

Chapter Two

Case Study: Creating A Solar Office

Energy Efficiency and Conservation Lead the Way

Since the mid-1980s, I've been consulting on and designing custom passive solar homes for the Midwest USA. When I decided in 1999 to run my home office on solar electricity, I knew the supply and demand balancing act would be similar to passive solar design. I would have to make my office way more efficient and incorporate lots of electricity storage to get me through a week or more of continuously cloudy weather during winter.

Motivated to be freed from responsibility for all the pollution caused by my coal-burning utility, I would have preferred to convert my whole house to solar electricity, but that goal was unaffordable for me, as it is for most folks I meet. As an optimist, I think progress doesn't need to be an all-or-nothing proposition. I wanted my office solar conversion project to be an educational tool to describe not only how we can make progress in small, more affordable steps, but also how each step can make the next step easier.

Starting with an Audit

First I needed to know about average sunlight at my general location. Charts and tables in *The Solar Electric Independent Home Book* by New England Solar Electric Inc. showed that Cincinnati, Ohio (about 40 minutes north), gets less than 2.5 average daily peak sun hours in winter, and less at the winter solstice. Since my work schedule is typically slow during Christmas holidays, I decided to use 2.5 daily sun hours as my design's worst-case scenario.

On the winter solstice, December 21 or 22, the sun rises and sets approximately 60 degrees east and west of south. Since this is the least sunny time of year for my location, I needed a mostly unobstructed window to this day's sunpath. But even the best site available for my array could not perfectly accomplish this. My southeast and south horizons were mostly clear, but my southwest horizon was partially obscured by a deciduous Maple tree. Even without its leaves, this tree's branches would partially reduce my clear solar access starting about two hours past solar noon during winter. My calculations showed that my worst-case winter solstice design scenario should be reduced to 2.0 daily sun hours.

Next I needed to audit my office to find out how much power I used. In 1999, I had two pre-Y2K desktop computers with 14" color monitors, a laser printer, high-temperature copier, a couple old plotters,



Figure 2.1: John Robbins with the PV panels that power his office.

a variety of lamps, a small boombox, answering machine, electric pencil sharpener and a variety of portable devices which used rechargeable batteries. With my WattsUp meter, I measured the power each piece consumed on average, at peak and when turned off. (Some appliances use energy when they are "off" - we call these "phantom loads.") I also kept records for a couple weeks of how long each device was on.

I input this data into Ben Root's "loadcalc" spreadsheet, which I downloaded from *Home Power* magazine's website (www.homepower.com). As shown in my initial audit, Table 2.1, I was using about 1.25 kWh per day and my peak electric demand was about 2 kW. I modified Ben's spreadsheet so that it ranked devices by power consumption and demand. As the process continued, I further expanded the spreadsheet until it became a group of spreadsheets representing steps in my efficiency upgrades, all linked to a final spreadsheet which sized the four major solar electric system components: PVs, charge controller, inverter and batteries.

In terms of total energy use, which determines the size of the solar array and battery capacity, my biggest loads were the computers, boombox, clock and answering machine. I was not surprised to see the computers there, but I didn't expect that several low-watt devices would be so highly ranked. It was the fact that they were on 24 hours a day, 7 days a week that made them into such big consumers.

Conversely, since many of my high-watt devices were

off most of the time, their overall consumption was lower than expected. For example, my 1100 watt copier consumed 11.4 times less energy than my 3-watt answering machine! I also noted that 4 of the top 6 consumers had phantom loads, including the multi-outlet strip!

In terms of my peak demand, which would drive inverter, breaker, fuses and distribution wire sizes, I could easily see that my copier, printer and computers were ranked highest, but I was surprised to see how much power the electric pencil sharpener demanded!

Finally, the sizing spreadsheet (Table 2.3, "Before" column) showed that I would need at least 747 watts of PVs, 1875 amp-hours of 12-volt batteries, 1886 watts of inverter AC output and a 52-amp charge controller. Based on a call to the local solar retailer, Randy Sizemore of Entropy Ltd. in Cincinnati, these 4 components could cost close to \$7,000, even before labor and all the other stuff which goes with a full installation. This was too much for my budget. So during late 1999 and well into 2000, I worked on reducing my consumption and demand.

Becoming As Efficient As Possible

Since I had started this process in the waning months of 1999 when Y2K concerns about computers were high, and since my computers were each several years old, I started by upgrading computers. Just about any newer computers would be faster and provide more features than what I had, so rather than looking

at new equipment, I checked into used computers. Desiring more portability, my first purchase was a notebook computer, a one-year-old factory-refurbished model with a 100 mhz processor and a 12" screen. It was about half the price of a brand-new notebook with similar features.

I did not initially realize that a notebook computer would use dramatically less energy, but I immediately found this to be true! The desktop computers and monitors I had and looked at were all "Energy Star" rated, so I assumed that meant they all were similarly energy efficient. But when I metered the notebook, I discovered that with optimum power-saving settings and with the 3.5" disk drive instead of the CD drive inserted into its main bay, the notebook used 1/8 to 1/6 as much energy as used by a similarly featured desktop I almost bought! (With the CD drive inserted, the notebook used significantly more power than without it, so it made sense to connect the CD only when needed.) I initially thought the 12" screen would be too small, but discovered it had about the same display area as the 14" monitors to which I was accustomed. I also discovered that while the notebook had phantom load from its battery-charging circuit, this was no more than the constant current drawn by the old desktop's UPS.

Almost immediately I replaced my second desktop computer with another notebook, a pre-owned one-year old 133 mhz computer still under warranty. It also used way less energy than the desktop it was replacing.

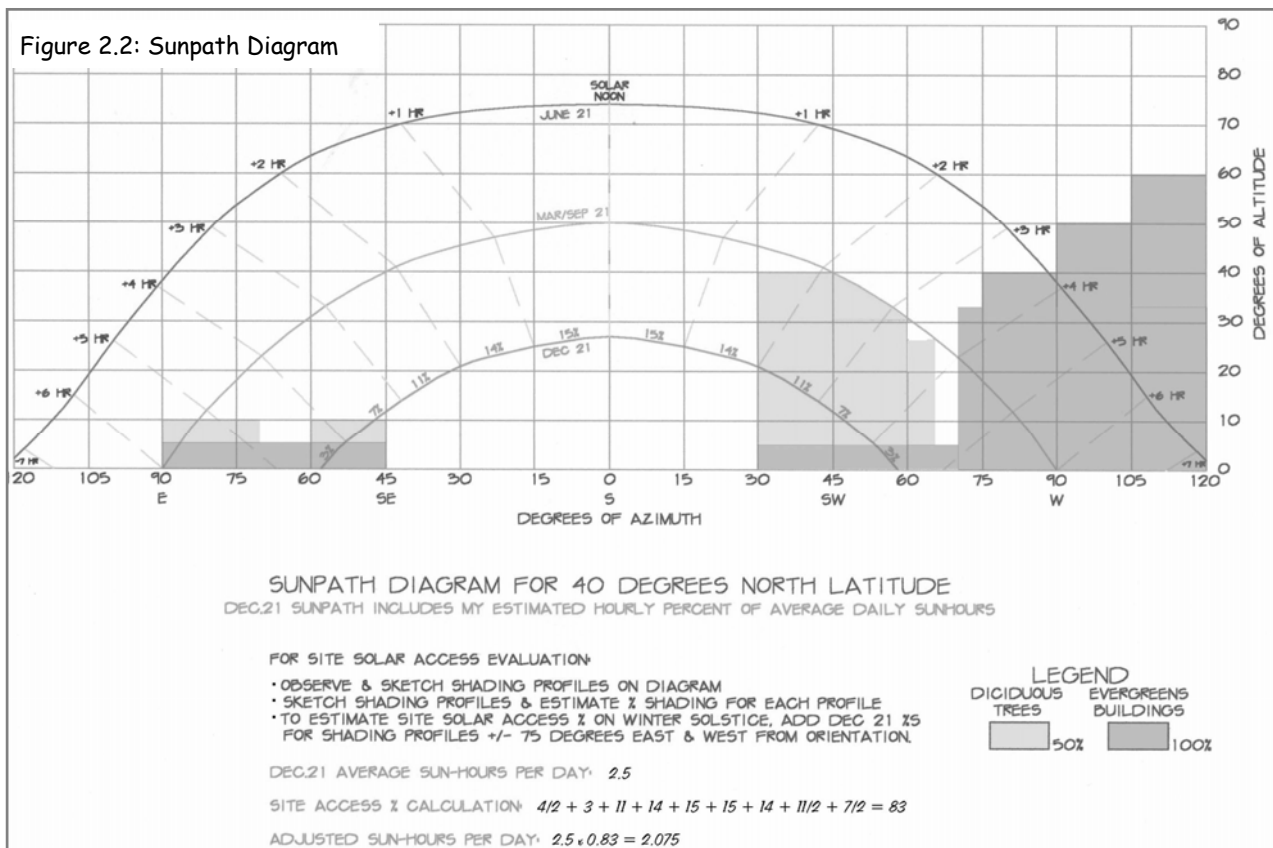


Table 2.1: Load Profile- Before

Electrical Loads	Priority 1=Yes	Run Watts	Hours / Day	Days / Wk	Phantom Watts	Avg. WH / Day	Percent of Total	Surge Watts	Rank by WH / Day	Rank by Demand
Desktop 586-133	1	131	3.00	7	5	498.0	40.2%	200	1	3
Desktop 486-133	1	93	5.00	4	5	371.4	30.0%	99	2	5
Boombox	1	8	4.00	1	6	145.1	11.7%	35	3	11
Electric Clock	1	4	24.00	7	0	96.0	7.8%	4	4	12
Phone Answering Machine	1	3	24.00	7	0	72.0	5.8%	10	5	13
AC Multi-Outlet Strip	1	0	0.00	7	1	24.0	1.9%	1	6	14
Pen Plotter	1	50	2.00	1	0	14.3	1.2%	150	7	6
Copier (16 copies/wk)	1	1100	0.04	1	0	6.3	0.5%	1100	8	1
Laser Printer (16 prints/wk)	1	400	0.06	1	0	3.4	0.3%	400	9	2
Twin Fluorescent Tube Lamp	1	37	0.50	1	0	2.6	0.2%	37	10	7
Single Fluorescent Tube Lamp	1	22	0.50	1	0	1.6	0.1%	26	11	8
Circline Fluorescent Lamp #2	1	20	0.50	1	0	1.4	0.1%	25	12	9
Circline Fluorescent Lamp #1	1	18	0.50	1	0	1.3	0.1%	25	13	10
Electric Pencil Sharpener	0	110	0.01	1	0	0.2	0.0%	140	14	4
Total		1996			17	1237.7		2252		
Inverter Priority Watts		1886								

While the two prior desktops together had averaged 224 watts when operating, the two notebooks averaged 31 watts when both were operating

Next, I traded my 400 watt B&W laser printer and 1100 watt copier for one of those 4-in-1 units which color-printed, copied, scanned and faxed. This allowed me to replace 1500 watts of equipment with a single multi-function piece with average consumption of only 24 watts and surges up to 50 watts. The only negative about this was its 4 to 6 watt phantom load.

Then I eliminated the clock and pencil sharpener from my desk, cutting another 114 average watts and 144 surge watts. The clock elimination was easy, since my computers displayed time and I wear a solar wristwatch. I decided to do my occasional pencil sharpening manually.

Next I attacked phantom loads. I got rid of the multi-outlet strip which had a phantom load and bought several multi-outlet strips which did not. I located these strips on my several tabletops. I then bought several single-plug subswitches for the devices with phantom loads. Although this setup brought more wires onto my tabletops, I could now control both operating and phantom loads individually or in groups much more easily than before.

Finally, I realized that my 3-watt AC answering machine would require an inverter to be on constantly. Even the most efficient small inverters draw up to 10 watts when idling, so I decided to find a DC answering machine. It turned out that I already had one! The plug on mine was also a converter which changed AC to 9 volts DC, consuming 2 watts doing so! So I bought a 12-to-9 volt stepdown converter at Radio Shack and fed the answering machine directly with DC. Now my answering machine draws only 1 watt for its standby power!

This brings us to Table 2.2, "Load Profile: After", which shows my office's energy consumption after my efficiency upgrades. Even though I added more lights, I now use only about one-sixth of a kWh per day, and my peak demand is less than 0.3 kW even if I have every device on at the same time, which never happens. According to my sizing spreadsheet (Table 2.3), I needed only 100 watts of PV, 250 amp-hours of 12 volt batteries, a 225 watt inverter and a 7-amp charge controller! Randy at Entropy informed me that I could get not just the four major components, but all the parts for about \$2,000, a \$5,000 savings from only about \$1,500 invested in reduced energy use!

My Solar-Electric System

As a home designer, I don't like roof-mounted collectors placed askew to roof lines. Unfortunately, the office roof was pitched 4:12 and oriented about 45 degrees west of south. I had roof-mounted solar hot water collectors on my last house, and I wanted to avoid climbing, since I'm getting older. So I decided to pole-mount my PVs near the ground.

I also wanted my setup to be as easy to dismantle as possible, since I often do presentations to schools and other public groups. And in case I ever have to move, I want to be able to take my solar equipment with me, since Midwest homebuyers and mortgage appraisers typically assign little or no real estate value to this equipment.

Finally, my experience and tools were mostly for woodworking, so although I'd read many articles preferring metal racks and poles, I wanted to use wood. Sized to resist a 100 mph wind load on the array, a 6x6 was selected for the pole. Double 2x8s create an adjustable angle arm that is attached to the pole with

Table 2. 2: Load Profile- After

Electrical Loads	Priority 1=Yes	Run Watts	Hours /Day	Days /Wk	Avg. WH /Day	Percent of Total	Surge Watts	Rank by WH / Day	Rank by Demand
Laptop 586-133 w/ 12" Screen	1	15	7.75	6	99.6	60.3%	50	1	12
Phone Answering Machine, DC	1	1	24.00	7	24.0	14.5%	10	2	14
Sub-shelf Fluorescent Lamp	1	22	1.00	5	15.7	9.5%	25	3	5
Pen Plotter	1	50	1.00	1	7.1	4.3%	150	4	2
Sub-shelf Fluorescent Lamp	1	22	0.25	5	3.9	2.4%	25	5	5
Laptop 586-100 w/ 12" Screen	1	16	0.25	5	2.9	1.7%	46	6	11
Business Machine, 4 in 1 (32 pg/wk)	1	24	0.80	1	2.7	1.7%	50	7	4
Twin Fluorescent Tube Lamp	1	37	0.50	1	2.6	1.6%	37	8	3
Smaller Boom box	0	4	4.00	1	2.3	1.4%	35	9	13
Single Fluorescent Tube Lamp	0	22	0.50	1	1.6	1.0%	26	10	5
Circline Fluorescent Table Lamp	1	20	0.50	1	1.4	0.9%	25	11	9
Circline Fluorescent Table Lamp	1	18	0.50	1	1.3	0.8%	25	12	10
Total		251			165.2		504		
Inverter Priority Watts		225							

through-bolts. The bottom bolt can be inserted in three different hole alignments to permit seasonal altitude angle adjustments of 45, 60 and 70 degrees. Three parallel 2x4 horizontal supports run east-west off the angle-arm to hold the PV panels.

To get my 100 watts of PV, I selected two Solarex SX-50 modules, rated at just under 3 amps each, wired in parallel for a 12-volt system. Total wire distance from the PVs to the batteries just inside the house was about 24 feet, so I decided on #6 gauge to hold line losses close to 1 percent. On the back of the pole under the angle arm, a combiner box joins the PV wires with the lightning arrestor and the two feeds from the ground rod and office.

Electrical Details

Inside the office wall nearest the array is where I put my system's electrical panel. It includes a breaker box, main fused disconnect box, TriMetric meter, inverter and two DC output jacks. The standard 100-amp QO-6 breaker box is setup with 4 single pole breakers. On one breaker bar, the solar power is received at a 10-amp breaker, then routed out through another 10-amp breaker to a Solar Converters 8-amp maximum power point charge controller. From there the power goes out to a 10-amp fuse and the disconnect before heading down to three 100-amp-hour Power AGM batteries. Battery output comes back up to a 30-

amp fuse and the disconnect, then into the breaker box, but on its other bar. A 25-amp breaker feeds power to an Exeltech 250 watt true sine wave inverter and a 10-amp breaker feeds two DC output jacks. An unswitched feed to the answering machine is protected by a 2-amp in-line fuse.

During my design and selection process, I had upgraded to a maximum power point tracking (MPPT) charge controller to deliver a few more amps to hungry batteries after long winter cloudy periods. Since my 100 watts of PV provided no oversize factor, the specs indicated an MPPT could add a 10 to 15 percent margin of security. I selected AGM batteries because they were approved for use in unventilated conditioned spaces. I started out with two batteries, but in the spring of 2002, I added a third battery to expand my storage capacity to 300 AH, thereby increasing my future security margin. Finally, I selected a true sine wave inverter because I'd heard too many tales of noisy fluorescent lamps and other equipment which didn't like modified square waves.

AC power is distributed around the office via green outdoor-grade 12-gauge 3-wire cord anchored to the baseboard. This cord feeds four green-painted AC receptacles in metal boxes also anchored to the baseboards. All the office's existing wall outlets are covered with plastic safety caps to show visitors that grid power is not being used.

Although all of the system components are firmly attached, secured and safely protected, everything except the underground wire and pole outside is relatively easy to disconnect and remove. The electrical panel with all its attached pieces is held with wing nuts onto 1/4" threaded posts anchored into a masonry wall. The outside PV wires are separately disconnectable from the combiner box and each panel is easily removable from the rack. The surface-mounted office distribution wires and receptacles are also easily

Table 2.3: Component Sizing, Before & After

Component	Before	After
Minimum PV Watts	747	100
Battery Bank, AH @ 12 VDC	1,875	250
Average Stored Energy, days	9.1	9.1
Minimum Charge Controller Amps @12V	52	7
Minimum Inverter Output, Watts	1886	225

removable.

How Has It Worked?

After some initial tests and a few glitches, on November 19, 2001, I flipped the switch and began running my office on solar power, as it's been ever since. At first I was very self-conscious and worried about the system, hoping it would work as designed. But all too soon, its smooth and reliable operation became part of my expectation and routine.

My typical daily power consumption has ranged from 160 to 250 watt-hours. I've learned to "shed load" during worst-case winter cloudy stretches by not listening to radio or leaving devices on unless absolutely necessary. I've also learned to keep electric lighting to a minimum by working during daylight, since my office is well lit by its two windows. Only once did I arrive in the morning to discover that I'd forgotten to turn off the inverter when I quit work the prior day. Fortunately that was not a day when the batteries were already substantially discharged.

The two longest stretches of cloudy days last winter were each 5 to 6 days, but according to the TriMetric meter, the batteries never dropped below about two-thirds of their 20-hour-discharge capacity (this was when I had just two batteries). When the winter sun comes out to recharge the batteries after a cloudy stretch, the MPPT charge controller routinely delivers as much as 10 to 15 percent more amps than the PV panels were expected to produce.

I often have occasion to talk with friends and neighbors about my system. Utility power around here is so cheap and poorly priced that restraining consumption to the extent I describe makes little sense to most people. Utilities don't charge per amp for new or expanding electrical service, so the idea of driving load reductions and efficiency to offset

generation costs is truly foreign. Generation is seen as something utilities are responsible for, so most homeowners around here don't typically buy their own generators. So while I'm often told how "cool" my solar-electric system is, I'm also commonly asked why I bought it!

Most grid-connected electricity consumers seem to be overwhelmed by the huge scale of the grid. Its seemingly ever-expanding scale makes it difficult to see small loads and personal conservation efforts as significant to the whole. When I'm showing off my small setup, I like to describe how I minimize loads and manage consumption both to minimize generation costs and to keep from running out of stored power. My hope is that understanding the basics of my small system promotes better and maybe different understanding of large grids. I try to explain that if enough people minimize their loads and consumption, it adds up to minimizing utility power costs, especially in the future.

Energy Future

Most people will continue to rely on utility grids, but it's naive to expect utilities to expand conventional generation capacity ad infinitum or as cheaply as in the past. Many people expect an eventual transition to solar power, but they want it to be affordable. Affordability starts with demanding less power through conservation, efficiency and simply turning off devices and equipment when operation is unnecessary.

Solar electricity is less complex, but more expensive than most people think. Conservation, efficiency and turning off stuff is not only easier still, but far cheaper than any kind of solar generation.

Least-cost solar power also requires that consumers sometimes implement no-power solutions and careful timing for their power demands. No-power solutions include sharpening pencils and opening cans manually, drying laundry on an outdoor clothesline, and relying on natural daylight, when available, instead of electric lighting. Careful timing of demand also refers to restraining consumption when there is less solar generation or stored solar power, and using more when the sun's shining and batteries are full. These kinds of lessons are not currently taught by most Midwest utilities, even though they would help restrain rising demand and the need to build (and charge for) new power plants.

It is helpful to understand that solar power *can be* implemented in small steps and for specific tasks. Sometimes I hear aspiring solar advocates tell me they can't afford to convert to solar, or that everyone in their household or company isn't interested in cooperating or helping with finances. I like to respond that we don't climb stairs in one giant leap. We climb in many small steps. So why not implement some solar for specific tasks, like recharging small batteries, powering

Table 2.4: PV System Costs

Item	Cost (\$)
2 Solarex SX50 PV Modules	\$ 530.00
Exeltech Inverter XP 250-12	400.00
TriMetric AH Meter	233.94
3 Power AGM Batteries, 110 AH	180.00
DC Wiring, Ground, Connectors & Conduit	142.99
SolarConverters Controller (PT 12/24-10)	122.00
6% Local Sales Tax	113.11
Combiner Box w/ Lightning Arrestor	103.78
QO Breaker Box & Assembly	90.60
Interior Distribution	77.39
Rack Assembly	76.05
Unused and/or unnecessary purchases	49.80
Fused Disconnect Assembly	46.56
Total	\$2,166.22

an office or vacation cabin, heating water?

If I hadn't taken an energy efficiency approach with my office, I would never have seen so many ways to drastically reduce my energy consumption. This would have left me paying much more for my PV conversion, or else postponing it until I saved up a lot more money. Load reduction was definitely my cheapest ticket to a faster conversion to solar electricity.

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RESOURCES

Publications

The Solar Electric Independent Home Book, 1998
New England Solar Electric, Inc.
401 Huntington Rd., Worthington, MA 01098
(800)914-4131 or (413)238-5974
Email: nesolar@newenglandsolar.com
www.newenglandsolar.com

"Doing a Load Analysis: The First Step in System Design," Benjamin Root, Home Power, Issue no. 58. Available on the Solar1 CD at the downloads section of www.homepower.com

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Figure 2.3: The Robbins home and office with PV module.