DOE/GO-120001-1171
FS122
August 2001

ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Assessing Climate to Improve Solar Design

Sunlight, weather patterns, and microclimates (the climate of a small area) affect the performance of solar energy systems. The more direct sunlight a system receives, the more electricity or heat it produces. In contrast, clouds, fog, frost, rain, and falling snow reduce the amount of energy that can be harnessed from the sun. Water and vegetation can make a solar energy system work better or worse, depending on where they are located. Solar designers assess climate to figure out how to work with specific environmental conditions to enhance the performance of solar energy systems.

Warren Gretz, NREL/PIX02361

Clouds are the predominant atmospheric condition that determines the amount of solar radiation reaching the earth.

Designing for Climate

Taking into account the characteristics of sunlight at a given location can greatly enhance solar design. The amount of sunlight, or solar radiation, reaching a specific site depends on latitude, time of day, and time of year. Generally speaking, locations nearer the equator receive more sunlight throughout the year than places at higher latitudes. In the United States, for example, the southern states receive more solar radiation than the northern states.

Two cities at the same latitude may vary in the amount of sunlight they receive during the year. A city that is often cloudy or rainy will receive less sunlight than one where the sun shines nearly every day. Clouds scatter and absorb solar radiation, creating diffuse sunlight. Dust, smoke, pollen, and suspended water droplets in the atmosphere also scatter and absorb the sun's rays. Diffuse sunlight contains less energy than direct sunlight, which travels unimpeded through the atmosphere. On cloudy days, most or all solar radiation is diffuse.

On a clear day, about 85 percent of the sunlight striking the Earth is high-energy, direct radiation. Locations that enjoy clear, sunny days throughout the year have the best solar resources. In the United States, the Southwest is one of the world's best areas

This document was produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory. The document was produced by the Information and Outreach Program at NREL for the DOE Office of Energy Efficiency and Renewable Energy. The Energy Efficiency and Renewable Energy Clearinghouse (EREC) is operated by NCI Information Systems, Inc., for NREL / DOE. The statements contained herein are based on information known to EREC and NREL at the time of printing. No recommendation or endorsement of any product or service is implied if mentioned by EREC.

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

The southwestern United States receives nearly twice as much sunlight in a year as other areas of the country.

for sunlight. This region receives nearly twice as much sunlight in a year as other areas of the country. Other parts of the world with lots of sunlight include desert and high plains regions of Asia, Africa, and Latin America.

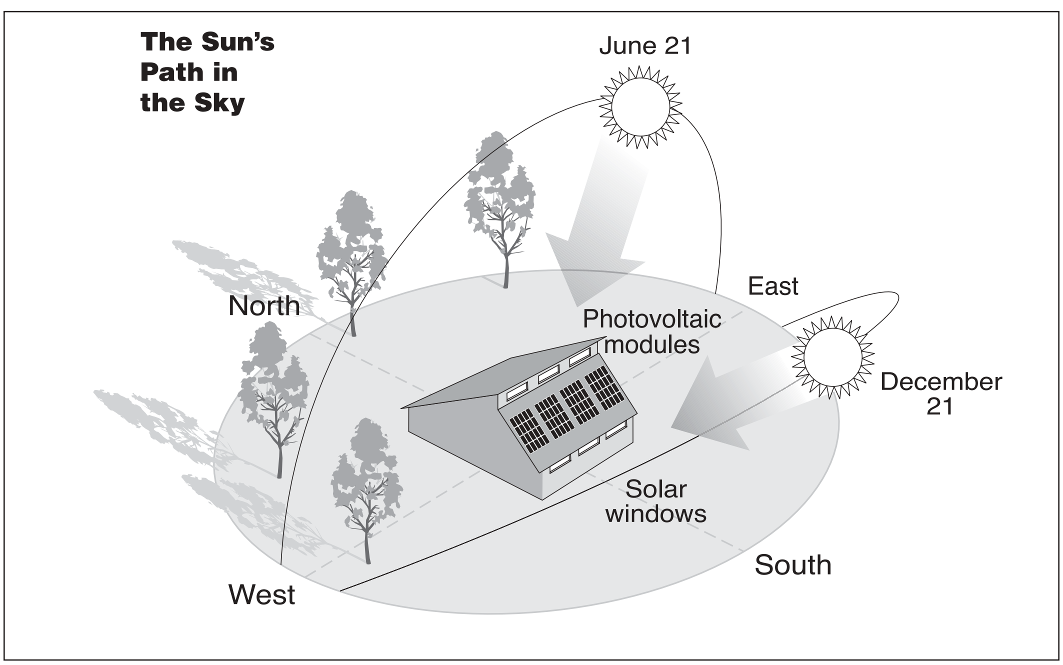
You can get a general idea about the quality of sunlight in your community from solar radiation maps. Bear in mind, however, that the amount of sunlight available for a solar energy system also depends on other factors, such as the angle of the solar system collector with respect to incoming sunlight. Remember, too, that sunlight is affected by the weather, microclimates such as a foggy river valley, and nearby tall buildings, trees or shrubs, hills, and fences that block incoming sunlight. Even building structures such as overhangs can shade a solar collector (or aperture). Good design considers all these factors.

Solar Radiation Basics

The evaluation of the solar resource for a specific project requires understanding the basic principles of solar radiation. Every location on Earth receives sunlight, at least part of the year. However, the amount of sunlight reaching the Earth varies according to geographical location, time of day, and season.

Three factors are responsible for variations in the amount and quality of sunlight striking the Earth: (1) the Earth is round, (2) the Earth revolves around the sun in an elliptical orbit, and (3) the Earth rotates on a tilted axis. Because the Earth is round, the sun strikes the surface at different angles ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the Earth's surface gets all the energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse. Because the Earth is round, the frigid polar regions never get a high sun. Because of the tilted axis of rotation, these areas get no sun at all during part of the year.

Because the Earth revolves around the sun in an elliptical orbit, it is nearer the sun during part of the year. When the sun is nearer the Earth, the Earth's surface receives a little more solar energy. The Earth is nearer the sun when it is summer in the southern hemisphere and winter in the northern hemisphere. However, the presence of vast oceans moderates the hotter summers and colder winters one would expect to see in the southern hemisphere as a result of this difference.



The United States receives far mor solar radiation in summer, when the sun is nearly overhead, than in winter when the sun's rays are more slanted.

Assessing climate can help you better define system requirements for solar heating and solar electric systems.

Active and passive solar features incorporated into the design of this off-the-grid Colorado home provide all of its energy.

The 23.5° tilt in Earth's axis of rotation is a more significant factor in determining the amount of sunlight 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 6 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 a solar energy system. Cities like Denver (near 40° N 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.

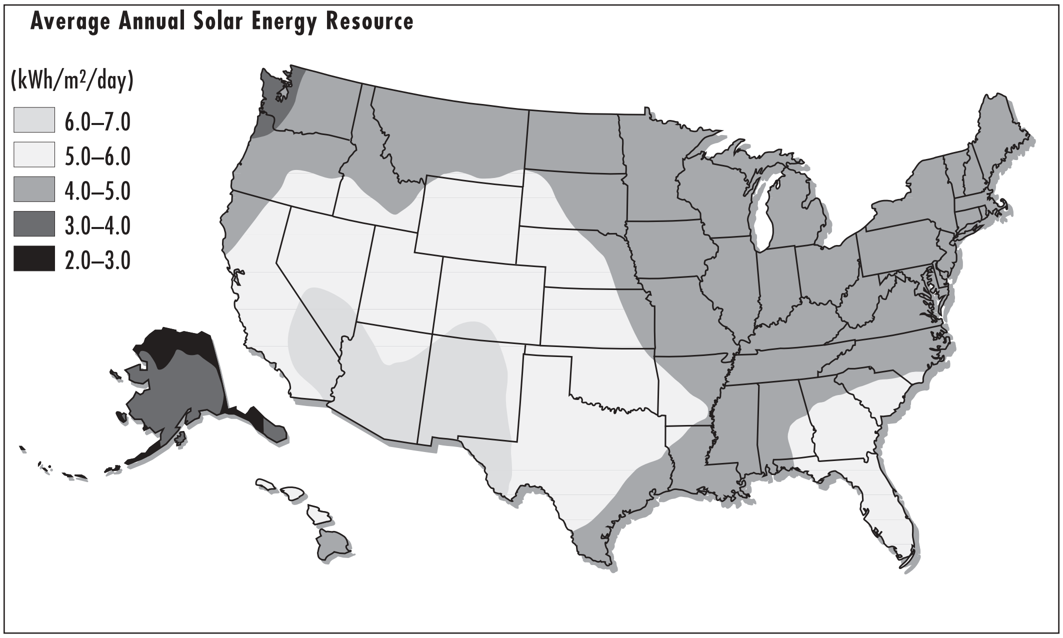
The rotation of the Earth is responsible for hourly variations in sunlight. In the early morning and late afternoon, the sun is low in the sky. Its rays travel further through the atmosphere than at noon when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches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

Solar Resource Assessment

Calculating the amount of sunlight available for a solar energy system is complex and challenging. Atmospheric conditions, the changing position of the sun, and local terrain interact to moderate the solar resources at a given time and place. Solar engineers rely on historical data about weather, climate, and air pollution to design a solar energy system for a specific site. They must consider the sun's position throughout the year. They must take care to use published information about solar radiation that applies to tilted, south-facing collectors. And they must understand not only how seasonal weather patterns affect sunlight, but also how they affect solar energy system requirements.

Whether sunlight is direct or diffuse can significantly affect solar energy system performance. Solar electric systems require direct sunlight. Collectors for solar heating systems, including passive solar buildings, capture both direct and diffuse solar radiation. In some areas, solar energy systems will capture significant amounts of sunlight reflected from nearby white surfaces such as snow, light-colored sand, or salt flats. Solar designers need to account for such surface reflection effects where they exist.

Designing according to your climate can also help you keep your home from over heating in the summer.



Obtaining specific data on the solar resources in your area will help you design the most effective PV system for your home.

Scientists measure the amount of sunlight falling on specific locations at different times of the year, and then estimate the amount of sunlight falling on regions at the same latitude with similar climates. Measurements of solar energy are typically expressed as total radiation on a horizontal surface. Radiation data for photovoltaic (PV) systems, which produce electricity, are often represented as kilowatt-hours per square meter (kWh/m2). Direct estimates of solar energy may also be expressed as watts per square meter (W/m2). Radiation data for active and passive solar energy systems, which produce heat, are usually represented in British thermal units per square foot (Btu/ft2). The following equation allows you to convert from one system of measurement to the other: 317 Btu/ft2 = 1 kWh/m2.

You can obtain basic information about the nation's solar resource from the National Renewable Energy Laboratory in Golden, Colorado, or the National Climatic Data Center in Asheville, North Carolina. The National Renewable Energy Laboratory also provides solar radiation resource maps of the United States. The maps are available for both horizontal and tilted surfaces for each month of the year. (See "Resources" below to obtain basic information and maps.)

Warren Gretz, NREL/PIX00041

A researcher measures solar radiation at the National Renewable Energy Lab.

System Requirements and Climate

Assessing climate can help you better define system requirements for solar heating and solar electric systems. Seasonal weather patterns affect heating and cooling requirements as well as the solar resource. In winter, heat loss is affected by the outdoor, or ambient, temperature. The colder it is outside, the faster a solar collector will lose heat, becoming less efficient. Low temperatures also increase heat loss from buildings. The lower the daily average outdoor temperatures, the greater the heating requirements will be.

Winter heating requirements usually increase when there is less solar energy available. For this reason, engineers often design solar heating systems to capture the maximum amount of energy from the winter sun. Then they can apply the principles of climatic design to keep the system from producing too much heat in the summer. For example, a roof overhang can be designed to shade south-facing windows in the summer.

The microclimate of a building can make or break a solar project.

People use more electricity in the winter when days are shorter. Solar electric systems produce more electricity in the summer when days are longer and there is more direct sunlight. Detailed information about your climate can help you figure out whether a solar electric system makes sense for you. If you live in the southwestern United States, for example, the answer may well be "yes." This region enjoys a significant amount of direct sunlight year-round, and its wintertime heating requirements are moderate. Your answer may also be "yes" if you want electricity for a summer cabin in Montana that is miles from the nearest power line. By carefully positioning your array of solar (PV) cells, you should be able to capture enough direct sunlight to run your lights and a small refrigerator.

A detailed discussion of solar resource, heating-, and electric-system requirements is beyond the scope of this fact sheet. These requirements vary throughout the United States and are specific to a particular project. Excellent software for determining solar energy system capacity requirements is available on the Internet from Web site resources listed at the end of this publication.

Microclimates

The microclimate of a building site can make or break a solar project. Shadows cast by nearby buildings, trees, or hills are important considerations in orienting a solar collector or designing a passive solar building. So, too, are local conditions that predispose a site to fog or an unusual amount of snow. For instance, low-lying areas near rivers and lakes may have an early morning fog that burns off before noon. In such a location, a solar designer might want to orient a collector to take advantage of the clear afternoon sky. Similarly, local weather patterns may result in frequent and larger snowfalls in certain areas, increasing heating requirements and reducing the amount of solar energy available in the winter months. The solar designer who factors in such considerations will reap dividends in terms of improved system performance.

Winds can affect how a solar system performs. It is important to analyze whether nearby hills, trees, and buildings funnel winds into or away from a particular site. In winter, cold winds can accelerate heat loss from a building, increasing solar heating requirements. In summer, cool breezes can help disperse heat from a well-designed building, making it more comfortable and reducing cooling requirements.

Using climate assessments in design involves more than creating a building or solar system within the context of a specific environment. Solar engineers can use landscape design and building structures themselves to enhance solar system performance or to keep buildings warmer in winter and cooler in summer. For instance, overhangs and eaves can shade windows when solar heating is not desired. Landscape designers can strategically place deciduous trees and shrubs outside to help keep buildings cooler and more comfortable during the warmer months. Courtyards filled with trees, flowering vines, shrubs and a large fountain can create a cool oasis even in the hottest desert climate.

Paul Torcellini, NREL/PIX10059

Overhangs shade windows in hot climates or in summer.

Software tools give homeowners access to high-technology measurements of solar radiance in various regions.

Warren Gretz, NREL/PIX04102

This instrument in Billings, Oklahoma measures total hemispheric irradiance.

Design Assistance

Climates can play an important role at four stages in the solar energy system design process: 1) the evaluation of the solar resource, 2) the definition of system requirements, including the impact of climate-related factors on system design, 3) the analysis of existing site-specific microclimates, and 4) the design of systems, buildings, and landscapes to maximize performance. Until recently, solar designers had to perform a series of complex calculations to determine the size of the solar resource, figure out heating and cooling requirements in different parts of the country at different times of the year, and decide the optimal size and orientation of a solar heating or electric system. Once this information was obtained, designers then integrated it into plans for a new system or building and the landscape surrounding it.

Today, the design process is made easier because of the number of resources available on the Internet or on CD-ROM. Internet resources offer something for everyone, from the amateur home builder to the experienced solar designer. Several programs can provide you with a detailed analysis of your local solar resource along with information on long-term weather patterns. All you need to do is fill in your exact location (latitude and longitude). Other resources for climate and design on the Internet include:

- Learning tools for newcomers to green design
- Green design checklists
- Strategies for finding the best locations for new solar energy systems
- Strategies for reducing the time and cost of pre-feasibility studies
- An easy-to-use method for estimating the performance of PV systems connected to the U.S. power grid
- A program that calculates the location of the sun in the sky—any place, any day, any time.

Ongoing efforts in countries around the world to develop and refine new design assistance resources will continue to support the use of climate assessment in design and other improvements to solar energy system design.

Resources

The following are sources of additional information on the role of sunlight and microclimates in solar energy system design. The list is not exhaustive, nor does the mention of any resource constitute a recommendation or endorsement.

Ask an Energy Expert
DOE Energy Efficiency and Renewable Energy Clearinghouse (EREC)

P.O. Box 3048
Merrifield, VA 22116
Phone: 1-800-DOE-EREC (1-800-363-3732)
TDD: 1-800-273-2957
Fax: (703) 893-0400
E-mail: doe.erec@nciinc.com

Online submittal form:
http://www.eren.doe.gov/menus/energyex.html

Consumer Energy Information Web site:
http://www.eren.doe.gov/consumerinfo/

Energy experts at EREC provide free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

DOE Energy Efficiency and Renewable Energy Network (EREN)

Web site: http://www.eren.doe.gov/

A comprehensive online resource for DOE's energy efficiency and renewable energy information.

Organizations

American Solar Energy Society, Inc. (ASES)
2400 Central Avenue, G-1
Boulder, CO 80301
Phone: (303) 443-3130
Fax: (303) 443-3212
E-mail: ases@ases.org
Web site: http://www.ases.org

A national advocacy organization dedicated to the use of solar energy in buildings.

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001
Phone: (828) 271-4800
Fax: (828) 271-4876
E-mail: info@ncdc.noaa.gov
Web site: http://www.ncdc.noaa.gov/

The world's largest active archive of weather data. Produces numerous climate publications and responds to data requests from all over the world.

National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Web site: http://www.nrel.gov
The U.S. Department of Energy's premier laboratory for renewable energy research & development, and a lead lab for energy efficiency.

Renewable Resource Data Center
E-mail: rredc@nrel.gov
Web site: http://rredc.nrel.gov

Provides maps and information on solar radiation, biomass, geothermal, and wind energy resources.

The Center for Buildings and Thermal Systems
Web site: www.nrel.gov/buildings_thermal

Provides information on energy-efficient buildings.

Sustainable Buildings Industry Council (SBIC)
1331 H Street, NW, Suite 1000
Washington, DC 20005-4706
Phone: (202) 628-7400
Fax: (202) 393-5043
E-mail: sbic@sbicouncil.org
Web site: http://www.sbicouncil.org

Promotes the use of energy-efficient and passive solar building design and construction.

Web Sites

Building Energy Software Tools
DOE Office of Building Technology, State and Community Programs
Web site:
http://www.eren.doe.gov/buildings/tools_directory/

Describes many energy-related software tools for buildings, with an emphasis on renewable energy and energy efficiency.

(Continued on page 8)

(Continued from page 7)

Dynamic Maps of Monthly Direct Normal Solar Radiation
NREL Center for Renewable Energy Resources
Web site: http://maps.nrel.gov/

Online atlas of monthly solar resource maps includes a user demonstration.

Energy Design Tools
Department of Architecture and Design
University of California, Los Angeles
Web site: http://www.aud.ucla.edu/energy-design-tools/

Features downloadable software to help design energy-efficient homes, including those concerning solar and climatic design.

PV Watts: A Performance Calculator for Grid-Connected PV Systems
NREL Renewable Resource Data Center
Web site:
http://rredc.nrel.gov/solar/codes_algs/PVWATTS

Provides non-experts with performance estimates for grid-connected PV systems.

Solar Position and Intensity
NREL Renewable Resource Data Center
Web site:
http://rredc.nrel.gov/solar/codes_algs/solpos/

Provides a code that computes the sun's position and intensity in the sky. Includes links to other solar and climate analysis tools.

Solar Radiation Data Manual for Buildings
NREL Renewable Resources Data Center
Web site: http://rredc.nrel.gov/solar/pubs/bluebook

Provides methods for calculating solar radiation and deriving climatic data.

Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors
NREL Renewable Resources Data Center
Web site: http://rredc.nrel.gov/solar/pubs/redbook

Provides methods for calculating solar radiation for flat-plate and concentrating collectors.

Reading List

The Climatic Dwelling: An introduction to climate-responsive residential architecture, E. Cofaign, J. Olley, and J. Lewis. London: James & James Ltd., 1996. Phone: +44 20 7387 8558; http://www.jxj.com.

CRC Handbook of Energy Efficiency, F. Kreith and R. West, editors. Boca Raton, Florida: CRC Press, Inc., 1997. Phone: 800-272-7737; http://www.crcpress.com/us/.

Energy and Climate in the Urban Built Environment, M. Santamouris. London: James & James, Ltd., 2000. Phone: +44 20 7387 8558; http://www.jxj.com.

The Green Vitruvius – Principles and Practice of Sustainable Architectural Design, E. Cofaign, E. Fitzgerald, R. McNicholl, and J. Lewis. London: James & James Ltd., 1999. Phone: +44 20 7387 8558; http://www.jxj.com.

The Role of the Sun in Climate Change, D. Hoyt and K. Shatten. New York: Oxford University Press, 1997. Phone: 212-726-6000; http://www.oup-usa.org.

Solar Radiation and Daylight Models for the Energy Efficient Design of Buildings (with Software Compact Disk), H. Kambezidis, T. Muneer, and P. Tregenza. Oxford, UK: Butterworth-Heinemann, 1997.
Phone: 800-366-2665; http://www.bh.com.