Living off-grid in the Yukon

Efficient renewable energy use and practices

Natural Resources Canada
Ressources naturelles Canada

energy solutions centre

Yukon
Energy, Mines and Resources

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All photos by Peter Long, Joel Luet or Energy Solutions Centre.

This document is available with live links at www.esc.gov.yk.ca/pdf/living_off_the_grid.pdf..

ABOUT THE PROJECT

Natural Resources Canada (NRCan) manages a research program that fosters renewable energy technologies and integrated systems. Its goal is to improve the reliability, cost effectiveness and social and environmental advantages of these technologies and systems so that they become the preferred energy options for people who live off the electrical grid.

The Yukon Energy Solutions Centre (ESC) provides technical services, undertakes research and demonstration projects, and manages programs to facilitate efficient and renewable energy solutions for residential, commercial, First Nations and government clients.

The Yukon off-grid residential renewable energy project is a collaborative effort of NRCan and ESC. The project consisted first of a survey of 254 Yukon off-grid residence owners. This was followed by a baseline study of the renewable energy usage and energy efficiency of 30 of these off-grid residences. Finally, an integrated design charrette was held to focus on three of these residences.

Other parts of the project include the provision of technical support for the upgrade of renewable energy systems and the energy efficiency of the participating homes, as well as the creation of this guide.

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Introduction

The Yukon's energy grid reaches only a small part of the territory. Those who wish to live outside that area must do without electricity or produce their own. Off-grid living generally refers to living unconnected to the public electric utility system. This document discusses how to live off-grid, the parts of the puzzle that make up a home renewable energy system, and some advice from others who have embarked on an off-grid lifestyle.

Is it for you?

There are many reasons to choose to live off-grid. Maybe it's geographic — you have found your little bit of paradise to build your dream home, but it is too far from the electrical grid to be economically feasible to connect to it. Maybe you have a cabin back in the bush and would like to have a few modern conveniences. Or maybe it's an ethical or environmental choice — you want to produce and use clean energy so that you can reduce the environmental and social costs associated with non-renewable energy sources.

Whatever your reason for living off-grid, your quality of life can be as good, or better than, it would be living connected to the grid. You will need to be more involved in the workings of your energy system: monitoring the state of your batteries, deciding when to run your generator, conserving energy, and planning for the use of items that consume a lot of electricity. The first rule of off-grid living is that the electricity you produce must be equal to or greater than the electricity you consume. If you can manage your demands to keep them within a reasonable level through conservation and wise use of energy then your renewable home energy system can provide for you without being too costly or unwieldy. One dollar worth of energy conservation can save three to five dollars in energy generation equipment costs.

Your home energy requirements will be greatly affected by your lifestyle. Do you work at home? If so, are you working on a computer, a table saw, a sewing machine or in a recording studio? If you want all the latest bells and whistles (there's an off-grid home with its own climate-controlled wine cellar!) and aren't prepared to conserve energy, then you will pay more for a larger energy system.

As your lifestyle changes over time your energy requirements will also change. A growing family or a new big-screen TV entertainment system means growing energy demands. Think ahead when planning and try to build in flexibility.

If you are new to photovoltaics (solar), wind or micro-hydro power, they may seem confusing and complicated. But the same thing can be said about computers, CD players, microwave ovens, cell phones and programming the clock on your VCR. Living off-grid will soon become part of your routine, as will the satisfaction of knowing the source of your power. And you won't be subject to the occasional blackout suffered by those connected to the grid.

This rustic-looking cabin has a simple renewable energy system yet houses a growing family and a home-based business.

This off-grid home could be built in any northern neighbourhood and not look out of place.

Who is living off-grid in the Yukon?

There are people producing their own electricity all over the world. They live in the middle of large cities, in the middle of vast wilderness, and in points between.

A 2002 survey of off-grid homeowners in the Yukon showed that there is a wide range of housing, from rustic cabins to modern R2000 style homes, varying in distance from the grid.

Similarly, renewable energy systems ranged from a simple single photovoltaic panel and car battery to very sophisticated hybrid systems operating with varying degrees of efficiency.

The people living off-grid are equally varied. Among them are designers, artists, Yukon Quest dog mushers, government workers, outfitters, builders, social workers, growing families, and families that have grown up off-grid. Here are some more interesting facts from the Yukon homeowners who responded to the off-grid survey.

- 60 percent operated a business from the property.
- 46 percent were more than five kilometres from the grid.
- 34 percent did not want to connect to the grid.
- Wood was the primary source of heat and 40 percent of the residents used wood for heating hot water.
- Propane was the primary energy source for cooking (84 percent) and heating water (62 percent), generally with a propane hot water tank.
- Almost everyone had a gasoline or diesel powered generator.
- 57 percent also used renewable energy, mostly photovoltaic (53 percent), with some wind (7 percent) and one used micro-hydro. Most of those using a renewable energy source were able to generate the bulk of their summer electrical requirements from renewable energy. Only a few were able to meet the bulk of their winter electrical needs with renewable energy.
- The median cost for a generating system was $10,000. However, those using photovoltaics had double the median cost ($12,500) of those who did not ($6,000). The average number of photovoltaic panels was five, with a median of 295 total watts generating capacity.
- The most popular small appliances were TVs and VCRs.
- Almost all people had numerous power tools such as table saws; 56.5 percent had compressors and 44.7 percent had welders.

What off-grid living means: Characteristics of an off-grid home

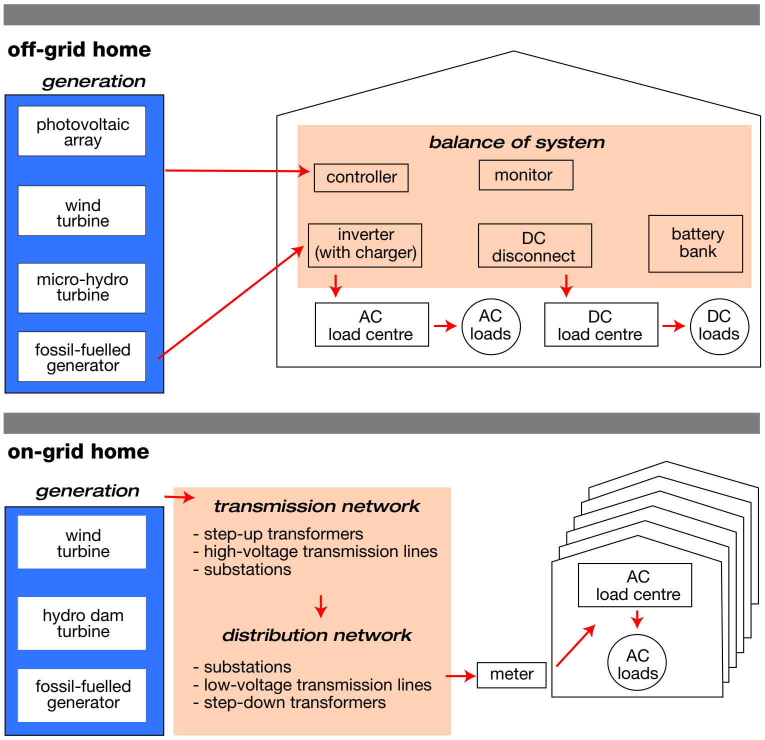
People in both grid-connected homes and homes off the grid use electricity. Grid-connected homes get 120/240 volt alternating current (AC) electricity from hydro dams and large diesel generators (and nuclear and coal-, oil- and gas-fired power plants) via long power lines that connect, through a meter, to the electrical panel in the house.

Off-grid homes have shortened the line and have the electricity generating equipment in their backyards. Their electricity comes from a photovoltaic array, wind turbine, micro-hydro turbine and/or a fossil-fuelled generator. Collectively, the other parts of the system equipment are known as the balance of system (BOS) and include low-voltage (12 volt) direct current (DC) electrical storage (batteries) and regulating equipment (controller, inverter, battery charger, DC disconnect and monitor) right in the house. Instead of paying for someone else to look after the supply of electricity, people living off-grid need to be their own power managers.

Many of the topics covered in this document may seem obvious on their own, but when brought together they will provide an integrated skeletal picture of an off-grid home that you can flesh out into a finished product using proven, available technology.

There is no definitive statement that says, “This is the way to do it!” Rather, this document will provide you with insights into living off-grid, ideas for how to design your system and resources to tap into.

Many people who think of living off-grid only consider the method of producing electricity. Instead, you need to take an integrated approach, taking into consideration the design of the building itself, how you will heat it, how you procure and heat water, and your lifestyle.

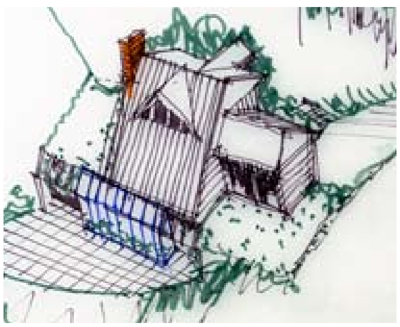


Consider the following.

- If you heat your house with a forced air furnace and its attendant electric fans, it will affect the size of your renewable energy system.
- Radiant heat from a woodstove lends itself better to open-concept house designs.
- How well your home is insulated and sealed will affect the size of your heating system and the amount of fuel needed to keep you warm.
- The size, type and placement of windows will affect passive solar heating as well as the time of day you need to start turning on electric lights. This in turn affects the size of your energy system.
- Your choice of appliances will affect the size of your electrical system. An electric hot water tank would be a huge drain, while an on-demand, propane water heater or a solar water heater may be good options.
- Your ventilation choices, whether mechanical or passive, will affect the size of your home’s renewable energy system.

If you currently have a home and are trying to upgrade or convert it to a renewable energy system, your options may be more limited. You will need to start by evaluating all aspects of your house and its systems. In short, designing the whole package at the beginning will result in a more efficient, comfortable, cost effective and satisfying home.

Figure 1. Electric system components for an off-grid and on-grid home



Where to build an off-grid home: Site layout

What is the perfect location for an energy efficient off-grid home? Ideally, it will be a place that enables the best use of the available renewable energy — sun, wind or micro-hydro. It will be a south-facing slope with a small- to medium-sized lake at the foot of the slope. The lake will be deep enough to supply domestic water. Down one side of the slope, a stream will flow all year into the lake. The slope will be mostly devoid of trees except for a few deciduous trees in an area from the southeast to the southwest. The rest of the area will be covered with a mixed coniferous forest, except for the top of the hill, which will be bare of trees. The surrounding mountains will be close enough to provide beautiful vistas but distant enough that they won't block the sun on the shortest days of the year. As an added bonus, the winds at the top of the hill will average six to seven metres per second.

The components of a site like this are commonly referred to as aspect, slope, ground cover, exposure and view. While these rarely combine to form the perfect spot, careful analysis of your location should provide the optimal site and layout for your off-grid home.

Aspect

Aspect refers to the direction that your house and location face. To make the most of the sun in the north, face your photovoltaic modules and house due south (not magnetic south).

If you look at slopes you will notice that the vegetation on south-facing slopes tends to be composed of species more adapted for drier, warmer conditions. You will also notice that the snow disappears earlier in the spring. This is because of warmer southern winds and the amount of sun a south-facing slope gets compared to a north-facing slope. Obviously, if you want to use the sun to warm your home and to produce electricity, building it on the south side of a hill is best.

Aspect is not as important a consideration for maximizing your wind resource because a wind turbine can rotate to face any direction.

This house, built into the side of the slope, uses the insulating qualities of the earth to regulate temperature.

Don't be afraid to put windows on the north side of your house to enjoy the view.

Slope

A sloped site may make construction of a house more difficult, however, you can dig the house into the hillside and benefit from the insulating properties of the ground. Placing it there may also provide some protection from cold north winds and reduce heat loss from the house. The slope may provide a route for water tumbling to a micro-hydro turbine. The top of that slope could be a good site for a wind turbine.

Ground cover

Coniferous trees on the north side of your house provide some protection from cold north winds in the winter. Deciduous trees on the south and west sides provide shade in the summer but, when they lose their leaves in the fall, allow the sun to shine into your house.

Exposure

Clear, unobstructed access to whatever energy source you are using is ideal but rarely achieved. Topography (hills, mountains, valley orientation) and ground cover (large trees) often get in the way.

A small hill or ridge may be tall enough to block the low winter sun if it is close enough to your photovoltaic panels, while a higher mountain may not be an obstruction. The key is the distance between the obstacle and your photovoltaic modules.

Under certain circumstances a lake can be an obstacle. When the weather is cold and still, mist can form and, if the lake is sufficiently large, rise off the water high enough to block the sun.

In order for a wind turbine to work as efficiently as possible it needs a laminar, or smooth flow of air through the blades. Hills, ridges and trees cause the wind to become turbulent. A turbine needs to be raised nine metres above any obstacles within 90 metres of the tower.

View

The view from your windows may not affect how well you harvest energy for your home but it will affect the pleasure you get from your surroundings. You will get more solar energy for electrical generation and passive heating from the south but, if you have a beautiful view to the north, by all means, put in a window that will allow you to enjoy that view. It would make sense, of course, to make that window as energy efficient as possible.

An open area in front of a house is good for solar exposure and better wind flow.

How to build an off-grid home: Case study of the Luet house

The Luet house was one of three off-grid homes used in the Whitehorse integrated design charrette focusing on off-grid living in the Yukon (see Appendix 1). Joel and Trish Luet have been living off-grid in the Yukon for 10 years. Their interest in alternate energy, born out of necessity, has grown into a lifestyle.

When they moved to the Yukon in 1995, Joel and Trish lived in a thin-walled trailer with no electricity, no running water, and only a small woodstove. They started out using candles and propane lights, then progressed to a small photovoltaic system with two solar panels and four golf cart batteries that powered a few DC lights, a stereo and a radiophone. The system had a 2200 watt generator as backup.

Trish and Joel enjoyed producing their own power, so when they built their new home they decided to stay off the grid even though connecting to it would have been very easy. They used many of the principles of integrated design when they planned and built their home and its heating and electrical systems.

The home was designed and constructed by Trish and Joel to be energy efficient and to minimize the impact on the environment by reducing the embodied energy (the energy used to produce the materials) in the construction of it. The result is a very energy efficient home that is completely powered by renewable energy for nine months of the year.

In addition to their sweat equity, the house cost approximately $165,000 to build and $15,000 for the renewable energy system, demonstrating that an energy efficient house powered by the sun can be affordable, even in remote areas of Canada.

Timber frame raising was a co-operative effort.

Features and considerations

The Luet house sits on a flat, three-acre lot, surrounded by aspen forest. The house is two stories plus a loft, with an attached garage. Its rectangular design, while not as space efficient as a square footprint, maximizes southerly exposure for passive solar heating and allows the low winter sun to penetrate all the way to the back wall. Its open concept floorplan simplifies heating and cooling systems and will be easy to modify to accommodate future lifestyle changes.

The timber frame style of construction was chosen for its beauty and history of craftsmanship. There are thousand-year-old timber frame buildings still standing. The timber frame is constructed with locally grown and milled timbers. The enclosing walls were constructed with Larsen trusses, which use approximately 50 percent less wood than a standard wood frame house and significantly reduce thermal bridging.

Insulation is blown cellulose to R45 in the ceiling (R59 over the loft) and a combination of blown cellulose and fibreglass to R38 in the walls. Cellulose was chosen because of its good insulating qualities and because it is made from recycled newspapers. The fiberglass used had a 40 percent content of recycled glass.

Larsen trusses used in construction.

> "I like knowing that our house could be standing much longer than the time it took the trees used to build it, to grow."
>
> *Joel Luet*

A Tulikivi soapstone masonry heater warms both the house and the eye.

The metal roof was chosen for its ease of installation, durability, fire resistance and ability to be recycled at the end of its life.

The Luets wanted to be able to enjoy the mountain views that surround their home and make the best use of natural light, so choosing energy efficient windows was a high priority. Their windows are all hard coat low-e, half-inch argon filled, with insulating spacers. They are primarily triple-glazed with one double-glazed window. There are a minimum number of windows on the north side of the house.

The primary heat source is locally harvested wood burned in a Tulikivi soapstone masonry heater. The Tulikivi, although more expensive than most conventional woodstoves, uses about 50 percent less wood, burns cleaner and is as much a sculpture as a source of heat. Backup heat is from a Rinnai, direct vent propane space heater.

Cooking is performed on a Heartland Oval wood cookstove which also provides supplementary space heating and increases the versatility of the home heating system. A propane two-burner cook top is used for smaller cooking jobs.

Their Bosch on-demand propane water heater is 30 percent more efficient than a conventional hot water tank.

Electricity is primarily generated by an eight-panel, 680 watt photovoltaic array and stored in a battery bank of six, two volt Surrette batteries with a capacity of 1575 amp hours. A Trace SW2512 inverter converts the stored electricity into 120 volt household power. This system provides 100 percent of the electricity used from February through mid-November. A

Blown cellulose insulation.

Energy efficient windows let the light in without letting too much heat escape.

3500 watt gasoline generator provides back-up power and is only required from mid-November to the end of January, for about four hours per week.

Photovoltaic array of 680 watts.

Suggestions for improvements

As part of the integrated design charrette process, suggestions were put forth for how the houses that were studied could improve their energy efficiency. The consensus was that the Luet house was very energy efficient, with a high use of renewable energy. There were some actions that could be taken to increase efficiency and comfort, but very few of these would have a payback of less than five years.

By employing only those actions that have a payback of five years or less, the renewable content of the annual energy supply could be increased by two percent from 64.4 percent to 66.4 percent.

These actions were primarily related to better insulating the crawlspace, separating the ground floor living space from non-living spaces such as the garage and fresh water tank, switching to a better sized generator, and using more electrical appliances during the summer months to take advantage of excess solar capacity.

HOME RENEWABLE ENERGY SYSTEMS DESIGN

Planning

A renewable energy system is composed of many parts. First, because it needs to harvest energy, there must be photovoltaic modules, a wind turbine, a micro-hydro turbine or (though it can't be called renewable) a fossil-fuelled generator. With this energy, the system can then produce electricity. Often, it's a combination of methods that creates a hybrid renewable energy system.

The balance of system equipment consists of the battery bank (which can be considered the heart of the system) and the equipment that controls and monitors the electricity as it flows into and out of the batteries. These are the controller, inverter, charger, monitor, DC disconnect and the AC and DC load centres.

If it sounds like the system is confusing and complicated, then the services of a qualified, experienced dealer and installer can help you make good choices and set up your system so that it almost looks after itself. Doing your own research will help you find that person and increase your understanding as your system is designed and installed and you begin to use it.

When deciding how to size your system you should do it in the following order. First, do a load calculation to determine your energy needs. This will tell you what size battery bank you need.

Then, size a power generation system that will properly supply those energy needs and efficiently charge your battery bank.

Finally, choose the balance of system equipment that will keep everything working, delivering the energy where it is needed.

Load calculation

In order to determine the size of your energy system you will need to estimate how much electricity you use on a daily basis. Appendix 2 contains two work sheets and instructions to help you calculate this and assess the size of battery bank you require.

As you do the calculations, remember that you likely use your appliances differently, depending on the day and the season. Therefore, the calculation needs to be done twice: once for a typical week in winter and, again, in summer.

You can decide which numbers to base your system on depending on what your lifestyle is like. Perhaps you just need to average the two results. Of course, if you holiday somewhere warm for December and January, then you need to take that into account.

You will find that any energy efficiency improvements you make will result in a reduction in the size of your system.

This is the balance of system equipment typical of an off-grid home.

Batteries

Design tools

There are two design software tools available, free of charge, from Natural Resources Canada.

The first NRCan tool, Hot 2000, is a tool for designing and performing energy analyses on low-rise residential housing. It provides current heat loss and heat gain calculations in order to evaluate building designs. It is available at www.buildingsgroup.nrcan.gc.ca/software/hot2000_e.html.

The second NRCan tool, RETScreen, is used for assessing the feasibility of renewable energy projects and may be applicable to assess options for your off-grid home. It is available at www.retscreen.net/ang/d_o_view.php.

Remember, the output from these tools is only as good as the information you put into them. Therefore, you may want to leave the fine details of your system design to a professional.

There are other software tools that allow you to monitor and record your system's performance day-to-day and over the longer term. A few such tools are listed in Appendix 4.

Energy monitors are used to measure the power consumption of individual items. A selection of these meters is also listed in Appendix 4.

Unless you have a continuous, unlimited, uninterrupted supply of power you will need somewhere to store it. This is where batteries come in. They store electrical energy until it is needed, provide a stable source of power, and provide power beyond what the renewable energy generators can produce.

For example: let's say you have a photovoltaic array that generates 500 watts but your table saw draws 1800 watts, and much more than that when first starting up. The photovoltaic array itself does not have enough power but your battery bank can store enough power to run the table saw at any time.

Basics

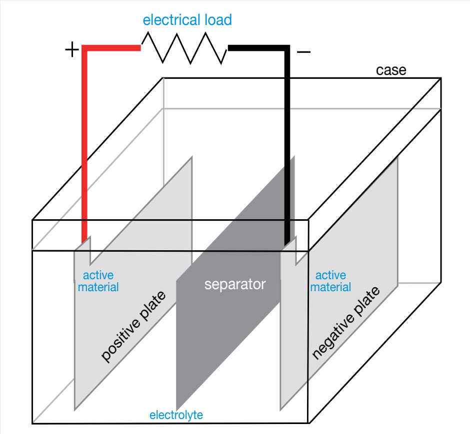
There are many types and sizes of batteries but all construction is similar (Figure 2). The most common type of battery used in renewable energy systems is the lead acid battery. A battery cell is composed of a positive plate of lead dioxide and a negative plate of sponge lead divided by a separator. These are immersed in a diluted sulphuric acid solution called the electrolyte and enclosed by a case.

Each cell has a voltage of approximately two volts. Cells are combined to create batteries of two or more volts.

Batteries of different sizes have different capacities for storing electricity. They will be rated for a specific capacity in amp hours (Ah). You can compare a battery to a bucket. A bucket (battery) of a certain size can store a certain amount of water (electricity). If you want to store more water you can get more buckets or you can get a bigger bucket.

When an electric load is connected to the battery, sulphur molecules in the electrolyte bond to the plate material. Electrons are released and their flow creates an electric current. When all the available

Figure 2.
Typical battery cell construction.
(Adapted from James P. Dunlop, 1997)



The 12 volt battery bank in the Luet house is made up of six 2 volt Surrette batteries and has a capacity of 1575 Ah.

sulphur molecules have bonded to the plates, and the electrolyte is water, the batteries are said to be discharged. Applying an electrical current to the batteries in the opposite direction causes electrons to bond with the sulphur molecules on the plates and return to the electrolyte. Because batteries are less than 100 percent efficient, slightly more than 1 amp must be returned to the battery for every amp taken out.

Types of batteries

An automotive battery is built with many thin plates so it can produce a short, powerful burst of electricity to start the vehicle. Once started, the generator immediately starts recharging the battery. An automotive battery may be suitable for a weekend residence with a few small electric loads but your money would be better spent on a recreational vehicle or marine "deep-cycle" battery. This type is a compromise between an automotive battery and true deep-cycle batteries.

Deep-cycle batteries are designed with thicker plates to withstand a greater depth of discharge and to go longer periods before being recharged. They come in 2, 6 and 12 volt configurations and various sizes and capacities. This type of battery is more suitable for a home renewable energy system.

Lifespan

There are a number of factors that affect the lifespan of a battery. The first is the appropriateness of the batteries for their intended use. A car battery is not designed for repeated deep discharges. It might be sufficient in a weekend residence with a very small load but would not last long in a year-round home.

Next, it is important to determine the proper size of your battery bank. Doing a careful load calculation is crucial. Once you know your daily energy requirements and how many days of autonomy (days between charging) you want, then you have the answer to the size of the battery bank you require.

A battery bank that is too small will be discharged more quickly and go through more cycles, shortening its lifespan. The less a battery is discharged (i.e. the less electricity is used) the longer its life will be. Figure 3 shows that a battery discharged only 10 percent has a much longer lifespan than one discharged by 80 percent. Rechargeable batteries of any kind should never be completely discharged.

A battery bank that is too large will discharge more slowly but may not get completely recharged on a regular basis. A battery that is left in a state of discharge for too long may have sulphates form on the plates, which will diminish its performance. Your batteries may not get fully charged over the winter and, while this is not a desirable state of affairs, running the generator to completely charge them is horribly inefficient.

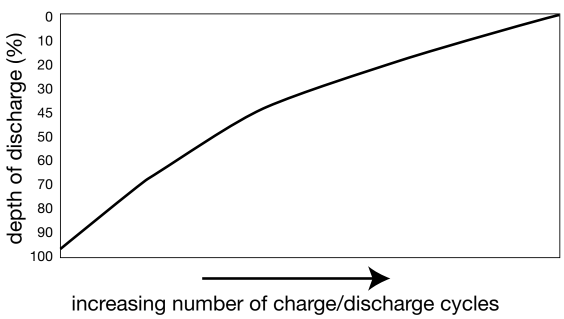


Figure 3.
Number of cycles vs. depth of discharge. The less electricity taken from the battery each cycle, the longer the lifespan of the battery. The actual numbers will vary depending on the battery. (Adapted from BCIT photovoltaic course material)

The temperature a battery is stored at has an effect on its lifespan as well (Figure 4). Battery temperatures above 20°C reduce the rated float life, while lower temperatures will increase the float life but reduce the usable capacity. The electrolyte of a discharged battery is more susceptible to freezing. Batteries should be kept where there is no danger of freezing or overheating.

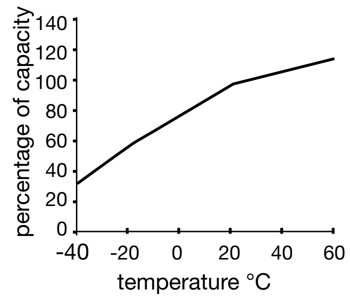


Figure 4.
Battery temperature vs. capacity.
(Adapted from BCIT photovoltaic course material)

The speed at which you discharge your batteries will affect how much power you get out of them. The faster you discharge them, the less capacity they have. You can compare it to a car's gas consumption: the faster you drive, the less distance you will get out of a tank of gas. A rapidly and deeply discharged battery can produce enough heat to cause damage to the plates. (This is true for batteries in cordless power tools as well.)

A battery also has a shelf life or float life. If it sits unused on a shelf at 20°C it will eventually deteriorate until it will only hold 80 percent of its rated charge. At this point, it is considered by the manufacturer to be dead.

If you decide later you need more battery capacity, it is not a good idea to add new batteries to old batteries because your bank will only perform as well as the weakest battery. The older, weaker batteries will drag the new ones down to their level. Because of this, and the effect of speed and depth of discharge, it is better to err on the side of too big rather than too small in estimating the size of your battery bank. If your budget is limited, buy the biggest battery bank you think you will need, and can afford. You can add photovoltaic modules or increase the size of your wind turbine later, as funds allow.

Charging

When your battery bank becomes discharged the energy used must be replaced in a controlled manner. The charge rate is the amount of current applied to your batteries to bring them back up to capacity over a specific period of time. It is determined by the size of your battery bank and the size of your charging system. Charging the batteries too much or too fast can result in damage to the plates and can also cause gassing. This is bubbling of the electrolyte, which breaks down the water, and gives off potentially explosive oxygen and hydrogen. This also lowers the level of electrolyte in the batteries, which necessitates topping up the electrolyte levels. Since the batteries are important — and one of the most expensive components in your system — it is wise to treat them well.

Charging your batteries is usually accomplished in a three-stage process (Figure 5, next page).

1. As charging begins, all the current (amps) is directed into the batteries and the battery voltage begins to climb. This is called the bulk stage. The length of this stage will depend on the depth of discharge the batteries reached and the amount of current available for charging.

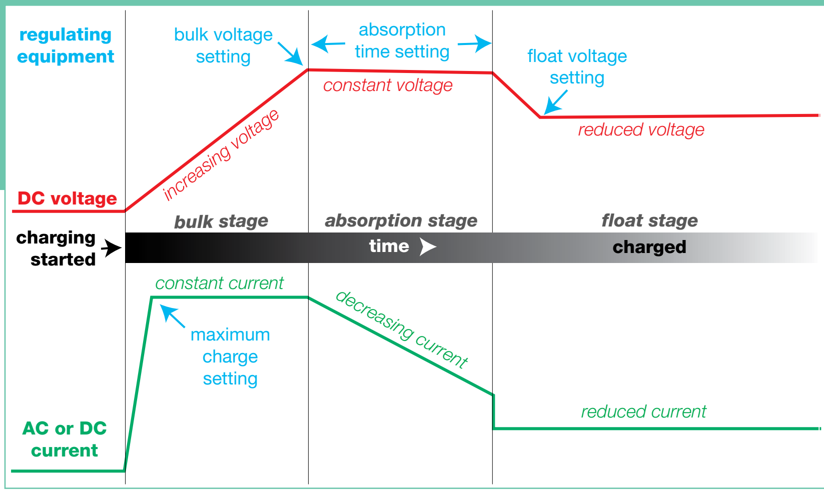


Figure 5.
This shows what is happening with the current and the voltage during the three-stage battery charging process.
(Adapted from Trace Inverter owner's manual)

2. Once the batteries reach a certain voltage, called the bulk voltage setting, the absorption stage begins. In this stage, the battery voltage is held at the bulk voltage setting and the current is gradually decreased. The length of the absorption stage is predetermined by the settings of the equipment controlling the process.

3. Once the batteries are at 80 to 90 percent of their capacity, the last stage, the float stage, begins. The current going into the batteries drops again to lower the battery voltage to the float voltage setting. The float stage will continue until the charging stops or the voltage drops below the float voltage for a predetermined length of time, initiating another bulk charging stage. This maintains the batteries in a fully charged condition and reduces gassing.

Another way to describe the three stages is by using the bucket and water analogy again. As you begin to fill your bucket with water you have the water flowing full blast. As the water level nears the top of the bucket you slow the flow of water so it doesn't splash over the edge. When it reaches the top you reduce the flow again to a mere trickle and leave it like that to compensate for evaporation and leakage and to ensure the bucket remains full.

Equalization charge

After a number of charge/discharge cycles and/or long periods of low charge levels, individual cells in your batteries may acquire unequal states of charge. The electrolyte can become stratified (the acid concentrates at the bottom of the battery, which can corrode the plates) and sulphates can build up on the plates. If left, the sulphates can harden and seal off part of the plate. This can reduce the battery's capacity and also cause the cell to fail prematurely.

The remedy is to give the batteries an equalization charge. Basically, this means overcharging the batteries, but in a controlled way.

The batteries are charged at a high voltage for one to two hours. This breaks down the sulphates on the plates and causes the electrolyte to bubble, which mixes it up.

It is a good idea to make sure the electrolyte level in each cell is at recommended levels before and after equalizing. An equalization charge is not recommended for sealed or non-vented batteries.

According to the literature, you need to equalize your batteries anywhere from weekly to bi-weekly to once a year, and everything in between. The best advice is to do it based on the state of your batteries. If they are not taking or holding a charge, or the individual cell specific gravity (more about specific gravity on page 28) varies more than about 15 points, it may be time for an equalization charge. Batteries are more likely to need equalizing at times of the year when your renewable energy system is not producing much electricity and your batteries are spending more time at low levels of charge.

Battery storage

Your batteries should be kept in a room close to the rest of your renewable energy system equipment and household electrical panel, and not too far from the generation source. Make sure you have enough room to move around while doing maintenance and to store any supplies you may need nearby. Keeping the batteries in an enclosed container will protect them from dirt and other objects which could damage them or cause a short circuit. Batteries are heavy so keeping them on the ground floor will make it easier to move them in and out.

Generation

Capturing energy in its various forms to generate electricity is the job of solar or photovoltaic modules, wind and micro-hydro turbines, and fossil-fuelled generators.

PHOTOVOLTAICS

Solar cells are made from crystalline silicon (one of the earth's most common elements). Pure silicon is a good insulator so solar cells are grown from crystalline silicon with a small amount of boron to increase their conductivity.

The crystal is sliced into very thin wafers, and then treated with a thin layer of phosphorus on one surface. The phosphorus has more electrons than pure silicon, making it an n-type (negative) semi-conductor, and the boron has fewer electrons, making that part of the wafer a p-type (positive) semi-conductor. The area between the two semi-conductors is called the p-n junction.

The solar cells are connected on both sides with metallic conductors, in series and parallel, and in various numbers to achieve specific voltages and amperages. The cells are sandwiched between tempered glass and a weatherproof backing, then wrapped in a frame to create a solar or photovoltaic module (or panel). These modules can then be connected together to form an array (Figure 6, next page).

When light strikes the surface of a solar cell, electrons are liberated and flow across the p-n junction and along the conductors to an external electrical circuit. This electricity can be used to charge batteries or run electrical loads.

In two to four years, photovoltaic modules will produce as much energy as it takes to make them. They usually have a 25-year warranty and, although they deteriorate slowly, they can continue to produce clean electricity for many more years. In fact, the first solar cell ever produced by Bell labs 50 years ago is still working!


Ground (left) and pole-mounted photovoltaic arrays.

Battery maintenance and safety

Hydrogen gas produced by batteries is highly explosive. Vent the batteries to the outside air to prevent hydrogen fumes from building up in the house, and never smoke or have open flames near the batteries, especially when charging.

When working around batteries wear old clothes and use rubber gloves and goggles. The sulphuric acid in your batteries can put holes in your clothes and burn your skin and eyes. Keep a box of baking soda and clean water in the battery area to neutralize the acid and flush it away.

Wrap any metal tools in tape or dip them in liquid plastic. A metal wrench dropped across a battery's terminals can short circuit the battery and quickly become red hot and damage or destroy the battery.

Store batteries in a cool room but keep them safe from freezing.

Keep the tops of the batteries clean and the terminals and connections free of corrosion.

Check the fluid levels once a month and, if necessary, top them up to the manufacturer's specified levels. Use distilled water.

Monitor the state of charge to ensure they are not being over charged or too deeply discharged.

Photovoltaic building materials, such as glazing and shingles, are also available. There are even thin, flexible photovoltaic laminates with a peel and stick backing that can be adhered to metal roofing or siding.

All installations should be in unobstructed direct sunlight, mounted on a sturdy structure and accessible for cleaning and maintenance. The modules should face true south (not magnetic south). If the location is shaded for part of the day, change the direction to take better advantage of the sun during other times of the day. For example, if shaded in the morning, turn the modules more to the west to take advantage of the afternoon sun.

Ideally, the vertical angle of the modules should be perpendicular to the sun. In summer, when the sun is high overhead, the modules can have a flatter angle. For lower winter sun, they should be angled more vertically (Figure 7).

To determine the best angle in the winter, add 23 degrees to your latitude. In the Whitehorse area, that would be 83 degrees (60+23). Many mounting systems allow the angle to be adjusted for different seasons but it may not be worth changing the angle of your modules at different times of the year. If the spring and summer sun provides as much, or more, power than you may need, it may be possible to leave them at the winter angle to maximize your winter energy production.

Solar modules (in arrays) can be sized and mounted in a variety of locations (on a roof, a wall or on a mount standing on the ground) according to system design requirements. Some are fixed mounts, but many allow the angle of the array to be changed seasonally and the direction to be changed during the day.

Tracker mounts move to follow, or track, the sun, keeping the photovoltaic modules facing it. This is accomplished either passively, using the heat of the sun, or actively, using a small amount of power from one photovoltaic module and some electronic equipment. In the right location and at the right time of year, tracker mounts can improve the

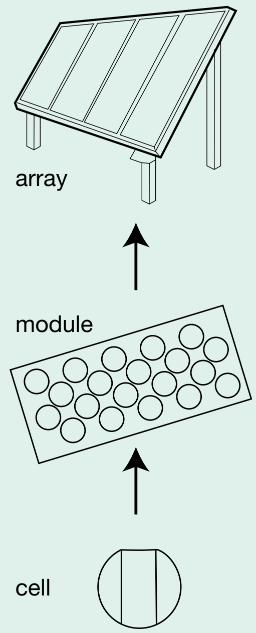


Figure 6. The building blocks of a solar array. (Adapted from "Photovoltaic systems design manual," Energy Mines and Resources Canada)

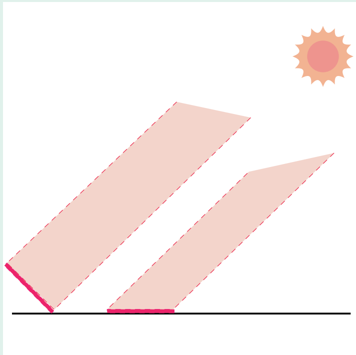


Figure 7. Photovoltaic modules receive more light energy if angled perpendicular to the sun's rays. (Adapted from "Photovoltaic systems design manual," Energy Mines and Resources Canada)

Wall-mounted photovoltaic arrays.

performance of the solar array by as much as 50 percent. However, there are some limiting factors for tracker mounts.

- A location with a long period of clear solar exposure is required. Mountainous terrain and northern latitudes in the winter may not provide this. Winter performance may only improve by 10 to 20 percent.
- High winds may prevent proper tracking.
- Cold temperatures may delay the operation of a passive tracker.
- The addition of electronic equipment and moving, mechanical parts is more likely to cause a malfunction to a photovoltaic system that, previously, had the advantage of having no moving parts.
- Tracker mounts are expensive. It may make more sense to spend the money on additional photovoltaic modules to boost your energy production rather than on a tracking mount.

Roof-mounted photovoltaic arrays.

Sizing the array

The size of your array will depend on your energy requirements and the amount of solar exposure. The more energy you need and the less sun you get, the larger the solar array you will need, and vice versa. Ideally, it should be possible to get all the energy needed from the sun, a clean, never-ending source. Though this is possible, it may be very expensive.

If your solar array and battery bank are big enough to supply 100 percent of your energy needs in the darkest days of winter, the solar array will be vastly oversized for the long days of summer. A balance needs to be reached, unless money and space are no object.

Once you have determined the size of your battery bank you will need an array with enough current to replace the energy used and to charge the bank in a reasonable time. The following formula can be used as a rough calculation:

$$\text{array current} = \frac{\text{battery bank capacity}}{\text{charge rate}}$$

Take the Luet's system as a sample. They have a battery bank with a 1575 Ah capacity. If you divide that by the 40-hour charge rate of their controller, then they should have a photovoltaic array with a current of 39.4 amps. Their photovoltaic array consists of eight 85 watt modules with a rated current of 4.72 amps each, for a total of 37.8 amps. A pretty good fit! If the charge rate is increased to 30 hours they would need to increase their charge current to 52.5 amps by adding three more modules to the array.

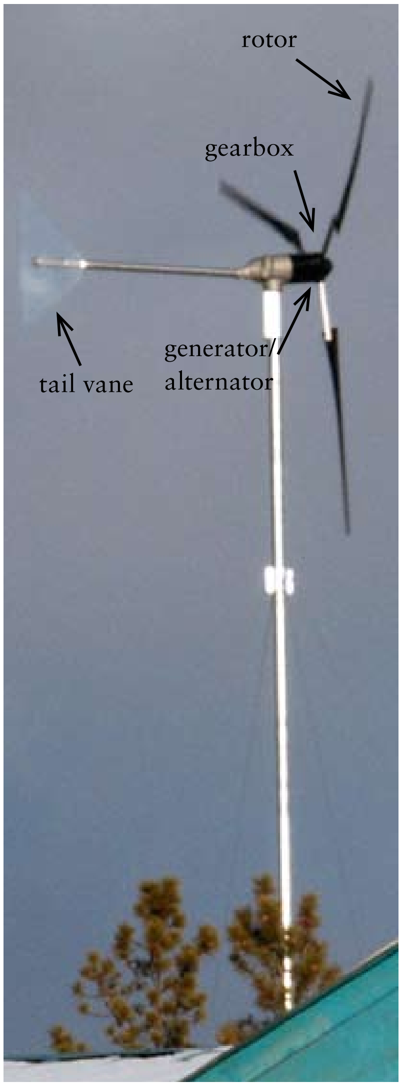
A more detailed calculation to size an array can be done using the solar radiation chart in Appendix 3.

For more detail on photovoltaics, refer to NRCan's publications, "Photovoltaic systems: A buyer's guide" available at http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier/80674/ and "An introduction to photovoltaic systems" available at http://www.energyalternatives.ca/PDF/Photovoltaic%20Systems%20Introduction.pdf.

WIND

For thousands of years, humans have been harnessing the wind to pump water, grind grain and sail the world's oceans. Now, with wind turbines, you can use the wind to produce electricity.

A typical wind turbine looks like a small airplane with a big propeller. It is comprised of a rotor or propeller assembly, a body (which contains the generator or alternator and the tower attachment point) and a tail vane. The wind flows over the rotor blades, causing them to spin, and turning the generator housed in the body, which then produces electricity. The tail vane keeps the rotor turned into the wind. It can also turn the turbine out of the wind when wind speeds get too high. The turbine is mounted on top of a tower to keep it above obstructions to the wind's flow.



While the sun rises and sets every day without fail, and for predictable periods throughout the year, wind is a more difficult resource to pin down. The time of year, time of day, weather, location and topography create wide variations in the amount of available good wind. In general, the following is true.

- Winds vary throughout the day near large bodies of water. The land heats up faster early in the day, causing winds to blow onto the land, and cools faster in the evening, causing winds to blow from the land.
- Winds tend to be stronger during the hotter times of the day.
- Winds are faster higher above the ground where friction from the earth and turbulence from obstructions is less.
- Winds near the ground speed up going over hills, then slow down, often becoming turbulent as they go down the other side. This makes the tops of hills and ridges good sites for turbines.

Monitoring the wind at your location with an anemometer for a year or two will give you a good idea whether your site will have enough wind to make it a viable resource. Don't rely on data from your neighbours five kilometres down the valley because that location may have a very different wind profile than your site does.

The Luet home gets some winds that rock the house, and winter in the Yukon is generally the windiest time of year. A wind turbine would seem to be a good complement to their photovoltaic system. However, a year of monitoring the wind at their site showed that winter was the least windy time and the average yearly wind speeds were not high enough to make wind a viable power source.

Sizing a wind turbine

Once you have determined that wind power is the way to go, you will need to decide whether it can be your sole source of electrical production or a complement to another source. Then you will need to find the right size of turbine for your site's wind profile and your energy needs.

Two factors affect the amount of power produced by a wind turbine: wind speed and the rotor diameter (i.e. the area swept by the blades). When shopping for a turbine, note that the rotor diameter and a rated power or wattage output at a certain wind speed will be stated. For example, the Windseeker 503 has a rated power of 500 watts at 45 kilometres per hour and a rotor diameter of 1.5 metres.

If you look at a wind speed chart, you will see that this turbine will produce that amount of power only in a site with exceptionally excellent wind quality or at times when the wind speed is well above average.

Other specifications to look at are the cut-in wind speed (the wind speed at which the turbine will start producing power) and the power curve rating (Figure 8).

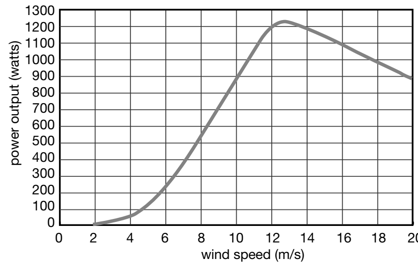


Figure 8. Power curve rating for a wind turbine. *(Adapted from www.bergey.com/Products/XL1.Spec.pdf)*

The power curve rating shows the power production of the turbine at various wind speeds. If you compare the power curve rating with the wind speeds at your location you will get a more realistic picture of how much power you can expect from that particular turbine. Keep in mind that there will be times when your batteries are fully charged and will not take any of the power the turbine will be producing.

Location

A wind turbine needs to be located where the wind speeds will be the highest and the flow of air will be smooth, or laminar. Obstructions such as trees, buildings and hills make air flow turbulent and reduce the efficiency of the turbine. Carefully locating your wind turbine in an area clear of obstacles will improve its performance.

A wind turbine should be mounted with the bottom of the rotor blades at least nine metres higher than any obstruction within 90 meters of the tower. The taller the tower on which the turbine is mounted, the better the wind.

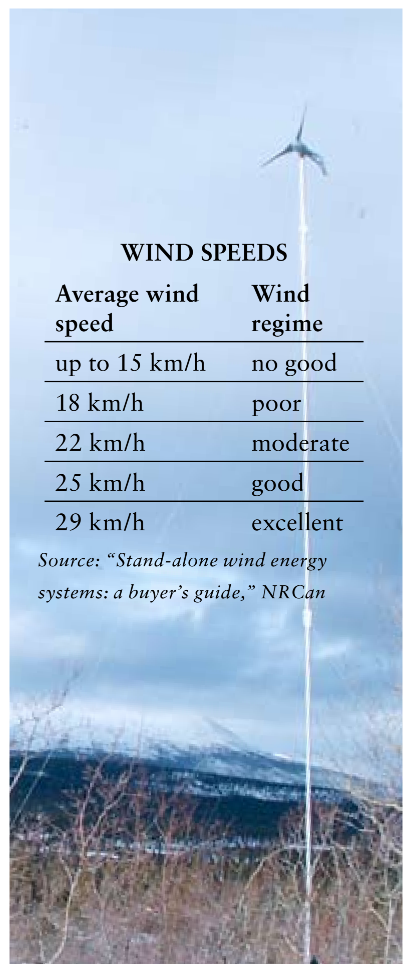
Generally, three types of towers are used: tilt-up guyed towers, fixed guyed towers and freestanding towers.

Tilt-up guyed towers

Tilt-up towers are usually constructed with sections of pipe joined together to make the tower the required height. Four sets of guy wires are attached at each of the joints and anchored to the ground around the tower. The anchor points are equidistant around the base, with a radius of 50 percent of the height of the tower.

To raise the tower, a gin pole is attached to the base at 90 degrees and one set of guy wires is attached to the end of it. By pulling on a cable attached to the end of the gin pole, the tower raises as the gin pole is pulled down.

It is a good idea to raise the tower once without the turbine attached to be sure that everything goes smoothly. An advantage of the tilt-up tower is that it can be lowered whenever maintenance needs to be done on the



WIND SPEEDS

Average wind speed	Wind regime
up to 15 km/h	no good
18 km/h	poor
22 km/h	moderate
25 km/h	good
29 km/h	excellent

Source: "Stand-alone wind energy systems: a buyer's guide," NRCan turbine. It does, however, require a large cleared area to ensure that the tower goes up without the guy wires becoming snagged in trees or other obstacles.

Fixed guyed towers

Fixed towers are usually triangular in cross section. They are guyed with a minimum of three sets of guy wires, with a guyed radius of 50 to 80 percent of the tower height. Though sections of the tower can be lifted and bolted in place sequentially, it is usually raised by a crane in one piece and fixed in place, not to be lowered again.

Fixed towers do not need as much cleared space as tilt-up towers. Maintenance on the turbine is done by climbing the tower. Make sure you take all the maintenance equipment and tools you will need so you only have to climb the tower once.

Freestanding towers

Freestanding towers are the most expensive (as much as 33 to 50 percent more than tilt-up or fixed towers) and use no guy wires for support. To keep them standing, they rely on a lot of steel and a substantial concrete foundation.

Freestanding towers come in two types: a tapered, triangular shape or a large diameter tube. The tubular towers are usually used for larger commercial wind turbines like the two on Haeckel Hill in Whitehorse. Freestanding towers are usually raised by a crane and require the least cleared space.

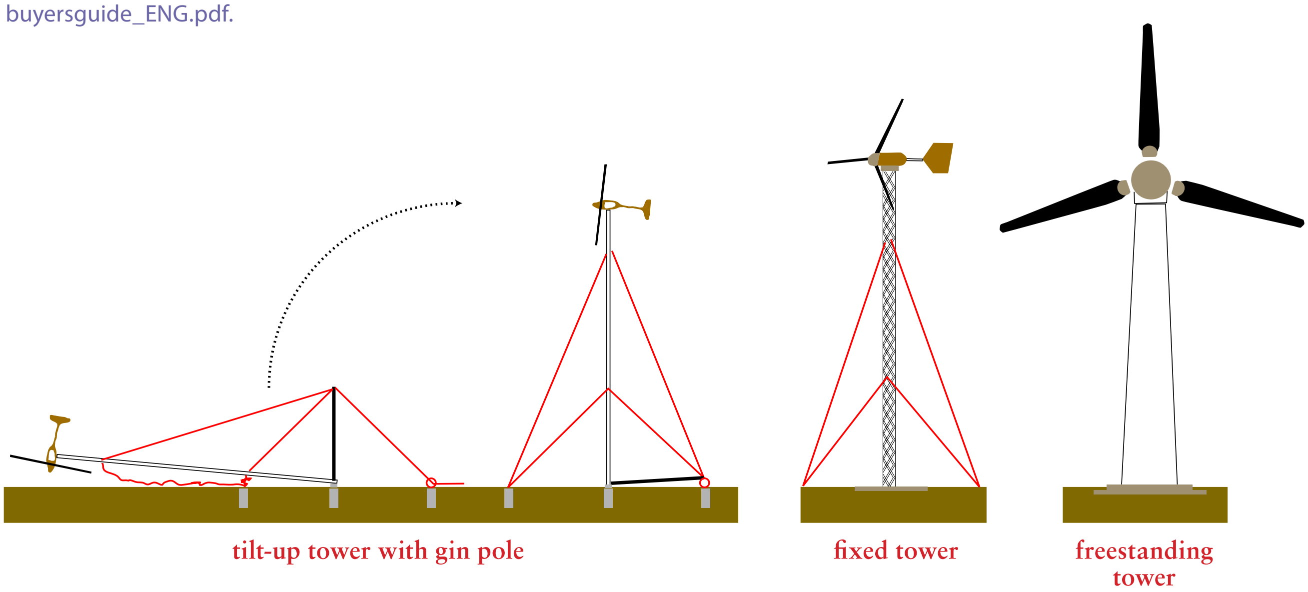
If you are thinking of building your own tower, research it well and build it strong! You may need to get it approved by an engineer before a permit will be issued. If you are unsure or inexperienced in tower building, it is probably wiser to go with a professionally designed and built tower.

When choosing your tower, make sure it is strong enough to support the weight of your wind turbine and resist the thrust loads of the wind. Determine how tall it needs to be — keep in mind that nearby trees will grow while your tower won't. Err on the side of height. A taller tower will improve the performance of your wind turbine. Check on any regulations that may affect the installation of your wind turbine and tower.

A word on safety

You probably would not survive a fall off your tower. Invest in some safety gear and use it when you are maintaining your turbine. A visit to your local safety supply store should get you what you need.

For more detail on wind energy, refer to NRCan's publication, "Stand-alone wind energy systems: A buyer's guide" available at http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier.php/codectec/En/ISBN%200-662-37706-0/WindEnergy_buyersguide_ENG.pdf.



(Adapted from "Stand-alone wind energy systems: A buyer's guide," NRCan)

MICRO-HYDRO

If you live by a stream that has a reasonable year-round flow, then you may be in a very enviable position from a renewable energy standpoint. While micro-hydro systems may take more effort to install, they can cost considerably less than photovoltaic or wind systems and can provide an uninterrupted supply of energy, rain or shine.

A micro-hydro system uses water to turn a turbine and, since water is denser than wind, the turbine can be much smaller for the same amount of energy production.

A typical system consists of a dam and water intake, a penstock (system of pipes) that brings the water to the turbine, and a tailrace that takes the water away from the turbine back to the stream.

The water from the penstock is directed at the turbine wheel by nozzles, causing the turbine to spin. A generator or alternator attached to the turbine turns the rotational energy into electrical energy, which is delivered to the batteries. From there, it is used to run household electrical loads.

Because power is produced continuously, a smaller battery bank is needed only to cover electric loads too large for the turbine alone. When the batteries are fully charged, excess energy is diverted by a regulator to a "dump" load — usually to a water or space heating element. If the turbine has no electrical load it might spin at excessive speeds and be at risk of damage.

Evaluating your site

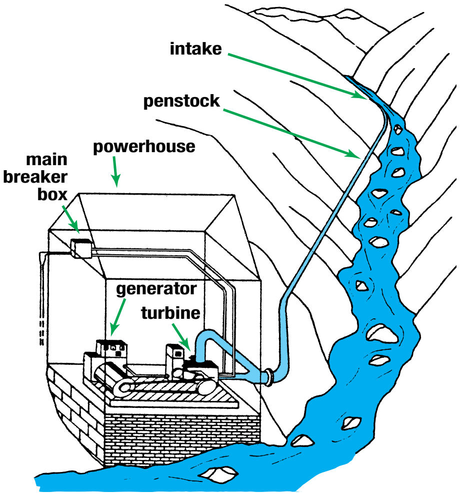
You need more than just water at your site; you need enough flow, or volume, expressed in litres per minute, and pressure, or head. Head is the height the water falls from the water intake to the turbine and is expressed in metres. Micro-hydro systems tend to be either high volume with low head or low volume with high head; in other words, a flat river with a lot of water or a small river with a lot of vertical drop.

Keep in mind that once the system is installed the head will remain the same but flow will vary during the year. Design your system to maximize the head. If you have access to weather data for your location, you can make adjustments based on whether it is a dry or wet year and how that has affected water flow. There will also be extra design considerations if there are fish in your stream.

For more detail on micro-hydro, refer to NRCan's publication, "Micro-hydropower systems: A buyer's guide" available at http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier.php/79276/buyersguidehydroeng.pdf.

This micro-hydro turbine has been operating smoothly for the owners since it was installed in 1982.

These are the component parts of a micro-hydro system. (Adapted from "Micro-hydro in Yukon," March 1985)



FOSSIL-FUELLED GENERATORS

Cars, wind turbines and micro-hydro systems all have an attached generator that produces the electricity used to charge the batteries. In fossil-fuelled generators, an internal combustion engine is used to drive the generator.

The term "generator" is often used to refer to the engine and generator set together (more correctly called a genset).

Because the amount of renewable energy available to you is sometimes not consistent, but energy demands are, a fossil-fuelled generator may be necessary to make up the shortfall. There are many types and sizes of generators and your choice will depend on the size you need and the fuel used to run it.

Fuel types

Gasoline generators are the most common and least expensive. They run at high speeds, 3600 rpm, which leads to rapid wear. Gasoline generators are noisy and can suffer from carbon buildup.

Propane is a more abundant and cleaner fuel source than gasoline or diesel. Propane generators are quieter than gasoline generators but have a higher rate of consumption. Their engines will last about 50 percent longer due to their heavier design and slower engine speeds (1800 rpm). As well, they produce a more stable supply of power due to their heavier design.

Diesel is one of the most efficient and least expensive fuel sources. Though noisy, diesel generators run at low engine speeds and are heavy, long-lasting machines. The power they supply is more stable due to their heavier design. Diesel generators are the dirtiest, producing sulphur oxide and nitrous oxide pollutants.

Size of generator

Sizing a generator to your system depends on how it will be used, whether as your main source of power or as a backup to wind, photovoltaic or micro-hydro for charging your batteries.

If it is your main power source you need to know the size of the largest electrical load you will be running and get a big enough generator to handle that. If you are using it to charge your batteries, then size will largely be determined by the size of your battery bank.

The generator needs to be big enough to push energy into your battery bank as quickly as possible, but not so big that most of its power is wasted.

The Luet's 3500 watt gasoline generator.

Location

Noise, exhaust fumes and the distance you need to run wires need to be considered when locating a generator. Place it close enough to be convenient to operate but not so far from the battery bank that excessively large wires are needed to transmit electricity to the batteries.

Put the generator in a shed insulated to minimize the noise and direct the exhaust away from the house. Provide air and ventilation to deal with excess operating heat. Build the shed large enough that you can move around the generator to do any maintenance and to store necessary tools and supplies.

Efficient use of a generator

A generator is most efficient, and it is better for its engine, when it is run near peak capacity — using almost all the electricity it can generate. Unfortunately, this is often not the case.

When using a generator as your main power source, but not running large loads, much of the energy in the fuel used to run the generator is being wasted. It's similar to city driving where you spend much of your time sitting in traffic with your engine idling; you may be running the radio but the car's not moving.

To greatly improve efficiency, add a battery bank and inverter to your system. You can run most of your electric loads off the batteries and only turn on your generator for the really big loads and to charge the batteries. You can further reduce generator running times by adding a renewable energy source to the system and only running the generator to charge the batteries during those times when the renewable energy system can't produce enough electricity.

During the initial state of charging batteries, the battery charger is pushing most of the power supplied by the generator into the batteries. As the batteries become more charged, or start to fill up, less and less of the generator's electricity goes to the batteries. (See the three-stage charging process, described on pages 13-14.) Again, the energy in the fuel is being wasted.

In order to get the most out of every watt produced by your generator, charge your batteries in the evening or early morning when you would normally be using lights and appliances and your batteries are low. Run big electric loads such as the washing machine and vacuum cleaner as the charger is tapering off the amount of power going to your batteries. This way, electricity not being used by the charging process can be used to run electric loads.

Trying to bring your batteries to a 100 percent charge with the generator will take a long time and, for most of that time, only a small amount of power will be going into your batteries. Once your charger starts tapering off, shut down the generator and use the renewable energy system to finish it off.

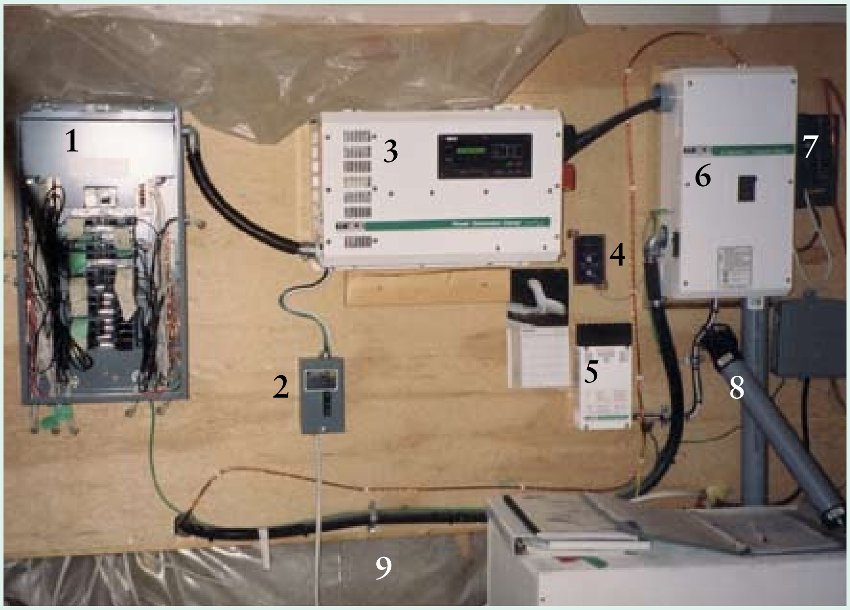
As well as making more efficient use of your generator you will also increase its lifespan, reduce fuel and maintenance costs, decrease noise and pollution, and reduce your reliance on a non-renewable energy source.

The Yukon off-grid survey revealed that generators are being used to provide a significant proportion of power. Better use of renewable energy sources can greatly reduce the need for fossil-fuelled generators, if not eliminate it.

You can decide if it is worthwhile to add more renewable energy capacity (more photovoltaic modules or a larger wind turbine, for instance) to your system. Look at the cost of running and maintaining your generator and the actual amount of electricity it provides you versus the cost of the new capacity and how much generator running time it is likely to replace. You should also factor in the noise and pollution you won't be producing. You will probably still need a backup generator but you could sell your existing generator and replace it with a smaller unit, further reducing your operating costs.

Eight kilowatt (left) and six kilowatt diesel generators.

Regulating and monitoring



Balance of system equipment in the Luet house: 1) AC load centre, 2) generator disconnect, 3) inverter, 4) monitor, 5) controller, 6) DC disconnect, 7) DC load centre, 8) vent for battery box, 9) battery bank.

Balance of system equipment makes sure the electricity flows where it is required (to the batteries or a light bulb or the TV) and in the proper form, that is, AC or DC, 12 volt or 120 volt. It also prevents damage to the system from overcharging, excessive discharge or electrical mishaps, such as a short circuit.

Controllers and regulators

An unregulated flow of current from the generating component (photovoltaic, wind, micro-hydro or generator) could damage the batteries by overcharging them. A controller regulates the current to the battery bank using the three-stage charging process.

A controller can regulate the voltage of the batteries by opening and closing the circuit, effectively turning the power off and on very quickly. The amount of time the power is off or on varies to regulate the flow of current, allowing it to be tapered off. A very small amount of current is allowed through to keep the batteries fully charged. This type of regulation, called charge control or series control, is used with photovoltaic arrays.

Another method of regulation, called diversion control, takes excess current and diverts it to a diversion load, usually a water heating element or a space heater. This type is generally used with wind and micro-hydro turbines but can also be used with photovoltaic systems.

Two charge controllers.

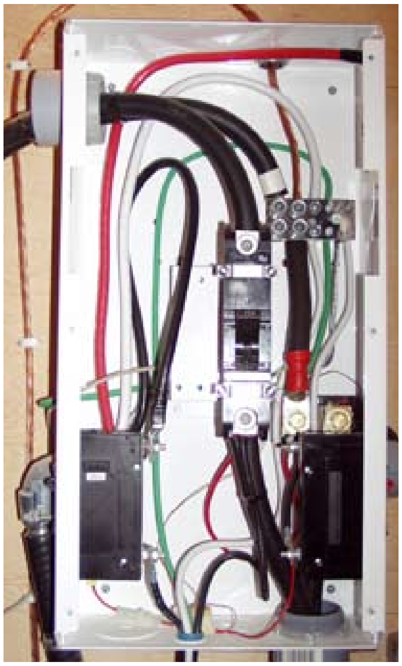
A controller can also act in a DC load control mode to prevent the batteries from becoming overly discharged. If you have any DC loads, such as a DC water pump or lights, it will disconnect them if the batteries reach a low voltage point. It may also have a feature that protects against excessively high currents by interrupting the circuit when they are detected.

A Maximum Power Point Tracker or MPPT controller is used only with photovoltaic systems. When you buy a photovoltaic module, it will list on its specifications a peak power (also called maximum, ideal or rated power) in watts. To determine the peak power, the rated volts of the module are multiplied by the modules's rated current in amps under ideal conditions (maximum solar exposure). This is the maximum power point. An MPPT controller monitors the battery voltage and the flow of current and determines the maximum power point, given the amount of sunlight hitting the module. It adjusts the voltage and current of the array to keep it as close to the maximum power point as possible.

An MPPT controller can increase the output of the array by 15 to 30 percent but is intended for use only with photovoltaic systems. It is best used when winter electrical loads are higher than summer loads.

DC disconnect/over-current circuit protection

This piece of equipment is the point where all the other equipment connects. Its main job is to provide the batteries, inverter, photovoltaic array, wind and micro-hydro turbines and DC cables with protection from damage by short circuits or overloads. It does this with DC-rated circuit breakers similar to the ones in an AC household circuit breaker panel.



This is the DC disconnect from the Luet house, with cover closed and cover open.

The DC disconnect also provides a disconnect point where the components of the system can be shut down and isolated from each other by throwing the switch on the breaker and interrupting the circuit.

Inverters

An inverter is the device used to convert the low voltage (12, 24, 48 volts) DC of the batteries to 120 volt AC household current.

Your off-grid home could be run on 12 volt DC but there is a much wider and less expensive choice of AC appliances, lighting, tools and other electrical items typically found in a home.

Inverters come in many shapes and sizes, from 100 watts that can be plugged into a car cigarette lighter to models of thousands of watts that can easily power a house or business. They are used in stand-alone systems (not connected to the grid) and grid-connected systems that use some power from the grid and sell power back to it when there is excess energy from renewable energy generators.

An inverter may have a built-in battery charger that can be used in conjunction with a generator or power from the grid. It can automatically start a generator to charge the batteries and shut it down again. It can turn off loads if the charge level in the batteries is getting too low. If there are no loads, it can go into search mode, shutting itself off and saving power (like a computer in sleep mode). While in search mode it periodically sends out a pulse searching for the presence of a load. When one is detected, the inverter activates itself. Inverters can also be stacked (two connected together) to increase capacity or provide 240 volt power.

This Trace SW2512 (2500 watt, 12 volt) inverter is the brain of the electrical system in the Luet house.

This Tri-Metric monitor monitors the state of the batteries and their power flow.

The Luet's original inverter was a new model, which was less expensive and quieter, and had less radio interference than older models. Within a couple of days of installing it, however, they realized they had made a mistake. The water pump and some of the power tools were constantly tripping the circuit breaker in the inverter. The inverter was a 2500 watt model, which should have been plenty for their needs. The problem was that many electrical loads, especially those of the pump and power tools, require a surge of electricity — sometimes two to four times their rated capacity — when they first start up. For example, the table saw runs at 1800 watts. If it surges to four times that much, it draws 7200 watts when it starts up. The inverter didn't have the surge capacity to handle that. and therefore had to be replaced.

Make sure you research inverters carefully to find the one that will best serve your needs. Look at the continuous power rating and the surge capacity.

The quality, sophistication and reliability of inverters and the power they provide have improved significantly in the last number of years and can be more stable than the grid. (When the Luets had a blower door test done on their house to see how airtight it was, the tester commented that the quality of their power was better than grid power, as noted by how smoothly the fan in the blower door ran.)

Note that there is a special consideration when wiring your house for electricity. According to the electrical code, all the plug outlets on kitchen counters must be split duplex receptacles. This means that each of the receptacles in the outlet must be controlled by a different circuit breaker so that you can't overload a circuit with too many appliances. Each half of the outlet has a separate wire bringing power to it (a "hot" wire) but only one wire leading away from the outlet (a "neutral" wire).

In a house using grid electricity, if you plugged an appliance into each of the receptacles, the electricity would come down each hot wire to the receptacle at a slightly different time and go back along the common neutral wire, at a slightly different time. In a house with a single inverter supplying the 120 volt AC power, the electricity comes down the hot wires at the same time and back along the common neutral wire at the same time.

This isn't a problem for the separate hot wires but now the neutral wire has twice as much current flowing down it. This can cause the wire to overheat, eventually breaking down the insulation of the wire, and possibly cause a fire.

After consulting with the electrical inspector to make sure it would be safe to do, the Luet's wired their house according to code but only connected one half of the outlet and put an outlet guard in the other half. Another way around this would have been to wire each receptacle to a completely different circuit.

Monitoring equipment

In order to maintain your batteries in a healthy state, and use your renewable energy system most efficiently, you need to know what is happening with your system. This requires some sort of monitoring.

A monitor can provide much information, such as whether the batteries are being charged or are already charged, what the battery voltage is, the net amps coming into or going out of the system at any one time, and a cumulative count of amp hours going into and out of the batteries. Other statistics may be provided but the volts, amps and amp hours are enough to give a good idea of the state of your system.

To measure the batteries' state of charge, you need an accurate reading of the electrolyte's specific gravity or density (Figure 9). Remember, the electrolyte is a dilute solution of sulphuric acid and, as a battery becomes more discharged, the sulphates leave the solution and bond to the battery plates. As this happens, the solution becomes closer to water.

Specific gravity is measured with a hydrometer. It looks a bit like a turkey baster with a glass float inside. Buy a good one. They are not very expensive and will give you accurate readings for years.

To get a true reading, specific gravity should be measured when the batteries have been at rest, that is, there is no electricity flowing into or out of them for at least an hour or longer.

To measure the batteries' specific gravity you need to take the cap off each cell of the battery, one at a time, and draw some of the electrolyte into the hydrometer. Make sure the hydrometer is clean before putting it into the cell and don't let anything fall into the cell. Draw the electrolyte in and out a few times to get a better reading. When you have enough electrolyte in the hydrometer the interior float will float. Keep your eye at the same level as the fluid in the hydrometer and read the numbers on the side of the float. The higher the float rises, the higher the specific gravity.

Remember, you are working with sulphuric acid. Wear safety goggles, rubber gloves and old clothes or an apron.

Record your reading, completely empty the hydrometer back into the cell, and continue in the same manner for the rest of the cells.

Trish using a hydrometer to measure the specific gravity of her lead acid batteries.

Specific gravity	Open circuit voltage	Percent charged
1.265-1.280	12.6	100
1.225-1.235	12.4	75
1.190-1.200	12.2	50
1.155-1.165	12.0	25
1.120-1.130	11.7	0

Figure 9.
Battery state of charge. The specific gravity of a fully charged battery's electrolyte will be in the range of 1.265 to 1.280 and sometimes higher.

Record keeping

It is important to keep good records of your renewable energy system, including all the manuals for each component. When you first start out, you will get a quicker handle on how well it performs, what keeps it healthy, and what directions it may need to evolve. Keep records on the state of charge of the batteries and how much the generator is run to charge the batteries. You can track your energy consumption and solar generation. During the winter, when consumption is higher and production may be lower, keep a closer eye on the monitor. In the spring, you can joyously record the last time the generator is used to charge the batteries and the first time the batteries are charged by the sun.

Efficient power use

Part of the Yukon off-grid project showed that, with minimal cost and lifestyle impact, homeowners can reduce their total energy consumption while increasing the proportion of energy they derive from renewable sources. Here are some suggestions for doing just that.

Winter is obviously the most challenging time for relying on renewable energy. Options for managing winter loads include tightening the building envelope, as well as replacing or modifying big energy users. This includes changing AC water pumps to DC water pumps and furnace blowers to high efficiency motors, and using heavy workshop equipment when the generator is being used to charge batteries.

Most generators are oversized, resulting in inefficient use, and should therefore be downsized. Run your generator more efficiently to maximize its life, ensure proper battery charging, and save fuel.

Manage your laundry loads to coincide with generator use. Replace equipment such as electric dryers with propane dryers and/or a clothes rack or drying closet. Replace top-loading clothes washers with more energy efficient front-loading clothes washers.

Replace conventional lighting with compact fluorescent and other low wattage task lighting.

Explore ways to use the summer solar resource in the north to greater advantage. In many cases, summertime photovoltaic energy generation exceeds electrical demands.

Use and maintain your batteries well. Very few off-grid houses are using their storage capacity to its maximum potential. The survey found that batteries are, in general, not being maintained or charged in the most efficient manner.

Select an optimum site to maximize your photovoltaic generation.

A front-loading washing machine uses up to 50 percent less water and 25 percent less energy than a top-loading machine, and gets clothes cleaner. The spin cycle takes more water out of the clothes. Finish the job with a drying rack.

A modern Heartland Oval wood-burning cookstove is a beautiful alternative to a propane cookstove in the Luet house.

Appliance choice

You can have every labour saving device and appliance known but your energy system will have to grow in size to accommodate them. Decide which appliances you really want and need, and then find those that are most energy efficient.

Any electric appliance that is used to produce heat will be a large drain on your batteries. A propane cookstove or clothes dryer is a better choice than an electric model.

A coffeemaker may be essential to you, but a drip or plunge style will do the job as well as an automatic electric model.

An electric kettle or toaster may not be a good choice in December for those with a photovoltaic system, but may help to optimally use your photovoltaic energy production in the summer when there is an abundance of power from the sun.

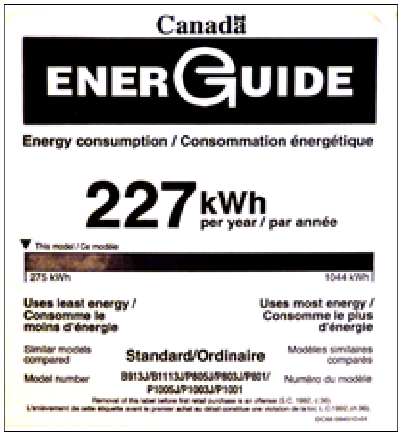
Electric refrigerators are energy pigs and often are not compatible with living off-grid. Propane refrigerators are either small and expensive or large and really expensive, but for a small, off-grid system they may be the only choice. Cold rooms and root cellars are viable options, too.

The summer sun easily provides enough power to run an energy efficient electric refrigerator but would require increased renewable energy capacity or more use of a generator in the winter. Another consideration is that the propane saved by eliminating the propane refrigerator may not offset the extra gasoline used by the generator. In addition, gasoline is a dirtier fuel than propane and an electric refrigerator is noisier than a propane refrigerator.

Most large appliances these days have an EnerGuide label, which will tell you how much energy they will use under average conditions. (Energy consumption information is often stated on a sticker on the bottom or back of appliances, or on a tag somewhere on the appliance.)

According to the EnerGuide label (right) for a front-loading washing machine (which uses considerably less energy and water than a top-loading model), this model uses 227 kWh/year. Other washing machines would use between 275 and 1044 kWh/year. These numbers are based on

Winter (top) and summer (bottom) appliance sets.



doing 392 normal cycle loads of laundry per year or about 7.5 loads per week. Energy usage will be less in households washing fewer loads and using cold water.

The EnerGuide system is a good way to compare the energy use of different models to make a more energy efficient choice when buying large appliances. If you know the way the calculations are made (e.g. 392 loads per year) you can compare it to your own use patterns and estimate how much power it will use in your household.

The Energy Star logo is an especially good tool for appliance selection. Currently, the Energy Star logo is applied to appliances that exceed the minimum Government of Canada efficiency level by five to 50 percent (depending on the type of appliance).

Many modern electronic appliances use very small amounts of power compared to older models. A computer, stereo system and television can easily be part of an off-grid home. Like anything else, however, the bigger it is the more power it will use.

A laptop computer uses much less electricity than a desktop computer. An LCD screen TV uses about a third to a half the power of a regular TV.

Consider using an on-demand, or instantaneous, water heater, which uses approximately 30 percent less energy than the familiar hot water tank. It heats water only when you need it, not 24 hours a day. This kind of heater is small, takes up less space, is more repairable and has a longer lifespan than a regular hot water tank. It costs a bit more but will pay for itself in fuel savings.

There are DC appliances and lights available. Setting up your house for DC loads will mean you don't need an inverter but you will have to wire with heavier gauge wire. In general, DC lights and appliances are harder to find, there is a narrower selection and they are more expensive. The possible exception to this is DC water pumps, which are more efficient than AC pumps. The advantage to using DC appliances is that you avoid the electrical cost involved in the inefficiencies of converting DC power to AC by an inverter and the motors work much more efficiently.

Use a propane fridge to reduce electrical needs.

This LCD TV uses 56 watts compared to as much as 150 watts for other similar-sized TVs.

An on-demand propane water heater uses up to 30 percent less energy than a hot water tank.

Type of light bulb	Average lifespan (hours)	Efficacy (lumens per watt)
Incandescent	1,000	20
Halogen	3,000	30
Compact fluorescent	10,000	85

Figure 10. Comparison of different common light bulbs and their relative energy use. Halogen lighting is slightly better than incandescent lighting and compact fluorescent lighting is 75% better than incandescent lighting. (Adapted from lighting design workshop manual, Yukon government, May 2000)

Plug electrical items with a phantom load into a power bar that can be switched off when they are not in use.

Phantom loads

Phantom loads are electrical loads that are not doing any apparent work. Examples include electronic controls on a stove, internal transformers, the clock on a VCR, the thermostat on a space heater, small battery chargers and a television with a remote control. In the case of a TV, there is a small amount of electricity keeping it warmed up so that when you hit the on switch the TV comes on instantly.

Although very small individually, these phantom loads are constant and, when added together, represent a significant drain on your energy system. They can also keep your inverter on at all times, which uses more power. The Luet's Trace SW2512 inverter, when activated, uses 10 times as much power as in search mode (2 amps versus 0.2 amps).

There are a few ways to deal with the problem of phantom loads. First, plan ahead as you are building your off-grid house. Electrical outlets that will service appliances you know will have a phantom load can be wired with a switch so that their power can be switched off when they are not in use.

Plug appliances with phantom loads into a power bar that can be switched off when not in use.

Unplug battery chargers (such as your cordless drill, toothbrush or shaver) or other phantom loads when not in use.

Then there are the electrical loads that are too small to activate your inverter. While in search mode, the inverter needs a certain size of electric load to turn itself on. This can be adjusted to suit individual system needs. A load smaller than the threshold size will not be enough to activate the inverter, or it may activate it but not keep it on and the inverter will cycle on and off. Here are a few examples of how the Luets dealt with this problem.

The first time they used a new router it wouldn't work. They thought it was defective and had started to take it apart to locate the problem before remembering it had a "soft start" feature. It didn't draw enough power, initially, to activate the inverter. Now, they make sure something else is turned on before using the router.

When their washing machine pauses between some cycles it draws little or no power. If the pause is long enough, the inverter reverts to search mode and the wash is interrupted. To circumvent this problem they turn the inverter on manually if there is nothing else on.

The Luet's propane backup heater has an electronic thermostat that acts like a phantom load and turns the inverter on and off. In the few seconds the inverter is on the thermostat senses the temperature is low enough to ignite the heater. The heater takes too long to power up and the inverter turns off. Now, both the inverter and the heater are going on and off, on and off. The heater is used infrequently, so generally it is just left unplugged. When needed, it is plugged in and the inverter is turned on manually.

Renewable heat sources

Passive solar heat

The sun can provide a portion of your space-heating needs, more so if your house is located and designed to take advantage of it.

- Orient the long side of your house to face true south.
- Plant (or keep) deciduous trees on the south side to allow the winter sun in and to shade the house from the summer sun. Plant (or keep) coniferous trees on the north and east sides to protect the house from cold winds.
- Locate the majority of your windows on the south side of the house to let the sun shine in. They should be shaded to provide protection from the heat of the high summer sun but let in the low angled winter sun.

  Windows that are angled away from the vertical are too hard to shade and let in too much summer sun, leading to overheating. Too much glass can be as bad as not enough. It can be a major source of heat loss in the winter and lead to overheating from late spring to early fall.

Energy efficient windows are a benefit in everyone's home. In an off-grid house they work in conjunction with sealing and insulating to reduce heat loss.

- Use the most energy efficient windows you can: triple-glazed, gas-filled, low-e coated with insulating spacers. The low-e coating on windows greatly reduces the amount of heat that radiates out through the window, but also reduces the amount of solar radiation coming into the house. Some people say it should not be used on windows on the south side of the house because of a reduction in solar gain. Others say that the potential heat loss through the window is greater than the potential heat gain in a northern climate.
- Place opening windows to catch prevailing winds for cooling and ventilation.
- Insulate and make your house as leak free as possible. It's a losing battle if you collect all that solar heat only to lose it through the walls, roof and windows.

Inadequate sealing in a log home results in warm air leakage and frost build-up.

Interior thermal mass, often in the form of concrete or stone walls and floors, is usually part of the recipe for passive solar heating. This is unlikely to work very well in northern latitudes because the sun won't strike the mass long enough to warm it up enough to contribute much to the warming of the house. A small way to increase the thermal mass of interior walls that the sun reaches is to fill them with leftover drywall scraps. It costs nothing, requires little extra work and diverts some material from the landfill.

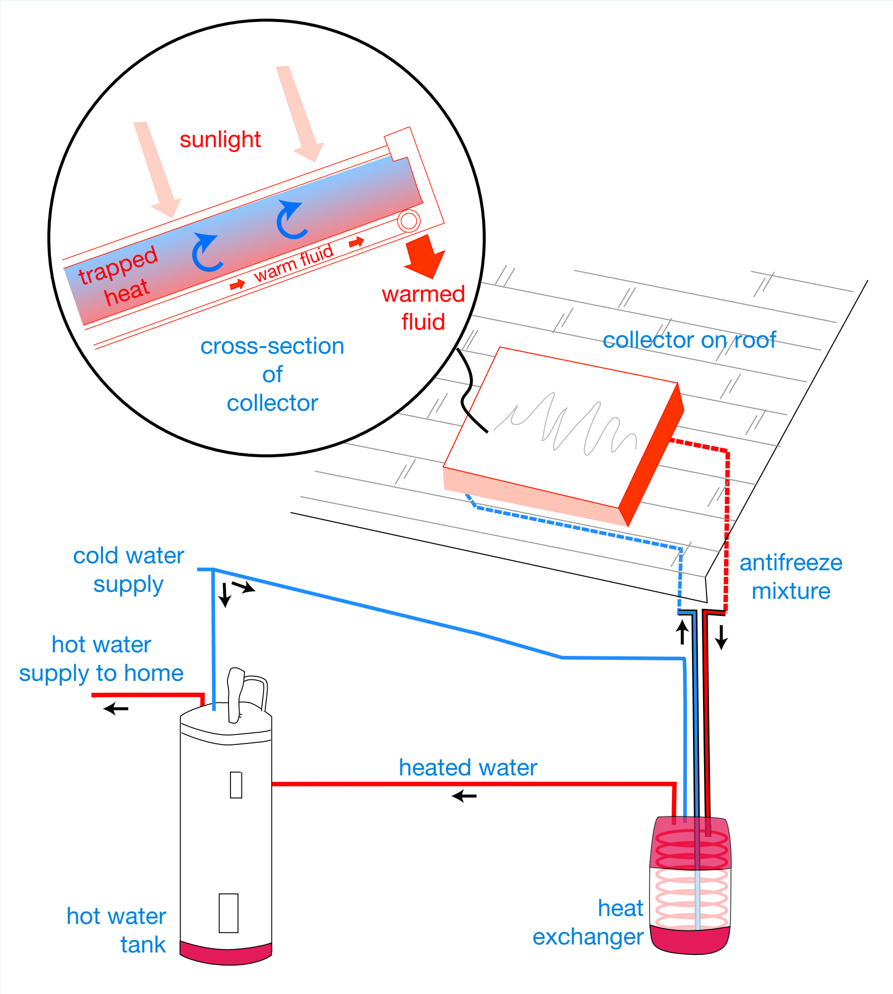
This Whitehorse house has been pre-heating its domestic hot water with solar energy nine months out of 12 for more than 25 years.

Active solar space and water heating

The difference between passive and active solar heating is that active heating requires fans and pumps to move the heat where it is needed and passive does not. These, of course, require electricity to operate. Active solar heating is most often used to heat domestic hot water. Solar collectors (which look like larger, thicker photovoltaic modules) use heat from the sun to warm a water-antifreeze mixture in tubes inside the collector. The mixture is pumped to a heat exchanger where it warms domestic water, which is pumped into a regular hot water tank located next to it. The hot water tank will only need to fire up enough to bring the water up to the required heat, reducing the amount of non-renewable energy used.

An active solar space heater works in a similar way to an active solar water heater. In this case air, instead of the water-antifreeze mixture, is heated in the solar collector. A fan then blows it through ducts into the rooms of the house.

Heat from the sun is trapped in the collector. The warmed fluid from the solar collector goes to a heat exchanger which preheats the water going to the water tank. (*Adapted from "Solar water heating systems," NRCan*)



Wood

Wood is considered a renewable energy source, but it will remain that way only if society uses it wisely. There are places and times in the world where the consumption of wood for heating and cooking has outstripped the supply, resulting in deforestation. If everyone in Canada used wood as their primary source of heat, it is questionable whether wood would continue to be a renewable resource.

Like any resource, renewable or not, wood should be used as efficiently as possible. There are many types and models of efficient wood burning stoves on the market today. The US Environmental Protection Agency (EPA) certifies woodstoves that meet stated emission requirements and produce less smoke and use less wood to heat a home. The Canadian Standards Association (CSA) sets safety standards for woodstoves but does not test for emissions.

Masonry heaters are cleaner and more efficient than non-EPA approved woodstoves, though not rated by the EPA. A masonry heater uses convoluted heat passages through a large mass of stone, brick or soapstone, for example, to store the heat produced by a quick, hot fire. It then radiates the stored heat over a long period of time.

Most wood boilers are also not rated by EPA, and are less efficient and produce more smoke than EPA-approved woodstoves.

A stove that is too big may turn your home into a sauna or have to be turned down so low that it burns inefficiently. A stove that is too small may not heat your home enough or last through the night without being refuelled. If your home is well insulated you may be able to use a smaller stove than if your home is poorly insulated. There are many types and models of woodstoves on the market today. Consult with a knowledgeable retailer to help you find a suitable stove for your home.

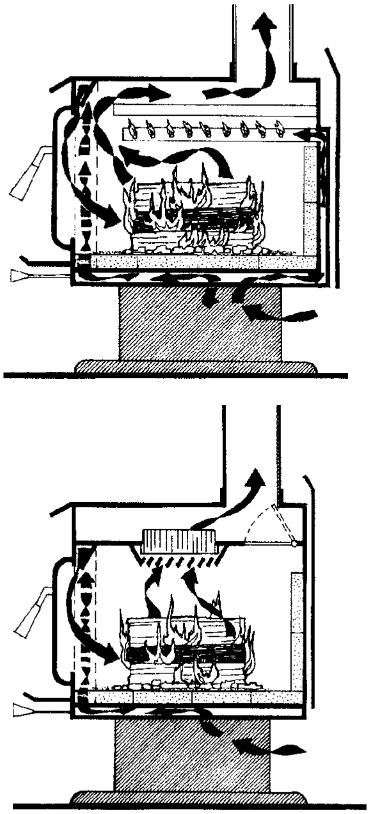
There are two main types of wood burned in the Yukon — spruce and pine — and they produce similar amounts of heat. Even if you feel that wood is plentiful, an older, less efficient wood heater just means you have to buy more, split more, stack more, carry more and burn more wood to heat your home. That's a lot of extra work and expense.

Using a properly installed, efficient wood heater of the appropriate size in a well insulated home will keep you comfortable on even the coldest winter day.

To ensure that your stove is properly set up, have it installed or inspected by a Wood Energy Technology Transfer (WETT) professional (WETT@funnel.ca).

For more detail on wood heat, refer to NRCan's excellent publication, "A guide to residential wood heating" available at http://www.cmhc-schl.gc.ca/en/co/maho/enefcosa/upload/wood_heating_EN_W.pdf.

The Energy Solutions Centre has published a Yukon-specific publication entitled "The lure and lore of wood: A look at the Yukon's natural fuel." This is also available online at www.esc.gov.yk.ca/pdf/lure_and_lore_of_wood.pdf.



Two examples of energy efficient stoves using advanced burning technology: advanced combustion stove (top) and catalytic stove. (Adapted from "A guide to residential wood heating," NRCan)

RECOMMENDATIONS

Lessons learned

Part of the Yukon off-grid housing project included technical support, in the form of an electrical audit report, for homeowners who were audited. This included the load calculation sheet from the original audit and a second load calculation incorporating suggestions for improving the energy efficiency of these homes. Here are two examples to illustrate the amount of energy savings that can be accomplished through relatively simple changes.

The first example is a small photovoltaic-gasoline generator hybrid system. The original load calculation sheet had a required battery bank size of 798 Ah, which would need five photovoltaic modules with a current of 27 amps. The suggested changes included replacing lights with compact fluorescent light bulbs and reducing the amount of time the water pump and ceiling fan operated. In the new scenario, the battery bank size was reduced by 65 percent to 287 Ah and required only two photovoltaic modules (a 60 percent reduction) to adequately charge and equalize it. This is a significant change for minimal work.

The second example is a larger photovoltaic-diesel generator hybrid system. The original load calculation sheet showed a required battery bank size of 5702 Ah, needing 27 photovoltaic panels, with a current of 190 amps to adequately charge and equalize it. Suggestions included changing to compact fluorescent lights, converting to a propane fridge and freezer, changing to a front-loading washing machine, changing to a simple wired-in phone, reducing use of the ceiling fan to 12 hours per day, not using the microwave in winter, upgrading from two desktop computers to laptop computers, and changing to a DC water pump. This is a long list of changes but the battery bank size was reduced by 70 percent to 1732 Ah and the photovoltaic array was reduced the same amount, to eight modules with a current of 64 amps.

Generally, off-grid homes have fewer electrical appliances than on-grid homes, though that's not always the case.

Update to the Luet house, as told by Joel

Trish and I are proud of our energy efficient home but we know it is not perfect. As a result of the integrated design charrette, the electrical audit report and researching we have done, we have become aware of areas that need improvement and ways in which it can be accomplished. Because we had energy efficiency in mind as we designed and built our home, what we need to do will not require major renovations or large amounts of money.

To that end, we have purchased an electric toaster and kettle to use from March to October, insulated the fresh air intake for the wood cookstove, repaired and increased the weather-stripping on the door connecting the house to the garage, walled off and insulated around the water tank to decrease the amount of heat it draws out of the house, and added insulation to the crawlspace floor.

We noticed that the lights we used the most were halogen bulbs that are more efficient than incandescent bulbs but not as efficient as compact fluorescent bulbs. We have therefore replaced a number of them with compact fluorescent bulbs.

We have determined that our generator is the right size for the amount of time it is used (although a small propane generator would be cleaner, quieter, last longer and require less maintenance). Our attention will be spent on finding more ways to reduce our need for it and using it to its maximum potential.

We still need to improve the weather-stripping on our exterior doors and complete a warm air return system to get the warm air at the peak of our cathedral ceiling down to the first floor.

We are investigating putting unused electricity from our photovoltaic array to work as a space heating diversion load in the spring and fall.

As you can see, our system, while good to start with, is still evolving. We are keen on learning more, improving the performance of our renewable energy system, and reducing our use of non-renewable energy sources.

With the electrical audit report on our house, I redid the load calculation using the changes we have made since the original audit. Having lived in the house with our renewable energy system for about four years, I feel I have a better understanding of our usage patterns and think this recalculation is more accurate. In our report, it was suggested that we upgrade to compact fluorescent lighting (in process), warm up the battery room to improve the capacity of the batteries (in process), reduce the use of power tools (this has happened naturally as the house nears completion), switch to a regular phone from a radiophone (done), upgrade the stereo (not yet done), and switch to an electric refrigerator to make better use of the spring and summer sun (still thinking about it).

As well, we have added a TV, DVD player and washing machine to our house.

The original scenario had us needing a battery bank of 6326 Ah, which would require at least 34 photovoltaic modules with an array current of 159 amps to adequately charge and equalize it. The new scenario shows us needing a battery bank of 1075 Ah and eight photovoltaic modules with an array current of 36 amps. This is an 83 percent reduction in the size of the battery bank and a 76 percent reduction in the size of the photovoltaic array! We never had a renewable energy system the size of the original scenario, nor could we have afforded it. I think our original load calculation estimate was a little high, however, we have noticed a reduction in the amount of time we use our generator.

Design advice

Here is a summary of the advice from this guide.

- Make a realistic analysis of your lifestyle needs.
- Be prepared to conserve energy. One dollar in energy conservation can save you three to five dollars in equipment costs.
- Do a careful load calculation to determine your electrical requirements.
- Evaluate your home site: catalogue its resources and choose the best site.
- Spend some time planning your house size, style, layout, construction methods, materials, and everything else necessary.
- Design your house to take the best advantage of the sun for light, electricity and heat.
- Think about the energy used to produce the materials used in constructing your house and transporting it to the building site as well as the energy used to operate your house.
- Insulate, insulate, insulate! The north has a cold climate. The money spent on insulation will be paid back in comfort and reduced heating bills.
- Buy the best windows possible so you can capture the sunlight, enjoy the views and not loose all your heat through them.
- Make energy wise choices about lighting and appliances. It can have a substantial effect on your electrical requirements. Use the EnerGuide Appliance Directory and look for Energy Star qualified appliances.
- Buy an inverter with sufficient operating capacity *and* surge capacity.
- Do some homework on renewable energy systems and find a knowledgeable dealer and installer.
- Keep your phantom loads to a minimum and plan ways of dealing with those you have.
- Use safe practices when installing your system and maintaining it.
- Minimize the need for a fossil-fuelled generator by properly sizing your system, conserving energy and using your generator efficiently.
- Size your battery bank to fit your needs so it won't be discharged too deeply, too quickly or too often.
- Learn about any special wiring considerations that go along with a renewable energy system and make sure your electrician is aware of them.
- Having good monitoring equipment will keep you informed of the state of your system and help you learn about it.
- Keep records.
- Use an EPA-approved woodstove or other efficient, clean burning wood heater, if heating by wood.

Living off-grid may seem like a strange new world but it doesn't mean living primitively. It's a chance to learn something new so go for it!

Is it for you?

After reading about off-grid houses in the Yukon, you may still be wondering if living off-grid is a lifestyle for you. Perhaps it seems like a lot of work. Yes and no.

Initially, it is more work because it's not the usual way of doing things. Some extra research, expense and labour are required to get set up. But after that, the maintenance and monitoring can be accomplished in minutes a week. It takes less time to check the specific gravity of your batteries than it does to wash the dishes, and you don't have to do it as often. Checking your monitor only takes seconds, but you will probably do it more often than you need to just to see how much clean, renewable energy is flowing into your home!

There are more and more people choosing to live off-grid in the Yukon. If you see solar panels on a roof or a wind turbine in the yard, chances are these people will have good advice to offer you.

Appendix 1: Integrated design charrette

An integrated design charrette is a multi-disciplinary workshop that allows discussion and design among a diverse range of stakeholders and experts over a period of about three days. While originally used as an architectural tool, charrettes are useful for addressing complex policy and planning issues in many disciplines.

A design charrette typically involves three stages. The first is the "talking" stage, in which participants familiarize themselves with the challenge at hand and how best to approach it.

The second stage, known as the "doodling" stage, is where the proposed ideas are revisited with pen and other graphic material in hand. The images tend to be diagrammatic and undeveloped, but are used as a mechanism for synthesizing the initial conceptual ideas. Sometimes this stage involves breaking out into smaller sub-groups in order to develop specific ideas in a more focused manner.

The third stage is the "drawing" stage, during which time ideas are pooled and refined through more detailed drawings, graphics, concepts, calculations and modelling.

The Whitehorse off-grid design charrette, held in December 2003, included each of these stages. The core goal of the charrette was to find ways for Yukon off-grid homeowners to increase their use of renewable energy without increasing their total energy consumption and, in doing so, contribute to research on integrating and optimizing energy systems in off-grid houses across the north. Additional design issues integrated into the charrette included suggestions for reducing water consumption and waste production (both of which are important concerns for isolated dwellings), improving indoor air quality, and, in general, improving the liveability of the home.

To accomplish these goals, 30 participants from a wide range of backgrounds and locations in Canada and Alaska came to Whitehorse. The participants had a mix of practical experience and leading edge research knowledge in the application of renewable energy systems and energy efficiency as it applies to the construction and renovation of homes. They were divided into three teams and each team was given a case study of an existing off-grid house in the Whitehorse area. These case studies came from among the top 10 most energy efficient homes in the energy survey of Yukon off-grid residences undertaken prior to the charrette. The teams were instructed to develop design changes or adjustments to the energy supply system and building envelope of their given house which could result in an increase in the renewable energy portion of the home's total energy supply by 30 to 50 percent.

To accomplish this task the participants had a very full schedule that included a field trip to their case study house, individual, team and group working sessions, presentations, early morning breakfasts, and a late night bonfire on the banks of the Yukon River.

The design teams came up with several recommendations with a payback period of five years or less that, if implemented by the homeowners, could increase the renewable energy portion of their total energy supply from as low as five percent (at a cost of $6,000) for

the most energy efficient home, to as high as 76 percent (at a cost of $20,000) for the least energy efficient home. The recommendations could also result in noticeable reductions in total annual fuel consumption for these homes by eight and 28 percent respectively.

Recommendations for the third case study house, with a payback period of 10 years or less (at a cost of $22,000) could result in an 18 percent increase in the renewable energy portion of the total energy, and an 11 percent reduction in total annual fuel use. For this house, the design team also developed a "fresh start" design, for which money was no object. In this scenario, the suggested improvements and design recommendations resulted in an off-grid residence with 95 percent of its total energy supplied by renewable energy sources and only about five percent with fossil fuel, which was used for back up and auxiliary power.

The Whitehorse charrette provided the case study homeowners with immediate recommendations on options to increase the renewable energy portion of their annual energy consumption. As well, the charrette provided an exchange of ideas and opinions on increasing the use of renewable energy in northern climates. Participants left with a greater knowledge of current renewable energy use north of 60°.

Appendix 2: Load calculation

Use the renewable energy system load worksheet and the battery bank sizing worksheet (samples on the next two pages) to figure out how much power you use on a regular basis. The following steps will guide you through the process.

1. *Fill in the information about each major appliance on the top of the first worksheet. Then go to each room and list in the "other loads" column every item that uses electricity (called a load). In the second column, beside each item record how much energy it uses in watts.* This can usually be found on the base or glass of a light bulb and on a plate on the bottom or back of appliances. If the power usage is listed as amps, multiply the number by the voltage to get watts.

2. *Estimate how much time every item is used each day and record this in the third column. Skip this column for big loads that you may only use a couple times a week.* This step is critical so take some time and get the whole family involved. They may find loads you have missed, and they will become empowered to stick to the load calculation if they are involved from the beginning.

3. *Figure out how many days a week you will be using each item and record that in column four.*

4. *Multiply column 2 x column 3 x column 4 to get the weekly load for each item you listed. Now add up all the weekly loads to get your total weekly load (and yes, it will only be an estimate) in cell A.* This is in units of watt hours (Wh) and represents the average amount of power you will need each week.

5. Because the size of battery banks are usually expressed in amp hours (Ah), *divide your total weekly load (cell A) by your system voltage (cell B; it will be 12, 24 or 48V) to get your weekly load in Ah. Now divide by seven to get the daily average Ah.* This represents your average daily power requirements and goes in cell C.

6. Now that your daily power requirements are known you can figure out what size your battery bank should be. (You may want the help of an experienced dealer or installer with the rest of this procedure.) Because the efficiency of the inverter you will use is not 100 percent you will then need to *correct the daily average, based on the efficiency of your inverter (cell D).* If, as an example, your inverter is 90 percent efficient convert that to a decimal figure (.9) to use in the calculation in cell E. Let's say your daily load is 100 Ah. The calculation in cell E would be:

   100 + (100(1-.9)) =110 Ah

   110 Ah is your required system power. Record this in cell F on the battery bank sizing worksheet.

7. Hang in there! You're almost done. *Decide how many days you want to go without any input from sun, wind or water (days of autonomy) before you need to fire up your generator to charge your batteries.* Three days of autonomy are suggested for photovoltaic systems and five days are suggested for wind systems. You can use these suggested times or decide for yourself. Keep in mind that the more days of autonomy you want will require a larger renewable energy system and/or more efficient use of electricity, i.e. conservation. (Days of autonomy aren't relevant for a micro-hydro system because the batteries for these continuous energy supply systems are used just to help meet peak loads.) *Multiply this number by your required system power in cell F to get the total capacity. Record this in cell G.*

8. No rechargeable battery should be completely discharged. Many are designed to be discharged up to 80 percent without damage but if you want them to last longer, the maximum discharge shouldn't be more than 50 percent. That means you only have half your total battery capacity to play with. *Convert the percent into a decimal again and follow the calculation in cell I on the second worksheet (p.42) to find your required capacity.*

9. The temperature your batteries are stored at affects their performance. *Multiply cell I by the multiplier from the multiplier table that corresponds to the lowest temperature at which you will store your batteries, and record the result in cell J.*

Finally!! The magic number!
This is the required battery bank, expressed in amp hours that should suit your needs.

With this number you can go on to determine the size of your solar array, wind turbine, micro-hydro turbine and/or generator, and the other equipment to control the renewable energy system.

On the back of each appliance is a specifications plate which details its energy draw.

Renewable energy system load worksheet

Major loads	EnerGuide rating (kWh)				Weekly load (Wh)
refrigerator			divide by 52 X 1000	=	
deep freeze				=	

	Standard rating (Wh)		# hours used per week		Weekly load (Wh)
dishwasher	1300	X		=	
washing machine (front load)	160	X		=	
washing machine (top load)	500	X		=	
dryer	600	X		=	

Other loads (includes smaller appliances and power tools)	Watts AC		# of hours used per day		# of days used per week		Weekly load (Wh)
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
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		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
		x		x		=	
Total weekly load (Wh)							**A** total the column above

System voltage (V)	**B** 12, 24 or 48	**Load in Ah/day**	**C** cell A/cell B/ 7 days per week
Inverter efficiency	**D**	**Required system power (Ah/day)**	**E** cell C+(cell C x (1 - cell D))

Battery bank sizing worksheet

Required system power (Ah/day)	X	Number of days of autonomy	=	Total capacity
F cell E from load worksheet		3 recommended		G

Maximum discharge	H 50%

Required capacity	I cell G + (cell G x (1-cell H))	X	*Multiplier to correct for battery storage space temp.	=	Required battery bank (Ah)
					J

Average daily depth of discharge	cell F/cell J

Average daily depth of discharge tells us what the cycle life of the battery will be. To calculate average daily depth of discharge, divide required system power by required battery bank

***Multiplier table**

Battery storage space temperature (˚C)	Multiplier
20	1
15	1.02-1.05
10	1.05-1.11
5	1.09-1.17
0	1.11-1.25
-5	1.17-1.43
-10	1.25-1.67

Note: The best use of your battery dollars is to match the cycle life and float life of the batteries. The float life is the life of the batteries if they were never to be used at all.

SAMPLE WORKSHEET

Reducing the power requirements from 1266 Ah per day (four years ago) to 137 Ah per day (current) meant that the size of the battery bank for the Luet house was down from 6326 Ah to 1075 Ah.

Battery bank sizing worksheet: Existing scenario

Required system power (Ah/day)	X	Number of days of autonomy	=	Total capacity
F 1266 (cell E from load worksheet)		3 (3 recommended)		G 3799

Maximum discharge	H 50%

Required capacity	I	X	*Multiplier to correct for battery storage space temp.	=	Required battery bank (Ah)
	5699 (cell G x (1-cell H))		1.11		J 6326

Battery bank sizing worksheet: New scenario

Required system power (Ah/day)	X	Number of days of autonomy	=	Total capacity
F 137 (cell E from load worksheet)		5 (3 recommended)		G 683

Maximum discharge	H 50%

Required capacity	I	X	*Multiplier to correct for battery storage space temp.	=	Required battery bank (Ah)
	1024 (cell G + (cell G x (1-cell H)))		1.05		J 1075

Appendix 3: Solar radiation

The following table illustrates the amount of sun hitting a photovoltaic array and the potential power output of the array. Actual power output will be affected by factors such as season, latitude, shading and weather.

Values for average daily insolation for various locations can be found at the NASA Surface Meteorology and Solar Energy dataset website (eosweb.larc.nasa.gov/sse). Insolation is the amount of solar energy hitting a surface over time. It is usually referred to as megajoules per square metre, peak sun hours or kilowatt hours per square metre. One megajoule per square metre divided by 3.6 equals one peak sun hour, which equals one kilowatt hour per square metre.

To determine power output for your situation, insert the insolation values for your area, and multiply by the power rating of your array.

Refer to the part of your load calculation that states the required system power in Ah/day. Multiply the Ah/day by your system voltage to get a value in watts and compare it to the expected power output column below.

Another way to use the information would be to take the required system power from the load calculation (converted to watts) and divide it by the peak sun hours to give you the array wattage needed to meet your daily power needs.

You will get a different value for each month but you can decide whether to go with the December numbers, the summer numbers or an average.

Month	Average daily insolation at 75° array tilt, Whitehorse		Average daily power output (watts)		Expected daily power output (watts)	
	1 megajoules per square metre	2 Peak sun hours (column 1 divided by 3.6)	3 Sample array of 500 watts (column 2 times 500)	4 Write your array size ________ (column 2 times your array size)	5 Sample array of 500 watts (column 3 times .75)	6 Write your array size ________ (column 4 times .75)
January	6.42	1.78	890		667.5	
February	11.62	3.23	1615		1211	
March	16.27	4.52	2260		1695	
April	16.54	4.59	2295		1721	
May	15.91	4.42	2210		1675.5	
June	15.11	4.2	2100		1575	
July	14.12	3.92	1960		1470	
August	13.8	3.83	1915		1436	
September	11.57	3.21	1605		1204	
October	9.29	2.58	1290		967.5	
November	6.13	1.7	850		637.5	
December	4.24	1.18	590		442.5	
Annual	**11.77**	**3.27**	**1635**		**1226**	

Adapted from "Photovoltaic systems design manual," Energy Mines and Resources Canada

Appendix 4: References

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SW Series Inverter/Chargers: Owner's manual. Xantrex Technologies, Arlington, WA, 2001.

Product suppliers

The Renewable Energy World suppliers database (http://www.repp.org/gem.html) provides contact information for companies and organizations around the world which specialize in renewable energy products and services. Search the database or browse by business type, geographic location or alphabetically. Note that this database lists companies specializing in both large and small wind turbines.

Solar

For general information on solar energy in Canada, go to the website for the Solar Energy Society of Canada, http://www.sesci.ca/.

To find a qualified solar professional who abides by the industry's code of conduct go to the Canadian Solar Industries Association website (www.cansia.ca).

Wind

The Canadian Wind Energy Association has a web page (http://www.smallwindenergy.ca/en/SmallWind.html) devoted to Canadian companies specializing in small wind systems.

The American Wind Energy Association lists US wind energy suppliers on its website (www.awea.org/faq/smsyslst.html).

Momentum Technologies LLC provides contact information for companies that make, sell, install, consult on, or service wind turbines smaller than 50 kilowatts (energy.sourceguides.com/index.shtml). Search the database or browse by business type, geographic location or alphabetically.

Power meters

For meter suppliers, look for "Kill A Watt" by P3 International (www.p3international.com/products/special/P4400/P4400-CE.html) and "Watts Up?" by Electronic Educational Devices (https://www.doubleed.com/products.html).

As well, Brand Electronics sells several models (www.brandelectronics.com).

Monitoring and data logging software

The following companies sell tools for renewable energy systems:

- Right Hand Engineering (www.righthandeng.com)
- Upland Technology, Energy Viewer (www.uplandtechnologies.com)
- Solar Guppy Software, Henry Cutler (http://www.solar-guppy.com/forum/index.php)
- Fat Spaniel (www.fatspaniel.com)

Northern off-grid information network

Canada Yukon Energy Solutions Centre (867) 393-7063, www.esc.gov.yk.ca; esc@gov.yk.ca.

CANMET Energy Technology Centre, Varennes, Quebec, Department of Natural Resources Canada, Josef.Ayoub@RNCan-NRCan.gc.ca.