Home Sweet Solar Home

A Passive Solar Design Primer

Ken Olson & Joe Schwartz

Photo courtesy of www.sunplans.com

A modern passive solar home can compete with the Jones' for style, *and* make them envious of its energy and fiscal efficiency.

Home dwellers in the United States spent US$138 billion on energy for their residences in the year 2000. As an average home dweller, your share of that energy pie was US$1,300. Heating and cooling typically account for more than 40 percent of the energy consumed in a given home, or US$520 worth each year. The good news is that passive solar design can offset the majority of the energy (and money!) you spend heating and cooling your home.

Passive solar design has come a long way from the tilted windows, water walls, and roof ponds of the 1970s. Today's passive solar house has more in common with conventional residential structures than not. Modern designs create living spaces that are bright, attractive, comfortable, and inexpensive to heat and cool.

Passive solar construction may add less than 5 percent to the cost of building a new home. Any additional cost typically yields a 15 to 20 percent tax-free return on investment through energy savings. Most homes built today will likely still be occupied 50 to 100 years from now. Good design results in huge energy and resource savings over the life of the building. So why isn't everyone incorporating passive solar design into new construction? Why isn't it required by local building codes? Good questions!

A passive solar energy system is designed to collect, store, and distribute solar energy without the aid of mechanical or electrical devices. There you go—a definition suitable for any glossary. But passive solar design isn't about a definition. It's about a better life—any way you measure it. Passive solar design uses sunlight to create energy efficient living and work spaces that are a pleasure to be in, and minimizes the use of fossil fuels and associated pollution. To top it all off, the principles of passive solar design are easy to grasp and implement in new construction.

Design Basics

Passive solar design is based on the following five principles that optimize the use of solar energy for heating and cooling your living space:

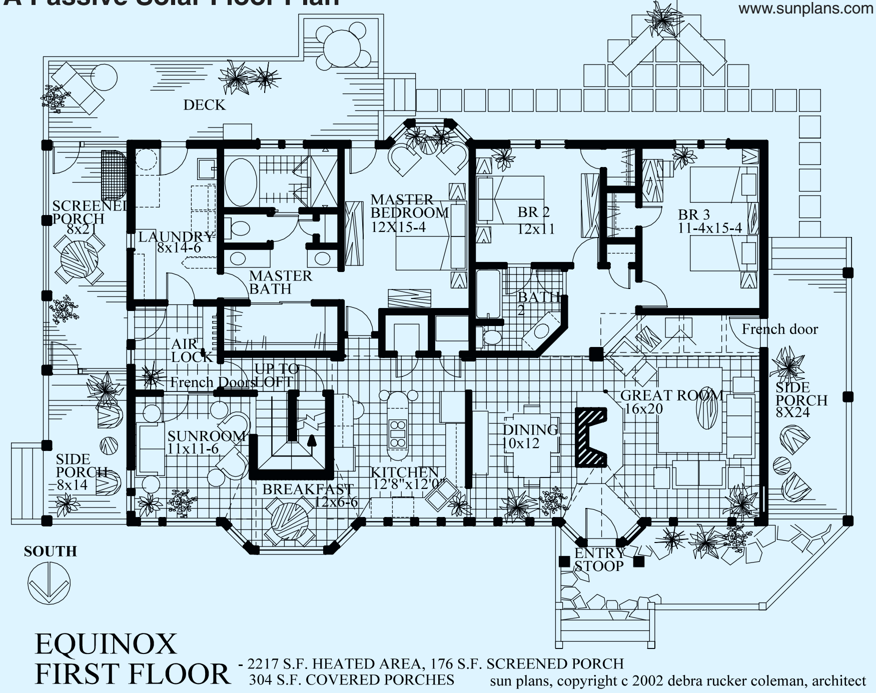
- Building orientation towards true south (in the northern hemisphere)
- Properly placed, energy efficient windows
- Calculated roof overhangs
- Thermal mass for energy storage
- Thermal efficiency and insulation

Passive solar design uses south-facing windows to bring the sun's energy into your home. Thermal mass, such as a tiled, concrete floor, stores the heat and minimizes temperature fluctuations inside the building. Ample insulation conserves energy for both heating and cooling. That's the concept—plain and simple.

In the winter, when the sun's path is lower in the sky, calculated roof overhangs let the sun shine directly into the building and warm the slab. The happy coincidence is that the sun's path is higher overhead in the summer, and these same overhangs shade the windows then, keeping the sun out and your home nice and cool.

A Passive Solar Floor Plan

Image courtesy of www.sunplans.com



Passive solar heating and cooling designs are easy and inexpensive to incorporate into new buildings, but can be difficult to retrofit into existing structures. This is because many passive solar design elements and materials are integral to the home. This article focuses on new home design and construction.

Face the Sun—Building Orientation

Step one in passive solar design is to simply orient the building toward the sun. This is a "no added cost" element of passive solar design. Orientation toward true south (magnetic south adjusted for declination) or true north if you live in the southern hemisphere, allows your home to capture as much solar energy as possible. Elongating the building's east-west dimension allows direct solar energy to reach more of the building interior compared to a structure that has a deeper north-south dimension.

Fortunately, we have some room to play with orientation. A building orientation 20 degrees east or west of true south will only lose about 6 percent of the solar gain possible. This minor design penalty gives you some room to accommodate other factors, like the view, into the design of your home. For comparison, orientations 25 degrees off true south will lose about 10 percent—a more significant loss, but still worthwhile if that is the best you can do with your site.

Since you're reading *Home Power,* you may be planning to install solar-electric or thermal panels on the roof of your new home. If this is the case (and we hope it is!) the closer to true south you can orient your house, the more energy these systems will produce, and the more cost effective they will be.

Room layout is important too. Open floor plans passively distribute both warm and cool air throughout the building. Living spaces like kitchens, living rooms, and dining rooms are best located along the south, east, and west sides of the house. Place bedrooms, bathrooms, storage closets, laundry rooms, hallways, and other less used spaces along the north. The west side of the house is a prime location for a covered porch. The porch roof will shade any windows on this side of the house, keeping out unwanted afternoon sun. It will also double as an excellent place to sit and watch the sunset.

Passive solar design creates open, well-lit, and temperate indoor environments that are comfortable to be in. And it's interesting to note that these same open floor plans are now commonly used in conventional home designs. Passive solar homes fit right in with today's architectural styles.

Windows—Location, Location, Location

Windows are the solar collectors of a passive solar building. But windows also have low insulative values, compared to well-insulated walls. In a typical American home, 25 percent of the energy used to heat and cool the house goes—you guessed it—right out the window. Even energy efficient windows are responsible for the majority of heat loss from a well-sealed building envelope. Because of this, passive solar design optimizes the amount of south-facing windows to collect solar energy, and minimizes the use of nonsouth-oriented windows to limit heat loss. Window placement is another “no additional cost” principle of passive solar design. The materials are the same as the ones used in conventional, energy efficient construction.

South-facing windows provide the greatest amount of solar heat over the course of the day. Southeast or limited east-facing windows allow for a quick heat-up, and provide a pleasant light in which to sip coffee or tea during the “up and at ’em” process.

West and southwest-facing windows should be kept to a minimum. They tend to cause overheating since they allow low-angle sunlight to enter the house in the afternoon when the house is already up to temperature. North-facing windows should be kept to the minimum needed for light and ventilation. They’re the hands-down energy loser of the four compass directions.

In the 1970s, many passive solar designs specified south-facing windows that were tilted to the latitude of the building site. Solar collectors (PVs, thermal panels, or windows in this case) capture the greatest amount of energy when oriented perpendicular to the sun. Nowadays, tilted glass surfaces are not recommended for living spaces because they make it more difficult to control direct solar gain with the changing seasons.

It’s much easier to control seasonal shading on a vertical wall. Properly calculated roof overhangs are built once and don’t have to be operated on a daily basis, like window shades. It’s a hands-off approach. So keep your windows vertical and let the building do the work!

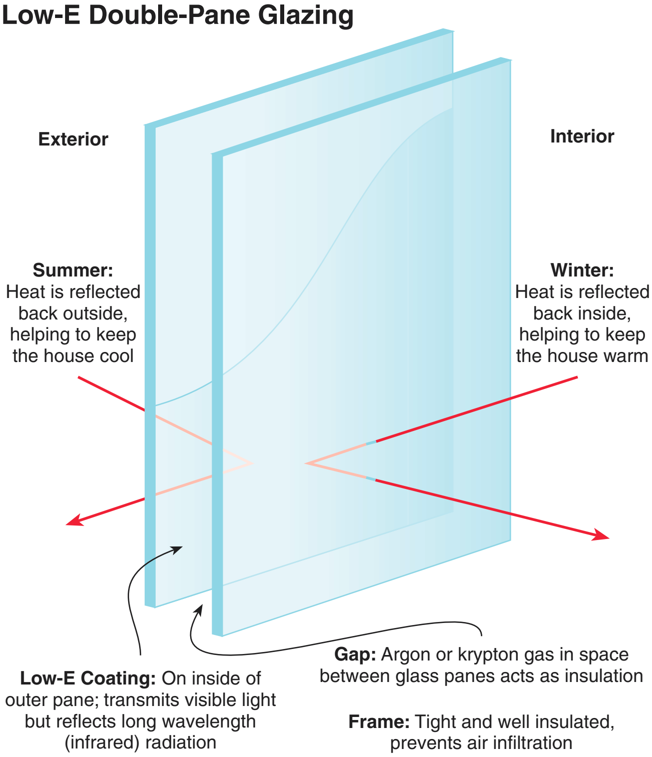
A conventional house has its windows evenly distributed in each of the four compass directions. South-facing windows typically have an area equal to approximately 3 percent of the total floor area of the house. In a passive solar house, south-facing window area is increased to a range of 7 to 12 percent of the floor area depending on the amount of thermal mass that’s integrated into the design. Higher percentages than this will likely result in overheating during the day and adds cost to the wall’s structural design and construction. Too much glass also results in greater heat loss at night.

Remember, compared to well-insulated walls, even windows with high insulative values are pretty much “big holes in the wall” when it comes to thermal efficiency. In fact, the most common mistake made in passive solar home designs is too much glass. High temperature swings and high heating and cooling bills characterize these designs. It’s a real life example of a case where “more is not better.”

High Performance Windows

High performance, energy efficient windows also make a big difference. An ideal window maximizes solar heat gain in winter and minimizes solar heat gain in summer.

Low-E Double-Pane Glazing

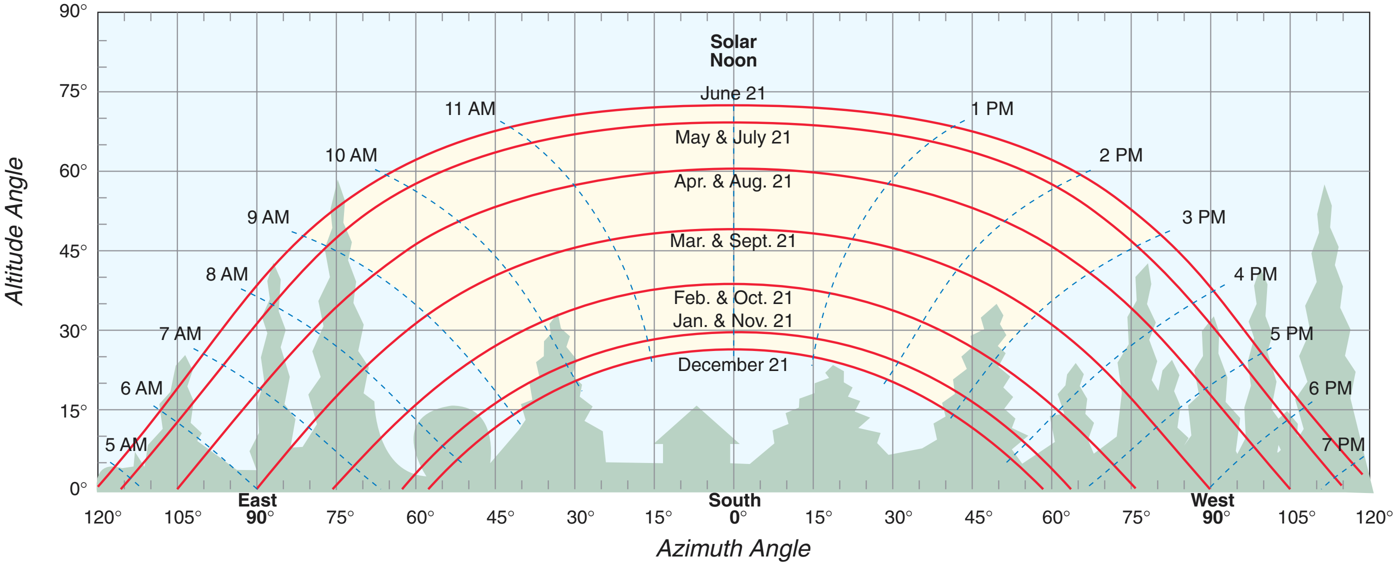


The window may also need to maximize or minimize light transmittance, depending on its use. The good news is that super smart windows are available in the builder’s market these days. And compared to standard, double-pane windows, high performance windows only add a small percentage to the total cost of an average-sized home.

Modern window designs demonstrate an understanding of the dynamics of conduction, convection, and radiation well enough to be nearly ten times more efficient than single-pane windows. The rate of heat loss of a given window is referred to as its U-value (BTUs per hour per square foot per degree Fahrenheit). For heating purposes, the lower the U-value, the better. In northern climates, select windows with U-values of 0.35 or below. Some triple-pane windows have U-values as low as 0.15. In southern climates, select windows with U-values 0.60 or less. For comparison, single-pane windows with clear glass have a U-value of about 1.0 depending on the frame material.

Early versions of modern window technology were referred to as transparent insulation, and so they are. Low emittance glass surfaces, often referred to as “low-E,” optimize the effects of radiation. Low-E is part of a family of spectrally selective surfaces. This means that they are highly transparent in the visible region of the light spectrum, yet they are nearly opaque to the longer wave, infrared end of the electromagnetic spectrum. We

Sun Path Chart for 40° North Latitude



To use this chart for southern latitudes, reverse horizontal axis (east/west & AM/PM)

can't see the infrared, but we can feel it. Warm interior surfaces of your house emit low temperature, infrared radiation toward every colder surface they see. Low-E glass functions like a mirror to reflect infrared radiation back into the house rather than allowing it to escape.

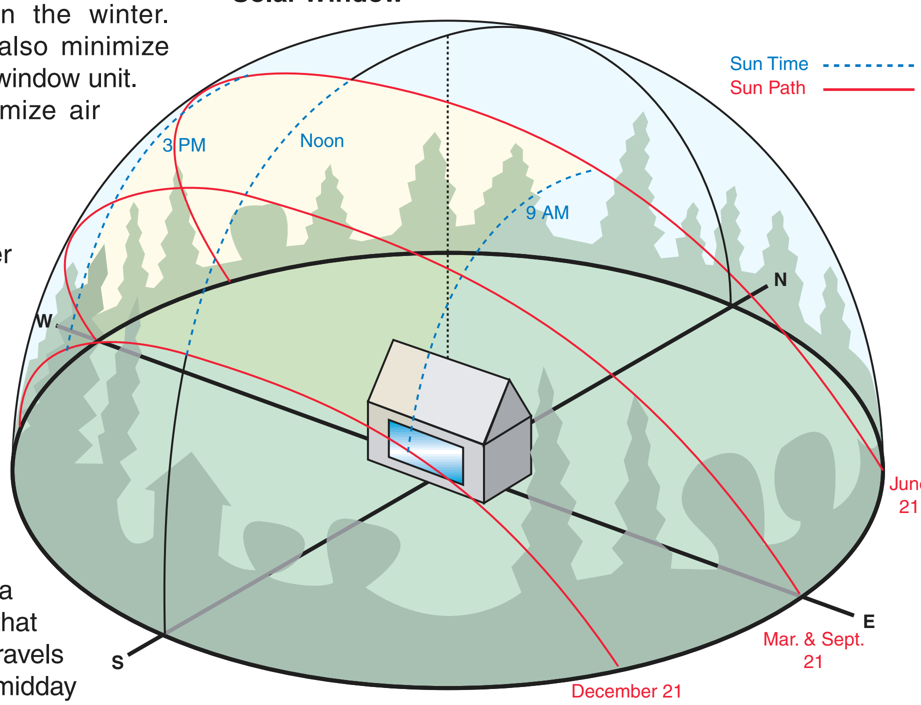
Air spaces between panes of glass reduce summer heat gain as well as winter heat loss. Multiple layers of glass create air spaces that act as insulation. To effectively eliminate the convective air flow within an air space, manufacturers use heavy gases, such as argon or krypton. The result is a window that keeps your home cooler in the summer and warmer in the winter. Insulated frames and thermal breaks also minimize conductive heat loss and gain through a window unit. Tight seals on operable windows minimize air infiltration.

The Solar Window & Calculated Roof Overhangs

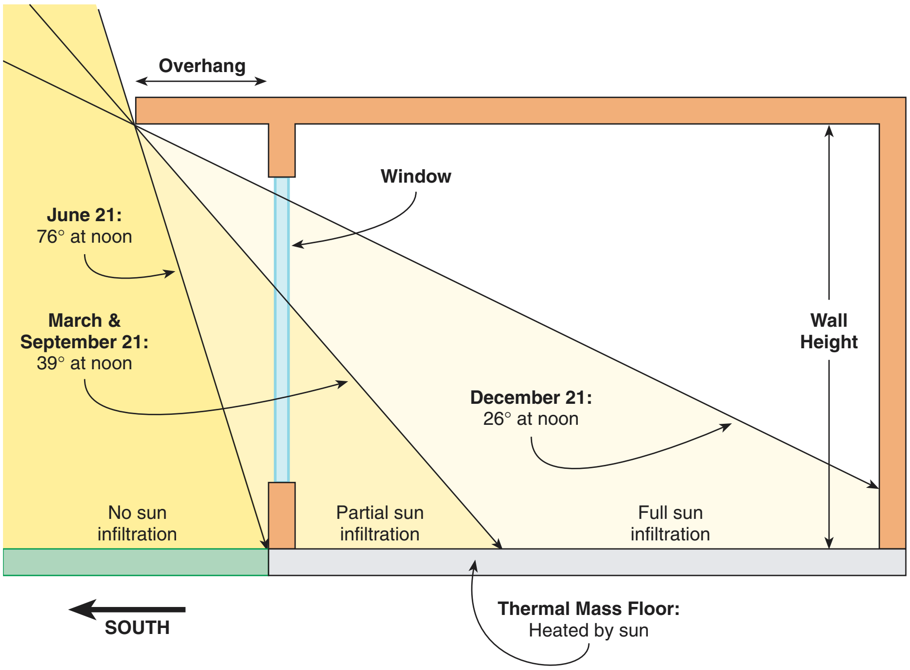
In passive solar design, as well as other solar thermal technologies, the amount of shading you receive during the day results in a corresponding reduction of heating. Midday sun is more intense than early morning or late afternoon sun. So that is your most valuable resource if you are heating, and your enemy if you are cooling.

The concept of a "solar window" identifies the available hours of sun in a location, and any areas or times of day that your home will be shaded. Because it travels through less of the earth's atmosphere, midday sun is more intense than early morning or late afternoon sun. Direct solar gain between 9 AM and 3 PM is your most valuable resource if you are heating, and your enemy if you are cooling. The bottom side of the solar window is defined by the sun's path on December 21st (in the northern hemisphere). The left and right sides of the solar window are defined by 9 AM and 3 PM in each month of the year. The top of the solar window is defined by the sun's path on the longest day of the year—June 21st.

Solar Window



Example Roof Overhang for 40° North Latitude



An effective passive solar home design makes use of the same concept. The notable difference is that, depending on the climate in which you live, you may need to adjust the top side of the solar window downward to block the sun from striking your windows in the months when heating is unwanted, and cooling is the name of the game. In passive solar design, shading windows in summer, late spring, and early fall is taken care of by building appropriately sized roof overhangs.

The optimum size of the roof overhang varies with latitude and window height. A simple approach for calculating roof overhangs is to make a scale drawing of the cross-section of the house (looking east or west), that details the south window height dimension relative to the floor. By adding the noon sun angle at various times of the year, the width of the overhang can be easily determined.

Information on sun angles at different latitudes is provided in the classic, but long out-of-print *Passive Solar Energy Book,* by Ed Mazria. For those of you with Web access, the folks at Sustainable By Design in Seattle, Washington, have a great Web site with calculators for sun angles, sun position, window overhang design, and window heat gain. Check them out at: www.susdesign.com.

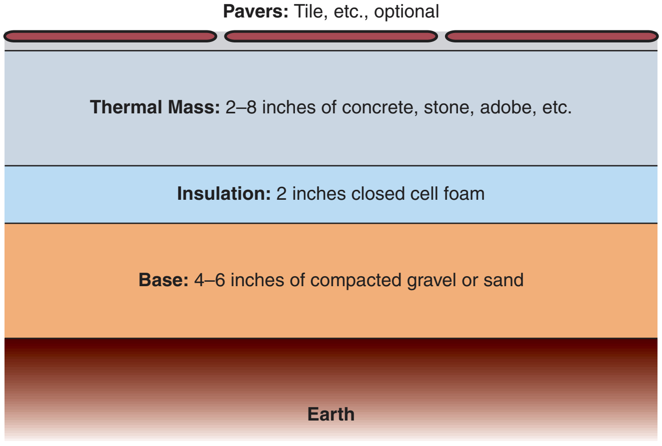
Other helpful resources include two building design software packages that take all aspects of heat gain and heat loss into account. *Guidelines for Home Building* is a great book that comes with a software program called *Builder Guide.* The book and software package present clear concepts and guidelines suitable for owner builders at a cost of US$100. Building design professionals will be interested in a publication and software package entitled, *Designing Low-Energy Buildings with ENERGY-10* at US$250. (See Access.)

Thermal Mass

Thermal mass is a general term for any material that can absorb large amounts heat. Mass within a building acts as a thermal flywheel. It stabilizes indoor temperatures. Heat it up—it stays warm; cool it off—it stays cool. The degree to which a building can be solar heated depends upon its ability to store heat for times when there is no sun. Its mass slowly absorbs heat like a sponge soaks up water, and then releases the heat slowly for winter warmth. The same mass, shaded from the sun, will help keep your home cool during the summer months. The slab will help keep the building cooler if you have a ventilation strategy that cools the slab down overnight.

Although every building already has a minimal amount of thermal mass in its structure, drywall, and furnishings, its ability to store excess heat delivered through south-facing windows is limited. If you want to achieve a higher percentage of heat from the sun, you will have to add substantially more thermal mass. Concrete, brick, tile, adobe, and other masonry materials are the most common choices for thermal mass in a building.

Thermal Mass Floor



How Does Heat Move?

Heat always moves from hot to cold. Conduction, convection, radiation, and evaporation are the four ways heat is gained and lost. The end product of any design will be the combined effect of these four phenomena.

Conduction
Conduction is the transfer of thermal energy between objects in direct contact. If you hold a metal poker in a fire, the heat will pass from the hot end (in the fire) to the cold end (in your hand). The molecules of the metal are in contact with each other and pass heat, always from hot to cold, by virtue of conduction.

Metals are excellent conductors of heat energy because their molecules are so close. Other materials such as wood or plastics are poor conductors because their molecules have spaces between them. Poor conductors are good insulators.

Conduction in a building's structure occurs through walls, windows, roof, floor, etc. If we want to minimize the rate of heat transfer from one side of the wall to the other, we use materials that are good insulators. Insulative properties are rated with what is called an R-value. R stands for resistance. The greater the R-value, the better the insulation.

Convection
Convection is energy transfer between any surface and a fluid medium, such as moving air or water. The movement of air or water across the surface of a solid accelerates the transfer of heat—once again always from hot to cold.

A cold wind will accelerate heat loss because the cold air removes heat from the outside surfaces of your home. A more subtle example occurs within your home, particularly at the surface of windows, which become cold because of their low, conductive R-value.

Put your hand near the glass on a cold day and you will feel a cold draft as the indoor air in contact with the cold glass surface becomes cooler. As the air cools, it becomes more dense and it sinks. This descending draft pulls warm air from near the ceiling toward the window, where it cools at the surface of the window and feeds the draft. If you live in a hot climate, you will experience the very same phenomenon, except that everything will work in reverse.

Radiation
Radiation is energy transported by electromagnetic waves. Unlike conduction and convection, radiation requires neither contact nor the presence of moving air or water. Its only requirement is that surfaces exchanging heat can "see" each other. Once again, the warmer surfaces always radiate to the cooler surfaces. The heating comfort you receive from a fire is 100 percent radiant. Conversely, you don't have to be a rocket scientist to search for shade on a hot, sunny day in Tucson, Arizona. Shade immediately eliminates the radiant heat coming directly from the sun.

Radiation is how the sun's energy is delivered to us every day. At night, the earth's surface is warmer than the deep sky temperature, particularly in arid climates with clear skies, and the radiation serves to cool all surfaces that see the sky. In fact, these surfaces can become colder than the ambient air temperature under clear night skies.

In building design, you may want to maximize or minimize the radiant effect, depending upon the climate and the application. Rooftop surfaces in Phoenix, Miami, or Houston are better off being highly reflective or light in color. Sunbathed floors, walls, and roofs in cooler climates are better off in darker earth tones.

Evaporation
Relative humidity and air movement contribute to comfort, or discomfort. Everyone who lives in a hot climate knows that a fan keeps the comfort level bearable on a hot, humid day. A fan is forced convection that passes air over the surface of your skin to help remove heat and moisture. As moisture evaporates from liquid to vapor, it absorbs heat from your body. It is easier to keep cool in hot, dry climates than it is in hot, humid climates, because the evaporative effect is so much stronger when the air is dry. Evaporative coolers are popular in hot, dry climates, and dehumidifiers are popular in humid climates.

Conversely, maintaining a higher level of relative humidity indoors is wise in a cold climate. As cold, dry air infiltrates your home in winter and your heating system increases the temperature, the relative humidity of the air drops. Relative humidity is a measure of how much moisture is contained in the air relative to how much the air can hold when saturated. The lower the relative humidity of the air, the easier it is to evaporate moisture from your skin. This is why humidifiers are popular in cold winter climates.

Thermal mass can be incorporated into ceilings and walls, but the most cost effective location for thermal mass in a residential structure is a floor that receives direct sun. Mass that is not illuminated by the sun absorbs heat mostly by convection from the warm air in the space, and provides much less benefit in terms of heating.

A slab thickness of 2 inches (5 cm) is sufficient to absorb and release heat on a daily basis. Some passive solar designers are after a rapid response or quick warm-up of the slab on a daily basis. Thin, 2 to 3 inch (5–7.6 cm) slabs lend themselves to this. Compared to thicker slabs, they are less expensive, and can be poured over wood-framed floor systems, designed to handle the added weight of the concrete.

But additional mass provides heat storage that can last through several days of cloudy weather. A 6 to 8 inch (15–20 cm) slab is optimal in most applications, providing it receives direct solar gain over the majority of its surface during the heating season. The increased mass of a thicker slab raises the average minimum room temperature, compared to a thinner slab. It also lowers the average maximum room temperature. This limits daytime overheating and reduces the need for nighttime cooling. Thicker slabs also help keep the building cool during the summer. Slabs thicker than 8 inches provide little additional benefit in most applications.

Two inches (5 cm) of high density, closed cell, rigid foam should be laid under the slab and around the perimeter. This approach thermally isolates the slab from outdoor and ground temperature swings.

The color of thermal mass is another important aspect of passive solar design. When exposed to sunlight, earth tones and dark-colored objects absorb heat more easily than light-colored objects. Extremely dark surfaces, however, may become too hot for bare feet. Also, carpets covering the mass floor should be kept to a minimum. A small throw rug here or there is not a problem. But covering the floor with carpet will insulate the slab and radically decrease its ability to absorb and release heat.

Thermal Efficiency—A Mantra

Just as energy efficiency is the most important step for solar-electric systems, it should not be any surprise that energy efficiency is also vital to any successful passive solar building project. This mantra is to be repeated over and over—the less energy you consume or waste, the less you need to produce. Remember that efficiency is the only energy resource that is 100 percent efficient, and it is almost always the most economical investment. Thermal efficiency has three main applications in passive solar design: windows (discussed earlier), insulation, and a tight building envelope.

The most cost effective investment you can make to improve the thermal efficiency of your home is insulation. It not only helps keep your house warm in the winter; it helps keep it cool in the summer. And when it comes to insulation, more is almost always better. General insulation guidelines for efficient passive solar homes are R-30 walls and R-60 roofs in temperate climates, and R-40 walls and R-80 roofs in extremely cold or hot climates.

Air leakage causes the single greatest loss of energy in most homes. You want to minimize air leakage in the building envelope that surrounds your indoor space. Caulk the trim around windows and doors on the inside and outside, install and adjust the weatherstripping around the operable surfaces of doors and windows, use expanding foam to seal all the penetrations the plumbers and electricians made, and use sill seal between the wall's bottom plate and the foundation. As you build, make sure you take care of those air leaks all the way through the construction process. It will never be easier or more effective.

Note that airtight building envelopes can be a potential hazard to your health. Fresh air—free of dust, spores, bacteria, and any chemicals that may off-gas from

Common Mistakes

- Trying to heat too large or inefficient spaces. Passive solar works better in smaller buildings, such as residences, and where the building envelope design controls the energy demand.
- Overheating as a result of excessive glazing. In hot climates, buildings having large glass areas with direct solar gain may overheat.
- Failing to minimize southwest and west-facing windows, and not sizing shading devices properly.
- Providing inadequate quantities of thermal mass for the amount of direct gain glazing. In passive solar heated buildings with high solar contributions, it can be difficult to provide adequate quantities of effective thermal mass.
- Having too much sun glare. Room and furniture layout needs to be planned to avoid glare from the sun on equipment, such as computers and televisions.

paints, petroleum-based carpets, and furniture upholstery—is important to human well-being.

Mechanical ventilation may be desirable or even necessary to ensure adequate indoor air quality. Ventilation systems bring fresh air into living spaces and exhaust it from bathrooms, kitchens, and laundry rooms where moisture and less desirable air are more concentrated. Super-insulated homes can also use an air-to-air heat exchanger to retrieve the heat content of exhaust air.

Other Design Considerations

In addition to cutting your energy costs for heating and cooling, passive solar home design may integrate daylighting and passive ventilation. Daylighting design uses natural sunlight to supplement and minimize the use of electric lights during the day. When designing your home, pay attention to window location in relation to where light is needed—a window over the kitchen sink, a desk, your favorite reading chair, and in the bathroom can be helpful. Properly positioned skylights or light tubes can be a great source of daylighting as well. Light-colored walls help to distribute light throughout the house.

Passive ventilation optimizes natural air flow by convection and can be used to distribute warm, cool, or fresh air throughout the house. Doors and operable windows and skylights can provide the majority of air transfer in a passive solar house with a tight building envelope. Windows located on opposite walls will create cross-ventilation and maximize air movement.

During warm months, the common practice of shutting windows and doors during the daytime keeps unwanted heat out. In the evening, opening the windows and doors brings in cool, nighttime air that helps cool the thermal mass. In the morning, the windows and doors are shut again and the chilled out mass helps to keep the building cool during the day.

In a home with a tight building envelope, it's amazing how few windows or doors need to be opened to create a whole house draft that cools the house overnight. Open floor plans help this process, as well. This draft effect can be increased by the inclusion of skylights or second stories with an open stairway between floors. Hot air rises. So opening a first floor window and a second floor window or skylight creates a chimney effect that pushes and pulls the warm air out of the building.

Reaping the Harvest

By now you have grasped the fundamental concepts of passive solar design for heating and cooling. The five principles are: building orientation towards true south, properly placed energy efficient windows, calculated roof overhangs, thermal energy storage, and thermal efficiency. Future issues of *Home Power* magazine will detail some successful passive designs, and delve deeper into the concepts introduced in this article.

Conventional home building is responsible for a large percentage of our culture's energy excesses. But it has been undergoing a quiet revolution. Not everywhere or fast enough of course—but you can claim another victory for the revolution just by letting the sun into your home. Thanks to the passive solar pioneers of the 1960s, '70s and '80s, the mistakes have already been made for us, and the successful strategies have been refined. The guidelines presented in this article were generated over the course of several decades of bold front yard experiments, common sense technology, passionate professionalism, and lessons learned and freely shared. Considering that a building built today will last 50 to 100 years, you can be sure that your investment in passive solar will continue to pay off well beyond your mortgage—and your lifetime.

Access

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Design tools and consulting

Guidelines for Home Building and *Designing Low-Energy Buildings With ENERGY-10,* book and software packages, US$100 and US$250 respectively, available from Sustainable Buildings Industry Council (SBIC), 1331 H St. NW, Ste. 1000, Washington, DC 20005
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"Build Better Buildings" PDF available at:
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