar water heater may also meet your hot water needs (contact Natural Resources Canada for *Solar Water Heating Systems: A Buyer's Guide*[2]).

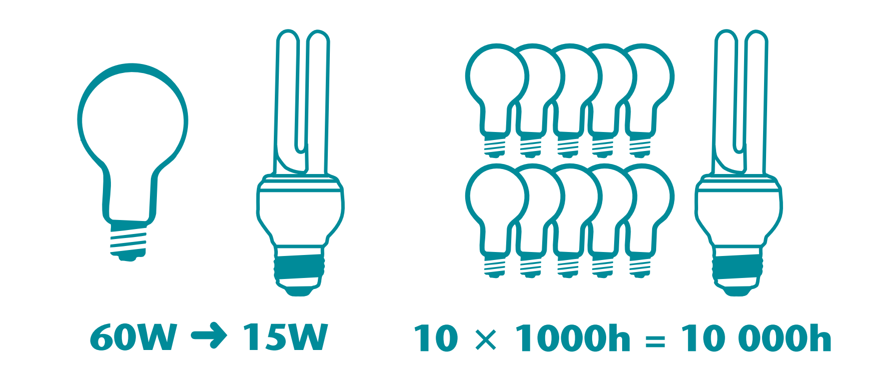
About Efficient Lighting

For lighting, consider AC or DC compact fluorescent lights instead of incandescent bulbs. They give four times more light per watt of electricity and last 10 times longer. Consult a specialized supplier for information on high-efficiency lighting for outdoor applications.

To estimate your power needs, first list all the loads you want to power, note whether they are AC or DC, and obtain their rated wattage and the number of hours per day they will be used (see Step 1 of the worksheet in Appendix A).

If available, use the rating indicated on the label of the appliance or tool you need to power. Also use the typical values given in Appendices B (page 42) and C (page 43) for common appliances and lighting.

Next, for each load, multiply the power rating (using actual or typical values) by the number of hours of estimated daily usage to obtain the total watt-hours of power needed per day. If consumption is already given in watt-hours per day (or kilowatt-hours per year, as on EnerGuide labels), you can skip columns A and B in Step 1 of the worksheet and simply fill in column C using the watt-hours per day.



Fluorescent lights use one quarter the energy of incandescent bulbs and last 10 times longer.

[2] *For your copy of* Solar Water Heating Systems: A Buyer's Guide, *call Natural Resources Canada at 1 800 387-2000 toll-free, or visit the Web site at http://www.canren.gc.ca.*

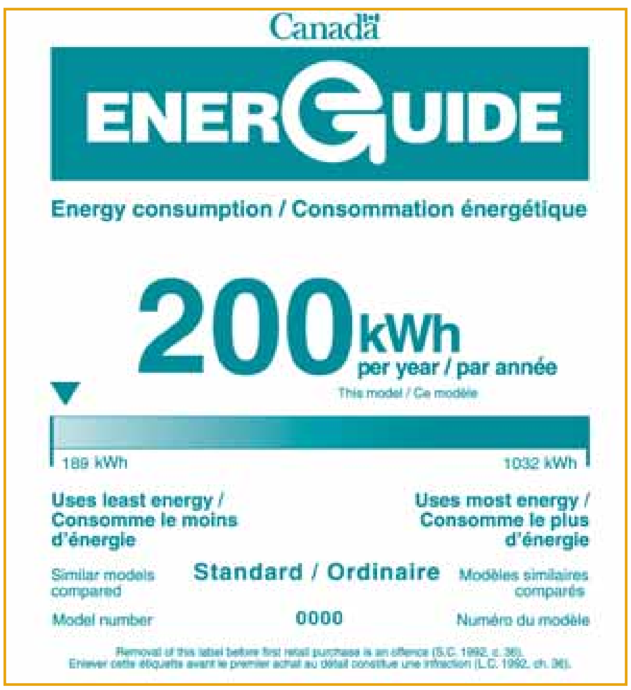
EnerGuide Labels

If there is an EnerGuide label on your appliance, you can use the electrical consumption rating (in kilowatt-hours per year) given on the label for your worksheet. Note that the EnerGuide ratings for clothes washers and dishwashers include the electricity consumed in heating the water used in those appliances. These ratings are less useful to you if, as we recommend, you heat your water with solar water heaters, propane or wood (instead of PV-generated electricity).

If you use the value on an EnerGuide label, convert the kilowatt-hours per year (kWh/a) into watt-hours per day (Wh/d) for inclusion in column C of the worksheet in Appendix A. To make this conversion, multiply by 1000 and then divide by 365.

Finally, fill in the subtotal(s), calculate the adjusted AC loads (for inverter losses) using 0.90 as your initial conversion efficiency, and fill in the "total daily load" value at the bottom of the first side of the worksheet.

Smaller, efficient appliances will require less PV equipment. Some PV dealers also carry high-efficiency appliances and lighting.



S *EnerGuide labels provide energy consumption ratings (in kilowatt-hours per year) for major home appliances.*

Always keep in mind that your energy requirement has a direct impact on the following:

- the area of PV modules needed to power the load or recharge the batteries;
- the capacity of the batteries required to meet your needs without running a generator at night or on cloudy days; and
- the amount of fuel used by a generator or the size of a wind generator.

Watch Out For "Phantom" Loads!

A growing number of electronic appliances draw power even when they are turned off. Examples are a TV or VCR that maintains program memory, runs its clock and keeps the remote-control receiver active. The stand-by power required can appear to be negligible, and it is often not even mentioned in appliance owner's manuals. But it may represent a substantial amount of energy because power is drawn 24 hours a day. For example, the stand-by power for a remote-controlled portable TV may be as low as 5 W, but it will still require 120 Wh/d (5 W x 24 h). This represents the same amount of energy as using this TV (60 W) for two hours a day (120 Wh/d)!

Power or Energy?
The following two terms are used to characterize electricity usage:

- the power or "instantaneous power required"; and
- the energy or "energy consumption over a period of time."

Power

The power you need (the wattage) is the instantaneous intensity of electricity that is required to power the appliances you use. The more appliances used at the same time, the more power required. Power is expressed in watts (W). A watt is a convenient SI unit in electricity because it is simply the product of the current – in amperes (A) – and the voltage – in volts (V).

$$1\ \mathrm{W} = 1\ \mathrm{A} \times 1\ \mathrm{V}$$

This simple formula indicates, for example, that a 12-W compact fluorescent light will require 1 A when connected to a 12-VDC (volt direct current) power source.

Energy

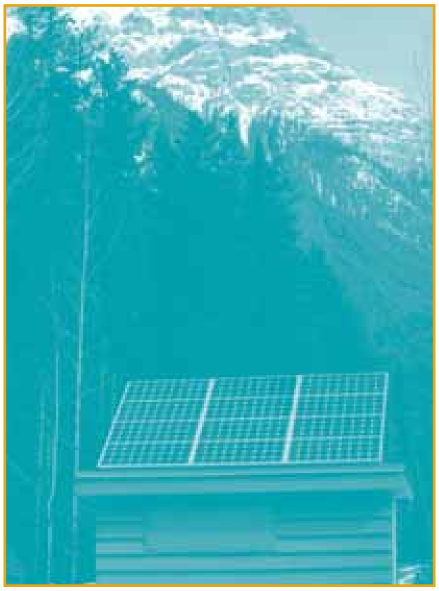
Energy depends not only on the power required by your appliances, but also on how long and how often you use them. Energy is expressed in watt-hours (Wh) for a given period of time (per day, month or year). It is defined as the power times the number of hours the equipment is used over this time.

$$1\ \mathrm{Wh} = 1\ \mathrm{W} \times 1\ \mathrm{h}$$

For example, using a 1650-W hair dryer for eight minutes draws the same amount of energy as using five efficient lights (11 W each) for four hours: about the amount that one 50-W PV module produces in an average day.

Hair dryer:
1650 W x 8/60 = 220 Wh

Fluorescent lights:
5 x 11 W x 4 = 220 Wh



S *The autonomous PV system in Yoho National Park, British Columbia, supplies electricity for the amphitheatre projector and recharges the batteries of a golf cart that the staff uses to collect camping fees. Photo courtesy of Sovran Energy Inc.*

Step 2. Make a Rough Evaluation of PV System Size

2.1 Evaluate Which Stand-Alone System Is More Suitable: Autonomous or Hybrid

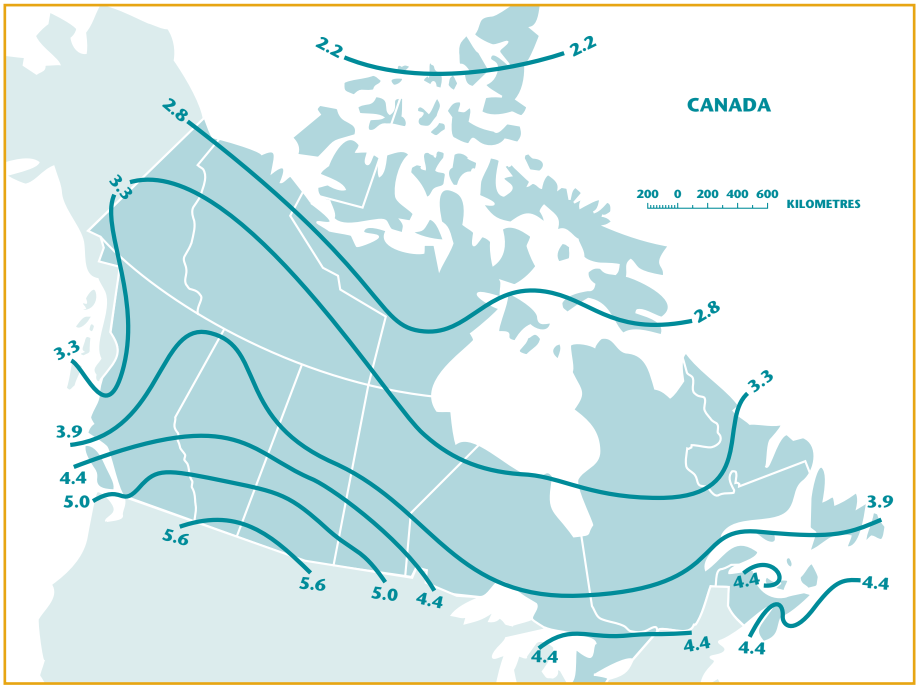
Stand-alone PV systems can be either autonomous (with or without storage batteries), relying only on solar energy, or hybrid. Hybrid systems combine PV with one or more other electrical generating sources and normally include storage batteries. Factors that influence the type of system include the following: total and peak power requirements; when power is needed; required power reliability; whether the application is seasonal or year-round; and whether the system will be easily accessible or installed in a remote location.

Autonomous Systems

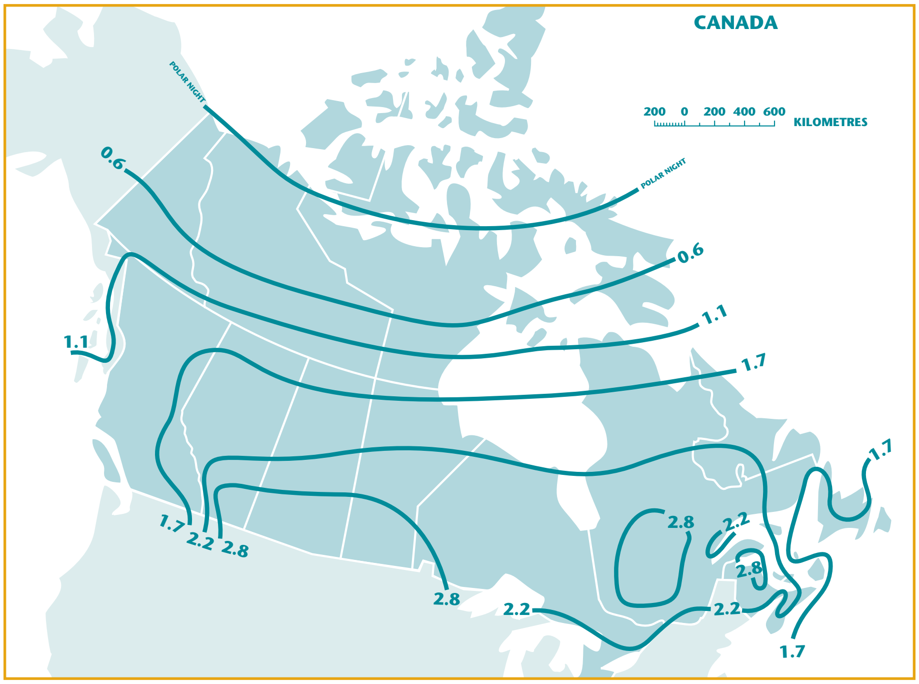
As the name suggests, autonomous systems are self-sufficient and not backed up by another generating source. They normally include battery storage. Some applications, such as irrigation, pumping or greenhouse ventilation, require power only when the sun is shining. Therefore, an autonomous system without storage would be suitable in such cases. In most cases, however, power is needed whether the sun is shining or not, so the system includes battery storage.

In Canada, about twice as much sunlight is available in summer than in winter. To guarantee power year-round using a solar-only system, a significantly larger (and hence more costly) array and battery system is needed. Such systems are practical for applications in remote, unattended sites, which are difficult and expensive to visit, and where the capital costs are rapidly offset by avoiding costs for maintenance and fuelling visits. Thus, solar-only systems with storage are used for electric fencing in remote areas, and in communications, marking and warning signs, monitoring sites and other situations where reliability and low maintenance are critical.

Autonomous systems are also appropriate for summer vacation properties, sailboats and other applications where the period of use corresponds to the period of greatest available sunlight. If you consider power a luxury instead of a necessity and can tolerate the odd occasion when the system cannot meet your loads, an autonomous system may be suitable at a reasonable price. However, if you want guaranteed power on a year-round basis and can easily access the site, some sort of hybrid system will likely be more affordable.



S *Average daily number of peak sunlight hours in September (use for seasonal summer autonomous systems). Source: Environment Canada.*



S *Average daily number of peak sunlight hours in December (use for year-round-operated autonomous systems). Source: Environment Canada.*

Hybrid Systems

Hybrid systems use a combination of PV and other power sources. Usually, hybrid systems use a wind generator with a diesel, propane or gasoline generator as backup. Hybrid systems may be suited for applications such as residences and commercial buildings that are not connected to the grid. If you need more than 2.5 kWh of energy per day year-round and already have a generator, or if you live in an area that has poor sunlight for long periods, a hybrid system is probably a good choice.

Hybrid systems generally include battery storage; the load draws power from the batteries. When there is enough sunshine, the PV array keeps the batteries charged. If a wind generator is incorporated, it charges the batteries during windy periods, which are often when it is overcast or at night. For this reason, wind and solar equipment are a perfect complement to one another. The diesel or gasoline generator is needed only once in a while to charge the batteries during extended overcast and calm periods. The generator operates at nearly full capacity, and this results in a better generator duty cycle, more efficient fuel use, lower maintenance costs and longer generator life. Applications that involve both solar and wind equipment often do not need a gas or diesel generator.

2.2 Estimate the Available Sunlight

Knowing the solar resources available is key to the design of an efficient and affordable PV system. The maps on page 27 show the average daily values of peak sunlight hours that strike south-facing, fixed PV arrays in various parts of Canada in September and December. These values assume that the arrays are tilted at right angles to the sun at noon. Alternatively, you can get weather and solar radiation values for selected sites from Environment Canada's Meteorological Service of Canada or from RETScreen® International software (see "Learn More About Solar Energy" on page 46). Choose a value for your location from either the September or December map, and insert this value under Step 2 of the worksheet in Appendix A.

In the summer, September has the fewest hours of peak sunlight. Overall, December has the fewest hours of peak sunlight. To estimate the available sunlight design value for a seasonal (summer) autonomous system, use the values from the September map. To estimate the available sunlight design value for a year-round autonomous system, use the values from the December map.

For a PV-diesel hybrid system, you may choose December values or average the two values (September and December). This is described in the case study on pages 33 and 34.

S *Parks Canada's remote camp located in the far north on Ellesmere Island, Nunavut, is powered by a PV array (on a tracker) combined with a wind generator and a gasoline generator.*

Technical Note: Definition of Units Used to Describe a PV System and Some Orders of Magnitude

Full (peak) sunlight:	1000 W/m^2 of energy density (about the intensity of the sun at noon on a bright sunny day)
1 hour of peak sunlight:	1000 Wh/m^2, the equivalent of 1000 W/m^2 during one hour (e.g. 2 h at 500 W/m^2 or 1 h at 600 W/m^2 and 2 h at 200 W/m^2)
100-W PV module:	Power capacity of a PV module able to produce 100 W of electricity when maintained at 25°C and exposed to full peak sunlight (1000 W/m^2)

100 W (PV) exposed to 1 h of peak sunlight = 100 Wh of electricity

Rule of thumb:	Typical annual radiation in Canada is 1500 h of peak sunlight (range of 1100–1700 h). 100 W installed = potential of 150 kWh/a.

Due to system losses and other causes of inefficiency, the energy production of PV systems is often estimated as follows:

100 W installed ≈ 100 kWh/a

2.3 Estimate the Required PV Array Size

The next step is to size the PV array. This takes into account power losses in battery charging (Eff_{bat} of 75 to 90 percent) and regulator efficiency (Eff_{reg} of 80 to 90 percent), especially if the controller does not include a maximum power point tracker (MPPT) (see the glossary on page 44). Typically, an MPPT is used only for medium to large systems when benefits related to energy gains are greater than the cost of this feature. Additional losses due to dust or snow accumulation on modules are likely, but they are relatively low.

After you determine the array size (in watts), estimate the number of modules required. To do this, divide the array size by the power rating of the module you intend to use in your installation (normally 20 W to 100 W).

Power, Voltage and Current Ratings of Typical PV Modules

Module	Rated Power (W)	Nominal Voltage (V)	Nominal Current (A)
Kyocera KC 120	120	16.9	7.1
Siemens SM100	100	17.0/34.0	5.9/2.95
Solarex SX-85	85	17.1	4.97
BP Solar BP-275	75	17	4.45
CANROM-65	65	16.5	4.2
Photowatt PWX500	50	17	2.8
UNI-SOLAR® US-21	21	21	1.27

Note: The above modules are examples of those available on the market. Each manufacturer provides a complete line of modules that have different sizes and power ratings. This list is not an endorsement of these products.

2.4 Estimate Battery Capacity for Autonomous Systems

The size of battery you need depends on whether you require uninterrupted power and how much you are prepared to pay for that privilege. For a weekend cabin or cottage, you may not really mind if the power fails occasionally during an extended overcast period. On the other hand, uninterrupted power may be a necessity for some applications.

For most applications, a good rule of thumb is to provide enough battery storage to supply power during three to five overcast days. (Battery capacity for hybrid systems is usually enough for only one or two days). A battery should not be completely discharged, so as not to shorten its life. Thus the available capacity of a battery is less than the nameplate rating. A "maximum depth of discharge" factor is already included in the equation in the worksheet (see Step 2 in Appendix A on page 41). It ensures that the battery charge never drops below 50 percent of full charge. This value depends on the type of battery you select. Consult your dealer.

Use the blank worksheet to help size your stand-alone PV system. Now that you have estimated the size of the PV array and the amount of battery storage you require, you are in a position to approach a dealer. Discuss costs and make decisions on what is best for your particular situation.

Technical Note: Battery Capacity Rating

Watts may be expressed in Wh (volts x amps). Likewise, energy may be expressed in Ah (amperes x hours) at a given voltage. This is often used in the battery industry to express battery capacity. For example, a battery with 960 Wh of capacity is generally referred to as a 12-V, 80-Ah battery (12V x 80 Ah = 960 Wh).

$$\mathbf{Wh = V \times Ah}$$

7. Sizing Worksheet Examples

In the following examples, two hypothetical case studies show how the worksheets can be used. The Smiths, for example, are interested in PV power for a remote vacation cabin. The Wongs, meanwhile, want a system that will provide reliable power year-round for their home and business. Both families are interested in renewable energy and want to know if a PV system would be appropriate for them.

Example 1. Summer Cabin Power System – The Smiths

The Smiths own a small vacation cabin where they spend most summer weekends and holidays, as well as the occasional weekend in the winter. The cabin has no electricity or running water and is far from the grid. After several years of filling oil lamps and hauling water, the Smiths would like to enjoy the benefits of electricity. However, the cabin is their escape from the noise and pollution of the city, and they would prefer a quiet, non-polluting power source. They are particularly interested in a PV system because it is durable and requires low maintenance.

The Smiths' main priority is to keep costs at a minimum, and they are willing to sacrifice power availability to do this. After all, they do not have power now, and the thought of the odd blackout does not bother them. They have a propane-powered refrigerator, and they are willing to switch to fluorescent lighting and make do with a minimum of appliances to keep their power needs low. For their needs, a system that is small, solar-only and is stand-alone appears to be a good solution.

Working through the worksheet, the Smiths find that roughly a 120-W (watt) system and about 211 Ah (ampere-hours) of batteries could meet their needs at a price they can afford.

Worksheet: The Smiths (Summer Cabin)

Step 1. Estimate Your Power and Energy Needs (watt-hours per day)

Appliance Load	AC or DC (check one) AC	AC or DC (check one) DC	(A) Rated Wattage (actual or typical values)	(B) Hours Used Per Day	(C) Watt-Hours Per Day (A) x (B) AC	(C) Watt-Hours Per Day (A) x (B) DC
Kitchen lights (2)		3 (12 V)	15	1 h (x 2) = 2		30
Bedroom lights (2)		3 (12 V)	15	1 h (x 2) = 2		30
Living-room lights (2)		3 (12 V)	15	4 h (x 2) = 8		120
Water pump		3 (12 V)	90	1 h		90
Stereo		3 (12 V)	6	4 h		24
TV (black and white)		3 (12 V)	20	3 h		60

Subtotal: AC: N/A Wh/d DC: 354 Wh/d

DC to AC inverter efficiency ($\text{Eff}_{dc\ ac}$) ranges from 80 to 95 percent (0.80 to 0.95). To help you with your first calculation, 0.90 has been inserted in italics. Adjust the efficiency figure, if necessary, once you have chosen the inverter for your system and have read the manufacturer's ratings.

The Smiths do not need an inverter because all their loads are 12 VDC (volt direct current). They can add one at any time.

Adjust AC loads for inverter losses: $\frac{\text{AC load}}{\text{Eff}_{dc\ ac}} = \frac{0}{\mathit{0.90}}$ Wh/d: 0

Total daily load: DC loads + adjusted AC loads = 354 Wh/d

Worksheet: The Smiths (Summer Cabin)

Step 2. Make a Rough Evaluation of PV-System Size

2.1. Evaluate Which Stand-Alone System Is More Suitable: Autonomous or Hybrid

This summer cottage will be equipped with an autonomous PV system.

☑ Autonomous

- seasonal use (summer mainly)
- year-round operation with
  low energy requirements (< 1 kWh/d)
  or
  low requirements for power availability
- limited/expensive access to the site
- maintenance is an issue

☐ Hybrid

- year-round operation and
  energy requirements > 2.5 kWh/d
  or
  higher latitudes
- already have a generator
- very high requirements for power availability

2.2. Estimate the Available Sunlight

Sunlight: 3.9 h/d (Consult maps on page 27 or see "Learn More About Solar Energy" on page 46.)

2.3. Estimate the Required PV Array Size (W)

$$\text{Array size (W)} = \frac{\text{Total daily load (Wh/d)}}{\text{Peak sunlight hours} \times 0.77^{*}}$$

$$= \frac{354 \text{ Wh/d}}{3.9 \text{ h/d} \times 0.77}$$

$$= 118 \text{ W}^{**}$$

** The factor 0.77 assumes a 90-percent battery charge regulator efficiency and an 85-percent battery efficiency.*

*** Based on rated power output of PV modules if an MPPT controller is used (see the glossary on page 44). If an MPPT controller is not used, further losses should be accounted for, resulting in an increased power capacity of 15–25 percent. Consult your dealer.*

2.4. Estimate the Required Battery Capacity (ampere-hours)

Nominal voltage of battery: (typically 12, 24 or 48 volts) — (V_{bat}): 12 VDC

Number of days of battery storage needed (a good rule of thumb is three days for an autonomous system): 3 d

Battery capacity (Ah):

$$\frac{\text{Total daily load (Wh/d)} \times \text{days of storage}}{\text{Battery voltage } (V_{bat}) \times 0.42^{***}}$$

$$= \frac{354 \text{ Wh/d} \times 3 \text{ d}}{12 \text{ V} \times 0.42}$$

$$= 211 \text{ Ah at } 12 \text{ V}$$

**** The factor 0.42 assumes an 85-percent battery efficiency and a 50-percent maximum depth of discharge. If the battery is used at temperatures lower than 25°C, its capacity (ampere-hours) will decrease. Consult your PV system supplier.*

Example 2. Year-Round Remote Residential Power System – The Wongs

The Wongs are a young couple who have been living beside a small lake for several years, away from the electric grid. They run a small handicrafts business, manufacturing woven goods. The Wongs use a propane generator to provide power for their home and studio. But they have grown tired of constant noise and pollution, increasingly high fuel bills and frequent maintenance requirements. Their electrical consumption is low despite many loads because the fridge and stove run on propane. (Running large loads on propane greatly reduces the up-front cost of a PV system.)

After filling out the worksheet, the Wongs find that meeting their needs with an autonomous system would be too expensive. They figure that they can currently afford only a small fraction of the PV panels required, but they may be able to add more panels in a few years. In the meantime, they decide to combine their existing propane generator with PV panels to make a hybrid PV system that offers the potential to reduce the aggravation and costs linked with using a generator. Based on their current resources, this appears to be their best option. Knowing this, they are now in a better position to talk to a PV dealer about the type of system they want.

Worksheet: The Wongs (Year-Round Residence)

Step 1. Estimate Your Power and Energy Needs (watt-hours per day)

Appliance Load	AC or DC (check one) AC	AC or DC (check one) DC	(A) Rated Wattage (actual or typical values)	(B) Hours Used Per Day	(C) Watt-Hours Per Day (A) x (B) AC	(C) Watt-Hours Per Day (A) x (B) DC
Fluorescent:						
Kitchen lights (2)	3		15	3h x 2 lights	90	
Living-room lights (2)	3		15	5 (x 2)	150	
Bedroom lights (2)	3		11	2 (x 2)	44	
Basement, bathroom and hall lights (4)	3		15	1 (x 4)	60	
Freezer (very efficient)	3				600	
Water pump		3 (12 V)	90	2		180
Outdoor lights (2)	3		15	8 (x 2)	240	
Clothes washer (front load)	3		160	1 (1 load)	160	
Furnace fan	3		250	4	1000	
Workshop lights (4)	3		15	7 (x 4)	420	
Radio (in workshop)	3		5	7	35	
Colour TV (no remote control)		3 (12 V)	60	3		180
Vacuum cleaner	3		800	0.25	200	
Intermittent loads (e.g. coffee-maker, iron, small power tools, block heater, etc.)	3		1000 (estimate)	1	1000	

Subtotal: AC: 3999 Wh/d DC: 360 Wh/d

DC to AC inverter efficiency ($Eff_{dc\ ac}$) ranges from 80 to 95 percent (0.80 to 0.95). To help you with your first calculation, 0.90 has been inserted in italics. Adjust the efficiency figure, if necessary, once you have chosen the inverter for your system and have read the manufacturer's ratings.

Adjust AC loads for inverter losses: $\frac{\text{AC load}}{Eff_{dc\ ac}} = \frac{3999}{\mathit{0.90}}$ Wh/d: 4443

Total daily load: DC loads + adjusted AC loads = 4803 Wh/d

Worksheet: The Wongs (Year-Round Residence)

Step 2. Make a Rough Evaluation of PV-System Size

2.1. Evaluate Which Stand-Alone System Is More Suitable: Autonomous or Hybrid

This summer cottage will be equipped with a hybrid PV system.

☐ Autonomous

- seasonal use (summer mainly)
- year-round operation with low energy requirements (< 1 kWh/d) or low requirements for power availability
- limited/expensive access to the site
- maintenance is an issue

☑ Hybrid

- year-round operation and energy requirements > 2.5 kWh/d or higher latitudes
- already have a generator
- very high requirements for power availability

2.2. Estimate the Available Sunlight

Sunlight: 3.4 h/d (consult the maps on page 27 or see "Learn More About Solar Energy" on page 46.)

2.3. Estimate the Required PV Array Size (W)

$$\text{Array size (W)} = \frac{\text{Total daily load (Wh/d)}}{\text{Peak sunlight hours} \times 0.77^{*}}$$

$$= \frac{4803 \text{ Wh/d}}{3.4 \text{ h/d} \times 0.77}$$

$$= 1835 \text{ W}^{**}$$

** The factor 0.77 assumes a 90-percent battery charge regulator efficiency and an 85-percent battery efficiency.*

*** Based on rated power output of PV modules if an MPPT controller is used (see the glossary on page 44). If an MPPT controller is not used, further losses should be accounted for, resulting in a required power capacity increase of 15–25 percent. Consult your dealer.*

2.4. Estimate the Required Battery Capacity (ampere-hours)

Nominal voltage of battery: (V_{bat}): 24 VDC
(typically 12, 24 or 48 volts)

Number of days of battery storage needed (a good rule of thumb is two days for a hybrid system): 2 d

Battery capacity (Ah):

$$\frac{\text{Total daily load (Wh/d)} \times \text{days of storage}}{\text{Battery voltage } (V_{bat}) \times 0.42^{***}}$$

$$= \frac{4803 \text{ Wh/d} \times 2 \text{ d}}{24 \text{ V} \times 0.42}$$

$$= 953 \text{ Ah at } 24 \text{ V}$$

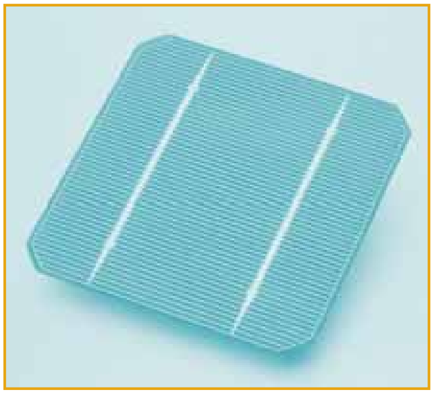
**** The factor 0.42 assumes an 85-percent battery efficiency and a 50-percent maximum depth of discharge. If the battery is used at temperatures lower than 25°C, its capacity (ampere-hours) will decrease. Consult your PV system supplier.*

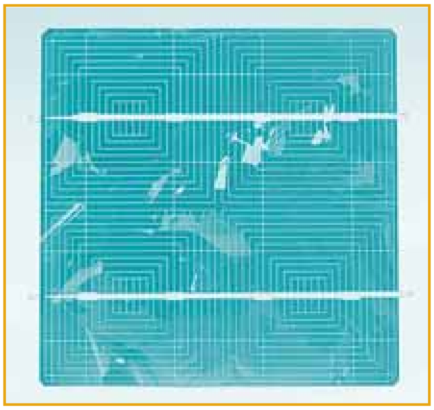
PV Technology

The most common photovoltaic (PV) cell material is silicon. It is one of the most abundant elements on earth: sand from the beach is an oxide of **silicon**. The first commercial PV cells were **monocrystalline silicon**. Other manufacturing techniques resulted in **polycrystalline silicon** cells. A monocrystalline cell is made of a single crystal; a polycrystalline cell contains many crystals. Commercial polycrystalline cells are only slightly less efficient than monocrystalline cells and are, therefore, widely used because their cost-performance ratio is similar.

The development of **thin-film technologies** reduces costs further by decreasing the amount of material needed to make a cell. **Amorphous silicon** modules require only a thin layer of silicon and can be mass produced. New production techniques led to the manufacture of "multi-junction" amorphous cells, which contain two or three layers of semiconductor. Because of the lower efficiency, modules that are physically larger are needed in order to generate a given amount of power.

Other thin-film technologies have been developed – such as **cadmium telluride** and **copper indium diselenide** – and are beginning to appear on the market.



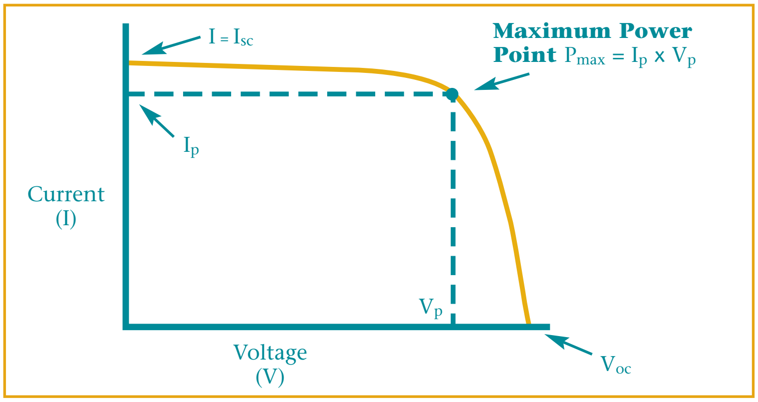


S *Monocrystalline, polycrystalline and flexible amorphous silicon cells. Photos courtesy of Siemens Solar Industries, Photowatt International S.A. and United Solar Systems Corp., respectively.*

The Electric Characteristics of PV Modules: The Current-Voltage (I-V) Curve

The PV module can be operated at any combination of current and voltage found on its "I-V curve." But in reality it operates at only one combination at a given time. This favoured combination is chosen not by the modules, but rather by the electric characteristics of the circuit that is connected to the modules.

The voltage that occurs when current is zero is known as the **open-circuit voltage (V_{oc})**. On the other hand, the current when the voltage is zero is referred to as the **short-circuit current (I_{sc})**. While current and voltage are at their highest under short-circuit and open-circuit conditions, respectively, the power at these points is zero. In practice, a system operates at a combination of current and voltage at which a reasonable amount of power is produced. The best point is the **maximum power point (MPP)**. Corresponding voltage and current are called **V_p** (nominal voltage) and **I_p** (nominal current), respectively. This point of operation (MPP) is used to define the nominal rating and efficiency of a module.



Important points that characterize a PV module.

Model	ABC	**Serial number**	123456789		

Manufacturer XYZ

Made in WZC

Performance at 1999 W/m² solar irradiance and 25°C cell temperature

Max. power	**Short circuit current**	**Rated current**
48 Wp	3.35 A	3.02 A
Max. syst. open circuit voltage	**Open circuit voltage**	**Rated voltage**
600 V	19.8 V	15.9 V
Fire rating	**Series fuse**	**Field wiring**
Class C	5 A	copper only, 14 A WG min. insulated for 75°C min.

Typical information found on a PV module label.

You should find all of these electric characteristics (**V_{oc}, I_{sc}, MPP, V_p, I_p**) on the label of a good-quality PV module (note that the V_p and I_p values are also called nominal or rated voltage and current). Do not expect to get the rated power from your installed system – it is impossible for a fixed system to operate at the highest power point at all times. Temperature variations alone will change the amount of power your system generates.

Other Components in PV Systems

Batteries

Most off-grid PV systems use batteries to store power for use during periods of low or no sunlight. Certain specialized applications (e.g. some pumping and ventilation systems and calculators) do not require storage because power is needed only during periods of light. Some pumping applications use pumped water as the storage medium rather than electricity. However, most PV systems in Canada use batteries.

Your choice of battery size and type is an important design consideration, particularly for systems that have no backup power source. The batteries alone can represent 25 to 50 percent of total system cost, so it is essential to select the right type. You can use different types of rechargeable batteries, depending on the system's requirements. Batteries with a long expected life have higher initial costs but should cost less in the long run. Several batteries on the market are designed for use with renewable energy systems, such as PV and wind systems. Deep-discharge marine, golf cart or recreational vehicle (RV) batteries may also be suitable and are generally more affordable up front. An experienced PV dealer can advise on what type of battery is best for your needs.

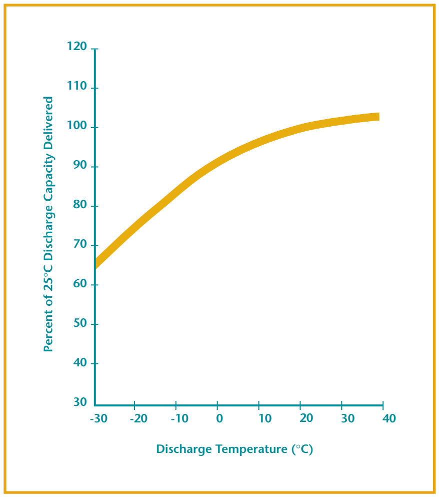
Most PV systems use lead-acid batteries such as deep-discharge lead-calcium or lead-antimony batteries. Do not use car batteries as they are not designed for repeated deep discharges. Nickel-cadmium (Ni-Cd) batteries are rarely used in residential applications. Although they can be deeply discharged many times without harm and are less affected by temperature changes than lead-acid batteries, Ni-Cd batteries are more expensive and very expensive to recycle. As a result, their use is primarily restricted to applications where their increased reliability and low maintenance are worth the premium price.

Battery storage capacity is generally rated in ampere-hours (Ah). This is the amount of current that a battery will deliver over a given number of hours at its normal voltage and at a temperature of 25°C. The rated capacity of any battery drops with temperature. The size of battery you require is determined by the total anticipated drain on the battery. You can calculate this if you know the following information: the voltage of the battery, the wattage of the load, the length of time the load is operated and the ambient temperature of the batteries.

For example, to run a 25-W bulb for eight hours from a 12-V battery that is maintained at 25°C, you would need a battery with a capacity of at least 16.7 Ah (200 Wh at 12 V). If the battery must operate at temperatures as low as

Technical Note: Selecting Batteries for PV Systems – Points to Consider

- voltage and current characteristics;
- storage capacity is quoted at a certain discharge rate. If the discharge rate (the rate at which power is being drawn out) is less than what the manufacturer quotes, the battery's capacity is greater. The opposite is also true;
- maximum depth of discharge (different for each type of battery);
- operating temperature range and how temperature affects performance;
- battery lifetime: the number of times the battery can be charged and discharged before it has to be replaced. This number depends on the depth of discharge of cycle. The less discharged the battery is at each cycle, the more cycles it can sustain;
- maintenance requirements: some batteries are almost maintenance-free;
- energy density: the amount of usable energy a battery can produce over a given time relative to its weight and volume;
- cost; and
- warranty.



S *Operating batteries at temperatures below 25°C implies that you will need more nominal capacity. (This will vary, according to the type of batteries and rate of discharge applied.)*

0°C, then at least a 20-Ah battery would be required for the same load. But in practice, to protect the battery against accelerated aging, a larger capacity is used to avoid a complete discharge. For deep discharge batteries, do not use more than 80 percent of their nominal capacity. Also, car batteries start to be damaged if discharged more than 20 percent of their nominal capacity; therefore, they are not well suited for this type of application.

In the sizing worksheet examples in Section 7 (Step 2.4), an average value of 50 percent was chosen for the depths of discharge (the portion of battery nominal capacity used) so that the recommended sizes for the examples above would be 40 to 50 Ah, depending on the temperature at which the battery is operated.

PV battery systems are usually designed to provide several days of storage in the absence of sunlight. In cases where longer overcast periods are anticipated, such as in the Far North, it is usually wiser to use a hybrid system rather than trying to provide enough battery storage. In this and many other cases, your most practical approach may be to use a combination of backup power and batteries.

Power-Conditioning Equipment

Power-conditioning equipment modifies the power from the PV array to make it more usable. Two power-conditioning devices – inverters and battery charge regulators – are described in the following.

Inverters

PV cells generate direct current (DC), and batteries store electricity as DC, but most common appliances require alternating current (AC). In cases where you need AC power, an inverter is used to change low-voltage DC (12, 24, 32, 36, 48, 96, 120) to higher voltage AC (120 or 240). Some power is lost in the conversion as inverters are, on average, about 80- to 95-percent efficient. AC wiring, components and appliances are more available and generally less expensive than similar DC products. Consequently, inverters are convenient for many systems.

Inverters cover a wide range of power capacity, and the type needed depends on the application. Light-duty inverters (100–1000 W) are suitable for small systems (e.g. power for lights). They are available with 12- or 24-volt direct current (VDC) input voltages and 120-volt alternating current (VAC) output. Larger inverters (1000–4000 W) are available, mainly with 12, 24 and 48 VDC input and 120 or 240 VAC output. For high-start power surges (e.g. from large electric motors), heavy-duty inverters are needed.

Low-cost inverters produce a modified square wave, which is not as good as utility power. Roughly a dozen electrical loads do not run well on this type of inverter. Your dealer can help you overcome most of these load problems by choosing proper appliances, tools, etc. Sine-wave inverters generally produce power that is similar to the quality of utility power.

Some PV modules even come with built-in inverters. Such modules are called AC modules. You can build up a complete AC system, AC module by AC module, increasing the capacity with each addition. (These inverters are used only for grid-connected systems.)

Many of today's inverters also come equipped with the following features:

1) **Metering:** a display to provide volts input/output, frequency output, voltage and frequency of a fuel-fired generator.
2) **Fuel-fired generator start capability:** Extra relays are provided to auto-start a generator if the batteries reach a programmed state of low

capacity. Some can even be programmed to keep the generator from starting during the night (to avoid the noise), unless the batteries reach a second programmed low, in which case the generator will start regardless.

3) **Grid-connected capability:** The inverter can convert the DC output from the array to AC power that can be synchronized with the grid (utility). This feature makes it possible to reduce or even eliminate monthly utility bills.

4) **Charging capability:** Inverters can draw power from either the grid or a fuel-fired generator to charge the battery bank while, at the same time, continuing to pass that power through to the electrical loads in your house. Some inverters vary the charge rate and voltage to certain types of batteries and their current temperature.

5) **Stacking:** Some inverters can be linked together, either to produce twice the output or to produce power that is out of phase from inverter to inverter in order to produce 240-VAC power.

Battery Charge Regulators

Battery charge regulators control the amount of current entering the battery and protect it from overcharging and from completely discharging. They can also measure battery voltage to detect the state of charge. Regulators range from 2 to 300 A for voltages from 12 to 48 volts DC.

Different types of controllers exist: the on-off and the pulse-width modulation controls are the most common types. More sophisticated controllers are more efficient, but you and your dealer should evaluate whether their performance justifies the investment. For example, some controllers include a maximum power point tracker (MPPT) feature. It allows a PV module or array to work at its highest power point depending on solar intensity, even if the battery is recharged at a constant voltage. This feature provides about 10 percent more power in the summer and roughly 30 percent more in the winter. These gains are generally higher for panels with high voltage peak (Vp) values.

PV Trackers

The sun "tracks" across the sky every day. To get maximum output from your PV array, a tracker can be a cost-effective feature. The main issue is economics. Does the increased output from a reduced number of tracked panels outweigh the cost of the extra panels bought for a fixed array? Generally speaking, the larger the array, the more cost-effective the tracker. Remember, a fixed array must be mounted on a structure, so the true cost of a tracker is the difference between its cost and the cost of a fixed array mounting structure.

Trackers are usually mounted 3 m (10 ft.) off the ground, avoiding the need to drill through a roof. Less snow and ice accumulates out in the open and off the ground, compared with a roof. Ask your dealer to explain the pros and cons of manual and automatic trackers that are currently on the market.

When considering the use of a tracker, remember that it will not significantly increase the performance of the PV system during the winter in Canada. The use of a tracker is more cost-effective for applications operating from the spring to the fall, especially those located at higher-latitude sites.

Because automatic trackers make the system more complex, they are rarely used for applications where no one is present for extended periods of time, such as telecommunications.

Appendix A: Worksheet to Evaluate System Size

This worksheet will help you get a rough estimate of the size of your PV system. For this level of design, you need only choose a nominal battery voltage and collect the information on the available hours of peak sunlight in your area. The results that you will obtain below are only estimates and do not replace the technical design and expertise required for a proper system. If you wish to undertake such a technical design, consider ordering *Photovoltaic Systems Design Manual* from Natural Resources Canada (for contact information, see "Learn More About Solar Energy" on page 46).

Note: Figures in the equations below must be expressed as fractions, not percentages. For example, an efficiency of 90 percent should be written as 0.90 in your calculations.

Worksheet

Step 1. Estimate Your Power and Energy Needs (watt-hours per day)

Appliance Load	AC or DC (check one)		(A) Rated Wattage (actual or typical values)	(B) Hours Used Per Day	(C) Watt-Hours Per Day (A) x (B)	
	AC	DC			AC	DC

Subtotal: AC: _______ Wh/d DC: _______ Wh/d

DC to AC inverter efficiency ($Eff_{dc\ ac}$) ranges from 80 to 95 percent (0.80 to 0.95). To help you with your first calculation, 0.90 has been inserted in italics. Adjust the efficiency value, if necessary, once you have chosen the inverter for your system and have read the manufacturer's ratings.

Adjust AC loads for inverter losses: $\frac{\text{AC load}}{Eff_{dc\ ac}} = \frac{\_\_\_\_\_\_\_}{\mathit{0.90}}$ Wh/d: _______

Total daily load: DC loads + adjusted AC loads = ________ Wh/d

Worksheet

Step 2. Make a Rough Evaluation of PV System Size

2.1. Evaluate Which Stand-Alone System Is More Suitable: Autonomous or Hybrid

☐ Autonomous

- seasonal use (summer mainly)
- year-round operation with low energy requirements (< 1 kWh/d) or low requirements for power availability
- limited/expensive access to the site
- maintenance is an issue

☐ Hybrid

- year-round operation and energy requirements > 2.5 kWh/d or higher latitudes
- already have a generator
- very high requirements for power availability

2.2. Estimate the Available Sunlight

Sunlight: ______ h/d (consult the maps on page 27 or see "Learn More About Solar Energy" on page 46.)

2.3. Estimate the Required PV Array Size (W)

$$\text{Array size (W)} = \frac{\text{Total daily load (Wh/d)}}{\text{Peak sunlight hours} \times 0.77^{*}}$$

$$= \frac{\_\_\_\_\_\_\_\_\_\_\_\_\ \text{Wh/d}}{\_\_\_\_\_\_\_\_\_\_\_\_\ \text{h/d} \times 0.77}$$

$$= \_\_\_\_\_\_\_\_\_\_\_\_\ \text{W}^{**}$$

* *The factor 0.77 assumes a 90-percent battery charge regulator efficiency and an 85-percent battery efficiency.*

** *Based on rated power output of PV modules if an MPPT controller is used (see the glossary on page 44). If an MPPT controller is not used, further losses should be accounted for, resulting in a required power capacity increase of 15–25 percent. Consult your dealer.*

2.4. Estimate the Required Battery Capacity (ampere-hours)

Nominal voltage of battery: (V_{bat}): ____ VDC
(typically 12, 24 or 48 volts)

Number of days of battery storage needed (a good rule of thumb is two days for a hybrid system and three days for an autonomous system): _____ days

Battery capacity (Ah):

$$\frac{\text{Total daily load (Wh/d)} \times \text{days of storage}}{\text{Battery voltage } (V_{bat}) \times 0.42^{***}}$$

$$= \frac{\_\_\_\_\_\ \text{Wh/d} \times \_\_\_\_\ \text{days}}{\_\_\_\_\ \text{V} \times 0.42}$$

$$= \_\_\_\_\_\_\_\ \text{Ah}$$

*** *The factor 0.42 assumes an 85-percent battery efficiency and a 50-percent maximum depth of discharge. If the battery is used at temperatures lower than 25°C, its capacity (ampere-hours) will decrease. Consult your PV system supplier.*

Appendix B: Typical Loads

Typical Power Ratings of Some Common Appliances

	Power Rating (watt)
12-V DC loads	
Auto stereo	6
CB radio:	
Receive	4
Transmit	6
Digital clock (LED)	2
Coffee-maker	140
Drill ($^3/_8$ inch)	144
Lighting:	
Incandescent	25
Compact fluorescent	4–20
Four-foot type (double-ended)	40
Portable TV:	
Black and white	20
Colour	60
Vent fan (15-cm blade)	24
Water pump	50–300
Hair dryer	400

	Power Rating (watt)
120-V AC loads	
Block heater	600
Clock	2
Clothes washer, excluding hot water	300–500
Front-loading washer	160
Coffee-maker	900
Dishwasher, excluding hot water	1300
Drill ($^3/_8$ inch)	300
Fan, portable	115
Furnace fan motor (varies greatly)	350
Hair dryer	1000–1500
Curling iron	25
Iron	1000
Lighting:	
Incandescent	25–100
Compact fluorescent	4–20
Four-foot type (double-ended)	40
Microwave oven	600–1500
Personal computer:	
Desk model	250
Laser printer (while printing/standby)	600/30
Laptop in use	25
Laptop charger	100 (max.)
Radio	5
Saw	400–1000
Radio-telephone (transmitting/idle)	96/12
Single-side band radio (idle)	4
Stereo	30
TV (19 inches):	
Black and white (in use)	60
Colour (in use/standby with remote control)	100/5
Remote control (standby)	5
Toaster	1100
Vacuum cleaner	200–1400
VCR (on/standby)	30/5
Water pump ($^1/_2$-hp jet)	1000

Note: These are typical values only. For exact numbers, consult product literature or supplier.

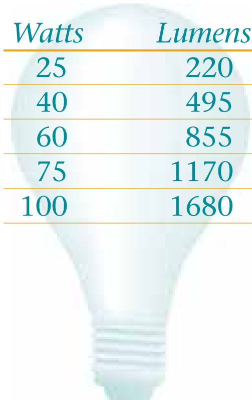
About Electric Motors

Power is often expressed in horsepower (hp) for motors. This refers to the mechanical power output of the motor. If you have information on current and voltage, always use this information rather than converting hp into watts. A watt (W) is the SI unit for power (1 hp ≈ 746 W). However, this may differ from the actual electric power requirements, due to the power factor of a motor in AC or other sources of inefficiency found in any motor. If you intend to power a standard AC motor with a PV system, you can use the following formula to estimate your electric power requirement: 1 hp (mechanical output) ≈ 1 kW (electrical input).

Appendix C: Energy-Efficient Lighting

Comparison of Typical Lighting Systems

Incandescent Bulbs



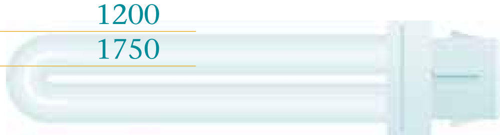
Watts	Lumens
25	220
40	495
60	855
75	1170
100	1680

Compact Fluorescent Lights (CFLs) with Magnetic Ballast

Watts	Lumens
5	220
7	400
9	550
13	860
18	1160
26	1700

CFLs with Electronic Ballast

Watts	Lumens
15	900
18	1100
20	1200
25	1750



S *Source:* Energy-Efficient Lighting Products for Your Home *(Natural Resources Canada's pulication)*

Glossary

Ampere-hour (Ah)
A current of one ampere running for one hour.

Autonomous system
A stand-alone photovoltaic (PV) system that has no backup generating source and relies only on solar energy to meet the needs of the load. May or may not include storage batteries.

Balance of system
The parts of a PV system other than the PV array and batteries. This may include switches, controls, meters, power-conditioning equipment, trackers and a supporting structure for the PV array.

Easement
An oral or written legal agreement defining an interest in exclusive, common or bipartisan use of private property or air/space above that property. A common form of easement is the concept of "right of way," as when an electric utility has the right of way to extend electrical transmission lines across private property. See also "Restrictive covenant."

Horsepower (hp)
An imperial system unit of power equivalent to 746 W.

Hybrid PV system
A PV system that includes other sources of electricity generation, such as a wind or diesel generator.

Kilowatt (kW)
One thousand watts.

Kilowatt-hour (kWh)
One kilowatt acting over one hour.

Load
Anything in an electrical circuit which, when the circuit is turned on, draws power from that circuit (lights, appliances, tools, pumps, etc.).

Lumen
A metric measurement of the rate at which light is emitted from a source.

Maximum power point tracker (MPPT)
Charge controller that continuously tracks the maximum power point (MPP) of a PV module or array, thus increasing its efficiency. The MPP is the point on a current-voltage (I-V) curve where a PV device produces maximum power.

Open-circuit voltage
The voltage across a PV cell in full sunlight when there is no current flowing; the highest possible voltage.

Parallel connection
A method of interconnecting two or more devices that generate or use electricity, such that the voltage produced, or required, is not increased, but the current is the sum of the two. Opposite of "series connection" (see entry).

Photovoltaic (PV) array
An interconnected system of PV modules that function as a single electricity-producing unit. The modules are assembled as a discrete structure with a common support or mounting. In smaller systems, an array can consist of two modules plus a support structure or mounting.

Photovoltaic (PV) cell
A device that converts light directly into electricity. The building block of a PV module.

Photovoltaic (PV) module
A number of PV cells electrically interconnected (in either series or parallel) and mounted together, usually in a sealed unit of convenient size to make shipping, handling and assembly into arrays easier.

Photovoltaic (PV) system
A complete set of components for converting sunlight into electricity by the PV process, including the array and balance of system components.

Power-conditioning equipment
Electrical equipment used to convert power from a PV array into a form suitable for subsequent use. A collective term for inverter, converter, battery charge regulator and blocking diode.

Restrictive covenant
A specialized type of easement that can be used to protect access to sunlight or wind flow for solar or wind energy applications. See also "Easement."

Series connection
A method of interconnecting devices that generate or use electricity so that the voltage, but not the current, is additive. Opposite of "parallel connection" (see entry).

Short circuit current
The current flowing freely from a PV cell through an external circuit that has no load or resistance; the highest current possible.

Stand-alone (PV system)
A photovoltaic system not connected to a main electric grid. May be solar-only or hybrid. May or may not have storage batteries, but most stand-alone systems require batteries or some other form of storage (e.g. water reservoir for pumping).

Stand-off mounting
Technique for mounting a PV array on a sloped roof that involves mounting the modules a short distance above the pitched roof and tilting them to the best angle.

Telemetry
The remote measurement of any physical quantity using instruments that convert the measurement into a transmittable signal.

Watt-hour (Wh)
A quantity of energy. One watt-hour of electricity is consumed when one watt of power is used for one hour.

Learn More About Solar Energy

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Weather and Solar Radiation Data

Monthly climate data and 1961–1990 normals are available on CD-ROM. To order your copy, visit Environment Canada's Web site at http://www.msc-smc.ec.gc.ca/climate/products_services/climate_products/climate_data_e.cfm.

Some data is available directly on-line at http://www.msc-smc.ec.gc.ca/climate/climate_normals/index_e.cfm.

You can also find some of that data in the RETScreen® International software previously mentioned.

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Thank you for your interest in Natural Resources Canada's (NRCan's) *Photovoltaic Systems: A Buyer's Guide*. In order to improve this guide, we would like to ask you to take a few moments to answer the following questions:

1. Where did you receive your copy of this guide?

Introductory brochure (from NRCan) ☐ Dealer ☐ Retail store ☐
Canadian Solar Industries Association ☐ Trade show ☐ Other ☐

2. Did you find this publication informative? Yes ☐ No ☐

3. How much did you know about solar electric systems before reading this guide?
Everything ☐ A lot ☐ A little ☐ Nothing ☐

4(a). Please rate this guide on the following attributes:

	Excellent	Good	Average	Satisfactory	Poor
Easy to understand	☐	☐	☐	☐	☐
Length	☐	☐	☐	☐	☐
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Completeness	☐	☐	☐	☐	☐
Photographs	☐	☐	☐	☐	☐
Graphics	☐	☐	☐	☐	☐
Format/organization	☐	☐	☐	☐	☐

4(b). Please feel free to add any comments or suggestions.

5. If you were to install a photovoltaic system, it would be for:
☐ A house ☐ A farm ☐ A cottage ☐ Other (specify):

Please provide your name and address (please print).

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Street:

City: Province: Postal code:

Telephone: E-mail:

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Thank you!

Notes

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