

Passive Solar Design for the Home

Your home's windows, walls, and floors can be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices, such as pumps, fans or electrical controls to move the solar heat.

To understand how passive solar design works, you first need to understand how heat moves.

Heat-Movement Physics

As a fundamental law, heat moves from warmer materials to cooler ones until

there is no longer a temperature difference between the two. A passive solar building makes use of this law through three heat-movement mechanisms—conduction, convection, and radiation—to distribute heat throughout the living space.

Conduction is the way heat moves through materials, traveling from molecule to molecule. Heat causes molecules close to the heat source to vibrate vigorously, and these vibrations spread to neighboring molecules, thus transferring heat energy. For example, a spoon placed into a hot cup of coffee conducts heat through its handle and into the hand that grasps it.

Convection is the way heat circulates



This house in North Carolina features a passive solar design.

Paul Torcellini, NREL/PIX04813



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The difference between a passive solar home and a conventional home is design.

through liquids and gases. Lighter, warmer fluid rises, and cooler, denser fluid sinks. For instance, warm air rises because it is lighter than cold air, which sinks. This is why warmer air accumulates on the second floor of a house, while the basement stays cool. Some passive solar homes use air convection to carry solar heat from a south wall into the building's interior.

Radiant heat moves through the air from warmer objects to cooler ones. There are two types of radiation important to passive solar design: solar radiation and infrared radiation. When radiation strikes an object, it is absorbed, reflected, or transmitted, depending on certain properties of that object.

Opaque objects absorb 40 to 95 percent of incoming solar radiation from the sun, depending on their color—darker colors typically absorb a greater percentage than lighter colors. This is why solar-absorber surfaces tend to be dark colored. Bright-white materials or objects reflect 80 to 98 percent of incoming solar energy.

Inside a home, infrared radiation occurs when warmed surfaces radiate heat towards cooler surfaces. For example, your body can radiate infrared heat to a cold surface, possibly causing you discomfort. These surfaces can include walls, windows, or ceilings in the home.

Clear glass transmits 80 to 90 percent of solar radiation, absorbing or reflecting only 10 to 20 percent. After solar radiation is transmitted through the glass and absorbed by the home, it is radiated again from the interior surfaces as infrared radiation. Although glass allows solar radiation to pass through, it absorbs the infrared radiation. The glass then radiates part of that heat back to the home's interior. In this way, glass traps solar heat entering the home.

The term *thermal capacitance* refers to the ability of materials to store heat, and *thermal mass* refers to the materials that store heat. Thermal mass stores heat by changing its temperature. This can be from a warm room or by converting direct solar radiation into heat. The more thermal mass, the more heat can be stored for each degree rise in temperature. Masonry mate-

rials, like concrete, stones, brick, and tile, are commonly used as thermal mass in passive solar homes. Water also has been successfully used.

Basic Passive Solar Design Techniques

Passive solar homes range from those heated almost entirely by the sun to those with south-facing windows that provide some fraction of the heating load. The difference between a passive solar home and a conventional home is design. And the key is designing a passive solar home to best take advantage of the local climate. Elements of design include window location and glazing type, insulation, air sealing, thermal mass, shading, and sometimes auxiliary heat.

You can apply passive solar design techniques most easily to new buildings. However, existing buildings can be adapted or "retrofitted" to passively collect and store solar heat. In some ways, every home is a passive solar home because it has windows, but designing a home to work in its climate is the basis for these techniques.

Every passive solar building includes five distinct elements: the aperture (or collector), the absorber, thermal mass, the distribution, and the control (see page 3). But there are three basic types of passive solar design—direct gain, indirect gain, and isolated gain—that differ in how these five elements are incorporated.

Direct Gain

Direct gain is the simplest passive design technique (see Fig. 1 on page 3). Sunlight enters the house through the aperture (collector)—usually south-facing windows with a glazing material made of transparent or translucent glass. The sunlight then strikes masonry floors and/or walls, which absorb and store the solar heat. The surfaces of these masonry floors and walls are typically a dark color because dark colors usually absorb more heat than light colors. At night, as the room cools, the heat stored in the thermal mass convects and radiates into the room.

Five Elements of Passive Solar Design

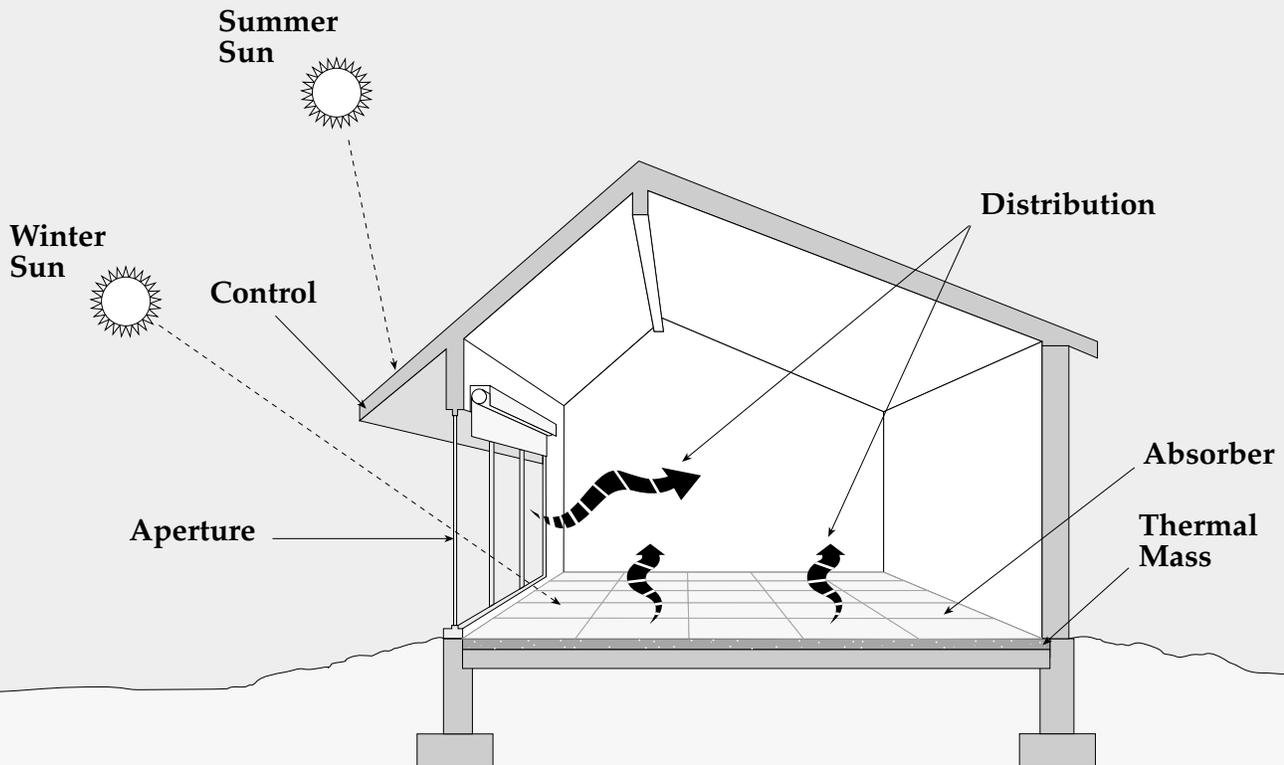


Fig. 1 Direct Gain

Here are the five elements that constitute a complete passive solar design, using a direct gain design as an example. Each performs a separate function, but all five must work together for the system to be successful.

Aperture (Collector): the large glass (window) area through which sunlight enters the building. Typically, the aperture(s) should face within 30 degrees of true south and should not be shaded by other buildings or trees from 9 a.m. to 3 p.m. each day during the heating season.

Absorber: the hard, darkened surface of the storage element. This surface—which could be that of a masonry wall, floor, or partition (phase change material), or that of a water container—sits in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.

Thermal mass: the materials that retain or store the heat produced by sunlight. The difference between the absorber and thermal mass, although they often form the same wall or floor, is that the absorber is an exposed surface whereas storage is the material below or behind that surface.

Distribution: the method by which solar heat circulates from the collection and storage points to different areas of the house. A strictly passive design will use the three natural heat transfer modes—conduction, convection, and radiation—exclusively. In some applications, however, fans, ducts, and blowers may help with the distribution of heat through the house.

Control: roof overhangs can be used to shade the aperture area during summer months. Other elements that control under- and/or overheating include: electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; and awnings.

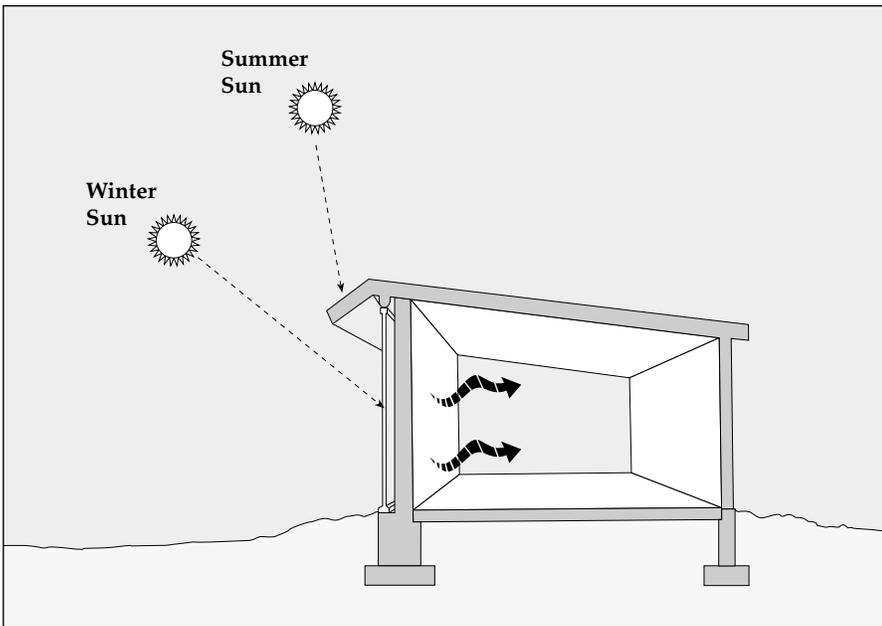


Fig. 2 Trombe Wall

The amount of passive solar depends on the area of glazing and the amount of thermal mass.

Some builders and homeowners have used water-filled containers located inside the living space to absorb and store solar heat. Water stores twice as much heat as masonry materials per cubic foot of volume. Unlike masonry, water doesn't support itself. Water thermal storage, therefore, requires carefully designed structural support. Also, water tanks require some minimal maintenance, including periodic (yearly) water treatment to prevent microbial growth

The amount of passive solar (sometimes called the *passive solar fraction*) depends on the area of glazing and the amount of thermal mass. The glazing area determines how much solar heat can be collected. And the amount of thermal mass determines how much of that heat can be stored. It is possible to undersize the thermal mass, which results in the house overheating. There is a diminishing return on oversizing thermal mass, but excess mass will not hurt the performance. The ideal ratio of thermal mass to glazing varies by climate.

Another important thing to remember is that the thermal mass must be insulated from the outside temperature. If it's not, the collected solar heat can drain away rapidly, especially when thermal mass is directly connected to the ground, or in contact with outside air whose temperature is lower than the desired temperature of the mass.

Even if you simply have a conventional home with south-facing windows without thermal mass, you probably still have some passive solar heating potential (this is often called solar-tempering). To use it to your best advantage, keep windows clean and install window treatments that enhance passive solar heating, reduce nighttime heat loss, and prevent summer overheating.

Indirect Gain – Trombe Wall

An indirect-gain passive solar home has its thermal storage between the south-facing windows and the living spaces.

Using a Trombe wall is the most common indirect-gain approach. The wall consists of an 8 to 16 inch-thick masonry wall on the south side of a house (see Fig. 2 on this page). A single or double layer of glass is mounted about 1 inch or less in front of the wall's surface. Solar heat is absorbed by the wall's dark-colored outside surface and stored in the wall's mass, where it radiates into the living space.

The Trombe wall distributes or releases heat into the home over a period of several hours. Solar heat migrates through the wall, reaching its rear surface in the late afternoon or early evening. When the indoor temperature falls below that of the wall's surface, heat begins to radiate and transfer into the room. For example, heat travels through a masonry wall at an average rate of 1 hour per inch. Therefore, the heat absorbed on the outside of an 8 inch-thick concrete wall at noon will enter the interior living space around 8 p.m.

Isolated Gain – Sunspace

A sunspace—also known as a solar room or solarium—is a versatile approach to passive solar heating. A sunspace can be built as part of a new home or as an addition to an existing one.

The simplest and most reliable sunspace design is to install vertical windows with no overhead glazing. Sunspaces may experience high heat gain and high heat loss through their abundance of glazing. The temperature variations caused by the heat losses and gains can be moderated by thermal mass and low-emissivity windows (see "Window Options for Passive Solar" on page 6).

Most successful passive solar homes are very airtight.

The thermal mass that can be used include a masonry floor, a masonry wall bordering the house, or water containers. The distribution of heat to the house can be accomplished through ceiling and floor level vents, windows, doors, or fans. Most homeowners and builders also separate the sunspace from the home with doors and/or windows so that home comfort isn't overly affected by the sunspace's temperature variations.

Sunspaces may often be called and look a lot like "greenhouses." However, a greenhouse is designed to grow plants while a sunspace is designed to provide heat and aesthetics to a home. Many elements of a greenhouse design, such as overhead and sloped glazing, which are optimized for growing plants, are counterproductive to an efficient sunspace. Moisture-related mold and mildew, insects, and dust inherent to gardening in a greenhouse are not especially compatible with a comfortable and healthy living space. Also, to avoid overheating, it is difficult to shade sloped glass, while vertical glass can be shaded by a properly sized overhang.

Design for Summer Comfort

It makes little sense to save money on winter heating just to spend it on summer cooling. So in most climates, a passive solar home design must provide summer comfort as well. The solar heat in the sum-

mer must be blocked by a roof overhang or other devices, such as awnings, shutters, and trellises.

The physical dimensions of an overhang are an important element because overheating will occur unless the overhang provides enough shade. Many variables—including latitude, climate, solar radiation transmittance, illuminance levels, and window size and type—need to be considered for properly sizing an overhang in a specific locale. Therefore, it's best to have an experienced solar designer or builder calculate the proper overhang dimensions. (The *Solar Radiation Data Manual*, listed on page 8 under "Further Reading," has appropriate overhang lengths for many U.S. locations.)

Design, Options, and Cost

A passive solar home is an exceptional home, differing from standard construction in the thermal integrity of its shell and its well-considered design. The design options, employing the principles and methods described here, are endless. However, workmanship is always extremely important when installing insulation, air sealing the building envelope, and installing the windows.

Most successful passive solar homes are very airtight. As a result, they may require mechanical ventilation systems to main-



A sunspace within a home in Minden, Nevada.

Windows transmit not only sunlight but also both indoor heat and solar heat through the building envelope.

Window Options for Passive Solar

Most of us are aware that windows provide us with natural light, ventilation, and a view. But windows still remain the least understood building design component, even though many homeowners place much importance on the functioning and energy efficiency of their windows.

Windows transmit not only sunlight but also both indoor heat and solar heat through the building envelope. That's why they may account for major heat losses in winter as well as major solar heat gains in summer. Since the energy crises of the 1970s, however, manufacturers have improved window design to allow less unwanted heat transmission during both hot and cold seasons. Many energy-conscious consumers, except those in the warmest climates, prefer insulated or double-paned glass windows.

A window's heat transmittance is measured by U-factor. A smaller U-factor provides more insulating value than a larger one. The smaller the number, the better. With today's technology, a window is considered energy efficient if its U-factor is less than 0.40. To achieve this energy-efficiency standard, the glass is coated with a very thin layer of material that is engineered to transmit or reject certain frequencies of radiation. This coated glass is called low-emissivity (low-e) glass.

Glass's transmittance is measured by solar heat gain coefficient (SHGC), which is a decimal number less than one. A number of 0.60 means that 60 percent of the solar radiation passes into the house and 40 percent is rejected back into the environment. Passive solar heating requires a high SHGC—in other words, a window that lets solar radiation pass into the space.

Quite often passive solar homes are built using glass that rejects solar energy (low SHGC). This can be a costly mistake. When selecting the glass, here are some general rules of thumb you can follow:

- East- and west-facing glass should have a low SHGC (less than 0.40).
- South-facing glass should have a high SHGC if the house has a proper overhang. If it doesn't, you'll need a low SHGC glass, but then you won't have a solar house because you're rejecting the solar gain.
- The SHGC makes little difference on the north facade. Because most windows get low U-values by adding low-e coatings, it comes at a price.

Typically, the low U-value windows also reject most solar gains (low SHGC). Therefore, it may be difficult to buy a low U-value window with a high SHGC. The right choice is dependent upon the climate.

As you can see, selecting windows can be complicated. That's why it's best to have an experienced solar design professional use a simulation tool to determine the best windows to use in your home's climate.



Nancy Carlisle, NREL/PIX02778

If you're lucky enough to be working with an experienced solar designer and builder, a passive solar home may cost no more than a conventional one.



Dwight Stone, NREL/PIX008414

This passive solar home in Pueblo, Colorado — made from concrete forms, a high thermal mass material — only cost about 10 percent more to build than similar, conventional homes in the area.

tain good indoor air quality. A heat-recovery ventilator (HRV) is often the best choice to conserve the home's hard-won solar heat. An HRV takes heat from the departing indoor air and transfers this heat to the entering outdoor air.

Passive solar technology may still be new to many designers and builders. So you're sometimes required to pay extra for them to master unfamiliar design and construction details. But if you're lucky enough to

be working with an experienced solar designer and builder who are committed to excellence, a passive solar home may cost no more than a conventional one or even less in some situations. Also, properly sized heating equipment, which are typically smaller in passive solar homes, will sometimes offset the cost of the passive solar features.

Resources

The following are sources of additional information on passive solar heating and design. This list is not exhaustive, nor does the mention of any resource constitute a recommendation or endorsement.

Ask an Energy Expert

DOE's Energy Efficiency and Renewable Energy Clearinghouse (EREC)

P.O. Box 3048

Merrifield, VA 22116

1-800-DOE-EREC (1-800-363-3732)

E-mail: doe.erec@nciinc.com

Online submittal form:

www.eren.doe.gov/menus/energyex.html

Web site: 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: www.eren.doe.gov

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

Organizations

American Solar Energy Society (ASES)

2400 Central Ave., Suite G-1

Boulder, CO 80301

Phone: (303) 443-3130; Fax: (303) 443-3212

E-mail: ases@ases.org

Web site: www.ases.org

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

Efficient Windows Collaborative

Alliance to Save Energy

1200 18th St. NW, Suite 900

Washington, D.C. 20036

Phone: (202) 857-0666; Fax: (202) 331-9588

Web site: www.efficientwindows.org

Provides information on energy-efficient windows, including their benefits and how they work.

National Renewable Energy Laboratory (NREL)

Center for Buildings and Thermal Systems

1617 Cole Blvd.

Golden, CO 80401

Web site: www.nrel.gov/buildings/

Provides information on energy-efficient buildings, including passive solar design.

Sustainable Buildings Industry Council (SBIC)

1331 H St. NW, Suite 1000

Washington, DC 20005

Phone: (202) 628-7400; Fax: (202) 393-5043

E-mail: sbic@sbicouncil.org

Web site: 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: www.eren.doe.gov/buildings/tools_directory/

Describes many energy-related software tools for buildings, including those for passive solar design.

Further Reading

Passive Solar Buildings, J.D. Balcomb, MIT Press, 1992, 528 pp.

Passive Solar Design, DOE, December 2000. Available in print from EREC (see "Ask an Energy Expert" above) and in PDF at www.eren.doe.gov/buildings/documents.

The Passive Solar Design and Construction Handbook, M. Crosbie (ed.), J. Wiley, John Wiley & Sons, 1997, 291 pp.

The Passive Solar House, J. Kachadorian, Chelsea Green Publishing Co., 1997, 220 pp.

Passive Solar House Basics, P. Van Dresser, Ancient City Press, 1996, 136 pp.

The Solar Home: How to Design and Build a House You Heat with the Sun, M. Freeman, Stackpole Books, 1994, 240 pp.

Solar Radiation Data Manual for Buildings, W. Marion, S. Wilcox, NREL. Available online at <http://rredc.nrel.gov/solar/pubs/bluebook/>.

Solar Today. Published by ASES (see "Organizations" above). This bimonthly magazine covers all solar energy technologies, including passive solar.