



The Kentucky Solar Energy Guide

by

Andy McDonald and Joshua Bills

A publication of
Appalachia– Science in the Public Interest
and the Kentucky Solar Partnership
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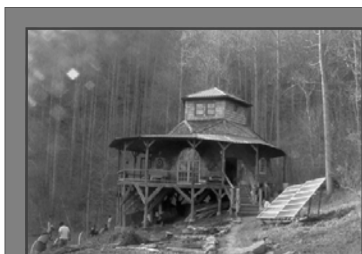






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Guide to Cover Photos

Photos by Andy McDonald except where noted

Geodesic dome house, off-grid solar electric system, Rockcastle County, Ky.

Off-grid timber frame passive solar home with solar electric and solar water heating systems, Franklin County, Ky.

Solar hot water collectors on garage roof, Louisville, Ky.
Photo: Johnny Miller

Solar hot water collector at ASPI Office,
Mt. Vernon, Ky.

Close-up of solar collectors on garage roof, Louisville, Ky.

Ground-mounted photovoltaic panels power net-metered PV system at Berea College Eco-Village. Residence includes solar water heater and passive solar design. Berea, Ky.

Solar cooker, Taquile Island, Peru.

Passive solar home with solar water heater integrated into second story, Louisville, Ky.

2.7 kW net-metered solar electric system at ASPI office, Mt. Vernon, Ky.

Solar hot water collector mounted to optimize solar gain in wooded location, Berea, Ky.

Conventional home renovated for passive solar heating, solar water heating, and grid-intertied PV system, Berea, Ky.

Photovoltaic panels tilted to receive winter sun, Franklin County, Ky.

Grid-intertied PV system and solar hot water collector, Berea, Ky.

TABLE OF CONTENTS

Chapter		Page
1	Introduction	1
	SECTION I: SOLAR ELECTRIC SYSTEMS	7
2	Case Study: Creating a Solar Office Energy Efficiency and Conservation Lead the Way	9
3	Introduction to Solar Electric Systems	15
4	PV System Equipment and Maintenance	25
5	Designing Solar Electric Systems	29
	SECTION II: SOLAR THERMAL TECHNOLOGIES	35
6	Introduction to Solar Water Heating Systems	37
7	Components of Solar Water Heating Systems	45
8	Types of Solar Water Heating Systems	51
9	Water Conservation and Energy Efficiency	59
10	Additional Solar Water Heating Applications Solar Pool Heating, Radiant Floor Heating, and Concentrating Solar Collectors	63
11	Space Heating with Active Solar Energy Systems	69
12	Solar Cooking, Food Drying, and Water Purification	73
	SECTION III: FINANCIAL INCENTIVES AND RESOURCES FOR FINDING SOLAR INSTALLERS AND EQUIPMENT	81
13	Incentives that Support Renewable Energy and Energy Efficiency	83
14	Choosing a Solar Installer: Recommendations for Choosing Solar Energy Contractors, Professional Consultants, and Equipment Suppliers	91
15	The Kentucky Sun Pages: A Directory of Renewable Energy and Green Building Businesses and Professionals Serving Kentucky	95
16	Solar Energy Equipment Suppliers, Retailers, and Manufacturers	101
	Appendix A: PV System Sizing Worksheets	105
	Appendix B: Solar Radiation Charts for Selected Cities in Kentucky, Indiana, and Tennessee	109

Chapter One
Introduction

Solar energy is an abundant, renewable resource that can meet many of our energy needs here in Kentucky. It can be used to generate electricity; to heat water for bathing, washing, space heating, and other purposes; to cook and dry food; and to purify water. Through passive solar building strategies, the sun's energy can heat and cool buildings and provide daylighting. Solar energy can meet a substantial portion or even all of a home's energy needs, greatly reducing monthly utility bills. For the Commonwealth and our nation, investing in solar energy could increase our independence from foreign energy sources and polluting forms of energy.

The need to develop clean, sustainable energy sources is imperative. The use of conventional energy sources, especially fossil fuels and nuclear power, incurs widespread environmental and human health costs. Disruptions to the global climate, international conflict, and the spread of nuclear materials that could be used as weapons are among the results of our dependence on these conventional fuels. Freeing ourselves from this dependence will give us cleaner air and water, healthier families, communities, and environments, and increased security from nuclear accidents and terrorist attacks.

Solar energy is one of the key components of a safer, healthier, more sustainable energy economy. It provides greater independence and energy security, protecting its users from interruptions to the power grid and fluctuating fuel prices. On a regional and national level, solar energy systems could become part of a "distributed energy network" in which many thousands of smaller and decentralized energy producers would make the whole system less vulnerable to interruption. By developing the use of solar and other renewable resources, our nation becomes less dependent upon foreign sources of energy. This reduces the justification for using the military to protect our fuel supplies in foreign lands, allowing all of our resources to be used more wisely and profitably.

Solar energy is widely used around the world in climates as diverse as northern Europe and southern California. Solar photovoltaic technology has developed rapidly over the past four decades, with prices falling dramatically and global installations growing at a rate of 30 percent per year over the past five years.[1] Solar water heating technologies have been in widespread use for the past century. Countries such as Israel and Japan have witnessed a consistently increasing use of the technology. Tokyo had over 1.5 million solar water heaters in use in 1991 and Israel now requires solar water heaters in all new buildings.[2] Global experience has shown that the use of solar is not limited to the sunniest climates, and that it is capable of making a significant contribution to meeting the world's energy needs.

Despite its many advantages, solar energy is still in competition with very cheap energy in places such as Kentucky. For most people, solar photovoltaics (PV) remain the most expensive option for providing electricity. Solar water heating systems, which usually produce substantial long-term financial savings, have a higher up-front cost than conventional water heaters. These economic realities have hindered the growth of the solar industry and the use of these technologies in Kentucky. However, higher energy prices or the availability of financial incentives to off-set solar's higher up-front costs can shift the economics enough to make solar economically competitive. These forces have helped drive the growth of the solar industry in California and Europe, and as the industry has expanded, prices have come down, making solar even more competitive.

Even in Kentucky the economic comparison can favor solar. Solar electricity is often the least-costly option at sites more than ¼ mile from the nearest utility line. In these situations the cost of running a new power line can exceed the cost of installing a solar electric system. In the case of solar water heaters, the energy savings they produce can pay for the cost of the system in as little as five to ten years. The economic returns are even better for homes and facilities that use high volumes of hot water. Once a solar water heater is paid for, its energy savings are like tax-free income and can amount to hundreds of dollars per year. Solar energy systems also insulate their owners from rising fuel prices for decades to come, while providing greater independence and self-sufficiency.

The Importance of Energy Efficiency and Conservation

The development of a clean, sustainable energy system depends as much on energy efficiency and conservation as on the development of renewable energy sources such as solar. Improved efficiency enables us to do the same or more work while using less energy. Through conservation, we find alternate ways of doing things that reduce our energy demands. Efficiency and conservation allow us to meet our needs at a lower cost and with less pollution. This principle applies nationally and at the personal level. Nationally, investing in energy efficiency is like building power plants that don't pollute, at a fraction of the cost. For example, a report from the Alliance to Save Energy states that if all homes in America used the most energy efficient refrigerators available, the electricity savings would eliminate the need for about 30 power plants.[3] Those energy savings would translate into pollution not produced and money saved by American families.

Achievements of the Federal Energy Management Program (FEMP) illustrate the enormous potential of energy efficiency. According to the Alliance to Save Energy, the FEMP has saved taxpayers more than $8 billion through energy efficiency in government buildings. The further installation of currently-available, cost-effective technologies could save U.S. taxpayers an additional $1 billion per year.[4]

Energy efficiency offers tremendous opportunities at the personal level, as well. Compact fluorescent light bulb's (CFL) produce the same amount of light as standard incandescent bulbs, but use 25 percent as much energy (see Table 1.1).[5] High-efficiency models are now available for most appliances, and can be identified by the Energy Star label. The benefits to consumers from the move to efficiency are illustrated by the air conditioner efficiency standards approved in 2004, which are expected to save American consumers $5 billion in energy costs over the next 25 years.[6]

To minimize the up-front costs of solar energy systems, begin with energy efficiency and conservation. It is much less expensive to invest in energy efficiency than to buy an over-sized solar system, so spend your first energy dollars on efficiency and conservation. Start by reviewing all the ways you use energy. Figure out how you can reduce your demand or find alternate ways to meet your energy needs before selecting a system. A good rule of thumb before installing a solar system is to first cut energy consumption by two or three times. For instance, when considering solar lighting, use as much daylighting as possible during the day, then use only fluorescent lighting at night, since fluorescent lighting usually uses 1/3 or 1/4 as much electricity as incandescent lighting. When solar-powering computers, switch first from desktop units to notebook models, since laptops usually use 1/4 to 1/8 as much electricity.

Also consider what you need the energy for. This will guide you to the appropriate type of solar technology and will help you use your resources most wisely. For example, to heat your home, electric resistance heaters powered by solar photovoltaic panels would be a very poor and expensive choice. This is because electricity is the least efficient means of generating heat, and photovoltaic panels convert only 10 to 15 percent of the sun's energy into electricity. Solar water heater collectors, meanwhile, capture and transfer the sun's heat energy efficiently and cost-effectively, and are well-suited for use in home heating systems. Therefore, if you're considering how best to heat your home, look instead into solar water heaters, passive solar design strategies, and active solar space heaters. This approach will help you get the most from your solar system and the money you invest in your energy needs.

Passive Solar Building Design

Solar energy can be used effectively and economically to provide space heating, cooling, and lighting for homes and other building types. Through passive solar building design, buildings capitalize upon the freely available solar resources at a given site,

Table 1.1: Comparing Incandescent and Compact Fluorescent Light (CFL) Bulbs

Bulb Type	100W Incandescent	23W Compact Fluorescent
Purchase Price	$0.75	$11.00
Lumens (light output)	1,690	1,500
Life of Bulb	750 hours	10,000 hours
Number of Hours on Per Day	4 hours	4 hours
Number of Bulbs Needed	5.84 (6) over 3 years	1 over 6.85 years
Total Cost of Bulbs	$4.50	$11.00
Total Cost of Electricity over 3 Years (@ 6.5 Cents/kWh)	$28.47	$6.55
Total Cost over 3 Years	$32.97	$17.55
Total Cost Savings over Three Years using a CFL in place of an Incandescent Bulbs- $15.42		
Total Cost Savings over Three Years if Five Incandescents are replaced with CFLs- $77.10		

Power$mart, by the Alliance to Save Energy and U.S. Department of Energy, Energy Information Administration.

Steps to Choosing a Solar Energy System

The following chapters illustrate that there are many ways to utilize solar energy. To choose the appropriate type of solar energy system, ask yourself the following questions:

1. What do I need the energy for? Heating, lighting, water heating, powering appliances, or other needs?
2. How will the energy be used, specifically? Study your patterns of energy use. The way you use energy and the appliances you use will influence the type of solar technology you should employ. For example, if you need light in a workshop where you mainly work during the day, maybe a well-placed window to provide daylight would work just as well- and be cheaper- than a solar electric system to power electric lights.
3. How can I reduce my energy demand through efficiency, conservation, and behavior changes? When you study how you use energy, you begin to discover many opportunities for reducing waste and doing things more efficiently. Applying efficiency and conservation measures will reduce your energy demand, while still enabling you to do the things you need to do. This will save you money right from the start, while also reducing the cost of whichever solar energy systems you choose to use.
4. What solar technologies and strategies will best meet my energy needs?

Now you are ready to choose among the various solar systems and design strategies.

reducing the need for external heat sources. Proper design can also substantially reduce the need for electric lighting during the day, through the use of natural daylight.

These design strategies are part of a broader approach known as *climate responsive design*, which understands buildings within their local context. Through this approach, buildings are designed to suit the local climate and utilize the resources available on-site. These resources include wind, vegetation, topography, water, soil, the earth's capacity to moderate temperatures, and solar energy. Integrating all of these resources into the building design can effectively assist with heating, cooling, and lighting, reducing the need for external energy sources. This approach can also produce a more functional and beautiful home.

A complete discussion of daylighting and passive solar building design is beyond the scope of this Guide and numerous resources already exist to assist with the design of passive solar buildings. For new building construction and many renovation projects, passive solar design makes enormous sense. Whether you are planning to build a new home or commercial building, or trying to improve the energy efficiency and comfort of an existing building, we encourage you to learn more about passive solar design and apply its principles on your projects. Please refer to the Resources section on page five to learn more about this topic.

Layout of the Guide

The first two sections of *The Kentucky Solar Energy Guide* provide an introduction to solar energy technologies. Section One addresses solar electric (photovoltaic) systems, including general information related to solar system design, relevant to many solar energy technologies, including photovoltaic systems (see Chapter Five, Designing Solar Electric Systems). Section Two, Solar Thermal Technologies, discusses many of the ways the sun's heat energy can be harnessed to do useful work. This section emphasizes solar water heating systems (including solar swimming pool heaters), and also includes active solar air heating, solar cooking and food drying, and solar water purification. Both sections are interspersed with case studies of solar energy systems in use in Kentucky.

Section Three provides a guide to resources that can help you find the support you need to use solar energy at your home, farm, or business. Chapter Thirteen discusses incentives that support investments in renewable energy and energy efficiency within Kentucky. Chapter Fourteen presents guidelines for choosing a solar energy installer, offering advice for making wise decisions when contracting professionals to work on your home. Chapter Fifteen presents the

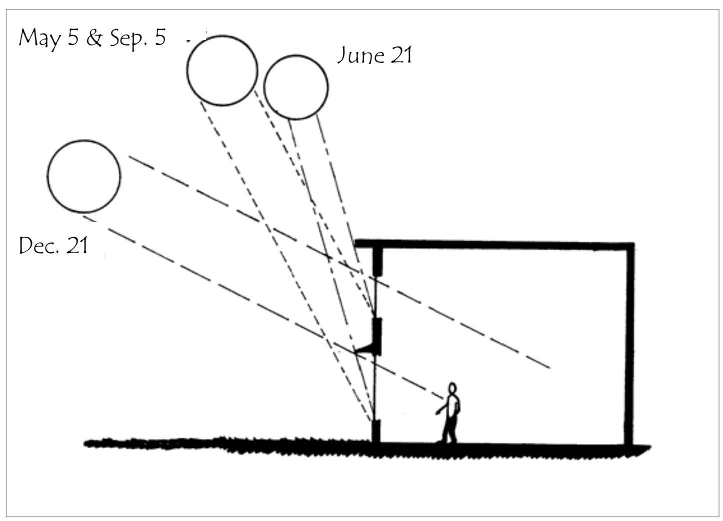

Figure 1.1: Awnings and roof overhangs can be used to control the sunlight that enters a building, an important element in passive solar design, *Andy McDonald*

Kentucky Sun Pages, a directory of renewable energy and green building businesses and professionals serving Kentucky. The Sun Pages connects those seeking to install solar systems or build with environmental protection in mind to installers, professionals, and businesses skilled in these fields. In Chapter Sixteen you will find a list of suppliers, manufacturers, and retailers of renewable energy products and equipment.

Each Section includes lists of references to publications, websites, and organizations where you can learn more about each of the topics discussed in this Guide.

End Notes

1. Joel Makower, Ron Pernick, and Clint Wilder, "Clean Energy Trends 2004," Clean Edge, March 2004. Available at: www.cleanedge.com/reportstrends2004.php
2. Daniel M. Berman and John T. O'Connor, *Who Owns the Sun? People, Politics, and the Struggle for a Solar Economy*, 1996, Chelsea Green Publishing Company, White River Junction, Vermont.
3. *Power$mart*, 2002, Alliance to Save Energy, Washington, DC.
4. Alliance to Save Energy, Washington, DC. On-line fact sheet available at: www.ase.org/programs/federal/femp.htm
5. Adapted from *PowerSmart.*
6. American Council for an Energy-Efficient Economy, Washington, DC. On-line fact sheet. URL: www.aceee.org

RESOURCES: Energy Efficiency and Conservation

Publications

Consumer Guide to Home Energy Savings, A. Wilson, J. Thorne, and J. Morrill, ACEEE, Washington, DC, 2003. The Consumer Guide will help you find energy-saving products and show you how to use them most effectively. From light bulbs to furnaces, air conditioners to washing machines, windows to refrigerators, all are covered in this guide for consumers who care about the environment and about their budget. Can be purchased on-line at: www.aceee.org

"Home Energy Briefs," Rocky Mountain Institute, Snowmass, Colorado, 2004. These nine reports address energy efficiency and conservation in the following areas: building envelope, lighting, space cooling, space heating, water heating, cleaning appliances, electronics, kitchen appliances, and whole system design. Free downloads available on-line at: www.rmi.org/sitepages/pid194.php

Home Energy Magazine, see below for contact info.

The Most Energy Efficient Appliances 2004, ACEEE Washington, DC, 2004. A listing of appliances based on product directories and manufacturers' data regarding energy performance. Available at www.aceee.org

Southface "Fact Sheets" and "Technical Bulletins," Southface Energy Institute. These Fact Sheets and Technical Bulletins cover a wide range of topics and provide extensive information related to energy efficient, environmentally-sound, high performance home building. They can be downloaded for free from their website, www.southface.org

"What You Can Do to Save Energy and Money: A Checklist for Action," ACEEE, Washington, DC. Available on-line at www.aceee.org

Organizations

American Council for an Energy-Efficient Economy
1001 Connecticut Avenue, NW
Suite 801
Washington, DC 20036
(202) 429-8873
www.aceee.org

The American Council for an Energy-Efficient Economy is a nonprofit organization dedicated to advancing energy efficiency as a means of promoting both economic prosperity and environmental protection. Publishers of the *Consumer's Guide to Home Energy Savings* and *The Most Energy Efficient Appliances 2004*.

Energy Efficiency and Renewable Energy Network
(800)DOE-3732
www.eren.doe.gov

EREN provides an enormous database and search engine on all aspects of energy efficiency and renewable energy. The web site provides access to a wealth of information about renewable energy and energy efficient technologies.

Energy Star Products and Programs
(888)STAR-YES
www.energystar.gov/

The U.S. Environmental Protection Agency and the Department of Energy promote the purchase and use of energy-efficient appliances and equipment by awarding the Energy Star label. Their web site includes program descriptions, product specifications, lists of qualifying products and manufacturers, news and updates.

Home Energy Magazine
2124 Kittredge St., #95
Berkeley, CA 94704
(510) 524-5405
www.homeenergy.org

Home Energy Magazine is dedicated to housing quality, comfort, and energy efficiency. The Home Energy web site includes an index to all feature articles, some full articles, and energy links.

Rocky Mountain Institute
1739 Snowmass Creek Road
Snowmass, CO 81654-9199
(970)927-3851
www.rmi.org

RMI is a national leader in the field of energy efficiency. Among their many excellent publications are their *Home Energy Briefs* (see Publications list above).

Southface Energy Institute
241 Pine St. NE
Atlanta, GA 30308
(404)872-3549
www.southface.org

The Southface Energy Institute works to promote environmentally sustainable homes, workplaces and communities through education, research, advocacy and technical assistance. Their *Fact Sheets* provide extensive information related to energy efficient, environmentally-sound, high performance home building, and can be downloaded for free from their website.

RESOURCES: Passive Solar Heating, Cooling, and Daylighting

Publications

Direct Use of the Sun's Energy, F. Daniels, Yale University Press, New Haven, 1964.

Heating, Cooling, Lighting: Design Methods for Architects, N. Lechner, Wiley Publishers, 2000.

"Passive Solar Design," Technical Bulletin published by Southface Energy Institute and the Office of Building Technology, State and Community Programs, U.S. Department of Energy. No date. Available on-line at: http://www.southface.org/web/resources&services/publications/factsheets/sf_factsheet-menu.htm

The Passive Solar Design and Construction Handboook, Michael J. Crosbie (ed.), Wiley Publishers, 1997.

The Passive Solar Energy Book: A Complete Guide to Passive Solar Homes, Greenhouses, and Building Design, Edward Mazria, Rodale Press, 1979.

The Passive Solar House, James Kachadorian, Chelsea Green Publishing Company, 1997.

The Solar House: Passive Heating and Cooling, Daniel Chiras, PhD., Chelsea Green Publishing Company, 2002.

Sun, Wind & Light: Architectural Design Strategies, G. Z. Brown and M. DeKay, Wiley Publishers, 2000.

Organizations

North Carolina Solar Center
Box 7401
North Carolina State University,
Raleigh, NC 27695-7401
(919)515-5666
www.ncsc.ncsu.edu/

The North Carolina Solar Center offers numerous publications addressing passive and active solar energy. These documents can be downloaded for free from their web site (follow the link for "Information Resources"). They will also mail printed copies upon request. A sample of the titles available include:

- "Sunbook: A Guide to Solar Energy in North Carolina"
- "Passive Solar Options for North Carolina Homes"
- "Passive Solar Design Checklist"
- "Selecting a Site for Your Passive Solar Home"
- "Passive Cooling for Your North Carolina Home"

Section I
Solar Electric Systems

Solar electric systems offer the ability to generate power without creating pollution, in locations remote from power lines as well as in cities and towns. As the case studies in Section I illustrate, Kentucky's climate is well-suited to solar electric systems, making it possible to meet all of the electricity needs in a home or office with solar energy. However, as John Robbins makes clear in Chapter Two, *Case Study: Creating a Solar Office*, energy efficiency and conservation are of fundamental importance when designing a solar electric system. They enable us to get the most from our solar systems, while minimizing overall energy costs. Building on the detailed case study of Robbins' solar office, Chapter Three describes how stand-alone and grid-intertied solar electric systems work, and discusses their many applications. This chapter also discusses the historical development of PV technology, the future outlook for the PV industry, and the environmental costs of manufacturing and using PV systems. Chapter Four discusses the primary equipment used in photovoltaic (PV) systems and their maintenance. Guidelines for designing and sizing PV systems are presented in Chapter Five, which includes a section explaining the sun's movements through the sky and how this influences solar design.

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.

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

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, 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.

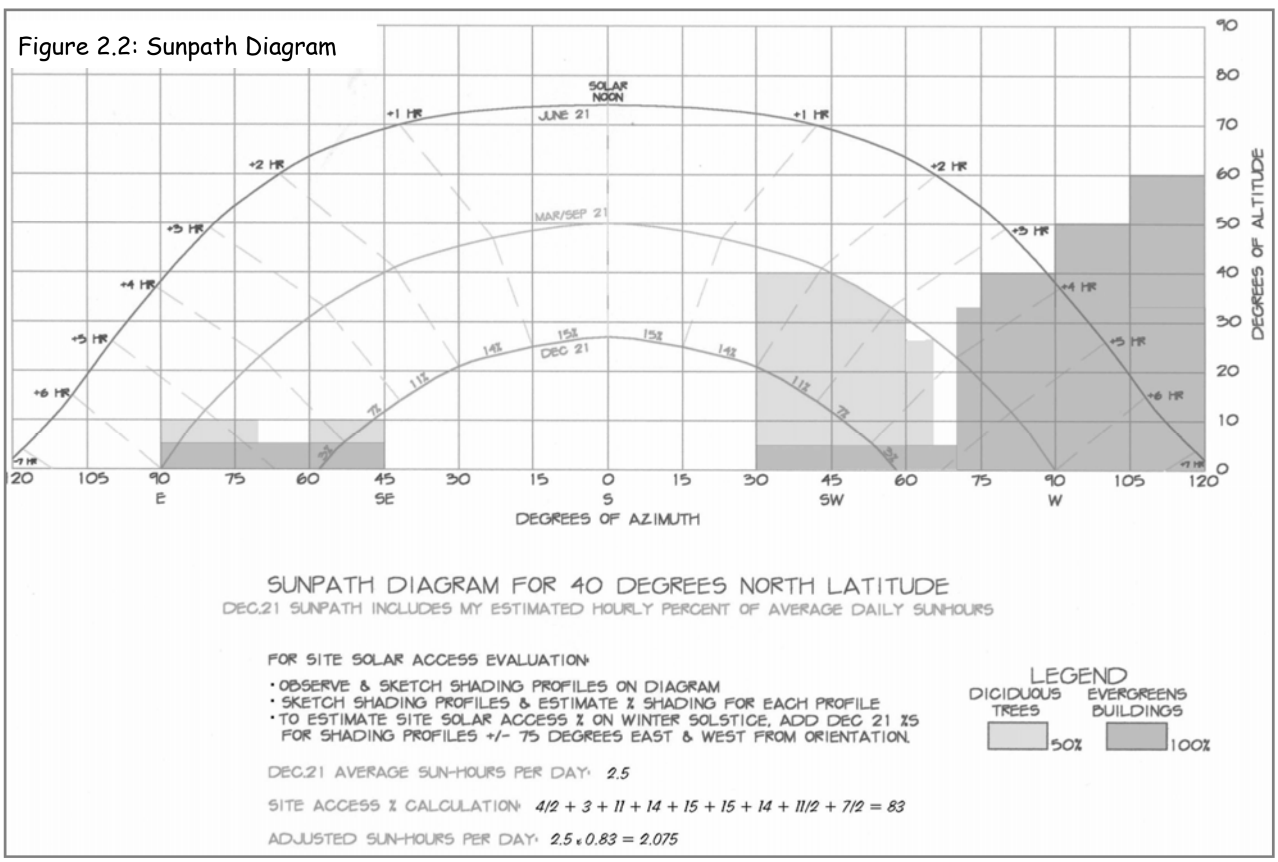

Figure 2.2: Sunpath Diagram

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.

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

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 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!

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**

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 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.

Reprinted from "Recipe for a Solar Office: One Part Solar, Five Parts Load Reduction" [Original Article title], by John Robbins, CEM, Home Power, No. 97, October/November 2003, with permission from the author.

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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Cincinnati area networking and info

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

Chapter Three
Introduction to Solar Electric Systems

In 1954 scientists at Bell Laboratories introduced the first photovoltaic cells that produced useable amounts of electricity directly from sunlight. Since that time the use of photovoltaics has grown exponentially and spread throughout the world. The initial phase of research and development of photovoltaic (PV) technology was driven by the US space program, which developed PVs as a power source for satellites in outer space. Today, PVs are used in a wide range of applications, ranging from common consumer products like calculators, to systems that power entire homes and communities.

PV cells do not use the sun's heat to produce electricity. They produce electricity directly when sunlight interacts with semiconductor materials in the PV cells and they work whenever they are exposed to the sun. They produce more electricity when the sunlight is more intense (on a sunny rather than a cloudy day) and when the light strikes the PV cells directly (when the rays of sunlight are perpendicular to the PV cell). PV electricity output is also greater when cells are cold, and reduced when cells are hot. A PV panel (also known as a "module") consists of a number of cells linked together to provide power suitable for charging batteries or running loads directly (see Figure 3.1). Shading greatly reduces the power output from PV cells and panels. In fact, if only one cell in a PV panel is shaded, it can rob the energy from the rest of the cells in the panel. This is a very important factor when designing PV systems and special attention is given to preventing things like tree limbs and overhead wires from shading even a small portion of a PV panel. In contrast, partial shading is not as significant for solar water heater collectors. A PV panel with 50 percent of its surface shaded will produce virtually no electricity, whereas a solar water heater will still produce about 50 percent of its rated output with 50 percent of its surface shaded. As a result, solar water heaters can be mounted behind deciduous trees and still function effectively, so long as the trees only shade the collectors when their leaves are off. It generally would not be appropriate to put PV panels in such a location.

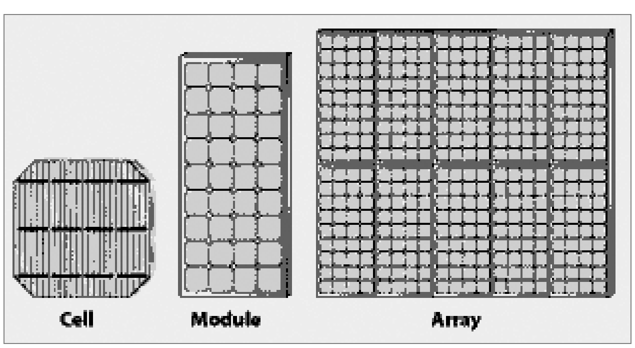

Figure 3.1: PV cells are combined to create PV modules, which are linked to create PV arrays.
Office of Energy Efficiency and Renewable Energy, US DOE

The Photovoltaic Cell

Figure 3.2: A PV Cell
Office of Energy Efficiency and Renewable Energy, US DOE

"A typical PV cell made of crystalline silicon is 12 centimeters in diameter and 0.25 millimeters thick. In full sunlight, it generates 4 amperes of direct current at 0.5 volts or 2 watts of electrical power. PV modules consist of PV cells connected in series (to increase the voltage) and in parallel (to increase the current), so that the output of a PV system can match the requirements of the load to be powered. If more power is required, modules can be appropriately connected in series or parallel to form what is called a PV array (see Figure 3.1). Thin film PV cells are newer forms of PV with different semiconductor materials, geometries, and dimensions but the series and parallel connection of thin film cells and modules is similar to crystalline PV."[1]

Trends in the Photovoltaics Industry

The global photovoltaics industry has undergone rapid expansion. Solar and wind power generation capacity have each grown by an average of more than 30 percent per year over the past five years. The solar photovoltaics (PV) industry grew to more than 700 MW of new solar PV manufacturing output in 2003, up from about 500 MW the year before.[2]

At a conservative 20 percent rate of growth each year, PV production worldwide would amount to 2.5 gigawatts in 2010, and 15.5 gigawatts by the year 2020. As of January 2005, there was such a demand for PV panels that most orders have a two- to three-month waiting period. In October 2003, SHARP opened its first PV plant outside of Japan in Memphis, Tennessee. Sixty-seven people are directly employed at the plant.

Current annual PV production capacity at SHARP's new plant is 20 megawatts (MW). The total US market was 48 MW in 2002, and is estimated to be 120 MW by 2005.[3]

The popularity of net metering and other forms of distributed generation have affected the demand for solar photovoltaics. In 2002, 270 MW (51 percent) of PV shipments went into grid-intertied residential and commercial buildings. Even with the increased demand for PV, prices in mid-2004 were still lower than they had ever been, which reflects the progress that has been made in the manufacturing process. Much of this progress has been due to the support of the US Department of Energy's PV research program, and the industry has seen solar manufacturing prices fall by more than half in the last ten years.[4]

A plan developed by the Solar Energy Industries Association (SEIA) would utilize annually declining federal tax incentives to speed the commercialization of photovoltaics in the United States. According to SEIA's projections, implementing their plan would reduce the price of solar electricity from its current rate of 18 to 25 cents per kilowatt-hour to 5.7 cents per kilowatt-hour by 2015, thereby making it the least expensive retail electricity option. SEIA's *Photovoltaics Industry Roadmap* projects that this plan would generate more than $34 billion in new manufacturing investments over the next ten years. By 2025, photovoltaics would provide half of all new electricity generation in the US, and by 2030, the US solar industry would employ 260,000 people.[5]

Environmental Costs of PV Systems

Photovoltaics can help us achieve a more sustainable energy system because they generate electricity using a renewable resource and without emitting pollutants. However, when we review the life cycle of a PV system from the manufacture of the PV cells and associated equipment, through installation, use, and final decommissioning or disposal, we find that their use is not without environmental costs. The greatest areas of environmental concern are associated with the energy required to manufacture and install PV equipment and the hazardous materials used to make PV cells and batteries.

Building and installing a PV system requires resources and energy, and it is necessary to know our return on this initial energy investment. The National Renewable Energy Laboratory (NREL) reviewed research into the "energy payback" of PV systems to assess how long they must operate to generate the amount of energy that was used to make and install the system. NREL reports that, depending on the type of PV cell being used, the energy payback for PV systems is one to four years. Assuming a 30-year operational life for PV systems, this means that 87 to 97 percent of the energy they produce will be free of the environmental costs of the energy used in their manufacture.[6]

Numerous hazardous materials that could threaten the environment and human health are used in the manufacture of PV cells. These materials vary depending on cell type and include explosive and toxic gases, solvents, cadmium, and lead solder. After assessing the environmental and safety impacts of PV technology, the Brookhaven National Laboratories concluded that, "routine conditions in manufacturing facilities should not pose any threats to health and the environment" and that "the US industry is vigilant in preventing health risks and has established proactive programs in industrial hygiene and environmental control."[7] They saw accidents at manufacturing plants as the greatest potential threat to workers and the surrounding human and natural communities.

Once installed, the PV module poses minimal health and environmental risks, according to the Electric Power Research Institute (EPRI). They state that "the potential for chemical releases appears to be small since the chemicals are present in the sealed PV modules. Releases are likely to occur only due to fires or other unusual accidents."[8] At the end of a PV system's useful life, its disposal could contaminate the environment if it were landfilled or incinerated. The PV industry is currently developing processes for recycling old PV modules.[9]

Batteries, an integral part of many PV systems, present perhaps the most serious environmental and human health concerns. Batteries can contain lead, heavy metals, acids, and other hazardous chemicals, and their limited life spans (typically three to ten years) creates an ongoing demand for their production and disposal. The commonly-used deep cycle, lead-acid batteries require regular maintenance which may expose system users to hazardous chemicals. Although recycling rates for lead-acid batteries are high and new batteries contain, on average, 60 percent recycled lead,[10] lead recycling has for the most part moved to Third World countries with lower wages and minimal or non-existent environmental and worker safety standards. Greenpeace has documented the flow of tens of thousands of tons of lead waste from the US, UK, Australia, and Japan to countries such as Indonesia, the Philippines, and Thailand. They have also documented the suffering of the workers and communities impacted by the lead smelters and recycling factories in these places.[11] The solar industry and renewable energy advocates should focus attention on this issue to motivate the lead and battery industries to meet the highest environmental and safety standards.

Despite the environmental costs of PV systems, solar electricity still offers distinct advantages that make it an important part of a renewable energy economy. Compared to electrical generation from conventional fossil fuel power plants, "producing 1,000 kWh of electricity with solar power reduces emissions by nearly eight pounds of sulfur dioxide, five pounds of nitrogen oxides, and more than 1,400 pounds of carbon dioxide."[12] For a PV system that produces one-half of a modern household's electricity needs for 28 years, the system "would avoid conventional electrical plant emissions of more than half a ton of sulfur dioxide, one-third ton of nitrogen oxides, and 100 tons of carbon dioxide."[13] As coal-burning power plants are the single largest source of mercury emissions in the United States, using solar electricity also prevents the emission of this highly toxic element.[14] If a PV system displaces nuclear-generated power, it reduces the demand to operate and build new nuclear power plants.

Many of solar energy's benefits derive from the fact that it displaces the need for conventional, polluting energy sources. As we stressed in Chapter One, these benefits can be attained most cost-effectively and with the least environmental impact by implementing energy efficiency and conservation measures first. If you cut your utility bill by 50 percent, whether by means of a solar system, efficiency, or conservation, your reduced electrical demand reduces the need for power from the power plant. By itself this helps to slow growth in demand for new power plants. If enough households, businesses, and institutions were to significantly reduce their power needs, the accumulated reductions could even make it possible to shut down power plants. Remember, solar is a means, not an end. The ends are a cleaner environment, independence from fuel supplies that contribute to global conflicts, a safer energy supply, and a sustainable society.

Figure 3.3: This off-the-grid home in Rockcastle County, Kentucky is powered by the PV array in front of the house, *Andy McDonald*

Stand-Alone PV Systems

PV systems not connected to the electric utility grid are known as 'stand-alone systems.' Direct systems use the PV power immediately as it is produced, while battery storage systems can store energy to be used at a later time, either at night or during cloudy weather. Examples of direct systems are water pumps that operate during sunny days to fill storage tanks for later use, and ventilation fans that ventilate attics whenever the sun is shining. Battery storage systems often include an inverter to convert the PV-generated electricity from DC to AC, allowing standard AC (alternating current) appliances to be used. Having AC power available is convenient because AC appliances are more commonly available and are usually less expensive.

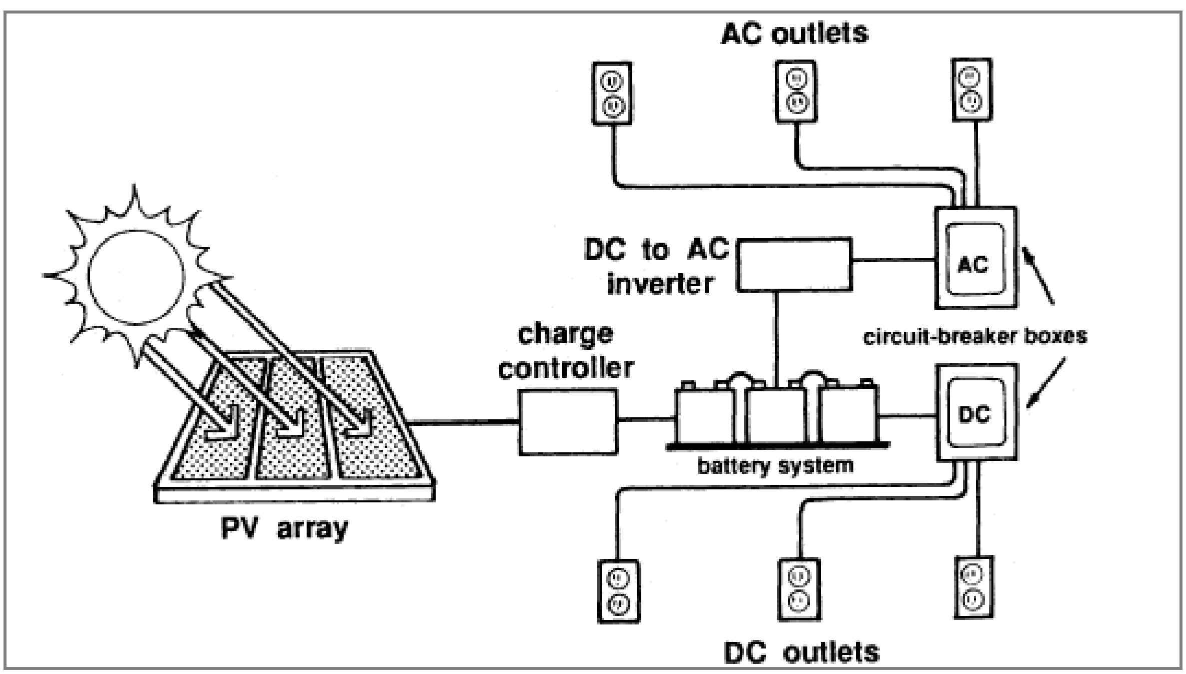

Figure 3.4: Stand-alone PV system, *North Carolina Solar Center*[15]

Applications for Stand-Alone PV Systems

Remote Site Electrification
- Rural homes, vacation cabins, hunting lodges
- Barns, outbuildings
- Visitor centers in parks, park ranger sites, campgrounds, public beach facilities
- Village/island electrification
- Health clinics and remote research facilities
- Electric fencing, farm workshops
- Highway rest stops
- Military test areas
- Refugee camps

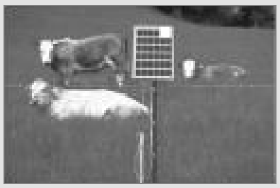


Figure 3.5: Solar-charged electric fencing, *Sureguard Fencing*

Water Pumping and Control
- Livestock watering, irrigation
- Remote village water supplies
- Rural homes, campgrounds

Refrigeration for*
- Off-grid homes and facilities
- Remote or mobile storage of medicines and vaccines

** Refrigerators and freezers are well-suited to photovoltaics because they demand more power when more solar energy is available. At least one manufacturer, SunDanzer, produces a battery-free solar refrigeration system.[16]*

Lighting
- Billboards, highway information signs
- Public facilities, parking lots, marinas, piers
- Homes, vacation cabins

Communications
- Radio, television, and telephone towers
- Traveler's information transmitters
- Portable computer systems, cellular phones, mobile radio systems
- Emergency call boxes

Figure 3.6: PV-powered water pumps provide water for livestock.
National Renewable Energy Laboratory

Remote Monitoring for
- Meteorological information, seismic recording
- Scientific research in remote locations
- Highway/traffic conditions, structural conditions
- Irrigation control

Signs and Signals
- Navigational beacons, lighthouses, buoys
- Railroad signals, highway signs, aircraft warning beacons

Charging Vehicle Batteries
- Direct charging electric vehicles, boats, recreational vehicles (RV's)
- "Trickle charging" little-used vehicles to maintain high battery state of charge, such as fire trucks, snow removal equipment, National Guard vehicles, and agricultural machines

Disaster Relief
- Providing power after natural disasters and extended power outages

Cathodic Protection (preventing corrosion of metals)
- Underground pipes, tanks, wellheads
- Wharves, bridges, buildings

Consumer Products
- Appliances for recreational vehicles
- Watches, calculators, lanterns, radios, televisions
- Flashlights, outdoor lights, security systems, gate openers
- Golf carts
- Attic fans, other types of fans

Building-Integrated Photovoltaics
- PV cells integrated into building materials such as roof shingles and windows

Adapted from "Photovoltaic Applications," North Carolina Solar Center at North Carolina State University, June 2002.

Figure 3.7: Building Integrated Photovoltaics (BIPV) can replace roofing shingles, as in this home.
www.stanford.edu/class/ ee293a/BIPVlarge.html

Figure 3.4 illustrates the basic layout of a stand-alone system with battery storage, including both AC and DC circuits.

Stand-alone systems are used in a wide range of applications, especially in remote locations where access to the utility grid is unavailable. Due to the high cost of extending utility lines, PV systems commonly cost less than extending grid-power for sites located more than one-fourth mile from the nearest utility line.[17] This is especially true for sites needing less power, where PV system cost is low relative to the high cost of power line extension. PV systems can also be the most economical option when a utility line would need to be buried beneath an existing hard surface, such as a road or sidewalk.

For large portable power needs (greater than 500 watts) or in remote locations, people commonly use diesel, gasoline, or propane generators. This option entails high maintenance costs along with the need to purchase and transport fuel. As a fuel-free and low-maintenance power source, PV is an ideal alternative in these situations.[18]

Stand-alone PV systems can be coupled with conventional fossil fuel generators, wind electric generators, or micro-hydroelectric generators (which can generate electricity from pond overflows and streams). In such "hybrid" systems, the generator is only used to recharge the batteries during long periods of cloudy weather. This can provide peace of mind for people concerned about losing power during extended periods of bad weather. Such a system requires much less fuel and generator maintenance, and can extend the life of both the generator and the batteries. (In the case of wind and micro-hydroelectric generators, no fuel is required at all).

Stand Alone PV System with Backup Generator Powers Off-the-Grid Home

Figure 3.8: The tracking array shown on the left follows the sun throughout the day, increasing power output, *Andy McDonald*

Wayne Allen's house, set on the edge of a sloping field encircled by woods, looks like a typical American home. If you were paying attention, you might notice that there are no power lines running to the house. That's because Wayne's house is powered by a 540-watt PV array, located across the stream on the south side of the house. Underground cables carry power from the shed where the batteries are stored into the house, preserving the view of the land. "This is such a beautiful place we have here," commented Wayne. "When my wife and I moved out here, we didn't want power lines ruining the view, so we asked the power company if they would bury the power lines. They refused to work with us, so we decided to put in a PV system instead."

The Allen's PV system uses two 120-watt and four 75-watt PV panels mounted on two separate posts. One of the mounts has a tracking mechanism that follows the sun through the sky, enabling the panels to generate more power. The other mount is fixed facing due south. The system includes 16 golf cart batteries (Trojan T-105) and an inverter which provides AC power to the house. A back-up generator recharges the batteries when they get low, mainly during extended periods of cloudy weather in the winter. Wayne says he's never needed to recharge the batteries in the summertime, but occasionally it's needed in the winter. They also use the generator periodically in the summer to directly operate their air conditioner.

Wayne says he doesn't feel like he's sacrificing any comforts or conveniences to be living off-the-grid with a solar system. "We have all of the appliances people typically have," he said. "My wife and I watch TV and use the computer quite a bit. We have enough lighting and use ceiling fans. The PV system has met our needs just fine." They also use the PV system to pump water from their cistern. The PV system is supplemented by a propane refrigerator, water heater, and clothes dryer.

The Allen's have been very satisfied with the PV system since they installed it in 1999. "It's actually been less bothersome than I had expected," said Wayne. Adding water to the batteries a couple times per year has been about all the maintenance the system has required. Their batteries have begun to age, however, and are not holding a charge as long as they used to. They expect to replace the batteries in the near future.

The installed cost for the Allen's PV system was less than $8,000, including labor and equipment. Wayne did most of the work himself, but hired an experienced PV installer (Joshua Bills) to help with some of the technical details. They are expecting to install an additional 360-watts of PV power in the coming year, and hope to some day install a solar water heater, as well.

Grid-Intertied Systems and Net Metering

Grid-intertied (or utility-interactive) PV systems use the electric utility grid as a back-up power supply. The PV system is connected to the utility grid using a high quality inverter, which converts DC power from the solar array into AC power that conforms to the grid's electrical requirements. Connecting the PV system to the grid enables users to take power from the grid whenever they use more power than the PV system is generating (such as on cloudy days and at night). Any time the PV system generates more power than the building is using, the excess power is delivered back to the grid, rotating the electric meter *backwards*. This happens automatically through the inverter, which distributes the power to the loads in the house or to the grid, as needed.

In *net metering* arrangements, the customer-generator is credited for the amount of PV power they deliver to the grid. If during a billing period you consume more energy than you generate, you are billed for the *net* electricity consumed. If, on the other hand, you generate more energy then you consume during a billing period, you are *credited* for the *net* electricity generated, which is then used to offset the energy consumed during future billing periods.

Grid-intertied systems can be installed with or without a battery back-up. Having battery back-up provides power when the electric grid goes down. Systems without battery back-up are less expensive and require less maintenance than systems with batteries. However, they are also at the mercy of the grid. Should grid power fail, systems without batteries stop producing electricity regardless of whether the PV panels can produce power. This is necessary to protect electric line workers from unknown power sources. Systems with battery back-up automatically transfer power from the grid to batteries when the grid fails.

Net Metering in Kentucky

Net metering in Kentucky started March 15, 2002 when the Kentucky Public Service Commission (PSC) approved a three-year pilot net metering program for Kentucky Utilities (KU) and Louisville Gas & Electric (LG&E). Union, Light, Heat, and Power (ULH&P) and Berea College Utilities soon followed suit with their own pilot net metering programs. KU and LG&E's pilot program allows net metering for solar, wind, and hydropower systems whose generating capacity is no greater than 10 kilowatts for residential customers and 25 kilowatts for commercial systems. The pilot programs are limited to 25 systems each for the KU and LG&E service areas. Participation in these pilot programs has been limited, due primarily to the large investment required for net metered systems, combined with the uncertainty of whether the programs would continue after the pilot period.

These pilot programs were followed by the passage of a statewide net metering bill, which was signed into law on Earth Day 2004. The Kentucky net metering law (unlike the pilot programs) allows net metering only for solar electric systems of 15 kilowatts or less. Every regulated utility in Kentucky (including Rural Electric Cooperatives), except for TVA (which has its own solar production incentive), is required to net meter customer solar generation. Unfortunately, municipal electric utilities are not regulated by the PSC, and thus are not included in the law. Typically, however, municipal electric utilities are more open to net metering then their investor-owned counterparts, so you may find them receptive to allowing net metered systems in your area.

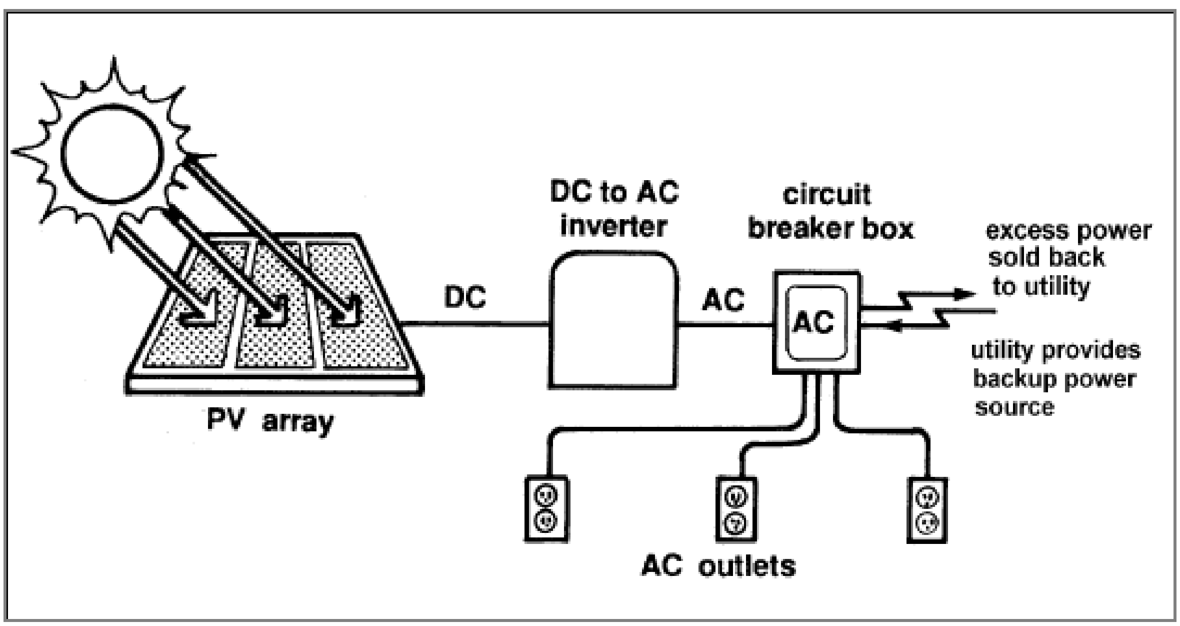

Figure 3.9: Utility-interactive PV system, *North Carolina Solar Center*[19]

Advantages of Net Metering

By permitting PV systems to legally tie into the electric grid and compensating system owners for the power they generate, net metering provides an important incentive for solar energy development. It helps people access the numerous advantages that net metered and grid-intertied systems have to offer.

One advantage of grid-intertied systems over stand-alone PV systems is that batteries are not required. This reduces the up-front cost of a grid-intertied system (compared to a similarly-sized stand-alone system) by about 20 percent. Eliminating the need for batteries also eliminates battery maintenance, the expense of periodically replacing them, and the environmental costs associated with them.

Another advantage of grid-intertied systems is that they maximize power production from the PV array, because all power generated is either used immediately on-site or flows into the grid, with credit going to the system owner for use anytime in the future. In this way all usable electricity from the PV array is utilized. This allows grid-intertied systems to be sized smaller and still provide as much usable energy as larger stand-alone, battery-based systems. Such stand-alone systems are often designed to meet demand in the winter when the available sunlight is at a minimum. This results in the system being over-sized for meeting summer demand. During the summer months most stand-alone systems generate more energy than the batteries can take in. Often batteries are full by 1:00 pm. The panels then stop charging the batteries and only generate as much power as the occupants are using at the time.

By contrast, all production from net-metered systems will either be used immediately on-site, or flow into the grid and be credited to offset future consumption. Should more energy be generated during a sunny summer billing period, a credit is given to the customer-generator which can be used to offset winter billing periods when more energy is consumed than generated. Most state net metering laws allow credits to be carried forward for an annual period, after which they are given to the electric company or sold to them at a less-than-retail, avoided cost rate. The Kentucky net metering law is unusual in that credits are carried forward until the customer-generator uses them up or moves to another location.

Net metering can also benefit electric utilities whose peak demand is in the summer. Photovoltaics generate the most power on sunny summer days, when demand on the electric grid is often highest. With air conditioner use at its peak during the hot summer months, many electricity providers have to increase production in order to keep up with demand. Widely distributed PV systems could match this need, enabling utilities to avoid reliance on expensive peaking power generator systems.

"A major benefit of utility-interactive PV is that it can be widely distributed. This asset will lead to the installation of many small scale "distributed generation" power plants located on buildings. Over time, this could reduce the need for additional large centralized power plant construction and costly utility grid distribution network expansion. The nature of distributed generation can increase national energy security by increasing the number of power plants that would have to be targeted in order to shut down the national utility grid. Other examples of distributed generation technologies are wind turbines, fuel cells and micro turbines."[20]

Many electric utilities now offer a green power choice for their customers. Not everyone wants to install a solar electric system on their rooftop or in their backyard. However, they might still consider paying an extra premium for "green power" from their utility company. Green power sources include landfill gas, wind, and solar energy. While utility-scale PV systems require a large initial investment, a network of net metered homes can supply utilities with a source of solar electricity for their green power programs.

Figure 3.10: This grid-intertied PV array at the office of Appalachia– Science in the Public Interest in Mt. Vernon Kentucky was one of the first net-metered systems in the state. The inverter is shown at left and the PV array above the entrance at right, *Andy McDonald*

Figure 3.11: PV panels double as roofing for this pavilion at the Lover's Lane soccer complex in Bowling Green, Kentucky, *Tennessee Valley Authority*

Utilities gain by tracking the output from their customer's net metered systems, which they then can sell at a premium to other customers. In this arrangement some utilities even pay their net metered customer-generators a premium for the solar power they produce. TVA's Green Power Switch Generation Partners Program is one example.[21]

Refer to Chapter Thirteen to learn more about net metering and purchasing green power in Kentucky.

TVA Purchases PV and Wind Generation from Small Producers

TVA's Green Power Switch Generation Partners Program offers the best solar energy incentives currently available in Kentucky to customers of participating power distributors. TVA will pay $0.15 per kWh and $500 upon installation of a new grid-intertied PV or wind generator. See Chapter Thirteen for more information.

Guerilla Solar

What if you live in an area of Kentucky serviced by a municipal electric company that is not responding favorably to your plans to install a net-metered solar electric system? Or what if you were unsuccessful in convincing your TVA power distributor to participate in TVA's Green Power Switch Generation Partners Program? Or maybe you're not interested in jumping through the local utility's regulatory hoops. Many people around the country have confronted obstacles like this by simply not informing their utility that they've installed a grid-intertied PV system.

This phenomenon is known as "guerrilla solar." It developed in response to utilities refusing to cooperate with homeowners wishing to install net-metered solar systems. Many guerilla systems have been installed in areas without net metering and have been approved by code inspectors, but were then denied approval by the electric utility. Many in this situation have simply gone guerilla and hooked up their systems anyway. If you do install a guerilla system, ensure that it is as safe as an approved, net metered system would be, utilizes UL approved equipment, and meets the National Electric Code.

Although guerilla solar is an option, it should no longer be necessary in most parts of Kentucky now that state law requires all regulated utilities to permit net-metering. For those who are connected to the utility grid but want to avoid dealing with the utility when hooking up a solar system, there remain many ways to utilize solar without "going guerilla." Stand-alone systems of any size can be set up to meet needs independent of the electric grid. These include powering rechargeable batteries, water pumps, computers, outdoor lights, and out-buildings. Beyond solar electric, consider that a solar water heating system connected to an electric water heater will substantially reduces one's electricity consumption. Similarly, using a solar oven will reduce the electricity otherwise used by an electric oven. These all represent easy and legal ways for people to use solar without having to deal with regulatory hassles or paperwork.

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End Notes

1. "Photovoltaics: Electricity from the Sun," North Carolina Solar Center, Fact Sheet no. SC108, Raleigh, NC, June 2002, p.1.
2. Joel Makower, Ron Pernick, and Clint Wilder, "Clean Energy Trends 2004," Clean Edge, March 2004. Available at www.cleanedge.com/reports-trends2004.php
3. "Our Solar Power Future: The US Photovoltaics Industry Roadmap Through 2030 and Beyond," Solar Energy Industries Association, September 2004. Available at: www.seia.org/media/pdfs/pvroadmap.pdf
4. Ibid.
5. "Influential US lawmakers, solar industry leaders share vision for solar power future," Press Release from the Solar Energy Industries Association, Washington, DC, January 28, 2005.
6. "Energy Payback: Clean Energy from PV," National Renewable Energy Laboratory Report, US Department of Energy, NREL Report No. NREL/FS-520-24619), no date.
7. "Overview of Potential Hazards," V.M. Fthenkis, National Photovoltaic Environmental, Health and Safety Assistance Center, Department of Environmental Science, Brookhaven National Laboratory, Upton, NY, 11973. This report and others on this topic are available at www.pv.bnl.gov).
8. "Potential Health and Environmental Impacts

Associated with the Manufacture and Use of Photovoltaic Cells," Electric Power Research Institute, Inc., Palo Alto, CA, Nov. 2003, p.5-1. Report available on-line at: www.epriweb.com/public/000000000001000095.pdf
9. Ibid, p.5-1.
10. Richard Perez, "Myth: Lead-Acid Batteries Wind Up As Toxic Disasters in Our Landfills," Home Power, April/May 2004, no. 100, pp.32-38.
11. Madeleine Cobbing and Simon Divecha, "The Myth of Automobile Battery Recycling," Greenpeace, no date. Available at: www.things.org/~jym/greenpeace/myth-of-battery-recycling.html
12. "Energy Payback: Clean Energy from PV."
13. Ibid.
14. J. Motavalli, "Heavy Metal Harm," E: The Environmental Magazine, May/June 2002, vol.XIII, no.3, p.32.
15. "Photovoltaics: Electricity from the Sun," p.2.
16. SunDanzer's web site is www.SunDanzer.com
17. Joe Schwartz, "Myth: Solar Electricity is too Expensive," Home Power Magazine, April/May 2004, no. 100, p.35.
18. "Photovoltaics: Electricity from the Sun," p.2.
19. "Photovoltaics: Electricity from the Sun," p.3
20. Ibid, p.3.
21. See Chapter Fourteen or visit the web site for the Green Power Switch Program at: www.tva.com/greenpowerswitch/partners/

RESOURCES:
Solar Electric Systems

Publications

"A Consumer's Guide to Buying a Solar Electric System," National Renewable Energy Laboratory, US Department of Energy, September 1999. Available on-line at www.nrel.gov/ncpv/pdfs/26591.pdf

"Assessing Climate to Improve Solar Design," Energy Efficiency and Renewable Energy Clearinghouse, US Department of Energy, Document no. DOE/GO-120001-1171, FS122, August 2001. Available on-line at www.eren.doe.gov/

Consumer Guide to Solar Energy, S. Sklar & K. Sheinkopf, Bonus Books, Inc., Chicago, 1995.

Home Power (magazine), see below for contact information.

"Photovoltaics: Basic Design Principles and Components," Energy Efficiency and Renewable Energy Clearinghouse, U.S. Department of Energy. (DOE/GO-10097-377, FS231), March 1997. Available on-line at www.eren.doe.gov/

"Photovoltaics: Electricity from the Sun," North Carolina Solar Center, Technical Paper no. SC108, North Carolina State University, Raleigh, North Carolina, June 2002. Available at www.ncsc.ncsu.edu

"Siting of Active Solar Collectors and Photovoltaic Modules," North Carolina Solar Center, Technical Paper no. SC112, North Carolina State University, Raleigh, North Carolina, September 2001. Available on-line at www.ncsc.ncsu.edu

The Solar Electric House: Energy for the Environmentally-Responsive, Energy-Independent Home, Steven J. Strong and William G. Scheller, Sustainability Press, 1993.

The Solar Electric Independent Home Book, New England Solar Electric, Inc., Worthington, Massachusetts, 1998.

Solar Today (magazine), American Solar Energy Society, see below for contact information.

The catalogs and web sites produced by solar equipment suppliers are often excellent resources concerning solar equipment and design. Refer to the list of PV equipment suppliers in Chapter Sixteen for more information.

Organizations

American Solar Energy Society
2400 Central Ave
Suite A
Boulder, Colorado 80301
(303)443-3130
www.ases.org

The American Solar Energy Society (ASES) is a national organization dedicated to advancing the use of solar energy for the benefit of U.S. citizens and the global environment. ASES promotes the widespread near- and long-term use of solar energy. Publishers of *Solar Today* magazine (www.solartoday.org).

Florida Solar Energy Center
1679 Clearlake Road
Cocoa, Florida 32922
(321) 638-1000
www.fsec.ucf.edu

The Florida Solar Energy Center researches and promotes energy efficiency and solar energy in Florida. Their site includes project descriptions, on-line research reports, software demonstrations, news and events.

(Continued on next page)

Home Power Magazine
PO Box 520
Ashland, OR 97520
(800)707-6585
(541)512-0201 (outside the U.S.)
www.homepower.com

Home Power is "the hands-on journal of home-made power." Each issue offers in-depth, clearly-written, well-illustrated articles discussing the entire array of renewable energy technologies, educating and empowering their readers toward more sustainable lifestyles.

Midwest Renewable Energy Association
7558 Deer Road
Custer, WI 54423
Phone: (715)592-6595
www.the-mrea.org

The Midwest Renewable Energy Association offers workshops and training that cover a variety of topics related to renewable energy. Their annual Renewable Energy Fair, held each year on the summer solstice in Wisconsin, offers excellent educational and networking opportunities, and is billed as the largest RE Fair in the country.

National Renewable Energy Laboratory
www.nrel.gov

The National Renewable Energy Laboratory is the nation's leading center for renewable energy research. Their web site features publications, program and project descriptions, partnership opportunities, news and events.

North Carolina Solar Center
Box 7401
North Carolina State University
Raleigh, NC 27695-7401
(919)515-5666
www.ncsc.ncsu.edu

The North Carolina Solar Center serves as a clearinghouse for solar and other renewable energy programs, information, research, technical assistance, and training for the citizens of North Carolina and beyond. The Center offers numerous publications addressing passive and active solar energy. These documents can be downloaded for free from their web site (follow the link for "Information Resources"). They will also mail printed copies to those who do not have access to the internet.

Solar Energy Industries Association
805 15th Street, NW
Suite 510
Washington, DC 20005
(202) 682 - 0556
www.seia.org

The Solar Energy Industries Association (SEIA) is the national trade association of solar energy manufacturers, dealers, distributors, contractors, installers, architects, consultants, and marketers. They work to expand the use of solar technologies in the global marketplace. On their web site you can find out how to get involved as an individual or a solar business, keep up on the latest solar policy news, and find out about contractors and incentives for buying solar yourself.

Solar Energy International
PO Box 715
76 S. 2nd St.
Carbondale, CO 81623
(970)963-8855
www.solarenergy.org

Solar Energy International (SEI) offers hands-on workshops in solar, wind and water power and natural building technologies in eleven locations. SEI also offers internet-based online courses.

Chapter Four
PV System Equipment and Maintenance

PV System Equipment

Solar modules are only one of the components needed to create a safe and reliable solar electric system. The additional components, referred to as "balance of system" (BOS) equipment, include "battery charge controllers, batteries, inverters (for loads requiring alternating current), wires, conduit, a grounding circuit, fuses, safety disconnects, outlets, metal structures for supporting the modules, and any additional components that are part of the PV system… Note that, in many systems, the cost of the BOS equipment can equal or exceed the cost of the PV modules."[1]

PV systems should be installed according to local electrical codes (insofar as this is possible in places where the code does not address PV), following all standard safety guidelines, using approved equipment appropriate to the applications for which it will be used. Proper grounding, adequate fuses or circuit breakers, appropriate wire sizing, and all other standard wiring practices are required to ensure the safety of a PV system. Ensure that you or your installer adheres to these safety practices. Also be aware of the risks associated with working on roofs, and follow best practices for ensuring that any roof penetrations are fully sealed to prevent leaks.

Figure 4.1: Charge controller *Morningstar Corporation*

Primary Balance of System Equipment

CHARGE CONTROLLER– "The charge controller regulates the flow of electricity from the PV modules to the battery and the load. The controller keeps the battery fully charged without overcharging it. When the load is drawing power, the controller allows the charge to flow from the modules into the battery, the load, or both. When the controller senses that the battery is fully charged, it stops the flow of charge from the modules. Many controllers will also sense when loads have taken too much electricity from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature [commonly referred to as the Low Voltage Disconnect (LVD), ed.] can greatly extend the battery's lifetime."[2]

Charge controllers can cost as little as $20 to more than $600, depending on their size (ampere capacity), the sophistication of the controller, and the monitoring features you select. "When selecting a controller, make sure it has the features you need; cost should be a secondary consideration."[3] Maximum power point tracking (MPPT) charge controllers are more expensive but deliver more power to the batteries than other types, improving the efficiency of the entire system.

Figure 4.2: Deep cycle lead acid batteries, *Trojan Battery Company*

BATTERIES- In a stand-alone system, batteries provide electricity when the PV panels are not producing sufficient power, such as at night or during cloudy weather. Batteries also allow the system to incorporate appliances that use more power than the PV panels are rated to deliver. PV systems require deep cycle batteries to provide electricity for extended time periods. Deep cycle batteries are designed to slowly discharge and recharge over 50 percent of their capacity hundreds of times. Automotive batteries are all shallow cycle and should NOT be used with PV systems. They are designed to discharge only 20 percent of their capacity and to recharge immediately. If discharged beyond 20 percent more than a few dozen times, automotive batteries will be damaged and will lose their capacity to hold a charge.

Golf cart batteries and the L-16 and L-16H industrial batteries (often used in industrial forklifts) are the most common deep cycle lead acid batteries used in solar electric systems. Regular maintenance for these batteries requires checking the water level on a monthly or semi-annual basis, and fully charging the batteries every three weeks. Lead acid and wet cell batteries give off explosive hydrogen gas when they are being charged near their fully charged point. For this reason they must be stored in a well-ventilated area, isolated from any flames or sparks. Depending upon the specific battery and how well they are maintained, lead-acid deep cycle batteries can last from three to ten years.

Maintenance-free deep cycle batteries are also available for PV systems. These types of batteries are sealed, do not off-gas hydrogen or other fumes, and cannot be spilled. Gel and AGM (absorbed glass mat) are two types of maintenance-free batteries. These batteries are more easily damaged from overcharging or improper charging and therefore require specialized charge controllers. They are typically more expensive than lead-acid or wet cell batteries and have a shorter life expectancy (ranging from three to five years).

Figure 4.3:
L-16 deep cycle battery
Real Goods/Gaiam, Inc.

Battery maintenance is the homeowner's primary responsibility with solar electric systems. Preventing batteries from being excessively discharged and carrying out regular maintenance will help to ensure the maximum life and performance from your batteries. Neglecting these responsibilities will significantly shorten battery life. That being said, these tasks are not difficult. Proper system design that includes enough battery storage capacity for your climate and energy use, and conscientious energy usage will help to ensure that your batteries are not overly-discharged on a regular basis. Equipment for monitoring battery conditions can be very helpful. These can include meters to measure voltage, amperage, or battery state-of-charge (expressed as a percent or in amp-hours). The low-voltage disconnect feature on the charge controller can also protect battery-life, if a potential loss of power is not a concern. Refer to the section on *PV System Maintenance* later in this chapter for more information on battery maintenance.

Figure 4.4:
175 watt inverter
Creative Energy Technologies, Inc.

INVERTERS– Inverters convert DC electricity into AC electricity, enabling conventional AC appliances to be used with a PV system. They are also essential components of a grid-intertied PV system, harmonizing the power from the PV module with the power from the grid and distributing it to the loads or the grid as appropriate. Inverters are rated by their maximum continuous output in watts, as well as the maximum power surge they can provide.

Inverters vary in the quality and waveform of AC power they provide, which affects which appliances can be used with the inverter. Modified sine-wave inverters are less expensive and slightly more efficient, but cannot operate appliances that are very sensitive to the waveform of the electricity. Some fans and stereo equipment may give off an audible "hum" with modified-sine wave inverters. Photocopy machines, laser printers, some computers, some battery chargers for portable power tools, and other sophisticated electronic equipment often require high quality, pure sine-wave electricity to operate properly. Pure sine-wave inverters are also required for grid-intertied systems. Your choice of inverter therefore depends upon the quality of AC electricity required by the appliances you'll be using, the average number of watts they demand during continuous use, and the maximum number of watts they will draw when surging. Note that some equipment will operate fine on modified sine wave inverters for short periods or with occasional use, but will overheat or be damaged under continuous operation. Unfortunately, most appliances do not indicate which form of AC electricity they require, and the requirements of your equipment may not be apparent until the equipment fails.

Figure 4.5: Sunny Boy inverter for grid-intertied systems
Real Goods/Gaiam, Inc.

PV System Maintenance

PV systems require very little maintenance. Grid-intertied PV systems without battery back-up require virtually no maintenance at all. If the PV racks require manual adjustments each season, this task must be carried out according to the appropriate schedule (see Chapter Five, Table 5.2). Due to Kentucky's latitude, winter PV positions tend to shed snow easily. The sun usually warms panels enough to allow snow build-up to slide off, but they may need to be swept clean after heavy snowfalls. To ensure maximum PV output after snowfalls, locate your PV array where the snow can be easily removed (on a ground-mounted pole, for instance). Typical Kentucky rain patterns keep PV surfaces clean without the need for hand washing.

If a tracking rack is used some minimal maintenance will be needed to keep moving parts in working order. Installation documentation for Wattsun active tracking racks, Zomeworks passive tracking racks, and other systems cover maintenance for their equipment.

Typically, various parts are greased and the tightness of nuts are checked once a year.

Most stand-alone battery-based systems are wired at a lower voltage than grid-intertied systems. For this reason ensure that all low voltage DC wire connections in a battery based system are clean and tight. This is particularly important for connections at the battery and the contacts on the inverter, especially if the inverter has a large output. A system monitor is a necessity for stand-alone battery based systems of all sizes, except perhaps very small systems, such as sign lights, fence chargers, etc.

Battery Maintenance

Of all the components in a solar electric system, the battery bank requires the most maintenance in order to ensure a long life. The greatest problems with batteries occur when more electricity is consistently withdrawn than is put back into them. This usually occurs during the winter months when batteries may go weeks without being fully recharged. Standard liquid electrolyte deep cycle lead acid batteries should be brought up to a complete charge at least every three weeks. Leaving them discharged over long periods of time will cause a coating of sulfate to crystallize on the surface of the internal plates. This impedes the normal charging process of the battery, and the battery will start to behave like a smaller battery. To remedy such a situation the batteries must be overcharged in a controlled fashion to drive off the sulfate coating.

When batteries are left discharged for extended lengths of time, unequal cell charge levels can also result. It is wise to test all cells every three months with a hydrometer, which measures the specific gravity of the electrolyte in the battery. Hydrometers can be bought from solar dealers and auto parts stores. Most batteries are full at a specific gravity of 1.265 and are overly-discharged if below 1.175. Batteries have multiple cells. If the cell measurements are unequal by a difference of more than 0.02, manually overcharge the batteries through an *equalization charge* which will cause the lesser cells to come up to the specific gravity of the rest of the battery pack. An *equalization charge* is a controlled overcharge, which is often accomplished by pressing a switch on the charge controller that allows the charger to slightly overcharge the batteries for a set length of time. Some charge controllers will even do this automatically on a regular schedule. In non-automatic systems, a manual charge control bypass switch can be used to equalize the batteries, but this requires careful monitoring and an understanding of the process. When using a hydrometer (or doing anything else around batteries), always follow battery and hydrometer manufacturers' cautions regarding safety. Battery acid is dangerous, especially to eyes.

The electrolyte level for each cell in a battery will have to be checked at least every three months. This is especially important during summer months. Only distilled water should be used to bring the electrolyte up to its proper level. This should be done when the batteries are near full, but not while being charged heavily. Often when distilled water is added to a discharged battery, the electrolyte will be overfilled and spill out of the battery when it becomes fully charged.

Keep battery tops clean and dry by wiping them occasionally with a rag. Wet, acidy tops provide a conductive path between terminals resulting in energy loss and more corrosion. If evidence of cruddy green buildup appears on the tops of batteries they should be wiped off with distilled water, then wiped dry. If there is heavy corrosion you might consider diluting a small amount of baking soda in the cleaning water. Be aware that this runs the risk of getting some of the baking soda solution into the battery cells, which is not good for them. Do without the baking soda for cleaning purposes if you can. However, it is a very good idea to keep a box or two of baking soda near the battery bank in case a spill ever occurs. The baking soda can be dumped on the spill to neutralize it.

In an enclosed space batteries should be vented to the outside. An enclosed box with a 1" pipe venting above the battery tops to the outdoors will suffice. Batteries are the nasty part of a PV system and usually warrant being located outside of living spaces (but still indoors). Be careful around batteries. They contain strong acids. Rubber gloves and safety glasses are minimum safety measures when working with them.

Figure 4.6: A tracking PV array at Berea College's Eco-Village
Andy McDonald

Component Failures

Solar equipment is generally high quality and equipment failures are rare. When problems do occur, PV owners often suspect equipment failure when the problem has another source. To identify the source of problems, check fuses and circuit breakers and look for loose or disconnected wires. If you have experience with voltmeters, trace the supply of electricity to the problem to see if it can be resolved. If your system was installed by a professional installer, do not hesitate to contact them, and be prepared with notes on all conditions and checks that you have made. In off-the-grid systems, consider using DC-power for refrigeration and maybe a few lights so they will continue to operate in case of inverter failure.

End Notes

1. "Photovoltaics: Basic Design Principles and Components," Energy Efficiency and Renewable Energy Clearinghouse, US Department of Energy, Document no. DOE/GO-10097-377, FS 231,March 1997, p.5.
2. Ibid, p.6.
3. Ibid, p.6.
4. Real Goods Summer 2004 Resource Guide, Hopland, California, p.85.

Battery Maintenance Checklist

Figure 4.7: Maintenance-free, deep cycle gel battery
Real Goods/Gaiam, Inc.

Though most consider lead-acid batteries the "weak link" in renewable energy systems, today's batteries are better than ever, and so are the devices that regulate and protect them. In fact, battery failures are rarely the fault of the batteries themselves. Follow these guidelines to ensure that your batteries have a long, productive life.

1. Size the battery bank and PV array properly. Your battery bank should hold at least a five day load, and your PV array should produce (on average) 30 percent more energy than the load requires.

2. Buy high-quality batteries. Deep-cycle batteries can be expected to last from three to ten years, and sometimes longer.

3. Maintain even temperature distribution. Avoid uneven exposure to heat sources, and leave at least one inch of air space around each battery.

4. Prevent corrosion. Apply a non-hardening sealant to every terminal's metal parts BEFORE ASSEMBLY.

5. Keep batteries as close to room temperature as possible. Batteries work at a wide range of temperatures, but they lose capacity at very low temperatures and deteriorate faster at higher temperatures.

6. Rinse battery tops with water twice per year.

7. Avoid multiple parallel strings. If you must use them, distribute current evenly by connecting the two main cables to opposite corners of the battery bank and maintaining symmetry in wire size and lengths. If you exceed three parallel strings, it's time to move to a bigger battery.

8. Use a charge controller, power center or battery charger with temperature compensation.

9. Install a system monitor. Would you drive a car with no dashboard?

10. Bring batteries to a full state-of-charge at least every ten days.

11. Don't completely discharge batteries- it can cause immediate, irreversible loss of capacity. Monitor batteries, or use an inverter or charge controller with a low-voltage disconnect.

12. Add distilled water as needed. Most batteries require additional water every three to six months.

Adapted from, originally published by and copyright Dankoff Solar Products, Inc.[4]

Chapter Five
Designing Solar Electric Systems

The proper design of solar electric and solar thermal systems depends on an understanding of the sun's movements through the sky and the way local site conditions and climate influence the availability of sunlight at any particular location. While the following discussion is oriented towards the design of solar electric systems, it is relevant to the design of solar thermal systems, as well.

Site Assessment: Understanding the Path of the Sun

The specific site where a PV system will be located plays a crucial role in the design and performance of the system. The amount of power generated by a solar cell depends upon the intensity of sunlight striking it, and the amount of available sunlight varies with latitude, climate, and local conditions, such as the presence of trees. It is helpful to understand how the sun moves through the sky throughout the year when evaluating your site's solar potential.

There are three factors responsible for variations in the amount and quality of sunlight reaching the Earth. First, the Earth is round. Second, it revolves around the sun in an elliptical orbit. Third, the Earth rotates on a tilted axis. As the Earth is round, sunlight strikes its surface at differing angles ranging from 0° (just above the horizon) to 90° (when the sun is directly overhead). When the sun's rays are perpendicular to the surface of the Earth, they transmit the most energy. When the sun is low in the sky and its rays are at a very low angle, they must pass through a longer portion of the atmosphere, making the sunlight scattered, diffuse, and reducing its energy. The Earth's polar regions never see the sun high in the sky because the Earth is round. The tilted axis of rotation explains why the polar regions receive no sun at all during certain times of year.

The Earth's elliptical orbit causes the Earth to be closer to the sun during certain times of the year, allowing somewhat more solar energy to reach the planet. We are closer to the sun when it is winter in the northern hemisphere and summer in the southern hemisphere. Why isn't it hotter in the northern hemisphere when we are closer to the sun? The North Pole is tilted away from the sun at this time, which lowers the angle of the sunlight reaching the northern hemisphere, thereby reducing its energy content. Why does the northern hemisphere have summer when the

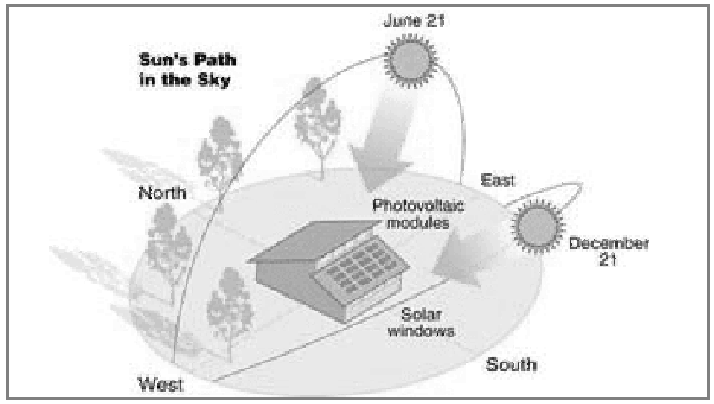

Figure 5.1: The United States receives much more solar radiation in the summer when the sun is higher overhead than in the winter when it is lower in the sky.
Energy Efficiency and Renewable Energy Clearinghouse, US DOE

Earth is farthest from the sun? Because the North Pole is tilted towards the sun at this time, increasing the angle of incoming sunlight and its energy content. Why isn't the southern hemisphere even hotter during its summer, when Earth is closest to the sun and the south pole is tilted towards it? This is explained by our vast oceans, which absorb much of the sun's energy and moderate the hotter summers and colder winters we would expect to see in the southern hemisphere as a result of these conditions.

The 23.5° tilt in the Earth's axis of rotation is a very significant factor in determining the amount of solar energy striking the Earth at a particular location. "Tilting results in longer days in the northern hemisphere from the spring (vernal) equinox to the fall (autumnal) equinox and longer days in the southern hemisphere during the other six months. Days and nights are both exactly 12 hours long on the equinoxes, which occur each year on or around March 23 and September 22.

"Countries like the United States, which lie in the middle latitudes, receive more solar energy in the summer not only because days are longer, but also because the sun is nearly overhead. The sun's rays are far more slanted during the shorter days of the winter months. The result is a big difference in the amount of direct sunlight available for solar energy systems. Cities like Denver (near 40° latitude) receive nearly three times more solar energy in June than they do in December. That's why winter is so much colder than summer.

"The rotation of the Earth is responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon."[1]

Sun Hours: The Power of the Sun

When calculating how much power a PV panel can generate in a particular location, we need to know how much energy the sun can provide in that place. A "Sun Hour" is the conventional term used to express the total amount of solar energy that falls on a one square-meter surface over the course of one day. One Sun Hour is equivalent to 1 kW/m^2. On a typical day in June, Lexington, Kentucky will receive 6.2 Sun Hours of solar energy on a one square-meter horizontal surface (see Table 5.1). A vertical surface will receive 2.4 Sun Hours on that same day. The difference is due to the fact that the high summer sun in June will strike a horizontal surface more directly, imparting more of its energy to that surface. On a typical day in December, by contrast, a horizontal surface will receive 1.7 Sun Hours and a vertical surface 2.6 Sun Hours. This illustrates how much more solar energy is available in the summer versus the winter in Lexington. This also indicates the significance of the angle of the sun's rays as they strike the solar collector surface. Figure 5.2 illustrates the average annual solar insolation throughout the United States. Appendix B provides solar insolation data for locations in or near Kentucky.

Table 5.1: Average Solar Insolation in Lexington, KY[2] (in Sun Hours (KWh/m^2/day))

	June	December
Horizontal Surface	6.2	1.7
Vertical Surface	2.4	2.6

Module Orientation and Tilt Angles

As the Lexington example illustrates, the orientation and tilt angle of a solar panel make a big difference in terms of the amount of solar radiation that can be absorbed. A PV panel will receive the most energy when it is perpendicular to the incoming solar rays. Ideally, a panel would rotate to follow the sun throughout the day, and there are tracking systems that can do this. A single-axis tracker will rotate from east to west following the sun. A double-axis tracker also moves to follow the sun as it gets higher and lower in the sky during the day, and from season to season. Active tracking systems use electric motors to move the panels, while passive systems do not require a power source. One type of passive system uses freon to move the panels.

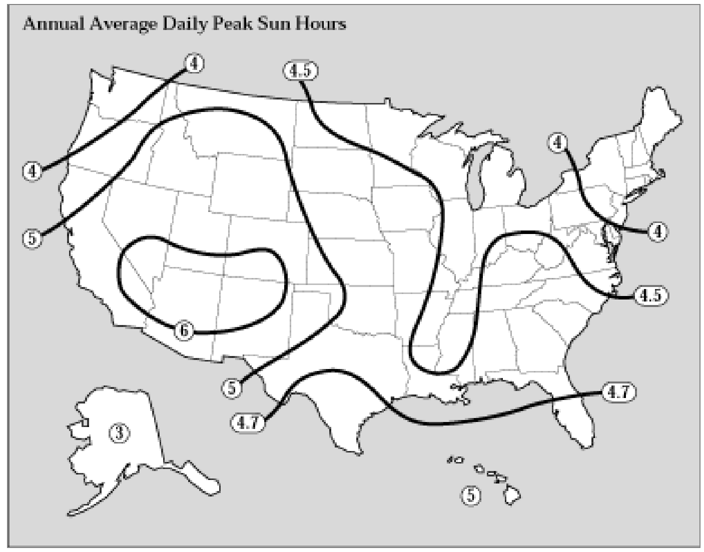

Figure 5.2: Annual Average Daily Peak Sun Hours in the US
Energy Efficiency and Renewable Energy Clearinghouse, US DOE

Depending upon the circumstances, tracking PV systems can produce 20 to 40 percent more power than fixed panels. "Most tracking systems require climates with a high fraction of direct beam versus diffuse sunlight to work well. Climates with high humidity have lower fractions of direct beam sunlight."[3] To choose between a tracking and a fixed PV array, one must weigh the additional power the tracking array will produce against the added expense, maintenance, and complexity it will bring to the system. In Kentucky, using a tracking rack typically only makes sense for large PV arrays (more than 450 watts of PV panels) that are in a wide-open location not exposed to any shading obstacles from sunrise to sunset, and when the extra power generated, mostly in summer, can actually be used.

PV panels with a fixed orientation should face as

Figure 5.3: The tracking PV array on the left is facing the afternoon sun, while the fixed array on the right faces due south, *Andy McDonald*

close to true south as reasonably possible. Sometimes local conditions prevent this, such as the orientation of an existing roof that will mount the panels or the presence of shade trees. In such cases, "deviating … from true south by as much as 20° to 30° east or west will not significantly reduce the total solar radiation received."[4] There are several options to choose from regarding the tilt angles of PV panels. To minimize maintenance on the system, panels can be permanently fixed at a given angle. For maximum annual electricity production in this situation, set the tilt angle equal to the latitude. For example, at 38° latitude, the angle between the surface of the PV module and a level line would be 38°. To maximize winter electricity production, use a tilt angle equal to the latitude plus 15°. Situations when this would be recommended would be when winter electricity demand would exceed summer demand. Another reason would be to balance year-round PV output, since solar insolation is normally lower in the winter than in the summer.

To increase overall annual power production, the tilt angles can be adjusted four times per year according to the schedule in Table 5.2. This will increase production during each season versus using a single fixed tilt angle.

Magnetic Declination: Finding True South

True south is not the same as magnetic south in most places. Due to the Earth's magnetic field, true south varies from magnetic south in Kentucky by about minus 4.5°. (Declination is considered positive east of true north and negative when west.) In western Kentucky, the variation is -1.5°, in central Kentucky – 4.5°, and in Eastern Kentucky –6.0°. To orient solar panels due south in central Kentucky, they should be installed 4.5° west of compass south. The degree of magnetic declination is slowly yet continuously changing.[5] You can find the current magnetic declination, along with the latitude and longitude, for any location in the U.S. at the following website: http://www.ngdc.noaa.gov/seg/geomag/jsp/Declination.jsp

Microclimate, Shading Effect, and the Solar Window

The local microclimate can significantly impact the solar radiation at a site. Local conditions that dispose a site to early-morning fog, for example, might lead you to orient your solar panels towards the west to capture more of the afternoon sun. Shading produced by trees, mountains, or other buildings will also affect the performance of a PV system. "Shading of only one cell within a PV module can reduce the module's power output by as much as 75 percent."[6] The optimum PV site will have an unobstructed "solar window" between the hours of 9 am and 3pm, when nearly 85 percent of the sun's energy is transmitted. (Note that 9am and 3pm refer to "solar time," not Eastern Standard or daylight savings time. For instance, in central Kentucky around the I-75 corridor, solar noon is about 12:40pm EST). The solar window is the portion of the sky that the sun passes through over the course of the year. A professional site assessment using a tool known as a Solar Pathfinder[7] can help you determine, at a glance, the size of your solar window, for every month of the year. If there is any question as to the availability of a clear solar window on your site, a solar site assessment is highly recommended.

Table 5.2: Preferred Seasonal Tilt Angles for PV Arrays in Central KY (at 38° Latitude)

Season	Position Array	General Formula	Array Angle
Spring/ Fall	March 1/ September 1	Tilt angle = latitude	38°
Summer	April 15	Tilt angle = latitude – 15°	23°
Winter	October 15	Tilt angle = latitude + 15°	51°

Sizing Stand-Alone PV Systems

The worksheets in Appendix A will help you form an initial estimate of the number of PV modules and batteries you would need for a stand-alone system. While this will give you a sense of the size and cost of the equipment you would need, we recommend that you consult with an experienced PV system designer/ installer to ensure that your system is properly and safely designed.

Sizing your PV system begins with an assessment of your electricity demand. You need to know how much power you need on a daily basis and at different times of the year in order to calculate how much generation and storage capacity you need to install. This demand assessment should be followed by critical analysis of every opportunity to reduce your power needs. These opportunities come in the form of alternative, more energy-efficient appliances, alternative energy sources, and behavior changes. Remember John Robbins' advice from Chapter Two that using solar electricity is "one part solar, five parts load reduction." The money you spend on energy-efficient appliances and reducing waste will more than pay for itself by reducing the size (and therefore, initial cost) of the PV system.

Sizing Grid-Intertied PV Systems

For grid-intertied PV systems, sizing the solar system is not as critical as it is for stand-alone systems, because the electric grid provides backup power. Thus, if your PV system fails to meet all your needs, you'll still have power, albeit from the utility rather than the sun. The security provided by the utility grid might lead you to ignore the process of analyzing your energy demands and optimizing the efficiency with which you use energy. This would be an error, however, because saving energy will still cost you less than installing PV panels, and will keep saving you money, month after month. Furthermore, the more you can reduce your demand for energy, the greater the proportion of what you use will be supplied by solar. So as you would do for a stand-alone system, begin by assessing your energy needs and reducing your demand as much as possible.

There are two approaches to sizing a grid-intertied PV system. In the first approach, you attempt to match the size of your PV system to your average annual electricity demand, so that over the course of a year, you produce just about as much electricity as you consume. This approach is based upon the "*daytime solar fraction*- the ratio between average daytime power consumption and average daily photovoltaic system output."[8] Performing the calculations to optimize a PV system in this way can be more complex than sizing a stand-alone system, due to the many variables that influence the economics of grid-intertie systems. Refer to *The Solar Electric House* by Strong and Schaller for further information on this approach.

One could conceivably install more PV panels than you need to meet your average electricity demand, and essentially become a small, independent power producer. However, there are rarely any financial incentives for doing this, so matching your grid-intertied PV system with your electricity demand makes more economic sense.

The second approach to sizing a grid-intertied system is for people who cannot afford to install a PV system large enough to match their electricity demand. This approach typically comes down to the question, "How much can I offset my electric bill if I invest *X* dollars in efficient appliances and a solar electric system?" The answer depends on the efficiency of appliances currently in use, the amount of electricity used, and the size of the solar electric system being considered, as well as site conditions, such as shading. Grid-intertied systems typically cost from $7 to $10 per installed watt of PV generation. In central Kentucky, a 1000-watt system costing $7000 to $10,000 will generate, on average, 135 kilowatt-hours (kWh) per month. At 6 cents per kWh this amounts to cutting $8 per month off the electric bill, or about $100 per year (a 1.0 - 1.5 % return on investment).

By comparison, replacing a standard refrigerator built before 1990 with a super-efficient refrigerator, at a cost of $2000, would also reduce your electricity bills by $8 per month, but at a fraction of the cost of installing a PV system. This example highlights how important energy efficiency is when considering purchasing a solar PV system. It only makes sense to install PV panels on buildings whose energy use is already streamlined. The qualifications of a PV system designer/installer should be seriously questioned if they do not address the energy demand and appliances/ equipment to be powered by the solar electric system, regardless of whether a stand-alone or grid-intertied PV system is being considered.

If funding does not allow the initial size of your net metered solar system to match your electricity demand, expanding the system at a later time is likely to cost much less per additional unit of power than the initial system cost. This is because the inverters used in grid-intertied systems are typically capable of handling more power than the initial number of PV panels can produce. Additional PV panels can easily be added later without incurring the same costs involved when setting up the system, providing a much greater return than with the initial investment.

Unlike battery-based systems, which can be quite small in size, grid-intertied systems have an entry level cost between $4,000 to $5,000. This is primarily a function of the inverter that connects the system to the utility grid. Unlike battery-based inverters, which simply have to convert the battery direct current (DC) into usable alternating current (AC), grid-intertie inverters (with or without battery back-up) have to match the AC output to the utility grid and safely disconnect themselves from the grid when the electric grid fails. This added complexity keeps the minimum inverter size to one rated for 700-watts (a battery-less inverter) of solar electric module input. By contrast, battery-based inverters for stand-alone systems can be as small as 50-watts of rated AC output.

The smallest grid-intertie inverter currently available in the U. S. is manufactured by SMA and is known as Sunny Boy 700U. It retails for approximately $1,800. This battery-less inverter requires PV panels with a minimum output of 300 watts, which will cost approximately $1,400. Add to this PV panel mounts, wiring, conduit, and safety equipment and the total cost approaches $4,000. In central Kentucky, such a system would generate, on average, about one kilowatt-hour per day. This system could be doubled in size (600 watts) for an added cost of only $1,400. If finances allow, larger systems (greater than 5000 watts) can be installed for as little as $5 to $6 per installed watt.

Typically, people install net metered solar electric systems on their homes or businesses for reasons other than economics. The majority (97 percent) of electricity supplied by the grid in Kentucky comes from burning coal. The combustion of coal and its extraction from Eastern Kentucky mountains comes at a price not reflected in electric bills. The price is paid in the form of lower air quality and associated health problems, rough roads damaged by heavy trucks, damaged property, scarred mountain views, creeks filled with coal slurry and fill dirt, and ruined watersheds.

As the price for solar equipment comes down and the price of grid supplied electricity goes up, PV's economic returns will improve and monthly utility bill savings will increase. At current electricity prices in Kentucky, a 1000-watt PV system would reduce your electric bill by about $8 per month. If electricity prices were to double, your monthly savings would double as well, and the payback time on your investment would be cut in half. If we add in financial incentives that can reduce the up-front costs of the PV system, or that increase on-going financial returns from the power produced (such as premium payments from the utility for the solar electricity you generate), the payback time can fall dramatically. In states such as New York, New Jersey, and California, the combination of high electricity rates and generous incentives makes net metered PV systems an economically-viable, long-term economic investment. As electricity and fuel prices rise over the coming decades, a PV system will guarantee you a fixed price for your electricity for the life of the system, which can exceed 30 years.

End Notes

1. "Assessing Climate to Improve Solar Design," Energy Efficiency and Renewable Energy Clearinghouse, US Department of Energy, Document no. DOE/GO-120001-1171, FS122, August 2001, p.3.
2. *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors,* National Renewable Energy Laboratory, U.S. Department of Energy. The manual is available on-line at:http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/sum2/
3. "Photovoltaics: Electricity from the Sun," North Carolina Solar Center, Fact Sheet no. SC108, Raleigh, NC, June 2002, p.1.
4. "Siting of Active Collectors and Photovoltaic Modules," North Carolina Solar Center, Fact Sheet no. SC112, September 2001.
5. Ibid, p.1.
6. Ibid, p.3.
7. To learn more about the Solar Pathfinder or purchase one for yourself, visit their web site at: www.solarpathfinder.com/
8. Steven J. Strong and William G. Scheller, *The Solar Electric House: Energy for the Environmentally-Responsive, Energy-Independent Home*, Sustainability Press, 1993, p.175.

Section II
Solar Thermal Technologies

Unlike solar photovoltaics, which convert the visible light in sunshine into electricity, solar thermal technologies use sunlight to produce heat. In the pages that follow, we will discuss how solar thermal energy is used for heating water and buildings, for preparing and preserving food, for purifying water, and even for generating electricity. Solar thermal systems have been proven to work effectively, reliably, and economically, and are in widespread use in the United States and around the world.

In November 2004, the International Energy Agency (IEA) reported that global capacity of installed solar thermal systems was equivalent to 69,320 Megawatts (MW).[1] This compares with 23,000 MW of global wind capacity and 1,100 MW of solar photovoltaics, and is equivalent to over 300 coal power plants. (The average US coal power plant has a capacity of about 200 MW.)[2] The IEA's report reveals that solar thermal technologies are proven and are making a substantial contribution to the world's energy needs.

End Notes

1. "Solar Thermal Capacity Three Times Higher Than Wind," Refocus Weekly, Brussels, Belgium, November 17, 2004. Available on-line at: www.sparksdata.co.uk/refocus/fp_showdoc.asp?docid=48322696&accnum=1&topics=
2. Energy Information Administration, US Department of Energy. Information on US electrical generating capacity based on fuel type available on-line at: www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html

Chapter Six
Introduction to Solar Water Heating

Solar water heaters are used for a variety of purposes in residential, commercial, and industrial settings. In homes, solar water heaters can serve as the primary source of hot water for washing and bathing, and can also be used for space heating and for heating swimming pools. In institutional, commercial, and industrial settings, wherever hot water is needed, the potential exists to use solar energy as either the primary or supplemental heat source. In addition to residential use, situations that are particularly well-suited to solar water heating include schools, hotels, laundromats, and car washes, due to their patterns of hot water use.

Solar water heaters used in homes for supplying domestic hot water are typically installed with some form of back-up heating system (such as electricity or gas) to ensure a hot water supply during the nighttime and cloudy conditions. Solar water heaters can often be considered pre-heaters. Systems are commonly set up so that the solar water heater raises the temperature of water before it enters the standard water-heating tank.

In Kentucky, domestic solar water heaters used with a back-up conventional water heater can reduce the annual energy required for heating water by 50 to 80 percent or more. Since water heating accounts for one-quarter to one-third of a typical family's energy costs, this can amount to substantial savings over the course of a year (see Table 6.1). For a typical family of four that uses 70 gallons of hot water per day, the annual savings would amount to $182- $502, depending on the type and cost of fuel. The total savings over the first 20 years of operation would range from $640-$7,040 (and solar water heating systems commonly last longer than 20 years).

The economic savings offered by solar water heaters is equivalent to tax-free income, and provides a fixed cost for water heating thus protecting homeowners against fuel price increases. The more fuel prices rise, the greater the savings solar provides. Considering that the US as a whole spends $20 billion per year to heat water, the overall economic benefits from the widespread use of solar water heating could be enormous.

Figure 6.1: A solar collector on the roof of ASPI's Small Town Demonstration Center in Mt. Vernon, Kentucky, *Andy McDonald*

Prior to the birth of the modern solar industry in the 1970's, solar hot water systems in the United States were primarily located in sunny southern climates, such as Southern California and Florida. In such locations solar often provides 100 percent of household hot water needs. In most other places, the possibility of winter-time freezing of pipes and water tanks presented a significant obstacle. To cope with this problem, systems outside of the Sunbelt were often drained in the winter and other forms of heat—wood, electricity, gas - were used instead. During the 1970's solar water heater designs were developed to

Table 6.1: Potential Economic Savings Over the Life of a Solar Water Heating System for a Typical Family of Four[1]

Fuel or Energy Source for Water Heater and Price	Annual Water Heating Fuel Cost	Potential Annual Savings, (50-80%)	Payback Time*	Total Savings over 20 Years**
Propane, $1.75/gal.	$627	$314-$502	5.8- 9.6 yrs.	$3,280 - $7,040
Natural Gas, $1.10/therm	$364	$182- $291	10.3 -16.5yrs.	$640- $2,820
Electric, $0.07/kWh	$464	$232- $371	8.1- 12.9yrs.	$1,640 - $4,420

*Payback time is the number of years needed for the energy savings to equal the installed cost of the system. (Based on an installed cost of $3,000 for the solar water heater.)
**Total savings assumes a fixed price for fuel. If fuel prices rise, total savings will increase and payback time will be faster.

address the issue of freezing, thereby expanding the capability for year-round use to the rest of the United States, including Kentucky. Solar hot water systems now offer significant savings to northern households. A 1990's study of 10 solar water-heating systems in Vermont showed that about 50 percent of the energy needed to heat water each year was being provided by the sun.[2] Installing a solar water heater replaces monthly payments to the utility company with an investment that adds value to your home and provides monthly savings for decades to come. If you heat water with gas, electricity, or oil and do not have a solar water heater, in five to fifteen years the money you pay to the utility will eventually equal what you could have spent on a solar water heater. Every year after that, you'll be sending hundreds of dollars to the utility company that you could have invested or spent on other needs- if only you had installed that solar water heater.

Environmental Benefits Of Solar Water Heating

Solar water heaters offer both reliable economic returns and the benefits of environmental protection. Apart from the resources invested in manufacturing the solar water heating equipment, these systems produce essentially no pollution. This contrasts with the use of conventional water heaters powered by electricity, gas, or oil, which have a significant impact on the environment and public health. These range from the effects of mining coal, to air pollution, acid rain, climate change, and the generation of nuclear waste. When we receive our utility bills in the mail, they do not include these "external" costs to society, the environment, and public health. If these "external" costs were included in our utility bills, the economic advantages of solar water heating would become much more apparent.

The environmental costs of heating water are significant. In 1980, four percent of the energy consumed in the United States was used for residential and commercial water-heating. When we consider that nuclear power supplied 3.5 percent of the nation's energy in that year, we realize that solar water heating could potentially displace as much energy demand as is produced by the nation's nuclear power plants.[4] If we took this path, we could potentially eliminate an energy source that presents enormous threats to our environment, national security, and public health, and replace it with a renewable source that generates virtually no pollution, is widely distributed and therefore not susceptible to interruption or attack, and which would create a great demand for skilled workers.

Table 6.2: Pollution Prevented by Using a Solar Water Heater in Kentucky[3]

Emission	Family of Two, Energy Savings 50- 80% (1,900- 3,033 kWh)	Family of Four, Energy Savings 50- 80% (3,317- 5,307 kWh)
Carbon Dioxide (CO_2)	4,343- 6,933 lbs.	7,583- 12,132 lbs.
Nitrogen Oxides (NO_x)	10- 17 lbs.	18- 29 lbs.
Sulfur Dioxide (SO_2)	24- 39 lbs.	43- 68 lbs.
Mercury (Hg)	35- 55 milligrams	60- 97 milligrams

Based on adding a solar water heater to a home currently using an electric water heater, and assuming 40 gallons of hot water use per day for a family of two, and 70 gallons per day for a family of four.

Inefficiencies in the Nation's Energy System

In a conventional electric power plant, water is heated to several thousand degrees Fahrenheit to produce steam, which turns a turbine, which generates electricity, which is sent over wires to your home, where it powers your electric water heater to produce 130° F water. After accounting for inefficiencies and energy losses at the power plant and in the transmission lines, we find that it takes approximately four units of energy at the power plant to get one unit of energy into your water heater. Three-fourths of the energy produced at the power plant is wasted before it even gets to your home. A solar water heater, by contrast, captures free solar energy that would otherwise go unused, to easily heat water from 50° to 130°F. This water can then be used on-site, with no need for long-distance transmission and the energy losses that entails.

A Brief History of Solar Water Heating

In 1891, the first commercial solar water heater patent was awarded to Clarence M. Kemp of Baltimore, Maryland. His invention, "The Climax," consisted of four galvanized metal water tanks painted black and enclosed in a pine box insulated with felt paper and glazed with a single layer of glass. The Climax was connected to the house plumbing and held 32 gallons of hot water. Although the Climax provided hot water on sunny days, the water would not be fully heated until the late afternoon, and it would cool off quickly at night. The system also had to be disconnected for half of the year because it had no freeze protection.[5]

The Climax solar water heater sold well in Southern California during the 1890's. The smallest and most popular model sold for $25 - a month's wages for an average worker – and saved the typical homeowner $9 per year on coal, or more if gas was used for water heating. By 1900, more than 1,600 Climax heaters had been installed in California.

In 1909, William Bailey began selling the Day and Night solar water heater, which provided an insulated indoor water storage tank, supplied by a separate solar collector located outside the house and facing south. The collector consisted of a coiled pipe inside a glass-covered box and had to be mounted below the storage tank. This allowed the hot water to circulate from the collector to the storage tank by natural convection. This became known as a "thermosiphon" water heater. The Day and Night heater sold for $180 plus installation, and it had the great advantage of keeping heated water warm all night, allowing for morning baths. The Day and Night heater eventually eliminated the Climax from California's market, and over 1,000 units were sold in 1920.

Since the early 1900's, the popularity of solar water-heating in the United States has waxed and waned, shifting back and forth between California and Florida. While over 4,000 Day and Night heaters were sold by the end of World War I, California's solar water heater industry collapsed during the 1920's when natural gas was discovered in Southern California. Gas companies fostered the collapse by subsidizing the purchase of gas water heaters. Florida's solar industry opened up at this time, when builder David Carruthers set up a factory to build the Day and Night water heater in Miami. The business expanded rapidly until it was shut down by a great hurricane in 1926.

Florida's solar industry was reborn in 1935, driven by Federal Housing Administration mortgage programs. "80 percent of homes built in Miami between 1937 and 1941 had solar water heaters. In the next five years, between 25,000 and 60,000 new residential heaters were installed (the estimates vary wildly), including 5,000 very large arrays on hotels, factories, and housing projects. By the time World War II began, over half of the residences in Miami heated their water with the sun."[6] Florida's solar boom was short-lived, however, as wartime restrictions on the use of copper brought the industry to an abrupt halt. In the decades following the war, cheap electricity and gas, combined with a lack of support from utilities and the government have kept Florida's solar industry a shadow of its true potential.

While support for solar water heating has been lukewarm in the United States, other countries have embraced the technology. During the early 1960's in Australia, Israel, and Japan, over 60,000 solar water heaters were being sold each year. By 1991, Tokyo had over 1.5 million solar water heaters in use. In Cyprus during the mid-1990's, 90 percent of homes had solar water heaters. Israel now requires solar water heating in all new buildings, resulting in the installation of 50,000 new heaters each year. Seventy percent of all buildings in Israel now have solar water heaters.[7]

The solar industry in the United States was revived in the early 1970's by the OPEC oil embargo. Skyrocketing oil prices and the prospect of long-term fuel shortages prompted a spurt of interest and investment in renewable energy sources. In 1974, more than 20 companies started production of flat-plate solar heat collectors in the United States. Most of these were active systems with anti-freeze protection. Federal and state tax credits instituted in 1978, combined with another oil embargo in 1979, led to the rapid growth of America's solar industry. It is estimated that over 50,000 solar water heating systems were installed in the United States in 1979.[8]

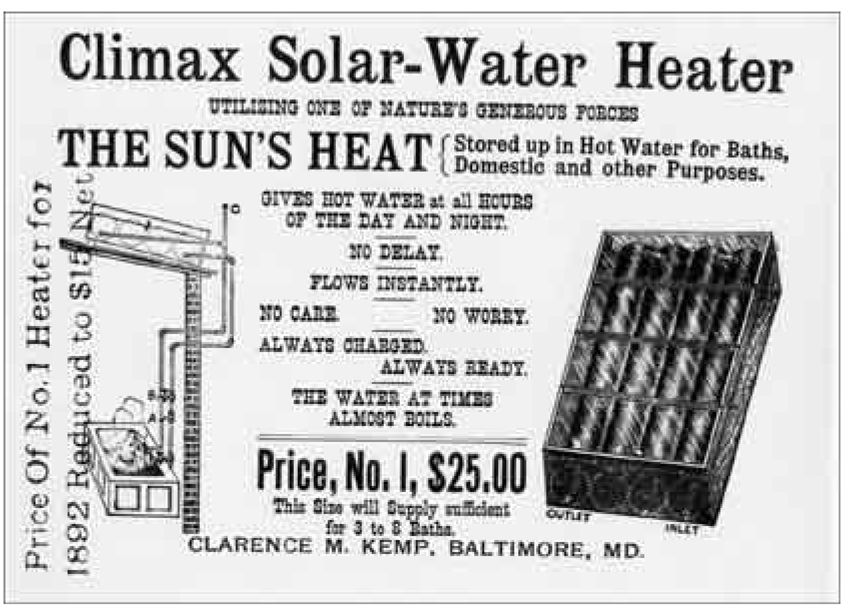

Figure 6.2: An old advertisement for the Climax Solar Water Heater

The industry's expansion was short-lived and had mixed results, however. The nature of the tax credits led inexperienced installers into the business, many of whom were just looking to exploit the tax credits and make some fast money. Many experimental solar water heater designs were tried and failed in short order. Over 100,000 solar water heaters were sold nation-wide in 1984, but the industry soon collapsed when the federal tax credits expired in 1985. The Reagan administration had refused industry appeals to gradually phase out the tax credits over a 10-year period, and instead eliminated them altogether on January 1, 1986.[9] The collapse of the industry not only meant the loss of numerous jobs, but also the professionals who could maintain the systems that had been installed.

America's experience with solar water heating in the 1970's and '80's gave solar

Solar Ratings & Certification Organization

"The Solar Ratings & Certification Organization (SRCC), www.solar-rating.org, is an independent ratings organization for solar systems and is widely recognized as the official standard in the field. The SRCC rates thermal performance of individual solar collectors as well as complete functional systems. Many state and utility rebate programs require SRCC ratings for products to qualify and system performance can be compared to others in the field using the product directory."[12]

Florida Solar Energy Center

"The Florida Solar Energy Center (FSEC), www.fsec.ucf.edu, is the primary testing lab that performs SRCC ratings. In addition to testing solar thermal systems, FSEC also has their own ratings system that is widely adopted in both Florida and the Caribbean. FSEC is also engaged in a wide range of energy efficient and renewable technologies ranging from photovoltaics to reflective roofs."[13]

energy a black eye that the industry is still struggling to overcome. This is in spite of the many qualified installers who are still working in the field, the many systems that continue to work reliably, and the millions of homes around the world that have been using solar water heaters for many decades. As of 2000, the great majority of solar thermal systems sold in the United States (including water and air heating systems) were used for swimming pool heaters (94 percent of the total). Between 1993 and 2000, over 59 million square feet of solar thermal collectors were shipped within the United States, an average of 7.4 million square feet per year. Four percent of this total was used in domestic hot water systems.[10]

Despite the setbacks that the solar water heating industry has endured, the experience of the past century has resulted in a variety of solar water heater designs that work effectively, reliably, and economically. The technology is available today and is one of the best, most secure long-term investments a homeowner can make. Numerous solar water heater systems have now been tested and certified by the independent Solar Rating and Certification Organization (SRCC). The Florida Solar Energy Center (FSEC) also has a testing and certification program for solar collectors. All solar water heater collectors that are manufactured or sold in Florida must be certified by the FSEC.[11]

Regenerating the Solar Hot Water Industry

Lessons learned over the past fifty years can help to regenerate and then stabilize the solar water heating industry. Arthur Shavit, a professor of mechanical engineering at Israel's foremost technical university, the Technion, has identified four conditions which helped to establish solar water heating in Israel:

1. Solar water heating must be cheaper than the alternatives;
2. People must know about this option;
3. Government building codes must require the use of solar; and
4. The equipment must be readily available."[14]

Further actions that could fundamentally benefit the industry:

- Any tax credits for solar collectors should be performance-based and available only for equipment certified by an entity such as the FSEC or SRCC.
- Low-interest loans should be available to the public for the purchase and installation of solar systems.
- The number of qualified installers must be greatly expanded, and the public made aware of whom these installers are.
- Property taxes and sales taxes should be eliminated for renewable energy equipment.
- Electric utilities should be given incentives to invest in demand-side management and renewable energy sources, and specifically, to support the installation of solar water heaters.
- Federal and state governments, real estate agents, developers, and home builders associations should become educated supporters of solar water heating
- Installers need to pay attention to the aesthetics of their installations. The appearance of solar systems on roofs and in other places influences their appeal to the general public, as well as the resale value of the homes on which they are installed.

Few of these conditions presently exist in Kentucky, although a low-interest financing program has recently been established through a partnership between the Mountain Association for Community Economic Development and the Kentucky Solar

Figure 6.3: A solar collector on the home of Steve and Patti Boyce in Berea, Kentucky, *Andy McDonald*

Solar Water Heater Cuts Energy Bills in Berea Home

Long-time Berea residents Steve and Patti Boyce decided that 2003 would be the year to make some energy-saving home improvements, and their investments have already begun to pay off. In the year that followed, they saw their electric bills drop by an average of 44 percent. Their home improvements included the installation of a solar water heater, energy efficient appliances, and greater reliance on their wood stove. Their first step was to convert nearly all of their lighting to compact fluorescent bulbs, which use a quarter of the energy of standard incandescent bulbs (while having much longer life-spans).

The Boyce's solar water heater utilizes a 4'x10' solar collector mounted on their roof. The collector uses a propylene glycol solution to transfer the sun's energy to the home's electric water heater via a heat exchanger. The electric water heater, heat exchanger, pumps and other equipment are located in the laundry room, which is below the collector panel.

Figure 6.4: Steve Boyce on his roof with his solar water heater collector, *Andy McDonald*

The solar water heater was installed in October 2003, along with a new 50 gallon electric water heater. The lower element of the electric water heater was disconnected while the upper element remains plugged in. In this arrangement the solar collector provides supplemental heating to the electric water heater, reducing its energy consumption while ensuring a continuous supply of hot water, regardless of the weather conditions. A switch enables residents to turn off the electric element during sunny weather when the solar collector can provide sufficient energy to maintain hot water in the water tank.

Table 6.3: A Comparison of Electricity Use Before and After Installation of Solar Water Heater and Home Energy Efficiency Improvements

Service Period 2002 - 2003	KWH	Service Period 2003 - 2004	KWH	% Change after energy improvements
Nov. 2002	811	Nov. 2003	590	- 27%
Dec. 2002	775	Dec. 2003	854	+10%
Jan. 2003	4005	Jan. 2004	1853	- 54%
Feb. 2003	3078	Feb. 2004	1406	- 54%
Mar. 2003	2389	Mar. 2004	770	- 68%
April 2003	1112	April 2004	978	- 12%
May 2003	843	May 2004	760	- 10%
June 2003	1300	June 2004	366	- 72%
July 2003	427	July 2004	317	- 26%
Aug. 2003	379	Aug. 2004	443	+ 17%
Sept. 2003	478	Sept. 2004	310	- 35%
Oct. 2003	732	Oct. 2004	450	- 39%
Total	**16,329 kWh**		**9,097 kWh**	**- 44%**

Amount Saved on utility bills: $506
Electricity rate $0.07/kWh

Steve and Patti have been very satisfied with the system and have not experienced any shortage of hot water. They noted that over the Christmas holiday they had seven guests visiting for a week and there was enough hot water for everyone's needs, although people did need to take shorter showers.

The Boyce's house is located on a wooded hillside in Madison County. At first glance one would not expect this to be a good site for an active solar system like a water heater, because the house is surrounded by trees. However, a site analysis determined that one spot on the roof had access to enough open sky for the system to work well. They did remove one tree in the front yard which would have shaded the solar collector panel. The system was installed by Joshua Bills for a total cost of $3,500.

To date there have been no maintenance problems with the solar water heater. The Boyce's are considering
expanding the system to provide hot water for radiant

Partnership.[15] These and other organizations are working to address the barriers to solar energy use in Kentucky.

End Notes

1. Formula's for calculating annual cost for heating water adapted from Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003, pp.96-97.
2. "Energy Source Builder," #38, April 1995.
3. Source for pollutant data: The Cleaner and Greener Program Emissions Reduction Calculator, available on-line at: www.cleanerandgreener.org/emission_reductions.htm
4. B. Keisling, *The Homeowner's Handbook of Solar Water Heating Systems*, Rodale Press, Emmaus, PA, 1983, p. ix.
5. Daniel K. Reif, *Passive Solar Water Heaters*, Brick House Publishing Company, Andover, Massachusetts, 1983, p. 13; and Daniel J. Berman and John T. O'Connor, *Who Owns the Sun?*, Chelsea Green Publishing Co., White River Junction, Vermont, 1996, p.13.
6. Daniel J. Berman and John T. O'Connor, *Who Owns the Sun?*, Chelsea Green Publishing Co., White River Junction, Vermont, 1996, p.15.
7. Ibid, p.14.
8. Arthur Allen, "Prodigal Sun" in Mother Jones, March/April 2000. Available on-line at: www.motherjones.com/news/feature/2000/03/solar.html
9. Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003.
10. Energy Information Administration. Data available on-line at: www.eia.doe.gov/cneaf/solar.renewables/page/solar/solarphoto_tab.html
11. "Passive and Active Solar Domestic Hot Water Systems," North Carolina Solar Center, Fact Sheet No. SC122, Raleigh, NC, June 2002, p.1.
12. Source: www.sunearthinc.com/industry_links.htm
13. Ibid.
14. Berman and O'Connor, p.14.
15. Mountain Association for Community Economic Development, 433 Chestnut St., Berea, KY 40403. www.maced.org. Kentucky Solar Partnership, 50 Lair St., Mt. Vernon, KY 40456. www.kysolar.org

RESOURCES: Solar Water Heating

Publications

"The Casa Juliana Solar Water Heater," Andy McDonald and David Omick, Proyecto Fe y Esperanza, 1998. Technical plans for a batch solar water heater.

Consumer Guide to Solar Energy, S. Sklar & K. Sheinkopf, Bonus Books, Inc., Chicago, 1995.

"Heating Your Swimming Pool with Solar Energy," North Carolina Solar Center, Technical Paper no. SC122, North Carolina State University, Raleigh, North Carolina, June 2002. Available on-line at www.ncsc.ncsu.edu

The Homeowner's Handbook of Solar Water Heating Systems, B. Kiesling, Rodale Press, Emmaus, PA, 1983.

Home Power (magazine), see below for contact information.

"Passive and Active Solar Domestic Hot Water Systems," North Carolina Solar Center, Technical Paper no. SC122, North Carolina State University, Raleigh, North Carolina, June 2002. Available on-line at www.ncsc.ncsu.edu

"Solar Water Heaters," Bob Fairchild, Appalachia–Science in the Public Interest, Technical Paper 9, Mt. Vernon, Kentucky.

Solar Hot Water Systems, 1977 to Today: Lessons Learned (26th ed), Tom Lane, Energy Conservation Services of North Florida, Inc., Gainesville, Florida, 2003.

Solar Today (magazine), American Solar Energy Society (see below for contact information).

Solar Water Heating, Bob Ramlow & Benjamin Nusz, New Society Publishers, British Columbia, 2006.

"Space Heating with Active Solar Energy Systems," North Carolina Solar Center, Technical Paper no. SC120, North Carolina State University, Raleigh, North Carolina, June 2000. Available on-line at www.ncsc.ncsu.edu

Organizations

American Solar Energy Society
2400 Central Ave., Suite A
Boulder, Colorado 80301
(303)443-3130
www.ases.org

The American Solar Energy Society (ASES) is a national organization dedicated to advancing the use of solar energy for the benefit of U.S. citizens and the global environment. ASES promotes the widespread near- and long-term use of solar energy. Publishers of *Solar Today* magazine (www.solartoday.org).

Florida Solar Energy Center
1679 Clearlake Road
Cocoa, Florida 32922
(321) 638-1000
www.fsec.ucf.edu

The Florida Solar Energy Center researches and promotes energy efficiency and solar energy in Florida. Their site includes project descriptions, on-line research reports, software demonstrations, news and events.

Home Power Magazine
PO Box 520
Ashland, OR 97520
(800)707-6585
(541)512-0201 (outside the U.S.)
www.homepower.com

Home Power is "the hands-on journal of home-made power." Each issue offers in-depth, clearly-written, well-illustrated articles discussing the entire array of renewable energy technologies, educating and empowering their readers toward more sustainable lifestyles.

Midwest Renewable Energy Association
7558 Deer Road
Custer, WI 54423
(715)592-6595
www.the-mrea.org

The Midwest Renewable Energy Association offers workshops and training that cover a variety of topics related to renewable energy. Their annual Renewable Energy Fair, held each year on the summer solstice in Wisconsin, offers excellent educational and networking opportunities, and is billed as the largest RE Fair in the country.

National Renewable Energy Laboratory
www.nrel.gov

The National Renewable Energy Laboratory is the nation's leading center for renewable energy research. Their web site features publications, program and project descriptions, partnership opportunities, news and events.

North Carolina Solar Center at North Carolina State University
Box 7401
North Carolina State University
Raleigh, NC 27695-7401
(919)515-5666
www.ncsc.ncsu.edu

The North Carolina Solar Center serves as a clearinghouse for solar and other renewable energy programs, information, research, technical assistance, and training for the citizens of North Carolina and beyond. The Center offers numerous publications addressing passive and active solar energy. These documents can be downloaded for free from their web site (follow the link for "Information Resources"). They will also mail printed copies upon request.

Solar Energy Industries Association
805 15th Street, NW
Suite 510
Washington, DC 20005
(202) 682 - 0556
www.seia.org

The Solar Energy Industries Association (SEIA) is the national trade association of solar energy manufacturers, dealers, distributors, contractors, installers, architects, consultants, and marketers. They work to expand the use of solar technologies in the global marketplace. On their web site you can find out how to get involved as an individual or a solar business, keep up on the latest solar policy news, and find out about contractors and incentives for buying solar yourself.

Solar Energy International
PO Box 715
76 S. 2nd St.
Carbondale, CO 81623
Phone: (970)963-8855
www.solarenergy.org

Solar Energy International (SEI) offers hands-on workshops in solar, wind and water power and natural building technologies in eleven locations. SEI also offers internet-based online courses.

Chapter Seven
Components of Solar Water Heating Systems

Solar collectors, storage tanks, and anti-scald valves are components common to most solar domestic hot water systems. A variety of other components are required depending upon the specific system used. These include heat exchangers, expansion tanks, circulator pumps, differential controllers and sensors, and small solar electric panels. These components will be discussed in the pages that follow. Other components specific to individual systems will be discussed in Chapter Eight.

Solar Collectors

A solar collector can be as simple as a straight or spiral plastic pipe, placed on the ground and used to pre-heat water for a standard water heater. While this set-up works, it has its limitations. The pipe will cool off quickly at night and exposure to sunlight will degrade the plastic pipe in fairly short order. In Kentucky, the pipe would need to be drained in the winter to prevent it from freezing.

The amount of heat produced by solar collectors varies according to the specific collector model, the area of collector, and the local climate and site conditions. The Florida Solar Energy Center and SRCC certification systems rate collectors according to their efficiency and the amount of heat they provide per square foot of collector. This data is used for calculating the area of solar collectors needed for any given application, which also depends on the amount of hot water storage needed. The final section of this chapter describes how to estimate collector area and hot water storage capacity based on daily hot water demand.

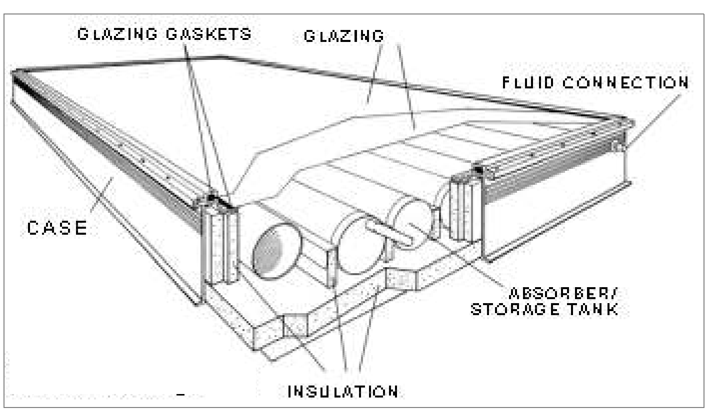

Figure 7.1: Cut-away of an integral collector storage (ICS) unit, *Back Woods Home Magazine, www.backwoodshome.com*[1]

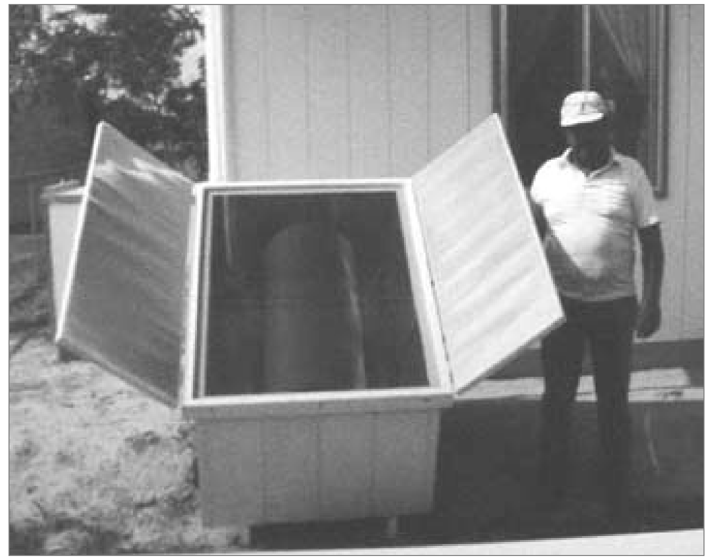

Figure 7.2: This batch solar water heater in South Texas provides year-round hot water, *David Omick*

Batch or ICS Collectors

In batch type solar water heaters (also known as integral collector storage (ICS) systems), the storage tank is built into the collector. The first commercial solar water heater, the "Climax" invented back in 1891, was of this type, as are the common solar shower bags used for camping. The solar water heater shown in Figure 7.2 is also a batch heater. It uses a recycled water heater tank inside of a glazed box. While batch collectors have the virtue of simplicity, they have no freeze protection and therefore are not suitable for year-round use in Kentucky, unless the water heater is built into a conditioned space. (See Chapter Eight for more information).

Flat Plate Collectors

The most common type of collectors used in areas that freeze in the winter are known as flat plate collectors (see Figure 7.3). These usually consist of an absorber plate made from copper pipe, thermally or mechanically attached to a tin or copper sheet blackened with paint or through an electrochemical process. Large copper pipe (3/4 to 1 ½ -inch diameter) header tubes run across the top and bottom of the absorber plate. Smaller copper pipes (½ inch diameter) run between the header tubes every three to six inches. The heating fluid (water or antifreeze) enters the collector at the bottom header pipe, which supplies

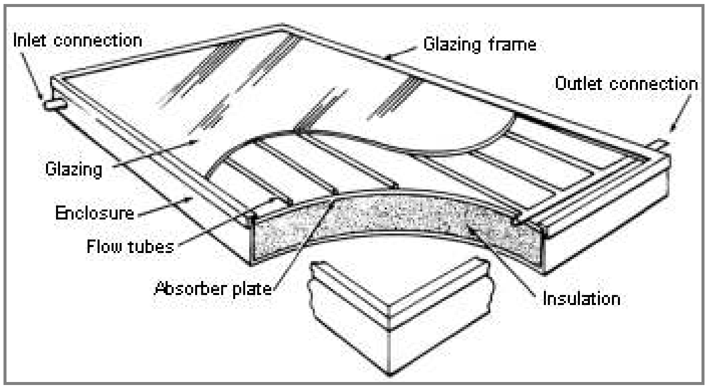

Figure 7.3: Cut-away view of a flat plate solar collector
Backwoods Home Magazine, www.backwoodshome.com[2]

the smaller vertical pipes. The fluid is heated as it flows to the top header pipe. The heated fluid then exits the collector out of the top header pipe. The absorber plate is placed in an insulated box shaped like a large shallow pan, with glass or plastic glazing placed over the exposed side of the box (facing the sun). The glazing allows the box and absorber plate to warm like a greenhouse, while slowing the rate of heat loss back to the sky. Collector sizes vary, ranging from 3 feet by 7 feet to 4 feet by 10 feet, with a depth of four to six inches. Manufactured collectors have boxes that are usually made from stainless steel or aluminum, while most homebuilt units are made from plywood. New flat plate collectors can operate for over 50 years, and they typically carry a ten-year warranty.

Homebuilt flat plate collectors can be durable when properly glued, screwed and sealed against weather. There are many plans available for making your own flat plate collectors. One, found in *The Homeowner's Handbook of Solar Water Heating Systems*[3], utilizes ready-made absorber plates around which a box is built. Absorber plates can be purchased at less than half the cost of complete manufactured collectors. One vendor's wholesale price for absorber plates ranges from $150 to $250, while their complete collectors wholesale for $400 to $600.[4] Many inexpensive used collectors are available that still have 20 or more years of useful life remaining. The experience of building one's own collector may help one appreciate how inexpensive used collectors really are.

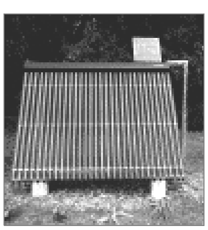

Figure 7.4: Evacuated tube collector, Thermomax. Inc.

Evacuated Tube Collectors

Evacuated tube collectors are more efficient than flat plate collectors and can heat water to temperatures between 170°F and 350°F. This feature makes them attractive for industrial applications, but they can also be used for domestic water heating when higher performance is desired in cloudy and cooler weather. They consist of rows of parallel transparent glass tubes, each containing an absorber plate covered with a selective coating to enhance heat absorption. A vacuum inside the tube minimizes heat loss, helping the collectors to achieve high temperatures. The absorber plate in each evacuated tube heats a fluid which transmits this energy to the water supply via a heat exchanger.

Figure 7.5: Evacuated tube collector doubles as an awning. *Thermomax, Inc.*

Evacuated tube collectors are more fragile and more expensive than flat plate collectors and are typically only recommended when water temperatures from 180°F to 211°F are required. If temperatures above 212°F are needed, concentrating solar collectors are recommended. Flat plate collectors are usually the best choice for heating water from 120°F to 140°F, which is the temperature range for normal domestic hot water needs.[5] However, evacuated tube collectors can be a good option for use with solar space heating systems, since they can generate more heat during winter's cloudy weather.

Storage Tanks

Solar-heated hot water is typically stored in standard 60, 80, or 120-gallon hot water tanks. Even for systems designed for residential space heating, it is unnecessary to get a custom- made storage tank unless more than 480 gallons of storage is needed. In some situations a home's existing hot water tank can be used to store solar-heated water. An existing water tank may be suitable if it is the proper size, relatively new, and among the most-efficient models. Otherwise, a new water storage tank is probably recommended. Even if an existing tank is used, an additional hot water storage tank may be included in a solar water heating system.

Standard 60 to 120-gallon hot water tanks with integral (built-in) heat exchangers are available and can be preferable for systems requiring a heat exchanger. A heat exchanger is a device that transfers heat from one fluid to another- in this case from the solar heated fluid to the domestic hot water in the tank. Some integral heat exchangers are removable, while others are not. External heat exchangers are commonly used with conventional hot water tanks that do not have integral heat exchangers.

The choice between these three types of heat exchangers is often based on the expected lifetime of the tank. Hot water tanks can last just a few years or as many as thirty years, depending on water quality and maintenance practices. Ask a local plumber or salesman at a wholesale plumbing warehouse what the expected lifetime is in your area for standard glass-lined electric and gas water heaters. If tanks don't last long in your

Figure 7.6: A conventional electric water heater tank uses an external heat exchanger in the solar water heating system at the ASPI office in Mt. Vernon, Kentucky, *Andy McDonald*

area, you may opt for an external heat exchanger that can continue to function long after the water tank has been replaced. Tom Lane, a long-time solar installer in Florida, recommends using either an external or removable heat exchanger if the expected tank life is less than 10 to 12 years.[6] If average tank life expectancy exceeds 15 years, choose an integral heat exchanger (either removable or non-removable.)

Hard water may also affect choice of tank. As water is heated, its capacity to scale the insides of pipes, and especially heat exchangers, increases. In Kentucky, where rocks and minerals such as limestone, gypsum, fluorspar, magnesium, and pyrite are common, well water is often high in calcium content, and therefore considered "hard". If you find that your water leaves a hard film on surfaces or if you find it hard for soap to lather, you probably have hard water. In this case we recommend against using direct active systems (in which the heated water is pumped through the system) and advise care in choosing a heat exchanger for an indirect system (see Chapter Eight for more information on system types). A good tank choice for areas with hard water would be the Rheem/Rudd tank with wrap-around heat exchanger. This heat exchanger is the only type available that does not come in contact with the water. It consists of copper pipe wrapped around and in contact with the outside of the storage tank, but underneath the tank's insulation.[7]

Solar hot water tanks, unless already manufactured with R-17 or greater insulation, should be wrapped to achieve a minimum of R-17 insulation. If the tank is placed on a concrete slab, it should rest on a pad of two-inch rigid polystyrene insulation or wood strips to keep the tank off the floor. If insulation is added to the tank and it is stored in a conditioned space, place a plastic water heater drip pan under the tank to catch any condensation that might form.

Heat Exchangers

In an indirect solar water heating system, the fluid used to collect heat (propylene glycol or distilled water) is separate from the fluid that distributes it (e. g. household water). In virtually all systems of this kind a liquid-to-liquid heat exchanger is needed, to transfer the heat gathered in the solar collector to the household water. The radiator in a car is an example of a liquid-to-air heat exchanger, in which the heat from the engine is transferred to the air in order to cool the engine. Direct solar water heating systems (such as the batch, thermosiphon, and open loop active systems) do not incorporate heat exchangers because the household water is heated directly in the solar collector. Each of these solar water heating systems will be discussed in detail in Chapter Eight.

Heat exchangers used in domestic solar water heating are made from copper or stainless steel. The efficiency of a heat exchanger is increased with:

- Highly conductive materials that readily transmit heat
- High surface-to-volume ratio
- High difference in temperatures between the two fluids
- Sufficient flow rate
- Sufficient heat capacity of the fluids (specific heat)

The Uniform Solar Energy Code (USEC) requires double-wall heat exchangers in solar water heating systems when a fluid that is not potable is used for the collector loop. This provides two walls of separation between the two fluids, with the space between the two walls vented to the outside of the exchanger. Thus, if one wall fails, there will be a visible leak in the system before any potential mixing of fluids can occur. Well-made double wall heat exchangers reduce system efficiency by less than five percent. A conductive paste is often used in the space between the two walls to increase efficiency.[8]

During the solar water heating boom of the 1970's, many systems were installed using toxic ethylene glycol solutions (traditional car anti-freeze) in the collector loop. The double-wall heat exchanger made it impossible for the toxic solution to mix with the potable domestic hot water supply. Today, virtually all indirect systems use non-toxic propylene glycol solutions. However, double wall heat exchangers are still almost universally required in case someone should mistakenly add car anti-freeze to a system. Single wall heat exchangers are more efficient and are used with radiant floor home heating systems, hot tubs, and other non-potable applications.

Heat exchangers that are incorporated into the storage tank are ideal since they eliminate the need for the water side of the heat exchanger to be pumped through the exchanger. Some external heat exchangers can be mounted on the side of the storage tank to allow natural thermosiphoning to circulate water from the storage tank through the exchanger. However, on sunny days these systems will only collect 80 percent as much energy as a tank with an internal heat exchanger, and only 65 percent as much energy as a double-pumped heat exchanger. Double-pumped systems pump fluid from the collector through one side of the heat exchanger, and household water through the other side. While these systems are more efficient, they cost more to install, require more components that could potentially fail, and require more energy to operate the second pump.

A tank with an internal heat exchanger may offer the best balance of cost, complexity, and efficiency. They are more expensive than external thermosiphon heat exchangers, however, and only a limited number of manufacturers offer these types of tanks. In some internal heat exchanger designs, the heat exchanger can be removed from the tank and replaced. In other models it is welded to the tank and cannot be removed. For areas with hard water, one choice exists that minimizes the potential scaling that can occur with both internal and external heat exchangers. This is the Rheem/Ruud wrap around (integral) heat exchanger, which consists of a copper pipe wrapped around and in contact with the outside of the storage tank, but underneath the tank's insulation. Unfortunately, this design is currently available only in an 80-gallon tank with an electric element backup.

Anti-Freeze Recommendations

The propylene glycol used in the solar collector needs to be mixed in solution with distilled water (see below for more information). In Kentucky, with average record-low temperatures around -20°F, a solution of 40 to 50 percent propylene glycol is recommended. To find out the specific amount of propylene glycol to use, follow the glycol manufacturers' recommendations for fluid concentrations, based on the lowest temperatures the solar collectors will be exposed to. Local freeze records can be found on-line at www.NOAA.gov. WARNING: Make absolutely sure not to use standard anti-freeze, toxic ethylene glycol.

Notes on Heat Exchanger Fluids[9]

1. The least expensive type of propylene glycol is sold at auto supply stores under the brand names "Prestone II Lotox" and "Sierra." These are sold as non-toxic automobile anti-freeze, but they work well in solar collectors. They should last for 10 years as long as the fluid does not suffer stagnation in the collectors (when the fluid does not flow at high collector temperatures due to a problem in the system. Stagnation leads to overheating, causing this type of anti-freeze to degrade, requiring replacement).
2. Many solar collector and system manufacturers recommend DOWFROST or DOWFROST HD "inhibited propylene-based heat transfer fluid (HTF)". An Engineering and Operating Guide on DOWFROST HD is available by calling 800-447-4369.
3. Camco manufacturing (800-334-2004 www.camco.com) makes an anti-freeze for solar systems called Premium BAN FROST 2000.
4. To prepare the proper propylene glycol solution, mix the glycol with distilled reverse osmosis or de-ionized water if the pH of the local water is below 7.5 and / or has excessive metals or chlorine content.
5. The pH of heat exchange fluid should be checked every two to three years. If the pH of the solution is less than 8 it was likely subjected to excessively high temperatures due to stagnation and should be replaced. The original problem allowing the stagnation to occur should also be resolved. If it was due to a power outage perhaps an uninterruptible power supply is in order. PH testers and pH litmus paper are available from Misco Products (1-800-358-1100). Do not use glycol solutions stronger than 50 percent. They will be too viscous for proper pump operation, especially solar-powered DC pumps.

Anti-Scald Valve

Solar hot water systems with flat plate collectors can get as hot as 190° F during periods when no hot water is being drawn from the system (especially when the collector is exposed to many consecutive sunny days). Anti-scald valves assure safe temperatures at plumbing fixtures by mixing cold water into the hot water as it heads from the storage tank to the fixture. Only passive batch-type systems are safe without anti-scald valves. Mixing and tempering valves should NOT be confused with anti-scald valves. The output temperature of mixing and tempering valves can vary with changes in water pressure, whereas anti-scald valves can set the output temperature. Honeywell Sparco and Amtrol Inc. manufacture anti-scald valves.

Circulator Pumps

Active systems use one or more pumps to circulate heat transfer fluids between the collector and storage tank/heat exchanger, and/or to pump water from the tank through the heat exchanger. AC powered pumps are operated by standard household electricity. DC powered pumps use appropriately sized photovoltaic (PV) solar electric panels to operate. Regardless of the power source the most common pumps for solar hot water systems are the centrifugal type. These pumps have rotating blades that spin and discharge the fluid from the pump by means of centrifugal force.

Pumps should always be mounted on the supply side to the collector in an orientation that allows air to pass through freely. Thus, the intake and output are lined up vertically with the output facing up. Grundfos, Taco, and March manufacture AC pumps for solar hot water systems and March, Hartell, and El Sid manufacture DC pumps.

Direct systems should use stainless steel or brass pumps, since air commonly gets into the system, which can corrode cast iron pumps. Indirect systems commonly use cast iron pumps since they are not constantly exposed to oxygen in the system. See Chapter Eight for descriptions of direct and indirect systems.

Whole solar hot water system kits are available that often specify the pump(s) used. However, if you were to size the pump(s) yourself, you would need to calculate the total system head the pump needs to overcome at the flow rates necessary to transfer heat efficiently. Once this information is solved for, pump curves are available from manufacturers to determine the appropriate pump(s) needed. Explaining these calculations is beyond the scope of this Guide, yet they are critical when designing systems that use pump(s) powered with solar photovoltaics. If you are installing a system yourself, you may want to stick with pre-designed kits or defer pump sizing work to a professional installer. Otherwise, friction loss tables are available in plumbing reference books.

Differential Controllers and Sensors

Active systems that rely on AC powered pumps require a differential controller and sensors in order to know when the collectors are hot enough to warrant circulating the fluids, which transfers the heat from the collectors to the storage tank. The controller turns the pumps on and off based on the temperatures it senses on the output side of the collector and at the bottom of the storage tank. When the fluid in the collector is sufficiently hotter than the water in the tank, the pumps turn on, circulating the fluids and transferring heat from the collector to the water tank. When night falls and the temperature in the collector drops, the pumps turn off, preserving the heat within the water tank.

The collector sensor is clamped with a stainless steel clamp to the collector output pipe within two inches of the collector. If there is more than one collector the sensor is often clamped to the header between the collectors. The storage tank sensor is slipped under the insulation, in contact with the metal wall of the coldest storage tank in the system. The sensors change resistance as the temperature changes. The controller compares the resistance of the two sensors and turns on the pumps when a temperature differential threshold is met.

Small Photovoltaic (PV) Solar Electric Panels

Active systems that rely on DC powered pumps utilize a solar electric PV panel for power as well as for timing their operation. This occurs via the synchronous action sunlight has on the solar heat collector and the solar electric panel. As sunlight increases on the collector, the collector gets hotter and the PV panel generates more electricity, turning the pump faster and circulating more fluid. The PV panel should be placed in the same location and orientation as the solar heat collector.

It is important to match the PV module with the DC pump performance curve in order to assure that adequate flow (not too much and not too little) occurs in all circumstances- morning start up, overcast, afternoon waning, etc. PV module and DC pump matching is beyond the scope of this manual. Manufacturers have recently been reducing the variety of PV modules in this size range (5-30 watts) as larger PV systems are becoming commonplace. Meanwhile there has been an influx of different DC pumps available for solar hot water systems.

For further information on solar module and pump matching refer to *Solar Hot Water Systems, 1977 to Today: Lessons Learned.*[10] You can also ask the DC pump manufacturer what PV module is recommended with their pump given the collector area and the total system head your installation requires. You may want to defer these calculations to a professional installer.

Estimating Collector Size and Storage Tank Capacity for Residential Systems

For residential solar water heating systems that require freeze protection, flat plate solar collectors and separate hot water storage tanks would typically be recommended. The area of collector panels required depends on the amount of hot water storage needed. While numerous solar water heating systems and collector models are available, a general rule-of-thumb for Kentucky is that you need 1.0 square foot of collector for every 1.5 gallons of hot water storage.[11] While the actual collector area required will depend on

Table 7.1: Estimated Storage Tank Size and Solar Collector Area Based On Average Daily Hot Water Use		
Daily Hot Water Use	**Tank Size**	**Collector Area**
0-30 gallons	30 gallons	20 square feet
0- 40 gallons	40 gallons	27 square feet
41-60 gallons	60 gallons	40 square feet
61- 80 gallons	80 gallons*	54 square feet
81- 120 gallons	120 gallons	80 square feet
* If you use 61- 80 gallons per day, a 120 gallon tank may be more economical.		

Table 7.2: Flat Plate Collectors are sold in the following sizes	
Dimensions	**Area**
4 feet x10 feet	40 square feet
4 feet x8 feet	32 square feet
4 feet x7 feet	28 square feet
4 feet x 6.5 feet	26 square feet
3 feet x8 feet	24 square feet
3 feet x7 feet	21 square feet

several factors, including the specific collector model and the available sunlight where the collector will be mounted, this rule-of-thumb can give you a general idea of how large your solar collectors need to be.

The hot water storage tank should be large enough to hold the amount of hot water used in a typical day, so figure out how much hot water your family uses each day. Table 7.1 shows what size tank you'll need based on your hot water use. (The average American family uses 20 gallons of hot water per day per person for the first two people, and 15 gallons per day for each additional person. Thus, a typical family of four will need 70 gallons of hot water per day.)[12] Note that if you need more than 60 gallons per day, a 120-gallon tank may be more economical than an 80-gallon tank.

Once you know the size of the storage tank, divide that by 1.5 to estimate the area of the collector panels. Bear in mind that the collector area required is based on the size of the storage tank, not actual daily usage. This is because the collector will need to heat all the water in the storage tank whether it is used or not, and the storage tank should be at least slightly larger than household demand (because storage tanks are only made in limited sizes, i.e. 30-40-60-80-120 gallons). With this ballpark figure in mind, you can estimate the cost of equipment needed for your system. A solar equipment vendor or installer can then help you integrate the other variables that influence collector and tank size, enabling you to purchase the system that's appropriate for your circumstances.

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End Notes

1. M. Hackleman, "Seven Solar Water Heating System Designs," Back Woods Home Magazine, # 65. Article available on-line at www.backwoodshome.com/articles/hackleman65.html
2. Ibid.
3. B. Keisling, *The Homeowner's Handbook of Solar Water Heating Systems*, Rodale Press, Emmaus, PA, 1983, p.116.
4. Prices according to Alternative Energy Technologies, Jacksonville, Florida, www.aetsolar.com, September 2004.
5. Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003, p. 69.
6. Ibid, p.8.
7. Rheem/Ruud 80 gallon heat exchange tanks are available nationwide. Rheem/Ruud Manufacturing Corporation, 5780 Peachtree-Dunwoody Road NE, Atlanta, Georgia 30342, Tel: 800-621-5622.
8. Chuck Marken, "Heat Exchangers for Solar Water Heating," Home Power Magazine #92, p. 69.
9. Tom Lane, pp.33 and 51.
10. Ibid, pp. 39-45.
11. Ken Olson, "Solar Hot Water: A Primer," 2001. Available on-line at www.azsolarcenter.com/technology/solarh2o.html
12. Tom Lane, p.97.

Figure 7.7: Solar water heater at Berea College.
Andy McDonald

Chapter Eight
Types of Solar Water Heating Systems

Solar water heating systems are categorized as *passive* or *active* and *direct* or *indirect.* Passive systems have no electrical pumps. They rely upon convection to circulate hot water through the collector and storage tank. In passive systems, hot water is either stored in the collector itself (batch systems) or is transferred to a storage tank located above the collectors by means of a thermosiphon. In a thermosiphon, the natural tendency of hot water to rise draws hot water out of the collector into an elevated storage tank, while cold water in the tank sinks down into the bottom of the collector.

Active systems use electrically driven pumps to circulate water or another heat absorbing fluid, and sometimes use electrically operated valves for freeze protection. The advantage provided by most active systems is that they are specifically designed for year-round operation in areas that freeze.

Be aware that the exposed glass face of solar collectors makes them susceptible to freezing on clear nights when temperatures are in the mid to upper 30s, due to radiation to the clear night sky. Freeze protection strategies for solar water heating systems need to account for this factor.

Solar water heating systems are also classified as *direct* or *indirect*. Direct systems use the sun's energy to heat household water directly. The water that flows through the solar collector also flows to the various hot water taps and faucets in the house. Indirect systems heat a separate loop of fluid (typically a propylene glycol solution or distilled water) and transfer the fluid's heat to the household water supply via a heat exchanger.

The terms *open* and *closed* are also often used to characterize solar water heating systems. Open systems are typically direct systems in which the fluid being heated (water) flows through the collectors. Batch systems are open systems. In closed systems, the heat absorbing fluid is contained in a closed loop, and circulates continuously between the collector and a heat exchanger. Table 8.1 (following page) summarizes the different types of solar water heating systems.

Figure 8.1: The Progressive Tube integral collector storage solar water heater
www.tctsolar.com

Batch-Type Systems

Batch systems are the simplest and historically the oldest type of solar water-heating system. In batch-type systems, also referred to as integral collector storage (ICS) or "bread box" systems, household water is heated directly by the sun and the storage tank serves as the solar collector. Batch water heaters are almost always passive systems in which hot water is delivered from the solar heated tank to a backup tank or the point of use by the water pressure in the house.

Among all the types of solar water heaters, batch systems are the type most commonly built from scratch by home-owners. They are the least expensive type, especially when home-built, have few parts, and are often made with recycled materials. Batch systems typically consist of one or more tanks painted black and encased in an insulated box, with a glazed covering over the side facing the sun. Optional features include an insulated cover that can be placed over the glazed surface at night to reduce heat loss, and reflectors to

Figure 8.2: This home in Louisville has a batch solar water heater located inside the living space, which provides freeze protection and allows for year-round use. The water heater is located behind the high windows on the left.
Andy McDonald

concentrate additional sunlight onto the water tank. These systems are often mounted on the ground or attached to the side of a residence due to the weight of the tanks. If roof mounted, the roof needs to be structurally capable of handling the full weight of the tank(s). For detailed plans on building your own batch solar water heater, see the Resources list at the end of Chapter Six.

Having but a few simple parts, batch solar water heaters are highly dependable in regions that do not freeze. In Kentucky, with wintertime lows that often dip below 0°F, batch systems must be drained during the freezing season or significant measures taken to prevent the water in the tank and associated plumbing from freezing. A system that is only used for six to nine months out of the year (known as a "three season solar water heater") can still have a significant impact on annual energy costs, especially since the installation costs for these systems can be much lower than those of other solar water heater types.

A number of steps can be taken to combat freezing. Be aware, however, that just one freeze can damage quite a bit of hardware (not to mention the wet icy mess on the ground or, even worse, in the attic). One novel solution is to place the batch system in an attached solar greenhouse. Although the added layers of glass in a greenhouse will reduce water-heating capacity slightly, the added freeze protection can

Table 8.1: Classification of Solar Water Heating Systems and Primary Characteristics

	DIRECT Water heated in the collector flows directly to hot water taps	**INDIRECT** Heat transfer fluid is separate from the home water supply, requiring a heat exchanger.
PASSIVE Relies on natural convection to circulate hot water or heat transfer fluid. No electric pumps.	**Batch, Bread Box, or Integral Collector Storage (ICS) Systems** Solar collector and storage tank are combined. These systems are less expensive and simple, but allow greater heat loss at night and do not provide adequate freeze protection. The most common home-made solar water heater type. **Thermosiphon (Direct) Systems** Uses solar collector panels and a storage tank. Hot water circulates from collector to tank via natural convection. Tank must be elevated at least 18" above collector. Not suitable for areas that freeze* or that have hard water. (*Can be modified with pumps, making it a direct (open) system, to provide freeze protection in areas with very limited freezes.)	**Thermosiphon (Indirect, with freeze protection) Systems** Uses solar collector panels and storage tank. Antifreeze fluid is circulated in collector panels and heat is transferred to water storage tank via a heat exchanger. Tank must be elevated at least 18" above collector. Suitable for areas that freeze. However, efficiency is low.
ACTIVE Uses electric pumps to circulate heat absorbing fluid.	**Draindown Systems** Water is pumped between collector panel and hot water storage tank. Freeze protection provided by an electric draindown valve with temperature sensors that drains water from collector and exposed plumbing before freezing temperatures are reached. Water empties into house drain. System automatically refills with water when temperature rises above freezing. Offers freeze protection. **Direct (Open Loop) Systems** Pumps circulate heated water between collector panels and storage tank. System has very limited freeze protection. Can be set up to offer minimal freeze protection or used for three seasons and shut down in winter. Not suitable with hard water.	**Pressurized Glycol Antifreeze Systems** Antifreeze fluid is circulated through solar collector panels and transferred to water storage tank via a heat exchanger. Offers freeze protection. **Drainback Systems** Distilled water or antifreeze circulates between collector panels and storage tank and is drained from system during freezes. Fluid in collector panel is separate from the home water supply and is saved in a holding tank when drained. System drains by gravity without the use of an electric drain valve. Requires heat exchanger to transfer heat to storage tank. Offers freeze protection.

extend use of the system into winter months. With an attached greenhouse, plumbing can be contained within the building's heated space. The home shown in Figure 8.2 has a home-made batch heater installed within the attic space of the house, which allows for year-round use and freeze protection.

In a well designed batch system the main component susceptible to freezing is the plumbing to and from the collector. These pipes need to be well-insulated (R-8 or higher). Running heat tape along these pipes can offer additional protection, but since power outages are not uncommon during freezing weather, heat tape is not a fail-safe solution.

One drawback of batch systems is that they can lose heat quickly at night or during cloudy conditions. An insulated cover placed over the glazing at night can help retain heat in the storage tank. Although a batch water heater that's drained in the winter cannot be used to heat water for space heating purposes, if the solar collector is wall-mounted, it is possible to blow hot collector air into the house during the cold season.

Manufactured batch units include the Servamatic™. Produced in the 1970s, many are still operational today. ProgressiveTube™ is a batch heater that's available on the market today (see Figure 8.1). Manufactured systems that are certified by the Solar Rating & Certification Corporation (SRCC) clearly state the temperature below which freeze damage can occur.

Thermosiphon Systems

Thermosiphon systems are usually passive (no electric pumps), direct systems that use flat plate collectors and rely on natural convection to move the heated water from the collector up into the storage tank (see Figure 8.3). These systems are reliable and relatively inexpensive but their installation requires careful planning to ensure that the house can structurally support the weight of the water tank(s).

Thermosiphon systems require the storage tank to be elevated above the collector plate by at least 18 inches to prevent a reverse thermosiphon from cooling off the tank at night. A reverse thermosiphon is driven by the cool night sky, which cools down the collector, pulling heated water from the tank and circulating it back through the collector, where it radiates its heat to the sky. By elevating the storage tank 18 inches above the collector, the reverse thermosiphon is prevented.

Sometimes it is not possible to elevate the tank 18 inches above the collector. In that case, ensure that the top of the water tank, at least, is above the collector. Then install a check valve (a valve which allows water to flow in one direction only) to prevent the reverse thermosiphon. (A check valve can be used even if the tank is optimally elevated to provide extra security against the reverse thermosiphon.) Avoid the standard pressure-type or swing check valves, which do not allow thermosiphon flow. Instead, use a spring-loaded inline check valve with a Teflon ball check. The check valve should be mounted vertically with the arrow pointing up, on the output side of the collector below the top of the storage tank. For standard spring type check valves, the spring should be removed in thermosiphon systems.

Heliotrope Thermal offers another check valve option, a low resistance solar check valve (SCV.75/.50) that can be mounted vertically or horizontally.[1] (Note: mechanical in-line check valves are notorious for losing their ability to seat properly when subjected to heated hard water, which is common in many Kentucky homes with well or spring water. If your home has hard water, we recommend an alternative that does not require a check valve on the hot output side of the collector).

Passive thermosiphon systems that directly heat household water are even more prone to freezing than batch solar water heaters. In areas that only have a few freezes each year, thermosiphon systems can be protected by a pump which re-circulates a small amount of heated water from the storage tank through the collector during those rare freezes. This is known as a re-circulation system and turns the passive thermosiphon system into a direct (open-loop) active

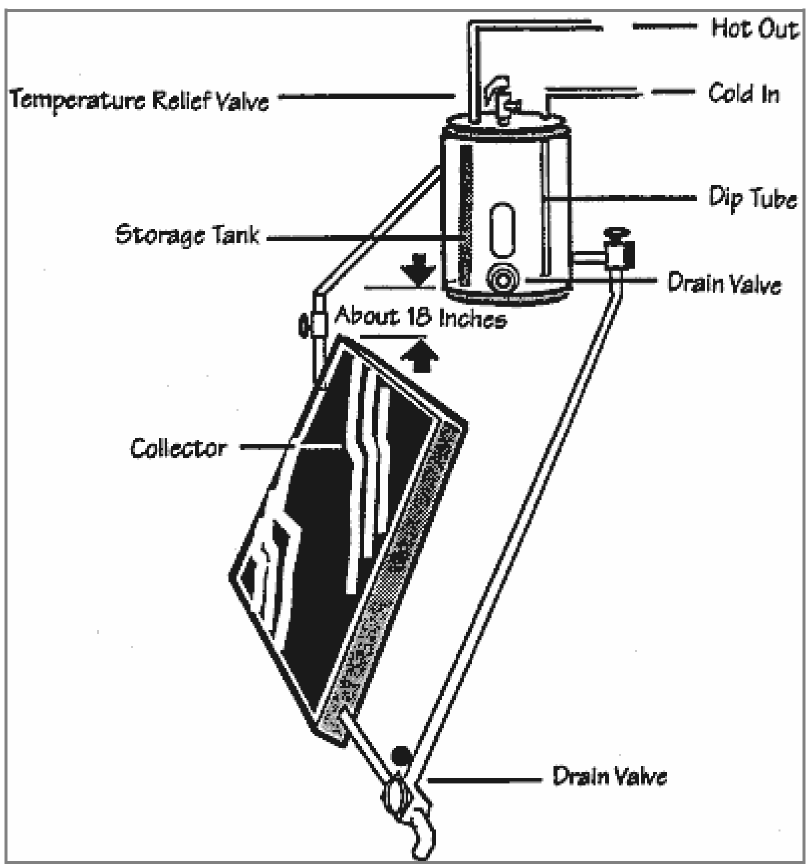

Figure 8.3: Thermosiphon Solar Water Heating System

type. If an AC pump is used, these systems would be at risk of freezing if power was lost during a freeze (because the re-circulating pump would not work). These systems also waste hot water that could otherwise be saved for domestic use.

Thermosiphon systems have also been successfully freeze-proofed using an indirect design. An antifreeze solution circulates between the collector plate and the storage tank, where the solution transfers its heat to the household water supply in a heat exchanger. In a passive system it is preferable to use an internal or integral heat exchange tank instead of a thermosiphon external heat exchanger (see Chapter Seven for more information on heat exchangers.) This arrangement produces only about 45 to 50 percent of the hot water a direct (open loop) active system produces.

Direct (Open Loop) Active Systems

Direct (Open Loop) Active Systems are similar to thermosiphon systems in that they are direct systems that use a solar collector separate from the storage tank. The difference with direct active systems is that they use an electric pump to circulate water from the storage tank to the collector, and back to the storage tank. These systems always require a check valve to prevent reverse thermosiphoning at night. Unlike thermosiphon systems, the check valve is now placed on the output side of the tank (the cold water pump side of the loop), instead of the output side of the collector, again with the flow (arrow) directed up. Remove the spring (or use a Heliotrope Thermal low resistance solar check) if a DC pump powered by a solar PV panel is used instead of an AC pump.

DC pumped systems rely on the varying amounts of sunshine on the PV panel to match the flow needed through the collector(s). AC pumped systems require a differential controller and temperature sensors to know when to turn the pump on and off (see Differential Controllers and Sensors in Chapter Ten for more information). Open Loop Active Systems are generally reserved for areas that receive on average less than one freeze per year. In freeze-prone areas, they are drained and shut down during the cold season.

Draindown Systems

A draindown system is a direct open loop active system which offers marginal freeze protection with a temperature controlled solenoid electric valve. The valve fills the collector loop with water for operation, then when freezing temperatures approach, the same valve opens to dump the water out onto the ground.

A draindown system has the high efficiency and merits of an open loop system with some additional protection against freezing. However, draindown systems have complex controlling systems and expensive parts. Since they are designed for areas with few light winter freezes, they may not be appropriate for Kentucky's climate.

Draindown systems have had freeze related problems, often the result of poor water quality. The solenoid valves and vacuum breakers can build up with scale which can keep them from seating properly. The solenoid and vacuum breakers need to be "exercised" or they can stick closed. To do this, install a timer on the power supply to the system, to cut electricity off at night. This will ensure that the solenoids and vacuum breakers will open at least once a day. The drawback of

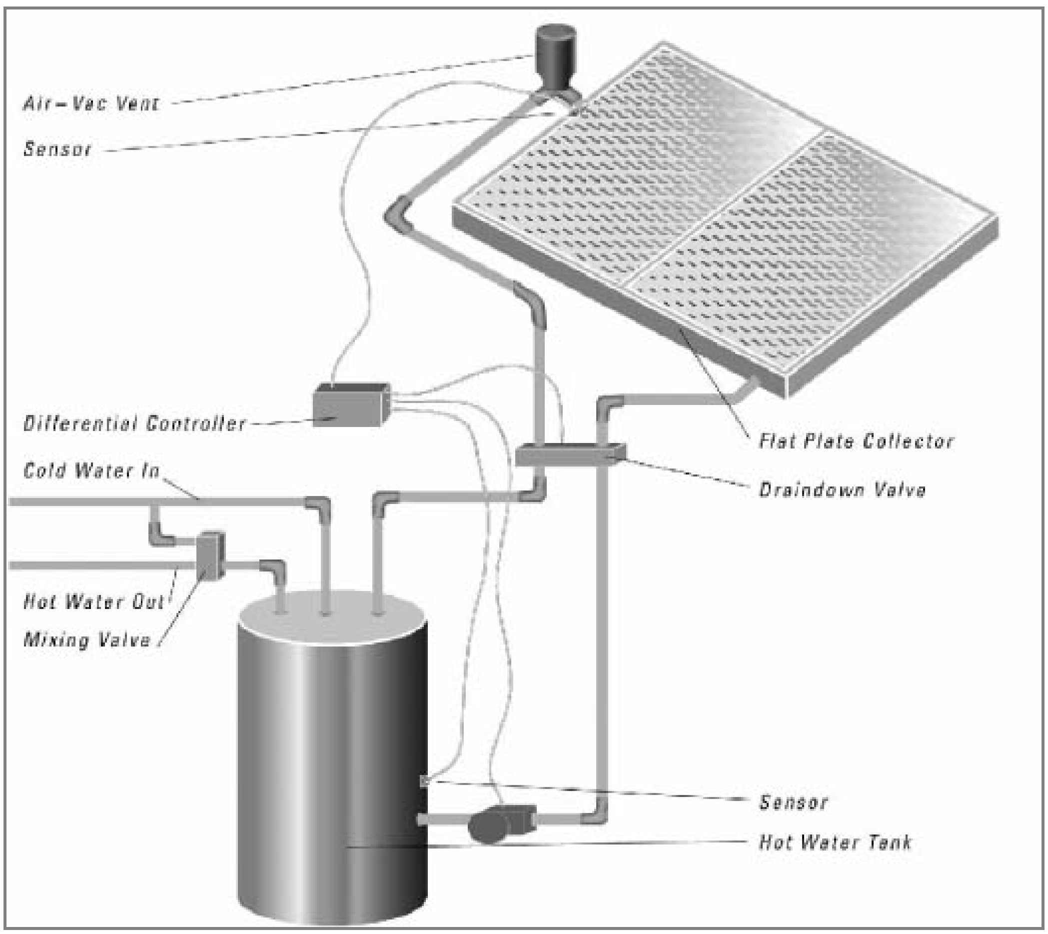

Figure 8.4: Draindown systems are direct active solar water heating systems.
North Carolina Solar Center

this strategy is that the collector loop will be drained once a day.

Indirect Active Systems

Glycol Antifreeze Systems

Glycol antifreeze systems are active, indirect systems with a heat exchanger (see Figure 8.5). Freeze resistant propylene glycol is circulated through the solar collector(s) and heat exchanger, while household water is circulated from the storage tank through the heat exchanger. The household water is heated inside the heat exchanger and then stored inside the tank until needed. (Note: if a storage tank is used which has a built-in heat exchanger, only the propylene glycol is circulated).

The antifreeze and water (if an external heat exchanger is used) are circulated using either AC pumps powered from the utility grid or DC pumps powered by a solar electric PV module. For AC pump systems, a controller allows power to the pump(s) only when the collector's temperature (measured at the header outlet) is sufficiently warmer than the temperature of the water in the bottom of the storage tank. The temperature sensors change resistance with changing temperatures. The sensor at the collector is clamped with stainless steel hose clamps to the collector outlet pipe within two inches of the collector. The collector sensor, as well as inlet and outlet piping are all insulated with elastomeric (Armaflex and Rubbatex) insulation. The sensor at the tank is slid between the metal tank surface and the tank's insulation near the lower thermostat (for an electric water heater).

Although solar electric DC pumping systems are more expensive than AC pumping systems with a controller, they offer many advantages:

Figure 8.6: This flat plate solar collector (left) is mounted on the ground outside a home in northern Kentucky. This glycol antifreeze system uses a small PV panel (center) to pump the antifreeze through the system, *John Robbins*

1. Solar DC pumps will keep operating even if power from the grid is lost. When pumps are dependent on the utility grid, if grid power is lost during a sunny period, the propylene glycol solution will sit stagnant in the collector and can start to overheat and degrade, losing its buffering qualities, which warrants replacement.
2. AC pumps require controllers and sensors. If the controller fails, stagnation can occur.
3. Controllers and sensors have more service problems and shorter life spans than solar PV modules.
4. Testing from TVA during the early 1980's found that an average glycol system using AC pumps and controllers consumed six to nine percent of the solar "harvest" to operate pumps and controls.

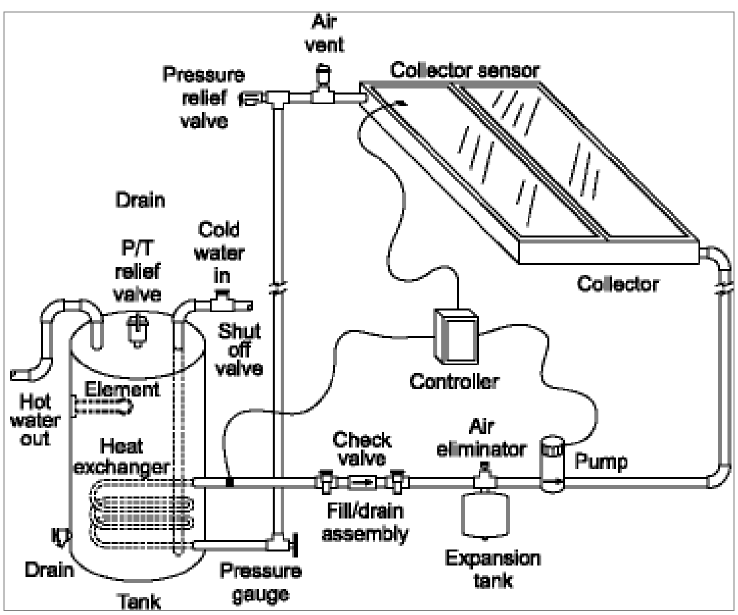

Figure 8.5: Pressurized glycol solar water heaters are active indirect systems.
Back Woods Home Magazine, www.backwoodshome.com

If AC pump(s) with a controller are used we recommend that a six-hour uninterruptible power supply be installed in case the power goes out on a sunny day. Other components that make up a glycol antifreeze system include a check valve to prevent nighttime heat loss. The valve should be a spring type with the spring removed (if using DC pumps), mounted vertically above the pump (arrow pointing up towards the collector). If AC pumps are used the spring does not need to be removed.

Closed loop systems often incorporate a "vacation bypass," which allows the water in the system to cool off at night. This may be desirable if no one will be using hot water for multiple days at a time. During cloudless weather, it is quite possible for the water in the storage tank to reach temperatures of 180° to 190° F. These temperatures can reduce the life of the storage tank if they are consistently reached. The "vacation bypass" consists of a valve placed in parallel to the line with the check valve. With the "vacation bypass" valve open, hot water flows out of the storage tank through the heat exchanger, and thermosiphons up to the collector, where its heat is released to the cool night sky.

Glycol antifreeze systems, like all pressurized indirect systems, require an expansion tank in order to handle the change in volume of the propylene glycol solution, which will expand and contract as it heats and cools each day. Without the expansion tank, the expanding glycol would blow the pressure relief valve, spraying glycol all over the place.

Drainback Systems

Drainback systems, like glycol systems, are active indirect systems with a heat exchanger, but in drainback systems the heat collection loop is unpressurized. Of all solar water heating systems, drainback and glycol systems offer the greatest freeze protection. Drainback systems typically use distilled water as the heat collection fluid, although regular water or a propylene glycol solution can also be used. The heat collection fluid is pumped between the solar collector panels and a heat exchanger, which transfers the heat to the water storage tank.

The unique feature of drainback systems is the reservoir incorporated in the heat collection loop (see Figure 8.7). For residential systems, this reservoir is usually a 10 to 15 gallon tank, and it must be located within the building envelope and protected from freezing temperatures (if water is used as the heat collection fluid). On sunny days, or whenever the temperature of the solar collector is sufficiently warmer than the temperature in the hot water storage tank, a pump lifts water out of the reservoir and circulates it through the heat collection loop.

When the collector cools during cloudy weather or as evening approaches, the pump in the heat collection loop shuts off and the collector fluid drains out of the collector back into the storage reservoir. The system drains by gravity, without the use of electric pumps, sensors, or controls, and is certain to drain whenever freezing temperatures approach. This provides guaranteed freeze protection. One can tell if the system is gaining heat and the collection loop pump is on by looking at a site glass on the side of the drainback reservoir. If the solution level in the site glass is low, then the system is gaining heat. If the solution level is high, the fluid has drained into the reservoir and the system is not gaining solar heat.

While the heat collection loop is closed in drainback systems, some reservoir tanks are vented to the atmosphere. In air-tight living spaces (such as super-insulated homes), un-vented (air-tight) reservoirs should be used to prevent excess humidity from building up in the living space.

The pump for the heat collection loop in a drainback system must be more powerful than the collector loop pump in a glycol system. This is because in a drainback system, the collector fluid has to be lifted up to the collector, whereas in a glycol system the pump only has to circulate the propylene glycol solution.

Due to this difference in size, it is not economically feasible to power the collection loop pump in a drainback system directly from a solar electric PV panel. Grid-powered AC pumps are required in these systems.

A drainback system also incorporates sloped piping to and from the collectors, which allows the solution to drain back to the reservoir. This gravity drain is the key to the system's freeze protection, and installers must take great care to ensure that all piping and the collectors drain properly.

Drainback systems have significant advantages in

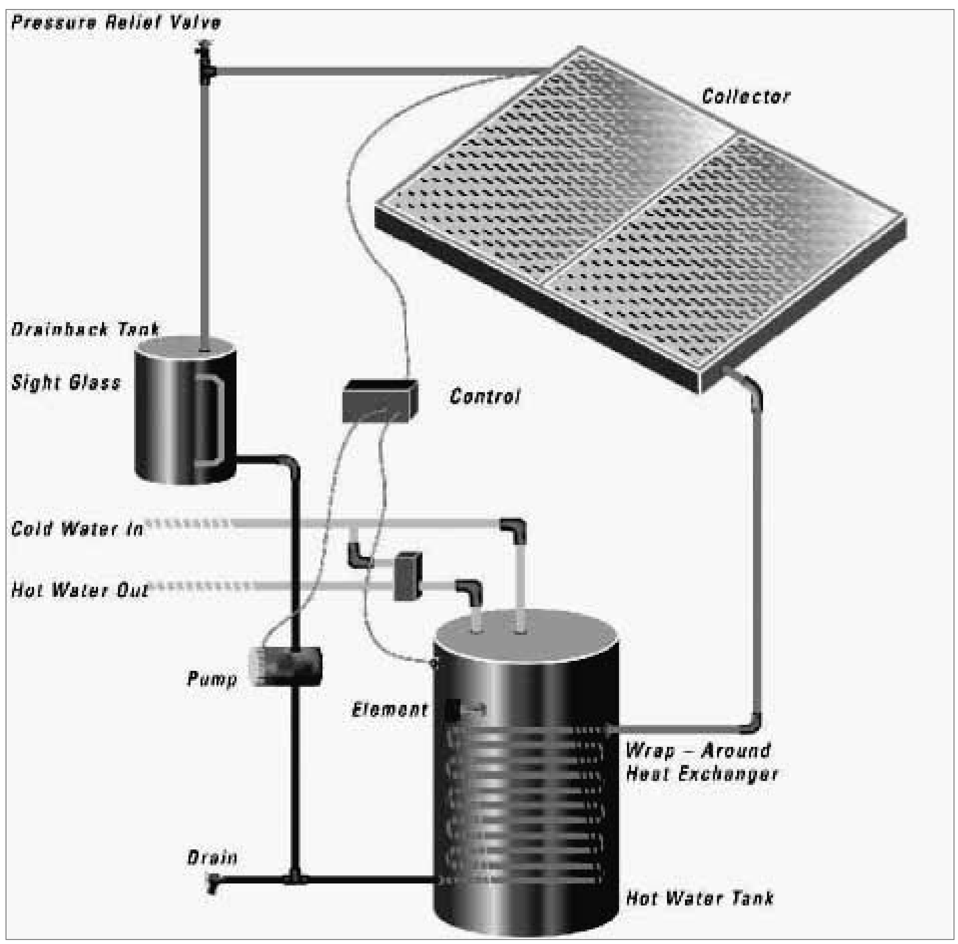

Figure 8.7: Drainback solar water heating system, *North Carolina Solar Center*

comparison with glycol antifreeze systems:

1. Fewer parts, even with the addition of a reservoir tank and sight glass. Drainback systems don't have the expansion tank, pressure gauge, collector loop temperature/pressure relief valve, collector loop check valve (and associated vacation bypass valve), nor an air vent (for purging air), all required for glycol antifreeze systems. With fewer parts, installation can be faster and easier, especially with designs which allow the reservoir to be placed on top of an electric storage/backup tank.
2. Drainback systems are not at risk of the collector solution stagnating in the collector on sunny days if the utility power goes out. Without power, the collector solution drains by gravity out of the collector to the reservoir. (This feature also provides additional freeze protection. If the power goes out during a freeze, the collector will drain automatically.)
3. Even though they require a more powerful collection loop pump, drainback systems can still be more efficient than glycol antifreeze systems. This is only true when pure water is used in the collection loop. Pure water has a greater heat transfer capacity than a glycol antifreeze solution.

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End Notes

1. Heliotrope Thermal, Inc., www.heliotropethermal.com

Chapter Nine
Water Conservation and Energy Efficiency

Hot water conservation is an important step to take before investing in a solar water heater. Learning how to use hot water more efficiently not only reduces current and future water-heating costs, it can also allow you to install a smaller, and therefore less costly, solar water heating system. The monthly energy savings resulting from conservation steps can be applied to paying for a future solar water heating system.

The steps to efficient hot water use begin with simple tasks that only need to be done once to save energy for years to come.

1. Turn Down the Thermostat

Turn down the thermostat on the water heater to 115°F or 120°F. The unit will still provide hot water but will use substantially less energy. For example, a typical 52-gallon water heater set back from 140°F to 120°F will save 410 kWh/year of electricity or about 17 therms/year of gas.[1] At $0.07/kWh, $28.70 would be saved, and at $0.60/therm, $10.20 would be saved, every year. Saving this much energy would reduce the size of solar collector needed by up to 10 square feet. This would result in significant savings, considering that a 52 square foot collector area, composed of two 4-foot by 6.5-foot collectors, retails for about $1030, whereas a 4-foot x 10-foot, 40 square foot collector retails for about $655.

Adjusting the Thermostat on a Water Heater

To turn down the thermostat on an electric water heater, first switch off the circuit breaker for the heater before removing the cover plates over the thermostats. Electric water heaters typically have an upper and a lower element. Set the upper thermostat five degrees higher than the lower one. For gas water heaters, the fuel doesn't have to be turned off to adjust the thermostat. Simply turn the knob. In either case, gradually adjust the temperature over a period of days until you find the minimum satisfactory setting. If you use a dishwasher, its cleaning power may be affected by lower water temperatures. If your dishwasher has an electric water-heating booster, that may compensate for the lower incoming water temperature.

Note: If it seems that you run out of hot water too quickly, your tank may have a broken dip tube (a tube that extends inside the tank from the cold water inlet to the bottom section of the tank). This is not uncommon and can easily be repaired by disconnecting the cold water supply line, removing the old dip tube, and replacing it with a new one (available at most hardware stores).

2. Insulate the Water Heater

Most water heaters have only one or two inches of insulation and adding an additional two to six inches can produce significant savings. You can buy a tank insulation kit or simply wrap the heater with six inches of fiberglass insulation. Tie the insulation with wire or cord and seal the seams with duct tape. Be sure not to obstruct the pressure-and-temperature relief valve at the top of the heater. On electric water heaters, cut out a plug of insulation over each thermostat, allowing easy access to the thermostat adjustment knobs. The insulating plug can be reinserted after the tank is wrapped. For gas fired heaters, make absolutely sure not to cover up the combustion air intake vents at the base of the unit. Also leave a gap a couple of inches wide between the insulation and the flue pipe at the top of a gas or oil heater. Insulating your water heater should take less than an hour and should cost $10 to $30. Within a year the insulation will save you this much on your electric or gas bill.

A slightly more expensive, but possibly more aesthetic, option would be to wrap two layers of "Reflectix" aluminum foil/"bubble-pack" insulation around the water heater. In tight spaces the Reflectix may be easier to install than fiberglass.

3. Prevent Heat Loss through Plumbing

Insulate exposed hot water pipes with pipe insulation rated R-4 or better. (Don't bother with pipes buried in walls - it's not worth the trouble of ripping apart walls.) Also insulate cold water supply pipes six to eight feet from the hot water tank. This will reduce heat loss from pipes and will at times allow hot water to flow immediately from the taps (alleviating the need to wait while cold water is flushed from the lines).

Install heat traps on the cold and hot water connections to the water heater. Heat traps are check valves that "prevent heat from migrating by natural convection into service pipes when in standby mode. Some look like a simple ball-check valve. A 360-degree loop in the piping can also serve as a heat trap."[2] Many newer water heaters are now sold with heat traps.

4. Install a Timer on the Water Heater

If you only use hot water during one or two distinct periods during the day, energy can be conserved by installing a timer. The timer will turn the heater on and off around those times of peak use. While one study by the Florida Solar Energy Center (FSEC) found the savings from using a timer to be minimal ($0.21/ month),[3] other studies have found substantial savings from the use of timers. These different findings may be due to factors such as hot water use schedules, water heater thermostat set-points, the temperature in the room where the water heater is located, water delivery temperatures, the cost of heating and cooling energies, and whether the water heater is also used for solar storage.[4]

Using a Timer in a Solar Water Heating System

Timers can be beneficial in solar water heating systems that use a single electric tank. Try to buy the tallest tank available with the proper volume, disconnect the bottom element, and install a water heater timer to control the operations of the upper element. (These specifications are difficult to achieve with a natural gas- or LP-burning water heater.) Especially in households where the major demands for hot water (i.e. pre-school and pre-workday showers, dishwashing, etc.) occur in the morning, set the timer to prevent the heater element from reheating water before the sun can accomplish its heating. For optimum timer operation, the element should be shut off BEFORE the start of early morning hot water demand, so that the coolest water is sitting in the tank, ready to be heated later by the sun. The timer's next on-cycle can be easily adjusted to ensure adequate hot water for the next major period of hot water use, like evening showers or dishwashing when everyone is home from school or work.

Since electric water heater timers offer at least two on-off cycles per day, you can easily turn the heater off again in the evening, to reduce standing losses when everyone is asleep. As with morning operation, it is most efficient to heat up the water right before it is needed, then make sure there is no reheating during the actual hot water use. Unless hot water use is so large that reheating during use is necessary to keep pace with demand, a well insulated tank will typically keep the water hot long after the heating elements are turned off. For more casual hot water needs, like mere hand washing, where warm water is usually adequate, no periodic reheating is required, if the water heater and pipes are well insulated.

If you are interested in reducing your demand for electricity during utility peak demand periods, you can also use timers to schedule major backup water heating between midnight and dawn when most electric utilities experience their lowest electric demand. Although not uniform in all areas, electric utility systems commonly experience their peak electric demand in early mornings and early evenings during the heating season, afternoons and early evenings during the cooling season.

5. Install a Non-Electric Flue Damper

For gas-fired water heaters, install a non-electric flue damper, which opens automatically when the hot exhaust from the gas burner flows up the tank. One model available from Advanced Conservation Technologies is priced around $50. The American Gas Association tested a water heater with no hot-water demand (it simply maintained a set water temperature), and found that the damper reduced heat loss per hour by 45 percent.[5]

6. Use Less Hot Water

Reduce hot water consumption without sacrificing convenience by using more efficient fixtures, appliances, and other strategies. Saving hot water doesn't necessarily mean taking fewer or shorter hot showers. Changes can be made that will go mostly unnoticed, except for the monthly savings in energy costs, which can range from 25 to 50 percent.

First, install low-flow showerheads and faucet aerators throughout your home. Low-flow showerheads can dramatically reduce water consumption in showers while still providing a powerful and comfortable spray. These low-low fixtures are inexpensive, easy to install (they just screw onto the end of existing fixtures), and can be found in most hardware stores.

Second, consider washing laundry with cold or warm water rather than hot water. Use hot water only when truly necessary, and look for detergents designed for washing with cold water.

Third, when you buy a new washing machine, consider buying a high-efficiency model. Look for the Energy Star label to help you identify washers that use water and energy most efficiently. These washers can produce dramatic savings in energy and water use.

Fourth, check the water pressure coming into your house. You can do this with a pressure gauge (available from most hardware stores) that can screw onto a hose faucet fixture. If the pressure is continuously above 45 pounds per square inch (psi) you could reduce your hot water use by installing a pressure-reducing valve. By reducing the pressure in your water lines, the flow rate of water will be reduced, thereby conserving both hot and cold water. The pressure-reducing valve, along with a pressure gauge, should be installed where the water main enters the house, downstream from the shutoff valve and water meter (between the shutoff valve and the house). You may also want to install the pressure-reducing valve downstream from an outdoor

Comparing Conventional and High-Efficiency Washing Machines[6]

In one year, compared to a typical new conventional (top loading) washing machine running 8 loads/week, the front-loading, Energy Star-rated Kenmore 41042 clothes washer can save:

6,377 gallons of water

683.8 kilowatt-hours of electricity

(from washer operation and heating the water)

$79 in energy and water costs

(at $0.847 per kWh of electricity and $2.45 per CCF (100 cubic feet) of water)

Figure 9.1: Front-loading washing machines can save tens of thousands of gallons of water and hundreds of dollars over their lifetime.
Andy McDonald

faucet fixture, so that you will still have full pressure available for washing cars, watering lawns, putting out a fire, etc. The reducing valve and pressure gauge can usually be acquired for $40 from a plumbing supply store.

Once the valve is installed, the pressure is reduced by turning an adjustment nut on the valve, while keeping an eye on the pressure gauge downstream. Open a cold-water tap to assess the water pressure, and reduce it until the flow rate is satisfactory, but not excessive (perhaps 30 psi). Lower water pressure will reduce monthly water bills and the amount of water that needs to be heated. It will also reduce sewer bills for homes whose bills are based on gallons of water used. Lower pressure will extend the life of the water heater and can solve “water hammer” problems—annoying rumbles caused by shaking pipes.

7. Using Solar-Heated Water More Efficiently

Some simple household habits can help you to use solar-heated water more efficiently. For example, scheduling large hot water demands (such as showering or washing clothes) in the early to mid-afternoon on sunny days will allow the sun time to reheat the water afterwards. Evening or early morning showers, by contrast, may trigger the thermostat to kick on the element in the back-up heater before the sun has a chance to re-heat the water.

Tankless Water Heaters

Tankless (a.k.a. instantaneous or on-demand) water heaters heat water as it is used at the tap, avoiding the need for a storage tank. Tests have shown that tankless water heaters offer from 10 to 20 percent savings versus conventional tank-type water heaters.[7] and their popularity is increasing due to their improved energy efficiency. However, this is one efficiency improvement that is best considered after installing a solar water heating system, because the solar water heater will require an insulated storage tank, in any case, and you may be able to use your existing conventional water heater in your solar system (especially if the tank holds 60 gallons or more). In this case the electric or gas heater can provide backup heating when the solar system doesn’t keep up with hot water demand.

A further consideration is that the price of a tankless water heater ($600 to $1000) could go a long way towards the purchase of a solar water-heating system. As a solar system can offer 100 percent savings during summer months and up to 80 percent annual savings, it represents a better investment than a tankless water heater.

Should a tankless water heater be purchased, be sure it has the ability to control the burner output based on the incoming water temperature, thus having the capacity to backup a solar water-heating system. Be aware that the gas supply line and flue size may have to be increased to handle the demands of an on-demand, tankless water heater.

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End Notes

1. B. Keisling, *The Homeowner’s Handbook of Solar Water Heating Systems*, Rodale Press, Emmaus, PA, 1983, p.4.
2. Source: www.jacksonemc.com/news/glossary.html
3. Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003, p.88.
4. John F. Robbins, CEM, personal communication, February 11, 2005.
5. Home Energy Magazine Online, July/August 1997. Article available on-line at: http://homeenergy.org/archive/hem.dis.anl.gov/eehem/97/970714.html
6. “Sustainable Energy Solutions: Buying Green Power

and Investing in Energy Efficiency," Andy McDonald and Thomas Reynolds, a poster presentation at Slippery Rock University of Pennsylvania, 2003.
7. Tom Lane, p.88.

Chapter Ten
Additional Solar Water Heating Applications
Solar Swimming Pool Heaters, Radiant Floor Heating & Concentrating Solar Collectors

In the previous chapters, we discussed the history of solar water heating and focused on domestic hot water systems, which provide hot water for household uses such as washing and bathing. However, there are other important uses for hot water for which solar water heaters are well-suited. These include solar swimming pool heaters, radiant hydronic heating systems (for space heating), and concentrating solar collectors for large-scale electricity generation.

Solar Swimming Pool Heaters[1]

An unheated swimming pool has a natural yearly temperature cycle that varies with climate and geography, which in most parts of the United States limits outdoor swimming to just the summer months. However, a comfortable three to four month swimming season can be stretched out to five or six months when a pool heater is added (even longer in warm climates).

While heating your pool can enhance and extend your enjoyment of your pool, the cost of keeping all that water warm is very high. However, if you take advantage of the strong summer sun, you can reduce those high heating costs while still obtaining the benefits of a warm pool.

Conservation First

If you already have a heating system, the first thing you should do is to conserve the heat in your pool. The easiest way to save energy is to turn down the thermostat on your pool heater; every one degree reduction on the thermostat will reduce energy consumption by five to ten percent. Once you have turned the heat down, the next step is to keep the heat from escaping. Since 95 percent of a pool's heat losses occur at the surface through evaporation, conduction, and radiation to the sky, a pool cover will substantially reduce your pool's heat loss. A cover will also help keep the pool cleaner and help extend the life of the chemicals in your pool. With a transparent plastic cover, you will actually gain some heat as the sun's rays pass through the cover and heat the water. At a cost of $0.40 - $0.80 per square foot, a pool cover can pay for itself in as little as one year, though you should be aware that the covers will deteriorate due to ultraviolet radiation, requiring replacement every three to five years. Make sure your cover's warranty specifies its life expectancy. Also check to determine the ease of handling and storing the cover.

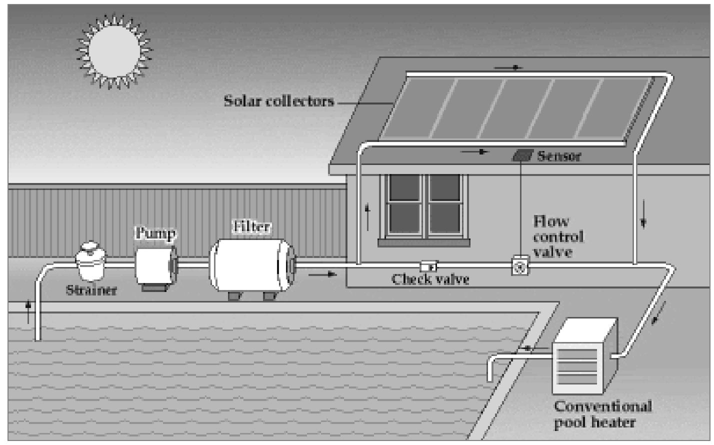

Figure 10.1: Schematic of a solar swimming pool heater
Energy Efficiency and Renewable Energy Clearinghouse, www.eere.energy.gov

Basic Components

If you have taken steps to retain your pool's heat but are still not happy with your heating bills, or if you are planning to install a new pool, a solar swimming pool heater may be a good investment for you. Figure 1 shows the basic components of a solar pool heating system including the pump, filter, collectors, and backup heating system. Solar pool heaters take full advantage of the fact that solar collectors are more efficient when working at low temperatures. Unlike domestic hot water systems which raise a relatively small amount of water to a high temperature at an efficiency of 30 to 50 percent, pool heaters raise the temperature of several thousand gallons of water only a few degrees, to around 80° Fahrenheit, but operate at an efficiency of 70 to 80 percent.

Collectors for pool heating normally do not require glazing or insulation since they are operated during those times of year when solar radiation and ambient temperature are relatively high. This allows for a simpler design that is far less expensive than domestic hot water collectors. In fact, many collectors are made of heavy duty plastic which is treated with an ultraviolet inhibitor to extend the life of the panels. The advantages of plastic collectors are that they weigh less than metal collectors and they are much less expensive.

Metal collectors are generally made of copper tubing mounted on an aluminum plate. The metal collectors last longer than plastic ones, and they are slightly more efficient in absorbing heat, therefore requiring less roof space than plastic collectors. The disadvantage of metal collectors is that the copper tubes may react with your pool's walls, producing discoloration that can only be removed by draining, cleaning, and repainting the pool. However, this problem can be entirely avoided if the pH level is always maintained above 7.2.

Since all swimming pools require a pump and related plumbing, the addition of a solar pool heater to an existing installation can be relatively simple. However, unless you are experienced with plumbing and electrical wiring, it is advisable to allow a professional to install your system. Often the existing filter pump can be used to circulate the pool water, though you should be sure it is able to maintain a high flow rate in order to keep the panels cool and operating at high efficiency. It is generally recommended that all the pool water circulate through the collectors every 8 – 12 hours. Your collector should require very little maintenance provided the pool's chemical balance and filtration system are regularly checked.

Collector Sizing and Location (Method 1)

The amount of collector area you need to heat your pool depends on a variety of factors, but a general rule of thumb is that the collector area should be equal to at least one half of the pool surface area in order to extend the swimming season into spring and autumn in a reasonably sunny climate.

Collectors can be mounted on roofs or in any other location near the pool that provides proper exposure, orientation, and tilt towards the sun. The optimum collector orientation is south, but west-facing orientations are satisfactory for pool heating as long as the collector area is increased to a minimum of 75 percent of the pool surface area. East facing orientations are marginal. The tilt of the collector is just as important as the orientation. To receive maximum solar radiation, collectors should be perpendicular to the sun's rays. For primarily summer heating, the tilt should be equal to the latitude minus 10 to 15 degrees. In situations where it is desirable to install the collector horizontally, the collector area should be increased to 75 percent of the pool surface area.

Heating a Swimming Pool in Central Kentucky

This family's 50,000 gallon swimming pool in central Kentucky is heated by six 4'x8' solar collector panels. The solar system, installed around 1994, has worked very well, according to the owner, who has been very happy with its performance. "There's no way I could afford to heat all this water with propane," he stated, adding that he does use a small amount of propane to top off the water temperature (to maintain it at 80° F). The system works by circulating the pool water itself through the collector panels, where it is heated and then returns to the swimming pool. A filter prevents particulates from the pool from entering the copper tubing within the panels. The collector panels are ground-mounted on a stand behind a fence and are not visible from the pool itself. The solar collectors are used whenever the pool is open, which is typically from March through October.

The flat plate solar collectors used in this system consist of copper tubing inside an insulated, glazed box. Flat plate collectors are more commonly used for domestic water heating, while heavy duty plastic, unglazed collectors are more common for heating pools. While flat plate collectors are more efficient than plastic collectors, the added efficiency is generally not needed for heating swimming pools. Plastic collectors are simpler and much less expensive than glazed copper panels, and also require less maintenance. As the owner of this system has found, the copper in the flat plate collector can react with the pool water to cause stains on the walls of the pool. The owner prevents this by adding certain chemicals to the pool water.

Figure 10.2: Six flat plate solar collector panels are located to the south of this swimming pool. The solar collectors are hidden behind a screen so that they cannot be seen from the pool itself, *Andy McDonald (right photo)*

Sizing Collector Panels for a Solar Swimming Pool Heater (Method 2)

Another rule of thumb for estimating the area of solar collectors needed to heat a swimming pool is that the area of collectors should be 20 percent the area of the pool for every 3°F rise in pool temperature desired.[2]

$$Ac = Ap \times 0.2 \times (\Delta T)/3°F$$

Where: Ac= Area of the Collector
Ap= Area of the Pool
∆T= Desired pool temp. — ambient water temp.

"The 3°F rise per 20 percent of pool area is based on the Florida Solar Energy Center (FSEC) rating at 1,000 BTU's per square foot of collector area at the low temperature test (95°F inlet test temperature) rating. A collector rated at 900 BTU per square foot would need 11 percent more collector area. Florida Solar Energy Center ratings are available at www.fsec.ucf.edu or (321)638-1000. You can add more collectors to your initial system over time. The best orientation of solar pool collectors is south/southwest…The manufacturer of the pool collectors will inform you of the square feet needed for your [roof] orientation and location to reach the desired temperature gain."[3]

The section on swimming pools adapted with permission from the North Carolina Solar Center at North Carolina State University

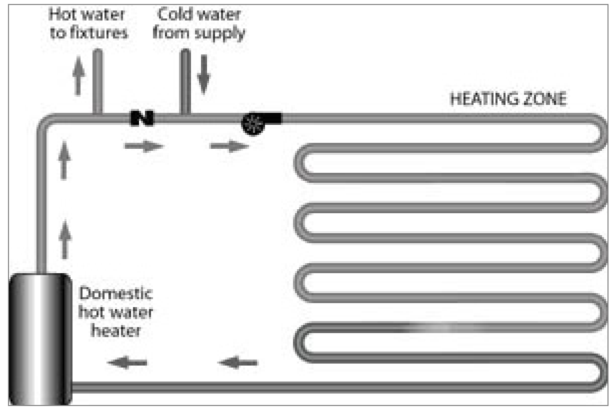

Figure 10.3: Radiant floor heating system schematic
www.radianttec.com

Space Heating with Radiant Hydronic Heating Systems

Radiant hydronic heating systems are used to provide very efficient, high quality space heating in homes and other building types. These systems produce a very comfortable indoor environment, and they are clean and quiet in operation. Radiant hydronic systems distribute heat throughout a building by circulating hot water through tubing embedded in floors (and in some cases walls and ceilings). The hot water in the tubing heats the floor, which in turn radiates its heat to building occupants and all other surfaces that are in a direct line of sight.

Radiant floor heating is not a new concept. The ancient Romans used it to heat their public baths (by routing the exhaust from fires underneath the floors of the baths). In modern times, Europeans have been using radiant floor heating systems for over 60 years. Servicemen returning from World War II were the first to spread the word about under-floor heating to the United States. Many radiant hydronic heating systems were installed in the U.S. during the 1960's and 1970's that used copper piping embedded in concrete slabs. Unfortunately, many of these systems leaked because copper is highly susceptible to corrosion when in contact with concrete. Today, polyethylene tubing is used instead of copper, which provides better flexibility, corrosion resistance, and a lifespan of over 100 years. According to the Radiant Panel Association, the sales of radiant heating tubing have increased almost tenfold since 1991.[4]

Radiant hydronic systems require an inlet water temperature between 100°F and 125°F. The source of energy to get water to that temperature could be gas, oil, wood, electricity, geo-thermal, or solar. When solar energy is used for radiant floor heating, a large hot water storage tank (or multiple tanks) will often be used to supply hot water to the radiant floor system and to provide for domestic hot water needs, as well. Solar thermal systems typically include an electric, gas, or oil water heater as a back-up. Solar water heating works well with radiant hydronic systems because the large thermal mass (i.e. a concrete slab floor) common in radiant systems provides an ideal storage medium for the solar energy harnessed during the day. At night, this stored thermal energy is slowly released into the building space in a steady, comfortable manner. One drawback to a large solar water heating system designed for wintertime radiant space heating is that an over-abundance of hot water could be produced during the summer months when the radiant heating system does not need hot water. In a situation such as this, the excess hot water could be used for heating a pool or hot tub. For further discussion about radiant floor heating and active solar space heating, see Chapter Eleven, Space Heating with Active Solar Energy Systems.

Concentrating Solar Collectors for Large-Scale Electricity Generation

Concentrating solar power technologies use reflective materials such as mirrors to concentrate the sun's energy. This concentrated heat energy is then converted into electricity.

Figure 10.4: Close-up (left) and aerial (right) views of the SEGS array of parabolic trough collectors.
www.eere.energy.gov/tribalenergy/guide/parabolic.html

Technologies

TROUGH COLLECTORS- Parabolic trough systems use curved mirrors to focus sunlight on an absorber tube filled with oil or other fluid. The hot oil boils water to produce steam, which is used to generate electricity. Since 1985, nine power plants in the Mojave Desert called the Solar Electric Generating Systems (SEGS) that use parabolic trough technology have been in full commercial operation.

POWER TOWERS- Power tower systems use a large field of sun-tracking mirrors, called heliostats, to concentrate sunlight onto a receiver on the top of a tower. The sun heats a fluid inside the receiver. An early U.S. demonstration plant, Solar One, used water as the fluid, generating steam in the tower to drive a turbine to generate electricity. The plant was later converted to Solar Two, which used molten salt as the fluid. The hot salt could be stored, then used when needed to boil water into steam to drive a turbine.

DISH/ENGINE SYSTEMS- A dish/engine system uses mirrors in the shape of a dish to collect and concentrate the sun's heat onto a receiver. The receiver transfers the solar energy to a heat engine—usually a Stirling cycle engine—that converts the heat into mechanical energy, which drives a generator to produce electricity. The receiver, heat engine, and generator are integrated into one assembly that is mounted at the focus of the mirrored dish. An alternative approach, called the open Brayton cycle, passes air through a porous medium in the receiver, causing the air to heat and expand rapidly. The hot air is then fed into a separate gas turbine that drives a generator to produce electricity.

Issues

MIRROR TECHNOLOGIES- Concentrators use reflective surfaces of aluminum or silver on the front or back surface of thin glass or plastic. Researchers are developing new reflective materials, such as advanced polymer films, that are less expensive to produce than glass. Stretched membranes are thin reflective membranes stretched across a rim or hoop. Another membrane stretched on the back creates a partial vacuum. This forces the membranes into a spherical shape, which is the ideal concentrator shape.

HYBRID SYSTEMS- Researchers are working with utilities on experimental hybrid power towers that run on solar energy and natural gas. A similar solar/fossil fuel hybrid is being developed for dish/engine systems. The advantage of hybrid systems is that they could run continuously.

MANUFACTURING COSTS- Concentrating solar power is the least expensive solar electricity for large-scale power generation, and has the potential to make solar power available at a very competitive rate. As a result, government, industry, and utilities have formed partnerships with the goal of reducing the manufacturing cost of concentrating solar power technologies.

Reprinted from "Concentrating Solar Power," Energy Efficiency and Renewable Energy Clearinghouse, US Department of Energy, April 27, 2004
www.eere.energy.gov/RE/solar_concentrating.html

End Notes

1. The section on solar swimming pool heaters adapted from, "Heating Your Swimming Pool with Solar Energy," North Carolina Solar Center at North Carolina State University, Fact Sheet SC122, June 2002. Used with permission.
2. Tom Lane, *Solar Hot Water Systems 1977 to Today, Lessons Learned*, 26th Edition, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003, p.163.
3. Ibid, p.163.
4. Radiant Panel Association, web site: www.radiantpanelassociation.org

RESOURCES: Solar Swimming Pool Heaters

The Homeowner's Handbook of Solar Water Heating Systems, B. Kiesling, Rodale Press, Emmaus, PA, 1983.

Solar Heat for Swimming Pools, D. Root, Jr., Florida Conservation Foundation, Inc., Winter Park, Florida, 1982.

Designing and Installing Commercial Pool Heating Systems: Solar Water and Pool Heating Manual, Vol. 1 Installation and Operation and Vol. 2 Installation Details, D. Root, Florida Solar Energy Center, Cocoa, Florida, 1992.

Solar Heating of Swimming Pools: A Question and Answer Primer, C.J. Cromer, Florida Solar Energy Center, Cocoa, Florida, 1997.

Solar Hot Water Systems 1977 to Today, Lessons Learned (26th Edition), Tom Lane, Energy Conservation Services of North Florida, Inc., Gainesville, FL, 2003.

See Resources List at the end of Chapter Six for further publications and organizations related to solar water heating. See Chapter Sixteen, "Solar Equipment Suppliers," for a list of equipment suppliers, retailers, and manufacturers.

Chapter Eleven
Space Heating with Active Solar Energy Systems

Solar space heating systems can be either active or passive. Passive systems use building components such as floors, walls, and sun spaces to collect and store heat. Often, small fans distribute heat, but mechanical equipment and the use of outside energy are kept to a minimum.

In contrast to passive systems, active space heating systems rely on hardware such as rooftop collectors to collect and distribute heat. They use air or a liquid that is heated in the solar collectors and then transported by small electric fans or pumps or by thermosiphon effect, to storage. Solar heat is stored in water tanks or rock bins to provide heat during sunless periods.

Quantity of Heat Provided

Active solar energy systems are usually designed to provide from 40 to 80 percent of a home's yearly heating needs. Data from systems installed through a government demonstration program, however, indicates that active space heating systems are most economical when they are designed to handle about 50 percent of a home's heating requirements. A system sized to provide much more than this would not be economical because some of the extra capacity would only be used during the coldest days. The rest of the time, the extra equipment would be idle.

Backup Heating

Heat not provided by the solar system will have to come from a backup system, which is usually a conventional furnace. (Backup systems are required by most building codes and mortgage lenders anyway). Homeowners can choose from furnaces that use two or three types of fuel and then select the one that is currently most economical. Solar systems and backup systems will sometimes share the same duct work. Some HVAC companies and manufacturers may object to their equipment sharing the same heating path with other heating equipment, so it is advisable to check with your heating equipment representative to make sure you do not violate any specifications or warranty conditions when planning to use existing HVAC ducts for a solar air-heating system.

A common heat delivery system also can be used when adding active space heating to an existing house. But in all cases, the backup heating system should be capable of supplying 100 percent of the home's heating requirements for periods of cloudy weather when little solar heat is available.

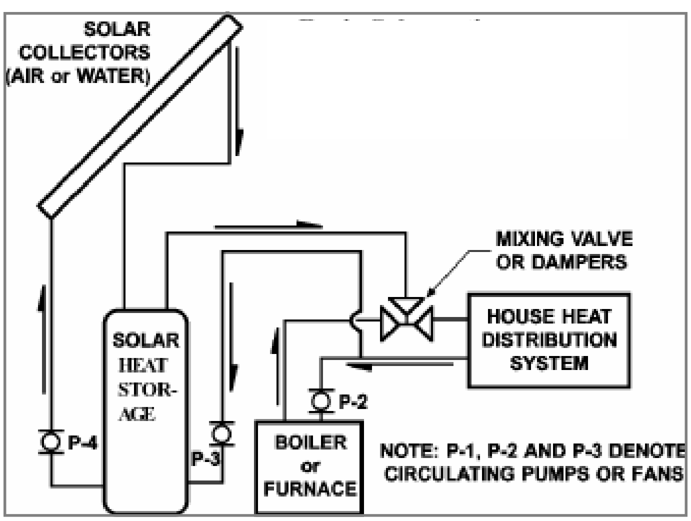

Figure 11.1: Basic schematic of active solar space heating system

Collector Mounting

Solar collectors usually are mounted in rows, on the roof or the south wall of a house. Collectors may also be ground mounted on a collector support structure.

Collectors should face true south, not magnetic south, which is what a compass shows. (For details on siting issues, see Chapter Five.) However, a deviation of 30 degrees or less from true south will not substantially reduce system performance. Collectors should be tilted at an angle equal to your latitude, plus 15 degrees above horizontal. Between 9 am and 3 pm, collectors receive the most radiation and should not be shaded by trees, buildings, hills, or any other obstructions. Performance can be significantly reduced if even a small portion of the collector area is shaded.

Air Systems

Air solar systems include collectors, fans, ductwork, controls, and usually a thermal storage system. An air system can heat the air in a home without heat exchangers or thermal storage. Larger air systems typically use thermal storage. For example, heat can be stored in a bin of small rocks one to three inches in diameter. These systems can be effective, but it is extremely important that they be kept free of moisture. Any moisture in rock bins or holding tanks can

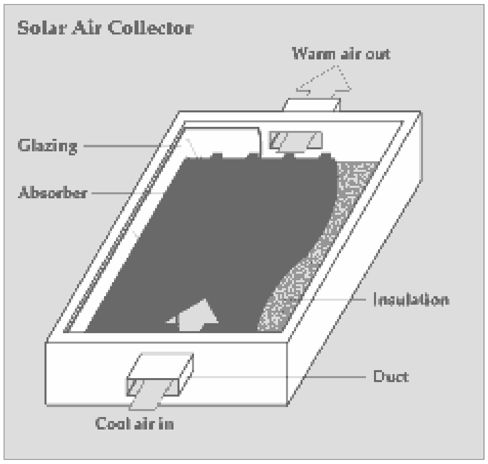

Figure 11.2: Solar air collector

enable mold and bacteria to grow, which can cause serious health problems. One alternative to rock storage is an air-to-water heat exchanger, which stores excess energy in water rather than rocks. A heat exchanger eliminates the problems with rock storage and provides a way to heat domestic water when the system is not being used for space heating.

Liquid Systems

Liquid solar systems include collectors, storage tanks, pumps, pipes, heat exchangers and controls. These systems operate similar to an air system except that liquid – rather than air – is heated in the collectors. Thus if the house has forced air heating, a heat exchanger is required to transfer the heat from the solar-heated liquid to the air.

Liquid systems usually use water to store solar heat. One to two gallons of water are needed for every square foot of collector. The tanks used to store water can be made of concrete, steel, or fiberglass-reinforced plastic. Tanks should be insulated to a value of R-19 or better.

The water in the storage tank is heated in one of two ways. In an open loop system, it is circulated directly through the collectors. In a closed loop system, the water is heated indirectly by a heat transfer fluid such as an antifreeze solution. The transfer fluid absorbs heat from the collector. The fluid then passes through a heat exchanger that transfers the heat to the water inside the storage tank. Thus, the antifreeze solution and household water are kept separate.

It is also possible to connect the solar system to small heat exchangers in individual rooms if the backup system is on a room-to-room basis; for instance, if electric baseboard heating is installed in individual rooms. These small heat exchangers are available as standard plumbing units in various sizes and contain their own blowers.

The temperature of the fluid in a liquid solar system reaches 90°F to 120°F. Conventional heating systems heat water from 160°F to 180°F. Therefore, if baseboards or radiators are used with solar heating, the surface area of the radiators should be significantly increased.

Radiant In-Floor Systems

The method of heat distribution most compatible with active systems is radiant slab heating. Radiant slab heating uses plastic, rubber or copper pipes embedded in a concrete floor and can operate effectively at relatively low temperatures. When solar-heated water circulates through the pipes, the floor heats up and then radiates its heat to the room.

Inserting a sizeable insulated solar-heated liquid storage tank between the solar collectors and the slab floor typically improves the percentage of solar contribution, simply by adding storage remote from the floor. In such a system, the building occupants can have more influence over the floor's temperature, using a thermostat to control circulation of solar-heated fluid through the slab. This strategy works particularly well when the slab is also used for absorbing passive solar heat from a large bank of south-facing windows. During or immediately after a sunny day, the slab will not need heat from the active solar system, but during long cloudy periods when passive solar gains do not occur, the thermostat will trigger circulation of the solar-heated liquid from the storage tank to the slab. This strategy also works when the slab's radiant distribution pipe systems are "zoned" in a passive solar building, allowing heated fluid to warm slab areas in rooms which do not directly benefit from passive solar effects on sunny days.

In-floor heating systems are beginning to catch on in different parts of the country. Although the Romans used wood-fired in-floor heating systems 2,000 years ago, systems for modern homes have not been popular until recently. Fifty years ago, many systems were installed using copper tubing. Unfortunately, prospective customers shied away because of leakage problems resulting from corrosion, poor soldering and

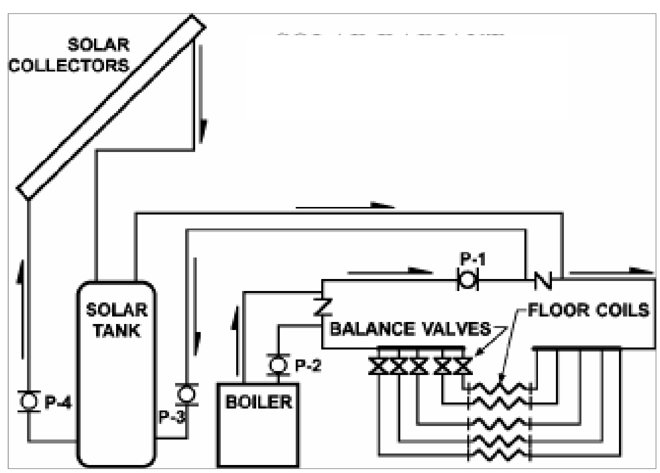

Figure 11.3: Solar radiant in-floor system

shifting slabs. With the advent of tough, low-cost plastic and rubber tubing, these systems are beginning to become popular again. With the proper design and installation, in-floor systems can be among the most efficient and comfortable heating systems available.

In-floor heating systems use moderate water temperatures to keep from scalding bare feet. These temperatures coincide with the temperatures easily reached in solar water heating systems. Typical inlet water temperatures range from 100°F to 125°F, which is precisely the range where active solar systems excel. Rather than heating a large water or rock storage tank, a concrete slab floor can be used to store the heat and slowly release the heat as needed.

Radiant floor heating systems can increase the efficiency of liquid collectors by reducing the collector operating temperatures to below the levels common to domestic solar water heating systems. As a result, they are more efficient since they lose less heat to the cold outside air.

Controls

Solar controls use sensors, switches, and motors to operate the system and to provide backup heating when the solar system cannot meet heating requirements. Other controls are used to prevent extremely high temperatures or to protect against freezing.

The heart of the control system is usually the differential thermostat. The thermostat measures the difference in temperature between the collectors and storage unit. When the temperature in the collectors is at least 10 to 20 degrees higher than the temperature of the storage unit, the thermostat will turn on a pump or fan to circulate heat to storage, or directly into the house.

Control systems vary in function, performance, and expense. A basic control system would perform the necessary functions to operate the solar system in three or four different modes. Some control systems monitor the temperature at different parts of the system to determine how the system is operating.

Maintenance

Periodic maintenance on the system can help prevent major problems. Solar systems are mechanical systems not unlike standard heating or cooling equipment in a home. Just as those systems require periodic maintenance, solar heating systems do as well. Maintenance manuals with recommended maintenance schedules should be included with each system.

Adapted with permission from "Space Heating with Active Solar Energy Systems," North Carolina Solar Center at North Carolina State University, Factsheet SC120, June 2000.

Pioneering Kentucky House Integrates Passive and Active Solar Heating

The Raven Run Solar House near Lexington, Kentucky, integrates active and passive solar heating systems. This home was designed and built during the mid-1970's by architect Dick Levine, co-director of the Center for Sustainable Cities at the University of Kentucky, and has been his home ever since. The home includes three solar heating systems. The active system uses patented multistage air collectors designed and built by Levine on-site. The heat collected by these collectors is stored in rock bins beneath the first floor of the house. The passive solar system utilizes "Sundows," rows of glazing that alternate with the active solar collectors on the south face of the house. The Sundows allow sunlight to enter the home for direct heating and lighting. Insulated shutters are closed at night to conserve heat within the home. The third system is an attached greenhouse, which provides additional heating as well as fresh vegetables and a lush greenspace within the house throughout the winter.

Figure 11.4: South face of the Raven Run Solar House. The permanent yet moveable ladder system allows for easy window maintenance and also provides shading during the summer months, *Dick Levine*

Figure 11.5: The solar design allows ample daylight into the home, as shown in these photos of the living room and central staircase, *Dick Levine*

RESOURCES: Space Heating

Publications

Active Solar Heating Systems Design Manual, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 1988.

Active Solar Heating Systems Operation and Maintenance Manuals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 1990.

Engineering Principles and Concepts for Active Solar, National Renewable Energy Laboratory, Golden, CO, 1987.

"Hydronic Radiant Floors for Beginners," Jay Stein, Owner and Builder Magazine, September 1989.

Modern Hydronic Heating, John Sieganthaler, Delmar Publishers, 1995.

"Premium Heating with Radiant Slabs," Mathew Friedlander, Solar Age Magazine, November 1996.

"Solar Assisted In-Floor Heating Systems," Bill Brooks, Builders Review Magazine, Louisville, KY, February 1990.

Solar Water Heating, Bob Ramlow & Benjamin Nusz, New Society Publishers, British Columbia, 2006.

Organizations

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle NE
Atlanta, GA 30329
(404)636-8400
www.ashrae.org

American Solar Energy Society
2400 Central Ave.
Unit G-1
Boulder, CO 80301
(303)443-3130
www.ases.org

Florida Solar Energy Center
1679 Clearlake Rd.
Cocoa, FL 32922
(407)638-1000
www.fsec.ucf.edu

Chapter Twelve
Solar Cooking, Food Drying, and Water Purification

Solar Cookers

There are a variety of solar cooker designs in use around the world. Most models are based on simple design principles and can be built using common materials by most anyone. Construction plans for common models are available from a number of organizations, either for free or at a low cost. Commercially-manufactured solar cookers can also be purchased from a variety of sources (see the Resources list at end of this chapter).

There are basically three types of solar cookers-parabolic, box, and multi-reflector. Parabolic reflector ovens focus solar energy on the cooking area, producing higher temperatures than the other types of cookers. The intense heat produced enables food to be fried, which is not possible with the other types of cookers. The disadvantage of these cookers is that they must be frequently repositioned to keep them focused on the sun. They are also susceptible to being blown over in the wind, since they are somewhat top-heavy.

Simple solar box cookers utilize well-insulated boxes, often made from cardboard and covered with a piece of glass. Cooking pots are placed inside the box, which can reach temperatures above 200°F on sunny days. Solar box cookers often have a single reflector, used to focus additional sunlight into the box. These cookers have been successfully used in many situations around the world, and have been one of the most popular solar cooker designs for many years. Their simplicity is one of their greatest virtues, as they can be built by almost anyone at a very low-cost. Box

Figure 12.1: The Casa Juliana solar cooker, designed by David Omick, reaches temperatures above 400°F, *Andy McDonald*

cookers need to be repositioned about once an hour, which makes them more convenient to use than parabolic cookers.

Multi-reflector cookers come in two varieties, those that use an insulated box and those that use a plastic baking bag. Multi-reflector box cookers achieve temperatures between 300°F and 400°F, depending upon the model, location, and sky conditions. They typically use a well-insulated box covered with glass, similar to the simple box cooker, but the box top is often angled to face the sun. This allows for greater collection of solar energy. These cookers do not need to be re-positioned as often as box cookers, but depending on the time of day and the type of food being cooked, it's still a good idea to reposition them every 60 to 90 minutes. The higher temperatures they

Figure 12.2: Joe Radabaugh's Heaven's Flame multi-reflector solar box cooker, *Solar Cookers International*

Figure 12.3: Parabolic solar cooker *Solar Cookers International*

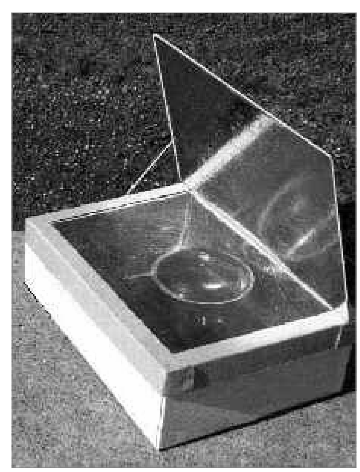

Figure 12.4: Classic solar box cooker, *Solar Cookers Int'l*

Figure 12.5: Solar oven saleswoman, Maina Manunure, in Zimbabwe
Solar Cookers International

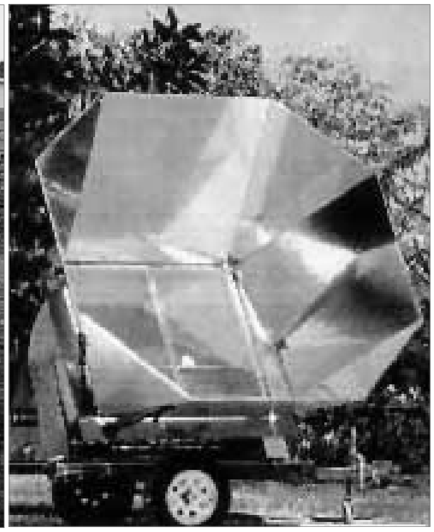

Figure 12.6: The Villager, a large oven for institutional cooking
Solar Cookers International

Figure 12.7:
The Bernard reflective box cooker
Solar Cookers International

Figure 12.8:
The SOS Solar Sport Cooker is sold commercially in the US and abroad, *Solar Oven Society*

achieve enable them to cook a wide range of foods, including beans, rice, meats, bread, baked goods, and vegetables.

The reflectors on solar ovens can be made with simple materials such as cardboard, plywood or sheet metal laminated with a reflective material like aluminum foil. Mirrors, polished aluminum, or mylar can also be used to increase the cooker's solar heat gain. The added expense of using these more reflective materials must be weighed against the fact that simple aluminum foil reflectors work very well. Multi-reflector solar cookers typically have four reflectors (one on each side of a rectangular opening), although some models use eight reflectors.

Solar box cookers can be insulated with a wide variety of materials, including cardboard, newspaper, and straw. The outer box can be made from cardboard or other more durable materials, such as plywood, sheet metal, or moulded fiberglass. The cost of a solar cooker depends primarily on the materials with which it is made. The simplest cookers can be made at home at a very low cost, while sophisticated

Figure 12.9: A multi-reflector cooker on Taquile Island, Peru.
Joshua Bills

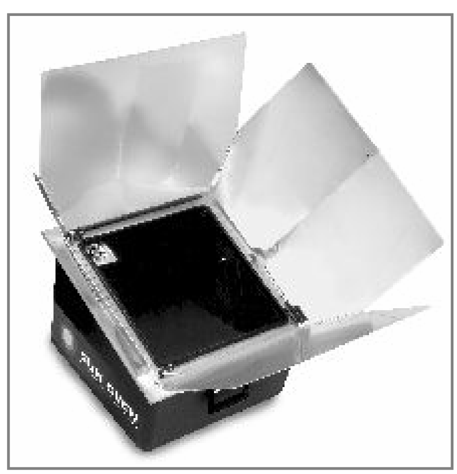

Figure 12.10: The Sun Oven, a commercially-available solar oven
Sun Ovens International, Inc.

Figure 12.11: A basket cooker at the Centre for Rural Technology in Nepal.
Solar Cookers International

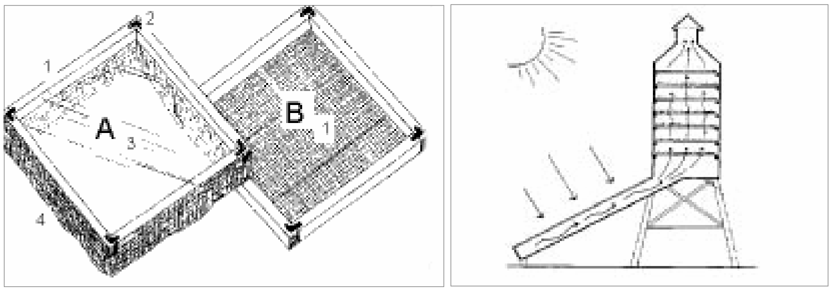

Figure 12.12: On left, Leaf for Life's simple solar food dryer. On right, a solar collector provides warm air to a stack of drying trays.
David Kennedy

manufactured models cost over $200. Both types perform very well, but the more durable and manufactured models will last longer and will be more resistant to weathering (which can make using the cookers more convenient).

The other type of multi-reflector cooker, promoted by Solar Cookers International and known as the Cookit, does not use a box at all- it uses a plastic baking bag set inside of a small reflector dish. The reflector dish is typically made of cardboard panels laminated with aluminum foil, and a black pot is placed inside the baking bag. This cooker is one of the simplest, least expensive, and most-portable varieties, yet still achieves temperatures in the mid 200's °F.

Solar cookers offer a number of advantages apart from the fact that they require no fuel or electricity. They are actually a labor saving device. Foods like rice and beans can be placed in the cooker early in the day and removed in the evening ready to eat. This can greatly reduce time spent preparing dinner, freeing one to do other things while dinner is cooking. By cooking outdoors, the solar cooker also keeps the kitchen cooler on hot summer days.

The Solar Oven Society (Figure 12.8) and Sun Ovens International (Figure 12.10) are two organizations that manufacture solar ovens for sale in the US and around the world. Both organizations are focused on halting deforestation and improving the lives of people in developing nations who rely on wood as a cooking fuel.

Solar cookers can also be used to pasteurize water. The Water Pasteurization Indicator (WAPI), available from Solar Cookers International, enables water to be reliably pasteurized in solar cookers, providing a free source of safe drinking water (see section on Solar Water Pasteurization later in this chapter).

Solar Food Drying

Solar food dryers can be used to dry vegetables and fruits at the home and commercial scale. Simple solar dryers can be easily built by most people using common materials such as lumber, wire mesh, insect screen, and plastic sheeting or glass. Leaf for Life, a non-profit organization that promotes improved nutrition through eating vegetables, offers plans for a simple solar leaf dryer (see Figure 12.12, drawing on left). This dryer consists of an upper panel glazed with plastic sheeting and a lower panel covered with wire mesh. The lower panel supports the drying greens and allows for ventilation, while the upper panel collects the sun's energy. A band of insect screen wraps around the edge of the two panels, preventing insects from entering the dryer.[1]

Leaf for Life offers plans for an improved solar food dryer (see Figure 12.13) which can dry a greater variety of fruits and vegetables. This model dries foods more quickly and works well on cooler and cloudier days.[2]

A different solar food dryer model (Figure 12.18) sandwiches the drying racks between two sheets of black metal and a sheet of glazing. The sheet of metal below the drying racks has raised ridges running from the bottom to the top of the dryer, enabling air to flow through the racks. The glazing rests on top of the upper metal panel, concentrating the sun's energy. The dryer must be located in an unshaded location and tilted at an angle, which will allow the heated air to rise through the dryer and out the top. Screened openings prevent insects and animals from entering the dryer and disturbing the drying food.[3] Each of the above-mentioned solar food dryers are used regularly in Kentucky to dry a variety of vegetables.

Another solar food dryer design uses a drying box attached to the top end of a solar collector. Multiple trays of food can be placed in the box, which has a chimney to facilitate proper air flow. Leaf for Life reports that the stack of trays in this design reduces airflow in the dryer, which often results in uneven drying and moldy food.[4]

Figure 12.13: Leaf for Life's improved solar food dryer
David Kennedy

Figure 12.14: Rainmaker solar water distiller
SolAqua, Inc.

Solar Water Purification

Many people lack access to safe drinking water or do not trust the quality of their water supply. In the United States, various water treatment systems are available, and many people now purchase bottled water, at relatively high prices. Many common water treatment systems, however, rely upon outside energy inputs, chemical disinfectants, and/or pressurized water to achieve purification. Two methods of purifying water using solar energy are available, and they operate without the use of electricity, fuel, or chemicals and do not require water under pressure. These methods are solar water distillation and pasteurization.

Solar Water Distillation

A solar water distiller (or solar still) purifies contaminated water through evaporation, separating the water from contaminants such as bacteria, micro-organisms, algae, salts, sediments, and other particulates. "Solar stills are highly effective in bringing water to the proper temperature. Water doesn't have to be boiled to be distilled. Simply elevating the temperature to a point near the boiling level will adequately increase the evaporation rate."[5] Solar stills are used by individual families, neighborhoods, and entire villages to provide safe drinking water in places such as West Texas, Mexico, the Bahamas, and Saudi Arabia.

"A solar still…is essentially an insulated, dark-colored container or shallow pan, covered by a sheet of clear glass or plastic that is tilted slightly to let the fresh water that condenses on it trickle down into a collection trough. The still is filled with six to twelve inches of water, and the water is evaporated by solar thermal energy, which condenses the water vapor onto the glazing material. The glazing also serves to hold the heat inside the unit. Several companies in the U.S. make simple solar distillers that can provide about two gallons of distilled water per day in sunny weather."[6]

Solar distillation is not effective for removing volatile chemical contaminants from water, such as gasoline, which has a lower boiling point than water. If you suspect that your water may be contaminated with such chemicals, have your water tested to determine the best purification method.

Solar Water Pasteurization

Pasteurization kills disease-causing organisms that may be present in water by exposing them to high temperatures over a given period of time. The higher the temperature used, the less time required to achieve pasteurization. Organisms such as giardia, protozoan cysts, cryptosporidium, bacteria (such as *V. cholerae, E. coli, Shigella, Salmonella typhi*), rotoviruses, and the hepatitis A virus are all killed rapidly at 149°F (65°C). While pasteurization is commonly used to ensure the safety of commercially-produced milk and juices, it can also be used to disinfect water for drinking and cooking.

Solar pasteurization can be achieved without the use of fuels or electricity. Pasteurizers do not require filters, chemicals, or other components that must be replaced on an ongoing basis. These characteristics make this a valuable treatment option in remote locations without access to other power sources. Solar cookers and the commercially-made SWS solar pasteurizer each work effectively at treating biologically-contaminated water. According to a report from the National Renewable Energy Laboratories cited on the SWS website, "the effectiveness of the SWS pasteurizer is superior to chlorine, slow sand filtration, ceramic filters, roughing filters, and UV radiation."[7] A simple, inexpensive device known as a water pasteurization indicator (WAPI) can be used to determine when water has reached pasteurization temperatures. WAPI's can be purchased from Solar Cookers International (see Resources list at the end of

Figure 12.15: Solar water pasteurizer
Safe Water Systems

this chapter).

Pasteurization does not remove salts, minerals, heavy metals, chlorine, pesticides, or other chemicals that may be present in water. It is strictly used for disinfecting biologically-contaminated water. Before selecting a water treatment system, it is important to know which contaminants may be present in the water, to ensure the final quality of the treated water.

Figure 12.16: Mark Schimmoeller and Jennifer Lindbergh's passive solar cabin, with solar cooker on the left, *Andy McDonald*

Solar Cooking is a Mainstay in a Franklin County Home

Mark Schimmoeller and Jennifer Lindbergh live on a hilly, partially forested homestead in the northern part of Franklin County, Kentucky. They and their family have been using solar cookers on a regular basis for over ten yeas. Mark built the solar cooker that he and Jennifer use, based on a design he helped develop during a work project in Peru. This multi-reflector solar box cooker is insulated with cardboard and newspaper, has a glass lid, and a door in the rear panel. Four reflectors made from plywood and aluminum foil concentrate the sun's energy inside the box, cooking the food.

The solar cooker is a mainstay in Mark and Jennifer's home from March through October. On nearly every day that's at least partly sunny, a main portion or their whole dinner is cooked outside with the sun's energy. Some of the foods they most commonly cook in the solar cooker are beans, rice, potatoes, and other vegetables. Mark is a writer and works from home, which makes it convenient for him to put food in the cooker at mid-morning and to reposition the cooker a couple of times during the day. They find that the solar cooker is a time-saver, because they can do other things while their main dishes are cooking outside. When the evening comes, they bring in the pots from the solar cooker and maybe add a few final touches to their meal. This helps them to get dinner prepared more quickly.

Mark's mother, sister, and some friends also use solar cookers on a regular basis. The dishes they prepare include casseroles, omelets, lasagna, pasta, tomato sauce, breads, cakes, cookies, granola, soups, pizza, and fruit canning. Mark's family-members are mostly vegetarian so they do not cook meat dishes, but the solar cooker does cook meat without any trouble. During his work in Peru, meat was commonly cooked in the solar cookers he built with Peruvian families.

A Solar Home, both Simple and Sophisticated

In January 2001 Mark and Jennifer moved into their 288 square foot post-and-beam cabin, which they had been building for the previous 18 months. Their cabin is off the grid and has no utility connections- neither water nor gas nor phone. The cabin was sited and designed to make optimum use of the sun's energy. Two 75-watt solar panels were installed on the roof before they moved into the house. The long south face of the house has windows carefully located to provide passive solar heating during the cold months, while the overhang was designed to prevent unwanted solar heat gain during the warm season. Open space in the yard around the cabin hosts the solar cooker and a solar water heater, both of which are used on a regular basis from March through October.

Since moving into their cedar cabin, Mark and Jennifer have built an addition onto the south and east portions of the house. The addition has doubled the area of the house (not counting a new root cellar beneath the addition). To accommodate additional electrical needs in the addition, another 75-watt PV panel was added to the roof, along with a new battery bank. The addition has enhanced the original passive solar design, by including thermal mass in the form of a Solar Slab, a concrete slab designed to circulate solar-heated air around the cabin.

The couple installed a third solar electric system to service a small (10'x16') guest cabin on their land. This 100-watt array provides electric lighting, can run small appliances like a radio or laptop computer, and operates a telephone answering machine (the guest cabin also serves as a phone booth).

The initial 150-watt solar array installed on the cabin powers a small, super-efficient DC refrigerator and two compact fluorescent lights, which can each be used for about 4 hours per day. They also have a stereo CD player which they occasionally use. (They have a radio with a built-in solar panel and battery which works very effectively). The cabin is wired for 12-Volt DC power and they have a battery back-up. The 75-watt PV panel installed on the addition was designed to power additional lighting, an attic fan, house fan, and a very efficient washing machine. The attic fan has its own small PV panel that runs it whenever the sun is shining. A switch enables the fan to be powered at night from the batteries.

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Jennifer and Mark have been very happy with the performance of their solar electric system. It has never run low on power, even in the dead of winter and the refrigerator, while small, meets their needs. "Honestly, I've been surprised at how well the solar system works," commented Jennifer. "Before we moved into the house I had thought that relying on solar energy would require some kind of sacrifice- and I was ok with that. But the reality has been that we have all the electricity we need, there's very little maintenance required (although I must confess, Mark does the maintenance), and the system just works really well."

The PV system at the guest cabin has also functioned well. The one problem they had was finding an answering machine that would operate on 12V DC at the proper amperage. They use a cigarette lighter adapter to plug the answering machine directly into the 12V power supply.

The solar water heater is a variation on the solar cooker, utilizing a large insulated box covered with glass but lacking reflectors. Since Mark and Jennifer do not have running water, they heat their water in a large pot inside the water heater, then carry the pot into the house for washing and bathing. (In the winter time they just keep the pot on the wood stove.) Mark's family also uses a solar food dryer, which he built for drying vegetables and herbs.

Figure 12.17: PV panels power the Schimmoeller-Lindbergh residence, *Andy McDonald*

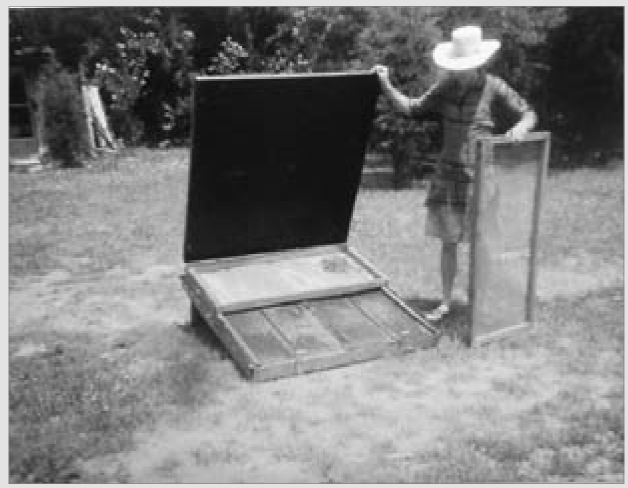

Figure 12.18: Mark Schimmoeller with his solar food dryer, *Chris Schimmoeller*

End Notes

1. Leaf for Life, CD-ROM, November 2002. Leaf for Life's publications are available at: www.leafforlife.org. They can be contacted at 260 Radford Hollow Rd., Big Hill, KY 40405, Tel: 859-986-5418.
2. David Kennedy, "Five a Day the Sun Dried Way," Leaf for Life, Big Hill, Kentucky, September 2002. Available at www.leafforlife.org
3. Dryer design courtesy of Larisa Walk, Rt. 3, Box 163A, Winona, MN 55987
4. David Kennedy, p.2.
5. Scott Sklar and Kenneth Sheinkopf, *Consumer Guide to Solar Energy*, Bonus Books, Inc., Chicago, 1995, pp.88-89. Contact information for SolAqua, manufacturers of the solar water distiller shown in Figure 12.14, can be found in the Resources list at the end of this chapter.
6. Ibid, p.90.
7. Information available at: www.safewatersystems.com/General%20Pages/Frames%20Page.htm. Contact information for Safe Water Systems, manufacturers of the water pasteurizer shown in Figure 12.15, can be found in the Resources list at the end of this Chapter.

RESOURCES: Solar Cooking

Publications

"A Solar Cooker," Mark Schimmoeller and Andy McDonald, self-published, Frankfort, Kentucky, 1996.

Cooking with Sunshine: The Lazy Cook's Guide to Solar Cuisine, L. Anderson, Our House Publishing, 1994.

Cooking With the Sun: How to Build and Use Solar Cookers, B. Halacy & D. Halacy, Morning Sun Press, 1992.

Heaven's Flame: A Guide to Solar Cookers, J. M Radabaugh & B. Root, Home Power Publishing, Oregon, 1998.

Solar Cooking: A Primer/Cookbook, Harriett Kofalk, Book Publishing Company, Tennessee, 1995.

Solar Cooking Made Easy, D. Stutzman, The Sunshine Cooks, 1980.

Solar Cooker Manual, Ron Alward, Brace Research Institute, MacDonald College of McGill University, Ste. Anne de Bellevue, Quebec. No date.

Organizations

Solar Cookers International
1919 21st Street #101
Sacramento, CA 95814
(916) 455-4499
www.solarcookers.org

Solar Cookers International (SCI) has headquarters in Sacramento, California, USA and an office in Nairobi, Kenya. Since its founding in 1987 SCI has spread solar cooking skills and technologies where they are needed most. Over 30,000 families have benefited directly from SCI's field projects and countless others have used SCI's resources to learn how to make and use solar cookers and teach others to do the same. Their website offers numerous publications for sale and other resources.

Solar Oven Society
3225 Hennepin Avenue East
Suite 200, Minneapolis, MN 55413
(612)623-4700
www.solaroven.org

The Solar Oven Society (SOS), manufacturer and distributor of the SOS Sport Solar Oven, works in the United States and developing countries to provide solar cooking technology, demonstrations, training, assembly, service, wholesale & retail sales, and to introduce other solar technologies.

Sun Ovens International, Inc.
39W835 Midan Drive
Elburn, IL 60119 USA
(630) 208-7273 or (800) 408-7919
www.sunoven.com

SUN OVENS International, Inc. is striving to develop and implement comprehensive solar cooking programs that will radically decrease the developing world's dependence on fuel wood and dung as the primary cooking fuels while benefiting the environment, raising the standard of living and improving the health of the poor worldwide. Manufacturers and distributors of the Sun Oven solar cooker.

RESOURCES: Solar Food Drying

Publications

A Survey of Solar Agricultural Dryers, Brace Research Institute, Technical Report T99, MF 07-283, 1975.

"Build PM's Solar Food Dryer," J. Hoffman, *Popular Mechanics*, (51:1) pp. 100-101, 128, January 1979.

"The Design, Construction, and Use of an Indirect, Through-Pass, Solar Food Dryer," D. Scanlin, *Home Power*, (No. 57) pp. 62-72, February/March 1997.

"Dry Your Own Fruits and Vegetables: The Dryer That Is Powered by the Sun, Stove, or Electricity," *Mother Earth News*, (No. 136), February/March 1993.

"Five a Day the Sun Dried Way," David Kennedy, Leaf for Life, Big Hill, Kentucky, September 2002.

How to Dry Food, D. DeLong, H.P. Books, 1992.

Making and Using Dried Food, P. Hobson, Storey Communications, 1994.

Putting Food By (4th ed.), R. Hertzberg and B. Vaughan, Viking Penguin Press, 1992.

Solar Convection Grain Dryer, Volunteers in Technical Assistance (VITA).

The Solar Food Dryer Book, S. Andrassy, Earth Books, Dobbs Ferry, NY, 1978.

Solar Food Dryers: Their Role in Post-Harvest Processing, B. Brenndorfer et al (Ed.), Commonwealth Science Council, 1987.

(continued on next page)

Solar Food Dryer: Preserves Food for Year-Round Use Using Solar Energy, R. Wolf, Rodale Press, Emmaus, PA, 1981.

Organizations

Leaf for Life
260 Radford Hollow Rd.
Big Hill, KY 40405
(859)986-5418
www.leafforlife.org

Leaf for Life helps people improve their health by showing them ways to make better use of vegetables, especially leaf crops, in their diets. Much of their work revolves around two techniques for converting leaf crops into more versatile and valuable foods: solar drying of leaf crops and making leaf concentrate. Their web site provides publications explaining how to build and use a solar leaf dryer.

Solar Cookers International

See Solar Cooking Resources for more information.

RESOURCES: Solar Water Purification

Safe Water Systems
2800 Woodlawn Drive, Suite 265
Honolulu, HI 96822
(808)539-3937
www.safewatersystems.com

Manufacturers of the Sol Saver and Family Sol Saver solar water pasteurizers.

SolAqua, Inc.
P.O. Box 4976
El Paso, Texas 79914-4976
(866)765-2782 or (915) 822-1132
www.solaqua.com

SolAqua provides solar water distillation products, do-it-yourself distiller kits, plans, and consulting. They manufacture and sell the Rainmaker™ 550 solar water distiller.

Solar Cookers International

See solar cooking resources for more information.

Section III

Financial Incentives and Resources for Finding Solar Installers and Equipment

Chapter Thirteen
Incentives that Support Renewable Energy and Energy Efficiency

Several types of incentives are available to support investments in renewable energy and energy efficiency in Kentucky. The specific incentives available vary in different parts of the state, and include rebates and cash payments, loans, financing assistance, tax incentives, programs that purchase power generated from renewable sources (including net metering), energy audits, and home weatherization programs. Incentives are available to the residential, commercial, agricultural, industrial, and public sectors. Incentives are provided from a variety of sources, including the Federal government, electric utilities, and private for-profit and non-profit organizations.

The available incentives change regularly. To find the most up-to-date information about incentives available in your region, refer to the Database of State Incentives for Renewable Energy (www.dsireusa.org). Contact your local electric utility or Community Action Agency to learn about programs that support home weatherization and energy conservation (see below for contact information).

If your electric utility is supplied by the Tennessee Valley Authority (TVA), their Generation Partners Program (described below) may be of interest to you. This program presently offers the best incentives for solar electricity in Kentucky. Although most TVA distributors in Kentucky are not actively promoting this program, if their customers call them wanting to participate, they may be open to working with you.

TAX CREDITS AND OTHER TAX INCENTIVES

Residential Energy Efficiency Tax Credit

Incentive Type: Personal Tax Credit, Federal
Eligible Technologies: Water Heaters, Furnaces, Boilers, Heat pumps, Air conditioners, Building Insulation, Windows, Doors, Roofs, Circulating fan used in a qualifying furnace, geothermal heat pumps
Sector: Residential
Amount: 10% of cost of building envelope improvements; 100% for qualified energy property (heating, cooling, water heaters)
Maximum Incentive: Varies by technology; no more than $500 credit for all energy property and envelope improvements for all tax years.
Dates of Availability: Jan. 1, 2006 – Dec. 31, 2007
Website: www.irs.gov/newsroom/article/0,,id=154657,00.html
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
800-829-1040
Source: www.dsireusa.org

Residential Solar and Fuel Cell Tax Credit

Incentive Type: Personal Tax Credit, Federal
Eligible Technologies: Solar Hot Water, Photovoltaics, Fuel cells. Solar swimming pool heaters are NOT included.
Amount: 30% of equipment and installation cost
Maximum Incentive: $2,000 for solar water heating and photovoltaics; $500 per 0.5 kW for fuel cells.
Carryover Provisions: Excess credit may be carried over to succeeding tax year.
Eligible System Size: Not specified.
Equipment Requirements: Solar water heating property must be certified by SRCC or by comparable entity endorsed by the state. At least half the energy used to heat the dwelling's water must be from solar in order for the solar water heating property expenditures to be eligible.
Dates of Availability: System must be placed in service between Jan. 1, 2006 and Dec. 31, 2007
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
800- 829-1040
Source: www.dsireusa.org
Additional information sources:
Kentucky Office of Energy Policy - 502-564-7192.
See KOEP's web page on the 2005 Energy Policy Act:
www.energy.ky.gov/2005federalenergybill.htm
Tax Incentives Assistance Project –
www.energytaxincentives.org

Solar & Geothermal Business Energy Tax Credit

Incentive Type: Business Tax Credit, Federal
Eligible Technologies: Solar hot water, solar space heating, solar thermal electric, solar thermal process heat, photovoltaics, geothermal electric and direct use geothermal, fuel cells, solar hybrid lighting, micro-turbines. [Note: geothermal heat pumps NOT included.]

Sectors: Commercial, Industrial
Amount: For equipment placed in service from January 1, 2006 until December 31, 2007, the credit is 30% for solar, solar hybrid lighting, and fuel cells, and 10% for micro-turbines and geothermal.
Maximum Incentive: No maximum specified for solar or geothermal. $500 per 0.5 kW for fuel cells; $200 per kW for micro-turbines.
Eligible System Size: Micro turbines less than 2 MW; fuel cells at least 0.5 kW
Website: http://www.irs.gov/pub/irs-pdf/f3468.pdf
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
800-829-1040
Source: www.dsireusa.org

New Energy-Efficient Home Tax Credit for Builders

Eligible technologies: Comprehensive energy efficiency measures/ whole building
Sector: Construction
Amount: $2,000 for new site-built homes and manufactured homes achieving 50% energy savings. $1,000 for manufactured homes achieving 30% energy savings.
Dates of Availability: January 1, 2006 – December 31, 2007
Website: www.irs.gov/newsroom/article/0,,id=154658,00.html
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
1-800- 829-1040
Source: www.dsireusa.org

Energy Efficient Commercial Buildings Tax Deduction

Eligible Technologies: Equipment Insulation, Water Heaters, Lighting, Lighting Controls/Sensors, Chillers, Furnaces, Boilers, Heat pumps, Air conditioners, CHP/Cogeneration, Caulking/Weather-stripping, Duct/Air sealing, Building Insulation, Windows, Doors, Siding, Roofs
Sectors: Commercial, Construction
Amount: $0.30-$1.80 per square foot, depending on technology and amount of energy saved
Maximum Incentive: $1.80 per square foot
Equipment Requirements: Must meet certification requirements.
Dates of Availability: January 1, 2006 – December 31, 2007
Web site: http://www.irs.gov
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
1-800-829-1040
Source: www.dsireusa.org

Modified Accelerated Cost-Recovery System (MACRS)

Incentive Type: Corporate depreciation
Eligible Technologies: Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Wind, Geothermal Electric, Fuel Cells, Solar Hybrid Lighting, Direct Use Geothermal, Micro-turbines
Sectors: Commercial, Industrial
Website: www.irs.gov
Summary: Under MACRS, businesses can recover investments in certain property through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from three to 50 years, over which the property may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class is five years. With the passage of the Energy Policy Act of 2005, fuel cells, micro-turbines, and solar hybrid lighting technologies are now classified as 5-year property as well.
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
1-800-829-1040
Source: www.dsireusa.org

Renewable Electricity Production Tax Credit

Incentive Type: Corporate Tax Credit
Eligible Technologies: Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Municipal Solid Waste, Refined Coal, Indian Coal, Small Hydroelectric
Sectors: Commercial, industrial
Amount: 1.9¢/kWh for wind, geothermal, closed loop biomass; 0.9¢/kwh for others. Applies to first 10 years of operation.
Dates of Availability: Varies by technology
Website: http://www.irs.gov/pub/irs-pdf/f8835.pdf
Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
1-800-829-1040
Source: www.dsireusa.org

Residential Energy Conservation Subsidy Exclusion (Personal and Corporate)

Incentive Type: Personal and corporate tax exemption
Eligible Technologies: Energy efficiency and conservation improvements; solar hot water, solar space heating, and photovoltaics may be eligible
Sectors: Residential, multi-family residential
Website: www.irs.gov/publications/p525/index.html
Summary: According to Section 136 of the IRS Code, energy conservation subsidies provided by public utilities, either directly or indirectly, are nontaxable: "Gross income shall not include the value of any subsidy provided (directly or indirectly) by a public utility to a customer for the purchase or installation of any energy conservation measure." Such measures include installations or modifications primarily designed to reduce consumption of electricity or natural gas, or improve the management of energy demand. *Dwelling unit* includes a house, apartment, condominium, mobile home, boat, or similar property. If a building or structure contains both dwelling and other units, any subsidy must be properly allocated.

Given the definition of "energy conservation measure" there is strong evidence that utility rebates for residential solar thermal and solar electric projects may be nontaxable. However, the IRS has not ruled definitively on this issue. For taxpayers considering using this provision for renewable energy systems, consultation with a tax attorney is advised. Other types of utility subsidies that may come in the form of credits or reduced rates may also be nontaxable.

Contact: Internal Revenue Service
1111 Constitution Avenue, N.W.
Washington, DC 20224
1-800-829-1040
Source: www.dsireusa.org

Alternative Fuel and Vehicle Tax Incentives

Eligible Technologies: Automobiles (hybrid gas-electric, "clean fuel", and electric vehicles)
Amount: Varies
Websites: www.fueleconomy.gov, www.eere.energy.gov/afdc/progs/fed_summary.cgi?afdc/US/0, www.ase.org/content/article/detail/2654
Contact: Visit the above websites for contact information

FINANCING ASSISTANCE

Low-Interest Loans for Solar Water Heaters (from MACED and the KY Solar Partnership)

Eligible Technology: Solar Water Heaters
Sector: Residential, commercial
Interest Rate: 6.0%, fixed
Terms: Maximum loan limit: $6,000; 6 year fixed term. Higher loans for larger systems (such as those used for radiant home heating or commercial systems) will be evaluated on a case by case basis.
Requirements: SRCC rated solar collectors required. See loan application at website below for full requirements and loan application.
Eligibility: Residents and businesses of Eastern Kentucky counties (see website or call for map)
Website: www.kysolar.org/swh_loans.htm
Contacts: Kentucky Solar Partnership
2235 Gregory Woods Rd.
Frankfort, KY 40601
solar@kysolar.org
1-888-576-6527

Or Mountain Association for Community Economic Development (MACED)
433 Chestnut St.
Berea, KY 40403
1-859-986-2373
www.maced.org

Low-Interest Loans for Renewable Energy Systems and Renewable Energy Businesses in Eastern Kentucky (from MACED)

Eligible Technologies: renewable energy systems
Sector: Commercial
Interest Rate: contact MACED for current rates and terms
Eligibility: Businesses located in the 51 counties of Eastern Kentucky served by MACED
Website: www.maced.org
Summary: MACED offers low-interest financing for businesses to install renewable energy technologies for use in their facilities. MACED also offers small business loans for new or developing renewable energy businesses.
Contact: MACED
433 Chestnut St.
Berea, KY 40403
859-986-2373

Loan Discounts for Sustainability Investments (Permaculture Credit Union)

Eligible Technologies: home energy efficiency upgrades, renewable energy generation, permaculture landscaping, water catchment and delivery, farm machinery, and fuel-efficient automobiles
Sectors: Residential, commercial
Terms: The PCU offers its members loan discounts of 0.75% for qualifying sustainability investments (for fuel-efficient automobiles, the discount is 0.75% for vehicles that achieve 35mpg average and 1.5% discount for vehicles that exceed 45 mpg on average).
Eligibility: Loans available to PCU members.
Website: www.pcuonline.com
Summary: The Permaculture Credit Union (PCU) offers its members loans with aggressive discounts for qualifying sustainability investments. The PCU is a credit union of members dedicated to the following ethics of Permaculture: care of the Earth, care of people, and reinvestment of the surplus to benefit the Earth and its inhabitants. Membership in the PCU is open to anyone who subscribes to the ethics of Permaculture, or has completed a Permaculture recognized design course, or is a member of an affiliated Permaculture Institute.

You can join the PCU by paying a membership fee of $5.00 and opening a share account with a minimum deposit of $50.00. You must maintain an average daily balance of $300.00 to accrue dividends (interest).

The PCU offers Share Accounts (Savings Accounts) and a variety of loan products, which include: signature loans up to $5,000; home equity and auto loans up to $40,000; and share-secured loans up to the full deposit amount.

Contact: Permaculture Credit Union
4250 Cerrillos Road
P.O. Box 29300
Santa Fe, NM 87592-9300
505-954-3479 or 866-954-3479 (toll-free); 505-424-1624 (fax)

Paducah Power System – Residential Energy Efficiency Loan Program

Eligible Technologies: Heat pumps, building insulation, and other energy saving measures
Sector: Residential
Terms: Fixed rate of 7%; maximum loan $7,500; loan term up to 5 years
Website: www.paducahpower.com/financingha.htm
Summary: Paducah Power System provides loans to their residential customers to help make their homes more energy efficient. The loans can be up to $7,500 and can be used to install new qualifying heating and cooling systems along with upgrades to insulation or other energy savings measures. The loan term can be up to 5 years and has a fixed rate of 7%. Heat pumps must be installed by a member of their Quality Contractor Network (QCN).
Contact: Paducah Power System
Ella Mayes
PO Box 180
Paducah, KY 42002
270-575-4000
Source: www.dsireusa.org

Energy Efficient Mortgages

Summary: A variety of mortgage and home improvement loan programs exist to help pay the cost of improving the energy efficiency of new and existing homes. Some programs will also finance investments in renewable energy systems. The specific benefits and conditions for participating in each program vary, and the amount of money involved can range from a few hundred dollars to tens of thousands of dollars.

Energy efficient mortgages (EEM's) are used by homeowners to pay for energy efficiency and renewable energy investments for new and existing homes. Any homeowner who qualifies for a mortgage also qualifies for an EEM. These mortgages are offered through a variety of agencies, including the FHA and VA, and private lenders associated with Fannie Mae and Freddie Mac. The Energy Star Homes Program, a project of the U.S. Department of Energy and U.S. Environmental Protection Agency, also encourages participating lenders to offer EEM's. The energy improvements gained through an EEM will result in reduced utility bills over the life of the home. Energy efficiency investments can reduce utility costs by up to 50%, an annual savings of up to $650 for a typical home. EEM's allow homeowners to qualify for up to 2% more debt if they use the additional financing to make energy-efficiency and/or renewable energy improvements to a new or existing home. While this increases mortgage payments, the combined monthly mortgage and utility payments for an EEM home will be less than those for a regular mortgage due to reduced utility bills. The EEM also provides a higher quality, more comfortable home with a higher re-sale value.

EEM's require a Home Energy Rating (HERS Rating) performed by an energy professional to determine the anticipated energy savings resulting from the home energy improvements.

Other energy efficiency financing assistance programs offer different packages of incentives. An Energy Star mortgage, for instance, may include incentives such as lower interest rates, a discount on closing costs and/or origination fees, up to a 4 percent extension of the debt-to-income ratio stretch, or payment of the cost for a home energy rating.

"You can benefit from energy-efficient

financing whether you're buying, selling, refinancing, or remodeling a home. If you're looking to buy an energy-efficient home, you can qualify for a better, more comfortable home because with lower utility costs, you can afford a slightly larger mortgage payment. You can also obtain financing to make energy-efficient improvements to an older home before moving in or to your existing home. And if you put your home on the market, you can use its energy efficiency as an attractive selling point."[1]

The following list identifies lenders in Kentucky who provide energy efficient mortgages or other types of financing assistance for energy efficiency and renewable energy. Although the national mortgage agency Countrywide Home Loans officially offers EEM's, many local branches in Kentucky are unfamiliar with them. If your local mortgage lender or loan office is unfamiliar with energy efficient financing options, let them know of your interest. Citizens play an important role in stimulating demand for programs such as this, and your interest can stimulate local lenders to begin offering these programs.

Sources:www.dsireusa.org, www.natresenet.org, www.erha.com

Countrywide Home Loans

800-669-6607

Countrywide has offices in many Kentucky locations. Check the phone book or call their national office to find the office nearest you.

Federal Housing Administration (FHA) Energy Efficient Mortgages

US Dept. of Housing and Urban Development (HUD)
451 7th Street SW
Washington, DC 20410,
www.hud.gov
www.hud.gov/progdesc/energy-r.html (EEM Program)

All FHA approved lenders can offer EEM's, although it is up to their discretion whether they actually do. A state by state list of FHA approved lenders is available on their web site, www.fha.com. FHA can be contacted through your local HUD office, which can be found in the phone book or on HUD's Web site.

Fannie Mae

3900 Wisconsin Avenue, NW
Washington, DC 20016-2892
1-800-7FANNIE (1-800-732-6643)
www.homepath.com, www.fanniemae.com

Freddie Mac

8200 Jones Branch Drive
McLean, VA 22102-3107
1-800-FREDDIE (1-800-373-3343)
www.freddiemac.com

Veteran's Administration (VA) Loans

1-800-848-4904
www.homeloans.va.gov/ (Home Loan Guaranty website)

All lenders offering VA loans can offer EEM's. If you call lenders listed in your phone book, many will offer VA loans. You can also find a list of lenders in your area by visiting: www.vba-roanoke.com/rlc/va-e-lenders/ . Chapter 7 (7.03) of the lenders handbook has additional information about EEM's.

***Further information about energy efficient mortgages*:**

ENERGY STAR Homes

1-888-STAR-YES (1-888-782-7937)
www.energystar.gov

National Home Energy & Resources Organization (HERO)

4005 Poplar Grove Road
Midlothian VA 23112
1-800-373-2416
www.national-hero.com

Provides state-by-state listings of the energy raters it trains and certifies.

Residential Energy Services Network (RESNET)

P.O. Box 4561
Oceanside, CA 92052-4561
1-760- 806-3448
www.natresnet.org

A national network of mortgage companies, real estate brokerages, builders, appraisers, utilities, and other energy and housing professionals dedicated to improving the energy efficiency of the nation's housing. It provides state-by-state directories of conventional EEM lenders and energy raters.

Veterans Housing Guaranteed and Insured Loans

Eligible Technologies: Equipment Insulation, Heat pumps, Caulking/Weather-stripping, Building Insulation, Windows, Doors, Roofs, Passive Solar Space Heat, Solar Water Heat, Solar Space Heat
Sectors: Residential, Veterans, Retired Service Personnel, Unmarried Surviving Spouses of Veterans
Amount: Varies
Maximum limit: $3,000 - $6,000
Terms: Department of Veteran's Affairs guarantees 50% of the loan
Date of Availability: Ongoing
Website:
www.federalgrantswire.com/veterans_housingguaranteed_and_insured_loans.html
Contact: Please visit the program website above.
Source: www.dsireusa.org

REBATE PROGRAMS

Solar Water Heater Rebate Program

Eligible Technologies: Solar Water Heaters
Sectors: Residential
Amount: $500
Eligibility: Available for systems installed on residences in Kentucky
Requirements: SRCC rated collectors are required. SRCC systems are recommended. (See rebate application for details.) All major system components must have at least a 1-year warranty. System must include at least a two-year installation warranty that covers any defect in the workmanship of the installation at no charge to the owner.
Website: www.kysolar.org/swh_rebate.htm
Summary: The Kentucky Solar Partnership, in collaboration with the Energy Center at the University of Louisville and the US Department of Energy, is offering a $500 rebate for solar water heaters installed on residences in Kentucky. Initial funding provided rebates for 25 installations and efforts are being made to expand the program. Owner-installed systems are eligible, but applicants must demonstrate that they have attended a solar water heater installation workshop or have the necessary skills to complete the project, and must meet all the terms and conditions of the program.

As a condition for receiving a rebate, recipients must agree to allow the Kentucky Solar Partnership to inspect the solar water heating system after installation and to perform monitoring of the performance of the system for up to two years. They also agree to allow information about their home and solar system to be used in educational materials produced for the purpose of promoting the use of solar energy.

Swimming pool heaters and radiant home heating systems are not eligible for the incentive at this time, nor are repairs to or expansion of existing solar water heating systems. Applications are available at www.kysolar.org/swh_rebate.htm.
Contact: Kentucky Solar Partnership
2235 Gregory Woods Rd.
Frankfort, KY 40601
solar@kysolar.org
1-888-576-6527

Duke Energy – Commercial and Industrial Energy Efficiency Rebate Program

Eligible Technologies: Lighting, heat pumps, air conditioners, motors, pumps
Sectors: Commercial, industrial
Amount: Motors: $4/HP -$10/HP, varies based on HP
Pumps: $160/unit - $400/unit, varies according to HP
Lighting: $2/unit - $125/unit, varies according to technology and system size
Heat Pumps: $20/ton - $45/ton, varies according to technology, system size and efficiency rating
Maximum Incentive: $50,000 per calendar year, per facility
Requirements: Rebates for lighting equipment are offered for retrofits only. All other incentives are valid for retrofits or new installations. Equipment must either be installed by a pre-approved contractor, or obtain site verification by Duke Energy personnel after installation.
Website: www.cinergyulhp.com/kysbus/energy_management/energy_efficiency_incentive_program.asp
Contact: Duke Energy
C&I DSM Programs - WP680
1000 East Main St
Plainfield, IN 46168
1-800-283-7741
Web site: www.duke-energy.com
Source: www.dsireusa.org

Duke Energy – Compact Fluorescent Light Bulb In-Store Rebate Program

Eligible Technology: Lighting
Sector: Residential
Amount: $2.00/ light bulb, maximum $24.00
Equipment Requirements: Must be Energy Star Rated
Website: www.cinergyulhp.com/kyres/savings/products/energy_star_products_and_rebates.asp
Summary: Duke Energy offers a rebate for their Kentucky electric customers to purchase compact fluorescent light bulbs for their homes. The rebate is redeemed by participating retailers at the time of purchase, and there is a limit of 12 bulbs. For a list of participating retailers, please refer to the program's website or the toll-free number provided.
Duke Energy
Customer Service
526 South Church St
Charlotte, NC 28202
1-800-573-3503
Web site: www.duke-energy.com
Source: www.dsireusa.org

REGULATIONS AND POLICIES

Net Metering Rules

"Kentucky Governor Ernie Fletcher signed statewide net metering legislation (SB 247) into law on April 22, 2004, requiring all investor-owned utilities and rural electric cooperatives to offer net metering to customers with PV systems of 15 kW or less. These utilities must file with the Kentucky Public Service Commission (PSC) a net metering tariff that includes all terms and conditions of their net metering programs, including interconnection standards, by Oct. 19, 2004.

"The legislation stipulates the use of a single meter capable of registering the flow of electricity in two directions. Any additional meter, meters or distribution upgrades needed to monitor the flow in each direction will be installed at the customer-generator's expense. If the electricity fed back to the utility by the customer-generator exceeds the electricity supplied by the utility during a billing period, the customer-generator will be credited for the excess kilowatt-hours at the retail rate. This electricity credit will appear on the customer-generator's next bill and carries forward indefinitely. Credit is not transferable.

"Although the legislation does not specify which sectors are eligible, the system capacity limit will not encourage large-scale electricity consumers to participate. If the cumulative generating capacity of net metering systems reaches 0.1% of a supplier's single-hour peak load during the previous year, the obligation of the supplier to offer net metering to a new customer-generator may be limited by the PSC.

"Electric generating systems and interconnecting equipment used by eligible customer-generators must meet all applicable safety and power quality standards established by the National Electrical Code (NEC), Institute of Electrical and Electronics Engineers (IEEE), and accredited testing laboratories such as Underwriters Laboratories (UL)."

Four Kentucky utilities initiated pilot net metering programs prior to the passage of the state net-metering law. Under these programs, PV systems, wind and small hydro facilities are eligible for net metering. These utilities and the expiration dates for their programs are Berea College Utilities (expires 9/30/06), Kentucky Utilities (KU) (expires 3/14/05), LG&E (expires 3/14/05), and ULH&P (expires 9/13/05).

Source: Excerpted from www.dsireusa.org

Solar Easements

In Kentucky, solar easements may be obtained for the purpose of ensuring access to direct sunlight. Easements must be expressed in writing and will become an interest in real property that may be acquired and transferred. Local zoning regulations may also have provisions requiring preservation of solar access. Contact the Kentucky Division of Energy for further information. Refer to KRS § 381.200.

Source: www.dsireusa.org

RENEWABLE ENERGY PRODUCTION INCENTIVES

Federal Renewable Energy Production Incentive (REPI)

Eligible Technologies: Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass, Geothermal Electric, Livestock Methane, Tidal Energy, Wave Energy, Ocean Thermal, Fuel Cells (Renewable Fuels)
Sectors: Municipal Utility, Rural Electric Cooperative, State/local governments that sell project's electricity, Tribal Government
Amount: 1.5 cents per kWh (indexed for inflation)
Terms: 10 years
Dates of Availability: Appropriations authorized through 2026
Website: www.eere.energy.gov/wip/program/repi.html
Summary: The Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Qualifying facilities are eligible for annual incentive payments of 1.5 cents per kilowatt-hour (1993 dollars and indexed for inflation) for the first ten year period of their operation, subject to the availability of annual appropriations in each Federal fiscal year of operation.
Contacts: Dan Beckley, U.S. Department of Energy
Weatherization and Intergovernmental Program
Washington, DC 20585
E-Mail: dan.beckley@hq.doe.gov
Or, Christine Carter, U.S. Department of Energy
Golden Field Office
1617 Cole Blvd.
Golden, CO 80401-3393
E-Mail: christine.carter@go.doe.gov
Web site: http://www.eere.energy.gov/
Source: www.dsireusa.org

TVA – Green Power Switch Generation Partners Program

Eligible Technologies: Photovoltaics, Wind
Applicable Sectors: Commercial, Residential
Amount: $500 (residential only) plus $0.15/kWh (residential/small commercial) or $0.20/kWh (commercial) for 10 years
Terms: $500 payment available only until program capacity reaches 150 kW
Website: www.gpsgenpartners.com
Summary: Through the Green Power Switch Generation Partners Program, the Tennessee Valley Authority (TVA) purchases the electricity produced by grid-intertied photovoltaic and wind turbine systems. TVA purchases the energy through participating power distributors and pays $0.15/kWh. TVA will also pay the owners of qualifying residential

systems $500 when a new installation is connected to the grid. The credit of $0.15/kWh is available for a minimum of 10 years from the signing of the contract, regardless of the amount produced.

In September 2004, larger commercial customers were included in the program. Under the larger commercial contract, TVA will purchase the output at $0.20/kWh.

Qualifying systems must have a minimum output of 500 W AC and a maximum of 50kW. They must provide at least a portion of the energy used at a particular site and must not have previously generated into the grid. Installations must comply with local codes and adhere to specific interface guidelines established by the program.

Participation in the program is entirely up to the discretion of the power distributors. Contact your electric utility to find out if they are affiliated with TVA. If you are in TVA's distribution area and would like to be a Generation Partner, contact your distributor and let them know. The Generation Partners Program has indicated that distributors are more likely to participate if their customers show interest in the program.

As of August 2006, 30 distributors in multiple states have signed up for the program. Thus far, the program includes several residential solar participants, a 20-kW wind project, a 50-kW commercial solar system, and a 10-kW commercial solar system.

Contact: Ginger Lawyer
Tennessee Valley Authority
Green Power Switch Generation Partners
26 Century Blvd.
OCP 2-F, NST
Nashville, TN 37229
E-Mail: gglawyer@tva.gov
Source: www.dsireusa.org

Mainstay Energy Rewards Program-Green Tag Purchase Program

Eligible Technologies: Photovoltaics, solar thermal electric, wind, biomass, geothermal electric, small hydroelectric, renewable fuels
Amount: Varies based on technology
Terms: Contact Mainstay for current information
Website: www.mainstayenergy.com
Summary: The Mainstay Energy Rewards Program purchases the power generated from renewable energy sources. "Mainstay Energy is a private company that purchases the 'green tags' or 'renewable energy credits' from small-scale renewable energy producers. Green tags represent the environmental qualities of the electricity generated by renewable energy systems. Mainstay pays participants per kilowatt-hour of production, and then re-sells the green tags it purchases to customers who want to purchase green power. The concept of green tags allows us to track the environmental benefits of renewable energy production once it enters the electrical grid.

"Payment amounts depend on the type of renewable energy technology, the amount of electricity produced, and the length of the contract period. Mainstay offers 3, 5, and 10-year purchase contracts. The longer the contract period, the more Mainstay pays per kWh. Participating systems must be grid-intertied and have been installed after January 1, 1999."

Contact: Mainstay Energy Rewards Program
161 E. Chicago Ave., Suite 41B
Chicago, IL 60611-2624
1-877-473-3682
www.mainstayenergy.com
Source: www.dsireusa.org

FEDERAL GRANT AND FINANCING OPPORTUNITIES

Tribal Energy Grant Program

Eligible Technologies: Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Photovoltaics, Wind, Biomass, Hydroelectric, Geothermal Electric, Geothermal Heat Pumps
Sectors: Tribal governments
Amount: Varies
Maximum Limit: Varies
Website: www.eere.energy.gov/tribalenergy/financial.html
Summary: DOE's Office of Energy Efficiency and Renewable Energy's Tribal Energy Program provides financial and technical assistance to tribes for feasibility studies and shares the cost of implementing sustainable renewable energy installations on tribal lands. This program seeks to promote tribal energy self-sufficiency and fosters employment and economic development on America's tribal lands.

Tribal Energy Program funding is awarded through a competitive process. Each solicitation will include instructions on how to apply, application content, and the criteria by which applications will be selected for funding. Consult the program Web site above for current funding opportunities and past solicitations.

Contact: Thomas Sacco, U.S. Department of Energy
Weatherization & Intergovernmental Program
Forrestal Building, MS 5G-045
1000 Independence Avenue SW
Washington, DC 20585
202-586-0759
E-Mail: thomas.sacco@ee.doe.gov
Web site: http://www.eere.energy.gov/wip/program/tribalenergy.html
Source: www.dsireusa.org

USDA Renewable Energy Systems and Energy Efficiency Improvements Program

Eligible Technologies: Energy efficiency equipment and improvements; Solar Water Heat, Solar Space Heat, Photovoltaics, Wind, Biomass, Geothermal Electric, Geothermal Heat Pumps, Hydrogen, Direct-Use Geothermal, Anaerobic Digestion, Renewable Fuels, Fuel Cells (Renewable Fuels)
Sectors: Commercial, Agricultural
Amount: Grants: 25% of eligible project costs; Guaranteed loans: 50% of eligible project costs
Maximum limits: Grants: $500,000 per renewable energy project; Guaranteed loans: $10 million
Dates of Availability: FY 2003 – FY 2007
Website: www.rurdev.usda.gov/rd/farmbill/9006resources.html
Summary: Section 9006 of the 2002 Farm Bill requires the U.S. Department of Agriculture (USDA) to create a program to make direct loans, loan guarantees, and grants to agricultural producers and rural small businesses to purchase renewable-energy systems and make energy-efficiency improvements. This program is known as the Renewable Energy Systems and Energy Efficiency Improvements Program.
Contact: Contact the Rural Energy Coordinator at your local USDA office or visit the program website.
Source: www.dsireusa.org

RESIDENTIAL WEATHERIZATION AND UTILITY-BASED CONSERVATION PROGRAMS

Kentucky Weatherization Program

Eligible Technologies: Home heating systems; insulation; energy audits; duct sealing and other weatherization services
Sectors: Residential
Terms: Kentucky Weatherization Programs service families with a total income at or below 125% of the poverty level
Amount: Average of $2,500 per housing unit
Website: www.kaca.org
Summary: "The Kentucky Weatherization Program provides energy conservation improvements to low-income households to help reduce energy costs while making homes healthier and safer. Eligible families must have a total income at or below 125% of the poverty level or have had a resident who received SSI or K-TAP (Kentucky Temporary Assistance Program) sometime in the previous twelve months. The Program is operated by local Community Action Agencies, which have offices throughout the State.

"The Weatherization Program typically spends about $2,500 per housing unit and weatherizes approximately 2,000 units each year. The services provided for each home are based on a site assessment and a computerized energy audit. Renovations may include repair or replacement of heating systems; elimination of carbon monoxide spillage and fuel leaks; reduction of air infiltration; carbon monoxide detectors and smoke alarms; or added insulation. Renovations are followed up with an energy education program for participants. Studies have found that participating households save about $300 annually on energy costs. About 50,000 homes have been weatherized in Kentucky since the inception of the program."[2]

Contact:
Kentucky Association for Community Action, Inc.
101 Burch Court
Frankfort, KY 40601
502-875-5863 or 800-456-3452

Project WARM

Summary: Project Warm promotes home energy affordability, safety and comfort through energy conservation services and education. They involve and empower the community, focusing on at-risk families and households in Jefferson County, Kentucky. Their home energy conservation services are free for low-income residents.
Contact: Project WARM
1252 S. Shelby St.
Louisville, KY 40203
502-636-9276

Utility-based Energy Conservation Assistance Programs

Summary: Some electric and gas utilities in Kentucky offer incentives to assist their customers with energy saving home improvements. Some utilities also offer green power purchasing programs or incentives that support the installation of renewable energy systems.

Types of assistance offered include:
- home energy audits;
- rebates for high efficiency appliances, heating, and cooling units;
- weatherization services, along with financing and rebates, in some cases;
- rebates for energy efficient homes;
- and rebates for home energy ratings for Energy Star certification.

Contact your utility to find out what programs they offer and how they can assist you to improve the energy efficiency of your home. If your utility does not offer the type of assistance that you need, let them know that there is demand for energy conservation and renewable energy in their region.

COMMERCIAL AND INDUSTRIAL ENERGY ASSISTANCE PROGRAMS

Kentucky Pollution Prevention Center, Commercial Energy Efficiency and Pollution Prevention Assistance

Summary: "The Kentucky Pollution Prevention Center (KPPC) is a non-profit organization established by the general assembly to provide waste reduction and pollution prevention technical services to Kentucky businesses and organizations. KPPC's services help existing facilities achieve higher performance in terms of energy efficiency, resource conservation, and waste minimization. Their free services include on-site visits to assist clients with problem waste streams, energy efficiency assessments and training, pollution prevention research, and a materials exchange program to find new uses for waste products. These services are non-regulatory, confidential, and have helped KPPC's clients save thousands of dollars."[3]

Website: www.kppc.org

Contact: University of Louisville
420 Lutz Hall
Louisville, KY 40292
502-852-0148

End Notes

1. "Financing an Energy Efficient Home," National Renewable Energy Laboratory, US Department of Energy, Document no. DOE/GO-10200-1072, FS104, October 2000.

2. Andy McDonald, "High Performance Buildings: Bringing Environmentally Sound Building Practices into the Mainstream in Kentucky," Appalachia– Science in the Public Interest, Technical Paper 71, Mt. Vernon, Kentucky, 2004, p.8.

3. Ibid, p.7.

Chapter Fourteen
Choosing a Solar Installer
Recommendations for Choosing Solar Energy Contractors, Professional Consultants, and Equipment Suppliers

You've made the decision to build a solar home or install a solar system. Now, what do you do? You may know little about solar energy. How do you make wise decisions along the way?

To be as prepared as possible, you should become informed about solar products, solar design and building practices. Take advantage of opportunities to visit and investigate as many operating solar systems and solar homes as you can. Review the tips below to help you avoid many of the painful mistakes of those who have gone before you. A happy solar homeowner is one whose house or solar system operates smoothly and efficiently. This is an achievable goal if you are willing to prepare yourself for the process that lies ahead. Don't let unfamiliar terms and equipment scare you. Take your time and do your research. Finally, always remember that, to minimize the cost and improve the reliability and performance of any solar system, it's best to begin by becoming as energy-conserving and efficient as possible.

Selecting a Contractor

The most basic question facing any consumer is how to choose a reputable and reliable firm or product. There may be claims of expertise and efficiency in solar energy, but it is important to verify these claims.

To obtain a list of builders, architects, engineers and contractors engaged in providing renewable energy or green building products or services in your area, contact the Kentucky Solar Partnership (KSP) at (606)256-0077, or visit the Kentucky Sun Pages: A Directory of Renewable Energy and Green Building Businesses and Professionals Serving Kentucky at www.greenprofessionals.org/ky. KSP maintains this directory of businesses and professionals who have completed a questionnaire and expressed a desire to be listed for certain geographical areas. We do not, however, attest to the quality of service or products by any of the firms in the directory – it is merely a resource to help you in the initial stages of your research. The Kentucky Solar Partnership and Appalachia – Science in the Public Interest do not endorse or recommend any firm or products provided on this list.

Another way to identify firms operating in your area is to check the "yellow pages" in telephone directories of surrounding communities. Once again, this will not give you any gauge of the quality or dependability of the firm, but it will help you form an initial list to consider in your search. Consult several builders, architects or contractors before making a final selection.

The most time-honored method of finding dependable firms and products, however, is through referral and information from clients who have used the services or a specific product. Ordinarily you should check with at least three former clients or consumers who have previously used a firm or product for information from first-hand experience. If you have friends or neighbors who have installed a system or built a house, check with them or ask the contractor for references. Check on customer satisfaction with the installation, the amount of service that has been required and the promptness of response to requests for service. If possible, inspect some of the buildings or installations personally and talk to the owners. It is also advisable to identify several firms and/or products, obtain prices or bids, and comparatively evaluate them. Such steps are time-consuming, but essential in receiving quality work at a fair price.

In determining whether a firm is qualified to perform the service that you desire, make sure that the individual or firm is properly licensed by the Commonwealth of Kentucky. State licensing and registration boards examine individuals prior to issuing a license or registration number. Firms and individuals who are registered and licensed have met certain standards set forth by these boards. Licenses must be renewed annually. Current information about a registered or licensed architect, engineer or contractor may be obtained from one of the following sources:

For Plumbing, Electrical, or HVAC Contractors:
Kentucky Office of Housing, Buildings, and Construction
101 Sea Hero Road, Suite 100
Frankfort, Kentucky 40601
http://hbc.ppr.ky.gov
Building Codes Enforcement (502)573-0373
Electrical Inspection Section (502)573-0382
HVAC Section (502)573-0395
Plumbing Division (502)573-0397

Kentucky Board of Architects
301 E. Main St., Suite 860
Lexington, KY 40507

(859)246-2069
www.kybera.com
Kentucky State Board of Licensure for Professional Engineers and Land Surveyors
Kentucky Engineering Center
160 Democrat Dr.
Frankfort, KY 40601
(502) 573-2680, (800) 573-2680
fax (502) 573-6687
www.kyboels.ky.gov

Kentucky has no licensing requirements for general contractors.

To check for complaints about any given firm or product, two avenues are available: the local Better Business Bureau and the Consumer Protection Division of the Office of the Kentucky Attorney General. These two agencies can inform you of any legal action or complaints filed against a particular business.

Office of the Attorney General for the Commonwealth of Kentucky
Consumer Protection Division
1024 Capital Center Drive, Suite 200
Frankfort, Kentucky 40601
(502) 696-5389
www.ag.ky.gov

Better Business Bureau
Central and Eastern Kentucky Office:
(800)866-6668
Louisville, Western Kentucky, Southern Indiana Office:
(800)388-2222

NABCEP Certification
Saratoga Technology and Energy Park
10 Hermes Rd., Suite 400
Malta, NY 12020
(518)889-8126
www.nabcep.org

The North American Board of Certified Energy Practitioners (NABCEP) has a voluntary certification program for solar electric installers, and is developing a certification program for solar water heater installers. A list of NABCEP certified professionals can be found on their web site.

There are no other national or Kentucky state licensing requirements or certifications for solar energy professionals.

Besides licenses, however, it is important to assess the contractor's solar qualifications. How many solar homes have they designed or built? Or, how many solar systems have they installed? In the case of solar equipment, does the contractor have support from the manufacturer of the equipment, such as a certificate of training or supervision/inspection of the job by a representative of the manufacturer?

Asking the Tough Questions

Don't ever be afraid to ask questions. It is essential to get through the marketing pitch to determine how the house or system will perform. Some questions to ask are:

- Who is qualified in my area to design and/or build solar homes? Who is qualified to install solar systems?
- How long has the firm been in business?
- Who will actually be doing the work – preparing the design, building the house, or installing the solar system? What subcontractors will be used?
- Will the solar features be covered by my home insurance policy?
- Who is responsible for obtaining and paying for any necessary local permits?
- How do I determine whether my present or future home is a good candidate to use solar energy?
- What modifications need to be done to my house to use this system?
- What information do I use to determine which solar features are best for me?
- Will the solar features (e.g. windows, collectors, thermal mass, etc.) have an obstructed view of the sun? Will they face true south? If not, how many degrees off south, in which direction, will they be?
- Will the house have sufficient thermal mass to keep the house from overheating and provide for cloudy weather?
- Is there sufficient room to accommodate the collectors and storage for an active solar system?
- Will a new solar heating feature or piece of equipment add heat to my home or building in the summer, when it's undesirable? What can be done to prevent this?
- Do the materials meet industry standards? If you are putting in a solar system, has the system been tested and received a rating from an independent industry or governmental authority (e.g. Solar Rating and Certification Corporation, Florida Solar Energy Center)?

- Will the performance of the house or system be monitored? What equipment or techniques will be used for the monitoring?

- Will the system operate without interfering with the operation, replacement and maintenance of existing equipment?

- How much will the solar features cost me? What will be the expected energy cost savings? What assumptions about inflation in energy prices are incorporated into these estimates?

- How long will the system last? How long do most solar systems last?

- Are there any tasks that I must perform to make the solar features operate properly?

- Who is responsible for maintaining the system? What are my responsibilities? Are parts easily available?

Signing a Contract

A written contract is a must for your protection. Some guidelines to consider include:

- Read and study the written contract to get a clear understanding of its contents before signing it.

- Never sign a contract unless all blanks have been filled in completely.

- Keep a copy of the contract for your own records.

- Obtain a written cost quote on the complete job. Consider the cost along with other factors, such as including specifications with the brand names and size of the materials and method of payment.

- Learn what the different types of contracts are and what they mean.

- Don't be pressured into signing a contract – take your time to consider what responsibilities and liabilities you will assume if you sign.

- Never sign a contract that has not been signed by the other party.

During and After Installation

Understanding the materials and equipment that are to be installed in your house will be helpful to you in operating and maintaining your house or solar system so that it is efficient. Some tips to guide you during this period include:

- Before and during installation, check to be sure the materials are exactly as you ordered or specified them. Do not accept them otherwise.

- Check to see that all indoor and outdoor solar water heating system plumbing is insulated.

- When the installation of a solar system is complete, have the installer test the system for leaks or malfunctions.

- With regard to solar systems, HVAC equipment, and other equipment, have the installer review the system so that you understand its operation and what, if anything, is required by you for its operation and maintenance.

- Be sure the builder, contractor, or installer supplies you with manuals for the operations of all equipment, such as a solar system. Have them review the manual with you. For active solar hot water or space heating systems, thermometers should be placed on the pipes or ducts going to and from the collector to monitor the system's heat gain; another thermometer can be placed in the storage area to measure how much heat is retained.

- Check to see if all moving parts and switches are functioning in a solar system.

- For solar water heating systems, get a system tune-up with the installation: this consists of adjusting pressure and removing air from pipelines to ensure proper water flow.

- Ask for instructions on how to correct problems. This way you can make sure you understand how the equipment or system is supposed to operate.

- For solar systems, the installed equipment should operate normally for at least a week and then be inspected by the installer.

- Be sure the collectors of a solar system face as true south as possible and are unshaded.

- Be sure you know specifically who will service the system or equipment.

Warranties: What Do They Mean?

Warranties are very important in ensuring that your home and solar system will be repaired if something should malfunction during the period of the warranty. Different items will be warranted for varying amounts of time. For example, most new homes are warranted for at least one year and warranties can often be purchased to cover parts of the house for up to ten years. For active solar systems used for space or hot water heating, the collectors, heat exchanger, and storage units, as well as their installation, should be covered for no less than two years. The remaining components of the system should be warranted for no less than one year.

Examine your warranties carefully. What are their limitations? Remember that a warranty and a guarantee are the same thing: A promise by manufacturers or sellers to stand behind their products. Federal legislation requires that they live up to these written promises.

Be sure you know who is responsible for honoring the warranty – the installer, the dealer, the builder, or the manufacturer. The seller should disclose the warranty responsibility of each party. Know the financial arrangements, such as contractor's bonds, to assure that the warranty will be honored. Remember, a warranty does not guarantee that the company will remain in business. Get a clear understanding of whom you should contact if there is a problem.

Finally, we hope we haven't scared you away from building a house or installing a solar system. The tips and guidelines listed above are intended to help you become a better educated consumer. Such preparation will help you obtain quality products and services at a fair price, while also preparing you for the maintenance and operating requirements that will be necessary to ensure your home and equipment run efficiently.

Remember, be especially careful about:

- References
- Contracts and fees
- Payment schedules
- Bonding and insurance
- Consumer complaints
- Specifications in design
- Warranties
- Completion deadlines
- Construction changes

Adapted with permission from "A Word to the Wise," North Carolina Solar Center at North Carolina State University,

Chapter Fifteen
The Kentucky Sun Pages
A Directory of Renewable Energy and Green Building Businesses and Professionals Serving Kentucky

The following businesses and professionals provide services and products in the fields of renewable energy, energy efficiency, and environmentally-responsible building. The companies listed include solar installers, architects, engineers, designers, consultants, the building trades, product manufacturers, and distributors. This list is maintained by the Kentucky Solar Partnership and is continually being updated. To find businesses that have been added to the list since the publication of The Kentucky Solar Energy Guide, *please visit our website at www.greenprofessionals.org/ky.*

Directory listings are free and completely voluntary. The Kentucky Solar Partnership (KSP) and Appalachia-Science in the Public Interest (ASPI) make no endorsement of the companies listed in the Directory. Readers should thoroughly research any firm before purchasing products or services. Please read Chapter Fourteen, "Choosing a Solar Installer," for recommendations about choosing solar energy contractors, consultants, and equipment suppliers.

Chapter Sixteen provides a list of national renewable energy and green building equipment suppliers. Again, listing does not constitute an endorsement by KSP or ASPI. This information is provided for the benefit of readers to help you find the services and products you need, but KSP and ASPI make no claims as to the quality or reliability of those listed or their products or services.

The Directory

Aur J Beck
Advanced Energy Solutions
Energy Service Company, Performance Contractor, Consultant, Designer, Ecological Design, Energy Rater
192 & 186 Gates Road
Pomona, IL 62975-2506
Phone: 618-893-1717 or 800-229- 0453
Email: info@advancedenergyonline.com
Web Site: theenergysolutions.com

Advanced Energy Solutions sells, installs, & educates about Renewable Energy, energy efficiency, conservation (including but not limited to: solar photovoltaic (PV), passive & active hot water & air systems, micro-hydro & wind, steam (solar and/or biomass produced), and some human & animal powered equipment. Although we have to sell & install equipment to stay in business we need to focus on the educational aspect due to a lack of knowledge within the general public. Therefore, we need to educate the general public while creating more installer/workers for the Renewable Energy industry. To accomplish these objectives we will continue promoting/teaching Renewable Energy through educational workshops, classes, the weekly radio show, newspaper column, the resource section on our website, trade articles, energy & earth day fairs, & the annual National Tour of Solar Buildings.

Joshua Bills
Sunbelievable Services
Engineer, Consultant, Designer, General Contractor, Renewable Energy Contractor, Retailer/ Distributor, Specialty Installer, Energy Rater
PO Box 64
Wildie, KY 40492
Phone: 859-985-9032
Email: sunbelievable@whale-mail.com

Sunbelievable Services specializes in solar electric systems, including battery-based and grid-intertied systems. We also work with wind and micro-hydro power systems. Sunbelievable Services is your source for renewable energy equipment, design, and installation. We also design, supply, and install solar thermal water heating systems (both swimming pool and domestic water heating).

R. Lee Bivins
Bivins Energy Service and Technology LLC
Consultant, Designer, Ecological Design
Rt. 1, Box 400
Mt. Vernon, KY 40456
Phone: 606-256-9646
Email: bivinsenergyserviceandtechnology@yahoo.com

BESandT offers the following services: Design of Solar Hot Water systems, solar space heating (radiant floors), stand alone solar electric (PV) systems, active and passive solar buildings, and energy efficient buildings. Through a solar site analysis using Energy 10 software, we can compare many energy efficiency practices with standard building practices, and compare energy use of the building samples. We offer design, consultation and supervision of projects by do-it-yourselfers. We can help customers get financing for solar hot water systems.

Terry Clausing
TrendFormers, Inc.
Consultant, Energy Rater
PO Box 44055
Cincinnati, OH 45244
Phone: 513-831-7020
Email: terry.clausing@trendformers.com
Web Site: www.trendformers.com

TrendFormers provides infrared inspection services and consulting engineering services specifically related to thermal and infrared analysis. These services are typically inspections of electrical and mechanical equipment for industrial and commercial clients, and energy audits and troubleshooting of comfort issues in residential buildings.

Jeremy Coxon
SunWind Power Systems, Inc.
Mechanical Engineer, Consultant, Designer, Renewable Energy Contractor, Retailer / Distributor, Specialty Installer, Energy Rater
5324 Hanka Rd
Floyds Knobs, IN 47119
Phone: 502-876-5174
Email: jcoxon@sunwindpowerinc.com

Complete energy conservation solutions with a focus on providing systems and components that make both economic and environmental sense. We perform energy audits and engineer each system to provide lasting results. We specialize in the design, installation, and supply of solar domestic hot water and pool heating systems. Additionally, we also work with solar electric systems (battery and grid intertie), wind, and micro-hydro. SunWind Power Systems is your source for renewable energy equipment, design, installation, and service. We stand behind what we sell!

Dawn Ecklar
Comfort & Process Solutions
Ecological Design
2456 Fortune Dr., #120
Lexington, KY 40509
Phone: 859-294-4400, ext. 206 or 859-806-7791
Fax: 859-294-4500
Email: dawn@cpslex.com
Web Site: www.cpslex.com

CPS/York will help design your HVAC building to be more environmentally friendly and add LEED points when needed. LEED points are available in our design: Energy & Atmosphere: Up to 10 points Indoor Environmental Quality: Up to 10 points Materials & Resources: Up to 4 points Innovation & Design Process: 2 or more points Up to 26 points possible.

Carl Eger
University of Dayton
Department of Mechanical and Aerospace Engineering
300 College Park
Dayton, OH 45469-0210
Phone: 937-229-3343
Email: egeriicw@yahoo.com
Web Site: www.engr.udayton.edu/udiac

The University of Dayton Industrial Assessment Center works on a wide range of topics related to sustainable buildings, including passive solar, solar water heating and solar electric, wind turbines, energy analysis, and more.

Robert Fairchild
Ecolotech/Eastern Kentucky Appropriate Technologies
Consultant, Designer, Ecological Design, Renewable Energy Contractor, Retailer / Distributor, Specialty Installer
150 Gravel Lick Rd
Dreyfus, KY 40385-9510
Phone: 859-986-6146
Email: bobkatfarm@yahoo.com

Provides a wide range of ecological consulting, design, and installation services, including solar electric, hydro-electric, wind electric, solar thermal, energy audits, and building design assistance.

David Gabhart
Solar Designs, Inc.
Energy Service Co. / Performance Contractor, Consultant, Designer, HVAC Contractor, Renewable Energy Contractor, Specialty Installer
10221 Taylorsville Road
Louisville, KY 40299
Phone: 502-297-6500
Email: dave@solar-designs-inc.com
Website: www.solar-designs-inc.com

HVAC mechanical contractor/designer with solar, geothermal, radiant heating and air conditioning experience. Licensed since 1971, solar trained since 1977; installations, designs, contracting and service ever since. Controls and energy recovery also a specialty. Visit our website: www.solar-designs-inc.com.

Jennifer Geoghegan
Lexington Real Estate Services
Real Estate Sales/ Broker
1740 Abbington Hill
Lexington, KY 40514
Phone: 859-509-0187
Email: jennifergeogheg@lexre.com

Licensed Residential Real Estate Agent in Lexington representing Alliance Builders, A Green Building Company ™. New, custom built homes $200-$500,000.

Robert Gieser
B'N E Enterprises
Consultant, Retailer, Distributor, Specialty Installer
RR 6 Box 8235
Pearl Smith Road
Monticello, KY 42633
Phone: 606-348-4101 or 916-214-4398
Fax: 606-348-4101
Email: icfbob@consultant.com
Web Site: www.holdfast.com

We are distributors and certified installers of Nudura brand insulated concrete forms for residential, commercial, institutional, governmental and agricultural buildings. We set up local dealer networks that empower local builders to buy direct at preferred pricing, train and certify local builders to install ICFs. We also supply additional materials that complement the concrete structure such as Insul-tarp (insulation for concrete slabs), Dietrich metal floor joists, waterproofing materials for below grade applications and all the necessary tools to make the local builder successful in his new green building technology venture. We frequently address local builders associations as to the benefits of Insulated Concrete Form construction, speak at state and national builders conventions, as well as show locally our products at local and regional trade shows. Our personnel are well versed in the use of Nudura ICFs as well as various other competitive brands.

Kevin Green
Custom Energy Services, L.L.C.
Energy Service Co. / Performance Contractor
9217 Cody
Overland Park, KS 66214
Phone: 913-888-8050 ext. 214
Email: keving@customenergy.com
Website: www.customenergy.com

Custom Energy is a national energy services company (ESCO). Dedicated to reducing facility operating costs, Custom Energy offers design, construction management and a full range of comprehensive energy conservation measures. Each measure is carefully selected to maximize operating cost reduction while enhancing building occupant comfort and safety. Delivering superior value and providing heroic customer service truly define our desire to become "Your Energy Partner for the Future."

Michelle Greenfield
Third Sun Solar and Wind Power
Renewable Energy Contractor
340 West State St. Unit 25
Suite 138
Athens, OH 45701
Phone: 740-597-3111
Email: michelle@third-sun.com
Website: www.third-sun.com

Third Sun Solar and Wind Power, Ltd. has been installing solar and wind power systems independently and as a subcontractor since 1997. The company is a full service renewable energy system dealer, installer and service provider. We provide consulting, system design, service and installation for wind and solar electric systems and solar thermal systems. Third Sun's owner and founder, Geoff Greenfield, is a NABCEP Certified Solar PV Installer. The Great Lakes Renewable Energy Association also certifies Geoff and another of Third Sun's chief installers as Photovoltaic Integrator/Installers. Third Sun's projects include new construction and retrofit projects for residential, commercial and institutional customers in the United States and worldwide. Our installers have tremendous experience in the field of renewables and have installed more than 85 systems in the last several years, with many more in process.

Nathan Jones
Power Source Solar, Inc.
Consultant, Designer, Renewable Energy Contractor, Retailer / Distributor, Specialty Installer, Manufacturer
3718 Ponderosa Ln
Springfield, MO 65803
Phone: 417-833-4274
Email: powersourcesolar@aol.com

Sales, service, design, and manufacturing of solar electric systems. Consulting, engineering, and manufacturing of solar electric systems for unique applications. Consultant to University of Missouri, Rolla, for their Solar Decathlon home for 2002. Engineered only solar electric system currently approved by Army Corps of Engineers for installation on Table Rock Lake. Consultant to City Utilities, Springfeld, Missouri, providing utility services to 98,000 customers. Currently assisting Burlington Northern Railroad in remote lighting design for Homeland Security requirements. Assisted Art Boyt, father of the solar car race across America, in designing a solar powered golf car. Consultant for Missouri Dept. of Conservation, as well as US Army Corps of Engineers, and National Parks Service.

Richard Levine
Center for Sustainable Cities Design Studio
Architect, Ecological Design, Interior Design
5675 Kidville Lane
Lexington, KY 40515
Phone: 859-272-6444
Email: rlevine@uky.edu
Website: www.centerforsustainablecities.com

The Center for Sustainable Cities design studio is an architectural design firm with more than thirty years of experience designing and building passive and active solar dwellings, ecological communities and sustainable cities. It has done extensive research in each of these areas, presenting lectures and research papers at national and international conferences. Richard S. Levine, the Center's director, built a pioneering solar house in Kentucky - Raven Run - beginning in 1975. It was the first project to incorporate active and passive solar heating, greenhouse, Sundows, superinsulation, earth tubes, composting toilets and many other innovative features. Professor Levine was one of the founders of the Passive Division of the American Solar Energy Society and was the founding chair of ASES' Sustainability Division.

Frank Lewon
BZ Products, Inc.
Manufacturer
7614 Marion Ct.
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Phone: 314-644-2490
Email: bzp@brick.net

BZ Products, Inc. manufactures solar electric and wind turbine generator systems for the residential, commercial and industrial sectors.

Mike Mahoney
Custom Energy Services, L.L.C.
Energy Service Company, Performance Contractor
9217 Cody
Overland Park, KS 66214
Phone: 913-888-8050
Fax: 913-888-5558
Email: mikem@customenergy.com
Web Site: www.customenergy.com

Custom Energy is a national Energy Services Company (ESCO). Dedicated to reducing facility operating costs, We offer design, construction management and a full range of comprehensive Energy Conservation Measures. Each measure is carefully selected to maximize operating cost reduction while enhancing building occupant comfort and safety. Delivering superior value and providing heroic customer service truly define our desire to become "Your Energy Partner For The Future."

Johnny Miller
Earthwell Energy Management, Inc.
Energy Service Co./Performance Contractor, Electrical Contractor, Specialty Installer
1300 West Main St.
PO Box 3044
Louisville, KY 40201
Phone: 502-587-8447
Fax: 502-587- 8272
Email: johnny.miller@earthwell.cc
Web Site: www.earthwell.cc

Earthwell is a licensed electrical contractor in Kentucky, Tennessee and Ohio and we specialize in energy conservation projects. Earthwell is best known for it's turn-key solutions in lighting retrofit/ replacements, electrical services, building automation, installation of standby generators, solar water heaters and photovoltaic systems. From a technological standpoint, Earthwell continues to explore the best and brightest solutions for our clients. There is a double benefit to conserving energy. Buildings that cost less to operate add to the bottom line and reduce harmful emissions that come from our dependence on fossil fuels.

Delia Montgomery
Chic Eco
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Web Site: www.ChicEco.com

Chíc Eco was founded in 1997 and published the first Directory late 1999, which pioneered the most thorough, earth-friendly, annual fashion and design source books available today. On October 31, 2003, this sole proprietorship became an official limited liability company, Chic Eco, LLC, where services for wholesalers, retailers and individuals continue to grow. The fifth annual Chíc Eco Directory went to press with a pending new identity, Chic Eco Resources, Inc., which is set to be a nonprofit organization under Section 201 (c)(3) of the Internal Revenue Code. The company mission is to help preserve our planet by supporting designers and their businesses which create sustainably made products.

Stephen Morrison
MoreSun Custom Woodworking Inc.
Specialty Installer
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Web Site: www.moresundesigns.com

MoreSun Custom Woodworking Inc. is a solar powered workshop specializing in Timber Frames, Cabinetry and Furniture. We strive for high quality work with a sensitivity to the environment. When possible, our lumber comes from salvaged, recycled or local sources. We also offer structural insulated panel packages to complement our Timber Frames. We encourage the public to visit our shop to learn about grid connected solar electric systems.

Garry Murphy
Prajna Design and Construction
Consultant, Designer, General Contractor
P.O.Box 54443
Lexington, KY 40555
Phone: 859-873-6477 or 859-948-4860
Email: prajna@prajnadesign.com
Web Site: www.prajnadesign.com

A design/ build company for over 20 years. Homes, offices, and renovations designed and built with passive solar principles, local and natural materials. See web site for complete details. Current projects include LEED project for Bernheim Forest.

Ronald Neal
Solar Designs, Inc.
HVAC Contractor
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Email: ron@solar-designs-inc.com
Website: www.solar-designs-inc.com

HVAC commercial & residential systems design, installation & service. Specializing in geothermal, energy recovery ventilation, solar and energy management controls and systems.

Matt Partymiller
Solar Energy Solutions LLC
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5326 Paris Pike
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Phone: 859-312-7456
Email: matt@solar-energy-solutions.com
Web Site: www.solar-energy-solutions.com

Solar Energy Solutions LLC is dedicated to bringing alternate energy to the Kentucky region. Our current focus is solar hot water, space heating, and pool heating, small PV applications, and solar lighting.

Carl Plested
TLConstruction
General Contractor
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Certified installer of Arxx Insulated Concrete Forms.

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Pohl Rosa Pohl
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Web Site: www.prparchitects.com

At Pohl Rosa Pohl we seek to design architecture that reflects clarity of purpose, inventiveness, honesty, and warmth. We foster a culture of collaboration, in which we are particularly attentive to client and environmental issues. To assist with the design process we build 3D computer models, allowing our clients to "walk thru" their projects and gain a thorough understanding of their design before breaking ground.

Richard Polk
EOP Architects
Architect
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Web Site: www.eopa.com

EOP Architects provides complete architectural and planning services for commercial, institutional, education and government clients. EOP is familiar with green building design and construction practices and has completed the first project in Kentucky designed to be LEED Certified. Richard Polk, a principal with EOP Architects, is a LEED Accredited Professional.

C.A. Post
Alliance Builders, LLC
1468 Corona Drive
Lexington, KY 40514
Phone: 859-494-3171
Email: info@alliancebuilders.org
Web Site: www.alliancebuilders.org

Alliance Builders offers environmentally sensitive custom built homes and is available for consultation on a wide variety of residential green building concerns.

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GRW, Inc. is a full service Architectural, Engineering and Planning Company with 7 offices in 5 States. Our home office is in Lexington, KY. Of our 250 employees, 3 are LEED accredited. The majority of our work is for Federal, State and local Government clients. We offer traditional Design-Bid-Build and Design-Build services. Services include Civil, Structural, Sanitary, Planning, Architectural, Mechanical, Electrical, Fire Protection, GIS and Aerial Surveying.

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Retail sales of Solar related products including panels, inverters, water purification systems, safety lights, etc.

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Entropy Ltd. specializes in design, installation, and maintenance of solar heating (water, air, pool, etc.), solar electric systems (stand-alone & utility interactive), radiant heating systems, high efficiency boilers, wood-fired boiler systems (especially those incorporating heat storage systems). Integration of all the above with each other or into existing systems.

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Manufacturer and design engineering of Solar Water Heating Systems. Also install Solar Pool Heating, Water Purification, Wind, PV, Sunlighting, etc.

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Remarc has been in the business of designing, manufacturing and constructing energy efficient buildings since 1979. We pioneered the whole house environment system, bug repellent EPS foam technology, building with synthetic wood materials and air quality coordination for the tight building envelope. We have designed, installed, and lived with PV power, composting toilets, and self-sufficient systems for homes and businesses. Our homes have won energy awards and we are EPA raters for the Five Star program. In Kentucky we design and fabricate timber frame homes and coordinate the systems required to provide a safe and energy efficient home environment.

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C.E.M (Certified Energy Manager) awarded through the Association of Energy Engineers (#10902) & Certified Radiation Safety Officer. "Applying engineering and technology to create a healthy, low maintenance, and energy efficient home" for new homes and additions. 1) Sustainable home design, IAQ (Indoor Air Quality) concerns & solutions, Safe room integration, life & property safety analysis/ recommendations, super-insulated technologies, solar daylight harvesting, window glazing optimization for passive solar heating & heat gain/loss control, radon & moisture prevention/mitigation, HVAC options analysis, electrical load analysis & design; 2) stand alone PV systems design & installation, household water heating options & system design; 3) Greenspec & Green Building products recommendations.

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We are certified dealers for Solar Energy.com, installing various solar energy products including solar water heaters, solar pool heaters, natural solar lighting, photovoltaics. We serve both residential and commercial properties and will specify each installation to the needs of the customer. Our products offer top of the line quality with long-term warranties backed by the manufacturer. Our mission is based on four simple principles and goals: 1. Decrease energy costs and consumption; 2. Help the environment; 3. Educate customers and the community about solar and renewable energy; 4. Provide excellent, prompt service.

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Ecoville architechs provides consultation, design and planning services for straw bale and earthen homes, including on-site facilitation of construction for professionals and owner-builders. We also provide natural building workshops.

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Watrous Associates Architects specializes in leading-edge green buildings that are extremely energy efficient, cost effective, and minimize impact on the environment. Our custom designed Sun-Earth Passive-Solar homes carry an energy performance guarantee. See our website for further information.

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Ideal Homebuilders offers general contracting, remodeling, and consulting on all types of energy-efficient residential construction projects. We are Energy Star Partners and have committed to having all of our homes rated through the Energy Star system. This results in Ideal Homes using as much as 40% less energy than standard construction in the area, saving our clients money every month.

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Founded in 1960, this firm provides architectural services for projects utilizing green architecture and planning, with concern for sustainability and livability. Our designs apply our research in use of appropriate, non-polluting, environmentally friendly materials and methods of construction. Soldiers Grove, the first solar town center, used our skills for planning and for architectural design. We also conduct seminars and workshops, discussing community planning issues, appropriate design for specific building types and green architecture. Our book, *The Hawkweed Passive Solar House Book*, was published in 1980.

Chapter Sixteen
Solar Energy Equipment Suppliers, Retailers, and Manufacturers

Renewable Energy Retailers (labeled "RE Retailer's" below) sell a wide range of solar and other renewable energy products and equipment directly to the public. Many also sell energy-efficient appliances and other sustainable living products. Many of these vendors will offer technical assistance and equipment recommendations over the telephone, and their web sites offer a wealth of information. If you do not use the internet, call to request a catalog. Retailers listed under "Solar Thermal" sell solar water, air, and/or pool heating equipment.

SOLAR THERMAL- WATER, POOL, AIR HEATERS

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RE retailer
www.aaasolar.com

American Energy Technologies
800-874-2190
Drainback solar water heaters
www.aetsolar.com/

American Solar
703-346-6053
Solar air heaters
www.americansolar.com/

Aquatherm
800-535-6307
Solar pool heaters
www.warmwater.com/

Atlanta Solar
423-265-0307
RE retailer
www.atlantasolar.com/index.php

Creative Energy Technologies
518-287-1428
RE retailer, Pool heaters
www.cetsolar.org

Dankoff Solar Products
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Solar water pumps, Equipment for PV, Solar Heating, Wind systems
www.dankoffsolar.com/

FAFCO
800-994-7652
Solar pool heaters
www.fafco.com/

Heliocol
407-831-1941
Solar pool heaters
www.heliocol.com/

Heliodyne
510-237-9614
Solar water heaters, Pool heaters
www.heliodyne.com/

KingSolar
800-589-5560
RE retailer
www.kingsolar.com/

The Lever Edge
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Solar water, Pool heaters
www.theleveredge.com/

ProgresivTube Passive Systems
904-358-3720
Passive solar water heaters
www.tctsolar.com/

Real Goods/ Gaiam
800-919-2400
RE retailer
www.realgoods.com

Rheem
334-260-1400
Hot water tanks
www.rheem.com/Entrance/index7.html

The Solar Biz
888-826-0939
RE retailer
www.thesolar.biz/

Solar Direct
800-333-WARM (sales)
941-360-WARM (Tech help)
RE retailer
www.solardirect.com/index.htm

SolarRoofs.com
888-801-9060
Solar water heaters
www.solarroofs.com/

SunEarth, Inc.
909-434-3100
Solar water heaters
www.sunearthinc.com/

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Atlanta Solar
423-265-0307
RE retailer
www.atlantasolar.com/index.php

Atlantic Solar Products, Inc.
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PV systems retailer
www.atlanticsolar.com

Backwoods Solar Electric Systems
208-263-4290
RE retailer
www.backwoodssolar.com

Big Frog Mountain Corp.
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RE retailer
www.bigfrogmountain.com

Creative Energy Technologies
518-287-1428
RE retailer, Pool heaters
www.cetsolar.org

Dankoff Solar Products
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Solar Heating, Wind systems
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Effective Solar Products, L.L.C.
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RE retailer
www.effectivesolar.com

Hutton Communications, Inc
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PV equipment retailer
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HuttonOnline/huttonsolar.aspx

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RE retailer
www.kingsolar.com/

New England Solar Electric, Inc.
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RE retailer
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OutBack Power Systems
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back-up power systems, including inverters
www.outbackpower.com/

Real Goods/ Gaiam
800-442-1972
RE retailer
www.realgoods.com/

The Solar Biz
888-826-0939
RE retailer
www.thesolar.biz/

Solar Components Corporation
603-668-8186
RE retailer, specializing in passive solar equipment
www.solar-components.com/default.htm

Solar Direct
800-333-WARM (sales)
941-360-WARM (Tech help)
RE retailer
www.solardirect.com/index.htm

Solatron Technologies
888-647-6527
RE retailer
www.partsonsale.com/

Sunelco
800-338-6844
RE retailer
www.sunelco.com/

Sunlight Products, Inc
770-300-0030
RE retailer
mikemacl@aol.com

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Thin film PV manufacturer
www.epv.net/

Evergreen Solar Inc
508-357-2221
String ribbon PV manufacturer
www.evergreensolar.com/

First Solar LLC
602-414-9300
Thin film PV manufacturer
www.firstsolar.com/index.html

GE Energy
303-451-7500
Mono-crystalline PV manufacturer
www.gepower.com/prod_serv/
products/solar/en/index.htm

Global Solar
520-546-6313
Thin film PV manufacturer
www.globalsolar.com/start.htm

Kaneka
212-705-4340
Thin film PV manufacturer
www.pv.kaneka.co.jp/

Kyocera Corporation
800-223-9086
Multi-crystalline PV manufacturer
global.kyocera.com/

Mitsubishi Electric Corporation
81-3-3218-2111
Poly-crystalline PV manufacturer
global.mitsubishielectric.com/bu/solar/index.html

PowerFilm
Thin film PV manufacturer
www.iowathinfilm.com/

Sharp Solar Division
81-745-63-3579
PV manufacturer (including triangular modules)
solar.sharpusa.com/solar/home/0,2462,,00.html

Shell Solar
805-388-6519
Mono-crystalline, multi-crystalline, and thin film PV manufacturer
www.shell.com/home/Framework?siteId=shellsolar

Solar Cells Ltd
385-21-374-510
Thin film PV manufacturer
www.solar-cells.net/solar.html

Solar Power Industries
724-379-2001
Multi-crystalline PV manufacturer
www.solarpowerindustries.com/

Sun Power Corporation
408-991-0900
High efficiency PV manufacturer
www.sunpowercorp.com/html/

Sunways AG
49-7531-99677-0
Multi-crystalline PV manufacturer
www.sunways.de/de/

United Solar Ovonic Corp.
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www.uni-solar.com/

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Appendix A
PV System Sizing Worksheets

I – Determine Your Power Consumption Demands

Use the following worksheet to list the appliances and/or loads that you will run with your PV system. Find out how much power each item consumes while operating. Most appliances have a label on the back that lists the wattage. Specification sheets, local appliance dealers, and product manufacturers are other sources of information. (NOTE: If an appliance is rated in amps, multiply amps by operating voltage (12V, 120V or 240V) to determine watts.) Table A.5 at the end of Appendix A lists power demands for common appliances. Once you have all the wattage ratings, fill out the load sizing worksheet below.

AC and DC Load Sizing Worksheets

1. List all AC loads, wattage, and hours of use per week (Hrs/Wk) in Table A.1. Multiply watts by Hrs/Wk to get watt-hours/wk (Wh/Wk). Add all the watt-hours per week to determine total AC watt-hours per week.

A Note on Phantom Loads- A phantom load is the power consumed by certain appliances even when they are "off." For instance, a stereo or telephone answering machine can consume 5 watts or more continuously, amounting to a substantial load over the course of a day (5 watts x 24 hr = 120 Wh/day). Be sure to account for all phantom loads when calculating AC and DC loads, or plan to eliminate the phantom loads by disconnecting power from these appliances when not in use (through the use of a power strip, for example).

Table A.1 - Calculate AC Loads. If there are no AC Loads, skip to Step 5, Table A.2.

Table A.1 – Calculate AC Loads					
Description of AC Loads Run by Inverter	Watts	X	Hrs/Wk	=	Wh/Wk
Total Watt-Hours per Week AC					

2. Convert AC Watt-Hours/week into DC Watt-hours/week. Multiply Total from Table A.1 by 1.2 to correct for inverter loss.__________

3. Enter inverter DC input voltage (usually 12V or 24V).__________

4. Divide Line 2 by Line 3. This is **Total amp-hours per week used by AC loads.__________**

Table A.2 – Calculate DC Loads					
Description of DC Loads	Watts	X	Hrs/Wk	=	Wh/Wk
Total Watt-Hours per Week DC					

5. **List all DC loads** in Table A.2 above.

6. DC System Voltage (usually 12V or 24V). Same as Line 3 above. __________

7. **Total amp hours per week used by DC loads**. Divide Total from Table A.2 by Line 6.__________

8. Enter Total amp hours per week used by AC loads from Line 4. __________

9. **Total amp hours per week** used by all loads. Add Lines 7 and 8. __________

10. **Average amp hours per day**. Divide Line 9 by 7 days. __________

II – Optimize the Demands on your Power System

At this point it is important to examine your power consumption and reduce your needs as much as possible. First, identify large and/or variable loads (such as water pumps, outdoor lights, electric ranges, AC refrigerators, clothes washers, answering machines, etc.) and try to eliminate them or examine alternatives such as propane, DC, or Energy Star models. The initial cost of DC appliances tends to be higher than AC, but you avoid losing energy in the DC to AC conversion process, and DC appliances are typically more efficient and last longer. Replace incandescent with fluorescent lights wherever possible. Fluorescent lamps provide the same level of illumination while using much less energy. If there is a large load that you cannot eliminate, consider using it only at peak sun hours, or only during the summer (in other words, be creative!). Revise your Load Sizing Worksheets now with your optimized results.

III – Size Your Battery Bank (if necessary)

To choose the proper battery, fill out the Battery Sizing Worksheet below. Other types of storage are available depending on the type of system you are considering (e.g. water storage tanks for pumping applications).

Battery Sizing Worksheet

You need to decide how much storage you would like your battery bank to provide. Often this is expressed as "days of autonomy" because it is based on the number of days you expect your system to provide power without receiving an input charge from the solar array. In addition to the days of autonomy, you should also consider your usage pattern and the critical nature of your application. If you are adding a PV array as a supplement to a generator based system, your battery bank can be slightly undersized since the generator can be operated if needed for recharging. Once you have determined your desired storage capacity, you are ready to consider the following key parameters.

11. Enter your daily amp-hour requirement (from Line 10).__________

12. Enter the maximum number of consecutive cloudy weather days expected in your area, or the number of days of autonomy you would like your system to support.__________

13. Multiply the amp-hour requirement by the number of days of autonomy (Line 11 x Line 12). This is the amount of amp-hours your system will need to store.__________

14. Enter the depth of discharge for the battery you have chosen. This provides a safety factor to help avoid over-draining the battery bank. (For example, if the discharge limit is 20%, use 0.2.) This number should not exceed 0.8. __________

15. Divide the amp-hours of storage needed (Line 13) by the depth of discharge limit (Line 14). __________

16. Select the multiplier from Table A.3 below that corresponds to the average winter-time ambient temperature your battery bank will experience. __________

17. **Total battery capacity needed**: Multiply the amp-hours (Line 15) by Line 16. This number ensures that your battery bank will have enough capacity to overcome cold weather affects. __________

18. Enter the amp-hour rating for the battery you have chosen________

19. **Number of batteries wired in parallel**: Divide the total battery capacity (Line 17) by the battery amp-hour rating and round off to the next highest number.__________

20. **Number of batteries wired in series**: Divide the nominal system voltage (12V or 24V) by the battery voltage and round off to the next highest number.__________

Table A.3: Battery Ambient Temperature Multiplier

°F	°C	Factor
80°F	26.7°C	1.00
70°F	21.2°C	1.04
60°F	15.6°C	1.11
50°F	10.0°C	1.19
40°F	4.4°C	1.30
30°F	-1.1°C	1.40
20°F	-6.7°C	1.59

21. **Total number of batteries required**: Multiply the number of batteries in parallel by the number of batteries in series. __________

IV – Size the PV Array

In Step IV you will calculate the total number of solar modules required for your system. To find the average Sun Hours per day in your area, refer to the tables in Appendix B for the city nearest to your location. If you require year-round autonomy, use the "minimum" figure. If you require 100 percent autonomy in the summer only, use the "maximum" figure.

The peak amperage of the module you will be using can be found in the module specifications. You can also determine peak amperage if you divide the module's wattage by the peak power point voltage (usually 17V to 17.5V).

22. Total average amp-hours per day (from the Load sizing worksheet, Line 10). __________

23. Multiply Line 22 by 1.2 to compensate for efficiency loss from battery charge/ discharge. __________

24. Average Sun Hours in your area (see Appendix B). __________

25. **Total solar array amps required:** Divide Line 23 by Line 24.__________

26. Optimum or peak amps of solar modules used. See module specifications.__________

27. To determine total number of solar modules *in parallel* required, divide Line 25 by Line 26, then round off to the next highest whole number.__________

28. Number of modules needed to provide DC battery voltage (see Table A.4). ___________

Table A.4: Number of Modules Needed to Provide DC Battery Voltage

DC Battery Voltage	# of Modules in Each Series String
12	1
24	2
48	4

29. To determine **total number of solar modules required**, multiply Line 27 by Line 28. ___________

Worksheet Summary

Load, average amp-hours per day (Line 10) __________
Battery capacity required (Line 17) _____________
Capacity and voltage of batteries selected (Line 18) ___________
Total number of batteries required (Line 21)__________
Peak amps of solar modules (Line 26) ____________
Total number of solar modules required (Line 29) __________

Figure A.5: Energy Use of Some Typical Appliances					
DC Appliance	**WATTS**	**AC Appliance**	**WATTS**	**AC Appliance**	**WATTS**
CEILING FAN	20	WASHING MACHINE	350 - 500	COMPUTER LAPTOP	20 - 50
TELEVISION (25cm)	45	CLOTHES DRYER (electric)	1800 - 5000	PC	80 - 150
FLUORESCENT LIGHT	5 - 13	GAS	300 - 400	PRINTER	100
STEREO / TAPE PLAYER	40	VACUUM CLEANER	200 - 700	TELEVISION	
REFRIGERATOR		HOT PLATE	1200	25"COLOR	150
16 cf	16	SEWING MACHINE	100	19"COLOR	70
12 cf	10	IRON	1000	12" B&W	20
		COFFEE MAKER	800 - 1200	VCR	40
		MICROWAVE OVEN	550 - 1500	SATELLITE DISH	80
		TOASTER	900 - 1100	STEREO	30
		POWER DRILL	450 - 1000	CLOCK RADIO	1 - 10
		WATER PUMP	250 - 500	CD PLAYER	35
		CEILING FAN	10 - 50	CB RADIO	5
		ELECTRIC BLANKET	200	ELECTRIC CLOCK	3
		BLOW DRYER	1000	FLUORESCENT LIGHT	7 - 26
		SHAVER	15	REFRIG / FREEZER	475 - 725
		DISHWASHER	1200 - 2400	DEHUMIDIFIER	785

Adapted from Creative Energy Technologies (www.cetsolar.com) and the Energy Efficiency and Renewable Energy Clearinghouse (www.eere.energy.gov/consumerinfo/factsheets/ec7.html)

PV System Sizing Worksheets adapted with permission from Creative Energy Technologies (www.cetsolar.com).

Appendix B
Solar Radiation Charts for Selected Cities in Kentucky, Indiana, & Tennessee

Source: *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*
National Renewable Energy Laboratory, U.S. Department of Energy
Charts for locations throughout the United States available on-line at:
http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/sum2/

Use solar radiation data for the city closest to your location.

LEXINGTON, KY

Latitude(N): 38.03
Longitude(W): 84.60

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.0	2.8	3.7	4.9	5.7	6.2	6.0	5.5	4.4	3.4	2.2	1.7	4.1
	Minimum	1.7	2.5	3.2	4.0	4.7	5.6	4.9	5.0	4.0	2.8	1.8	1.5	3.8
	Maximum	2.3	3.2	4.4	5.9	6.4	7.5	6.4	6.1	5.1	4.2	2.6	2.1	4.4
Lat - 15	Average	2.8	3.5	4.3	5.2	5.7	6.0	5.9	5.7	5.0	4.3	2.9	2.4	4.5
	Minimum	2.1	2.9	3.5	4.1	4.7	5.5	4.8	5.2	4.4	3.3	2.1	2.0	4.2
	Maximum	3.5	4.3	5.2	6.4	6.5	7.4	6.4	6.4	5.8	5.6	3.8	3.1	4.9
Lat	Average	3.1	3.8	4.4	5.1	5.4	5.6	5.5	5.5	5.1	4.6	3.2	2.7	4.5
	Minimum	2.3	3.0	3.6	4.0	4.4	5.1	4.5	5.0	4.4	3.5	2.2	2.1	4.2
	Maximum	4.0	4.7	5.3	6.3	6.1	6.7	5.9	6.2	6.0	6.0	4.3	3.6	4.9
Lat + 15	Average	3.3	3.8	4.3	4.7	4.8	4.8	4.8	5.0	4.8	4.6	3.4	2.9	4.3
	Minimum	2.3	3.0	3.4	3.7	3.9	4.4	4.0	4.6	4.2	3.4	2.2	2.2	4.0
	Maximum	4.3	4.9	5.2	5.9	5.4	5.8	5.2	5.6	5.8	6.1	4.5	3.9	4.7
90	Average	2.9	3.2	3.1	2.9	2.5	2.4	2.4	2.9	3.3	3.7	2.9	2.6	2.9
	Minimum	2.0	2.5	2.5	2.3	2.2	2.3	2.1	2.6	2.8	2.6	1.8	1.9	2.7
	Maximum	4.1	4.3	3.8	3.6	2.8	2.6	2.6	3.2	3.9	4.9	4.0	3.7	3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.7	3.7	4.8	6.3	7.3	7.8	7.6	7.1	5.9	4.7	2.9	2.3	5.3
	Minimum	2.1	2.9	3.8	4.6	5.6	6.8	5.9	6.4	5.1	3.4	2.0	1.9	4.9
	Maximum	3.5	4.7	6.1	8.2	8.7	10.2	8.4	8.3	7.2	6.4	3.9	3.0	6.0
Lat - 15	Average	3.3	4.2	5.3	6.6	7.3	7.8	7.6	7.4	6.4	5.4	3.5	2.8	5.6
	Minimum	2.4	3.2	4.1	4.8	5.6	6.8	5.8	6.6	5.4	3.8	2.3	2.2	5.2
	Maximum	4.4	5.4	6.7	8.6	8.8	10.1	8.5	8.6	7.8	7.3	4.7	3.8	6.4
Lat	Average	3.5	4.4	5.4	6.5	7.1	7.5	7.3	7.2	6.4	5.6	3.7	3.1	5.7
	Minimum	2.5	3.3	4.1	4.7	5.4	6.5	5.6	6.4	5.4	4.0	2.4	2.4	5.2
	Maximum	4.8	5.8	6.8	8.6	8.5	9.7	8.1	8.5	7.9	7.7	5.1	4.2	6.4
Lat + 15	Average	3.7	4.5	5.3	6.2	6.7	7.0	6.9	6.9	6.2	5.6	3.8	3.2	5.5
	Minimum	2.6	3.3	4.0	4.5	5.0	6.0	5.2	6.1	5.2	3.9	2.4	2.4	5.1
	Maximum	5.1	5.9	6.7	8.3	8.0	9.1	7.6	8.1	7.8	7.8	5.3	4.4	6.3

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	3.7	4.5	5.4	6.6	7.4	8.0	7.7	7.4	6.4	5.7	3.9	3.2	5.8
	Minimum	2.6	3.4	4.1	4.8	5.7	6.9	5.9	6.6	5.4	4.0	2.4	2.5	5.4
	Maximum	5.1	5.9	6.8	8.7	8.9	10.4	8.6	8.7	7.9	7.8	5.3	4.5	6.6

COVINGTON, KY

Latitude(N): 39.07

Longitude(W): 84.67

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	1.9	2.7	3.6	4.8	5.7	6.2	6.0	5.5	4.5	3.3	2.1	1.6	4.0
	Minimum	1.6	2.3	3.1	3.8	4.8	5.6	5.3	4.9	4.0	2.8	1.7	1.4	3.8
	Maximum	2.3	3.3	4.1	5.8	6.6	7.6	6.6	6.0	5.2	4.0	2.5	1.9	4.4
Lat - 15	Average	2.7	3.5	4.2	5.1	5.7	6.1	5.9	5.8	5.1	4.2	2.8	2.3	4.5
	Minimum	2.1	2.8	3.5	3.9	4.7	5.5	5.2	5.1	4.4	3.3	2.0	1.8	4.2
	Maximum	3.3	4.4	4.8	6.4	6.7	7.4	6.6	6.4	6.1	5.3	3.8	3.0	4.9
Lat	Average	3.0	3.7	4.3	5.0	5.4	5.6	5.5	5.6	5.2	4.5	3.1	2.5	4.5
	Minimum	2.3	2.9	3.5	3.8	4.4	5.1	4.8	4.8	4.4	3.5	2.1	1.9	4.2
	Maximum	3.8	4.9	5.0	6.3	6.3	6.8	6.1	6.2	6.2	5.7	4.2	3.4	4.9
Lat + 15	Average	3.2	3.8	4.2	4.6	4.8	4.9	4.8	5.1	4.9	4.5	3.2	2.7	4.2
	Minimum	2.4	2.9	3.4	3.5	3.9	4.4	4.3	4.4	4.2	3.5	2.1	2.0	3.9
	Maximum	4.1	5.2	4.9	5.8	5.6	5.8	5.3	5.6	6.0	5.8	4.5	3.7	4.7
90	Average	2.9	3.3	3.1	2.9	2.6	2.4	2.5	3.0	3.4	3.6	2.7	2.4	2.9
	Minimum	2.0	2.5	2.5	2.2	2.2	2.3	2.3	2.6	2.8	2.7	1.7	1.7	2.7
	Maximum	3.9	4.8	3.6	3.6	2.9	2.7	2.7	3.3	4.1	4.6	4.0	3.4	3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.6	3.6	4.7	6.1	7.2	7.9	7.7	7.2	6.0	4.5	2.7	2.1	5.2
	Minimum	2.0	2.8	3.8	4.5	5.7	7.1	6.5	6.1	5.1	3.5	1.9	1.6	4.8
	Maximum	3.3	4.7	5.6	8.0	8.7	10.2	8.8	8.1	7.3	5.7	3.8	2.8	5.9
Lat - 15	Average	3.2	4.2	5.1	6.4	7.3	7.9	7.7	7.5	6.5	5.2	3.3	2.6	5.6
	Minimum	2.4	3.1	4.1	4.6	5.8	7.0	6.5	6.3	5.4	3.9	2.1	1.9	5.2
	Maximum	4.1	5.6	6.2	8.5	8.9	10.2	8.8	8.4	8.0	6.7	4.7	3.6	6.4
Lat	Average	3.5	4.4	5.2	6.4	7.1	7.6	7.4	7.3	6.5	5.4	3.5	2.8	5.6
	Minimum	2.5	3.2	4.2	4.5	5.5	6.7	6.2	6.2	5.4	4.0	2.2	2.0	5.2
	Maximum	4.5	5.9	6.3	8.4	8.6	9.8	8.5	8.3	8.1	7.0	5.1	3.9	6.4
Lat + 15	Average	3.6	4.5	5.1	6.1	6.7	7.1	7.0	7.0	6.4	5.5	3.6	2.9	5.4
	Minimum	2.6	3.3	4.1	4.3	5.2	6.3	5.8	5.8	5.2	4.0	2.3	2.1	5.0
	Maximum	4.7	6.1	6.2	8.1	8.1	9.1	8.0	7.9	8.0	7.1	5.3	4.2	6.2

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	3.6	4.5	5.2	6.5	7.4	8.1	7.9	7.5	6.6	5.5	3.6	3.0	5.8
	Minimum	2.6	3.3	4.2	4.6	5.8	7.2	6.6	6.3	5.4	4.1	2.3	2.1	5.3
	Maximum	4.7	6.1	6.3	8.5	9.0	10.4	8.9	8.5	8.1	7.1	5.3	4.2	6.6

LOUISVILLE, KY

Latitude(N): 38.18

Longitude: 85.73

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.0	2.8	3.8	5.0	5.8	6.3	6.1	5.6	4.5	3.5	2.2	1.7	4.1
	Minimum	1.7	2.5	3.1	4.2	5.1	5.7	5.1	5.1	4.0	2.8	1.8	1.5	3.9
	Maximum	2.3	3.4	4.4	5.8	6.8	7.8	6.7	6.1	5.1	4.1	2.7	2.1	4.6
Lat - 15	Average	2.8	3.6	4.4	5.3	5.8	6.2	6.0	5.9	5.1	4.4	3.0	2.4	4.6
	Minimum	2.1	3.1	3.4	4.4	5.1	5.5	5.0	5.3	4.4	3.4	2.2	1.9	4.3
	Maximum	3.3	4.6	5.2	6.3	6.8	7.6	6.6	6.5	5.8	5.3	3.8	3.3	5.1
Lat	Average	3.1	3.9	4.5	5.2	5.5	5.7	5.6	5.7	5.2	4.7	3.3	2.7	4.6
	Minimum	2.3	3.2	3.5	4.2	4.8	5.1	4.6	5.1	4.4	3.5	2.3	2.0	4.3
	Maximum	3.8	5.1	5.4	6.2	6.4	6.9	6.1	6.3	5.9	5.7	4.3	3.8	5.2
Lat + 15	Average	3.3	4.0	4.4	4.8	4.9	4.9	4.9	5.1	5.0	4.7	3.4	2.9	4.4
	Minimum	2.3	3.3	3.3	3.9	4.2	4.4	4.1	4.6	4.2	3.5	2.3	2.1	4.1
	Maximum	4.1	5.3	5.3	5.8	5.7	6.0	5.4	5.7	5.7	5.8	4.6	4.1	4.9
90	Average	3.0	3.4	3.2	3.0	2.6	2.4	2.5	2.9	3.4	3.7	2.9	2.6	3.0
	Minimum	2.0	2.7	2.4	2.4	2.3	2.3	2.2	2.7	2.8	2.7	1.9	1.8	2.8
	Maximum	3.8	4.9	3.9	3.5	2.9	2.7	2.7	3.2	3.9	4.6	4.1	3.8	3.3

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.7	3.8	4.9	6.4	7.4	8.0	7.8	7.3	6.0	4.7	2.9	2.3	5.4
	Minimum	2.0	3.1	3.7	5.0	6.2	7.0	6.2	6.5	5.0	3.5	2.1	1.8	5.0
	Maximum	3.3	4.9	6.1	8.0	9.2	10.5	8.9	8.2	7.0	5.9	3.8	3.1	6.2
Lat - 15	Average	3.3	4.4	5.4	6.7	7.5	8.0	7.8	7.5	6.5	5.4	3.5	2.8	5.7
	Minimum	2.4	3.5	4.0	5.2	6.3	7.0	6.2	6.7	5.3	4.0	2.4	2.1	5.3
	Maximum	4.1	5.8	6.7	8.4	9.4	10.4	8.9	8.5	7.7	6.8	4.7	3.9	6.7
Lat	Average	3.6	4.6	5.5	6.6	7.2	7.7	7.5	7.4	6.6	5.7	3.8	3.1	5.8
	Minimum	2.5	3.7	4.0	5.1	6.1	6.7	6.0	6.5	5.3	4.1	2.5	2.2	5.3
	Maximum	4.5	6.2	6.9	8.4	9.1	10.0	8.6	8.4	7.8	7.2	5.2	4.3	6.7
Lat + 15	Average	3.7	4.7	5.4	6.3	6.8	7.2	7.1	7.0	6.4	5.7	3.9	3.2	5.6
	Minimum	2.5	3.7	3.9	4.8	5.7	6.2	5.6	6.2	5.2	4.0	2.5	2.3	5.2
	Maximum	4.7	6.4	6.8	8.1	8.6	9.4	8.1	8.0	7.6	7.2	5.3	4.6	6.6

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	3.8	4.7	5.5	6.7	7.6	8.2	8.0	7.6	6.6	5.7	3.9	3.2	6.0
	Minimum	2.5	3.7	4.0	5.2	6.3	7.1	6.3	6.7	5.4	4.1	2.5	2.3	5.5
	Maximum	4.7	6.4	6.9	8.5	9.5	10.7	9.1	8.6	7.8	7.3	5.4	4.7	7.0

KNOXVILLE, TN

Latitude(N): 35.82
Longitude(W): 83.98

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.3	3.0	4.0	5.2	5.8	6.2	5.9	5.5	4.5	3.7	2.5	2.0	4.2
	Minimum	1.8	2.7	3.5	4.4	5.3	5.4	4.9	4.8	3.9	3.2	2.0	1.8	4.1
	Maximum	2.6	3.6	4.6	6.0	6.8	7.4	6.7	6.1	5.3	4.7	2.9	2.3	4.5
Lat - 15	Average	3.0	3.7	4.6	5.5	5.8	6.1	5.8	5.7	5.0	4.6	3.3	2.8	4.7
	Minimum	2.2	3.2	3.9	4.6	5.3	5.3	4.9	4.9	4.2	3.8	2.5	2.3	4.5
	Maximum	3.7	4.7	5.4	6.5	6.8	7.2	6.6	6.3	5.9	6.0	4.1	3.4	5.0
Lat	Average	3.4	4.0	4.7	5.4	5.5	5.6	5.4	5.5	5.1	4.9	3.7	3.1	4.7
	Minimum	2.4	3.4	4.0	4.5	4.9	4.9	4.6	4.7	4.2	4.0	2.7	2.5	4.4
	Maximum	4.3	5.3	5.6	6.4	6.4	6.6	6.2	6.1	6.0	6.5	4.6	3.9	5.1
Lat + 15	Average	3.6	4.1	4.6	5.0	4.9	4.9	4.8	5.0	4.8	4.9	3.8	3.3	4.5
	Minimum	2.5	3.5	3.8	4.1	4.4	4.3	4.0	4.3	4.0	3.9	2.7	2.5	4.2
	Maximum	4.6	5.4	5.5	6.0	5.7	5.7	5.4	5.6	5.8	6.7	4.9	4.2	4.8
90	Average	3.2	3.3	3.2	2.9	2.4	2.2	2.3	2.7	3.2	3.8	3.3	3.0	3.0
	Minimum	2.0	2.7	2.7	2.5	2.3	2.0	2.1	2.4	2.6	3.0	2.2	2.2	2.7
	Maximum	4.2	4.5	3.8	3.5	2.7	2.4	2.5	3.0	3.8	5.2	4.3	3.9	3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	3.1	4.0	5.2	6.7	7.3	7.8	7.3	6.9	5.8	5.0	3.4	2.7	5.5
	Minimum	2.1	3.3	4.3	5.3	6.3	6.4	5.7	5.8	4.6	4.1	2.4	2.2	5.2
	Maximum	3.8	5.2	6.5	8.2	9.1	9.8	8.7	7.9	7.2	6.9	4.3	3.4	6.1
Lat - 15	Average	3.6	4.6	5.7	6.9	7.4	7.7	7.3	7.1	6.2	5.7	4.0	3.3	5.8
	Minimum	2.5	3.7	4.6	5.4	6.3	6.4	5.7	5.9	4.9	4.5	2.8	2.5	5.5
	Maximum	4.7	6.1	7.1	8.6	9.2	9.8	8.7	8.1	7.7	7.9	5.1	4.2	6.4
Lat	Average	3.9	4.8	5.8	6.9	7.1	7.4	7.1	7.0	6.3	5.9	4.3	3.6	5.8
	Minimum	2.6	3.8	4.6	5.3	6.1	6.1	5.4	5.8	4.9	4.7	2.9	2.7	5.5
	Maximum	5.1	6.5	7.2	8.6	8.9	9.4	8.4	8.0	7.8	8.3	5.6	4.6	6.5
Lat + 15	Average	4.1	4.9	5.7	6.6	6.7	6.9	6.6	6.7	6.1	6.0	4.4	3.7	5.7
	Minimum	2.7	3.9	4.5	5.1	5.7	5.7	5.1	5.5	4.7	4.7	3.0	2.8	5.3
	Maximum	5.4	6.6	7.2	8.3	8.4	8.7	7.9	7.6	7.6	8.4	5.8	4.9	6.3

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	4.1	4.9	5.8	7.0	7.4	7.9	7.4	7.2	6.3	6.0	4.4	3.8	6.0
	Minimum	2.7	3.9	4.7	5.4	6.4	6.5	5.8	5.9	4.9	4.7	3.0	2.8	5.7
	Maximum	5.4	6.6	7.3	8.6	9.3	10.0	8.9	8.2	7.8	8.4	5.8	4.9	6.7

EVANSVILLE, IN

Latitude (N): 38.05
Longitude (W): 87.53

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.1	2.9	3.8	5.0	5.9	6.5	6.3	5.7	4.6	3.5	2.3	1.8	4.2
	Minimum	1.8	2.5	3.4	4.1	4.8	5.8	5.3	5.0	4.1	2.9	1.9	1.5	4.0
	Maximum	2.5	3.3	4.3	5.9	7.0	7.7	6.9	6.3	5.2	4.2	2.7	2.2	4.6
Lat - 15	Average	2.9	3.7	4.5	5.3	5.9	6.3	6.2	6.0	5.3	4.5	3.1	2.5	4.7
	Minimum	2.3	3.0	3.8	4.3	4.8	5.7	5.3	5.2	4.5	3.5	2.3	2.0	4.4
	Maximum	3.5	4.5	5.2	6.4	7.1	7.5	6.8	6.6	6.0	5.5	3.8	3.4	5.2
Lat	Average	3.3	4.0	4.6	5.2	5.6	5.8	5.8	5.8	5.3	4.8	3.4	2.9	4.7
	Minimum	2.5	3.1	3.8	4.1	4.5	5.2	4.9	5.0	4.5	3.7	2.4	2.2	4.4
	Maximum	4.1	5.0	5.4	6.3	6.6	6.8	6.3	6.4	6.1	6.0	4.3	4.0	5.2
Lat + 15	Average	3.5	4.1	4.5	4.8	4.9	5.0	5.1	5.3	5.1	4.9	3.6	3.0	4.5
	Minimum	2.5	3.1	3.7	3.8	4.0	4.6	4.3	4.6	4.3	3.7	2.5	2.3	4.2
	Maximum	4.4	5.2	5.3	5.8	5.8	5.8	5.5	5.8	5.9	6.1	4.6	4.3	5.0
90	Average	3.1	3.4	3.3	3.0	2.6	2.4	2.5	3.0	3.5	3.8	3.1	2.8	3.0
	Minimum	2.2	2.6	2.7	2.4	2.2	2.3	2.3	2.6	2.9	2.9	2.0	2.0	2.8
	Maximum	4.1	4.5	3.9	3.6	2.9	2.6	2.7	3.3	4.0	4.9	4.1	4.0	3.3

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.9	3.9	5.1	6.5	7.7	8.4	8.2	7.6	6.2	4.9	3.1	2.4	5.6
	Minimum	2.2	3.1	4.1	5.0	5.8	7.2	6.5	6.4	5.2	3.7	2.3	1.8	5.2
	Maximum	3.6	4.8	6.1	8.2	9.6	10.4	9.1	8.5	7.3	6.3	3.9	3.3	6.4
Lat - 15	Average	3.5	4.5	5.6	6.8	7.7	8.4	8.2	7.8	6.7	5.7	3.7	3.0	6.0
	Minimum	2.6	3.4	4.4	5.2	5.9	7.1	6.5	6.6	5.6	4.2	2.6	2.2	5.6
	Maximum	4.4	5.7	6.8	8.6	9.8	10.4	9.1	8.8	7.9	7.2	4.8	4.2	6.8
Lat	Average	3.8	4.7	5.7	6.7	7.5	8.1	7.9	7.7	6.8	5.9	4.0	3.3	6.0
	Minimum	2.8	3.6	4.5	5.1	5.7	6.8	6.3	6.4	5.6	4.3	2.7	2.3	5.6
	Maximum	4.8	6.1	6.9	8.5	9.5	10.0	8.8	8.6	8.0	7.6	5.2	4.6	6.9
Lat + 15	Average	3.9	4.8	5.6	6.4	7.1	7.5	7.4	7.3	6.6	5.9	4.1	3.4	5.9
	Minimum	2.8	3.6	4.4	4.9	5.3	6.3	5.9	6.1	5.4	4.3	2.7	2.4	5.5
	Maximum	5.0	6.2	6.8	8.2	9.0	9.3	8.3	8.2	7.9	7.7	5.4	4.9	6.7

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	4.0	4.8	5.7	6.8	7.8	8.6	8.4	7.9	6.8	6.0	4.1	3.5	6.2
	Minimum	2.8	3.6	4.5	5.2	5.9	7.3	6.7	6.6	5.6	4.4	2.8	2.4	5.8
	Maximum	5.1	6.2	6.9	8.6	9.9	10.6	9.3	8.8	8.1	7.7	5.4	5.0	7.1

Appendix A
PV System Sizing Worksheets

I – Determine Your Power Consumption Demands

Use the following worksheet to list the appliances and/or loads that you will run with your PV system. Find out how much power each item consumes while operating. Most appliances have a label on the back that lists the wattage. Specification sheets, local appliance dealers, and product manufacturers are other sources of information. (NOTE: If an appliance is rated in amps, multiply amps by operating voltage (12V, 120V or 240V) to determine watts.) Table A.5 at the end of Appendix A lists power demands for common appliances. Once you have all the wattage ratings, fill out the load sizing worksheet below.

AC and DC Load Sizing Worksheets

1. List all AC loads, wattage, and hours of use per week (Hrs/Wk) in Table A.1. Multiply watts by Hrs/Wk to get watt-hours/wk (Wh/Wk). Add all the watt-hours per week to determine total AC watt-hours per week.

A Note on Phantom Loads- A phantom load is the power consumed by certain appliances even when they are "off." For instance, a stereo or telephone answering machine can consume 5 watts or more continuously, amounting to a substantial load over the course of a day (5 watts x 24 hr = 120 Wh/day). Be sure to account for all phantom loads when calculating AC and DC loads, or plan to eliminate the phantom loads by disconnecting power from these appliances when not in use (through the use of a power strip, for example).

Table A.1 - Calculate AC Loads. If there are no AC Loads, skip to Step 5, Table A.2.

Table A.1 – Calculate AC Loads					
Description of AC Loads Run by Inverter	Watts	X	Hrs/Wk	=	Wh/Wk
Total Watt-Hours per Week AC					

2. Convert AC Watt-Hours/week into DC Watt-hours/week. Multiply Total from Table A.1 by 1.2 to correct for inverter loss.__________

3. Enter inverter DC input voltage (usually 12V or 24V).__________

4. Divide Line 2 by Line 3. This is **Total amp-hours per week used by AC loads.__________**

Table A.2 – Calculate DC Loads					
Description of DC Loads	Watts	X	Hrs/Wk	=	Wh/Wk
Total Watt-Hours per Week DC					

5. **List all DC loads** in Table A.2 above.

6. DC System Voltage (usually 12V or 24V). Same as Line 3 above. __________

7. **Total amp hours per week used by DC loads**. Divide Total from Table A.2 by Line 6.__________

8. Enter Total amp hours per week used by AC loads from Line 4. __________

9. **Total amp hours per week** used by all loads. Add Lines 7 and 8. __________

10. **Average amp hours per day**. Divide Line 9 by 7 days. __________

II – Optimize the Demands on your Power System

At this point it is important to examine your power consumption and reduce your needs as much as possible. First, identify large and/or variable loads (such as water pumps, outdoor lights, electric ranges, AC refrigerators, clothes washers, answering machines, etc.) and try to eliminate them or examine alternatives such as propane, DC, or Energy Star models. The initial cost of DC appliances tends to be higher than AC, but you avoid losing energy in the DC to AC conversion process, and DC appliances are typically more efficient and last longer. Replace incandescent with fluorescent lights wherever possible. Fluorescent lamps provide the same level of illumination while using much less energy. If there is a large load that you cannot eliminate, consider using it only at peak sun hours, or only during the summer (in other words, be creative!). Revise your Load Sizing Worksheets now with your optimized results.

III – Size Your Battery Bank (if necessary)

To choose the proper battery, fill out the Battery Sizing Worksheet below. Other types of storage are available depending on the type of system you are considering (e.g. water storage tanks for pumping applications).

Battery Sizing Worksheet

You need to decide how much storage you would like your battery bank to provide. Often this is expressed as "days of autonomy" because it is based on the number of days you expect your system to provide power without receiving an input charge from the solar array. In addition to the days of autonomy, you should also consider your usage pattern and the critical nature of your application. If you are adding a PV array as a supplement to a generator based system, your battery bank can be slightly undersized since the generator can be operated if needed for recharging. Once you have determined your desired storage capacity, you are ready to consider the following key parameters.

11. Enter your daily amp-hour requirement (from Line 10).__________

12. Enter the maximum number of consecutive cloudy weather days expected in your area, or the number of days of autonomy you would like your system to support.__________

13. Multiply the amp-hour requirement by the number of days of autonomy (Line 11 x Line 12). This is the amount of amp-hours your system will need to store.__________

14. Enter the depth of discharge for the battery you have chosen. This provides a safety factor to help avoid over-draining the battery bank. (For example, if the discharge limit is 20%, use 0.2.) This number should not exceed 0.8. __________

15. Divide the amp-hours of storage needed (Line 13) by the depth of discharge limit (Line 14). __________

16. Select the multiplier from Table A.3 below that corresponds to the average winter-time ambient temperature your battery bank will experience. __________

17. **Total battery capacity needed**: Multiply the amp-hours (Line 15) by Line 16. This number ensures that your battery bank will have enough capacity to overcome cold weather affects. __________

18. Enter the amp-hour rating for the battery you have chosen________

19. **Number of batteries wired in parallel**: Divide the total battery capacity (Line 17) by the battery amp-hour rating and round off to the next highest number.__________

20. **Number of batteries wired in series**: Divide the nominal system voltage (12V or 24V) by the battery voltage and round off to the next highest number._________

Table A.3: Battery Ambient Temperature Multiplier

°F	°C	Factor
80°F	26.7°C	1.00
70°F	21.2°C	1.04
60°F	15.6°C	1.11
50°F	10.0°C	1.19
40°F	4.4°C	1.30
30°F	-1.1°C	1.40
20°F	-6.7°C	1.59

21. **Total number of batteries required**: Multiply the number of batteries in parallel by the number of batteries in series. __________

IV – Size the PV Array

In Step IV you will calculate the total number of solar modules required for your system. To find the average Sun Hours per day in your area, refer to the tables in Appendix B for the city nearest to your location. If you require year-round autonomy, use the "minimum" figure. If you require 100 percent autonomy in the summer only, use the "maximum" figure.

The peak amperage of the module you will be using can be found in the module specifications. You can also determine peak amperage if you divide the module's wattage by the peak power point voltage (usually 17V to 17.5V).

22. Total average amp-hours per day (from the Load sizing worksheet, Line 10). __________

23. Multiply Line 22 by 1.2 to compensate for efficiency loss from battery charge/ discharge. __________

24. Average Sun Hours in your area (see Appendix B). __________

25. **Total solar array amps required:** Divide Line 23 by Line 24.__________

26. Optimum or peak amps of solar modules used. See module specifications.__________

27. To determine total number of solar modules *in parallel* required, divide Line 25 by Line 26, then round off to the next highest whole number. __________

28. Number of modules needed to provide DC battery voltage (see Table A.4). ___________

Table A.4: Number of Modules Needed to Provide DC Battery Voltage

DC Battery Voltage	# of Modules in Each Series String
12	1
24	2
48	4

29. To determine **total number of solar modules required**, multiply Line 27 by Line 28. ___________

Worksheet Summary

Load, average amp-hours per day (Line 10) __________
Battery capacity required (Line 17) _____________
Capacity and voltage of batteries selected (Line 18) ___________
Total number of batteries required (Line 21)__________
Peak amps of solar modules (Line 26) ____________
Total number of solar modules required (Line 29) __________

Figure A.5: Energy Use of Some Typical Appliances					
DC Appliance	**WATTS**	***AC Appliance***	**WATTS**	***AC Appliance***	**WATTS**
CEILING FAN	20	WASHING MACHINE	350 - 500	COMPUTER LAPTOP	20 - 50
TELEVISION (25cm)	45	CLOTHES DRYER (electric)	1800 - 5000	PC	80 - 150
FLUORESCENT LIGHT	5 - 13	GAS	300 - 400	PRINTER	100
STEREO / TAPE PLAYER	40	VACUUM CLEANER	200 - 700	TELEVISION	
REFRIGERATOR		HOT PLATE	1200	25"COLOR	150
16 cf	16	SEWING MACHINE	100	19"COLOR	70
12 cf	10	IRON	1000	12" B&W	20
		COFFEE MAKER	800 - 1200	VCR	40
		MICROWAVE OVEN	550 - 1500	SATELLITE DISH	80
		TOASTER	900 - 1100	STEREO	30
		POWER DRILL	450 - 1000	CLOCK RADIO	1 - 10
		WATER PUMP	250 - 500	CD PLAYER	35
		CEILING FAN	10 - 50	CB RADIO	5
		ELECTRIC BLANKET	200	ELECTRIC CLOCK	3
		BLOW DRYER	1000	FLUORESCENT LIGHT	7 - 26
		SHAVER	15	REFRIG / FREEZER	475 - 725
		DISHWASHER	1200 - 2400	DEHUMIDIFIER	785

Adapted from Creative Energy Technologies (www.cetsolar.com) and the Energy Efficiency and Renewable Energy Clearinghouse (www.eere.energy.gov/consumerinfo/factsheets/ec7.html)

PV System Sizing Worksheets adapted with permission from Creative Energy Technologies (www.cetsolar.com).

LEXINGTON, KY

Latitude(N): 38.03
Longitude(W): 84.60

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.0	2.8	3.7	4.9	5.7	6.2	6.0	5.5	4.4	3.4	2.2	1.7	4.1
	Minimum	1.7	2.5	3.2	4.0	4.7	5.6	4.9	5.0	4.0	2.8	1.8	1.5	3.8
	Maximum	2.3	3.2	4.4	5.9	6.4	7.5	6.4	6.1	5.1	4.2	2.6	2.1	4.4
Lat - 15	Average	2.8	3.5	4.3	5.2	5.7	6.0	5.9	5.7	5.0	4.3	2.9	2.4	4.5
	Minimum	2.1	2.9	3.5	4.1	4.7	5.5	4.8	5.2	4.4	3.3	2.1	2.0	4.2
	Maximum	3.5	4.3	5.2	6.4	6.5	7.4	6.4	6.4	5.8	5.6	3.8	3.1	4.9
Lat	Average	3.1	3.8	4.4	5.1	5.4	5.6	5.5	5.5	5.1	4.6	3.2	2.7	4.5
	Minimum	2.3	3.0	3.6	4.0	4.4	5.1	4.5	5.0	4.4	3.5	2.2	2.1	4.2
	Maximum	4.0	4.7	5.3	6.3	6.1	6.7	5.9	6.2	6.0	6.0	4.3	3.6	4.9
Lat + 15	Average	3.3	3.8	4.3	4.7	4.8	4.8	4.8	5.0	4.8	4.6	3.4	2.9	4.3
	Minimum	2.3	3.0	3.4	3.7	3.9	4.4	4.0	4.6	4.2	3.4	2.2	2.2	4.0
	Maximum	4.3	4.9	5.2	5.9	5.4	5.8	5.2	5.6	5.8	6.1	4.5	3.9	4.7
90	Average	2.9	3.2	3.1	2.9	2.5	2.4	2.4	2.9	3.3	3.7	2.9	2.6	2.9
	Minimum	2.0	2.5	2.5	2.3	2.2	2.3	2.1	2.6	2.8	2.6	1.8	1.9	2.7
	Maximum	4.1	4.3	3.8	3.6	2.8	2.6	2.6	3.2	3.9	4.9	4.0	3.7	3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.7	3.7	4.8	6.3	7.3	7.8	7.6	7.1	5.9	4.7	2.9	2.3	5.3
	Minimum	2.1	2.9	3.8	4.6	5.6	6.8	5.9	6.4	5.1	3.4	2.0	1.9	4.9
	Maximum	3.5	4.7	6.1	8.2	8.7	10.2	8.4	8.3	7.2	6.4	3.9	3.0	6.0
Lat - 15	Average	3.3	4.2	5.3	6.6	7.3	7.8	7.6	7.4	6.4	5.4	3.5	2.8	5.6
	Minimum	2.4	3.2	4.1	4.8	5.6	6.8	5.8	6.6	5.4	3.8	2.3	2.2	5.2
	Maximum	4.4	5.4	6.7	8.6	8.8	10.1	8.5	8.6	7.8	7.3	4.7	3.8	6.4
Lat	Average	3.5	4.4	5.4	6.5	7.1	7.5	7.3	7.2	6.4	5.6	3.7	3.1	5.7
	Minimum	2.5	3.3	4.1	4.7	5.4	6.5	5.6	6.4	5.4	4.0	2.4	2.4	5.2
	Maximum	4.8	5.8	6.8	8.6	8.5	9.7	8.1	8.5	7.9	7.7	5.1	4.2	6.4
Lat + 15	Average	3.7	4.5	5.3	6.2	6.7	7.0	6.9	6.9	6.2	5.6	3.8	3.2	5.5
	Minimum	2.6	3.3	4.0	4.5	5.0	6.0	5.2	6.1	5.2	3.9	2.4	2.4	5.1
	Maximum	5.1	5.9	6.7	8.3	8.0	9.1	7.6	8.1	7.8	7.8	5.3	4.4	6.3

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	3.7	4.5	5.4	6.6	7.4	8.0	7.7	7.4	6.4	5.7	3.9	3.2	5.8
	Minimum	2.6	3.4	4.1	4.8	5.7	6.9	5.9	6.6	5.4	4.0	2.4	2.5	5.4
	Maximum	5.1	5.9	6.8	8.7	8.9	10.4	8.6	8.7	7.9	7.8	5.3	4.5	6.6

COVINGTON, KY

Latitude(N): 39.07
Longitude(W): 84.67

SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"

Tilt(deg)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	1.9	2.7	3.6	4.8	5.7	6.2	6.0	5.5	4.5	3.3	2.1	1.6	4.0
	Minimum	1.6	2.3	3.1	3.8	4.8	5.6	5.3	4.9	4.0	2.8	1.7	1.4	3.8
	Maximum	2.3	3.3	4.1	5.8	6.6	7.6	6.6	6.0	5.2	4.0	2.5	1.9	4.4
Lat - 15	Average	2.7	3.5	4.2	5.1	5.7	6.1	5.9	5.8	5.1	4.2	2.8	2.3	4.5
	Minimum	2.1	2.8	3.5	3.9	4.7	5.5	5.2	5.1	4.4	3.3	2.0	1.8	4.2
	Maximum	3.3	4.4	4.8	6.4	6.7	7.4	6.6	6.4	6.1	5.3	3.8	3.0	4.9
Lat	Average	3.0	3.7	4.3	5.0	5.4	5.6	5.5	5.6	5.2	4.5	3.1	2.5	4.5
	Minimum	2.3	2.9	3.5	3.8	4.4	5.1	4.8	4.8	4.4	3.5	2.1	1.9	4.2
	Maximum	3.8	4.9	5.0	6.3	6.3	6.8	6.1	6.2	6.2	5.7	4.2	3.4	4.9
Lat + 15	Average	3.2	3.8	4.2	4.6	4.8	4.9	4.8	5.1	4.9	4.5	3.2	2.7	4.2
	Minimum	2.4	2.9	3.4	3.5	3.9	4.4	4.3	4.4	4.2	3.5	2.1	2.0	3.9
	Maximum	4.1	5.2	4.9	5.8	5.6	5.8	5.3	5.6	6.0	5.8	4.5	3.7	4.7
90	Average	2.9	3.3	3.1	2.9	2.6	2.4	2.5	3.0	3.4	3.6	2.7	2.4	2.9
	Minimum	2.0	2.5	2.5	2.2	2.2	2.3	2.3	2.6	2.8	2.7	1.7	1.7	2.7
	Maximum	3.9	4.8	3.6	3.6	2.9	2.7	2.7	3.3	4.1	4.6	4.0	3.4	3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day), Percentage Uncertainty = 9"

Axis Tilt		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	Average	2.6	3.6	4.7	6.1	7.2	7.9	7.7	7.2	6.0	4.5	2.7	2.1	5.2
	Minimum	2.0	2.8	3.8	4.5	5.7	7.1	6.5	6.1	5.1	3.5	1.9	1.6	4.8
	Maximum	3.3	4.7	5.6	8.0	8.7	10.2	8.8	8.1	7.3	5.7	3.8	2.8	5.9
Lat - 15	Average	3.2	4.2	5.1	6.4	7.3	7.9	7.7	7.5	6.5	5.2	3.3	2.6	5.6
	Minimum	2.4	3.1	4.1	4.6	5.8	7.0	6.5	6.3	5.4	3.9	2.1	1.9	5.2
	Maximum	4.1	5.6	6.2	8.5	8.9	10.2	8.8	8.4	8.0	6.7	4.7	3.6	6.4
Lat	Average	3.5	4.4	5.2	6.4	7.1	7.6	7.4	7.3	6.5	5.4	3.5	2.8	5.6
	Minimum	2.5	3.2	4.2	4.5	5.5	6.7	6.2	6.2	5.4	4.0	2.2	2.0	5.2
	Maximum	4.5	5.9	6.3	8.4	8.6	9.8	8.5	8.3	8.1	7.0	5.1	3.9	6.4
Lat + 15	Average	3.6	4.5	5.1	6.1	6.7	7.1	7.0	7.0	6.4	5.5	3.6	2.9	5.4
	Minimum	2.6	3.3	4.1	4.3	5.2	6.3	5.8	5.8	5.2	4.0	2.3	2.1	5.0
	Maximum	4.7	6.1	6.2	8.1	8.1	9.1	8.0	7.9	8.0	7.1	5.3	4.2	6.2

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"

Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	3.6	4.5	5.2	6.5	7.4	8.1	7.9	7.5	6.6	5.5	3.6	3.0	5.8
	Minimum	2.6	3.3	4.2	4.6	5.8	7.2	6.6	6.3	5.4	4.1	2.3	2.1	5.3
	Maximum	4.7	6.1	6.3	8.5	9.0	10.4	8.9	8.5	8.1	7.1	5.3	4.2	6.6

LOUISVILLE, KY

Latitude(N): 38.18
Longitude: 85.73

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SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"
Tilt(deg)","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 2.0,  2.8,  3.8,  5.0,  5.8,  6.3,  6.1,  5.6,  4.5,  3.5,  2.2,  1.7,  4.1
         ","Minimum", 1.7,  2.5,  3.1,  4.2,  5.1,  5.7,  5.1,  5.1,  4.0,  2.8,  1.8,  1.5,  3.9
         ","Maximum", 2.3,  3.4,  4.4,  5.8,  6.8,  7.8,  6.7,  6.1,  5.1,  4.1,  2.7,  2.1,  4.6
Lat - 15 ","Average", 2.8,  3.6,  4.4,  5.3,  5.8,  6.2,  6.0,  5.9,  5.1,  4.4,  3.0,  2.4,  4.6
         ","Minimum", 2.1,  3.1,  3.4,  4.4,  5.1,  5.5,  5.0,  5.3,  4.4,  3.4,  2.2,  1.9,  4.3
         ","Maximum", 3.3,  4.6,  5.2,  6.3,  6.8,  7.6,  6.6,  6.5,  5.8,  5.3,  3.8,  3.3,  5.1
Lat      ","Average", 3.1,  3.9,  4.5,  5.2,  5.5,  5.7,  5.6,  5.7,  5.2,  4.7,  3.3,  2.7,  4.6
         ","Minimum", 2.3,  3.2,  3.5,  4.2,  4.8,  5.1,  4.6,  5.1,  4.4,  3.5,  2.3,  2.0,  4.3
         ","Maximum", 3.8,  5.1,  5.4,  6.2,  6.4,  6.9,  6.1,  6.3,  5.9,  5.7,  4.3,  3.8,  5.2
Lat + 15 ","Average", 3.3,  4.0,  4.4,  4.8,  4.9,  4.9,  4.9,  5.1,  5.0,  4.7,  3.4,  2.9,  4.4
         ","Minimum", 2.3,  3.3,  3.3,  3.9,  4.2,  4.4,  4.1,  4.6,  4.2,  3.5,  2.3,  2.1,  4.1
         ","Maximum", 4.1,  5.3,  5.3,  5.8,  5.7,  6.0,  5.4,  5.7,  5.7,  5.8,  4.6,  4.1,  4.9
90       ","Average", 3.0,  3.4,  3.2,  3.0,  2.6,  2.4,  2.5,  2.9,  3.4,  3.7,  2.9,  2.6,  3.0
         ","Minimum", 2.0,  2.7,  2.4,  2.4,  2.3,  2.3,  2.2,  2.7,  2.8,  2.7,  1.9,  1.8,  2.8
         ","Maximum", 3.8,  4.9,  3.9,  3.5,  2.9,  2.7,  2.7,  3.2,  3.9,  4.6,  4.1,  3.8,  3.3

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day),
Percentage Uncertainty = 9"
Axis Tilt","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 2.7,  3.8,  4.9,  6.4,  7.4,  8.0,  7.8,  7.3,  6.0,  4.7,  2.9,  2.3,  5.4
         ","Minimum", 2.0,  3.1,  3.7,  5.0,  6.2,  7.0,  6.2,  6.5,  5.0,  3.5,  2.1,  1.8,  5.0
         ","Maximum", 3.3,  4.9,  6.1,  8.0,  9.2, 10.5,  8.9,  8.2,  7.0,  5.9,  3.8,  3.1,  6.2
Lat - 15 ","Average", 3.3,  4.4,  5.4,  6.7,  7.5,  8.0,  7.8,  7.5,  6.5,  5.4,  3.5,  2.8,  5.7
         ","Minimum", 2.4,  3.5,  4.0,  5.2,  6.3,  7.0,  6.2,  6.7,  5.3,  4.0,  2.4,  2.1,  5.3
         ","Maximum", 4.1,  5.8,  6.7,  8.4,  9.4, 10.4,  8.9,  8.5,  7.7,  6.8,  4.7,  3.9,  6.7
Lat      ","Average", 3.6,  4.6,  5.5,  6.6,  7.2,  7.7,  7.5,  7.4,  6.6,  5.7,  3.8,  3.1,  5.8
         ","Minimum", 2.5,  3.7,  4.0,  5.1,  6.1,  6.7,  6.0,  6.5,  5.3,  4.1,  2.5,  2.2,  5.3
         ","Maximum", 4.5,  6.2,  6.9,  8.4,  9.1, 10.0,  8.6,  8.4,  7.8,  7.2,  5.2,  4.3,  6.7
Lat + 15 ","Average", 3.7,  4.7,  5.4,  6.3,  6.8,  7.2,  7.1,  7.0,  6.4,  5.7,  3.9,  3.2,  5.6
         ","Minimum", 2.5,  3.7,  3.9,  4.8,  5.7,  6.2,  5.6,  6.2,  5.2,  4.0,  2.5,  2.3,  5.2
         ","Maximum", 4.7,  6.4,  6.8,  8.1,  8.6,  9.4,  8.1,  8.0,  7.6,  7.2,  5.3,  4.6,  6.6

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"
Tracker  ","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
2-Axis   ","Average", 3.8,  4.7,  5.5,  6.7,  7.6,  8.2,  8.0,  7.6,  6.6,  5.7,  3.9,  3.2,  6.0
         ","Minimum", 2.5,  3.7,  4.0,  5.2,  6.3,  7.1,  6.3,  6.7,  5.4,  4.1,  2.5,  2.3,  5.5
         ","Maximum", 4.7,  6.4,  6.9,  8.5,  9.5, 10.7,  9.1,  8.6,  7.8,  7.3,  5.4,  4.7,  7.0
```

KNOXVILLE, TN

Latitude(N): 35.82
Longitude(W): 83.98

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SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"
Tilt(deg)","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 2.3,  3.0,  4.0,  5.2,  5.8,  6.2,  5.9,  5.5,  4.5,  3.7,  2.5,  2.0,  4.2
         ","Minimum", 1.8,  2.7,  3.5,  4.4,  5.3,  5.4,  4.9,  4.8,  3.9,  3.2,  2.0,  1.8,  4.1
         ","Maximum", 2.6,  3.6,  4.6,  6.0,  6.8,  7.4,  6.7,  6.1,  5.3,  4.7,  2.9,  2.3,  4.5
Lat - 15 ","Average", 3.0,  3.7,  4.6,  5.5,  5.8,  6.1,  5.8,  5.7,  5.0,  4.6,  3.3,  2.8,  4.7
         ","Minimum", 2.2,  3.2,  3.9,  4.6,  5.3,  5.3,  4.9,  4.9,  4.2,  3.8,  2.5,  2.3,  4.5
         ","Maximum", 3.7,  4.7,  5.4,  6.5,  6.8,  7.2,  6.6,  6.3,  5.9,  6.0,  4.1,  3.4,  5.0
Lat      ","Average", 3.4,  4.0,  4.7,  5.4,  5.5,  5.6,  5.4,  5.5,  5.1,  4.9,  3.7,  3.1,  4.7
         ","Minimum", 2.4,  3.4,  4.0,  4.5,  4.9,  4.9,  4.6,  4.7,  4.2,  4.0,  2.7,  2.5,  4.4
         ","Maximum", 4.3,  5.3,  5.6,  6.4,  6.4,  6.6   6.2,  6.1,  6.0,  6.5,  4.6,  3.9,  5.1
Lat + 15 ","Average", 3.6,  4.1,  4.6,  5.0,  4.9,  4.9   4.8   5.0,  4.8,  4.9,  3.8,  3.3,  4.5
         ","Minimum", 2.5,  3.5,  3.8,  4.1,  4.4,  4.3,  4.0,  4.3,  4.0,  3.9,  2.7,  2.5,  4.2
         ","Maximum", 4.6,  5.4,  5.5,  6.0,  5.7,  5.7,  5.4,  5.6,  5.8,  6.7,  4.9,  4.2,  4.8
90       ","Average", 3.2,  3.3,  3.2,  2.9,  2.4,  2.2,  2.3,  2.7,  3.2,  3.8,  3.3,  3.0,  3.0
         ","Minimum", 2.0,  2.7,  2.7,  2.5,  2.3,  2.0,  2.1,  2.4,  2.6,  3.0,  2.2,  2.2,  2.7
         ","Maximum", 4.2,  4.5,  3.8,  3.5,  2.7,  2.4,  2.5,  3.0,  3.8,  5.2,  4.3,  3.9,  3.2

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day),
Percentage Uncertainty = 9"
Axis Tilt","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 3.1,  4.0,  5.2,  6.7,  7.3,  7.8,  7.3,  6.9,  5.8,  5.0,  3.4,  2.7,  5.5
         ","Minimum", 2.1,  3.3,  4.3,  5.3,  6.3,  6.4,  5.7,  5.8,  4.6,  4.1,  2.4,  2.2,  5.2
         ","Maximum", 3.8,  5.2,  6.5,  8.2,  9.1,  9.8,  8.7,  7.9,  7.2,  6.9,  4.3,  3.4,  6.1
Lat - 15 ","Average", 3.6,  4.6,  5.7,  6.9,  7.4,  7.7,  7.3,  7.1,  6.2,  5.7,  4.0,  3.3,  5.8
         ","Minimum", 2.5,  3.7,  4.6,  5.4,  6.3,  6.4,  5.7,  5.9,  4.9,  4.5,  2.8,  2.5,  5.5
         ","Maximum", 4.7,  6.1,  7.1,  8.6,  9.2,  9.8,  8.7,  8.1,  7.7,  7.9,  5.1,  4.2,  6.4
Lat      ","Average", 3.9,  4.8,  5.8,  6.9,  7.1,  7.4,  7.1,  7.0,  6.3,  5.9,  4.3,  3.6,  5.8
         ","Minimum", 2.6,  3.8,  4.6,  5.3,  6.1,  6.1,  5.4,  5.8,  4.9,  4.7,  2.9,  2.7,  5.5
         ","Maximum", 5.1,  6.5,  7.2,  8.6,  8.9,  9.4,  8.4,  8.0,  7.8,  8.3,  5.6,  4.6,  6.5
Lat + 15 ","Average", 4.1,  4.9,  5.7,  6.6,  6.7,  6.9,  6.6,  6.7,  6.1,  6.0,  4.4,  3.7,  5.7
         ","Minimum", 2.7,  3.9,  4.5,  5.1,  5.7,  5.7,  5.1,  5.5,  4.7,  4.7,  3.0,  2.8,  5.3
         ","Maximum", 5.4,  6.6,  7.2,  8.3,  8.4,  8.7,  7.9,  7.6,  7.6,  8.4,  5.8,  4.9,  6.3

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"
Tracker  ","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
2-Axis   ","Average", 4.1,  4.9,  5.8,  7.0,  7.4,  7.9,  7.4,  7.2,  6.3,  6.0,  4.4,  3.8,  6.0
         ","Minimum", 2.7,  3.9,  4.7,  5.4,  6.4,  6.5,  5.8,  5.9,  4.9,  4.7,  3.0,  2.8,  5.7
         ","Maximum", 5.4,  6.6,  7.3,  8.6,  9.3, 10.0,  8.9,  8.2,  7.8,  8.4,  5.8,  4.9,  6.7
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EVANSVILLE, IN

Latitude (N): 38.05
Longitude (W): 87.53

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SOLAR RADIATION FOR FLAT-PLATE COLLECTORS FACING SOUTH AT A FIXED-TILT (kWh/m2/day), Percentage Uncertainty = 9"
Tilt(deg)","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 2.1,  2.9,  3.8,  5.0,  5.9,  6.5,  6.3,  5.7,  4.6,  3.5,  2.3,  1.8,  4.2
         ","Minimum", 1.8,  2.5,  3.4,  4.1,  4.8,  5.8,  5.3,  5.0,  4.1,  2.9,  1.9,  1.5,  4.0
         ","Maximum", 2.5,  3.3,  4.3,  5.9,  7.0,  7.7,  6.9,  6.3,  5.2,  4.2,  2.7,  2.2,  4.6
Lat - 15 ","Average", 2.9,  3.7,  4.5,  5.3,  5.9,  6.3,  6.2,  6.0,  5.3,  4.5,  3.1,  2.5,  4.7
         ","Minimum", 2.3,  3.0,  3.8,  4.3,  4.8,  5.7,  5.3,  5.2,  4.5,  3.5,  2.3,  2.0,  4.4
         ","Maximum", 3.5,  4.5,  5.2,  6.4,  7.1,  7.5,  6.8,  6.6,  6.0,  5.5,  3.8,  3.4,  5.2
Lat      ","Average", 3.3,  4.0,  4.6,  5.2,  5.6,  5.8,  5.8,  5.8,  5.3,  4.8,  3.4,  2.9,  4.7
         ","Minimum", 2.5,  3.1,  3.8,  4.1,  4.5,  5.2,  4.9,  5.0,  4.5,  3.7,  2.4,  2.2,  4.4
         ","Maximum", 4.1,  5.0,  5.4,  6.3,  6.6,  6.8,  6.3,  6.4,  6.1,  6.0,  4.3,  4.0,  5.2
Lat + 15 ","Average", 3.5,  4.1,  4.5,  4.8,  4.9,  5.0,  5.1,  5.3,  5.1,  4.9,  3.6,  3.0,  4.5
         ","Minimum", 2.5,  3.1,  3.7,  3.8,  4.0,  4.6,  4.3,  4.6,  4.3,  3.7,  2.5,  2.3,  4.2
         ","Maximum", 4.4,  5.2,  5.3,  5.8,  5.8,  5.8,  5.5,  5.8,  5.9,  6.1,  4.6,  4.3,  5.0
90       ","Average", 3.1,  3.4,  3.3,  3.0,  2.6,  2.4,  2.5,  3.0,  3.5,  3.8,  3.1,  2.8,  3.0
         ","Minimum", 2.2,  2.6,  2.7,  2.4,  2.2,  2.3,  2.3,  2.6,  2.9,  2.9,  2.0,  2.0,  2.8
         ","Maximum", 4.1,  4.5,  3.9,  3.6,  2.9,  2.6,  2.7,  3.3,  4.0,  4.9,  4.1,  4.0,  3.3

SOLAR RADIATION FOR 1-AXIS TRACKING FLAT-PLATE COLLECTORS WITH A NORTH-SOUTH AXIS (kWh/m2/day),
Percentage Uncertainty = 9"
Axis Tilt","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
0        ","Average", 2.9,  3.9,  5.1,  6.5,  7.7,  8.4,  8.2,  7.6,  6.2,  4.9,  3.1,  2.4,  5.6
         ","Minimum", 2.2,  3.1,  4.1,  5.0,  5.8,  7.2,  6.5,  6.4,  5.2,  3.7,  2.3,  1.8,  5.2
         ","Maximum", 3.6,  4.8,  6.1,  8.2,  9.6, 10.4,  9.1,  8.5,  7.3,  6.3,  3.9,  3.3,  6.4
Lat - 15 ","Average", 3.5,  4.5,  5.6,  6.8,  7.7,  8.4,  8.2,  7.8,  6.7,  5.7,  3.7,  3.0,  6.0
         ","Minimum", 2.6,  3.4,  4.4,  5.2,  5.9,  7.1,  6.5,  6.6,  5.6,  4.2,  2.6,  2.2,  5.6
         ","Maximum", 4.4,  5.7,  6.8,  8.6,  9.8, 10.4,  9.1,  8.8,  7.9,  7.2,  4.8,  4.2,  6.8
Lat      ","Average", 3.8,  4.7,  5.7,  6.7,  7.5,  8.1,  7.9,  7.7,  6.8,  5.9,  4.0,  3.3,  6.0
         ","Minimum", 2.8,  3.6,  4.5,  5.1,  5.7,  6.8,  6.3,  6.4,  5.6,  4.3,  2.7,  2.3,  5.6
         ","Maximum", 4.8,  6.1,  6.9,  8.5,  9.5, 10.0,  8.8,  8.6,  8.0,  7.6,  5.2,  4.6,  6.9
Lat + 15 ","Average", 3.9,  4.8,  5.6,  6.4,  7.1,  7.5,  7.4,  7.3,  6.6,  5.9,  4.1,  3.4,  5.9
         ","Minimum", 2.8,  3.6,  4.4,  4.9,  5.3,  6.3,  5.9,  6.1,  5.4,  4.3,  2.7,  2.4,  5.5
         ","Maximum", 5.0,  6.2,  6.8,  8.2,  9.0,  9.3,  8.3,  8.2,  7.9,  7.7,  5.4,  4.9,  6.7

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9"
Tracker  ","       ","Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec","Year"
2-Axis   ","Average", 4.0,  4.8,  5.7,  6.8,  7.8,  8.6,  8.4,  7.9,  6.8,  6.0,  4.1,  3.5,  6.2
         ","Minimum", 2.8,  3.6,  4.5,  5.2,  5.9,  7.3,  6.7,  6.6,  5.6,  4.4,  2.8,  2.4,  5.8
         ","Maximum", 5.1,  6.2,  6.9,  8.6,  9.9, 10.6,  9.3,  8.8,  8.1,  7.7,  5.4,  5.0,  7.1
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Appendix B
Solar Radiation Charts for Selected Cities in Kentucky, Indiana, & Tennessee

Source: *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*
National Renewable Energy Laboratory, U.S. Department of Energy
Charts for locations throughout the United States available on-line at:
http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/sum2/

Use solar radiation data for the city closest to your location.

Current annual PV production capacity at SHARP's new plant is 20 megawatts (MW). The total US market was 48 MW in 2002, and is estimated to be 120 MW by 2005.[3]

The popularity of net metering and other forms of distributed generation have affected the demand for solar photovoltaics. In 2002, 270 MW (51 percent) of PV shipments went into grid-intertied residential and commercial buildings. Even with the increased demand for PV, prices in mid-2004 were still lower than they had ever been, which reflects the progress that has been made in the manufacturing process. Much of this progress has been due to the support of the US Department of Energy's PV research program, and the industry has seen solar manufacturing prices fall by more than half in the last ten years.[4]

A plan developed by the Solar Energy Industries Association (SEIA) would utilize annually declining federal tax incentives to speed the commercialization of photovoltaics in the United States. According to SEIA's projections, implementing their plan would reduce the price of solar electricity from its current rate of 18 to 25 cents per kilowatt-hour to 5.7 cents per kilowatt-hour by 2015, thereby making it the least expensive retail electricity option. SEIA's *Photovoltaics Industry Roadmap* projects that this plan would generate more than $34 billion in new manufacturing investments over the next ten years. By 2025, photovoltaics would provide half of all new electricity generation in the US, and by 2030, the US solar industry would employ 260,000 people.[5]

Environmental Costs of PV Systems

Photovoltaics can help us achieve a more sustainable energy system because they generate electricity using a renewable resource and without emitting pollutants. However, when we review the life cycle of a PV system from the manufacture of the PV cells and associated equipment, through installation, use, and final decommissioning or disposal, we find that their use is not without environmental costs. The greatest areas of environmental concern are associated with the energy required to manufacture and install PV equipment and the hazardous materials used to make PV cells and batteries.

Building and installing a PV system requires resources and energy, and it is necessary to know our return on this initial energy investment. The National Renewable Energy Laboratory (NREL) reviewed research into the "energy payback" of PV systems to assess how long they must operate to generate the amount of energy that was used to make and install the system. NREL reports that, depending on the type of PV cell being used, the energy payback for PV systems is one to four years. Assuming a 30-year operational life for PV systems, this means that 87 to 97 percent of the energy they produce will be free of the environmental costs of the energy used in their manufacture.[6]

Numerous hazardous materials that could threaten the environment and human health are used in the manufacture of PV cells. These materials vary depending on cell type and include explosive and toxic gases, solvents, cadmium, and lead solder. After assessing the environmental and safety impacts of PV technology, the Brookhaven National Laboratories concluded that, "routine conditions in manufacturing facilities should not pose any threats to health and the environment" and that "the US industry is vigilant in preventing health risks and has established proactive programs in industrial hygiene and environmental control."[7] They saw accidents at manufacturing plants as the greatest potential threat to workers and the surrounding human and natural communities.

Once installed, the PV module poses minimal health and environmental risks, according to the Electric Power Research Institute (EPRI). They state that "the potential for chemical releases appears to be small since the chemicals are present in the sealed PV modules. Releases are likely to occur only due to fires or other unusual accidents."[8] At the end of a PV system's useful life, its disposal could contaminate the environment if it were landfilled or incinerated. The PV industry is currently developing processes for recycling old PV modules.[9]

Batteries, an integral part of many PV systems, present perhaps the most serious environmental and human health concerns. Batteries can contain lead, heavy metals, acids, and other hazardous chemicals, and their limited life spans (typically three to ten years) creates an ongoing demand for their production and disposal. The commonly-used deep cycle, lead-acid batteries require regular maintenance which may expose system users to hazardous chemicals. Although recycling rates for lead-acid batteries are high and new batteries contain, on average, 60 percent recycled lead,[10] lead recycling has for the most part moved to Third World countries with lower wages and minimal or non-existent environmental and worker safety standards. Greenpeace has documented the flow of tens of thousands of tons of lead waste from the US, UK, Australia, and Japan to countries such as Indonesia, the Philippines, and Thailand. They have also documented the suffering of the workers and communities impacted by the lead smelters and recycling factories in these places.[11] The solar industry and renewable energy advocates should focus attention on this issue to motivate the lead and battery industries to meet the highest environmental and safety standards.

Despite the environmental costs of PV systems, solar electricity still offers distinct advantages that make it an important part of a renewable energy