an introduction to new home solar design

Montana solar house

Funded by the NorthWestern Energy Universal Systems Benefits Funds
Prepared by the National Center for Appropriate Technology

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An Introduction to New Home Solar Design

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chapter 1:

introduction: the case for solar in montana

Now, as your new house is being planned, is the time to seriously consider solar energy. If you wait until after the house is built, it will likely be too late. While any house with a window that admits sunlight is utilizing energy from the sun, a solar home is specifically designed to collect and use solar energy.

The sun can heat both domestic water and living spaces, as well as provide electri This introduction to solar design explains approaches to collecting and using solar energy in a house. These design options range from the simple and inexpensive to the sophisticated and costly. One thing is certain: the decisions made during initial building design will determine a home's solar future.

A home reflects the likes, desires, and personality of the owners. A solar home expresses the owner's commitment to a cleaner environment and an interest in integrating lifestyle with natural processes.

Every New House Solar-Ready!
During the lifetime of new houses built today, building roofs will commonly be used to generate electricity and hot water. Not all new homeowners can afford to incorporate solar electric systems and solar water-heating systems in their new home at the time of construction. Therefore, at a minimum, all new houses should be designed and constructed to readily accept solar electric systems and solar water-heating systems in the future. We choose to call houses designed for future solar installations "solar-ready."

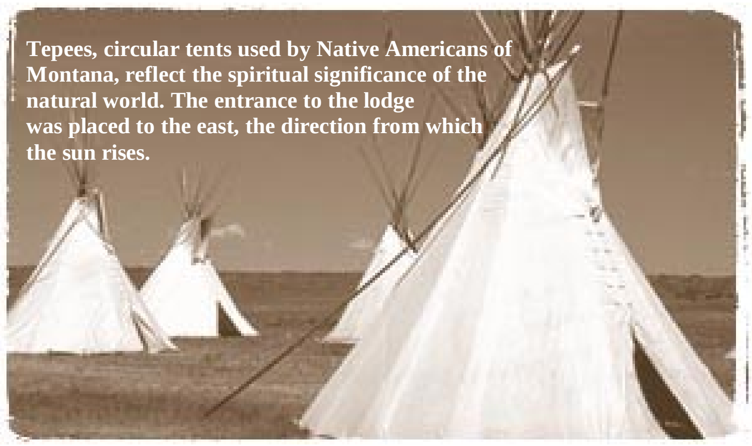
Passive Solar and Solar Tempering Must Be Included When the House is Built!
While solar electric systems and solar-water heating systems can be added in the future if the house is designed properly, other solar space-heating design features such as solar tempering and passive solar must be included in the original house design. These design approaches use building orientation, room layout, window placement, and interior construction to use energy from the sun.

About This Publication

This is not a technical guide for designing or installing your solar systems. For that information, we recommend that you consult an experienced architect, solar house designer, or solar electric system dealer ("photovoltaic installer") who will have detailed technical specifications and other information. Passive solar homes in particular require careful design analysis to provide optimum energy performance and acceptable comfort conditions. A number of useful references are included in Chapter 7. Many solar energy systems are a substantial investment and, as with any investment, careful planning will help ensure that you make the right decisions.

In this first chapter we make a case for solar houses in Montana and describe the basic steps in the solar design process. Chapter 2 explains how to evaluate your building site for solar energy. Solar electric systems are described in Chapter 3. Solar water-heating systems are explained in Chapter 4. Chapter 5 discusses climate-responsive or building-integrated design. Chapter 6 suggests useful consumer tips and Chapter 7 lists useful references.

The Case for Solar Homes



Tepees, circular tents used by Native Americans of Montana, reflect the spiritual significance of the natural world. The entrance to the lodge was placed to the east, the direction from which the sun rises.

The sun has been recognized throughout history as the giver of life on earth. It has played pivotal spiritual and functional roles in human development. The harnessing of fossil fuels in the last century allowed technological advances that created more comfortable lifestyles. With the widespread use of electricity for lighting in the early 1900s, we began to ignore the sun when designing our buildings. Now at the beginning of a new millineum we have, in large part, lost contact with the natural world. We are recognizing the widespread environmental degradation that has resulted from our dependence on non-renewable energy sources.

The design and construction of a new home is a unique and exciting opportunity. A home usually represents the single greatest investment most people make. The decisions made in the design of a new house will define the basic nature of the house for its life. This original house design will determine its durability, energy usage patterns, comfort, and marketability.

There are many reasons why more and more people in all regions of the country are including solar energy in their new homes. The following are several reasons why solar makes sense for your new home. Your site, lifestyle, and budget will determine which approaches are most appropriate for you.

energy Costs

The United States imports more than half of its oil. This makes energy prices susceptible to international conflicts and political decisions. Energy shortages and environmental degradation occur because we have relied on dwindling domestic oil supplies and imported fossil fuels. World oil production is expected to peak in 2010. With increasing demand and reduced supplies, the cost of fossil fuels can be expected to increase significantly over the life of the house built today. If history is a reliable gauge, the cost of conventional, centrally-distributed electricity will continue to increase while the cost of solar electric systems will continue to decrease.

In Montana, restructuring of the electric utility industry will lead to a 50% increase in electric costs in the Montana Power Company service territory beginning in July 2002. Natural gas costs are expected to remain high, or even increase, as that fuel is increasingly used to generate electricity on the national level. The best way to guard against future cost increases is to reduce dependency on purchased energy. Solar technologies can do just that.

self-sufficiency

The Y2K scare made many electricity consumers realize just how dependent we are on centralized energy systems. Solar technologies can reduce or eliminate that dependency. A lack of reliability in the centralized electric supply grid is motivating many homeowners and businesses to install their own electric-generation systems to assure continuous power for critical electronic equipment. For most of us, a totally independent energy systems is far too costly. However, this guide will suggest approaches that reduce dependence on centralized energy distribution systems.

environmental awareness

The last century, with its utilization of fossil fuels, saw unprecedented improvements in the global economy, population, and life expectancy. We are only now realizing the environmental consequences of that dependence on fossil fuels. Although the air pollution impacts of fossil fuel power plants and the biological impacts of dams have been documented for decades, the significance of global warming has been widely accepted only in the last few years. A home that depends less on traditional central power generation and fossil fuels will result in less impact on our environment. By using the sun to heat and power our homes, we can reduce our dependence on energy sources that are increasing in cost and polluting our environment.

Occupant Comfort and health

Many aspects of a solar home, specifically solar tempering and passive solar design, provide daylight and allow occupants to relate to the natural world around them. Often, design approaches that use solar energy also consider how construction materials impact a healthy indoor environment. When coupled with other sustainable design practices, the solar home becomes a safer and more enjoyable place to live.

Solar Energy Design Options

The type of solar technologies appropriate for a specific home will depend on the characteristics of the site, style preferences of the owners, and the construction budget. Solar home styles can range in character from modern to traditional. The owners' style preferences will in large part dictate the type and extent of the solar characteristics. For example, installation of solar electric panels on the roof can be incorporated into almost any house design with minimum visual impact. However, a passive design that obtains a substantial portion of the home's space heating needs from the sun will have a more significant influence on the building's appearance and character.

Solar technologies can generally be described as either solar thermal or solar electric. Solar electric systems produce electricity directly from the sun. Electrons are freed by the interaction of sunlight with semiconductor materials in photovoltaic cells. Solar thermal systems use the sun's heat for space conditioning and water heating. Solar thermal systems can either utilize the building's structural components (windows, walls, and floors) or solar collector panels constructed specifically for collecting the sun's energy.

solar design process

Before we describe the solar electric, solar water heating, and building-integrated solar design strategies, we suggest the basic steps in the design process. Although a site and neighborhood may not be optimum for solar design, there are almost always appropriate solar features that can be incorporated.

1. site selection

Choose your building site with solar design in mind. Topography, vegetation, surrounding buildings, and views can help you determine which solar features are feasible on your property. South-facing slopes are better than other slopes. Use care in locating the house on the site. Be sure that the winter sun will not be substantially shaded by mountains, trees, or buildings during the middle of the day. The remaining chapters in this guide will provide more information about the evaluating the site for solar applications.

2. solar professional

Choose a design professional, experienced and enthusiastic with solar energy, to assist with designing your house. If you plan to purchase a home already constructed, look for one that was designed with the solar features discussed in this guide.

3. energy-efficient design

While the purpose of this guide is to encourage the use of solar energy, the first design objective should be energy efficiency. We suggest that all houses in Montana be built to the 1994 Long-Term Super Good Cents specifications, an energy standard developed originally by the Northwest Power Planning Council in its Model Conservation Standards. Although this standard originally was developed for electrically heated houses, recent natural gas cost increases make the standard appropriate to all heating energy types. The Long-Term Super Good Cents standard is more efficient than the current state energy code. The USDOE Energy Star Home rating is another excellent energy-efficient design standard.

4. building and window Orientation

Orient your building to provide maximum southern exposure for rooms and windows. Although due south is best, the orientation of solar collectors (PV modules, hot water collectors, and windows) can be up to 30 degrees off due south and still collect 90 percent of the sun's energy. A deviation of 45 degrees or less from true south is considered acceptable for most applications. Therefore, a building's roof oriented 45 degrees or less from true south is considered excellent for solar electric or water-heating systems.

5. Shading

Your solar collector area, roof and window surfaces should be unshaded from 9 A.M. until 3 P.M. during the heating season for space-heating strategies and year-round for solar electric and water-heating systems. The landscape plan is critical to maintain unshaded access to the sun. Carefully plan the planting of trees or shrubs that could shade the solar system in the future. Even partial shading on a PV array will significantly reduce the system's electrical output. Solar thermal systems are more tolerable of some shading.

? 6. Solar System Selection

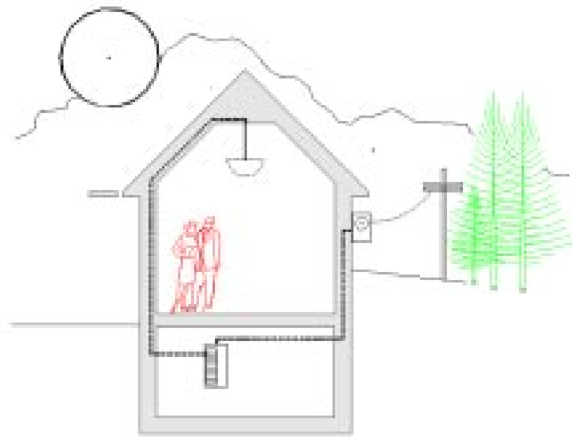
The solar technologies most appropriate for a specific home will depend on the characteristics of the site, lifestyle preferences of the owners, and the construction budget. Solar home styles can range in character from modern to traditional. The style preferences of the owners will in large part dictate the type and the extent of the solar design. For example, installation of solar electric panels or solar shingles on the roof can be incorporated in almost any house design with minimum visual impact. However, a passive design that obtains a substantial portion of the home's space heating needs from the sun will have a more significant influence on the building's appearance and character. Solar technologies can generally be described as either solar thermal or solar electric:

Solar Electric Systems produce electricity directly from the sun. Electrons are freed by the interaction of sunlight with semiconductor materials in photovoltaic cells.

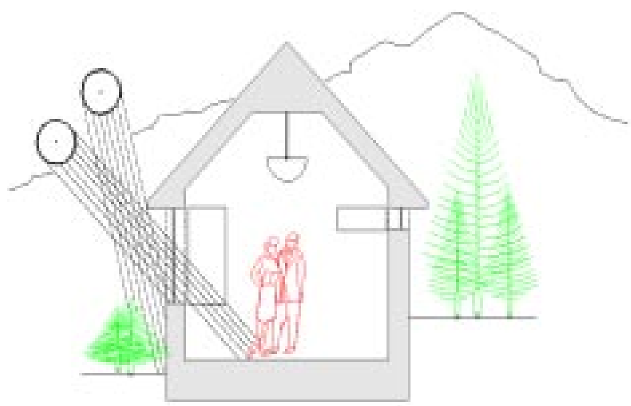
Solar Thermal Systems use the sun's heat for space heating and water heating. Solar thermal systems can utilize either the building's structural components (windows, walls, and floors) or solar collector panels constructed specifically for collecting the sun's energy.

Following is an introduction to solar house design options. These solar design approaches are discussed in more detail in later chapters.

Solar Ready



Every house with access to the sun for several hours during the middle of the day should be designed for future solar applications. At a minimum, new homes should include a south-oriented roof surface to allow future installation of solar electric panels or roofing. Not all homeowners will wish to adapt their dream house to include passive solar, but the vast majority of new homes can be designed to accept solar electric systems in the future as the cost of photovoltaics continues to drop. A solar-ready house design will include provisions for wire or pipe runs to the solar collector. For solar electric systems, a space should be designated for mounting the inverter and other control equipment as well as the breaker panel locations where the solar electricity will be connected to the house's electrical system. is advisable to install conduit at the time of construction so that wire runs from the solar array to the inverter can be easily installed.

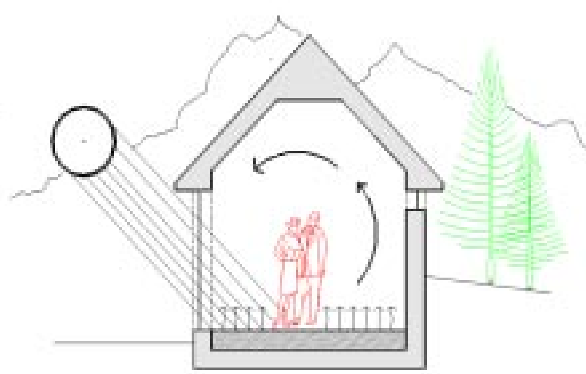


Solar Tempering

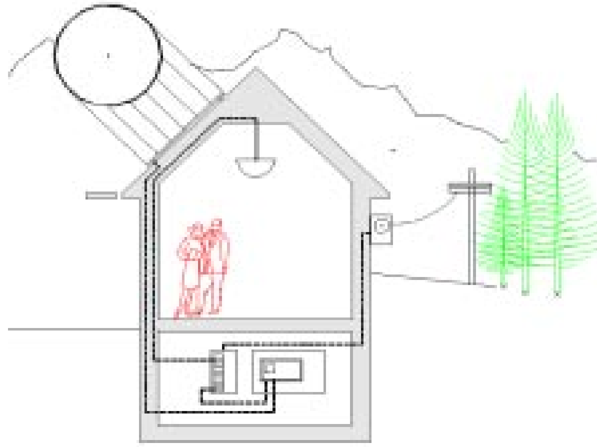
A solar-tempered house is oriented and shaped in response to the sun. Occupied rooms and windows are placed to the south but no internal thermal mass is added.

Passive Solar Space Heating

Passive solar strategies include the principles of solar tempering but allow for greater south glazing area by providing internal thermal mass. Insulating the glass area is critical in a cold, northern climate such as Montana if the system is to produce a significant amount of energy compared to night-time heat losses. There are three basic types of passive solar designs: direct gain, indirect gain, and isolated gain. As a rule passive solar design will increase the first cost of the home by adding window area and thermal mass in the form of concrete, tile, or brick. Passive systems normally will cost more for additional windows and internal thermal mass. Examples of thermal mass include concrete slabs with tile finish, and concrete block walls. The total incremental cost can range from a few hundred to a few thousand dollars.

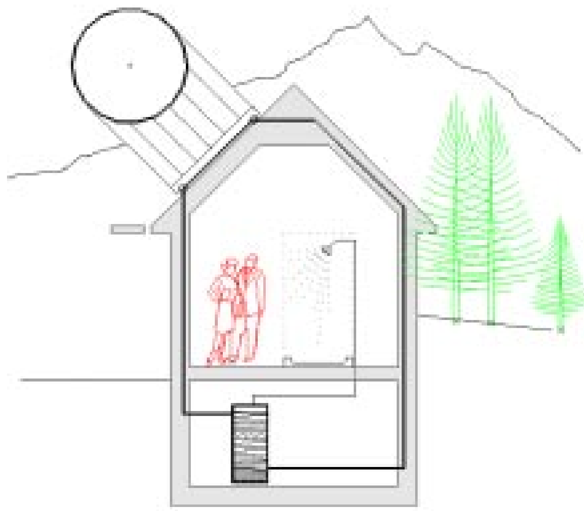


Solar Electric Systems



All new homes with appropriate solar orientation and adequate south-facing roof slope are suitable for solar electric systems. The added cost is $10 to $12 per watt. A 2000-watt system would cost about $20,000 and provide about half of the electric needs of a very efficient house without electric water or space heating. Net-metered solar electric systems currently produce electricity that costs between 20 and 24 cents per kilowatt-hour over the life of the system. Net-metering allows the owner of a solar electric system to run the utility meter backwards during times when the system produces more electricity than the house is consuming.

Solar Water Heating



Careful attention must be given to solar water-heating systems in Montana to prevent freezing. Solar collectors usually are mounted on the roof, and a hot water storage tank typically is installed adjacent to the standard water heater. In hard-freeze climates such as Montana, the cost of adding a solar water system is between $4,000 and $6,000.

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chapter 2:

solar potential: evaluating your site for solar

The last chapter introduced solar electric, solar water heating, and building-integrated solar design strategies. Regardless of the solar features selected, careful evaluation and use of the site is required for a successful solar design. Topography, vegetation, surrounding buildings, and views have a significant impact on the solar features that are appropriate for a new house.

A relatively open view of the sky to the south of your house is required, at least during the months when you plan to use the sun. As a general rule, the solar collector area, whether window or roof, should be unshaded from 9 A.M. until 3 P.M. during the heating season for space heating and year-round for solar electric and water-heating systems. The basic concepts of how the sun moves in the sky on a seasonal and daily basis are illustrated in the following diagrams. Understanding azimuth and altitude angles, illustrated in *Figure 1*, will help in evaluating solar potential.

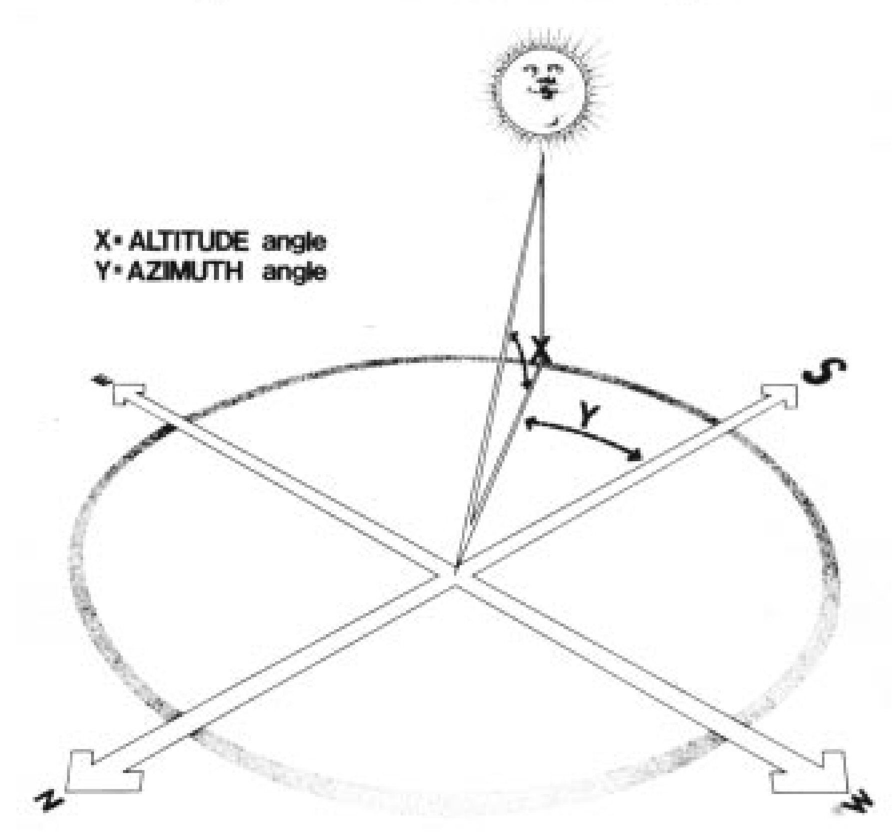


Fig.1: Two coordinates are needed to locate the position of the sun in the sky. They are called the altitude and azimuth (also called the bearing angle).

The drawing in *Figure 2* shows the path of the sun during the four seasons. To better estimate the available sunlight at a particular site the use a sun chart is recommended. Such a chart for the Montana latitude is shown. Sun charts show the sun's path at different times of the day and year for a given latitude. Using a protractor or homemade viewfinder, a homeowner can observe the sky from the point where the solar collector area will be located and determine if neighboring trees or buildings will block the sun. While you can construct your own viewfinder, you may choose to ask a local solar equipment dealer about checking your home's solar potential.

To use the sun chart, first draw the skyline of objects (tree, buildings, power lines, mountains) that might shade the site. A typical skyline is shown in *Figure 3*. In the adjacent table, enter the unshaded percent values that are not shaded for each month. For example, if the area is unshaded during the month of March from 9 A.M. until 2 P.M., the site will receive 63 percent of the sunlight available during that month.

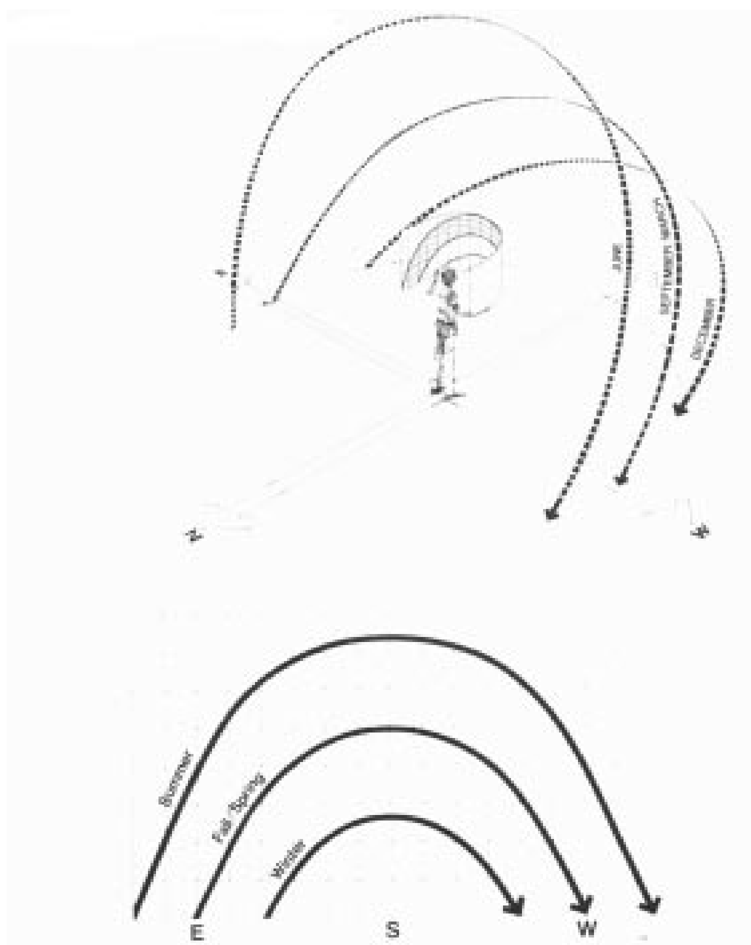
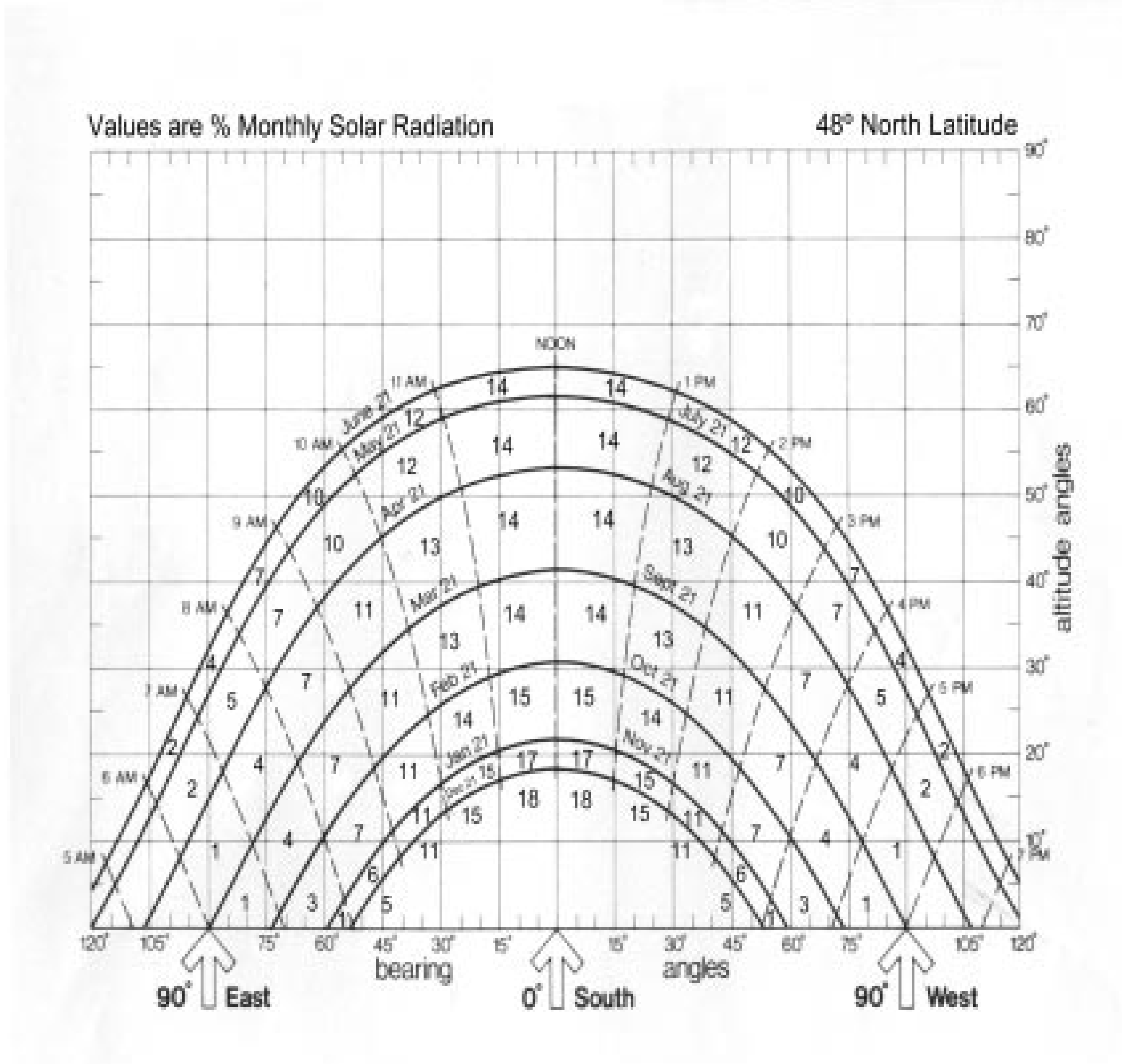


Fig. 2: You can plot the sun's path for any day of the year. The lines shown represent the sun's path for the 20th day of each month. The sun's path is longest during the summer months when it reaches its highest altitude, rising and setting with the widest azimuth angle from true south. During the winter months, the sun is much lower in the sky, rising and setting with the narrowest azimuth angles from true south.



This particular sunchart is for 48 degrees north latitude. The southern border of Montana is about 45 degrees north latitude and the northern border is about 50 degrees north latitude. The chart provided will provide a reasonable evaluation tool for the entire state. This chart includes values that allow you to calculate the percent possible solar energy available at a particular site.

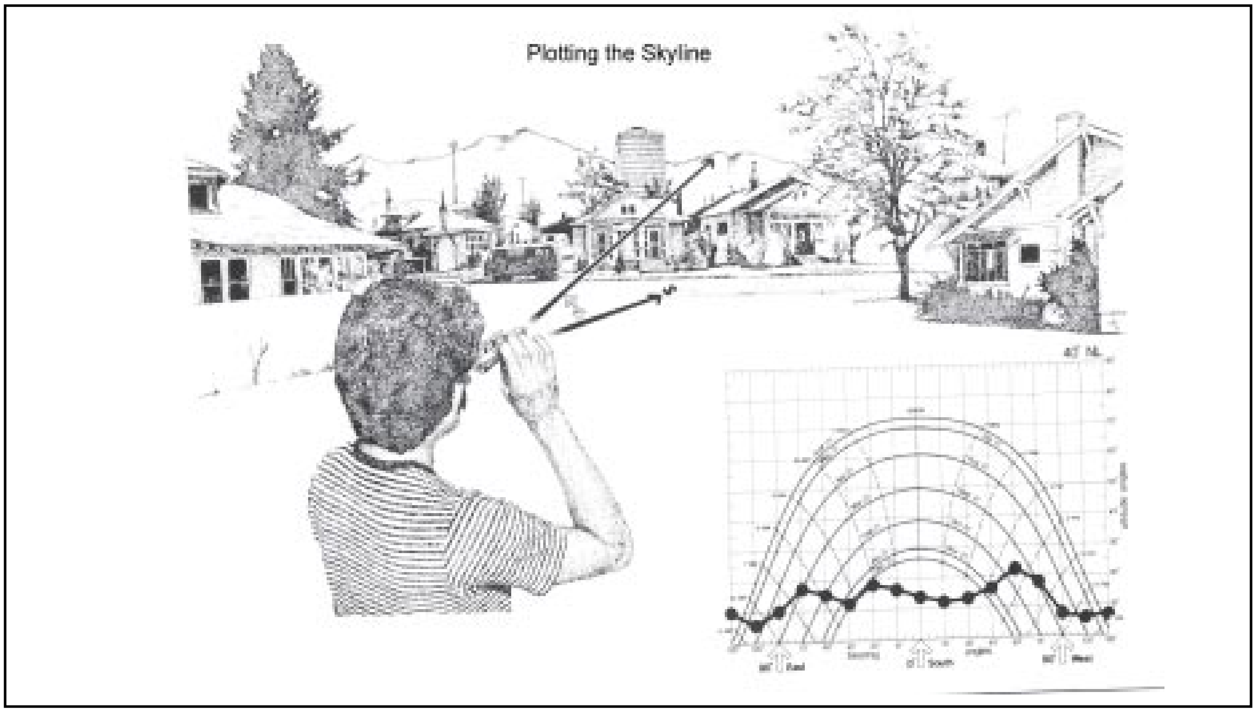


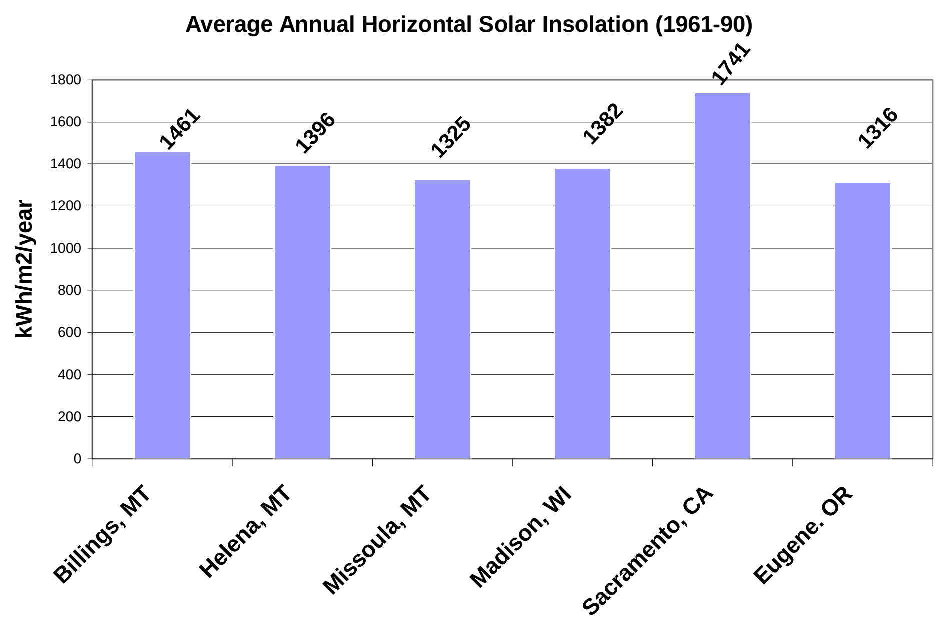
Fig. 3: Plotting tall permanent objects.

Sunchart Table	
Month	Monthy % *
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

* - Enter the sum of the % sun values for each month from the sun chart. Include on the values that are not shaded (below the skyline).

Although the availability of sunlight is a critical requirement of both solar electric and solar thermal systems, solar electric systems are much more susceptible to shading. Even the shadow cast by a utility pole or wire can have a significant impact on solar electric system performance and should be avoided. Solar thermal systems are much less susceptible to small areas of shading.

Montana's solar resource is comparable with that of other areas of the country that are aggressively using solar energy. The *Montana Solar Data Manual*, complied by Charles Fowlkes, PhD, PE, and published in 1985, is the most comprehensive collection of insolation data for the state. Tables with solar data from the manual for four Montana cities are included at the end of this publication.



The *Montana Solar Data Manual*, compiled by Charless W. Fowlkes, PhD, PE, and published in 1985, is the most comprehensive collection of insolation data for the state. The manual presents a summary of six years of solar measurements (50,126 days of data collected at 20 sites) taken between 1977 and 1982.

The orientation of the photovoltaic system (the compass direction that your system faces) will affect performance. In Montana, the sun at noon is always in the southern half of the sky and is higher in the summer and lower in the winter. Usually, the best location for a solar collector system is a south-facing roof or wall. Roofs that face east or west may also be acceptable for solar electric systems, although the performance of the system will be reduced.

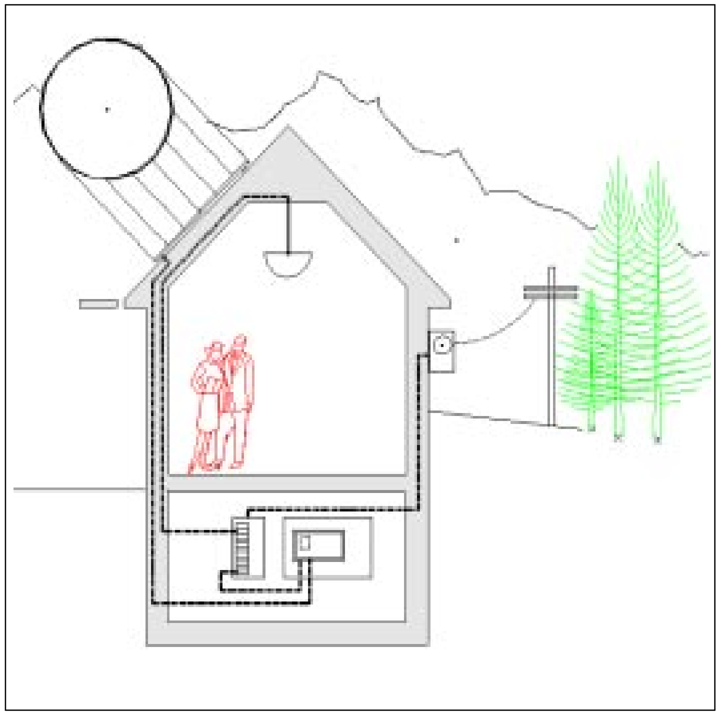
Flat roofs also work well for solar electric and solar water-heating collectors. The panels can be mounted on frames tilted toward the south at the optimal angle. For the most part, if your collectors are tilted at slopes between 30 degrees and 60 degrees and oriented within 30 degrees of south, your system will receive at least 90 percent of available solar energy.

3

chapter 3:

solar electric systems: generate your own power

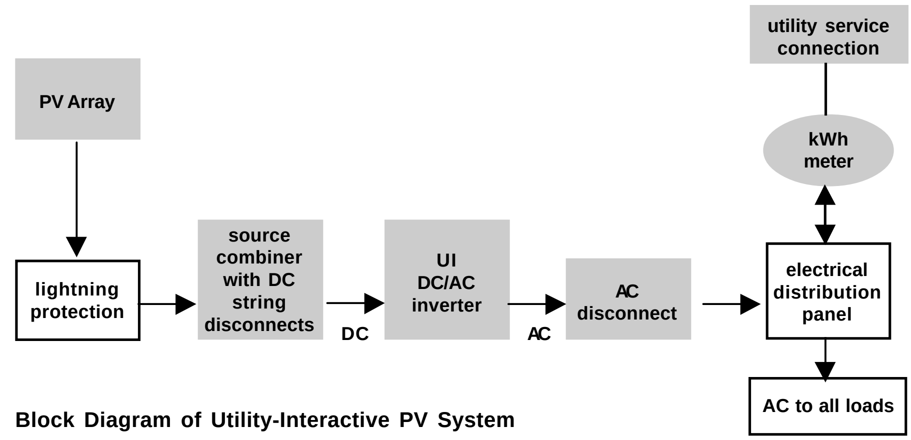
In the next few years, the potential for using solar energy to generate electricity—popularly known as photovoltaics or PV—at home will increase dramatically as technological breakthroughs continue on an almost monthly basis. Besides the technological advances, prices continue to drop as production methods improve and commercial applications increase. Already, thousands of homes nationwide use photovoltaic systems to generate electricity.



Solar electric systems can be classified as "stand-alone" and "utility-interactive." This guide emphasizes "utility-interactive" systems that use standard photovoltaic arrays. Solar electric systems connected to the utility grid usually are made up of a photovoltaic array, an inverter, wiring, and switches. The array is made of rigid panels comprising individual photovoltaic silicon cells.

PV panels demonstrate solar technology on a typical grid-connected home in Gardner, Massachusetts.

The heart of the PV system is an inverter that converts the direct current (DC) electricity produced by the PV panels into alternating current (AC) electrical power that can be used by conventional homes and appliances or fed back into the utility grid. The typical system includes meters to indicate how the system is performing and a discon-



Block Diagram of Utility-Interactive PV System

nect switch to deactivate the system at the utility meter to avoid possible harm to utility personnel by back-feeding power into a grid that is assumed to be harmless.

Systems that provide backup for power outages, as well as off-grid systems, also include batteries for storing power. Discussing battery storage options is beyond the scope of this guide.

Building-Integrated Solar Electric Products

Also beyond the scope of this guide are a group of exciting and promising building-integrated solar electric products. These products generate electricity while also acting as roofing, siding, skylights, and windows. Products that have been installed in Montana include solar roof shingles and solar roof slates. Photovoltaic cells also have been laminated to sheet metal roofing and installed on housing. Other products that have been installed on commercial buildings include glazing units with integrated photovoltaic cells. Unfortunately, these building-integrated solar electric products are more than double the cost of standard PV arrays. In the future, these building-integrated products will make the visual impact of adding photovoltaics to a building almost negligible.

Unisolar manufactures a product called Solar Shingles. These are thin-film amorphous silicon cells laminated to a substrate that can be installed like asphalt shingles. Unisolar also has laminated thin-film amorphous silicon cells to metal roofing panels.

Sunslates, manufactured by Atlantis Energy Systems, is an attractive roof product that can be integrated with a slate tile roof. In a few commercial applications, photovoltaic silicon cells are integrated with skylight or window glazing to allow light to penetrate into the space and also produce electricity.

Solar shingles (above left) do more than protect the building, while the metal roof (above right) generates electricity from the sun.

Utility-Interactive Systems

Utility-interactive systems are connected to the power line running into your house from the local power company. A utility-interactive system may have PV solar modules on the roof or mounted on a pole or poles. Because photovoltaic systems convert power the PV panels produce into alternating current, it is possible to sell any surplus power you might generate to the Montana Power Company. In essence this "net metering" arrangement allows the homeowner to run the meter backwards when the solar electric system is generating more power than the house can use at the time. Other than the renewable energy system and an appropriate meter, no special equipment is needed.

Even in the absence of net metering, consumers can use the electricity they produce to offset their electricity demand on an instantaneous basis. But if the consumer happens to produce any excess electricity (beyond what is needed to meet the customer's own needs at the moment), the utility purchases that excess electricity at the retail price.

Net metering simplifies this arrangement by allowing the consumer to use any excess electricity to offset electricity used at other times during the 12-month billing period, which can begin on January 1, April 1, July 1, or October 1 of each year, as designated by the customer-generator. Any remaining unused kilowatt-hour credit accumulated during the previous 12 months must be granted to the electricity supplier, without any compensation to the customer-generator.

Why is net metering important?

Net metering is important for three reasons. First, as increasing numbers of primarily residential customers install renewable energy systems in their homes, there must be a simple, standardized protocol for connecting their systems into the electricity grid that ensures safety and power quality.

Second, many residential customers are not at home using electricity during the day when their systems are producing power. Net metering allows them to receive full value for the electricity they produce without installing expensive battery storage systems.

Third, net metering provides a simple, inexpensive, and easily administered mechanism for encouraging the use of renewable energy systems, which provide important local, national, and global benefits.

Net metering provides a variety of benefits for both utilities and consumers. Utilities benefit by avoiding the administrative and accounting costs of metering and purchasing the small amounts of excess electricity produced by these small-scale renewable generating facilities. Consumers benefit by getting greater value for some of the electricity they generate, by being able to interconnect with the utility using their existing utility meter, and by being able to interconnect using widely accepted technical standards.

The only cost associated with net metering is indirect: the customer is buying less electricity from the utility, which means the utility is collecting less revenue from the customer. That's because any excess electricity that would have been sold to the utility at the wholesale or 'avoided cost' price is instead being used to offset electricity the customer would have purchased at the retail price. The revenue loss is roughly comparable to having the customer reduce electricity use by investing in energy efficiency measures, such as compact fluorescent lights and efficient appliances.

The bill savings for the customer (and corresponding revenue loss to the utility) will depend on a variety of factors, particularly the difference between the 'avoided cost' and retail prices. In general, however, the difference will be between $5 - $15 a month for a residential-scale PV system (2 kW), and between $25 - $70 a month for a farm-scale wind turbine (10 kW). Revenue losses associated with net metering are at least partially offset by the administrative and accounting savings, which are not included in the above figures.

Meters

The standard kilowatt-hour meter used by the majority of residential and small commercial customers accurately registers the flow of electricity in either direction. This means the "netting" process associated with net metering happens automatically—the meter spins forward (in the normal direction) when the consumer needs more electricity than is being produced, and spins backward when the consumer is producing more electricity than is needed in the building.

Safety

During the last decade there has been tremendous technological progress in the design of the equipment that integrates small-scale generators with the utility grid. Called "inverters" because they were originally designed only to 'invert' the DC electricity produced by solar arrays and wind turbines to the AC electricity used in our homes and businesses, these devices have evolved into extremely sophisticated power-management systems.

Inverters now include all the necessary protective relays and circuit breakers needed to synchronize safely and reliably with the utility grid, and to prevent "islanding" by automatically shutting down when the utility grid suffers an outage. Moreover, this protective equipment operates automatically, without any human intervention needed.

Most new inverters comply with all nationally-recognized codes and standards, including the National Electrical Code (NEC), Underwriters Laboratories (UL), and the Institute of Electrical and

Electronic Engineers (IEEE). These systems are now operating safely and reliably in every state in the nation.

By adopting net metering early, a utility establishes itself in a leadership role in providing customers the option of generating some of its own electricity. The 1997 Montana net metering legislation effectively applies only to the Montana Power Company and Montana Dakota Utilities. Electric cooperatives are not required to provide net metering. The electric cooperatives are free to adopt net metering requirements different than the state law.

The Montana Law

A "net metering system" is a facility for the production of electric energy that: (a) uses as its fuel solar, wind, or hydropower; (b) has a generating capacity of not more than 50 kilowatts; (c) is located on the customer-generator's premises; (d) operates in parallel with the distribution services provider's distribution facilities; and (e) is intended primarily to offset part or all of the customer-generator's requirements for electricity.

The legislation also requires that a distribution services provider allow net metering systems to be interconnected using a standard kilowatt-hour meter capable of registering the flow of electricity in two directions. The distribution services provider shall charge the customer-generator a minimum monthly fee that is the same as other customers of the electric utility in the same rate class.

Net Metering Calculation

In calculating the net energy measurement the distribution services provider measures the net electricity produced or consumed during the billing period, in accordance with normal metering practices. If the electricity supplied by the electricity supplier exceeds the electricity generated by the customer-generator and fed back to the electricity supplier during the billing period, the customer-generator must be billed for the net electricity supplied by the electricity supplier, in accordance with normal metering practices.

If electricity generated by the customer-generator exceeds the electricity supplied by the utility, the customer-generator must be billed for the appropriate customer charges for that billing period and be credited for the excess kilowatt-hours generated during the billing period, with this kilowatt-hour credit appearing on the bill for the following billing period. At the beginning of each calendar year, any remaining unused kilowatt-hour credit accumulated during the previous year is granted to the electricity supplier, without any compensation to the customer-generator.

Net Metering System — Reliability and Safety

A net metering system used by a customer-generator must include, at the customer-generator's own expense, all equipment necessary to meet applicable safety, power quality, and interconnection requirements established by the National Electrical Code, National Electrical Safety Code, Institute of Electrical and Electronic Engineers, and Underwriters Laboratories.

More about the Technology

A photovoltaic system produces power intermittently because it works only when the sun is shining. This is not a problem for PV systems connected to the utility grid because the additional electricity you need is automatically delivered to you by your utility. And, systems with batteries can provide energy even when the sun is not shining.

PV-generated electricity is more expensive than conventional utility-supplied electricity. Improved manufacturing has reduced the cost to less than 1 percent of what it was in the 1970s, but the cost (amortized over the life of the system) of electricity produced from the sun in Montana is still about 20 cents per kilowatt-hour. This is more than three times the retail price that Montana Power Company customers now pay for electricity. Solar tax credits help make PV more affordable, but it can’t match today’s price for electricity from your utility.

Finally, unlike electricity purchased month by month from a utility, PV power comes with a high initial investment and no monthly charge thereafter. This means that buying a PV system is like paying years of electric bills up front. You’ll probably appreciate the reduction in your monthly electric bills, but the initial expense can be an eye opener. By financing your PV system, you can spread the cost over many years.

How big should my PV system be?

As a starting point, you might consider how much of your present electricity needs you would like to meet with your PV system. For example, suppose that you would like to meet 50 percent of your electricity needs with your PV system. You could work with your PV installer to examine past electric bills and determine the size of the PV system needed to achieve that goal.

Ask your PV installer how much your new PV system will produce on an annual basis (also measured in kilowatt-hours) and compare that number to your annual electricity demand to get an idea of how much you will save.

As you size your system, you should consider the economies of scale that can lower the cost per kilowatt-hour as you increase the size and cost of the system. Labor costs for a small system may be nearly as much as those for a large system. Therefore, it’s worth remembering that your PV installer is likely to offer you a better price to install a 2-kilowatt system all at once, than to install a 1-kilowatt this year and another similar system next year because multiple orders and multiple site visits are more expensive.

Inverter manufacturers recently have developed smaller inverters that allow a modular approach to building a complete solar system. For example, Applied Power Corporation offers the SunSine module—a 300-watt photovoltaic panel with an inverter attached the back of the panel. Each of the units produces 300 watts of AC power. Although slightly more costly per watt than a standard PV system, the approach allows a homeowner to gradually add to the system.

When the utility grid is shut down, the inverter on a residential PV system also will automatically shut down. One optional feature you might consider if you have an office in your home is a battery system to provide back-up power in case of a utility power outage. Batteries add value to your system, but at a higher price.

How much electricity will your PV system generate?

Net metering allows you to be paid the retail electric rate for power generated by your system. This is a bargain since the utility pays about one-third the retail rate for wholesale power. A rough rule of thumb is that a one-kilowatt system will produce about 1,500 kilowatt-hours each year. Keep in mind that actual energy production will depend on a range of factors that include your geographic location, the angle and orientation of your system, the quality of the components of your system, and the quality of the installation.

Consider asking for a written estimate of the average annual energy production from the PV system installer. However, you should realize that even if an estimate is accurate for an average year, actual electricity production will fluctuate from year to year due to natural variations in weather and climate.

How much does a PV system cost?

There is no single answer. The price of your system will depend on a number of factors, including whether the home is under construction or whether the PV is integrated into the roof or mounted on top of an existing roof. Price also varies depending on the manufacturer, retailer, and installer. An installer who is busy may charge more for the system than one who is not.

The size of your system may be the most significant factor in any equation measuring costs against benefits. A 2-kilowatt system that will offset the needs of a very energy-efficient home may cost $20,000 to $24,000 installed, or $10 to $12 per watt. At the high end, a 5-kilowatt system that will offset the energy needs of many conventional homes may cost $40,000 to $50,000 installed, or $8 to $10 per watt. These prices, of course, are just rough estimates. Your costs will depend on the way your system is configured, your equipment options, and other factors. Your local PV installers can provide you with estimates or bids.

Solar Electric Installations

The quantity of solar energy collected depends on the angle at which the direct sunlight strikes the collector surface. The altitude and the azimuth must be considered. The *Montana Solar Data Manual* solar tables provide information for various tilt angles of south-facing surfaces and approximate correction factors for azimuth angles of 45 degrees and 90 degrees. Tables for several Montana cities are included at the end of this guide.

The area necessary for a PV system is based on the efficiency of the photovoltaic modules you purchase. Commonly, residential systems require 80 to 100 square feet of area per kilowatt of capacity. If your location limits the physical size of your system, you may want to install a system that uses more efficient PV modules.

Some roofing materials are simpler and cheaper to work with. Some PV system installers will not mount a solar array over wood shingles or shakes. Typically, composition shingles are easiest to work with, and slate is the most difficult. Ask your PV installer how the PV system affects your roof warranty.

For a direct-mounted PV system, the preferred roof slope is 45 degrees (a 12/12 pitch), but roof slopes between 23 degrees (5/12 pitch) and 60 degrees (21/12 pitch) are acceptable. Although most roofs can support the added weight of a PV system, you should assure that the roof structure can support the added dead load of the PV array and mounting rack and the temporary live load imposed by the installation crew. The PV array and mounting rack will add about three pounds per square foot of dead load to the roof.

Stand-Alone Systems

A stand-alone system operates independently of the utility power grid. Stand-alone systems usually include "battery storage systems" to store electrical power generated by the photovoltaic system. Stored electrical power is then available when the sun is not shining. The possibilities for stand-alone PV systems are extensive. Stand-alone systems currently are used for everything from water pumps and navigational signals to electrification of remote homes and area lighting. PV systems require no fuel other than the sun and have low maintenance costs. For developing countries, photovoltaics are an ideal source of power.

Solar-Ready Design Features for Solar Electric Systems

Every new house should be designed to readily accept the installation of a solar electric system. Following are the key design features for adding a solar electric system in the future.

1. Provide 200 to 500 square feet of appropriate solar electric collector area. In general, 100 square feet of photovoltaic area will provide one kilowatt of capacity using single-cell and polycrystalline modules. Refer to Chapter 2 for information about desired orientation, tilt, and solar access.
2. Pre-wire or provide an electric wire chase to connect the future solar array to the inverter.
3. Pre-wire or provide an electric wire chase to connect the inverter output to an electric circuit panel.
4. Provide a circuit in the breaker box for the solar electric feed.
5. Provide a vertical wall area to mount a four-feet by four-feet inverter panel in the mechanical area of house.
6. Minimize the distance (wire run) from the array to the inverter.
7. Install an electric disconnect switch for future solar electric system.

Solar Electric Array Design Guidelines

We all have seen thermal solar collectors sticking up above the roof of a house mounted at an angle that appears unrelated to the building. Unfortunately, this type of unsightly installation is how many people view solar. Following are a number of design guidelines to assure that solar electric arrays do not detract from the visual appearance of the house.

1. Roof Mount Applications

In new construction, mount PV arrays on roof to avoid using yard space for pole mounts.

2. Align with Architectural Features

Align PV arrays with major architectural elements such as roof lines, roof penetrations, windows, skylights, and doors. Treat solar arrays in the same way a good designer treats the placement of skylights. If the array is designed properly, it will be an integral part of the whole building design.

3. Low-Contrast Roof Color
Coordinate the color of roofing to minimize contrast with photovoltaic arrays. Select roofing material color and texture that are visually less contrasting with the PV array. In most cases this means selecting a roofing material that is dark in color with less texture.

4. Flush on Roof
Install arrays flush with the roof surface. Again, think about emulating skylights. A loss of a few percentage points in efficiency is a small price to pay for a more aesthetically pleasing installation.

5. Unbroken Surface
Install array panels as a continuous surface without gaps that detract from the monolithic appearance of the array.

6. Plan for Expansion
Plan now for system expansion. Imagine now how large the system might become. By planning now for a larger system, awkward and unsightly installations can be avoided.

7. Use Outbuildings
Consider constructing outbuildings porches, carports, or covered patios for mounting solar arrays. This approach may avoid mounting arrays on the main roof of the building and may be visually more attractive.

This home in Idaho Springs, Colorado, obtains most of its energy needs from the sun. Space heating comes from solar design with a Trombé wall for energy storage. Hot water comes from an active (pumped) system using collectors. Electricity is generated from a 1,200-watt PV system. In addition, the house takes advantage of a number of energy efficiency construction techniques and energy-efficient appliances.

This home in Hopewell, New Jersey, integrates passive solar design, PV power, solar hot water, and highly energy-efficient construction. Notice how the left side of the array is aligned with the edge of the clerestory dormer. The color and texture of the asphalt shingles minimize contrast

This home is designed to use active and passive solar energy. Unfortunately, the roof color does not complement the solar panels. Little effort was made to align the array with the architectural elements of the building.

This home features passive solar design (generally enough stored heat in the winter to keep the house warm overnight). Three 24-square-foot skylights provide daylight to most of the living area; windows are double glazed and use a heat reflective coating; eight solar panels on the 60 degree south facing roof heat an 80 gallon domestic hot water tank and 400 gallons of water for home heating.

4 chapter 4: solar water heating: northern climate solutions

In this chapter we discuss solar water-heating systems. The average person uses between 15 and 20 gallons of hot water a day. At 6 cents per kilowatt hour for electricity, an average family of four spends between $300 and $400 a year to heat water. That figure probably will continue to rise as the cost for energy rises. You can cut your hot water costs by half with a properly sized solar water heater.

After the 1973 Arab oil embargo, the solar water-heating industry grew rapidly. Many observers believe it grew too quickly due to dependence on generous tax credits. Some technologies installed were complex and not adequately tested. When oil prices dropped and political support faded, the industry shrank from hundreds of solar water heater manufacturers to only a few dozen today. Sales of solar domestic water-heating systems have been limited in northern climates. Enthusiasm for solar water-heating systems is not strong, if informal discussions with Montana solar dealers is any indication. Yet solar water-heating systems that are almost 20 years old are still operating in Montana. And there are hundreds of operating systems from Oregon to Wisconsin to Maine.

Solar-Ready Design Features for Water Heating

Every new house should be designed to readily accept the installation of a solar water system. Following are the key design features for adding solar electric systems in the future.

1. Provide a solar collector area approximately 20 feet by 20 feet in size, preferably on the roof or adjacent porch.
2. Provide pipe chase from collector area to hot water storage area.
3. Provide extra space for future solar water storage tank, approximately 4 feet by 4 feet, immediately adjacent to the existing water heater.
4. Minimize the distance between collector area and the future hot-water storage tank.
5. Access to area immediately below collector mount on roof.

The great challenge for solar water heating in a northern climate is freeze protection. The types of systems discussed below each take a different approach to solving this challenge.

A four-season domestic solar water-heating system will likely cost $4,000 to $6,000 installed, depending on the system purchased and the nature of the installation. Energy savings will depend on the energy source displaced and the water-usage patterns of the occupants. Although systems have been installed nationally for less than $2,000, these were not installed in a hard-freeze climate such as Montana.

To provide solar collector mounting that does not detract from the appearance of the house, follow the general design recommendations for mounting solar electric panels in Chapter 3. The solar collector area should be as close as possible to the solar storage tank and conventional water heater.

There are four basic types of solar water-heating systems available. These systems share three similarities: flat-plate collectors to gather solar heat; one or two tanks to store hot water; and associated plumbing with or without pumps to circulate the heat-transfer fluid from the tank to the collectors and back again.

North Carolina Solar Center Illustration

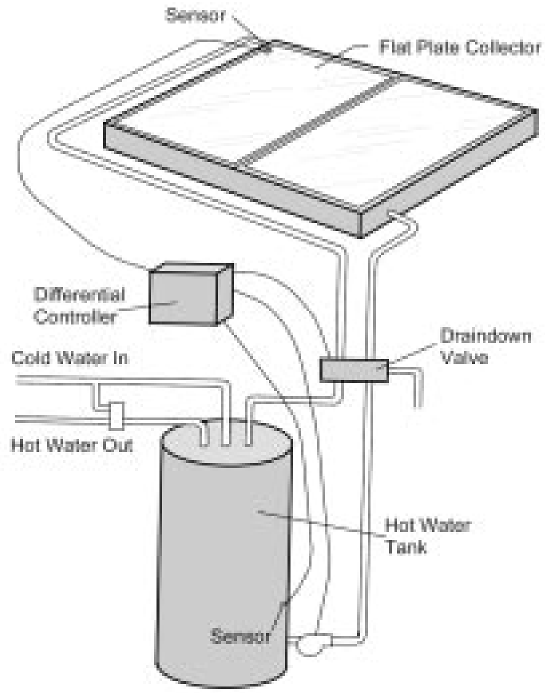


Fig. 4: Draindown solar water system.

Draindown Systems

The crucial difference in these systems lies in their freeze-protection methods. In a "draindown system," potable water from the home hot water tank is pumped directly through the solar collectors, where it is heated by the sun and returned to the tank *(Figure 4)*. Freeze protection is provided by valves that automatically open and drain the system when sensors detect freezing temperatures. The water usually is dumped down a sewer drain. The valves close when the danger of freezing has passed and fresh water is reintroduced into the system. Solar collectors and piping in a draindown system must be pitched so water will drain automatically, even during a power failure.

Draindown systems are classified as "open loop" because they are tied directly into the domestic water supply. You should test the hardness of your water before installing an open-loop system. Mineral deposits or acidity can ruin the collectors or other system components.

North Carolina Solar Center Illustration

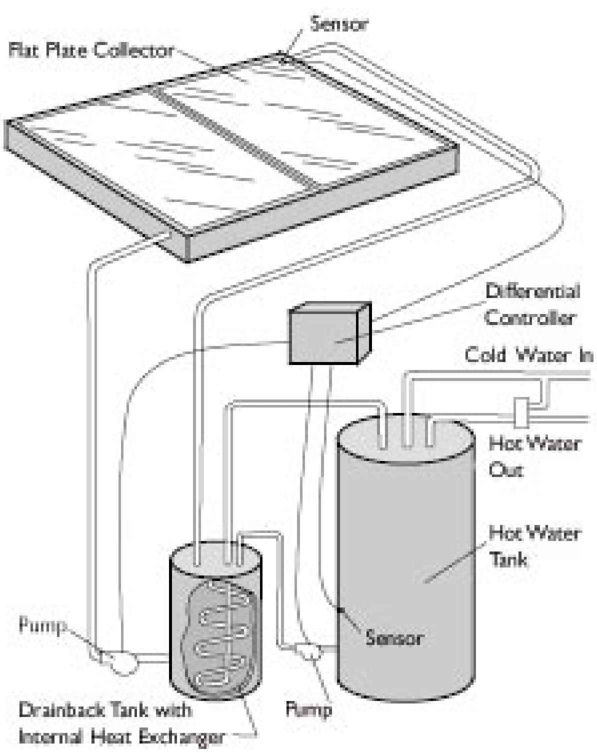


Fig. 5: Drainback solar water system.

Drainback Systems

The second general type is a "drainback" system, so called because fluid in the collector loop drains back into a solar storage tank whenever the

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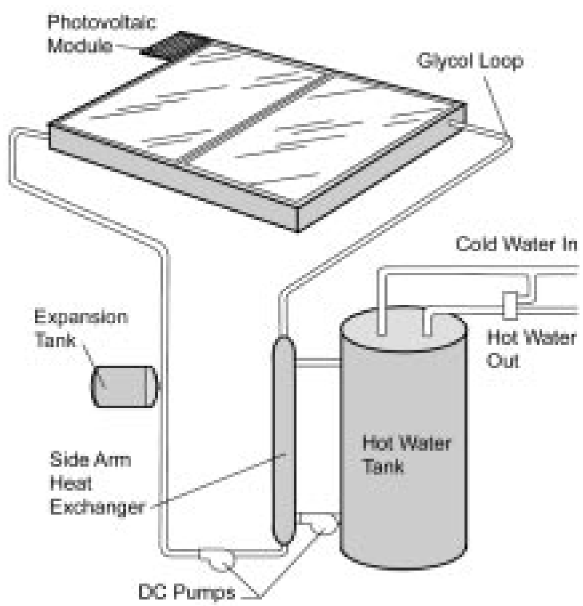


Fig. 6: Pressurized glycol solar water system.

pump shuts off. A drainback system does not circulate household water up to the collectors. Instead, it uses a separate plumbing line filled with distilled water or some other fluid to gather the sun's heat. The heat is transferred to the household water supply by means of a heat exchanger—a coil of copper pipe that runs into and out of the water tank. A drainback system (*Figure 5*) operates strictly on gravity—whenever the temperature is near freezing, the pump shuts off and the transfer fluid drains back into the solar storage tank. A drainback system lacks some of the controls of a draindown system and does not have to be pressurized.

However, a drainback system must have pitched collectors and piping to allow the transfer fluid to drain back into the tank. Drainback systems are classified as "closed loop" because the heat transfer fluid is contained in a separate plumbing line rather than being tied into the domestic water supply.

Antifreeze Closed-Loop Systems

A closed-loop system using an antifreeze solution represents the third basic type of solar water heater. The use of antifreeze allows the system to operate continuously throughout the winter months *(Figure 6)*. Because they are toxic, antifreeze solutions must be separated from household water by a double-walled heat exchanger. Several antifreeze solutions are used as transfer fluids in solar water-heating systems; two of the most popular are a propylene glycol/water mixture and silicone oils. Propylene glycol is far less expensive than silicone oil and is more widely used. However, the propylene glycol mixture can become acidic when constantly exposed to high temperatures and should be checked and replaced every few years to avoid corrosion. Silicone oils are noncorrosive, but they have a very low surface tension. This means they can seep through the smallest cracks.

North Carolina Solar Center Illustration

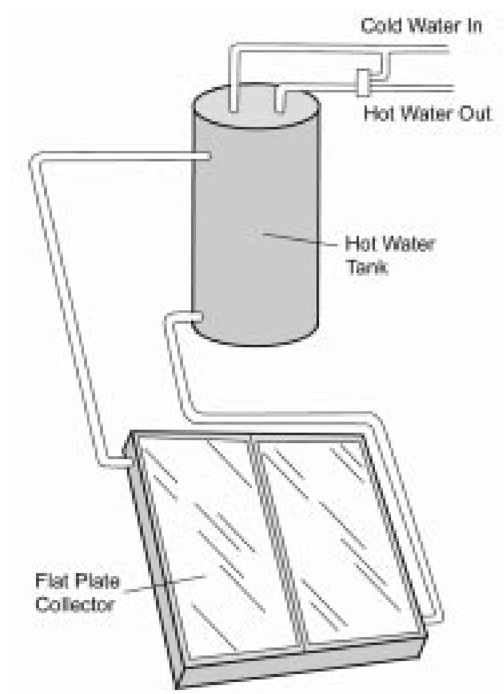


Fig. 7: Thermosiphoning solar water system.

Passive Systems

North Carolina Solar Center Illustration

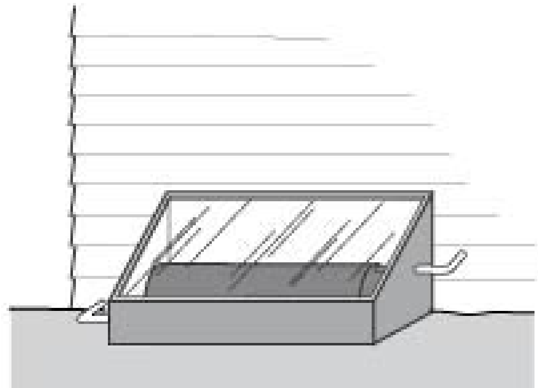


Fig. 8: Breadbox batch solar water heater.

The fourth type of system is the "passive" solar water heating design—"thermosiphoning" and "batch." These are available commercially and are popular among do-it-yourselfers. Both are classified as passive solar water-heating systems because they do not require pumps to operate.

A basic law of thermodynamics says that when a fluid—such as water—is heated, it becomes less dense and is then easily displaced by the relatively denser cold fluid. This is called thermosiphoning or convection. In a thermosiphoning solar water heater *(Figure 7)*, the storage tank is located at least two feet above the collectors so the cooler liquid from the bottom of the tank will naturally drop down into the collector and be heated. Warmer transfer fluid heated in the collectors will rise up to the tank. The cycle continues as long as the sun is shining.

Thermosiphoning solar water heaters are popular in non-freezing climates where domestic water can be circulated directly through the collectors. In freezing climates, an antifreeze solution contained in a separate loop is normally used. The main advantage of a thermosiphoning solar water heater is that it requires no mechanical energy to operate. The biggest disadvantage is that it heats only about one-fifth the volume of water that a pumped system does. Also, a thermosiphoning system can be hard to install because the water tank must be installed above the collectors. According to the results of a comparative study by *New Shelter* magazine, the most cost-effective of all solar water heating systems is the "batch" or "breadbox" water heater *(Figure 8)*.

In a batch heater, the water storage tank also functions as the collector. The tanks are used as collectors. One or two water tanks, painted black, are placed in a well-insulated box or other enclosure. The south wall of the box is made of clear glass or plastic and tilted at the proper angle so the sun shines directly on the tank and heats the "batch" of water. Freeze protection can be provided by adding an insulated cover to the enclosure, giving the system the appearance of a giant breadbox—hence, the name "breadbox solar water heater."

However, some homeowners find that the effort required to open and close the insulated cover during the winter is tiresome.

Also, the pipes leading to and from the insulated enclosure are prone to freezing. Thus, it may make more sense to drain the collector during the winter in climates like Montana. Even with the system shut down for several months, the breadbox heater can save considerable electricity than otherwise would be required to heat water. Materials for a breadbox water heater usually run no more than $500.

Commercial batch collectors also are available. They usually are assembled and come with instructions for interconnection to the household water supply. A plumber or a homeowner with plumbing experience can complete the installation. These already-assembled collectors use better materials than similar materials available at home-supply stores. Materials include low-iron insulating glass, selective surface coated tanks, and a parabolic reflector. Commercial batch collector systems also may offer warranties, such as guaranteed protection from freezing by virtue of their increased thermal performance. Costs for commercial batch collectors will range from two to four times the cost of homeowner-built systems.

Collector Panel

A crucial feature in all solar water-heating systems is the collector panel. The collector is exposed to the harshest elements of nature and must be made of strong, well-assembled materials if it is to last for 20 years as claimed by most manufacturers. A good-quality collector generally has a metal frame, double glazing (usually recommended for Montana), and a copper absorber plate and tube assembly through which the heat transfer fluid is circulated. The collector should be well-insulated on both the back and the sides.

As with other solar systems, the best orientation for a solar water-heating collector is due south. However, solar water-heating collectors can face up to 30 degrees east or west of south without a significant deterioration in performance.

Traditional wisdom has held that the proper tilt for solar water-heating collectors is equal to the latitude of the location where the system is being installed. However, keep in mind that hot water consumption is often greater and incoming water temperatures are lower during the winter months, which suggests that a steeper angle may be optimum.

You will find that a steeper angle (latitude plus 10 degrees) is often recommended in southern climates because it enables the collection of more of the sun's heat throughout the year. The optimum tilt for solar water-heating collectors in Montana is around 45 degrees. Collectors that tilt as much as 15 degrees off the optimum slope still will perform relatively well on an annual basis. This variation makes it possible to mount the panels flush with the roof for aesthetic reasons.

SRCC Certification

The Solar Rating and Certification Corporation (SRCC) tests collectors and solar hot water systems, establishes and enforces quality assurance guidelines, and serves as the institutional archive of field experience. Certified products and be obtained from over 15 manufacturers given in the *SRCC Product Directory*.

5

chapter 5:

building-integrated design: building as solar collector

Solar electric and solar water-heating systems can be added after the house has already been constructed. Building-integrated solar design must be added when the building is built. The concept of building integrated design has been called by various names. "Climate responsive" and "passive design" often are used to express this design philosophy.

Building-integrated design is not new. Before the introduction of modern heating and air conditioning building designers relied heavily on the sun, shade, and natural air movement for heating and cooling. Reliance on these natural elements was reflected in the building shape, floor plan, window size, window placement, and orientation.

> "Today, there is a strong, new interest in passive solar heating and cooling systems because they simplify rather than complicate life. Passive systems are simple in concept and use, have few moving parts and require little or no maintenance. Also, these systems do not generate thermal pollution, since they require no external energy input and produce no physical by-products or waste. Since solar energy is conveniently distributed to all parts of the globe, expensive transportation and distribution networks of energy are also eliminated.
>
> Since a building or some element of it is the passive system, the application of passive solar energy must be included in every step of the building's design. Whereas conventional or active solar-heating systems can be somewhat independent of the conceptual organization of a building, it is extremely difficult to add a passive system to a building once it has been designed."
>
> –Edward Mazria, *The Passive Solar Energy Book*

In the 1970s, solar enthusiasts believed building-integrated or "passive" solar design would become a standard part of house design. In reality, passive solar homes are few and far between, and currently little or no attention is given to solar in subdivision layout, site planning, and house design. Solar potential in this area remains largely untapped.

The simplest form of building-integrated solar design is "solar tempering," which involves proper building orientation and the placement of windows to the south. A more aggressive solar strategy, "passive solar," follows similar design principles but allows for greater south glazing area by providing internal thermal mass. There are four basic types of passive solar designs: direct gain, indirect gain, isolated gain, and isolated thermal storage.

The First Passive Solar Home Awards, published by the U.S. Department of Housing and Urban Development in 1979, provides a rough idea of the scale of energy savings that can be expected.

A typical energy-efficient home with windows placed randomly around the house may obtain up to 10 percent of its space-heating energy needs from the sun. That same house, designed to be solar-tempered, will receive up to 25 percent of its space-heating energy from the sun. A passive solar house that includes thermal mass for heat storage will receive more than half of its space-heating energy from the sun. In Montana's cold climate, a reasonable objective for passive solar designs would be to provide 50 percent of the home's heating needs. Passive system performance will depend greatly on whether night-time insulation is included.

Although the purpose of this guide is merely to introduce the concepts of passive solar home design, we have chosen to include a number of excerpts from Charless Fowlkes' *Montana Solar Data Manual 1985 Edition.* Fowlkes' research on how glazing performs in the Montana climate should be the basis for creating building-integrated solar designs that perform well in Montana from an energy and comfort point of view.

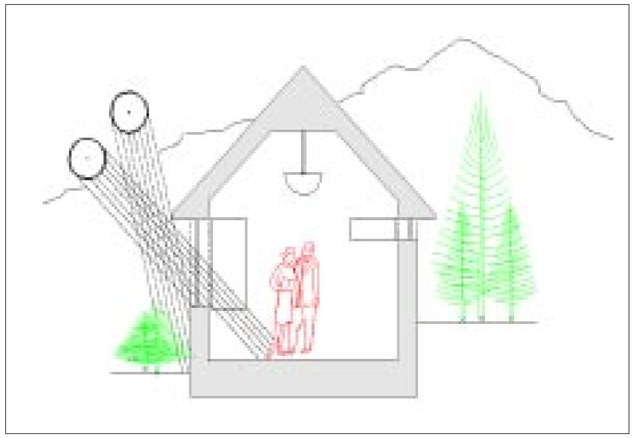
The Solar Data Tables (from *The Montana Solar Manual 1985 Edition*) included as attachments to this publication are intended to help the designer evaluate different passive solar window systems. Data for only four Montana cities are included here, although the full manual includes solar data tables for 30 Montana sites. This information can be used to estimate the thermal performance of vertical passive solar windows. The data tables considered four "typical" window systems: single, double, and triple glazing, and double glazing with movable, nighttime insulation.

The *Montana Solar Manual 1985 Edition* is now more than 15 years old. However the information it contains is still very useful. It should be noted that single pane glass is no longer considered for new construction. Instead the most common practice in new construction is double-pane glass with a low emmissivity coating (Low-E). Unfortunately, glazings with Low-E coatings were not included in Fowlkes' original research. However, the data for triple glazing is a good approximation for how double-pane glass with a Low-E coating will perform in a passive solar installation.

Solar Tempering

Builders of any new home, regardless of heating system, should follow basic design principles in orientation, landscaping and window layout. Designs that shape the building and

This solar-tempered home in Missoula is designed with the long axis in the east-west orientation. An open floor plan and fan to distribute air throughout the house minimizes overheating in the south spaces. Ponderosa pines to the southwest and west provide protection from afternoon sun.



window placement based on the movement of the sun, but without adding thermal mass to store the sun's heat, are call "solar tempered."

Ideally, one of the long sides of the building should face due south to expose as much of the roof and southern wall as possible to the winter sun. Moderate deviations off true south are acceptable and even advantageous in some instances. For example, if you are seldom home during the day, orient the home slightly west of south to allow more sunlight in during the afternoon.

Regardless of your heating needs, deviations of more than 30 degrees from due south should be avoided if possible. More than 30 degrees of deviation from due south will result in a sharp drop in the available solar heat and make effective shading solutions difficult.

Once you have decided how to locate the building on the site, you can begin designing the structure. Locate most of the windows on the south side of the house where they will pick up winter sunlight. Windows on other sides of the house, particularly the west side, should be kept to a minimum. Windows facing west pick up virtually no direct sunlight in winter, but can cause severe overheating in the summer when the afternoon sun lingers in the western sky. Windows should not be totally eliminated on any side of the house since they are needed for cross ventilation, balanced light, and a means of emergency escape.

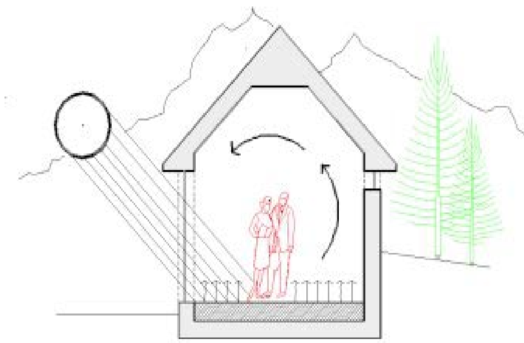
A house designed along these basic principles of "sun tempering" will provide as much as 25 percent of the winter heating load from solar energy. Further design changes that add thermal mass are discussed as "passive solar." Careful consideration must be given to the problem of overheating. A general rule of thumb for solar-tempered homes in a cold, northern climate is that south glazing should total no more than 7% of the floor area. Without solar mass or appropriate shading devices, solar-tempered homes with too much south glass can become uncomfortably warm during the spring, summer, and fall.

Another benefit of solar tempering is natural light. With proper design, natural light can eliminate use of some electric energy for lighting. But designers beware, direct sunlight is not always welcome. In commercial daylighting design it is unacceptable to allow direct sunlight to enter offices. Direct sunlight cause glare and creates contrasts that make performing visual tasks difficult. The designer of a solar-tempered or passive solar home is well advised to consciously deal with the problems associated with direct sunlight.

Passive Solar Design

Passive solar strategies follow the principles of solar tempering but allow for greater south glazing area by providing internal thermal mass. There are three basic types of passive solar designs: direct gain, indirect gain, and isolated gain. As a rule, passive solar design will increase the first cost of the home by adding window area and thermal mass in the form of concrete, tile, or brick.

Passive solar presents many design challenges. The problems of how to insulate windows at night night, how to integrate large glass areas in designs that are attractive--a major portion of the housing market--and how to inexpensively incorporate thermal mass must be addressed if passive solar design is to be widely used. A successful passive solar design will reduce energy costs and provide occupant comfort. These objectives require a thorough understanding of passive solar design principles and careful design.

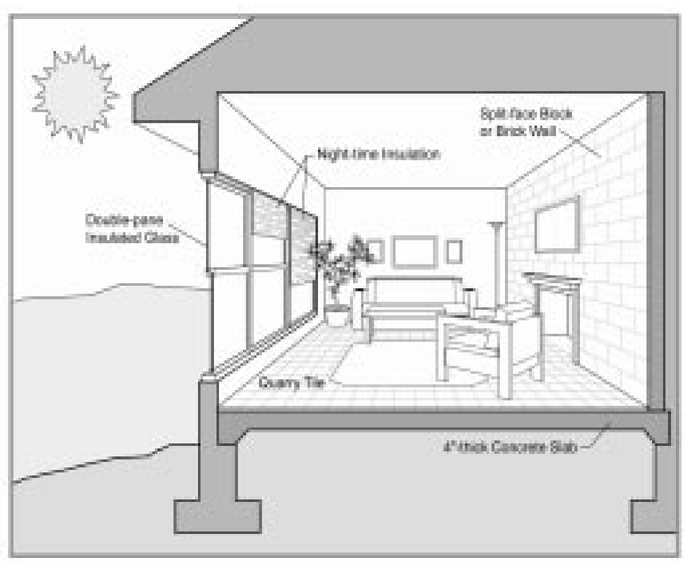


> "The crux of the passive solar design issue is to select a passive solar collector glazing system that will provide a net gain of heat and to provide adequate heat storage so that the maximum inside temperatures during clear days are not uncomfortable.
>
> Passive solar heating systems will need special glazing or movable insulation (to control heat loss) if they are to achieve efficient performance in midwinter. If large areas of glass are used, the heat storage system must be carefully designed and adequately sized to prevent overheating.
>
> The same glass that collects heat efficiently during the day will lose large amounts of heat during the night in cold weather. During a sunny, winter day in Montana, a south-facing window will gain heat for about five hours and lose heat for the other 19 hours! On a cloudy day the window will lose heat for 24 hours a day. The designer must weigh the solar gains against the added heat losses to arrive at a sensible passive solar design that will give a net gain of energy."

Direct-Gain Systems

Direct-gain systems allow sunlight into the living area of a home through large sections of south-facing glass. Direct gain can be the most cost-effective of all passive designs because the heat produced by sunlight hitting the walls, floors, and other objects does not have to be transferred to another part of the house.

However, the surface area of south-facing windows and the capacity of internal thermal storage

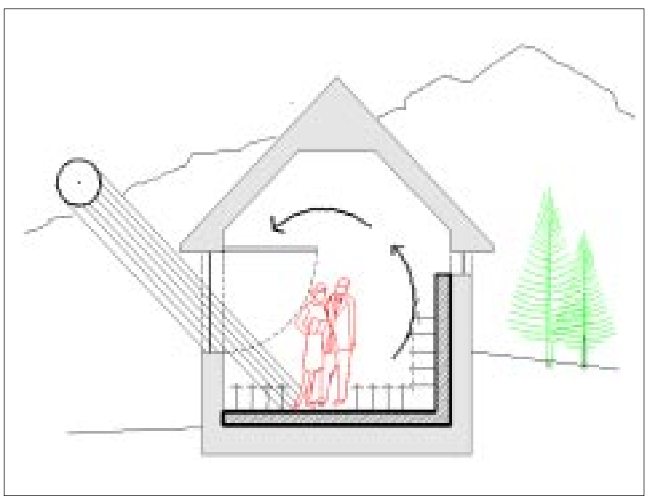


North Carolina Solar Center Illustration

An example of a passive direct-gain house.

should be balanced. If the windows collect more heat than the floor or walls can absorb, overheating occurs.

Building materials used in conventional home interiors—for example, wood and gypsum board—retain some heat, but their heat-storing capacity is limited. Masonry is much better at storing heat. Masonry, of course, can be used in interior walls and floors of buildings. Storage materials should be placed where they receive direct sunlight during the day. Materials out of direct sunlight store only one-fourth as much heat as materials hit directly by the sun.



When the sun begins to set and inside temperatures drop, the heat absorbed by these materials radiates back into the room, moving (as heat always does) from a warmer space to a cooler space. Properly designed thermal storage materials should keep inside temperatures from fluctuating by no more than 10 to 13 degrees over a 24-hour period.

While storage materials help maintain comfortable air temperatures in most of the house, an uninsulated glass wall loses a lot of heat at night and will make one side of the house markedly cooler. Even double-pane glass with a low emmissivity coating is uncomfortable to be near when the temperature outside drops below freezing. You can greatly reduce this discomfort and heat loss by covering the windows at night with accordion-type insulating blinds or insulated drapes. Other approaches to reduce nighttime heat loss include installing exterior or interior insulated shutters or quilted Roman shades.

Passive solar design can create a comfortable and efficient home, but the owner should understand the unique characteristics of a direct-gain house in Montana's cold winter climate. A direct-gain house usually will incorporate more exposed masonry, concrete, and ceramic or quarry tile than a typical house. This usually increases the cost of construction. Fabric in direct sunlight will fade at a faster rate because of the direct sunlight. Keep in mind that sunlight fades some materials faster than others. Temperature swings of between eight and 13 degrees can be expected for some designs.

With direct-gain systems, the thermal storage mass tends to be thinner and more widely distributed in the living space than with other passive systems. This allows an even distribution of heat throughout the room or rooms but requires some thought about how the living space will be used. Do not cover a significant amount of the thermal storage area with carpet or other materials that reduce storage capacity. Select and arrange furnishings carefully so they do not interfere with solar collection, storage, and distribution.

The Challenge of Movable Insulation

“Dramatic improvement in solar heat gain occurs with the addition of R-3, movable, night insulation. Note that there are several practical and operational problems associated with building a movable insulation system that will achieve an R-3 level of insulation. Research has shown that it is very difficult to get an adequate seal around the edges of a movable insulation panel or curtain. Unwanted air leaks and circulation will drastically reduce the effective insulation value of the system. Data on very thick panels and curtains (R-12 to R-20) show effective insulation values of only R-2 to R-5. It is difficult to build a movable insulation system having an effective insulating value of more than R-3 to R-5.

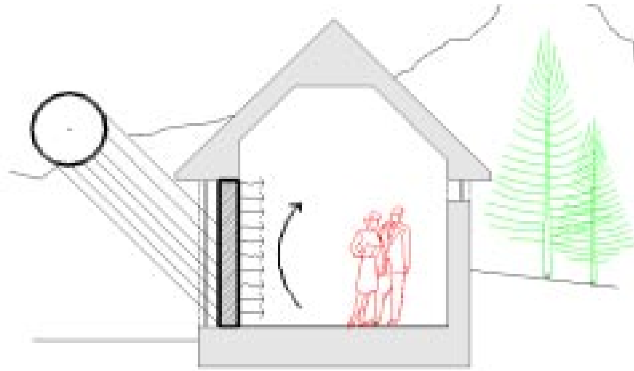
During a cold night, moist air from the living space that leaks into the cavity between the window and the insulating curtain will condense and sometimes freeze. This water may cause the window sill or the insulation to deteriorate. The movable insulation may not move if it is frozen along its edges. The designer should consider the effects of condensation.

If an (inside) movable insulation system is in place during a sunny day, the space between the insulation and the glazing will reach high temperatures. These high temperatures may damage the insulation and the glazing sealants, and may even cause the glazing to break. The designer should account for these situations.”

—Montana Solar Data Manual 1985 Edition

This house in Longmont, Colorado, uses a Trombé wall and direct-gain

Indirect-Gain Systems



Some problems of direct-gain systems often can be solved by using indirect methods of solar heating. As the name implies, indirect-gain systems do not admit sunlight directly into the living area. Instead, south-facing glass is placed in front of a massive wall that absorbs, stores, and transfers heat into the house. This approach has significant aesthetic ramifications and will be difficult to adapt to traditional house designs.

One of the most commonly used indirect gain systems is the Trombé wall named after its inventor, French scientist Felix Trombé. A Trombé wall usually is built of solid masonry—concrete, solid block, or brick—and is painted black or covered with a selective coating on the outside to absorb and transfer much of the heat to the living quarters. A sheet of glass or plastic covers the outside of the wall to trap additional heat.

Heat is distributed from the Trombé wall to the house in two ways. During the day, air trapped between the wall and the glass gathers heat and enters the room through vents at the top. Cool household air is drawn between the wall and glass through floor-level vents, where the cycle repeats itself as long as sunlight strikes the wall. Heat also is gradually conducted through the Trombé wall and reaches the living area near the end of the day. In a 12-inch wall, heat travels from between the wall and glass to the living area in about eight hours.

This cycle plays nicely to your advantage. Sunlight striking a living room Trombé wall between 10 A.M. and 3 P.M. is released inside as heat between 6 P.M. and 11 P.M. In a bedroom, you probably would prefer a 16-inch wall with an 11-hour heat-release cycle.

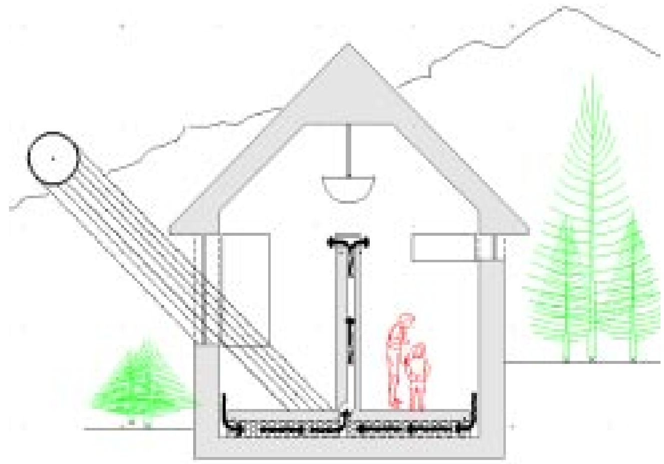
To prevent nighttime heat loss, you must close the vents along the Trombé wall after sunset, usually by hand. Solar designers have found that people often forget about the vents, wasting the heat that is stored along the wall. You can avoid this problem by building the Trombé wall without vents as long as the air space between the glass and masonry is vented or shaded in the summer. If daytime heat is needed in the adjacent room, windows incorporated into the wall will help heat the room. An added benefit of a sealed Trombé wall is that household dust cannot get into the space between the wall and glass. Moveable insulation or double glazing also is advisable for Trombé walls.

Isolated-Gain Systems

Unlike direct-gain and indirect-gain systems, isolated-gain passive designs capture solar radiation in an area thermally separated from the living space. Isolated-gain systems allow for the collection and storage components to function somewhat independently of the house itself, while heat can be drawn from them as needed. A sunspace or solarium is the most common type of isolated-gain system. The sunspace has much greater flexibility in

> “The simple notion of adding a greenhouse and thus getting a place for plants and “free heat” for the house obscures a fairly complicated design problem. Plants have one set of requirements for temperature, humidity, and light, while people have somewhat different requirements.”
>
> — *Montana Solar Data Manual 1985 Edition*

terms of design and performance when incorporated into plans for a new home.



Isolated-gain systems, such as the sunspace, collect solar radiation directly through a south-facing wall of glass. Heat is then transferred into the house as needed through vents, doors, or windows. In some sunspace designs, the back wall is made of solid masonry to store and transfer heat for use during nighttime hours. In this respect, the sunspace is simply an expanded Trombe wall system. Instead of the glass being a few inches in front of the wall, it is several yards away.

Several other options can improve the efficiency of a sunspace in new home construction. The sunspace can be designed into the house so that the south glass wall is flush with the rest of the structure, eliminating heat loss through the sides of the sunspace. On the other hand, temperatures inside isolated sunspaces fluctuate more than in the rest of the house, since no heating or cooling is provided. In this sense, sunspaces are considered semi-conditioned. If the sunspace is heated with traditional energy sources, it can quickly become a net energy user.

According to *Montana Solar Data Manual 1985 Edition*, “An attached greenhouse that is always open to (integral with) the living space will perform like a window without movable insulation. In the interest of energy conservation, it is clear that the greenhouse or sunspace should be insulated or shut off from the living space in midwinter.”

Remote Storage Systems

An alternative to having the thermal mass in direct sunlight is to locate the mass, usually a rock bed or concrete blocks. A fan pulls air warmed by the sun through the mass when the sun is providing heat. When the house cools, this heat can be distributed throughout the house in ductwork. This approach might be considered a hybrid design as it utilizes the sun while requiring ducting and fans.

One specific remote storage design that has received considerable attention in New England is detailed in *The Passive Solar House* by James Kachadorian. A number of these homes have been built and are performing well. The approach that is receiving significant attention is to isolate the thermal storage in a rock or concrete block storage bin below a concrete slab. The book mentioned above is worth the read as it has information that is useful for a wide range of solar designs.

Landscaping

Large deciduous trees can be excellent for maintaining the efficiency of a home. Deciduous trees shade the house in the summer and expose it to the sun when they drop their leaves in the fall. If you have deciduous trees on your lot, locate your house where it will be shaded in summer but open to sunlight in winter. The southeast and southwest corners of the house are prime locations for trees.

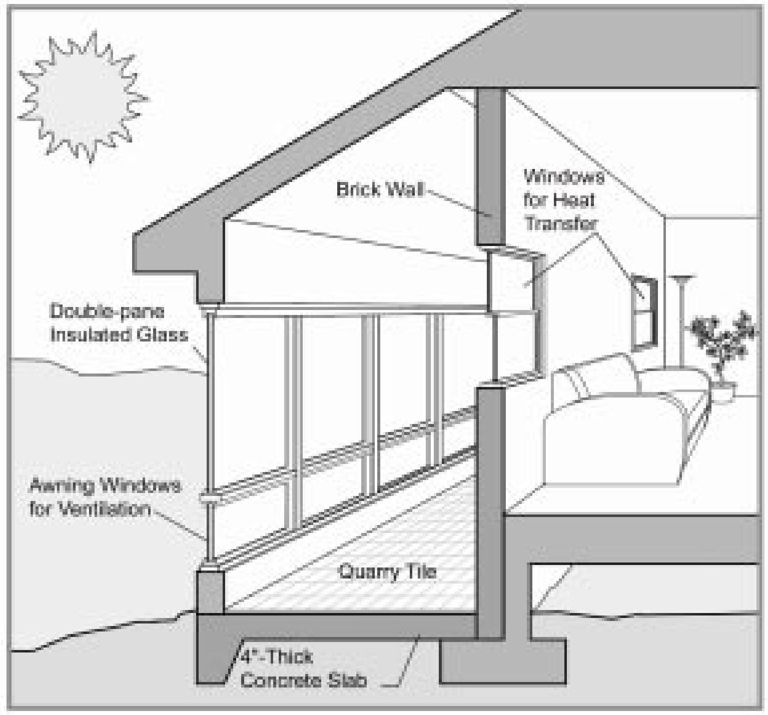
Climate-Responsive Cooling Techniques

In many areas of Montana, summer cooling is an important design consideration. In the plains, these techniques will significantly reduce the use of mechanical air-conditioning. In most mountain valleys areas of the state, climate-responsive design makes mechanical air conditioning unnecessary.

First, direct sunlight must be kept out of the home as much as possible. South-facing windows and mass walls can be shaded with extended roof overhangs or other forms of shading. The length of the overhang should be designed to shade the entire window through most of the summer.

Because we have so many warm days in late fall and early spring, it is impossible to design a fixed overhang that ensures a comfortable indoor temperature throughout the year. Many homeowners prefer adjustable awnings for windows facing south (*Figure 18*). A trellis with vines or grapes is an attractive and very effective method for shading but requires maintenance. Interior blinds help reduce heat buildup but are not as effective as shading that stops the sun before it hits the window glass.

Tile floors and masonry walls provide thermal mass to store solar heat. Doors between sunspaces and other living areas can be opened to allow warm air to circulate.



North Carolina Solar Center

Windows facing east and west cannot be protected as easily from the rising and setting sun. These windows are best protected by deciduous trees or solar window screens and films. If you have skylights, greenhouse roof glazing, or other horizontal glass hit by the sun to worry about, you still can use sunscreens, vegetation, or reflective shutters to reduce heat buildup. However, protecting skylights from the sun is obviously more difficult than shading windows.

Another approach to passive cooling includes design features that promote air circulation through natural convection. Vents or windows built into the lowest and highest parts of your house will release hot air trapped near the ceiling while letting in cooler air. The greater the temperature difference between the air at the top and bottom, the better your circulation will be. Clerestory windows or cupolas are often used in solar houses to provide high ventilation areas. Providing at least two windows on separate walls in a room will greatly improve cross ventilation.

6 

chapter 6: consumer tips

Note: *With the exception of the first tip, this section generally applies to "add-on" systems such as solar electric systems and solar hot-water systems.*

Use Professional Help for Passive Solar

Although the concepts behind solar heating are simple, their successful application in a solar home can be challenging. Homeowners creating their own designs should consult with a professional to "think through" possible solutions and problems. In solar-tempered or passive solar homes, designers should be careful to avoid overheating, discomfort from surfaces with low mean radiant temperatures, moisture problems, or visually unattractive designs. The right professional can help, but you may need to shop around for someone with the appropriate experience that you will enjoy working with. Designers of passive systems may be more difficult to locate. You may have to call architects to inquire about their experience with solar design. The experience and capabilities of architects and home designers vary widely.

Use Reliable Experienced Dealers

With a resurgence of demand for solar energy systems, new companies are entering the solar marketplace. Most companies offer high-quality products and use dealers and contractors who provide good service and installation. But that's not always the case. Some companies deal in shoddy products, hire fast-talking sales staff, and allow systems to be installed by untrained contractors. Just as you would with any major purchase, be alert to these possibilities from the moment you contact a salesperson to the day the solar system is installed and working.

One way to ensure that you get a good solar system is to deal with a local firm that has been doing business in your area for a number of years. The fact that a company is new does not make its service or products inferior. However, there are operators who will take advantage of your enthusiasm for solar energy.

To locate dealers of active solar systems, check the telephone yellow pages under "Solar Energy Equipment." You also can get a list of solar energy equipment dealers and designers in your area from the montanagreenpower.com Internet site.

Talk to More Than One Contractor

Call at least two or three dealers to get estimates on different solar systems. Never commit to buying a solar system after hearing only one sales pitch. Be skeptical if the dealer tries to force a sale on you immediately. A responsible solar dealer will not want you to regret your decision to purchase a solar system. Always ask the contractor for names of other customers and call them to ask about their experiences with the company. If possible, take a look at their installations—you don't have to be a solar expert to recognize poor workmanship. Fast, dependable service should be one of the biggest requirements in selecting a contractor.

Perform Analysis Before Signing Contract

Before the contractor gives you an estimate, make sure he or she performs a detailed analysis of the needs of your particular household. The estimate is crucial in determining the proper collection area and storage necessary for various percentages of solar space heating, hot water, or electricity. The contractor also should analyze the effect a less-than-optimum exposure to the sun will have on system performance.

Once the contractor has completed the analysis of your house, ask for a written estimate that includes a breakdown of all labor and material costs. Also ask to see a copy of the system warranty. Warranties are applicable only to "add-on" systems such as solar electric and hot water. Warranties offered by different solar manufacturers and contractors vary considerably, so compare them carefully.

Basically, there are two types of warranties—full and limited. A full warranty is preferable because it provides the consumer with the most protection. Full warranties guarantee the product in normal use and cover component repairs and replacement at no extra cost to the customer.

A limited warranty provides coverage only for certain parts or services. For example, a limited warranty may not cover the replacement of a pump or fan.

If a part has to be ordered, you also may be responsible for shipping costs. A full warranty should cover such expenses. If the individual components on your system are from different manufacturers, you should have a warranty from each manufacturer. These warranties should be backed by the seller and the distributor as well as the manufacturer. Regardless of the type of warranty provided, read it carefully to determine the actual coverage.

Written Contract

Your solar dealer should provide a written contract covering all aspects of the installation. Starting and completion dates should be in the service contract, along with a schedule for payment. Final payment should not be made until the system is fully installed and has operated normally for several days.

Insurance for Contractors

Your solar dealer and any subcontractors doing the installation should certify that they have insurance coverage, including workers' compensation, property damage, and personal liability. You should check with your own insurance company to see if your existing policy will cover potential damages to the system or the house. Make sure the contractor has obtained the necessary building permits and that the system will not violate any local or state building codes.

System Commissioning

Once the system is installed, it should be thoroughly tested by the contractor and, if installed on a new home, checked by the local inspector. Water systems should be pressure-tested for leaks. You also may want to have a temperature gauge installed so you can observe its performance from time to time. These checks provide one sure way for you to know the system is working properly. This testing after installation but before acceptance is called “commissioning.”

Be An Informed Consumer

Finally, the best way to guarantee that you get your money’s worth in the solar marketplace is to know as much about the subject as possible. It is hoped that this booklet has given you a good introduction to the basic types of solar heating, cooling, and hot-water systems. Additional information can be obtained by reviewing solar literature available at libraries and bookstores. Check the bibliography that follows this chapter. After researching the basics of solar technology, you will be better prepared to ask insightful questions about the particular systems offered by various solar dealers.

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chapter 7:

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