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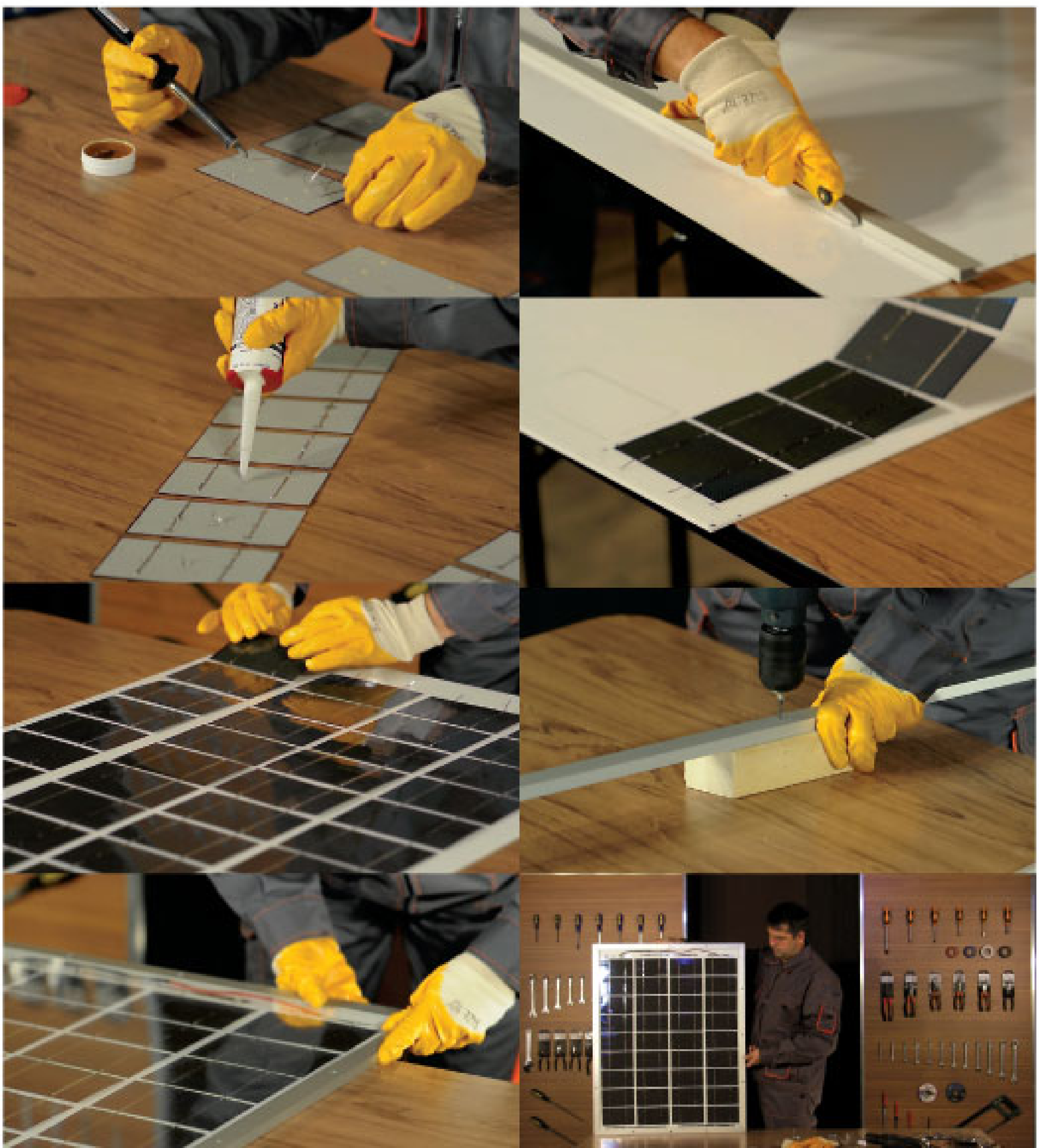

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INTRODUCTION

The Sun is the most prominent feature of our solar system and without it, there would be no life on Earth since sunlight is Earth's primary source of energy. In clear conditions, the amount of power that Sun deposits on the surface of the Earth is about 1,000 W/m2 (watts per square meter). Through the process of photosynthesis, plants capture the energy of the sunlight and convert it into life preserving oxygen.

Over centuries, people have found new ways of harvesting solar energy. In ancient times, we have used it to make fire. Today, with the invention of photovoltaic technology we have the means to make power for our homes by harvesting solar energy.

Photovoltaic research first began in 1873 when Willoughby Smith, a British electrical engineer, first noticed that selenium was sensitive to light. Through research, he came to the conclusion that selenium's ability to conduct electricity was in direct proportion to the degree of its exposure to light. His findings on the photovoltaic effect on selenium has lead to more research in the hope of finding means to use the material to create electricity and the first selenium based solar cell, which was able to produce electricity without generating heat or consuming any substance, was developed in 1880 by Charles Fritts. Nevertheless, it was not until Albert Einstein gave his account of the photoelectric effect that photovoltaics as a power source became widely accepted.

Selenium solar cell paved the way to the next generation of solar cells. The early 1950s brought a breakthrough in photovoltaics. The scientists of Bell Laboratories discovered that silicone created a substantial amount of voltage when exposed to light. In addition to being more efficient, the silicone solar cell was also cheaper to produce than the selenium solar cell because silicone was, and still is, the second most abundant element on Earth and by 1954, the first silicone solar cell was produced.

One of the first uses of photovoltaic technology was employed by NASA when a PV system consisting of 108 cells was installed on Vanguard I – the first satellite launched by the US. Today, more than 1.5 million homes in the US use photovoltaic technology to power or heat their homes and solar power technology has even found its way to laptops and cell phones.

In November 2009, the largest solar power facility in the United States was open in Arcadia, Florida. The DeSoto solar field produces over 25 megawatts of electricity and powers the entire town of Arcadia. In China, plans for the construction of world's largest Solar Plant are being carried out. It is estimated that it will produce enough solar energy to power 3 million homes. But by far the most amazing news from the solar community came on December the 3rd 2009 when the world was able to witness a small miracle in the form of the Solar Impulse prototype plane which left the ground for the first time.

Figure 1 Solar Impulse Plane

Solar Power and You

The photovoltaic market grows with each passing year causing it to be regarded as the future of energy production. This rapid growth has a myriad of ecological and economical benefits.
The continual use of traditional fuel sources has created environmental problems such as global warming, smog, water pollution, and acid rains. Ceaseless pollution has even caused the extinction of many species due to the destruction of their natural habitats. Photovoltaic systems, or PV systems, bring us a step closer to solving and alleviating these problems since they employ not only energy that is renewable but is also sustainable.
When considering the economical aspect of Photovoltaics the first thing that comes to mind is the reduction of our monthly electricity bill. However, the direct and indirect impacts it has on the overall economy of a country are by no means to be neglected. Research, development, production and education in Photovoltaics not only creates new jobs thus reducing unemployment of a country but it also initiates trade and decreases fossil fuel dependence. Indirectly, through the use of solar energy the amount of pollution is reduced hence bringing healthier living and reduction in health care costs.
Still having all this in mind, let us look at the impact that a PV system will have on your household and discuss the benefits and drawback of PV systems.

1.1.a Pros and cons of Photovoltaic Systems

PV systems offer considerable advantages over traditional power sources:

- Independence: Whether you want to power your home or your log cabin in the mountains, a PV system will allow you to be completely independent of the power grid.
- Zero fuel costs: Because solar cells generate electricity directly from the sunlight there are no costs connected to purchasing or transporting fuel.
- Reliability: Even in less optimal weather, PV systems guarantee power provision. Moreover, if you choose to install a system with battery storage you can even use the electricity generated by it during nighttime.
- Low maintenance: Once you create and install a solar panel there is hardly anything left for you to do to ensure its proper functioning except maybe to take off any leaves that might have fallen or give it a quick wipe to get the dust off .
- Durability: Most of panels today come with a 20 to 25 years warranty and even the older types of modules show no degradation after as much as 10 years of use.
- No pollution: As we discussed earlier, PV Systems produce clean reliable energy by directly tapping into the best renewable source available to man – sunlight – and therefore generate no pollution to the environment. However, because PV systems operate silently and with minimal or no movement, they also do not generate any sound pollution. This may be one of the greatest advantages of employing this particular type of renewable energy system. Just imagine having something on your roof or any immediate surroundings that causes constant noise.
- Safety: Since they do not require use of combustible fuels, PV systems are very safe if properly constructed and installed.
- Modularity: You can start your solar panel collection with one panel and add more incrementally. Therefore, once you build and install your PV panels they don't wear out, don't go away and you can add to them.
- Altitude consideration: Contrary to the loss in efficiency that a fossil fuel generator has in high altitudes, PV systems operate with more efficiency because of the increased insolation at higher attitudes.
- Flexibility: Depending on your needs, PV systems can be configured in many different ways.

All these advantages speak in favor of the PV systems; however, there are some disadvantages. Fortunately, these can easily be overcome or lessened with a little bit of ingenuity.

- Initial cost: One of the reasons why more and more people are looking in do it yourself solar panel system is because a commercial 3KW system – a 3000 Watt system – costs about $22,000! Although the rebates and incentives from the local governments, state and county sources will help you reduce those costs, it is expensive to have it done.
- Energy efficiency: To ensure cost-effectiveness, you might need to replace any inefficient appliances.
- Solar radiation variability: Weather greatly affects the power output of a PV system and changes in site conditions may require a change in design.

Having all these pros and cons in mind, I still believe that scales tips in favor of PV systems. Nevertheless, do not let my personal opinion influence you and before you decide to construct, or install a PV system take some time to weigh out the benefits and drawbacks of installing a PV system in your home.

1.2 Photovoltaic System Components

The basis of a PV system is the individual solar cell, which is a square or a disc made of semiconductor material that generates voltage and current when exposed to sunlight. To understand how the solar cell actually works here is a simplified explanation: photons in the sunlight are absorbed by the semiconducting material, such as silicone, causing the negatively charged electrons to become loose from their atoms and flow through the material thus producing electricity. However, due to the special structure of the solar cell, the electrons are able to move in one direction only. Meanwhile, complementary positive charges, the holes (holes should not be confused with positrons that are the antimatter analogue of the electrons) also created flow in the opposite direction of the electrons. The electronic behavior of a solar cell can be graphically portrayed with a circuit model electrically equivalent and based on distinct electrical components whose behavior is well known. Because no solar cell is ideal, a shunt resistance and a series resistance component are added to the model.

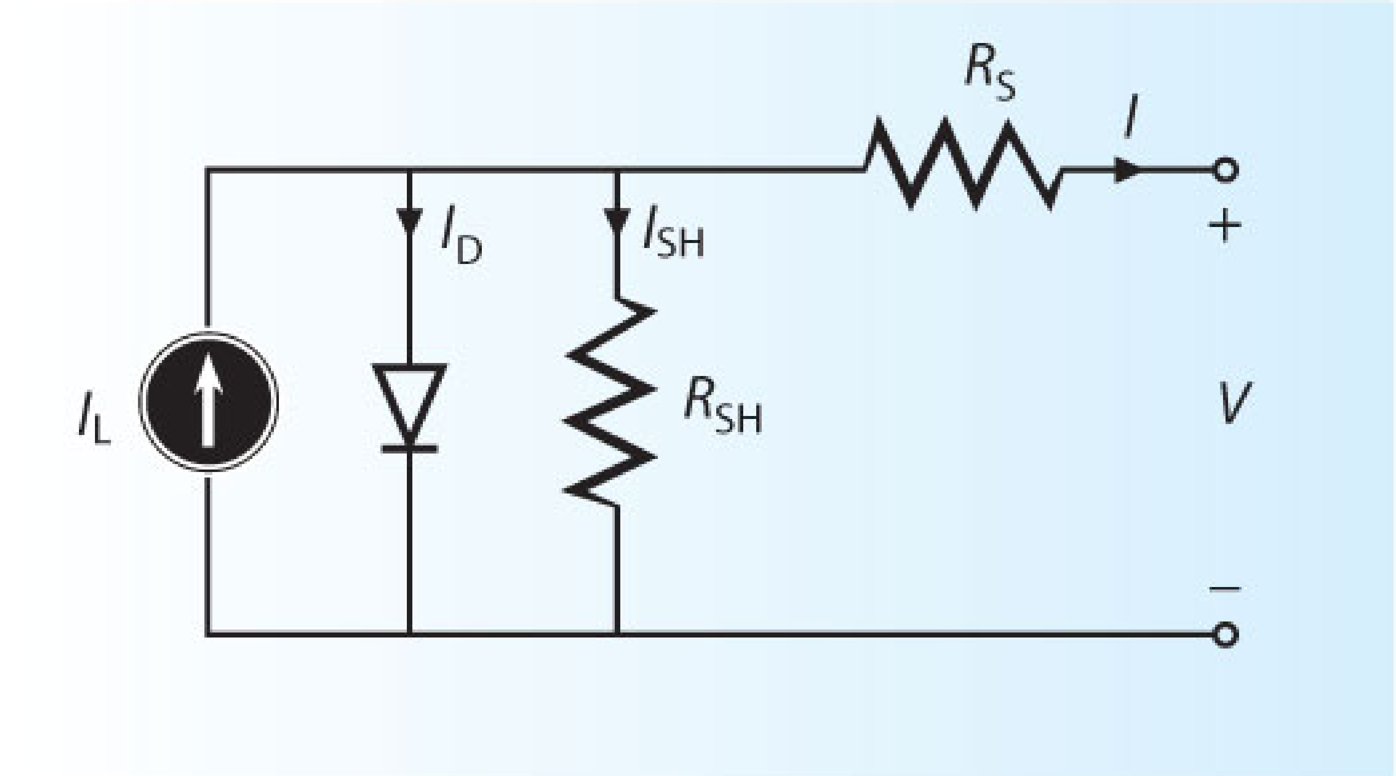
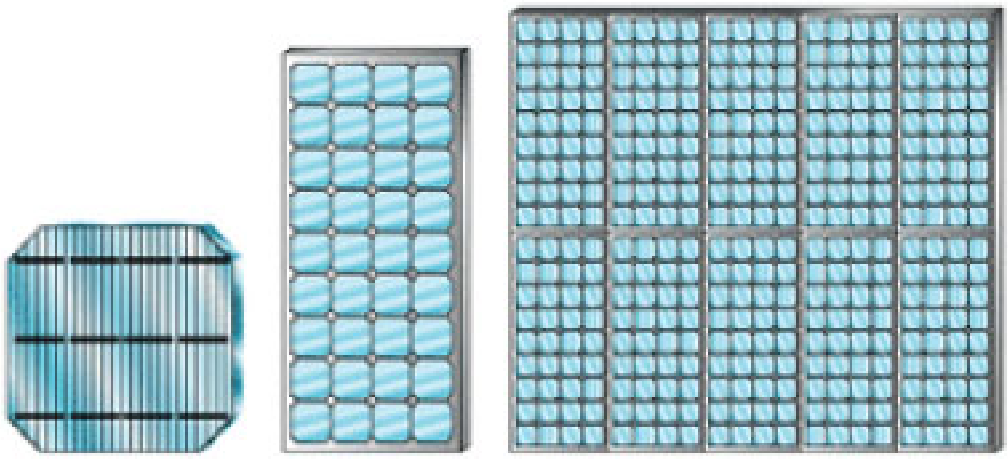


Figure 2 Solar cell circuit model[2]

Solar cells, which have a positive charge on one side and the negative charge on the other, are connected to create a module or panel. A panel consists of several rows of cells wired in parallel or series and placed between a clear and encapsulating substrate. Several panels wired at a specific voltage form an array.



cell Module Array

The power that solar panels produce is Direct Current (from now on referred to as DC) but the power that most of home appliances utilize is Alternating Current or AC. That is why an inverter is one of the standard components of any PV system. The inverter is a device that converts the DC power generated by the panels into AC.

If you want to have a fully independent PV System capable of storing energy, you will also need to install a charge controller and of course the batteries. Batteries are a medium that store the DC power produced by the solar panels that we will discuss in detail later. The main purpose of a charge controller is to regulate the level of power stored in the batteries. Not only does it prevent the battery or batteries from reaching a dangerously low charge level by stopping the supply of power to the DC load but it also protects the battery from being overcharged by automatically disconnecting the modules in your PV array from the battery bank when the batteries are fully charged. Therefore, to maintain battery performance, it is vital to install a charge controller in all but the simplest of PV systems is vital. Finally, the last piece of equipment for your PV system is a disconnect switch. As they are of vital importance, they need to be mounted within easy reach and every member of your family should know exactly how to turn the PV system off for safety reasons. Although most disconnect switches have fuses that will prevent equipment damage if the PV or the in electrical system is showing any abnormal behavior, shut off the solar system first.

1.3 Photovoltaic System Types

One of the positive characteristics of PV systems is that they are very flexible and depending on individual needs there are two different types of PV systems: off-grid systems and on-grid systems, or grid tied systems. The less common, off-grid systems are completely self-sufficient and are usually employed by people who have an RV, a cabin in the mountains or who want to get away from it all and, therefore, do not have a source of electricity close to them. Depending on individual needs these systems can power DC loads only or, by installing an inverter, can power both DC and AC loads.

In order to operate this kind of system at night or during cloudy weather, the system must include a means for storing energy – usually a deep cycle battery. The next system is an off-grid system with a generator or a hybrid system. Like the previous one it is completely off grid; however, this one does not have power storage. Instead, it has a generator – usually gas or diesel powered – that supplies DC power at night or in bad weather. Another example of a hybrid system is one that has an integrated wind turbine.

The day use system is the simplest form of an off-grid PV system. As its name suggests it designed for day use only. These systems are usually wired directly to the DC loads or appliances like a DC powered water pump, gate opener or a stand-alone solar powered calculator.
A more common PV system type is the on-grid system, grid-tied system or, as it is sometimes referred to, utility-interactive system. The basic components of this system are the solar panels and the inverter because this type is mainly used for residential purposes, i.e. in houses in which appliances are mostly AC powered. With this type of system, depending on the amount of independence you want your PV system to have, you can opt not to install batteries because the utility grid to which you are connected will act as a power reserve. Some homeowners who decide not to install batteries even sell the surplus of energy to their local power company through a specialized inverter.

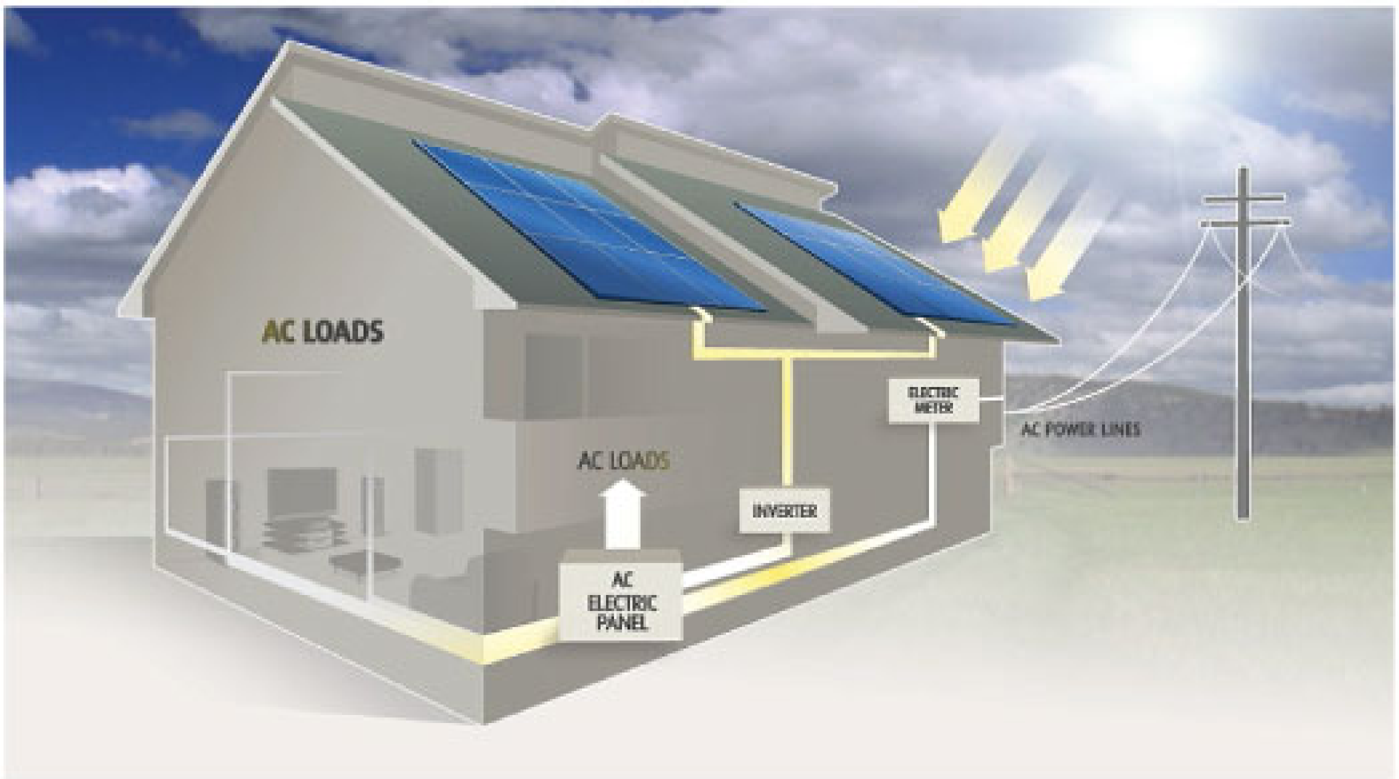


Figure 3 On-grid PV system without a battery bank

To achieve maximum independence, however, many homeowners choose to install a battery bank to their system as well. This type of system should also contain a charge controller to ensure battery longevity.

Figure 4 On-grid PV system with a battery bank

MAKING YOUR HOME ENERGY EFFICIENT

Since the main reason for switching to renewable energy is cost reduction, straining your PV system to its limits does not make much sense and that is why we are dedicating a chapter to ways in which you can reduce your power consumption. Always have in mind that the amount of money spent on power conservation is equally proportional to the amount of money reduced from the cost of a PV system and by making some changes in household habits energy consumption can be reduced up to 20%. However, sometimes to make some serious cuts to your monthly electricity bill some costly investments are necessary. Energy consumption can be reduced in many different ways and how much you want to invest is entirely up to you and even if you have already decided not to install a PV system please read the following sections on how you can help alleviate the strain on Earth's natural resources by conserving energy.

2.1 Changing Your Daily Habits

Have you ever wondered why two houses similar in size and the number of occupants have two very different electricity bills? The main difference between them can be seen in the habits of their respective occupants. For easier referencing, we will call them house A, the one with no energy conservation in mind, and house B whose residents are not wasteful energy wise. Here is a table of their daily habits.

HOUSE A	HOUSE B
Lights on all over the house	Lights on only in currently occupied rooms
Garage door open	Garage door closed
Noisy	Quiet
Closed windows (and blinds)	Windows (and blinds) open
No clothesline	Clothesline

2.1.a Lights

The first item on the list is self-explanatory. A well-lit house may seem comfortable and inviting but lighting up the whole house like a Christmas tree is not going to get you far if you are trying to reduce your bill. A golden rule when it comes to lights is that one light bulb per person is quite enough. However, if you still want every corner of your house to shine bright, try replacing your incandescent light bulbs with energy efficient LEDs or compact fluorescent bulbs and don't worry that your house will have the feel of your office because new versions of fluorescent bulbs have a much pleasanter spectrum. Another reason why incandescent lights are ineffective is that they put out a lot of heat. So in the summertime, when you are maximizing the output of your ACs, they are actually heating up your house. Consider this: for a 100 Watts of lighting, your AC spends an additional 80 Watts to cool down the place. Next, consider is using low wattage bulbs instead of dimmers.
Lighting the outdoors brings a sense of security to many people, but with some minute modifications, you can save a lot of energy. One-time investment in motion detectors can ensure that the outdoor lights are on only when necessary.

2.1.b Ventilation and Temperature

The amount of power you consume for heating and air-conditioning greatly depends on the climate in which you live in. All the same, unless you live in a place that has perpetual late spring conditions, heating or air-conditioning takes up approximately 25% of your entire energy costs. However, the problem lies not in the climate, but in the fact that your house is not properly insulated and by making some habitual and low-cost structural changes you can save a lot of money by saving power.

The changes you can make to your heating and cooling routine are simple but effective. Start by closing off any rooms that you are not using constantly. There is no need to heat or cool the laundry room or the attic the if you go up there once in a blue moon. Close the garage door. You would be surprised at how much energy you are wasting by keeping it open. Close up any fireplaces that are not in use. Do this especially during winter because hot air is lighter than cold air, therefore, it rises up and by leaving the fireplace open you are creating a perfect conduit for the hot air to escape. Minimize the use of exhaust fans because all they do is suck out the air that your HVAC has to replenish.

Turn down, or up, the thermostat as much as possible and whenever possible. Turning it down by 15ºF for 8 hours overnight, you can save up to 15% off your electric bill. Most people adjust their thermostat once a day or even less than that if the weather does not change significantly. However, thanks to the modern science you do not have to remember to turn it down or up. Programmable thermostats are a cheap investment that can go a great length in saving energy. By using these smart little gadgets, you can set weekly and daily programs that manage your temperature. Some of them even have the occupancy feature that monitors if someone is in the house – if not the temperature remains on standby.

You probably never gave much thought to energy conservation from the aspect of windows and blinds. Yet, by opening or closing windows, blinds or even curtains you can accomplish a lot. Instead of turning the AC on, try opening the window to ventilate your house. During winter and summer to either keep the house cool or warm close the blinds and pull down the curtains, as these are a great way to insulate your house. However, a good way to get some extra heat during winter is to open the blinds and curtains on those windows that are sunlit. In the end, wear a sweater in the winter or walk around the house naked in the summer – be sure to close the blinds first because you don't want to scare the neighbors.

Some other things you can do is check for leaks around frames and doors, seal the cracks in the building envelope, close hatches or replace any cracked window panes. Also, in the summer try cooking all your food on a gas barbecue. This way your stove will not generate heat around the house.

2.1.c Appliances and Electronics

Besides heating and air-conditioning, appliances and electronics are the items that are the cause of high electrical bills. Changing the way you use appliances and electronics around the house may lead to astonishing results.

Cookers, refrigerators and dryers consume massive amounts of energy. An easy way to save power is to turn off the oven before the food is finished cooking – as it doesn't cool off immediately your food will still get cooked but you will have saved power. Turn down the temperature of your refrigerator – chances are that the food will not lose any of its quality. If you have an ice dispenser use it instead of opening the door and letting the cool air out. Vacuum the coils at least twice a year because when dust and lint build up on the coils the compressor is much less efficient meaning that it has to work longer to generate the nominal amount of cold air. By cleaning the coils regularly, you also reduce the sound pollution created by the compressor.

To save power even more why not try drying your laundry on a clothesline and only using the dryer when absolutely necessary. However, if you are not up for that remember to keep the lint trap clean and clean out any clogged dryer vents.

You probably have not even noticed this, but electronic equipment about the house draws power even when it is off. Electronics are often referred to as phantom loads because they draw power constantly without you being aware of it. The most interesting thing about them is that some of them actually draw more power when they are off then when they are actually running. Examples of phantom loads are electronics and appliances with digital clocks and LEDs so you might want to consider placing them on a timer or a switch circuit to save power. Keeping these on all the time cost you about $60 per year. Not much but still $60 more than you should spend

2.1.d Water

This too is an area where you can reduce your electricity bill by employing several nifty tricks that will not reduce the quality of your lifestyle. First off, take showers instead of baths. Unless you had a hard day and need to unwind, a shower will clean you up equally well as a bath would and it will cost you less. Always try running a full dishwasher. Whether you wash 6 plates and 6 glasses or 12 plates and 12 glasses it is going to cost the same, but your dishwasher will have to run more times than necessary. Next, when you draw tap water, try using only cold water. In many households, sink taps have only one lever for controlling both hot and cold water that is usually pushed to the middle. This way you are drawing hot water from the tap as well, however, because it takes some time for the hot water to reach the tap you are actually not getting any hot water. What happens instead is that the hot water remains in the pipes where it is wasted. Making some minor household repairs will also help. Repairing the leaky hot water faucets and draining the heater twice a year to remove the crud that reduces efficiency is all you need to do. Finally, lower the temperature of the water heater. There is absolutely no need to set the temperature at 160ºF when 120ºF will get the job done. Yearly, you can save up to $270 [3] by making this small adjustment that you will not even notice. For further reading on how to make your home energy efficient visit **www.eere.energy.gov/consumer.**

2.2 Small Investments Can Go A Long Way

Some of the older appliances around your house are inefficient when it comes to energy consumption. To see if your appliances are inefficient check the minimum and maximum energy consumption for the model that you have with some of the newer models that have the Energy Star rating developed by U.S. Environmental Protection Agency and the U.S. Department of Energy. Essentially, it is a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. To learn more about the Energy Star ratings visit www.energystar.gov.

2.2.a Refrigeration Units

The refrigerator is one of the single largest loads in a residential home. If you are ready to trade in your old refrigerator, there are some things that you should be aware of. Besides looking for a refrigerator that has the Energy Star rating, it should also have superior insulation with a very high R-value. This value is not necessarily stated on the product itself but you can always ask the salesperson. Then you should look for a refrigerator that has a small current draw when operating and that has two separate compartments for the freeze and the refrigerator. Also, avoid side-by-side models and look for a refrigerator that has an efficient compressor waste-heat removal. Another consideration is if the unit has the compressor located on top because of the physics of hot air.
In a standalone PV system, an off-grid system, it is imperative that you have a very high energy-efficient refrigerator. In addition to the AC powered refrigerator, there are three basic models of refrigerators available for off-the-grid systems. The first one is the propane powered. This type of refrigerator has been used in RVs for over 70 years.

One of the drawbacks of propane, as well as the next model, which is the kerosene model, is that they both need to be refueled; they do not need electricity but they need refueling which is why you will need to make sure that you have a supply of fuel. Lastly, a common type of refrigerator on an off the grid system is a DC powered refrigerator, which could be 12, 24 or 48 volts. These do have a higher initial cost but they run directly off a battery or off the system with no inverter required.

2.2.b Structural Investments

When we talk about structural investments, we mean roofs and windows. While this can be a substantial investment, it can bring about huge savings in the long run. Next time you need to change your roof, consider installing an energy-efficient one. Although changing all the windows in your house is rather expensive besides having a huge influence on energy consumption of your household, it is also functional, aesthetically pleasing and will certainly raise the value of your property. Should you chose to replace the windows, do your research first as there are many new types of glass. There is glass especially designed for cold climates, which lets sunlight in and insulates for heat, and hot climates, which blocks off sunlight. Currently the standard for glass is that it should be double paned, but you can even get triple paned glass. The main thing you should remember is that you do not need to replace all the windows. You can replace just the windows on the rooms that are used the most like the living room or the kitchen.

BEFORE YOU START YOUR PROJECT

Before you begin your project, it is very important that you are familiar with all the electrical fundamentals pertaining solar energy. Knowing as much as possible about how electricity works will not only help you utilize it in the most effective way but it will also keep you safe.

3.1 Electrical Fundamentals: Definitions, Terminology and Applications

In its simplest form, electricity is a flow of electrons through an electrical circuit. There are three fundamental units of measure pertaining to electricity: volts, watts and amps. Since current is invisible, it is difficult to demonstrate the processes of electronics, therefore, the basics of electrical energy are often clarified through the so-called water flow analogy in which electrical circuits are compared to water-filled pipes.

Volts are the unit of electromotive force that tends to cause current (the actual electrons and ions) to flow. Simply speaking, volts are a measure of how much push or electrical pressure causes the electrons to move. Their abbreviated symbol is the capital V. In the water flow analogy, volts are equivalent to the water pressure in the pipes.

Voltages used in the electrical field are 12, 24 48,120 and 240 V an most of the appliances in your household use some or all of these voltages. For example, the air conditioner contactor that brings the compressor on and off is probably of 24-volt contractor, the TV is almost invariably running off 120 volts, however, the water heater, dryer or stove is most likely using 240 volts.

Amps are a measure of the amount of electric charge passing a point per unit time. Amps are abbreviated with a capital A and are expressed by the symbol I, which stands for the intensity of the current. As a water pipe is sized based on the amount of water per minute flowing through it, a wire is sized based on amount of amps that will be passing through it. Therefore, the greater the amount of amps the larger the conductor or wire we will have.

An amp/hour is the measure for current flow for one hour. Its abbreviated symbol Ah is widely used to rate how long it takes a battery to discharge. For smaller devices, the battery rating used is milliamp/hour or mAh. For example, a 500mAh battery will release 500 milliamps of current at a specific voltage for one hour before it is discharged. Essentially, this term is used to express the storage capacity of batteries. Storage batteries utilized in PV systems are referred to as deep cycle batteries and are rated by 105 amp/hours. What this theoretically means is that these batteries can be charged to produce 105 amps for one hour.
Watts, symbolized by the capital W, indicate the rate in which the electrical energy is either consumed or produced. One watt is equal to one amp under the pressure of one volt.

$$W = A*V$$

The size of your PV system will greatly depend on this unit and, in order to size it, you will have to calculate how much energy, measured in watts, you consume daily. This number will determine the amount of power your system will have to produce. The amount of watts consumed can vary greatly depending on what you run.
The most common use of the watt/hour and kilowatt/hour (Wh and kWh) unit is when energy is delivered by electric utilities to consumers. The electric bill we receive is calculated by multiplying the amount of watts consumed by the number of hours per day, per week and per month.
To calculate the number of watts consumed, we need to know two things:

- what is the rated wattage of the appliance or the appliances we are going to be utilizing and,
- we have to estimate the amount of time that appliance or those appliances will be running.

For example, a 100W light bulb left on for 10 hours consumes 1000 watts, which is equivalent to 1kWh. Energy consumption calculations will be explained in detail in Part IV chapter 3 of this book.

3.1.a Electrical Current

Electric current is the flow of electric charge carried by moving electrons, in a conductor such as wire. There are 2 types of current that we come in contact with: direct current, or DC, and alternating current, or AC.
Direct current is the unidirectional (flowing in only one direction) flow of electric charge and is produced by such sources as batteries, thermocouples and electric machines of the dynamo type. It is common in flashlights, smaller devices like TV remote control, calculator, phone, and PDAs. Its graphical symbol is a solid line with a dash line underneath it as shown in figure 5.

Figure 5 Direct current symbol

Direct current is also the type of current produced by PV or photovoltaic panels and is stored in batteries for later use.
In alternating current, the flow of electric charge periodically reverses direction. An electric charge can for instance move forward, then backward, then forward, then backward, over and over again. It is produced by your electric company and most homes and businesses use this type of current. Alternating current or AC is symbolized by what some people call the sine waves line, but this symbol represents the peaks and valleys of the AC as shown in Figure 6.

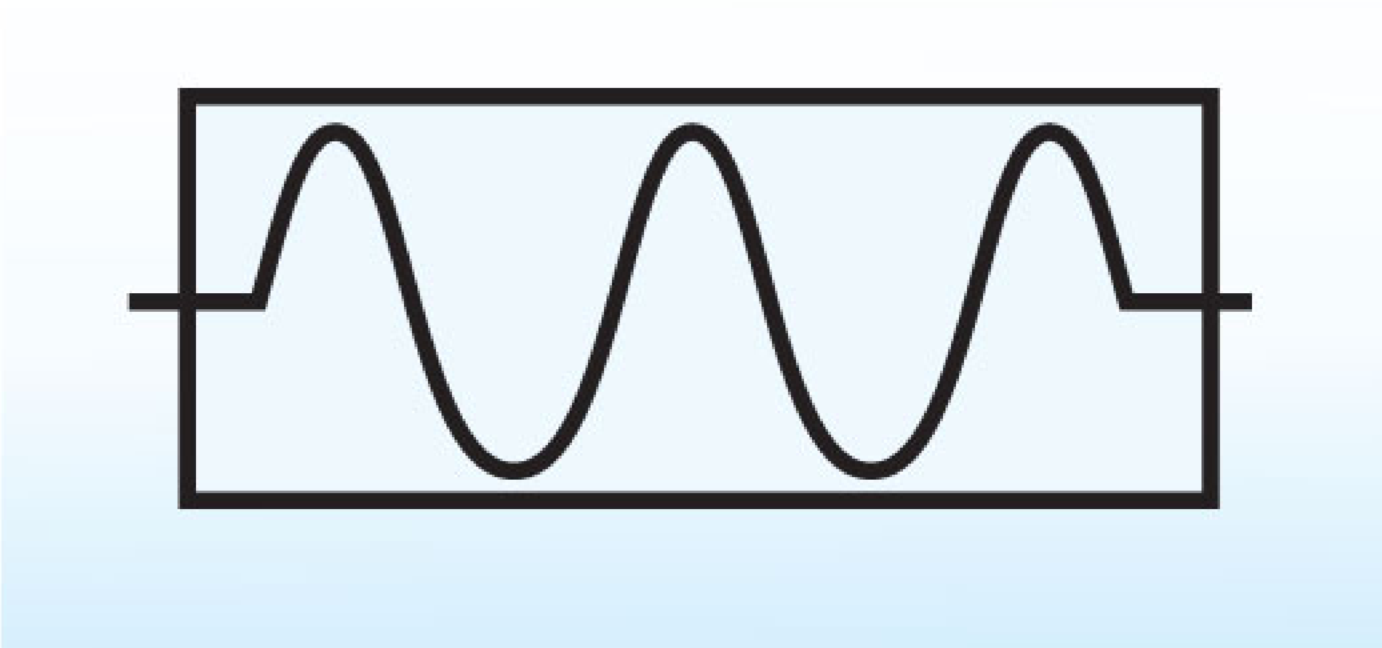


Figure 6 Alternating current symbol

3.1.b Electrical Circuits

An electric circuit is a continuous line of electron flow from a voltage source like a battery or a PV module through a conductor or a wire to a load through a switch and back to the source. Simply speaking, a circuit is nothing more than a never-ending looped pathway for electrons. Figure 7 is an example of a simple electrical circuit made up of a voltage source and a resistor.

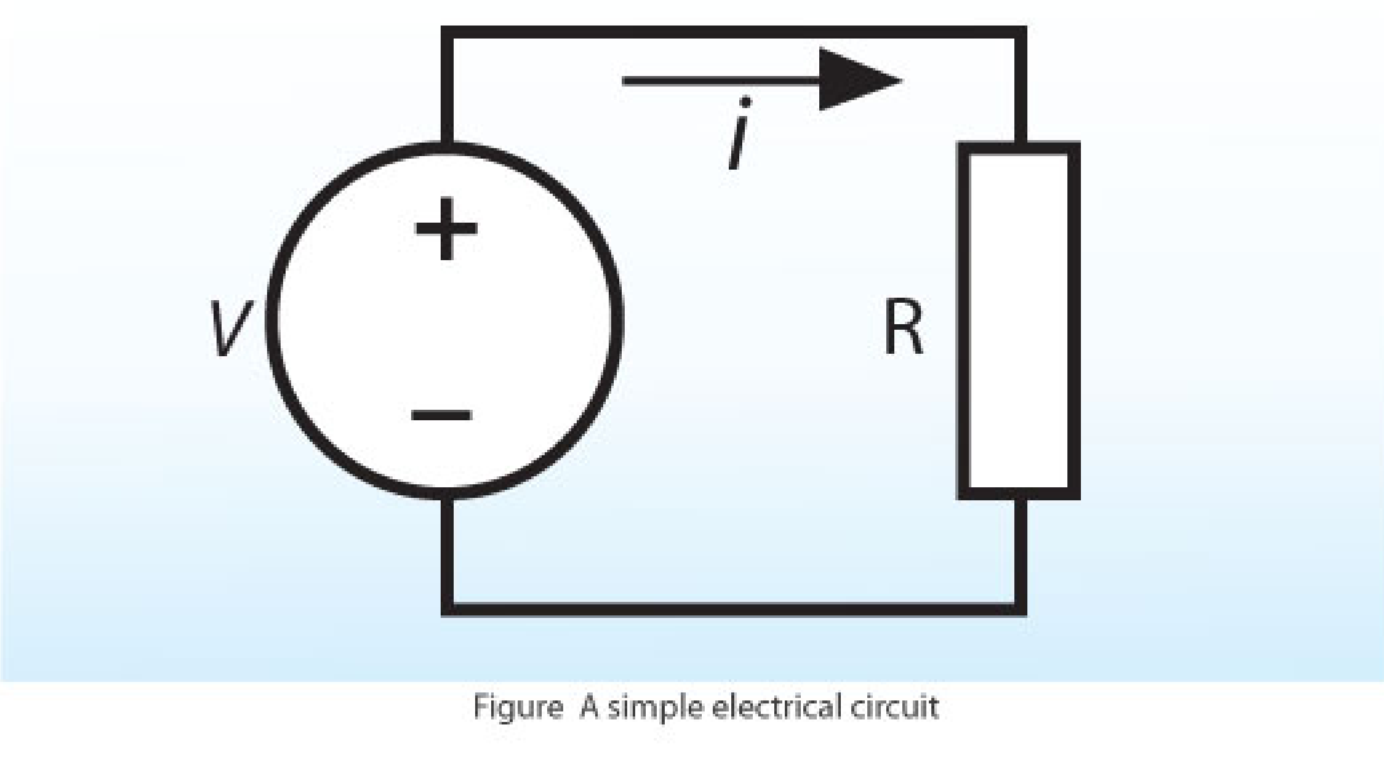


Figure A simple electrical circuit

One of the most important things in an electrical circuit is continuity. It does not matter how twisted the route of the conductor is; if it forms a complete circuit, current will run through it.

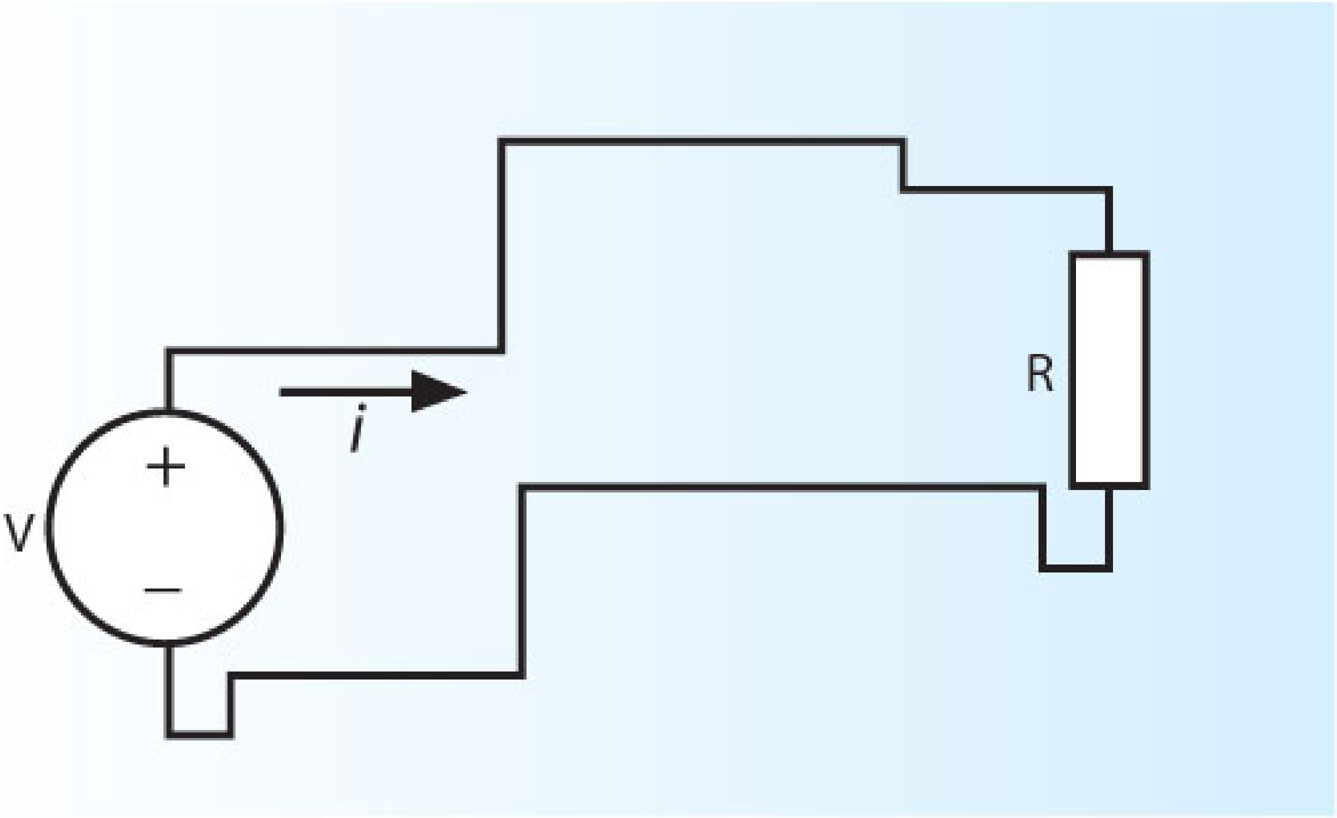


Figure Possible conductor path of a simple electrical circuit

Continuous electron flow cannot occur in a broken circuit. The following figure shows a circuit made up of a voltage source, in this case a battery, a load represented by the light bulb, a protection device serving as a protection device and a switch that serves as a control device.

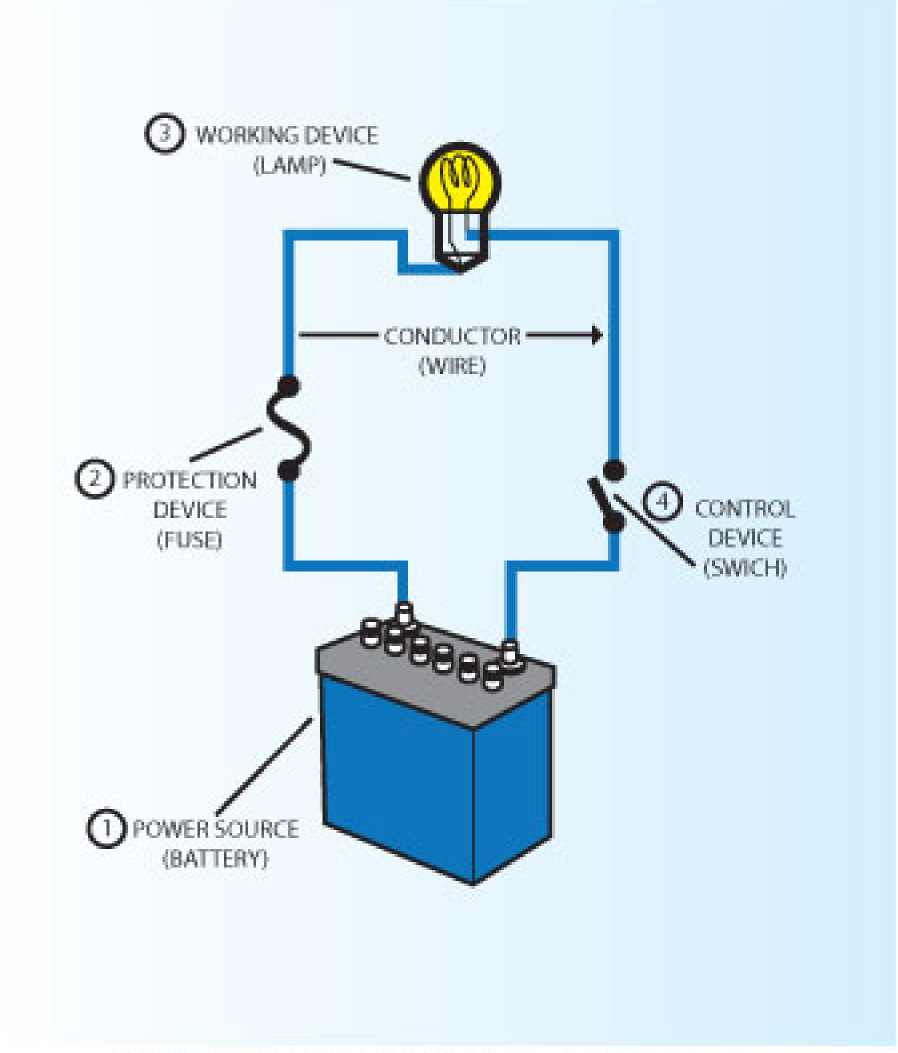


Figure A simple electrical circuit with a switch

The switch functions as a deliberately installed circuit break to be used when necessary. Therefore, when you switch off a light, you are actually making a break in the circuit resulting in discontinuation of electrical power delivery to the light. In this particular diagram, you can notice that the switch is open and the bulb would not be burning, until the switch is closed.
There are three types of electrical circuits: series, parallel and series-parallel circuit; however, in PV system assembly and installation you will encounter the first two types only.
Series circuits are the simplest of circuits. Figure 9 is actually a representation of such a circuit. However, series circuits can have more than one load – as shown in figure 10.

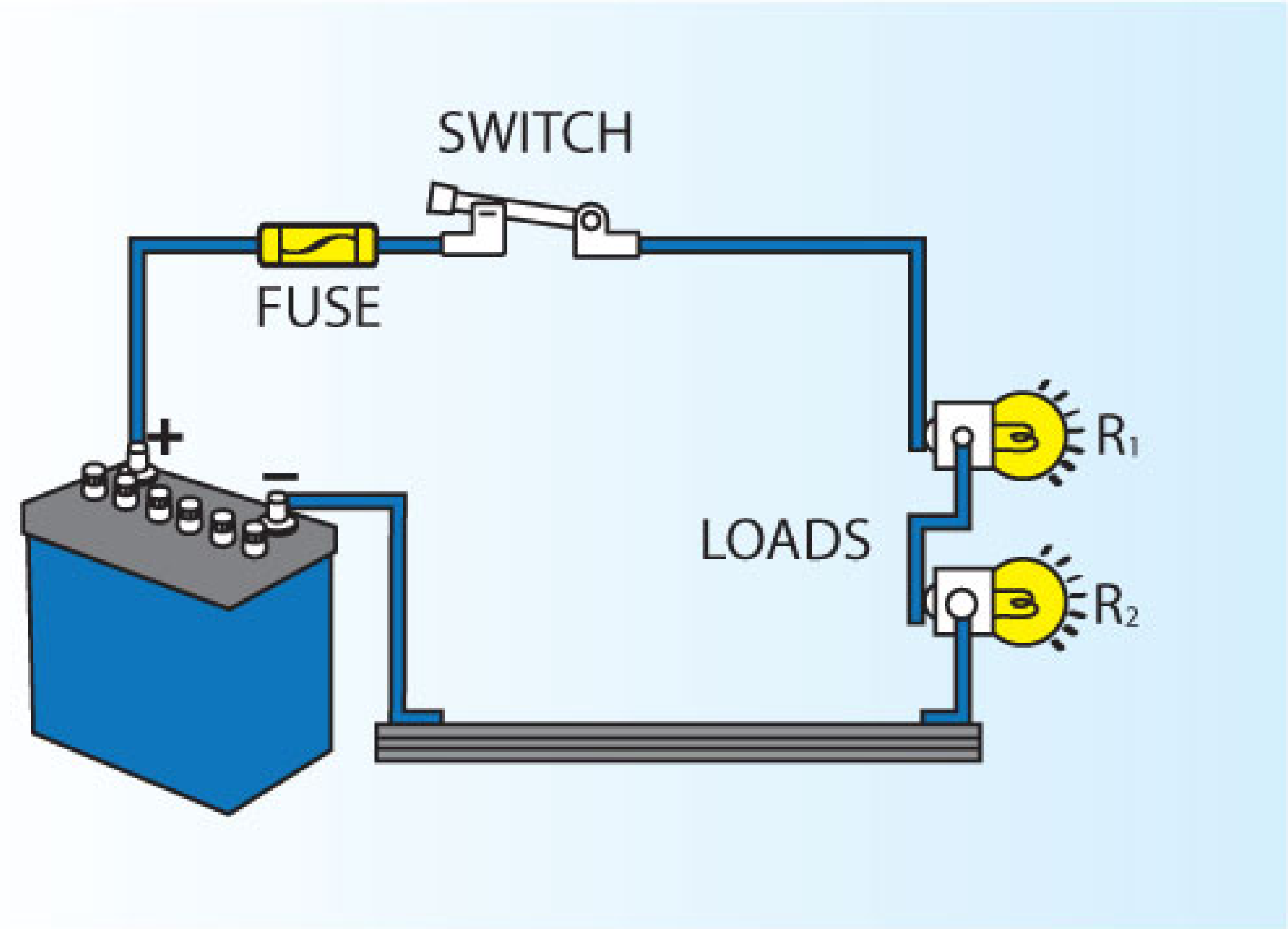


Figure A series circuit with two loads

In a series circuit, conductors, protection devices, such as fuses, loads, switches and power sources are connected with only one path for current and, although, the same amount of current will flow through each load, the voltage across each will be different.
A parallel circuit has more than one path for current flow. The loads of such a circuit are connected in parallel branches, which are called branch circuits, and the point where the current path reconnects or splits is called a junction. The voltage in each branch is the same; however, the current can vary. If the load resistance in each branch is the same, the current in each is the same. On the other hand, if the load resistance in each branch is different the current will differ in each.

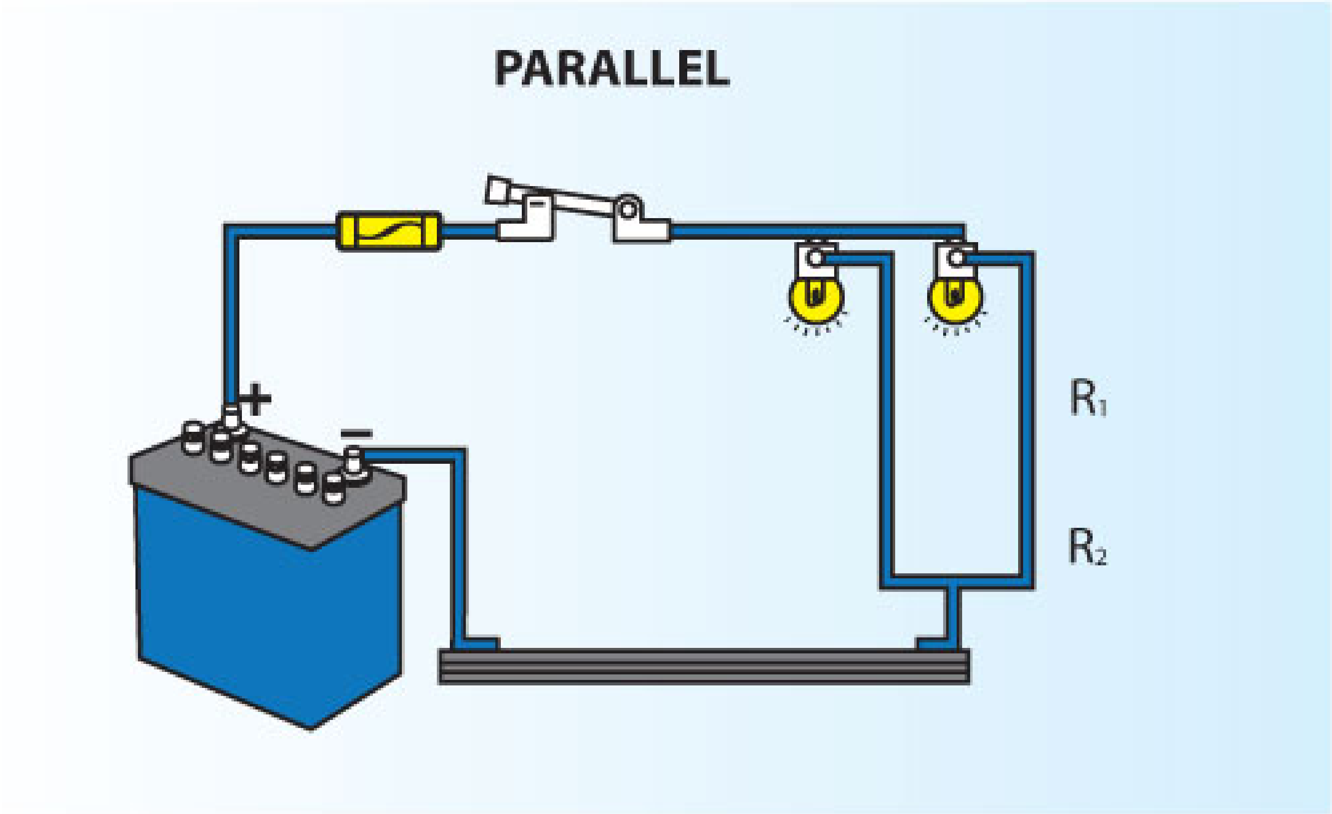


Figure A parallel circuit with two loads

If you look at the circuits in your house or the room in which you are sitting, you will probably see 4 or 5 wall plugs. In all likelihood, they have been wired in parallel. The reason most indoor wiring is done in parallel is that it assures electricity delivery. For example, if one of the plugs in the room would become defective the rest would not be prevented from working properly and you would still have a source of electricity available. In series wiring, this is not the case.
Lastly, series-parallel wiring is also uses and although you will not encounter these in PV system installation, it is important that you understand how it works. This kind of circuit has some components in parallel and others in series. The current flows through the series part of the circuit and then splits to flow through parallel branches. The loads are usually connected in parallel while the power source, switches and fuses are in series. The same current flows in series part of the circuit whereas different current flow in the parallel part. Parallel devices receive the same voltage and series receive different voltages. If a circuit break occurs in the series section, the current is cut off for the entire circuit. However, if the break is in the parallel section, the current still flows through the series section and its branches.

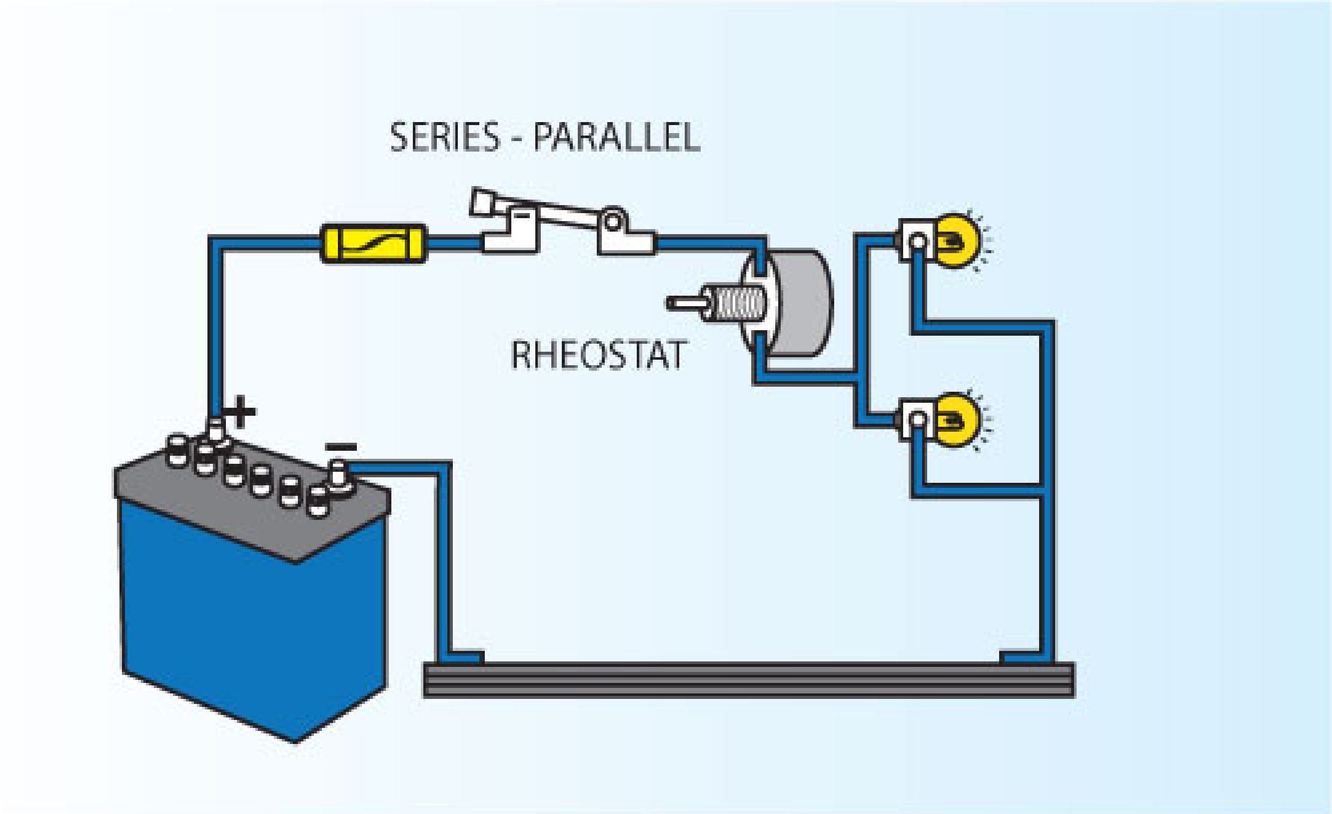


Figure An example of a series-parallel circuit

The rheostat is an electrical component that has an adjustable resistance used to control the flow of current in a circuit. It is used in light dimmers and motor controllers (found in small appliances such as mixers, blenders, fans and power tools).

3.1.c Electrical Circuits in Photovoltaic Systems

In building a PV system, it is important to understand how different circuits work because depending on which type of circuit wiring you are going to use you are going to affect either the voltage or the amperage produced by the PV panels.
To create a panel, solar cells are wired in series: positive to negative, positive to negative and so on until the entire panel is connected. Based on your individual needs once you have all of the panels assembled, you are going to connect those in series or parallel. Connecting panels in series is going to increase the amount of voltage they are producing while the amperage is going to stay the same.

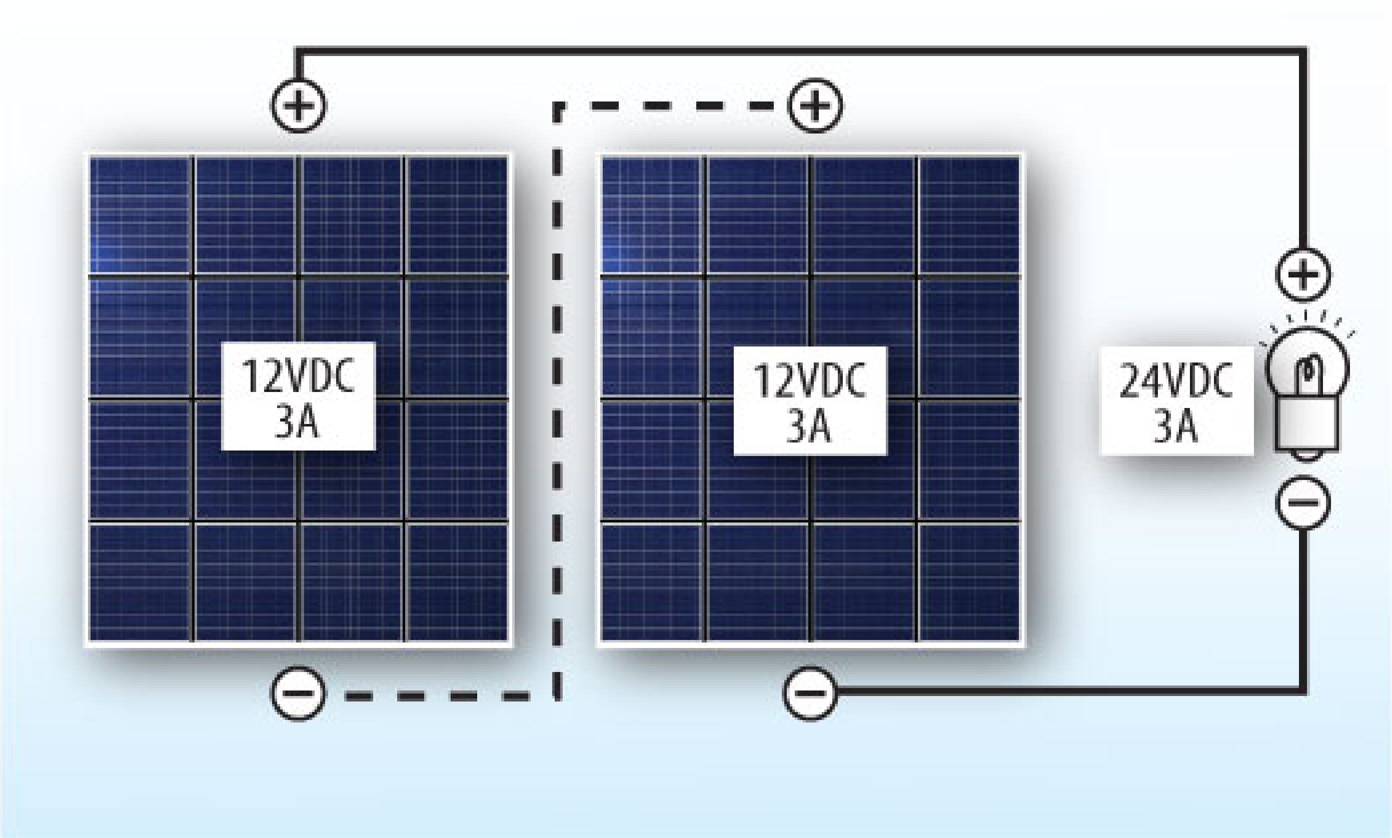


Figure PV panels connected in series

Here we have two panels each consisting of 36 cells and producing 12V and 3A. When they are wired together in series their combined voltage production increases to 24V, however, the amount of amperage production stays the same. In other words, when panels are connected in series, voltage is increased but not the load capacity.
Conversely, in parallel wiring, the load capacity of the circuit is increased but not the voltage. Figure 14 represents the same two panels wired in parallel with their combined production amounting to 12V and 6A.

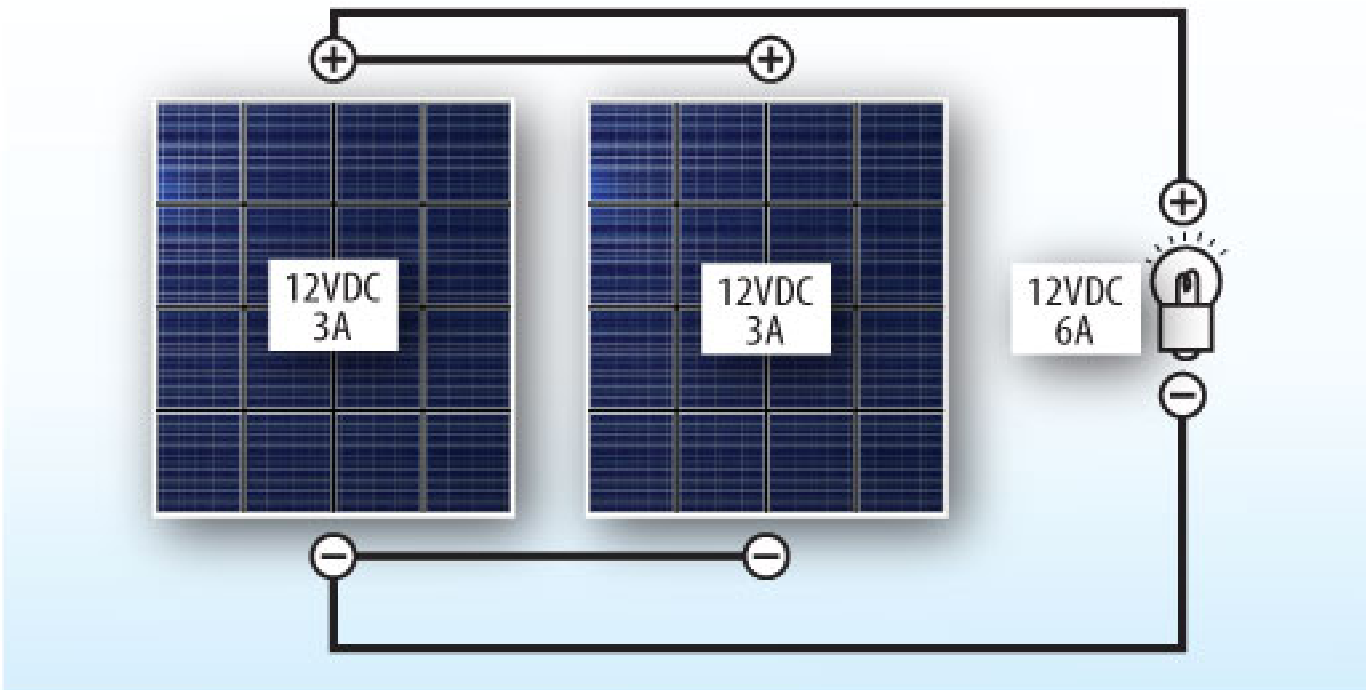


Figure PV panels connected in parallel

To create a high voltage PV panel array capable of carrying greater loads thus supplying power for the entire household, individual panels must be connected both in series and in parallel as can be seen in figure 15.

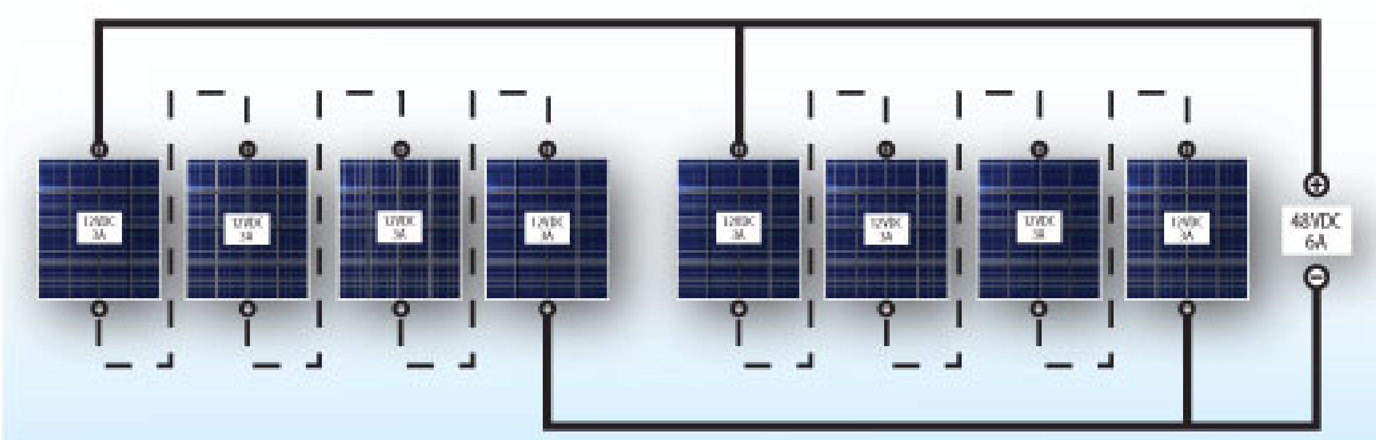


Figure PV panel array connected in series and parallel

The eight individual panels are divided into two groups of four. The first group and the second group are wired in series respectively by connecting the negative terminal of the first panel to the negative terminal of the second panel and so on. This amounts to 48V and 3A for each group. However, because the first group and second group are connected in parallel the amperage is increased while the voltage stays the same. Consequently, this total configuration utilizing the eight panels at 12V per piece with 3A capability gives us a net effect of 48V of DC potential with 6A load capability.

DETERMINING THE BEST PV SYSTEM FOR YOU

In this chapter, we are going show you how you can determine the best PV system for you, how to evaluate your solar potential and how to decide on between hiring a contractor and doing it yourself.

4.1 Evaluating Your Solar Potential

Since PV systems harness the energy of the Sun, one of the most important things that you need to take into account when considering installing a PV system is the daily amount of sunlight you have available. Estimating the amount hours of sunlight you can expect per day is an extensive subject and, although there are free solar calculators like the one at www.pvwatt.com available online, we feel that it is very important that you familiarize yourself with this subject as much as possible.

Depending on the climate in which you live, you get more or less sunlight. Climate includes elements such as temperature, precipitation, wind speed, pollution, air density and cloud cover. All of these can and will influence the power production of your PV system. Figures 16-20 show the average number of hours per day of sunshine in the US.

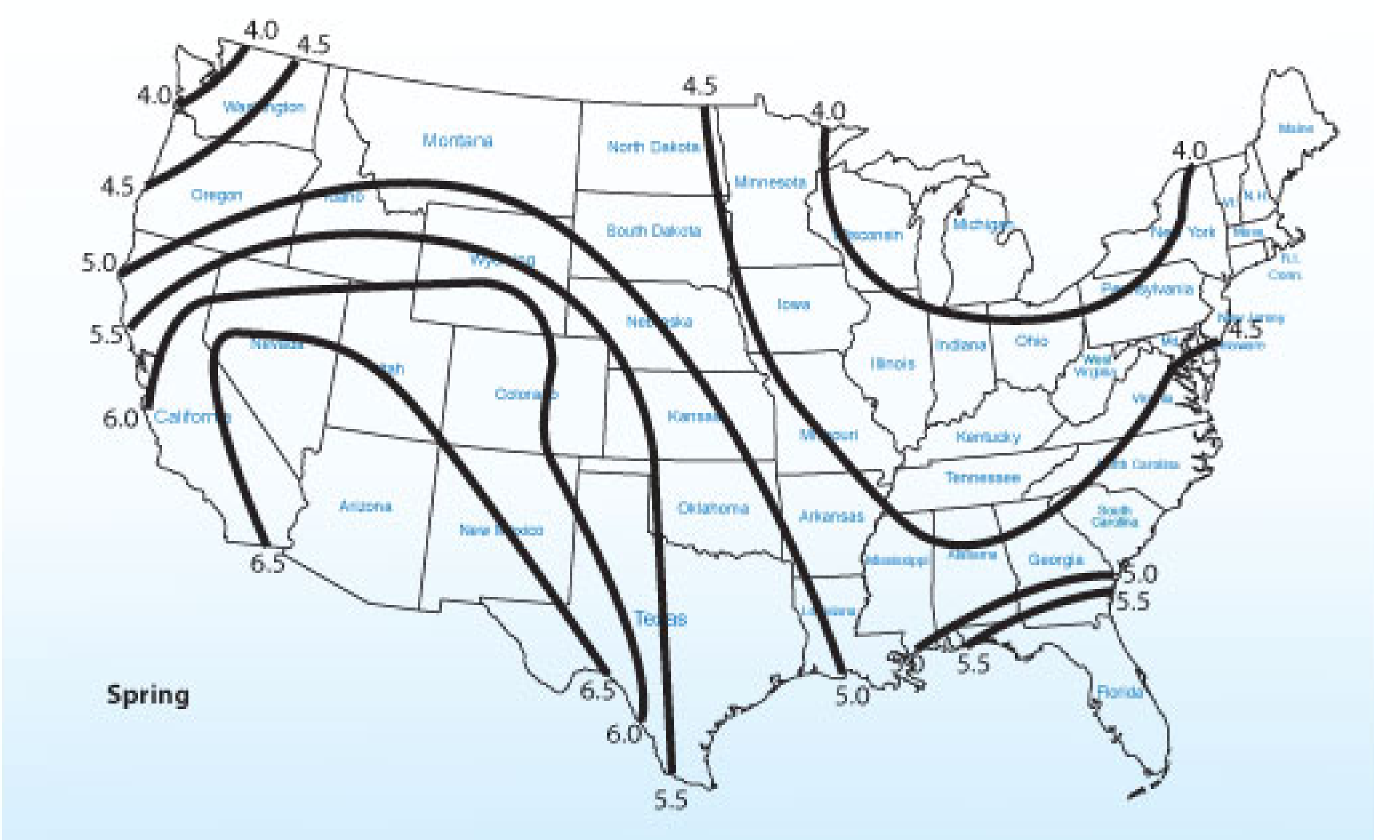


Figure 16 The average number of hours per day of sunshine in the US during Spring

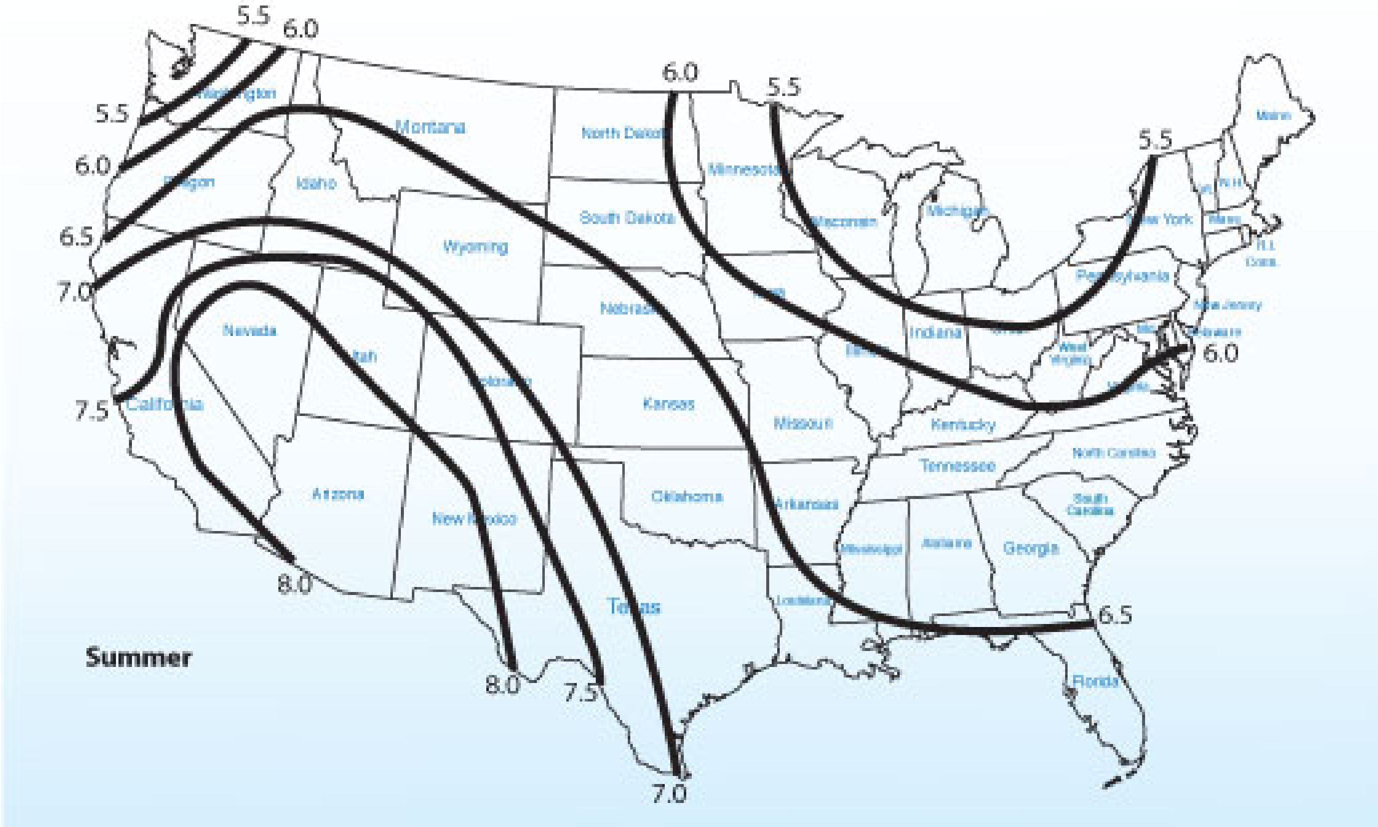


Figure 17 The average number of hours per day of sunshine in the US during Summer

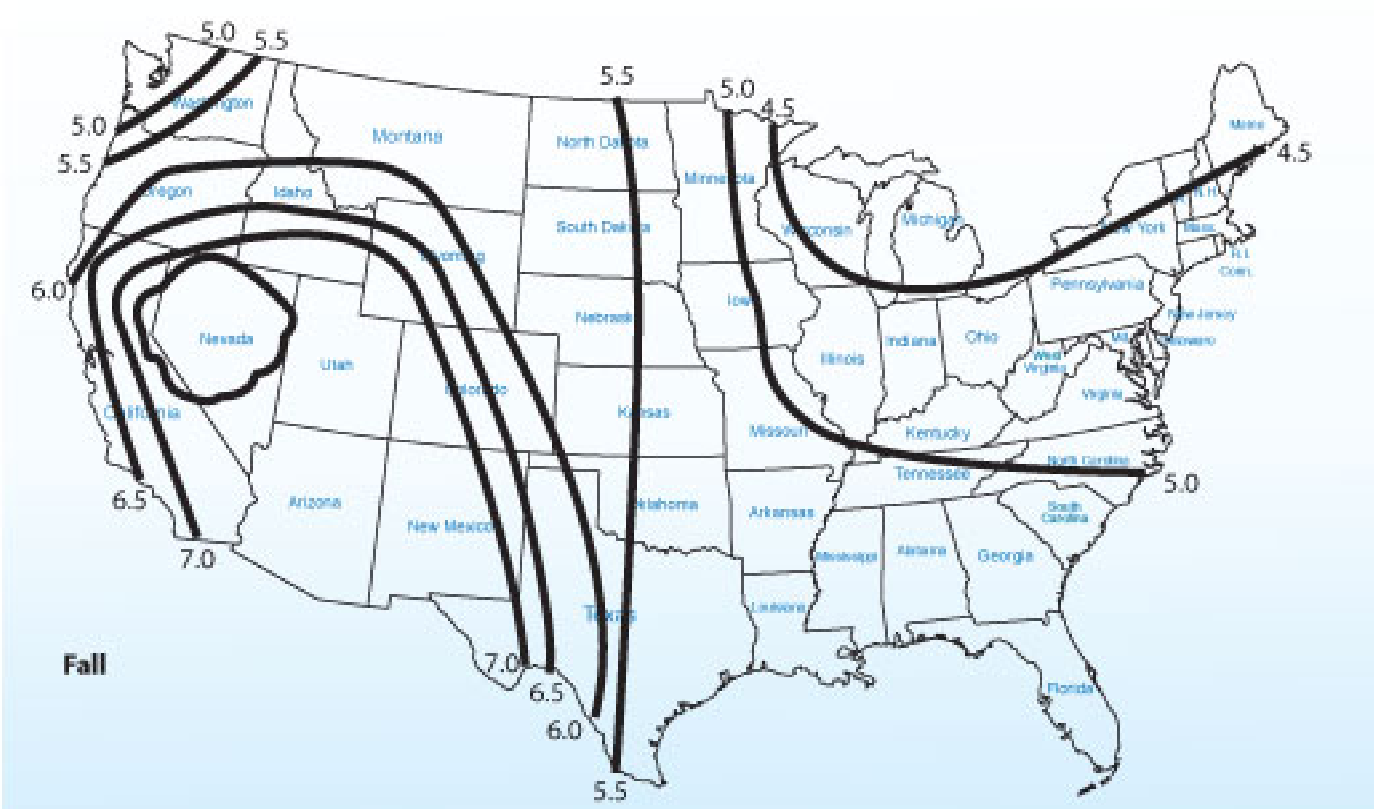


Figure 18 The average number of hours per day of sunshine in the US during Fall

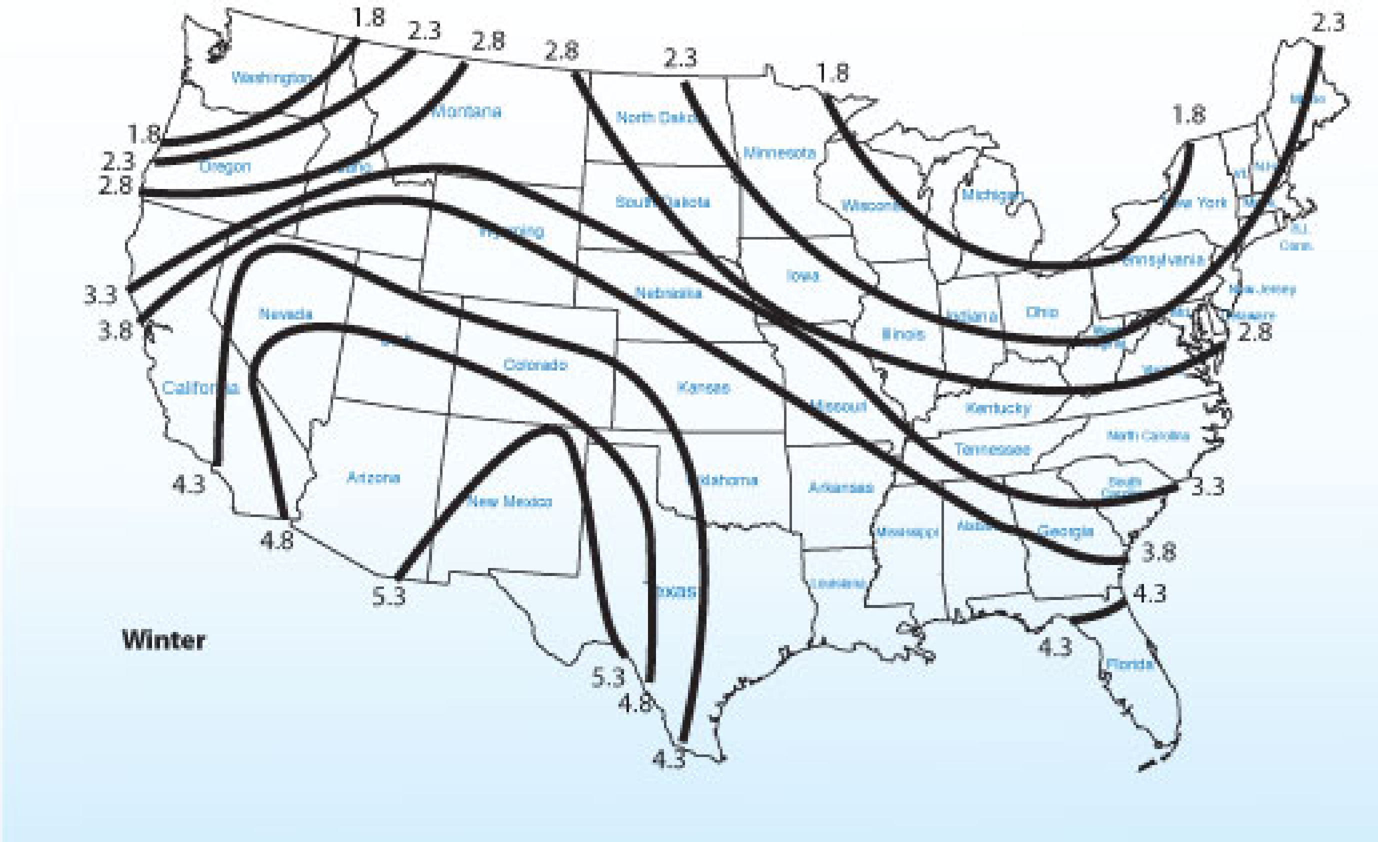


Figure 19 The average number of hours per day of sunshine in the US during Winter

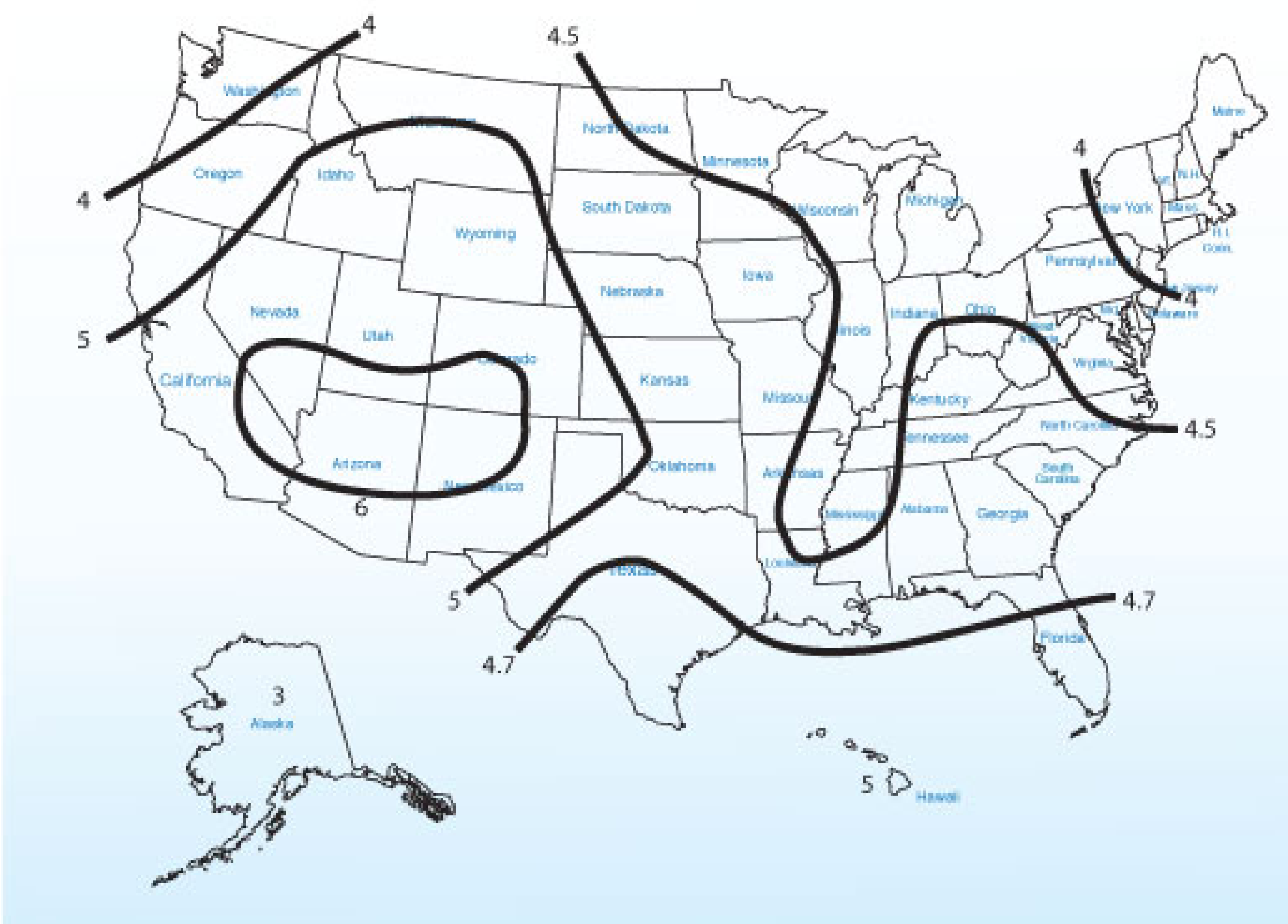


Figure 20 Annual average daily peak Sun hours in the US

There is not much you can do about the amount of sunlight you get per day, however, properly placing your solar panels is a very important factor in getting the maximum energy output of your PV system.
For maximum power output, PV modules should be exposed to the sun for as possible, especially during peak sun hours between 10 a.m. and 3 p.m. Second, the exposure must be clear of any obstructions such as trees, mountains or buildings that might shade the panels. Consider both summer and winter paths of the sun, as well as the growth of trees and future construction that may cause shading problems. The unobstructed exposure must also have sufficient space to install the PV system. Finally, there are some other considerations you must take into account when mounting your solar panels:

- If the area in which you live in is a cloudy one, you will receive diffused solar energy therefore it is not vital at what angle you mount the panels because light will come in at many different angles instead directly from the sun.
- If you live in an area that gets fog during a particular time of day, the best orientation for your panels is so that they catch the most sun when the fog clears. For example, if it is foggy in the morning, orient the panels in the direction from which the sunlight comes around noon.
- You might have noticed that some areas of your roof get heavy snow buildups. These are the areas you want to avoid when mounting your panels because if they get snowed under they will not produce electricity.

Other things you must be aware of when installing your solar panels are:

- Wind will not affect the productivity of your PV system but it might tear off your panels of their mounting hardware. Therefore, if you live in an area with lots of wind, you need to make sure that you are using some tough and durable mounting equipment.
- Smog affects the amount of sunlight you will receive.
- The semiconductor that makes up the solar cell actually works better in lower temperatures. You will get more energy output on a cold clear day than on a sunny day.
- Air density affects how much the sunlight scatters. At higher altitudes, the air is thinner hence less sunlight is scattered and solar exposure is better.

The best way of evaluating the daily amount of direct sunlight is plotting Sun Charts, which are a means of graphically displaying the movement of the Sun across the sky.

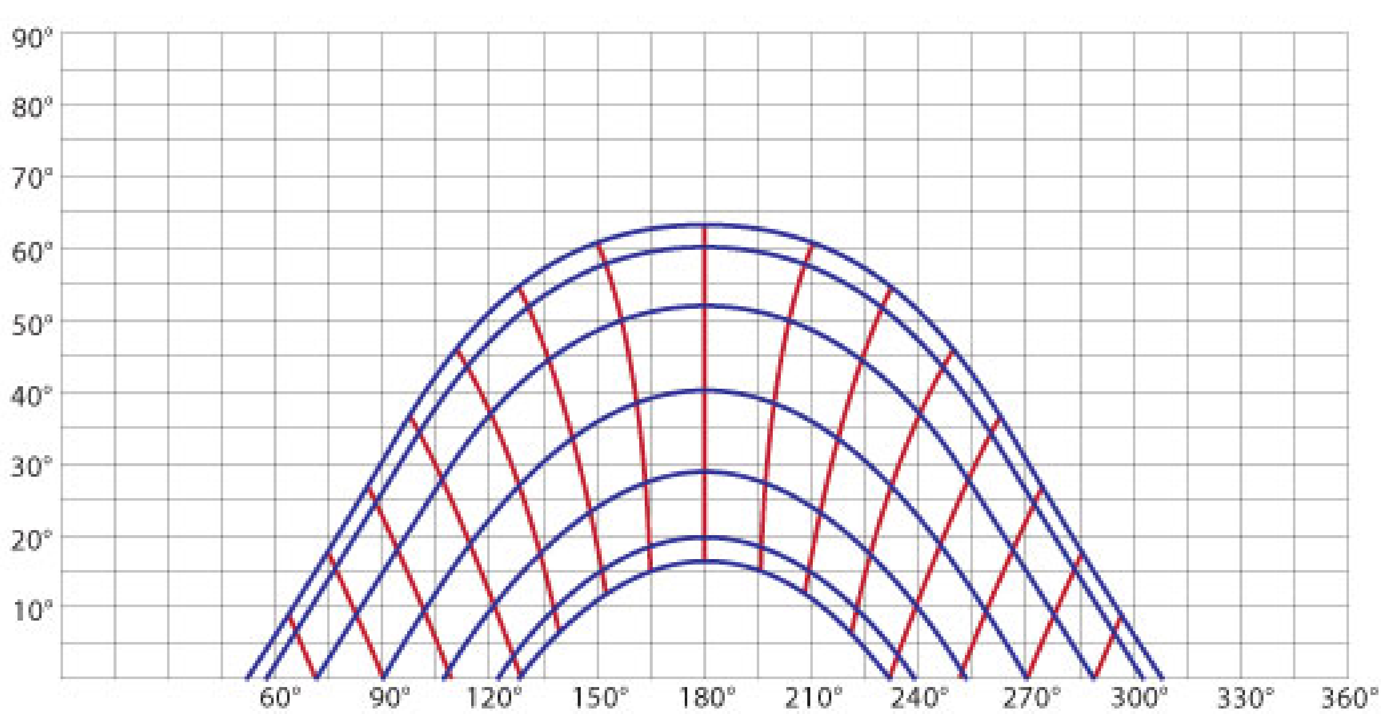


Figure 21 An example of a sun chart for latitude 50° N.

Plotting a Sun chart is a bit complicated and takes quite a lot of time. Fortunately, there are online resources like http://solardat.uoregon.edu/SunChartProgram.php for plotting your own Sun charts by simply entering the latitude and longitude of your residence.

However if you do want to make a Sun Chart yourself here's how:

To get proper readings you will need a watch, a compass, notepad and pen, large half-circle protractor and 10 inches of string. Choose a location where you can observe the sun's path across the eastern, southern and western skies. Place a solid nonmetallic chest-level high base that will remain stationery, because you will take your readings from there. Take readings three times a day always making sure you take them at the same time of the day for example at 8 a.m., noon, and 4 p.m. respectively.

If you have chosen to take the first reading at 8 am, just before then align your compass with magnetic north and at 8 am sharp turn your compass, as though it is nailed through its center into the base, until the sight lines up with the sun. Read the azimuth (direction in degrees), and jot it on your notepad. Repeat the same process at noon and 4 p.m. Be sure to mark the spot where you placed the compass and to put it there every time you take readings as well as to mark the stop where you were standing and stand there every time. During winter, you will see the lower elevation and shorter arc of the sun's daily movement.

On the flat bottom of the protractor, there should be a ruler marking of zero to six or more inches. At the far end of that ruler glue one end of the string, then lift the protractor to your eye level. Sight and align the horizon along the straight side of the ruler edge. Without moving the protractor, take the string with your free hand and align the sun along the string, holding it stretched tight against the protractor. Don't release this position until you read the angle, then jot it in your notepad.

Take a piece of sketching paper and draw a vertical (the sky) and horizontal line (the horizon) through the center of the page. Put the center of the ruler edge of the protractor over the intersection and put a dot above and below the same degree mark you noted during your sighting. Write this degree of inclination next to the dots. Draw a line from the intersection through these points, and label that line as the date and time of your sighting, for example: 12 December 2009.

Take your next series of readings in February or March and every month thereafter, until the autumnal equinox. Make sure to plot your readings carefully on your sun chart. After the final plotting of the year, connect the dots in a curved line and you will have made your Sun Chart.

How you orient your panels in relation to the angles of the Sun's movements on the Sun Chart is imperative. Evidently, the best way to mount the panels is so that they face the sun as much as possible. The tilt angle of the panels considerably influences the amount of sunlight you are going to get. If you match the position of the panels to the Sun's movements but do not set the proper tilt angle, you will not get maximum sunlight exposure for your panels. Figure 22 presents how an improper tilt angle reduces sunlight exposure.

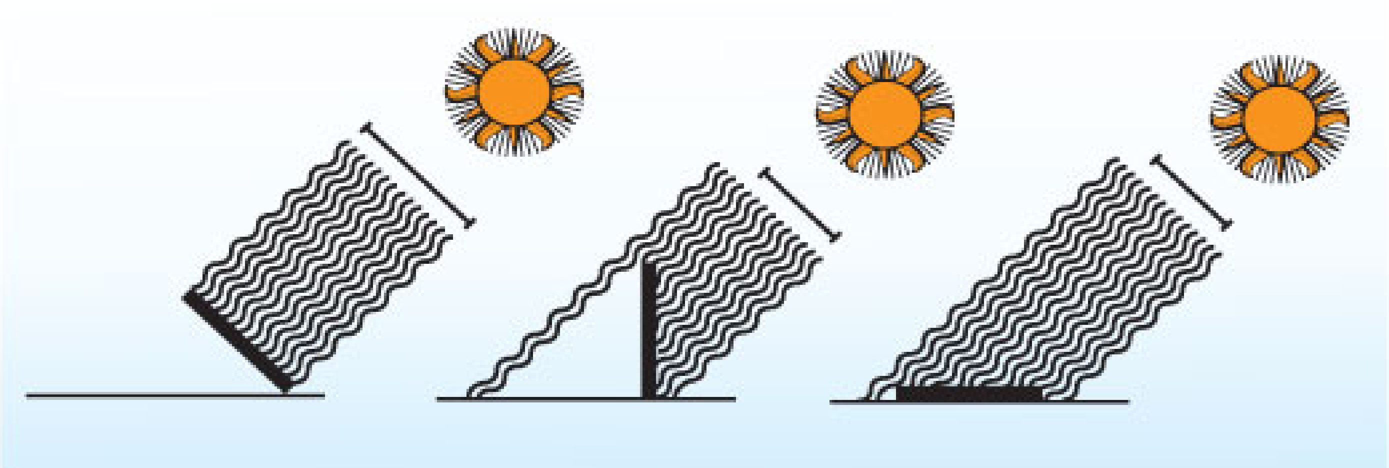


Figure Effects of tilt angle

To optimize a system's performance special considerations regarding tilt angle in different seasons must be taken into account. Panels with a tilt angle equal to the latitude will receive the highest insolation.

4.2 All You Need to Know About Batteries

Batteries are used to collect DC electrical energy produced by the PV system for later use. Since a PV system power output can and will fluctuate through the day depending on the clouds and the weather, the batteries are going to provide a relatively constant source for periods of reduced solar energy. Commonly used batteries come in two categories: the lead-acid and its variations, which are the liquid vented and the sealed battery, and the valve regulated lead-acid or VRLA. Alkaline batteries, such as Nickel-Cadmium and Nickel- Iron, are also used from time to time especially in very low temperature locations.

The lead-acid batteries are the most commonly used batteries for residential scale PV systems in the US. In many ways, if you were to judge by appearance, they resemble car batteries. However, they are different by design. Car batteries are intended to provide a huge amount of current for only a small amount of time, while batteries intended for use in PV systems provide relatively low-power output for longer periods and can be recharged under irregular conditions. Another difference between the two is the depth of charge, which is the amount of total capacity a battery is designed to lose between charges. Car batteries yield a small amount of their entire capacity, while PV system ones yield a substantial amount. That is why these batteries are also referred to as deep cycle batteries.

Figure 23 Lead-acid deep cycle battery

If the batteries are properly sized maintained, the life span for a PV system battery can be anywhere from 3 to 10 years or longer. Its lifespan mainly depends on the average depth to which you discharge a battery. Continually discharging a battery to 80% will accelerate it expiration and such a battery may die to as early as within 2 years. We recommend discharging the batteries up to 50% of their total capacity.

As previously mentioned there are two subcategories of the lead-acid battery – the liquid vented and the sealed or maintenance free battery. The liquid-vented battery has removable caps for adding water and maintaining the battery. It is built form positive and negative plates just like a car battery and the plates are made from the same material: lead and lead alloy, and are placed in a electrolyte solution of Sulfuric acid and water. Like an auto battery, this design requires voltage controller. In a PV system, this is referred to as a charge controller, which is used to protect your battery from over charging. When a battery is overcharged hydrogen gas, which is extremely explosive if it is contained, is produced thus posing a safety hazard. Other safety hazards when dealing with PV system batteries are high short-circuit potential, electric shock potential and causticity of the electrolyte. It is very important that all the necessary safety measures are taken when dealing with batteries.

The VRLA is a maintenance free battery because it is designed in such a way that they release the excess of pressure through a valve in the center in the case of overcharging. There are two types of sealed batteries used in PV systems. One of them is the gel cell in which the electrolyte is gelled by the addition of silica gel that turns the liquid into an actual gel mass. The other type of batteries is called the AGM batteries, which stands for Absorbed glass Material.

These batteries use a fibrous silica glass mat to suppress the electrolyte. The advantage of using these batteries lies in the fact that they are spill proof and will not even spill if the case is broken which is a perfect solution for RVs and since they require no periodical maintenance, they are a good choice for remote locations.

Figure 24 Valve regulated lead-acid

However, these batteries also have a few disadvantages. They usually cost more per unit of capacity per amp/hour when compared to the more conventional liquid batteries, are more susceptible to damage of overcharging particularly when they are installed in warmer climates, so you have to make sure your charge controller is working properly and they have shorter life spans then other batteries so not only do they cost more per amp/hour but they are going to last less time. Furthermore, they need to be charged to lower voltages and at lower amperage rate to prevent gas excess damaging the battery cell. This means that if you had a liquid lead acid battery and a gel one side by side you would want to recharge the gel cell at lower amperage and for a longer time than the liquid battery.

Previously we talked about charge controllers necessary when you are charging your batteries. Charge controller installation particularly applies to lead acid batteries because they need a device to protect them from overcharging and discharging. The charge controller performs several important functions one of which is to monitor the battery voltage so as the battery charges and discharges it is going to monitor the condition of the battery. It protects from overcharging which results in excessive loss of liquid, which causes hydrogen gas production, and protects the battery from excessive discharge. A lot of charge controllers today have an LVD, which stands for low voltage disconnect and which monitors the depth of discharge. When the battery gets to a certain threshold the LVD physically disconnects the load so that the battery is not completely discharged and damaged.

Battery capacity rated in amp-hours (Ah) is a measure of how much energy a battery can hold. To calculate the total energy capacity of a battery multiply the amount of amp-hours by the voltage. Therefore, a 100AH battery running at 12 volts yields 1.2kWh of energy. Batteries are available in 6 or 12 volts, which you can connect in series to get 6, 12, 18 or 24 VDC. However, if you are using an inverter it will not matter what the battery voltage is.

If you truly want to be independent from your utility company, you absolutely must have batteries installed in your system. Batteries store power not only for night use but also for day use. Your system will draw power from them when it is cloudy and when there is not enough sunlight to power all the loads of you household. Figure 25 shows the typical energy requirements of a household and energy production of a PV system.

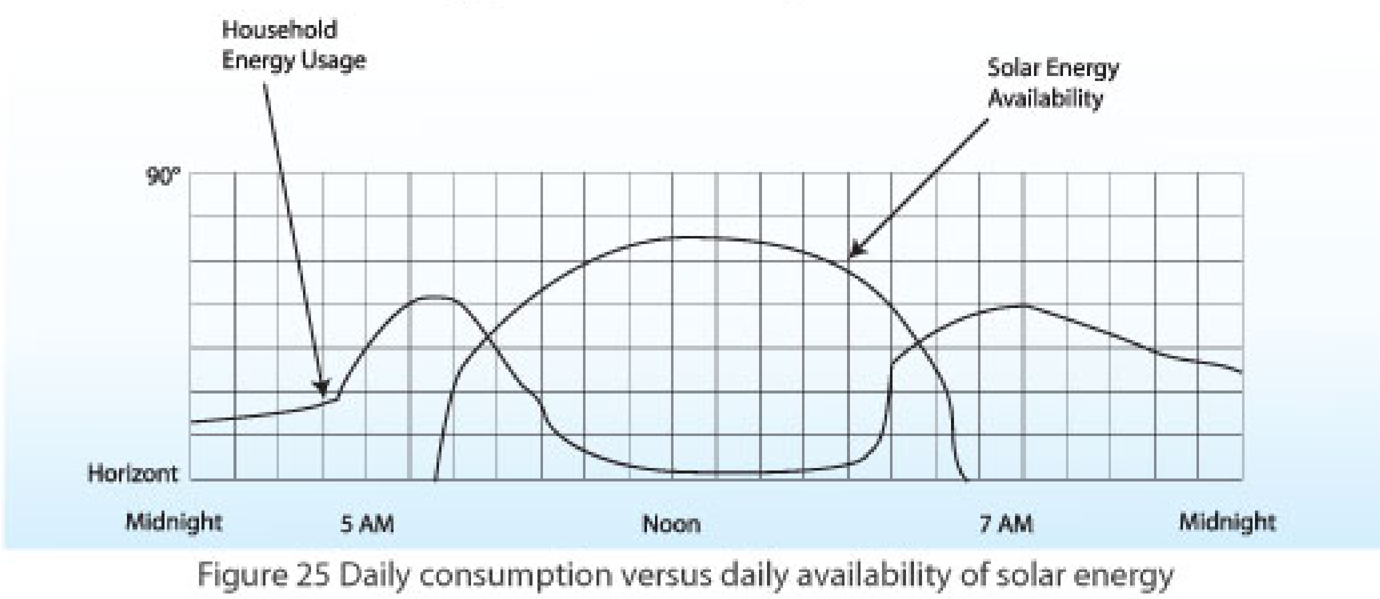


Figure 25 Daily consumption versus daily availability of solar energy

When the whole family wakes up in the morning, there is not enough sunlight to produce enough electricity for their energy requirements. During most of the day, when electricity production is at its highest, there is probably no one at home. Then, in the late afternoon when, again there is not enough sunlight, everyone returns. If this family didn't have batteries installed in their system their harvested solar energy would go to waste and their investment would have been futile because for the most of the day the solar energy is produced there is no one to consume that energy. With batteries, however, they store the collected energy and consume it when it suits them best.

4.3 Photovoltaic System Design and Sizing

One of the most important things when considering installing a PV system is to accurately determine its size. There are several factors you must take into account. First, the total amount of watt-hours per day that you will need. Then you will need to define the peak power output in watts and figure out the duty cycle. However, even if you should underestimate the size of the PV system best for you there is no need for worry because, as we said earlier, PV systems are modular and you can always increase power productivity by adding more panels.

4.3.a Load Estimates

The significance of the loads that we are going to power with our PV system lies in the fact that loads usually impose greatest single influence on the size and the cost of any PV system. We can minimize our PV system cost by efficiently using the energy we have available to us. Remember, reducing power consumption is a lot less expensive than building a PV system adequate enough to supply power for all the devices that we are currently using.

To start calculating your loads make a complete list of all the appliances and devices in your house and how much hours a day each is usually run (be sure to take seasonal variations into account). Some loads consume electricity all the time while others use electricity less often. Watts' consideration is the main component in designing and sizing photovoltaic system To determine the energy consumption of a load, multiply the wattage of the appliance by the number of hours it is used in a single day. Wattage can be read off the label of the appliance. If the label, however, states the amps instead of watts, multiply the amps by the voltage, which in most households is 120 volts, and that will result in the number of watts the device is using. For example, let us assume that you have a device plugged into the wall that is currently drawing 2 amps. When 2 amps are multiplied by 120 volts, the amount of wattage is 240 watts. By adding the totals of all appliances and including the phantom loads, you can determine what power output you need for your PV system.

Table 3.2-1 shows typical wattage requirements for some common household appliances.

Individual loads	Qty	X	Watts	X	Use Hrs/Day	=	Watt-Hours/Day
Lights (fluorescent)	10	X	9	X	6	=	540
VCR	1	X	30	X	1	=	30
TV	2	X	70	X	3	=	420
Computer	1	X	100	X	7	=	700
Energy Star Refrigerator	1	X	110	X	6	=	660
Clothes Washer	1	X	800	X	1	=	800
Clock Radio	1	X	1	X	24	=	24
Coffee Pot	1	X	200	X	0.5	=	100
Microwave	1	X	1400	X	0.25	=	350
TO TAL WATT - HRS/DAY							**3624**

Table 3.2-1

For the items listed above, you would need a system that produces an average daily energy output of 36.24 kWh. As we mentioned earlier, different locations receive varying amounts of sunlight, which must be taken into consideration when calculating the size of the PV system necessary. To give you a better understanding how much your location can influence the size and cost of your system, we will review two locations Albuquerque, New Mexico, in which a PV module will produce 6.2 watt-hrs of electricity daily[5] and Pittsburgh, Pennsylvania, in which the same module will produce 2.4 watt-hrs daily.

To calculate the size of the system (as represented in Table 3.2-2[6]) each will need we will divide the daily power requirements by the average daily output, divide that by 0.8 to account for battery inefficiency, add 10% to cover anything that has been overlooked or to allow for the growth factor and divide 140, which is the amount of watts each module will produce.

Albuquerque	**Pittsburgh**
$3624 \div 6.2 = 585$ $585 \div 0.8 = 732$ $732 + 74 = 806$ $806 \div 140 = 6$	$3624 \div 2.4 = 1510$ $1510 \div 0.8 = 1888$ $1888 + 189 = 2077$ $2077 \div 140 = 15$

Table 3.2-2

[5] Winter average of daily electricity production.

[6] All the numbers have been round up to the higher number.

Daily energy consumption can be calculated by using the simple calculation as the one above or through sophisticated computer programs· Whichever way you choose to calculate your daily power requirements· there are two more factors you need to consider·

The first one is duty cycle· which is a measure of how often the system will be in use· For example· a lake house might have a duty cycle of 25% while a residential home has a duty cycle of 100%· The second consideration is the peak instantaneous power output· which is the amount of power measured in watts for all the appliances running at the same time· This is a part of the system specification over which you have a lot of control because you can choose to run heavy power consuming appliances at different times·

The next feature of PV system installation that will have an effect on system design and cost are the batteries· It is very easy to calculate the size of the battery bank that you will require· For our example· we will assume a 12VDC system and the amount of watts·hour/day from the previous case· Divide the amount of watt·hours/day by 12VDC multiply by two in order to cover one day of reserve power and then multiply by factor 2 to make sure that the batteries are not drained more than 70 percent of their available energy·

$$3624Wh/day \div 12VDC = 302Ah$$
$$302Ah * 2 = 604Ah$$
$$604Ah * 2 = 1208Ah$$

Therefore, in order to have enough power to run all of their appliances and have a day of reserve power the household in Albuquerque or Pittsburgh needs 1208Ah of battery capacity.

As always, some useful online resources can help you calculate the size of your PV system. Some of them can be found at Alternate Energy Resource Network's website .

4.4 DIY or Hire a Contractor?

When considering a large-scale project such as constructing a PV system, understanding the entire process is the most important thing. There is a variety of factors to take into account when making the decision to either do the project yourself or hire a contractor.

4.4.a DIY

Designing, assembling and installing a PV system is a laborious and lengthy task. Nonetheless, this is not to say that you should get discouraged right away and hire a contractor, or even worse give up on the entire idea.

Most people are impatient and like to get things done right away, and when not everything goes the way they planned, they get frustrated. To avoid being one, you will need to pace yourself. Constantly remind yourself that some things in life do take time and that making a PV system is one of them. Do not set any deadlines or schedules that will cause you to speed things along and make mistakes.

Knowing more about the subject will ease the task of making a PV system immensely. Do not limit your knowledge to what is written in this book. Numerous easy-access free online resources can help you a lot.

Before actually buying all the necessary materials to construct your system, calculate, recalculate and re-recalculate your load power consumption and required power production. Making drawings of your would-be system can help as well – the more you go in detail the better. Contact stores that sell the equipment and materials that you are going to need and find the best deal. Contact contractors and ask them for advice – you will find that many are willing to give their recommendation without reimbursement. Finally, go to the county building department and inquire about the codes in your area.

4.4.a.a The Code

One of the major hassles in going solar is passing the code and getting all the necessary permits. Though government regulations, laws and codes exist to create a safer, more reliable environment for all, usually they irritate anyone who has ever tried to make any kind of modification to their property.

The first step is to visit the county building department, talk to an inspector and get his opinion on what you need to do to make the project viable, how long the entire process of getting permits lasts, what fees are involved and what inspections are necessary. No doubt, he or she will tell you that in order to apply for permits you will need drawings of all the modifications that you are planning to make. Make initial drawings – possibly based on other drawing that have passed code which you can find in the county building department – and go for an informal visit because once you submit your drawings that's it. Any adjustments to the original design require resubmitting the drawings and getting new permits. When you are finally ready to submit for permit, make sure the drawings are detailed as much as possible. Remember to include materials and specifications lists.

4.4.b Hire

A contractor can be hired to do the entire project – from design and obtaining permits to assembly and installation – or can be hired to do just part or parts of the project. When considering hiring a contractor there are several steps you must take.

First, shop around. Get bids from multiple contractors. Do not go for the cheapest bid without asking around why it is so cheap and without getting referrals. Get referrals even if you have complete confidence in a contractor. Visit a site where the contractor has installed a PV system, examine the system itself and, if possible, talk to the owner and get his or her opinion.

Hiring a contractor means that you are indirectly employing him, so it is a good idea to interview all the potential candidates. Make a list of questions beforehand and ask the same questions of each contractor. Take our time in deciding which the best one is. Above all, negotiate and get everything in writing.

Hiring a contractor can save you a lot of time and manual labor; however, it will not save you money. Expense is the main reason why people opt to build a PV system by themselves. A standalone PV system designed and installed by a contractor can easily cost more than $20.000 so ask yourself are you willing to pay such a price when you can build one yourself at only fraction of the amount.

DIY PV PANEL ASSEMBLY

The entire process of designing, assembling, installing and getting the PV system permitted may take up to 3 months – in some cases even longer mostly depending on the amount of time needed to get all the necessary permits. Furthermore, since a lot of money is in play you want to make sure that everything is done right.

Here is a step-by-step list of all you need to do to become utility independent:

1. Research the subject as much as possible.
2. Perform an energy review of your household to determine the amount of power you are consuming and on what.
3. Make your home energy efficient by changing some daily habits or by making some minor or major investments.
4. Decide on the amount of money you are willing to invest in the project.
5. Determine the size of the PV system that will satisfy your needs.
6. Determine the cost of the PV system that will satisfy your needs.
7. Determine if your household has enough space for the installation of the PV panels.
8. Create sun charts.
9. Determine the proper location for your PV system.
10. Determine the proper tilt of your PV system.
11. Make preliminary investigations into building codes and regulations and find out what steps are necessary for you to take to get a permit.
12. Make secondary investigations into building permits and remember to bring your drawings with you so that you can get some advice from the building department inspector.
13. Once you are sure that you design is feasible in the eyes of the county building department, apply for a permit.
14. Order or buy materials and necessary tools and start assembling your PV system. Take your time because you are dealing with delicate materials. Solar cells are paper thing and can break almost by simply breathing on them.
15. Once you have made your solar panels mount them.
16. Connect all the necessary wiring except the connection to the main electric panel of your household.
17. Wait for inspections by the county and the utility company.
18. Wait for the utility company to put in a new meter and connects you to the grid.
19. Submit paperwork for rebate payments.
20. Consume electricity prudently and in an energy efficient manner.
21. Maintain and repair the system.
22. Invest yourself in a new solar project like a solar water heater.

5.1. Assembling a Photovoltaic Panel

Before you actually start assembling your PV panel, let us make sure that you have all the necessary materials and tools for the job because the worst thing is being right in the middle of work and find out that you are missing something.
Tools:

1. Acrylic cutter
2. Drill and drill bits
3. Caulk gun
4. Multi-meter
5. Soldering iron
6. Respiratory and eye protection
7. Gloves
8. Stainless steel screws and nuts
9. A Phillips and a flathead screwdriver
10. Fine point needle nose pliers
11. Pencil or marker
12. Carpenter's square and measuring tape
13. Testing block

Materials:

1. Solar cells
2. White and clear acrylic sheaths
3. Caulk – liquid silicone
4. Flux, flux pen and solder
5. Chase Nipple and J-box
6. Tab and bus wire
7. C-profile aluminum frame
8. Low gauge wires
9. Double terminal strip

Before anything else is done, you must determine the size and design of your solar panels. The size of the panel will be determined by the size and quantity of the solar cells used, however, the most commonly used solar panels consist of 36 cells connected in three rows of twelve columns or in four rows of nine columns, which almost entirely depends on the amount of space available for mounting the panels. To demonstrate how to calculate the size of the acrylic needed for the front and the back of the panels we opted to use four rows of nine.

5.1.a Calculating the Size of the Panel

Start by measuring the size of the individual cell. For the purpose of this example, we are using cells that are 3¼" by 6". Four 6-inch wide cells equal to 24", but because we need some space in between them and on each side, we are going to factor in a ¼ of an inch for each space. Finally, we need room for the c-profile aluminum frame on both sides for which we add two times its width – in our case 1".

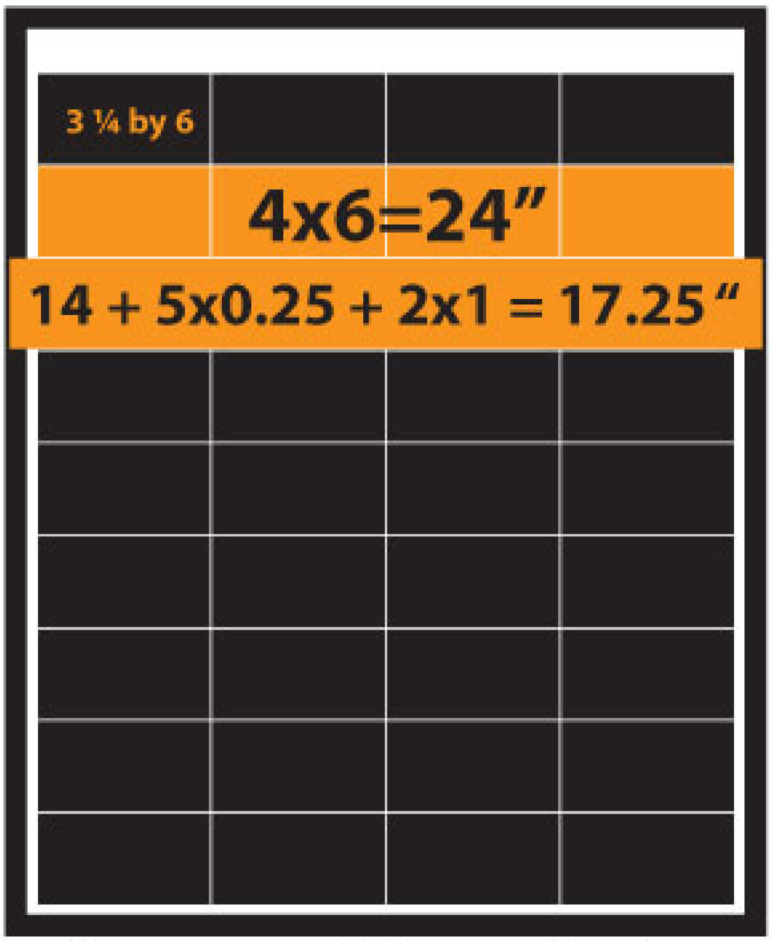


Figure 26 Calculation example of the width of the PV panel

The height of the panel frame is calculated similarly, however, some extra space at the top and bottom is needed for the bus wires and the J-box. 3¼" times nine cells, a ¼ of an inch for the space in between the rows, 2 times the width of the c-profile, 1" on the bottom for the bus wires and 3" on top for the bus wire and J-box.

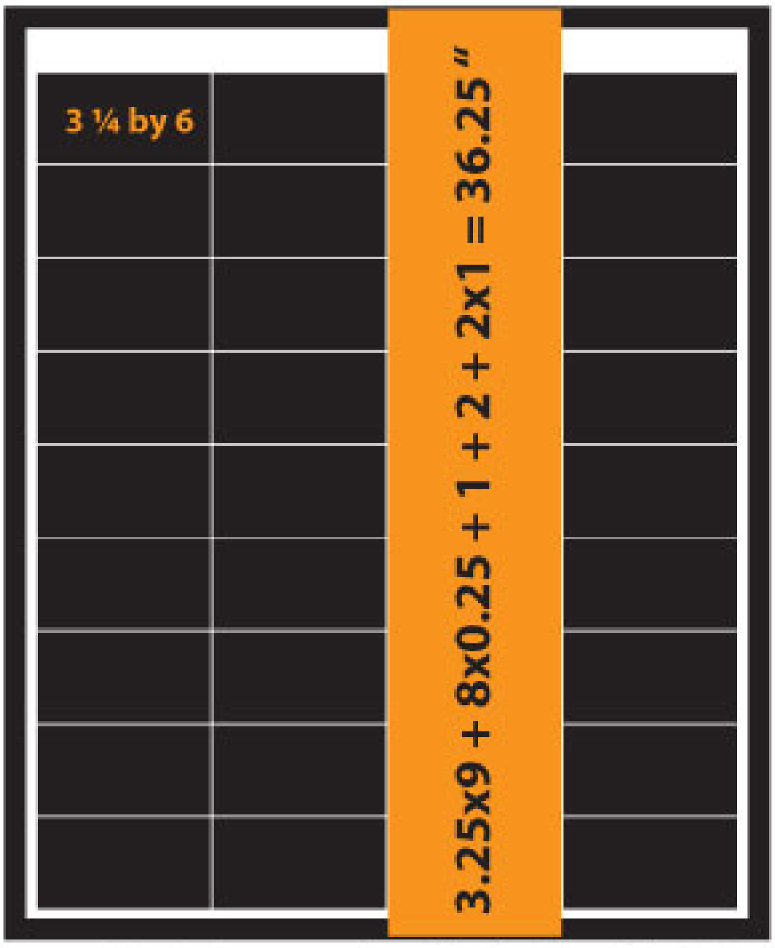


Figure 27 Calculation example of the height of the PV panel

5.1.b Soldering the Cells

Solar cells are extremely fragile paper-thin squares or discs. The front, or the negative, side of the cell is black with two contact strips across it whereas the backside, or the positive, is grey with two columns of three contact points. Because the front of the cells is easily stained you want to avoid touching it and should even wear gloves when handling them.
There are two types of solar cells: pre-tabbed and un-tabbed. Many people decide to get the pre-tabbed cells – even though they do cost a bit more – because they save a lot of time since the tabbing wire is already soldered. The tab wire on the un-tabbed cells must be soldered on each contact individually.
However, should you choose to use the un-tabbed cells here is how to solder the tabbing wire. First, cut out all the tabbing wire that you are going to need to connect all of your cells. The length of the wire should equal the height of 2 cells plus a 1/3 of an inch to allow for the expansion and contraction of the cells and the tab wire. Lay the cell face up (the black side of the cell), take the flux pen and apply it to the contact strips in order to clean them. Then take a piece of the precut tab wire and line it up with the contact. Dip the soldering iron into the flux and apply a bit of solder on the tab for the entire length of the strip.
When you have soldered the rest of the contact strips or if you chose to get the pre-tabbed cells, you can proceed onto soldering the cells together. Because you are trying to connect the front contact lines with the back contact points, lay two cells face down and align the contacts. Clean the contact points with the flux pen and dip the soldering iron into the flux. With the tip of the soldering iron take a bit of the solder, press the tab wire down against the contact points and apply the solder. Repeat the same process for all contact points in each of the columns and continue connecting the cells until you have four stringers consisting of nine cells or three stringers consisting of twelve cells. However, because the first (in the case of the un-tabbed cells) and the last cell of the stringers will not have the tabbing wire attached you need to solder those on as well.
If you should happen to break a cell in the process, gently pull up the tab wire with a knife or something handy, heat up the connection and the solder will come off.

5.1.c Attaching the Cells to the Acrylic and Making the Final Connections

Before attaching the stringers to the acrylic, a wise course of action would be to test if they are working properly with a multi-meter. Take the stringers outside and make sure you have enough sunlight. Place the first cell in the stringer on the testing block, which is just a highly conductive piece of copper attached to a piece of wood by two screws, measure the amps and the volts that the stringer is producing and compare the numbers with the cells specification. If everything is in range, you can proceed with attaching the cells.
Mark out on the acrylic where the cells are going to be placed to make sure that the stringers are lined up nicely. Then put a tiny dab of silicone on the back of each cell, pull up the stringer and flip over onto the acrylic. Because the silicone will not immediately dry, you have some time to move the cells around a bit, if you have not placed them on the markers accurately. When they are in place where you want them, make sure that your hands are clean and apply a bit of pressure in the middle of each cell to spread out the silicone evenly. Repeat the process for all the stringers making sure that their ends are in positive to negative sequence.
In order to have an unbroken circuit we will connect the stringers in series as follows: the bottom two cells of the 1st and 2nd row, the top two cells of the 2nd and 3rd row and, again, the bottom two of the 3rd and 4th row – in other words, positive to negative.

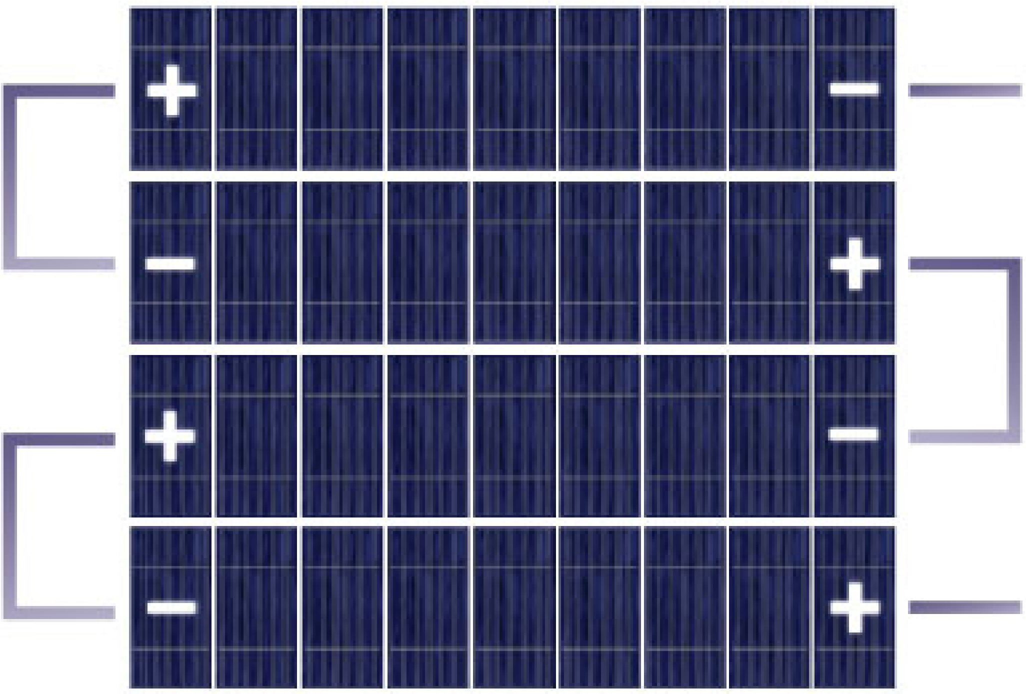


Figure 28 stringers connected in series

The principle of soldering the bus wire is the same as in soldering the tab wire to the cells except this time you are soldering two wires together. Wrap the tab wire around the bus wire, dip the soldering iron into the flux, take some solder and apply it to the connection. When you have connected the wires as shown in Figure 28, you will have the tab wires of the first and last cell unconnected. Take two pieces of bus wire and solder the two tab wires of each cell together.


Figure 29 Soldering the unconnected tab wires

However, before connecting them to the homeruns, you must drill a hole in the middle of the acrylic for the Chase Nipple and the J-box. Measure out the middle of the panel and drill a hole big enough to accommodate a ½ inch Chase Nipple. Then drill the exact size hole in the J-box as well because the Chase nipple is going to through both of them. Flip the panel so that it is backside up, apply silicone on the edges and in the middle of the J-box, and lay it on the panel so that the two holes are exact to one another. When the silicone has settled, you can proceed with placing the double terminal strip. Put the terminal strip into the j-box where you feel it is centered, mark of the edges with a pen, take out the terminal strip, apply silicone and set it down again. Carefully flip the panel over apply silicone on the rim of hole you have drilled and place the Chase Nipple into the hole. While the silicone is settling, you can work on the wires or the homeruns.

The wires that are going to be coming out of the panel should be insulated and in two colors so that you can determine the negative and the positive lead just by looking at them. The colors that are usually used are black for the negative and red for the positive.

Pull the red, positive, and the black, negative, wire through the chase nipple. Skin off the insulation of the end of the negative wire, apply some flux and solder to the soldering iron and solder the negative homerun to the negative bus wire. Repeat the process for the positive lead as well. Once you feel confident that you have made a good connection, pull up the soldered wires and apply some silicone beneath them in order to secure them in place.
When you are sure that the silicone has dried, flip the panel backside up in order to connect the homeruns to the terminal strip. Skin some insulation off the end, unfasten the screws a little bit and push the wire into the holes underneath the screws. Do the same with the other wire and after you have put together the entire panel box, you are going to pull two more wires that will be connected to the charge controller through the top holes of the terminal strip.

5.1.d Final Assembly

Final panel assembly entails completing the frame of the panel. For this stage, you are going to need the clear acrylic sheath, drill and drill bits, carpenter's square, screwdriver, screws and nuts. Take out the clear acrylic and put it over the panel in order to measure out where to cut the c-profile aluminum frame. Slide the frame onto the panel and, by using the carpenter's square, mark of a 45° angle on one side of the frame. Next, go to the other end of the panel, mark of another 45° angle, and cut the frame in those two places. Repeat the process for all four sides. Once you have the c-profile cut, mark off where the screws will be coming into place keeping in mind that they should be spread out evenly along the frame. However to ensure not break the acrylic or the cells, drill the holes into the frame first and then into the panel. Therefore, slide out the frame, take a smaller drill bit for the pilot holes that will ensure the drill stays in place. Once you drill out the pilot holes, change the drill bit and use the bit that corresponds to the bolt you are going to put in.
After the holes in the c-profile have been drilled out, slide the c-profile back onto the panel and drill out the holes into the acrylic while making sure you are drilling at a 90° angle so that all the holes align. Slide the bolts through, put the washers and the nuts and make sure that they are screwed on tight enough.

5.1.f Testing

Testing the entire panel and its connections is a very important step in installing your PV system because faulty wiring may cause electrical problems for your equipment.
In order to test a panel, the first requirement that must be met is to have enough sunlight so that the reading you get on the multi-meter will correspond to the voltage and amperage amounts you were striving for. The second requirement is to have the homeruns coming out of the terminal strip located in the J-box. Hence, as before, take two insulated wires, preferably black for the negative and red for the positive lead, loosen the screws and slide in the wires, the positive and the negative respectively and you are ready to take measurements.

5.2. Dos and Don'ts

Reckless behavior, negligence and not thinking things through in PV system installation can bring a mountain of harm. Take care of malfunctions, not only in your PV system but also in the entire electric wiring and appliances, immediately and as quickly as possible. Make sure to mend the malfunction in the most practical and safest way possible. Think before doing something from which there is no going back. Measure twice and cut once. Do not be greedy – there is no point in being greedy when it comes to solar energy. By making a PV system that generates more power than you can consume you are wasting because you get nothing for the excess power that you are not using. Be sensible when deciding to install a PV system. If you live in an area with low sunlight, exposure there is no point in installing a PV system because to install one that will satisfy your daily electricity needs will probably take a lot of money. Do not skimp on materials – cheaper materials equal substandard quality.

List of online resources:

1. US Department of Energy – Energy Efficiency and Renewable Energy
www.eere.energy.gov/consumer
Consumer website with valuable information on how to make your home energy efficient and where you can learn more on renewable energy.

2. The Energy Grid
www.pvwatt.com
Free solar energy calculators

3. US Environment Protection Agency and US Department of Energy
www.energystar.gov
Website where you can learn more about Energy star rated appliances.

4. University of Oregon Solar Radiation Monitoring Laboratory
http://solardat.uoregon.edu/SunChartProgram.html
A free online calculator for plotting sun charts.

5. Alternate Energy Resource Network
http://www.alternate-energy.net/calculateamp02.html
Online resource of free solar energy and energy usage calculators.

6. US Department of Energy database
http://tonto.eia.doe.gov/state/
Energy information about your state.

7. Home Power Monitoring
http://www.homepowermonitoring.com/
Website where you can learn more on the electricity usage of household appliances.

8. The Consumer Energy Center
http://www.consumerenergycenter.org/index.html
Website with the latest information about energy resources and how to use them wisely in our home, work and vehicles.

9. Clean Power Estimator
http://www.consumerenergycenter.org/renewables/estimator/index.html
An economic evaluation software program the California Energy Commission is licensing for use from Clean Power Research. The program provides California residential and commercial electric customers a personalized estimate of the costs and benefits of investing in a photovoltaic (PV) solar or small wind electric generation system.

10. Find Solar
http://www.findsolar.com/index.php?page=rightforme
The Solar Estimator is meant only to give you an idea of price, savings and system size.

11. Go Solar California
http://gosolarcalifornia.ca.gov/nshpcalculator/CECPV_2_0.msi
A detailed hourly calculation tool based on the 5-parameter model developed by Dr. Beckman's group at the University of Wisconsin, incorporating detailed inverter performance modeling and uses the weather data from the 16 climate zones in California.