3 PASSIVE SOLAR HEATING: REGION-SPECIFIC DESIGN

MY SECOND HOME was built by a contractor who had grand ideas about helping reduce energy use in homes. It was his first passive solar home. I was its second owner.

The house, which is shown in figure 3-1, was lovely to look at and breathtaking inside. It had 16-foot vaulted ceilings. I fell in love with it the instant I walked in the front door, as did my former spouse. I was especially excited about this house because it employed three different passive solar design features: direct gain, an attached sunspace, and a thermal storage wall, all of which are discussed in this chapter. The builder had oriented it properly, insulated the envelope well, and provided adequate mass—or so we thought. Even though the house was in the trees, it had a decent solar "window" with full

FIGURE 3-1
The author's first true passive solar house. Although this home was one of the best the author looked at during his search, it turned out to have many problems, most notably overglazing and undermassing.

HIGH CEILINGS

We all love high ceilings, but they can be a design nightmare in colder climates. Heat rises away from occupants where it is needed most, and is difficult to move back down. Much of this heat escapes through the ceiling, resulting in cooler night-time temperatures than you may prefer. High ceilings also mean there's more volume to heat during cold, cloudless periods. That increases heat bills and pollution.

access to the sun from 9 or 10 AM to 3 or 5 PM, depending on the time of year (and therefore the angle of the sun).

As well thought out as this home was, though, we soon discovered that it had some significant flaws. Too many skylights and some large, west-facing sliding glass doors that afforded a view of the 14,000-foot Mount Evans resulted in excessive solar gain during the summer. The builder also unknowingly exceeded recommendations for south-facing glass, causing the house to overheat in the winter as well. I often walked around in shorts and a T-shirt during the dead of winter, and still felt as if I were about to spontaneously combust. Moreover, the air inside the house was unbearably hot and dry.

Overheating was a problem in this house in the summer, fall, and winter! But there were other problems, too. The vaulted ceilings permitted heat to rise and dissipate through the skylights and the roof. So at night, this lovely little solar house that baked us in the day, chilled us down like fish in a freezer.

The builder had anticipated the problem of rising hot air and had installed two fans in plenums in the walls to gather the heat and transport it to the lower level of the house. This was a great idea, but the fans were undersized and thus ineffective. I replaced them with larger models, which were still ineffective. They barely made a dent in the problem. A ceiling fan we installed didn't help much, either.

Making matters worse, the builder had installed inexpensive sliding glass doors that leaked excessively during the winter, so at night they produced a bone-chilling draft.

The builder made another costly error. He had failed to install a vapor barrier and a roof venting system. A couple years after we moved in, during the house's fifth year of existence, the shingles on the roof began to buckle. When the roofer arrived to fix the problem, we found that the decking was soaked from water vapor escaping through the ceiling. The insulation was damp as well, which reduced its effectiveness.

As time went on, we discovered additional problems. One was that the direct-gain space was virtually unusable during daylight hours. The light was too intense to watch television, read, or work at a computer.

Over the years, I came to realize that my first inclination about this passive solar home being a great place to study solar design proved true. Unfortunately, it turned out to be a case study in well-intentioned design disasters. Fixing the mistakes consumed a lot of time and cost a great deal of money—about $15,000—for example, to install Plexiglass over skylights and sliding glass doors, to re-roof the house, and to install ridge and soffit vents to prevent moisture from building up in the insulation.

PASSIVE SOLAR HEATING

Passive solar heating systems provide space heat for a wide range of buildings from homes to banks to schools to dentist offices. Unlike other solar energy systems—for example, those that produce domestic hot water for homes—a passive solar heating system contains only one moving part: the sun. (Actually, the sun's movement across the sky is due to the Earth's rotation.) It travels in a daily arc across the sky that changes by season. In the summer, the sun carves a steep path across the sky. In the winter, its arc is low in the sky (figure 3-2). In the intervening seasons it travels an intermediate path.

Passive solar home designers take advantage of the sun's variable course, using south-facing glass to permit sunshine to enter and properly designed overhangs to regulate solar gain, permitting the sun to enter when it is needed and blocking its intrusion during the rest of the year. Passive solar designers use other standard elements of a building—walls and floors, for example—to store solar heat and release it over time, providing warmth.

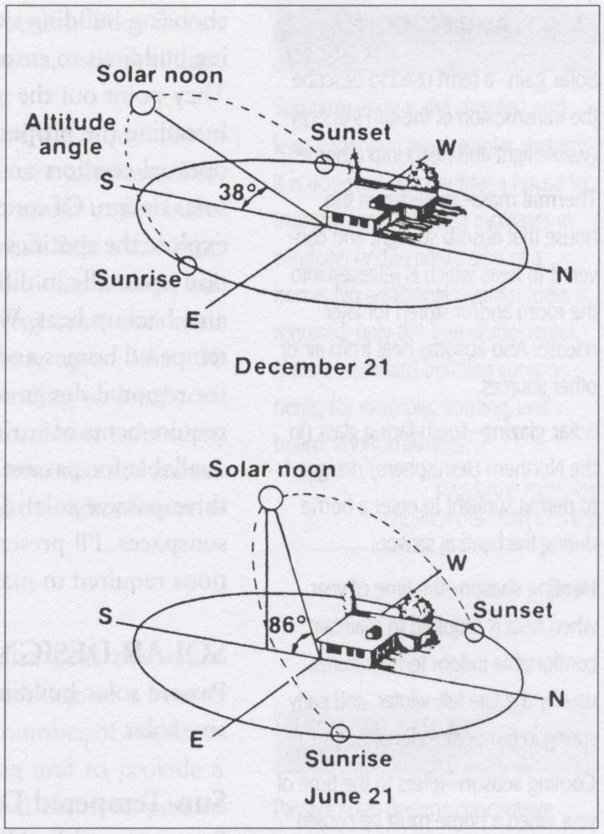


FIGURE 3-2
The sun cuts a low arc through the sky in the winter in Florida (shown here) and elsewhere and is thus able to penetrate south-facing windows to provide heat. During the summer, the sun cuts a high arc and thus very little sunlight can penetrate south-facing windows.

courtesy Florida Solar Energy Center

Sunlight contains energy of many different forms, such as visible light, heat, ultraviolet radiation, X-rays, cosmic rays, and gamma rays. For our purposes, visible light and heat (infrared radiation) are the most important. In a passive solar home, visible light entering south-facing glass (solar glazing) is absorbed by thermal mass within the structure and converted to heat. The fate of this heat depends on a simple law of physics: heat always flows from warm to cold. Thus, as the surface of thermal mass warms up, heat tends to migrate inward toward the cooler interior. Heat also radiates into the air around it, if it is cooler, or is stripped away by cooler air flowing over its surface. All three forces, conduction, radiation, and convection, help distribute heat within a building.

During daylight hours, visible light produces heat that charges the mass wall and warms a home's interior. At night or during cloudy periods, when room temperature falls below mass temperature, heat flows back into the room from thermal mass. In well-designed and well-constructed passive solar homes, very little human intervention is required beyond opening and closing window shades. Nor are any mechanical devices required to ensure comfortable indoor temperatures, and it is for this reason that the process is referred to as "passive."

In most climates where heating is required, passive solar design can easily provide 25 to 80 percent of a home's annual heat requirement, known as its *heating load*. To do so, *a passive solar house must be designed and built correctly.* Proper design begins by following the fourteen principles outlined in chapter 1. Among other things, these principles emphasize the importance of

A SOLAR LEXICON

Solar gain–a term used to describe the transmission of the sun's energy (visible light and heat) into a home.

Thermal mass–materials in the house that absorb sunlight and convert it to heat, which is released into the room and/or stored for later release. Also absorbs heat from air or other sources.

Solar glazing–south-facing glass (in the Northern Hemisphere) designed to permit sunlight to enter a home during the heating season.

Heating season–the time of year when heat is required to maintain comfortable indoor temperatures, usually the late fall, winter, and early spring in temperate climates.

Cooling season–refers to the time of year when a home must be cooled to maintain comfortable interior temperatures. Usually the summer, but in some climates also the later spring and early fall.

Heating load–an engineering term for a building's annual heating requirement. It can be satisfied by solar energy or a heating system, or a combination of both

choosing building sites wisely, orienting homes toward the south, and designing buildings to ensure the sun's unfettered entrance during the heating season. They point out the need to build homes that are airtight and energy efficient. Installing the proper amount of thermal mass and locating mass properly for optimal comfort and maximum solar gain are also vital to successful passive solar design. Of course, integrated design is also crucial. In this chapter, we will explore the specifics of passive solar design aimed at creating homes that function optimally in different regions, providing year-round comfort with little, if any, backup heat. We will begin by surveying two major design options–sun-tempered homes and true passive solar homes. Next, we will explore a system for regional design of passive solar homes that takes into account the heating requirements of various regions and solar availability—the amount of sunlight available for passive solar. In subsequent sections, we focus on the specifics of three passive solar designs: direct gain, thermal storage systems, and attached sunspaces. I'll present guidelines for designing each type, as well as modifications required to make each one work in mild, moderate, and severe climates.

SOLAR DESIGN OPTIONS

Passive solar buildings fall into two broad categories: sun-tempered and passive solar.

Sun-Tempered Designs

Sun-tempered buildings are the simplest and least expensive passively heated buildings. Sun-tempered homes are achieved by orienting the east-west axis of a house to true south and by modest increases in the number of windows on the south side of homes, which usually entails a shift of glazing from other sides of the house—and therefore is no additional cost (figure 3-3). In a sun-tempered design, south-facing glass should not exceed 7 percent of the total floor area. In other words, in a 2,000-square-foot home, the south-facing window glass should not exceed 140 square feet.

FIGURE 3-3
The sun-tempered solar home gains about 25 to 30 percent of its heat from the sun. This goal is achieved by orienting the east-west axis of the home to true south and shifting some of the windows to the south side.

Sun-tempered designs are the least costly passive solar option. They do not require any additional thermal mass. Incidental mass in floors, walls, ceilings, and furniture is generally sufficient to prevent overheating.

Sun-tempered designs do not require insulation beyond the requirements of local building codes, provided that local building codes are adequate. Following or exceeding the guidelines of EPA's Energy Star program or the International Energy Conservation Code boosts performance with little extra cost.

Sun-tempered homes typically cost the same as conventional homes, but reap fairly substantial benefits in comfort and reduced energy costs over their lifetime. With very little extra effort, these homes can satisfy up to 20 to 30 percent of the annual heating load from passive solar, depending on local conditions, house design, and construction details (including insulation). As such, sun-tempered homes are ideal for builders and developers who want to reduce the energy demand of their houses without making the slightly higher financial commitment to true passive solar design.

SUN-TEMPERED DESIGNS

Sun-tempering is the simplest and least expensive passive solar strategy. It is achieved by orienting a house to true south and modest increases in windows on the south side of a home. No additional thermal mass is required, only the free or incidental mass in standard building components, for example, framing, wall board, and furnishings.

PASSIVE SOLAR DESIGN STRATEGIES

Passive Solar Designs

True passive solar designs provide substantially more heat than sun-tempered designs. To do so, designers place a greater percentage of a home's windows on the south side of the building and reduce the number of windows on the north, east, and west sides. To prevent overheating and to provide a means of storing heat to ensure greater long-range thermal comfort, passive solar designs require much greater use of thermal mass than sun-tempered designs (figure 3-4). These changes boost the amount of heat generated by the home, which can easily climb to 50 to 80 percent or more of the annual demand. (The range depends on climate, the availability of sunshine, design, and construction.)

In this book, I will focus primarily on passive solar home designs, examining three options: direct gain, attached sunspaces (isolated gain), and thermal

PASSIVE SOLAR DESIGNS

Passive solar designs concentrate glazing on the south side of the house combined with thermal mass to store heat and prevent overheating. South-facing glass ranges from 7% to 12% of the total floor space. Three types of passive solar designs are encountered: direct gain, isolated gain, and indirect gain.

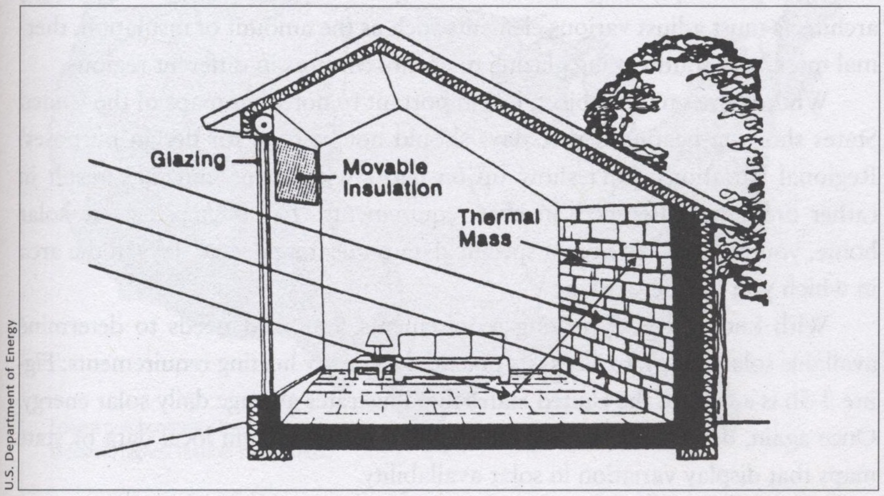


FIGURE 3-4
Direct-gain passive solar homes rely on south-facing windows to permit sunlight to enter during the heating season. Sunlight is converted to heat inside the living space, heating it directly, hence the name direct gain.

HEATING AND COOLING DEGREE DAYS

Heating degree days is a measure that tells us how many days each year, on average, the outside temperature falls below 65°F. At this temperature, internal heat sources (lightbulbs, people, and appliances, for instance) and solar gain in non-solar homes will result in internal temperatures around 70°F, deemed to be a comfortable interior temperature. Cooling degree days is a measure of how many days each year, on average, outside temperature exceeds 65°F.

HEATING AND COOLING DEGREE DAY SOURCE

To obtain heating and cooling degree day data for your location, log on to http://lwf.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html.

storage walls (indirect gain). Before examining the three types of passive solar design and how to modify them for optimal performance in different regions (reflecting differences in solar availability and heating loads), we need to examine two vital aspects of region-specific design: heating requirement and solar availability.

REGION-SPECIFIC DESIGN: HEATING REQUIREMENTS AND SOLAR AVAILABILITY

Designing a passive solar home for a particular region requires a knowledge of outdoor temperature during the heating season to estimate heating requirements. Rather than using average temperatures, however, most designers rely on heating degree days as their guidepost. (So does the software I'll introduce you to in chapter 7.)

Heating degree days is a measure of how many days each year, on average, the outside temperature falls below 65°F. At this temperature, internal temperature in a house usually hovers around 70°F, as explained in the sidebar.

To understand how the number is derived, consider a simplified example. If the outside temperature is 64°F for one full day, it is considered a 1-degree day. If the outdoor temperature is 60°F for a day, it is considered to be a 5-degree day. If the outside temperature averages 0°F for two weeks, the result is 910 heating degree days (65 degrees × 14 days = 910 heating degree days). The higher the degree heating days, the colder the climate.

Figure 3-5a is a map of the U.S. displaying heating degree day zones. Not surprisingly, heating degree days increase from south to north. As an example, northern Minnesota is rated at 10,000 heating degree days. Southern Florida is rated at 500 degree days.

As noted above, the heating degree day measurement indicates general heating requirements—how much solar heat or conventional heat a home will require to produce comfortable indoor temperatures. Obviously, the higher the heating degree days, the greater the heating challenge. In passive solar design, architects must adjust various elements such as the amount of insulation, thermal mass, and south-facing glazing to ensure comfort in different regions.

While we're on the subject, it is important to note that maps of the United States showing heating degree days should not be used for design purposes. Regional variations don't show up on nationwide maps and may result in rather dramatic differences in heat requirements. To design a passive solar home, you will need to obtain specific data on heating degree days in the area in which you will be working.

With knowledge of heating requirements, one next needs to determine available solar energy, to assess its potential to satisfy heating requirements. Figure 3-5b is a map of the United States that illustrates average daily solar energy. Once again, don't use U.S. maps to design a home. Obtain local data or state maps that display variation in solar availability.

courtesy Erwin Kubsch

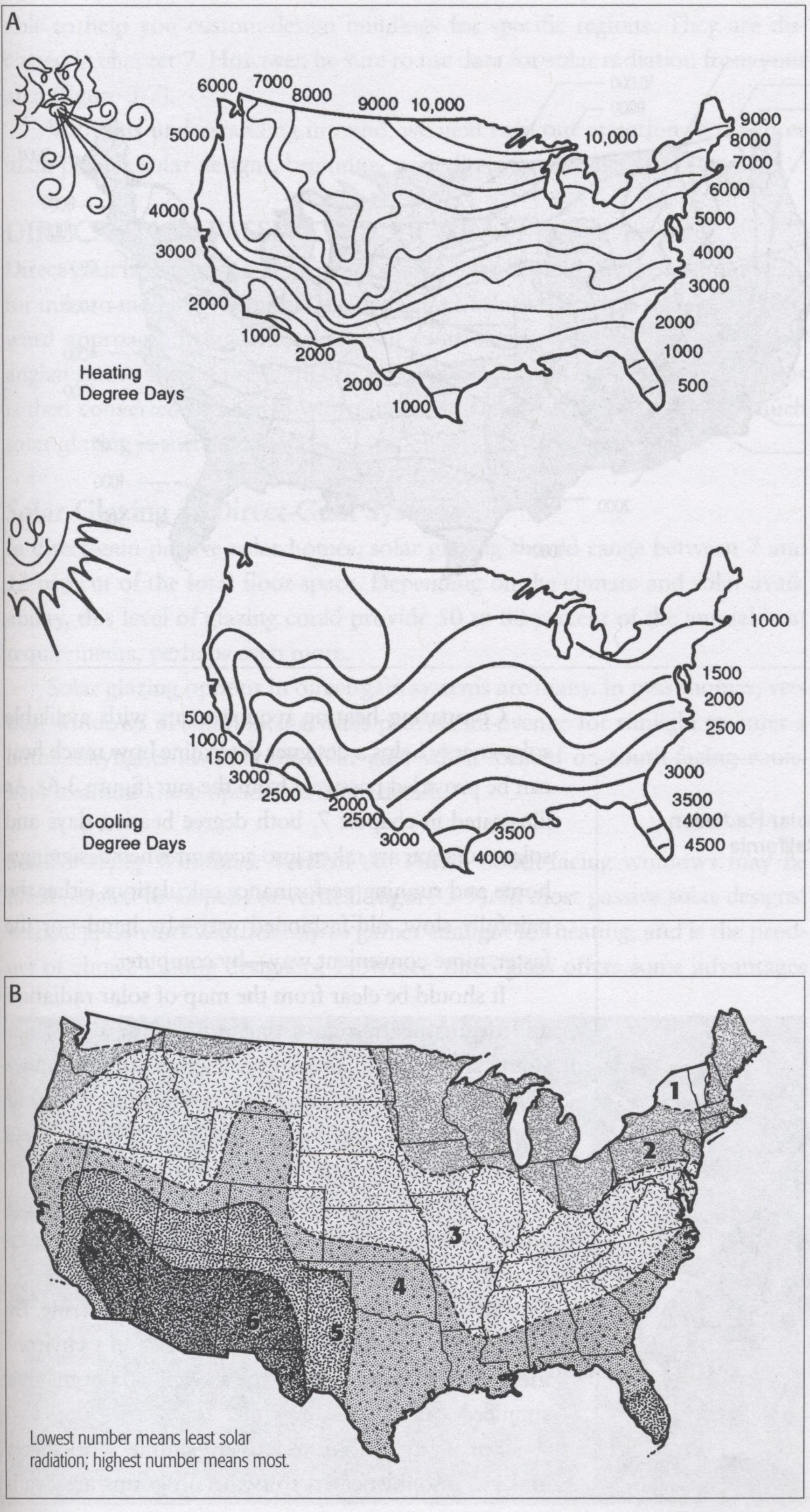


FIGURE 3-5
(a) Heating and cooling degree days indicate the heating and cooling challenges of an area. Be sure to use data from state maps for designing your home. (b) Average daily solar radiation. This information helps a designer determine solar availability. Again, be sure to use data from state maps for design.

FIGURE 3-6
Overlaying maps of the daily solar radiation and degree heating days helps the designer plot a successful strategy for passive solar heating.

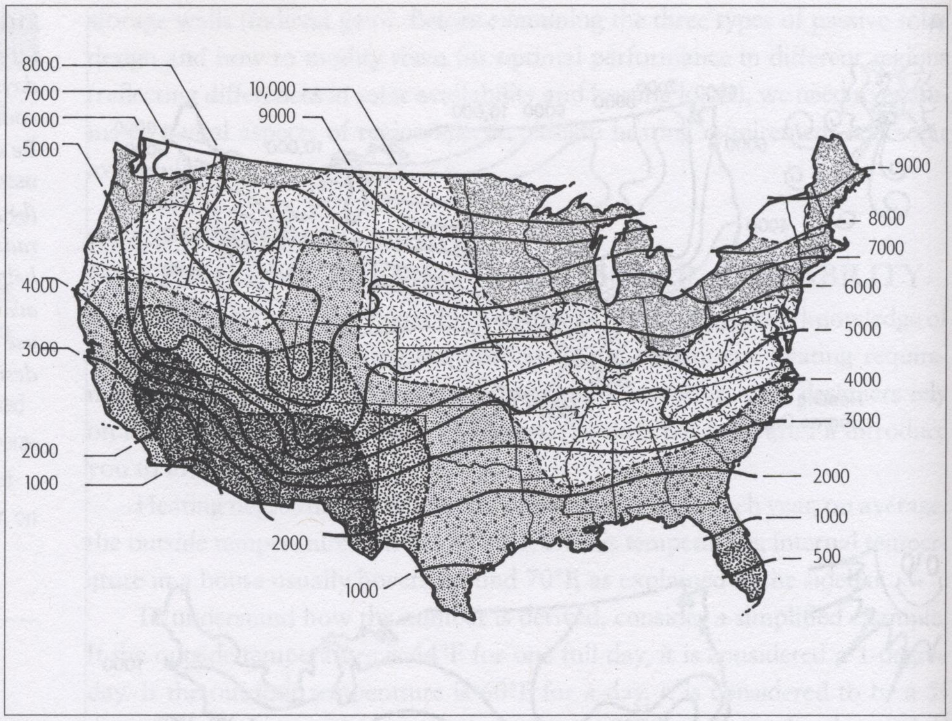
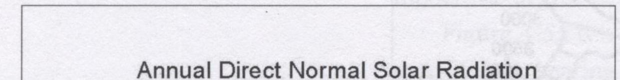


FIGURE 3-7
Solar radiation in California. This map shows that there is considerable variation in average daily solar radiation within a state.



Comparing heating requirements with available solar energy helps a designer determine how much heat can be provided passively from the sun (figure 3-6). As illustrated in chapter 7, both degree heating days and solar radiation are taken into account when designing a home and running performance calculations either the painfully slow, old-fashioned way—by hand—or the faster, more convenient way—by computer.

It should be clear from the map of solar radiation and degree heating days that a home in a cold but sunny climate such as eastern Montana obtains more solar heat than an identical home in a cold but cloudier climate, for instance, northern Maine, New Hampshire, and Vermont. However, a knowledge of heating requirements and available solar resources allows a designer to formulate effective compensating strategies to boost solar reliance in such instances — for example, increasing insulation or solar glazing. By taking such measures, a home in a less sunny environment can be made to perform as well as a home in a sunnier locale.

Fortunately, some relatively simple worksheets and some sophisticated software programs are available to help you custom-design buildings for specific regions. They are discussed in chapter 7. However, be sure to use data for solar radiation from your area (figure 3-7).

With this understanding in mind, we next turn our attention to the three main passive solar designs, beginning with direct-gain systems.

DIRECT-GAIN PASSIVE SOLAR HEATING

Direct gain is the most widely used passive solar heating strategy. Appropriate for mild to moderate climates, direct gain is a relatively simple and straightforward approach. It involves the use of south-facing windows to permit low-angled sun to enter a home (figure 3-8). Sunlight absorbed by interior surfaces is then converted to heat to warm interior spaces day and night. How much solar glazing is sufficient?

In direct-gain passive solar systems, window space should not exceed 7 to 12 percent of the total floor space. In this "more-is-better world," be careful to resist the temptation to overglaze!

Solar Glazing in Direct-Gain Systems

In direct-gain passive solar homes, solar glazing should range between 7 and 12 percent of the total floor space. Depending on the climate and solar availability, this level of glazing could provide 50 to 80 percent of the annual heat requirements, perhaps even more.

Solar glazing options in direct-gain systems are many. In most homes, vertical windows in south-facing walls provide an avenue for sunlight to enter a home. Skylights also permit solar gain when located on south-facing roofs. Let's examine these options in more detail.

South-Facing Windows: Vertical vs. Tilted. South-facing windows may be tilted (angled or sloped) or vertical (figure 3-9). In most passive solar designs, vertical glass works sufficiently to gather sunlight for heating, and is the product of choice among designers. However, tilted glass offers some advantages

James Plagmann

FIGURE 3-8
A direct-gain passive solar home. Sunlight streaming through south-facing windows is converted to heat inside the home, directly heating the interior space. This beautiful passive solar home in Morrison, Colorado, was designed by Colorado architect James Plagmann.

INDIRECT-GAIN PASSIVE SOLAR HEATING

Indirect-gain passive solar is the most widely applicable passive solar design option, good for the mildest to the most severe climates. Indirect-gain systems are also known as thermal storage walls or Trombe walls.

Thermal storage or Trombe walls are mass walls located on the south side of houses. As shown in figure 3-21, clear glass is situated three to six inches away from a mass wall, typically made from poured concrete, concrete block, rammed earth, or other similar dense masonry or earthen materials.

During the winter, low-angled sunlight streaming through the glass strikes the dark-colored surface of the mass wall. Heat forming at the surface of the wall follows two routes. First, much of the heat is absorbed by the mass. This heat slowly begins to migrate into the wall, flowing from hot to cold. Second, the remainder of the heat is transferred into air in the space between the glass and the mass wall. It may be lost to the outside or captured by venting the wall, as described shortly.

Thermal storage walls are designed primarily to provide nighttime heating in climates that range from mild to severe. They are, therefore, the most widely applicable form of passive solar.

Most thermal storage walls are designed so heat reaches the interior surface at about the time the sun sets in the winter, or slightly later. Thus, the solar-derived heat arrives at the inner surface of the wall just when heat is required. It then begins to radiate into the room and continues providing warmth and comfort throughout the night. The result is known as *delayed solar gain*.

The time lag, the time between the moment the sun begins to warm a thermal storage wall and the time the heat begins to radiate into a room, varies from a few hours to an entire day, depending on the thickness of the mass and

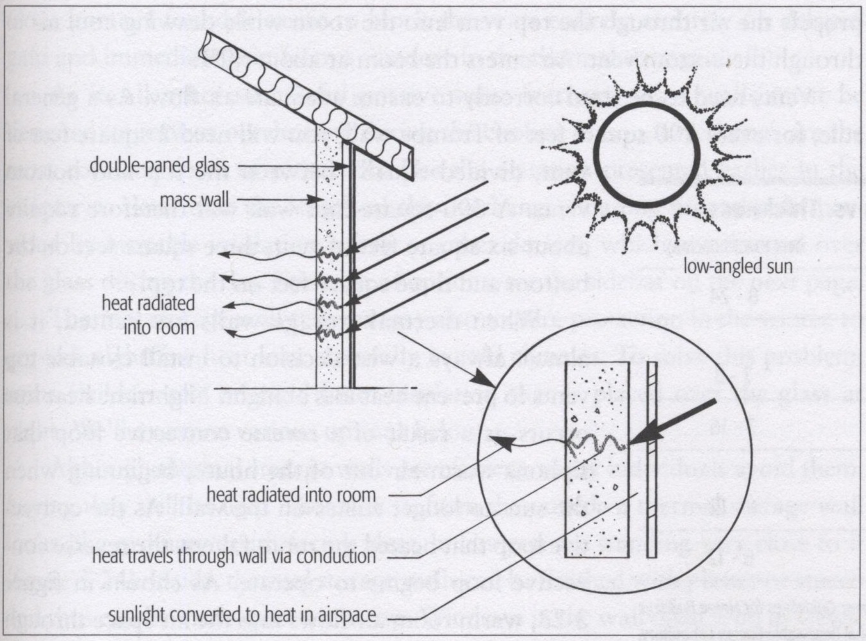


FIGURE 3-21
Cross section of a thermal storage wall or Trombe wall. Sunlight striking the dark surface of the thermal storage wall is converted to heat. In an unvented thermal storage wall, heat then migrates through the mass wall into the home.

its density. Thermal storage walls may vary in thickness from six to twenty-four inches, though eight to eighteen inches is most common. How thick the wall should be in a home depends on the masonry material and the time lag required. Table 3-3 shows the recommended thickness by material. The thicker the wall, the longer it will take the heat to reach a room. In addition, the thicker the wall, the less daily variation will occur in the surface temperature of the inside wall surface.

Some designers substitute water for masonry materials in thermal storage walls. Water has a higher heat capacity than masonry, meaning it holds more heat per unit volume. However, water releases heat more quickly.

In most cases, free-standing plastic water columns are situated behind the glass to absorb sunlight and store heat. At night or during cold, cloudy periods, the mass walls radiate heat into the adjacent room. In most installations, water tubes are visible to the occupants of the room to optimize their performance. Applying wall board may enhance the aesthetics, but it decreases heat transfer from the water to the room air.

Windows can be installed in thermal storage walls to permit an outside view, daylighting, direct-gain solar heating, and an escape route in case of fire. (Building codes typically will require openable windows for emergency egress in all bedrooms.)

Trombe walls may also contain air vents to siphon heat out of the space between the glass and the mass wall, providing immediate or daytime solar heat gain. Here's how they work: As shown in figure 3-22, cool room air enters the air space through the lower vent where it is warmed by sunlight. As it flows upward, it gains additional warmth, creating a convection current that propels the air through the top vent into the room while drawing cool air in through the bottom vent. Air enters the room at about 90°F.

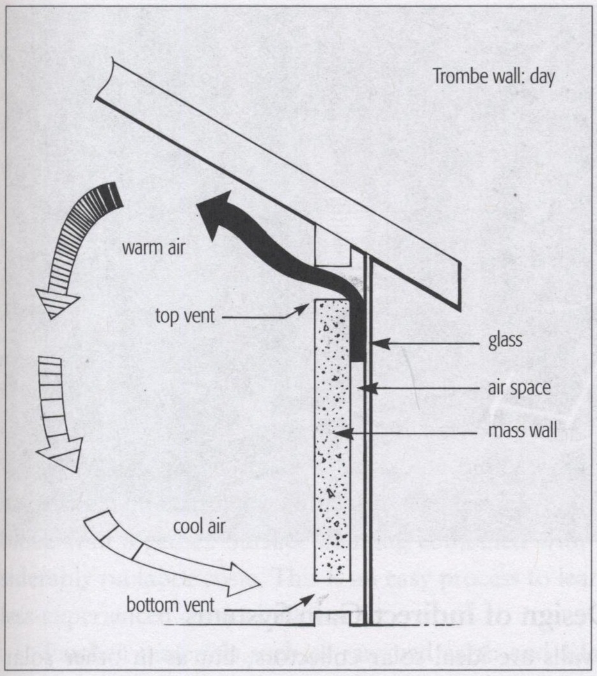
Vents need to be sized correctly to ensure adequate air flow. As a general rule, for every 100 square feet of Trombe wall, you will need 2 square feet of vent, divided equally between the top and bottom vents. A 300-square-foot wall will therefore require about six square feet of vent, three square feet on the bottom and three square feet on the top.

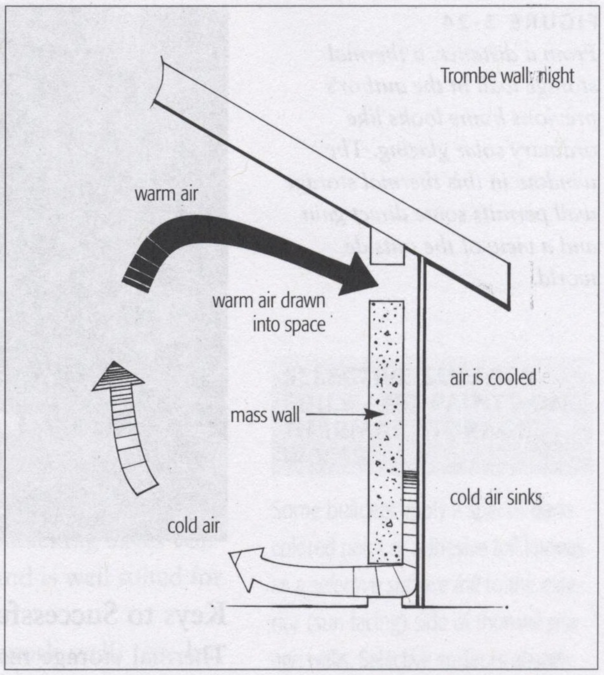
When thermal storage walls are vented, it is almost always a wise decision to install closable top vents to prevent heat loss at night. Nighttime heat loss occurs as a result of a reverse convective loop that siphons warm air out of the house, beginning when the sun no longer shines on the wall. As the convective loop that heated the room falters, the reverse convective loop begins to operate. As shown in figure 3-23, warm room air flows into the air space through the top vent. Inside the air space, the warm air cools

TABLE 3-3. Mass Wall: Materials vs. Thickness

MATERIAL	DENSITY (lb/cf)	THICKNESS (inches)
Concrete	140	8 - 24
Concrete masonry (concrete blocks)	130	7 - 8
Clay brick	120	7 - 16
Light Weight Concrete Masonry	110	6 - 12
Adobe	100	6 - 12

Source: *Passive Solar Design Strategies: Guidelines for Home Building,* Sustainable Buildings Industry Council, National Renewable Energy Laboratory, and Charles Eley Associates.





and sinks, sucking more warm air in through the top vent and pushing cold air in through the bottom vent.

The reverse convection loop draws heat out of a house, subtracting from heat gain unless backdraft dampers or operable louvers are installed in the vents. Both are effective deterrents, but do require daily operator involvement. That is, they must be opened and closed each morning and night. (In my previous home, I found it easier to block the vents entirely and rely on delayed gain and immediate gain from a window in the thermal storage wall.)

As in all other successful passive solar features, mass walls must be designed to prevent overheating during the cooling season. Overhangs are the most common form of protection. Use the equation presented earlier in the chapter to determine the length of the overhangs. Shading may also be provided by movable insulation panels or other devices, which are situated over the glass during the day. For a list of options, see the sidebar on the next page.

Thermal storage wall systems may also require protection in the winter, to prevent nighttime heat loss, especially in cold climates. To solve this problem, some builders rely on rigid foam insulation that is placed over the glass at night. We'll examine various options below.

Although thermal storage walls are efficient, many individuals avoid them, fearing they will be ugly. The truth is, from the outside a thermal storage wall looks like ordinary south-facing glass, unless you are standing very close to it (figure 3-24). Inside, thermal storage walls can be finished with plaster or stucco and thus can be made quite attractive. Windows in the wall open it up to views, so occupants don't feel as if they are imprisoned by massive concrete walls.

FIGURE 3-22 (left)
In a vented thermal storage wall, heat may also be transferred to the adjoining living space by natural convection.

FIGURE 3-23 (right)
At night, heat can be drawn out of a house by a vented thermal storage wall, if the vents are not closed off. Notice the reverse convection loop.

BUILDING NOTE

From a distance, a Trombe wall looks just like ordinary glass. Windows can be built into the wall, too, so a room need not be closed off from sunlight.

FIGURE 3-24

From a distance, a thermal storage wall in the author's previous home looks like ordinary solar glazing. The window in this thermal storage wall permits some direct gain and a view of the outside world.

SHADING OPTIONS FOR DIRECT-GAIN AND THERMAL STORAGE WALLS*

External Shade Options
- Overhangs
- Rigid foam with reflective surface (for increased heat gain in the winter)
- Arbors
- Trellises
- Awnings
- Louvers
- Wing walls

Internal Shade Options
- Curtains
- Blinds
- Roller shades
- Internal rigid shutters

*Some of these options provide nighttime insulation as well.

Keys to Successful Design of Indirect-Gain Systems

Thermal storage mass walls are ideal solar collectors, but as in other solar designs there is room for error.

First, be sure the thermal storage wall is oriented due south plus or minus 10 degrees. As in any passive solar system, the further you deviate from true south, the lower the winter heat gain and the greater the summer heat gain.

Second, high-performance glass is recommended for use in thermal storage walls, although some builders have successfully used fiberglass, acrylics, and polycarbonates (Plexiglass). Remember: The more opaque the glazing, the lower the solar gain.

As a rule, double-pane glass is best. The colder the climate, the more essential it is to choose a glass with a high R-value (or low-U value). High-performance glass includes products made with low-e coatings (thin films on the glass itself), suspended plastic films (for example, Heat Mirror glass), and gas fills (argon gas between the panes). Single-pane glass is generally not advisable, except in the mildest climates. In such instances, movable insulation may be required to optimize the system's performance.

Third, be sure that the glass facing is thermally isolated from the mass wall. If it isn't, heat may escape from the thermal storage wall via conduction at night or during cloudy periods. Metal framing is a source of thermal bridging and will conduct heat out of the wall at night, if it is not isolated from the mass. Wood framing is a better option; however, wood takes a beating in the intense (150 to 180°F) heat in the airspace between the glass and the mass wall.

Fourth, caulk and sealants used to construct thermal storage walls should be able to withstand considerable expansion and contraction resulting from daily temperature fluctuations. Don't skimp. Buy the best.

Fifth, paint applied to the surface of a thermal storage wall should be capable of withstanding high temperatures. Better yet, you may want to install a selective surface material to the exterior surface of the mass wall. Selective surface material usually comes in thin sheets that adhere to the wall. Because the dark solar surface of the material absorbs virtually all of the sunlight that strikes it, very little heat is released into the airspace, from which it can escape through the glass. The result: greater solar gain. The colder the climate, the more important this material becomes. (Note that the increase in efficiency created by the selective surface reduces the need for nighttime insulation.)

Sixth, thermal mass walls must be dense and capable of absorbing a significant amount of heat and giving it off slowly. Masonry materials such as concrete and brick are ideal. Concrete block filled with sand or concrete work well, too. To cut down on labor, some builders dry stack concrete blocks, rather than mortar them. They then use a surface-bonding material to hold the block wall together. Surface bonding combined with dry stacking saves considerably on labor costs. This is an easy process to learn, and is well suited for less-experienced owner-builders.

Earthen materials such as rammed earth and adobe work well, too, but they're less dense than the previously mentioned materials. Whatever you use, be sure to check with local building codes for any structural reinforcement requirements for mass walls. Remember, these walls generally also serve as load-bearing exterior walls.

Seventh, the interior surface of a mass wall should be minimally finished to enhance heat transfer. Earthen, gypsum, and lime plaster work well, as do cement or synthetic stucco. Drywall will work, so long as it is in direct contact with the mass wall. Furring drywall against a mass wall is a bad idea because it reduces heat conduction. (Note that all of these products, except earthen and lime plaster, outgas potentially toxic chemicals into the room; lime plaster is caustic and dangerous to work with.)

Eighth, remember that insulation is generally needed most in colder climates. As engineer Al Eggen, of K.T. Lear Associates in Ashford, Connecticut, notes, thermal storage walls can be a "disaster in climates where the sun does not shine every day." He goes on to say, "Unless you can wrap an R-20 or so blanket over the outside wall, a few cold, cloudy days results in a very large cold wall." To avoid this problem, designers rely on two basic options: (1) external insulation positioned against the exterior surface of the glass at night, for example, rigid foam insulation panels; and (2) internal insulation, that is, devices located in the airspace between the glass and the mass wall. Both internal and external insulation work well, although the latter is more difficult to install and service. Rigid foam exterior insulation generally ranges from R-4 to R-8 per inch. If you are using rigid foam, it should be at least the same size as the glazing and should fit tightly over the glass at night. If you choose interior

SELECTIVE SURFACE FOILS AND PAINTS ON THERMAL STORAGE WALLS

Some builders apply a special dark-colored paint or adhesive foil known as a *selective surface foil* to the exterior (sun-facing) side of thermal storage walls. Selective surfaces absorb solar radiation just like any black surface, but reduce the infrared emittance (heat radiation), thereby greatly reducing heat loss from the exterior surface of the mass wall. A high-quality selective surface performs similar to R-9 moveable insulation, but requires no operator involvement. However, because selective surfaces may not be aesthetically appealing, it is best to hide them with high-transmittance translucent glass instead of clear glass.

AUTOMATIC VS. MANUAL SHADING

Thermostatically controlled, motor-driven interior shades are generally most acceptable to the homeowner, but manually operated interior shades are generally less expensive, with fewer maintenance problems.

The Passive Solar Design and Construction Handbook, Steven Winter Associates

TO VENT OR NOT TO VENT?

Venting a thermal storage wall increases daytime heating and reduces the amount of heat available at night. In colder climates, when daytime heating is required, designers recommend venting a mass wall—that is, robbing some of the heat that forms in the airspace between the glass and the mass wall to heat adjacent rooms. In milder climates, this is generally not necessary, though you may want to install vents just in case. They can always be closed off.

insulation, you will need a more sophisticated system. Be sure that internal insulation does not interfere with the workings of the thermal storage wall.

Region-Specific Design of Thermal Storage Walls

The design features of a thermal storage wall, like other systems, depend in large part on the heating requirements and available sunlight. Sunny and mild climates are less demanding than cloudy and cold ones.

Mild Climates. In mild climates, a thermal storage wall should work well with single-pane glass, provided it has sufficient overhang to protect it from off-season heating. The thermal storage wall, however, serves primarily as a nighttime heat source via delayed solar gain. If daytime heating is desired, you may want to install a window or two in the wall (for direct gain) or vents to draw warm air into the room, as described above.

Moderate Climates. As winter heating requirements escalate, some modifications can be made to a house and a thermal storage wall system to optimize their performance. Closer orientation to true south increases heat output, as does double-pane glass with a high R-value (low U-value). As in mild climates, installing windows in a thermal storage wall or elsewhere on the south wall provides more immediate solar gain. Installing vents in the wall also provides daytime heat. However, as with many other design features, there's a tradeoff: venting decreases the amount of heat that is available at night. When asked about his preference, Ron Judkoff of the Natural Renewable Energy Laboratory emphatically sided with the direct-gain approach. His advice: "Design non-circulating (unvented) thermal storage walls instead of circulating (vented) TSWs. Install windows for direct gain."

In cold climates, insulation may also be required to reduce heat loss from the wall at night or during cloudy periods.

Moderate-Severe to Severe Climates. In still colder climates, thermal storage walls may require further modifications: even closer orientation to true south, low-U-value glass, installation of windows for immediate gain, and use of circulating fans. Selective surfaces create better thermal transfer. Builders should pay even more careful attention to reducing conduction losses and sealing air leaks, and care should be taken when applying interior finishes on the wall to permit maximum heat transfer into adjacent rooms.

External insulation to cover the glass at night is also highly desirable. Further gains can be made if the insulation panels are reflective. Insulated reflector panels may lie on the ground during the day or can rest on a wooden support structure. They should be tilted about 5° away from the house to permit water or melting snow to drain away from the foundation. When opened during the day, insulated reflector panels direct more light onto the thermal storage wall and can increase the heat gain by up to 30 or 40 percent. Reflective panels increase solar gain in situations in which thermal storage walls are shaded by trees. For those dedicated to achieving maximum self-sufficiency, they are highly recommended.

In more severe climates, designers can also increase the size (dimensions) of the thermal storage wall. As a general rule, the farther north the building is, or the colder the climate, the larger the thermal storage system should be. Table 3-4 provides helpful sizing information. To see how this table is used, let's assume you live at 48° north latitude and that the average outdoor temperature in January is 30°F. Go to the far right column, find 48° north latitude, then drop down to the third row. This number 0.70 is the ratio of masonry wall to floor area—that is, how large a mass wall should be in relation to the heated floor space. If the room is 400 square feet, you'll need 280 square feet of thermal storage wall (400 × 0.7 = 280). If average temperature and latitude are not shown on the table, you can interpolate—that is, find the value between measurements given on the table or use the closest one you can find.

Early in the development of thermal storage walls, reverse air flow in thermal storage walls caused many people to criticize them as inadequate. But as noted in the text, the problem can be easily remedied by installing backdraft dampers or operable louvers.

The Pros and Cons of Thermal Storage Walls

Like other passive solar design elements, thermal storage walls have their advantages and disadvantages.

On the positive side, thermal storage walls have the widest applicability. They can be used in mild to severe climates. They can even be used to passively cool homes, as explained in chapter 6. Secondly, thermal storage walls greatly reduce sun drenching, thereby lessening glare and damage to carpets, upholstery, and plants, which can be quite significant in direct-gain designs. Consequently, thermal storage walls are great for home offices, and reading or television rooms. I also recommend them for bedrooms, especially for those looking for a design that ensures a dark room at night.

TABLE 3-4. Sizing a Thermal Storage Wall

AVERAGE WINTER OUTDOOR TEMPERATURE (Clear day)*	RATIO OF MASONRY WALL TO FLOOR AREA 36°NL	40°NL	44°NL	48°NL
Cold Climates				
20°F	0.71	0.75	0.85	0.98 (with night insulation)
25°F	0.59	0.63	0.75	0.84 (with night insulation)
30°F	0.50	0.53	0.60	0.70
Temperate Climates				
35°F	0.40	0.43	0.50	0.70
40°F	0.32	0.35	0.40	0.44
45°F	0.25	0.26	0.30	0.33

* Temperatures listed are for December and January, usually the coldest months.

Source : Steven Winter Associates, *The Passive Solar Design and Construction Handbook*

Thermal storage walls work best when nighttime heating is the primary goal. However, as noted above, they are also quite adaptable. By installing vents and windows for direct gain they can be modified to contribute to daytime heat demand as well.

Another advantage of thermal storage walls is that they provide mass in a relatively concentrated area, taking up a minimal amount of living space. And they provide great comfort. Rooms tend to be thermally stable and quiet. Finally, thermal storage walls are aesthetically appealing, externally and internally.

Early in the development of thermal storage walls, reverse air flow in thermal storage walls caused many people to criticize them as inadequate. But as noted in the text, the problem can be easily remedied by installing backdraft dampers or operable louvers.

On the downside, thermal storage walls may add to the cost of construction, primarily by increasing the size of the foundation required to support the additional mass.

Thermal storage walls reduce daylight and access to views. Heat loss can be quite significant at night unless the exterior surface of the structure is insulated. Covering a wall each night and closing off the vents require additional effort on the part of the homeowner. Placing rigid external insulation over the glass, for example, requires the homeowner to venture outside on cold winter nights.

If you want to learn additional technical details about thermal storage walls, I recommend *The Passive Solar Design and Construction Handbook* by Steven Winter Associates. It provides numerous sketches of wall sections, showing various construction details.

ATTACHED SUNSPACES: ISOLATED-GAIN SOLAR SYSTEMS

Isolated-gain solar designs, or more commonly, attached sunspaces, are used in a wide variety of climates, ranging from moderate to severe. As its name implies, an attached sunspace is a passive solar structure attached to the south side of a house (figure 3-25). Attached sunspaces can be used alone or in conjunction with direct-gain and indirect-gain systems and often do double duty—that is, they produce heat and provide additional living space, although careful attention to detail is required to obtain this sometimes elusive benefit. In other instances, they are designed to gain heat and serve as growing areas, hence the name solar greenhouses or attached greenhouses.

In an attached sunspace, sunlight penetrating south-facing and (in some cases) roof glass is converted to heat after being absorbed by interior surfaces.

FIGURE 3-25
Attached sunspaces are an attractive solar design feature and are ideal for solar retrofits, but they are also fraught with problems. Be careful.