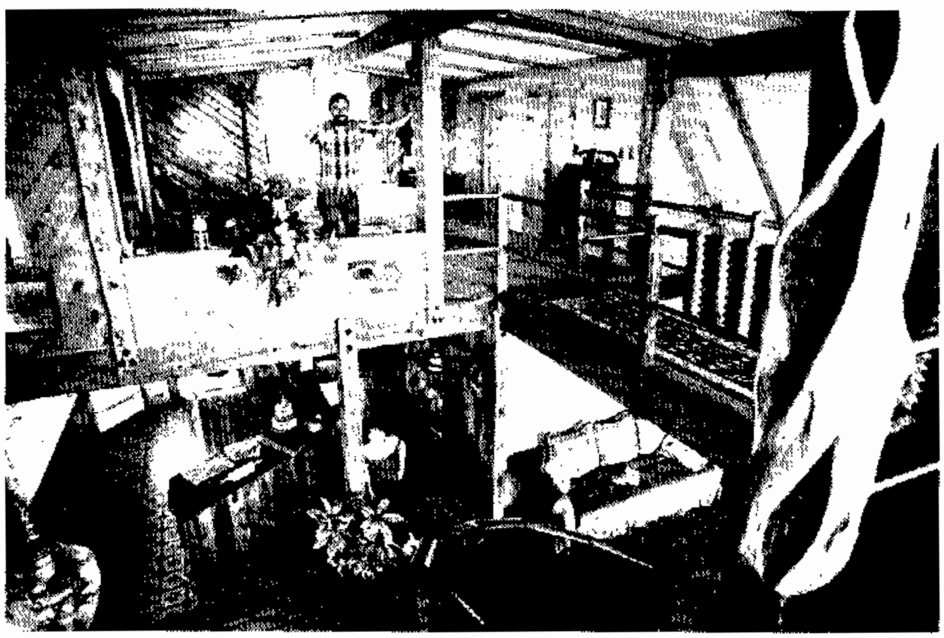
Living with Electricity from Sunlight

by Ed and Claudia Edmondson

Left: Front view of the Edmondsons' house showing the solar array panels. Below: Interior of the home, made all the more liveable by their photovoltaic electrical system. (Eric Muehling photos, courtesy of Fairbanks Daily News-Miner.)



NESTLED AMONG the birch trees on a south-facing slope north of Fairbanks, Alaska, sits our 2800-square foot home, electrically powered by sunlight. By using a photovoltaic system we operate lights, televisions, pumps, fans, stereos, tools, and a host of other appliances including a VCR and an Apple IIe computer system. Batteries charged during the day by photovoltaic modules power most of the 12 volt appliances, and an inverter that converts 12-volt dc battery power into 120-volt, 60-Hz ac current operates the other appliances.

The term photovoltaic is sometimes mispronounced, often confused with solar heating, and usually thought of as describing space-age technology. Although they promise much more for the future, photovoltaics can provide an alternative means of producing electricity now. They are especially useful and cost effective in rural areas where no utility-grid power is affordable or even available. Unlike diesel or gas generators, photovoltaic modules are silent, have no moving parts to break, do not produce any waste at the point of use, require little maintenance, actually work better in cold weather, and operate on free fuel—sunlight.

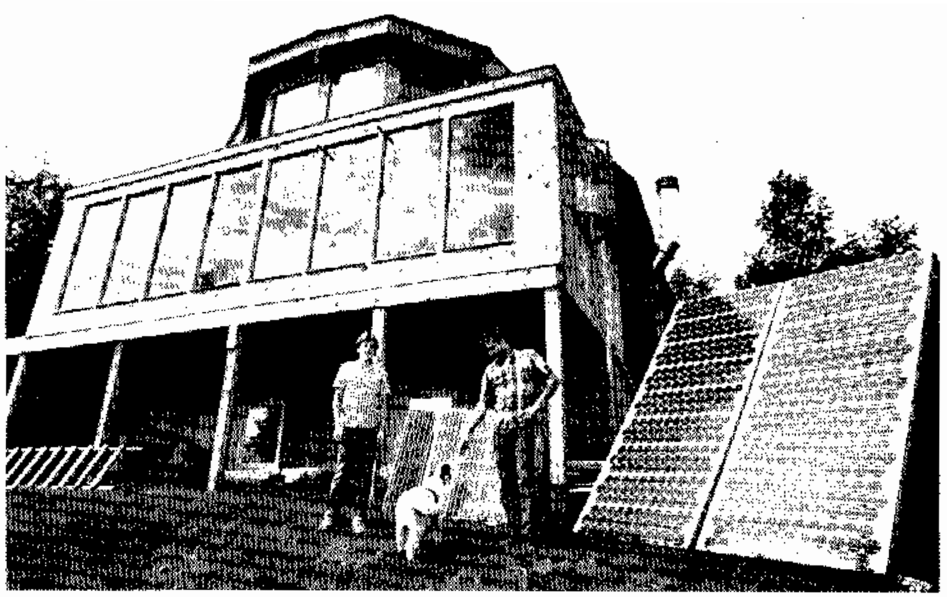
Ed and Claudia Edmondson *have lived in Alaska for 11 years. Ed is a fire management forester in the State Division of Forestry and Claudia works for the Alaska Railroad Corporation in customer relations. They have lived in their present home, along with their two sons, since 1983.*

PHOTOVOLTAICS: A TECHNICAL OVERVIEW

The term photovoltaic (pronounced fo'to-vol-ta'ik) is a combination of the words "photo," from the Greek word for light, and "voltaic," referring to electricity developed through contact, defined as *the direct conversion of sunlight into electricity by the use of solar cells.* The photovoltaic (PV) process was discovered in the mid-1800s by E. Basqueral,[1] but inherent inefficiencies prevented cost-effective production. Their development aided by the introduction of microchip technology, PV systems became commercially available in the mid-1950s. PVs really celebrated their birthday on 31 March 1958 when they generated solar electricity for the Vanguard 1 satellite,[2] at a cost that was, well, let's say astronomical.

To understand better how solar cells work, it may be helpful to know how they are made. There are several processes used in production, but the process described here gives the basic idea. (More detail and depth can be gained from the book *Practical Photovoltaics.*[3]) Quartz and carbon are ground and blended together. The mixture is smelted in a vacuum and the impurities are removed to the parts-per million range (although tiny amounts of specific impurities must be added for the finished cells to generate a current). The hyperpure molten silicon is then poured into a mold where it forms a crystal approximately 4 inches across and 18 inches long. The resultant crystal is sliced into extremely thin wafers, which are then treated in a diffusion furnace so that phosphorus atoms are added in a microscopically thin layer at the top of the wafer.

Radiated light energy, either direct from the sun and diffused through the atmosphere or from an artificial source such as a light bulb, contains streams of energy units called photons. When light strikes the solar cell, the photons generate free positive and negative charges in different portions of its surface, creating voltage that will drive a flow of dc electricity. By connecting wires to each side of the wafer, the current produced can be used in an electrical circuit. The electrical characteristics of a typical PV cell are shown in Figure 1. There are two major influences on the characteristic solar current-voltage (I-V) curve—sunlight intensity (insolation) and the operating temperature of the solar cells. Basically, the greater the insolation and the lower the operating temperature, the higher will be the electrical output of a PV cell. For any given set of temperature/insolation, there exists a unique operating voltage that will maximize the power output of a solar cell: this is called the maximum power point and will change as often as the cell temperature or insolation changes.[5]



Solar panels placed on the south-exposure hill "soak up the sun" and produce enough energy for lights and other electrical needs. (Eric Muehling photo, courtesy of Fairbanks Daily News-Miner.)

The maximum power output of a typical solar cell, rated at an insolation level of 1000 watts per square meter (peak sunlight) and a cell temperature of 25°C (77°F), is on the order of 1.0 watt at 0.5 volts.[6] A PV module, the building block of an array, typically contains 30 to 40 or more individual cells. The cells are electrically connected in both series and parallel to obtain a maximum voltage of 14 to 16 volts, and a current of 2 to 4 amperes, which is adequate to charge a 12-volt battery. The total voltage of the solar module or array must exceed the battery voltage to "push" the charge into the battery. Voltages less than the state of charge of the storage system will do nothing toward charging the battery, but may provide enough power to run some 12-volt appliances.

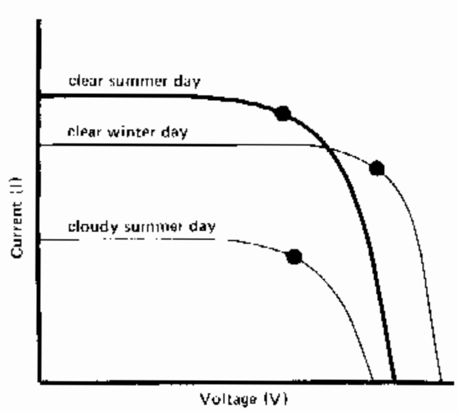


Figure 1. Typical electrical characteristics of a solar cell: as indicated, the cell produces more voltage on a clear winter day than on a warm, clear summer day, due to the decreased operating temperature of the cell. However, the current (amperes) is decreased due to the amount of available sunlight. The dots on each curve show the approximate points of maximum power.[4]

The current module efficiency is on the order of 10 to 12 percent. That is, each individual cell is capable of converting about 10 percent of the available light into electrical current. As research and development in producing different types of cells continue, this efficiency rating is going to increase. Cells are now being produced that are 17 to 24 percent efficient under laboratory conditions.

WHY WE CHOSE SOLAR

Seven years ago we purchased a cabin and five acres of land approximately ten miles outside of Fairbanks. We lived in the cabin for more than three years without electricity or plumbing while we constructed a new home on the site. By using propane for lighting, cooking and hot water, a wood stove for heat, and a gas generator when necessary, we found we not only could survive but could live comfortably virtually without electricity. However, in our new home we decided we would like at least a few more amenities, such as running water and better lighting. The estimate from our local utility to run power

Although the electric lights, color television, and computer are solar powered, the oven and refrigerator are fueled by propane. (Eric Muehling photo, courtesy of Fairbanks Daily News-Miner.)

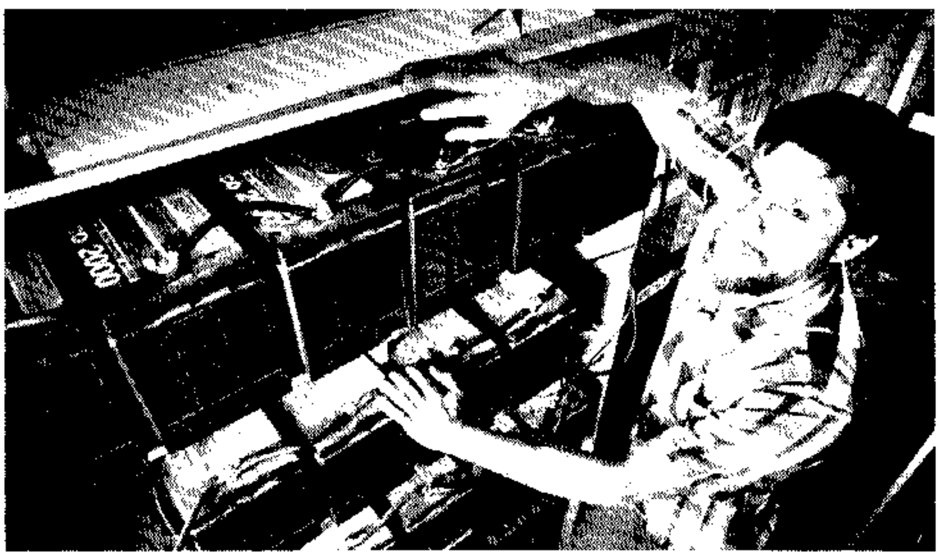
lines approximately three-quarters of a mile to our new home was a grand total of $18,750! Faced with an initial cash outlay of this astonishing magnitude plus a monthly charge per kilowatt hour estimated to increase at approximately 7 percent a year, we decided to investigate the alternatives.

After considerable research, we decided against fossil fuel generators, because of the associated noise and maintenance, and ruled out wind generators because our site lacked adequate wind. We decided that photovoltaics would be the logical choice, but the decision did not end the problem. Most inquiries into the subject were met with, "Photo-what?" After amassing and attempting to digest all of the information we could possibly find on the subject, we designed a photovoltaic system to suit our needs and invested $10,000 in the necessary components. With a 40 percent tax credit from the federal government, our purchase price was reduced to around $6000, one-third of the amount required to install conventional power — plus, we received no monthly utility bills. The system is virtually maintenance free and the life expectancy of the solar modules is approximately 20 years or more. Other components of the system, such as voltage regulators, meters, batteries, and the inverter may have shorter lives than the modules, but most have few moving parts, such as switches and relays, and are modularly constructed for easy part replacement.

After careful calculation of what our electrical needs would be in our new home, Ed designed the system to meet our requirements. He wired the house and installed everything himself, following what meager electrical codes could be found on 12-volt residential systems. Our PV array consists of 22 Arco Solar modules that have a peak output rating of 35 watts and approximately 2.2 amperes each. In the spring, summer, and early fall, about nine months of the year, the system operates at about 55 percent of peak output. However, even at this rating, more electricity is produced than can be stored in our battery system. From mid-November until mid-January, the system's effectiveness falls off considerably due to the lack of available sunlight. This is not to say that in midwinter the array does not produce electricity—it does, but not enough to meet our demands. The demand we place on the system is high in comparison to what most users of PVs require. We have a pressurized 12-volt water pumping system for the kitchen and two full baths, we operate three televisions (one color and two black and white), each room has at least one overhead light, and we operate a computer and VCR plus several small appliances.

During the months of low sunlight, the first basic rule of living with PV, or any alternative energy system, comes into effect: the system will work if you are energy conscious, willing to conserve electricity and to use it creatively. To put this rule into effect we simply watch less color TV which is a big energy consumer, use the computer less, and watch fewer movies on the VCR. During the period of low energy production, we rely on the black and white television, and even find time to read, play scrabble, and talk to one another.

Even with our conservation methods, it is difficult to maintain a high state of charge in the battery system. To compensate for this, we use two additional methods of battery charging. We run a gas-powered generator once a week to pump water from our 320-foot well into a holding tank located inside the house. While the generator is running, we do the vacuuming and charge the batteries with an industrial-type high-output charger. The other method



Ed Edmondson displays the line of batteries that are charged by the solar panels. The batteries provide current for the household lights and electrical appliances. (Eric Muehling photo, courtesy of Fairbanks Daily News-Miner.)

actually complements our PVs to form a hybrid system. With the recent introduction of small thermovoltaic (ThV) modules for residential use, wood-fueled space heating stoves can augment the limited electrical power available from a PV system during the winter months. We bought and installed one of these modules. The PV portion of our hybrid system is designed to optimize the use of the extensive summer insolation we have in Fairbanks, and the ThV portion can provide a majority of our winter energy needs, using wood as a fuel.

The ThV module we installed is rated to produce a maximum sustained power of around 50 watts. The module, a ThermovoltR, incorporates a series of semiconductor thermoelectric junctions mounted in a special heat transfer plate exposed to the flame in the stove. These thermoelectric junctions produce power for our 12-volt system proportional to the temperature difference between the hot and cold junctions. One junction is kept cool by pumping cold water through the module. As the cold water passes through the system, it is heated and stored in a hot water tank and used for domestic purposes. The efficiency of converting thermal to electrical energy is low, about 5 percent. However, since the system provides useful heated water, the overall ThV module efficiency approaches 99 percent and costs only the energy needed for pumping the cooling water.[4] Since we use the woodstove as our primary heat source, it seems like a gift that not only does our necessary wood supply provide heat, it provides electricity and hot water too.

An annual PV-ThV energy profile for the Fairbanks area is shown in Figure 2. The profile shows our PV energy output to be generally constant between March

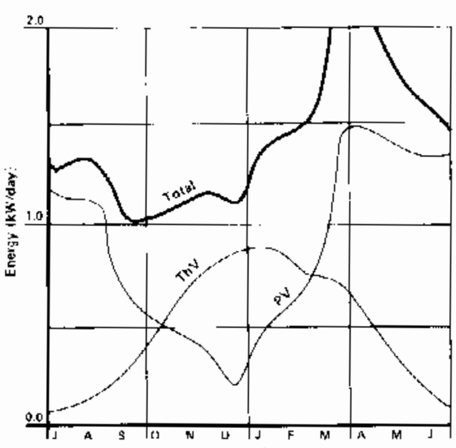
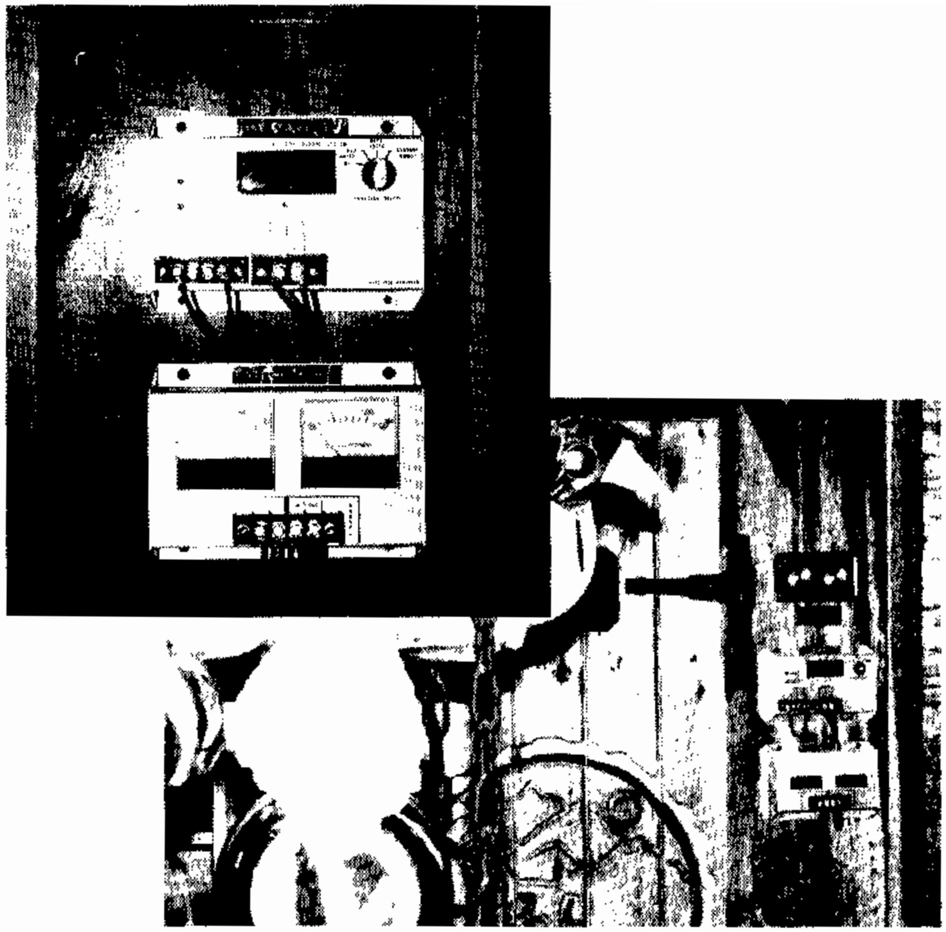


Figure 2. Annual thermovoltaic photovoltaic energy use profile for Fairbanks, Alaska.[4]



The visual control monitors for the battery banks are located on the first floor.

and September and to break off sharply in October to a low in December and then to increase in January and February. The ThV output picks up where that from the PV decreases, which allows for a more constant charging rate for our battery storage system.

Battery charging is the weak link in any alternative energy system. Discussion about batteries and their capabilities can become extremely complicated, but there are some important items that should be covered.

If our use of electricity coincided with the sunlight available for powering the solar generator, there would be few problems. However, in general we need the most power when there is the least sunlight, going by both time of day and time of year. Thus, we need a battery bank. Similar to an expansion tank on a plumbing system which smooths out the operation of the pump and provides a constant pressure, the battery bank smooths out the supply of electricity during cloudy or dark periods and provides for a constant "pressure," i.e., voltage.

Many types and styles of batteries have been produced for dc electrical storage systems. About the only thing they have in common is their ability to change electrical energy into chemical energy in a reversible chemical action. For photovoltaic and all other alternative energy systems needing storage, only deep-cycle batteries should be used because of their ability to take and give up charges repeatedly. Ordinary car batteries, on the average, can be charged and discharged about 20 times before the plates that cause the chemical action become worn out. Deep-cycle batteries, with plates that are thicker, that are made of different alloys, or that contain different chemicals, are capable of as many as 3000 cycles depending on the type and condition.

Our system contains 16 Delco photovoltaic-type batteries, each rated at 105 ampere-hours. This gives us about 1600 ampere-hours of capacity, or about 10 days' worth of power. This 10-day assumption is on the conservative side, to ensure that we don't dip too deeply into the storage capacity and cause permanent damage

A small "square wave" inverter in the kitchen can be used to operate appliances such as the 110-volt blender. This inverter has been installed for convenience, so that the user doesn't have to travel to the basement to turn on the larger inverter.

to the batteries. But even on cloudy, snowy days, as long as the array is kept free of snow, enough trickle charge will be produced to keep the chemical action going.

There are energy costs involved in retrieving stored power and getting it to the point of use, and monetary costs because of the batteries' limited life span. Our Delcos will probably last somewhere between 5 to 10 years before they have to be replaced - and that will be a major expense; presently, batteries suitable for photovoltaic systems cost from $600 to $1000. There are many batteries being produced that reputedly have longer life spans; even some older systems, such as telephone exchange batteries, have lasted 20 to 30 years. Research into the development of better batteries is continuing, and the super battery may be constructed within the next decade.

So far the PV system has required only simple, routine maintenance. Generally it includes checking for loose connections and corrosion on the batteries. During the winter months, snow must be brushed off the array to allow for a peak system performance.

Living with PV has been a learning and experimenting process. We learned the hard way, for example, that solar panels have a bit in common with sails when our array blew over in a windstorm. Two panels were damaged. The panels are now well secured, as they should have been from the first. If we were starting from scratch today, we would allow for more wiring for additional outlets and light fixtures; we would also take advantage of the improved equipment now available. Yet although there are some things we would now change if we could start again, we feel that photovoltaics have been the correct choice for our electrical needs. It is always enjoyable, on a bright sunny day when the battery bank has been fully charged by midmorning, to say, "Hey, let's turn on the television or something; we are on free electricity!"

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The large modulated sine wave inverter (lower right) is used for large appliances such as the VCR, computer, and vacuum cleaner. The charge control panel (upper right) monitors the batteries by giving back signals to the solar panels to decrease or increase the electrical charge. Circuit breaker switches are on the boxes, with individual 10-ampere fuses below. The battery bank is on the left.