Sun-Wise Design:

Avoiding Passive Solar Design Blunders

Dan Chiras, (Adapted from *The Solar House: Passive Heating and Cooling*)

Building or buying a home is a long-term financial commitment. Good passive solar design offers big payoffs in thermal comfort, energy efficiency, and conservation, with miniscule monetary commitment. Poor design has the opposite effect—it can obligate a homeowner to unnecessarily high energy bills and living in an uncomfortable house. The same holds for environmental performance. Over a structure's lifetime, well-designed buildings have less impact on the environment, while poor design results in a lifetime of high energy use and resource consumption.

Although solar designs have improved, an awareness of the lessons learned from the past is vital to the future of passive solar heating and cooling. By understanding the common problems, builders, architects, and designers can work diligently to avoid them—either in building new homes or when retrofitting existing ones.

Lessons Learned—The Hard Way

In the late 1970s, I purchased my first home, an attractive bungalow built in 1925. It wasn't a passive solar structure, but it had good southern exposure. Soon after moving in, I started to work on the house. I purchased solar collectors to heat domestic hot water. I removed some rather large, leaky north-facing windows, beefed up the attic insulation, and sealed air leaks. Next, I attached a small sunspace on the home's south side, my first attempt at passive solar heating. I based the design not on science and solar engineering, but on pure speculation.

Not surprisingly, the sunspace failed miserably. The reason? It was far too modest to meet my home's heating requirements. It did provide some warm air, but not enough to noticeably affect the home's temperature. Had I known more, I would have constructed a space commensurate to the home's square footage and installed a system to move air out of the sunspace that was more sophisticated than a portable fan.

Many other people experimented with passive solar heating in the 1970s and 1980s. Venturing boldly into the field, many of us designed intuitively. What could be so difficult about passive solar design? You concentrate windows on the south side of a house, provide overhangs for summer shade, insulate well, and then sit back and bask in the benefits of your labor. Trouble is, good passive solar heating design requires more than intuition—it requires understanding the concepts of orienting a home properly, balancing glazing and thermal mass, and allowing for good insulation and ventilation.

Blunder #1, Improper Orientation

A few years ago, a friend of mine called to ask if I'd assess a passive solar home she was considering buying. As we drove up to the house under question, my first impression was quite favorable. The house was on a nice, clear lot—no trees or hills obstructed the low-angled winter sun—and was built with a large thermal storage wall (also known as a Trombe wall). However, on the morning of that sunny September day, the owner revealed that he had started a fire in the woodstove to raise room temperature from a chilly 60°F (16°C). I was baffled. My own passive solar home was performing quite well, despite the frosty nights. Standing alongside the house, my puzzlement cleared when I realized that the thermal storage wall was on the *west* side of the house. The south side was an ordinary wood-frame wall without a single window for solar gain! Had the architect's compass been off?

The first and most important element in passive solar design is proper orientation. Ideally, a passive solar home should be oriented toward true south, exposing the greatest surface area and window space to the low-angled winter sun. The long axis of the home should run east and west. (Note that true south is not the same as magnetic south. In many regions of the country, magnetic north and south deviate significantly from true north and south.)

Bob was sure glad that he had a fireplace, because his fancy solar home never seemed to perform quite as he had hoped.

Blunder #2, Excess Shading

Ensuring that a home's south face can access sunlight is as critical as correct orientation. One of the most common problems is that people build their homes, and then plant trees on the south side. Some even plant evergreens. When they're small, the trees don't contribute much shade, but as they mature, they begin to reduce solar gain significantly.

Deciduous trees along a home's south side are less problematic than evergreens, because most lose their leaves in the fall and remain leafless throughout the wintertime. Some trees, like oaks, are not so cooperative—they tend to retain their leaves, shading throughout the fall and winter. But even leafless trees can block solar access. Limbs, branches, and tree trunks can produce wintertime shading levels between 25 and 50 percent. For maximum solar gain, keep the southern exposure tree-free.

South-facing windows collect no heat if the sunlight can't get to them.

Blunder #3, Overglazing

A local contractor who had grand ideas of helping reduce home energy use built my second home. I was especially excited about this house because it employed three different passive solar design features: direct gain, where south-facing glass admits the low-angled winter sun into a home's interior; an attached sunspace; and a thermal storage wall. The builder had oriented it properly, insulated well, and provided adequate mass, or so we thought. Additionally, the house had great solar exposure. The south-facing windows were exposed to the sun from 10 AM to 3 PM each day.

As well-thought-out as this home was, though, we soon discovered that the house had some fatal flaws. The builder had installed five large skylights, four of which were on the south-facing roof, and two large sliding glass doors in the west wall. In the summer, the skylights and west-facing sliders admitted an enormous amount of sunlight and heat, baking the house almost all day long.

In the winter, excess sunlight entering the house through skylights and south-facing glass and inadequate, poorly situated mass caused temperatures to rise into the mid-80s (29°C). I often walked around in shorts and a T-shirt during the dead of winter, and still felt as if I was about to spontaneously combust. The air inside the house was unbearably hot and dry.

The builder's overglazing zeal had more impacts on the house—the sliding glass doors were inexpensive models that leaked excessively during the winter, so at night they produced a bone-chilling draft. My wife and I installed a layer of Plexiglas magnetically attached to the door trim and a Warm Window insulated curtain to reduce this problem—at a cost of about US$400 for each slider. The skylights also permitted a lot of heat to escape at night. A layer of Plexiglas, mounted similarly on the interior, cut heat loss by about half.

As a general rule, the area of south-facing glass in passive solar homes should fall within 7 to 12 percent of the home's square footage. The more heat you need, the more south-facing glass. For optimal, year-round performance, designers and builders should also pay close attention to windows on the north, east, and west sides of homes. East- and north-facing glass should not exceed 4 percent of the total square footage. West-facing glass should not exceed 2 percent of the total square footage.

In a solar home in which solar glazing falls under the 7 percent mark, sunlight can satisfy 10 to 25 percent of a home's annual heat requirement. In solar homes with solar glazing greater than 7 percent, solar gain falls within the range of 25 to 90 percent. That is, homeowners can satisfy 25 to 90 percent of their annual heat requirement from the sun. Although 100 percent solar heating is possible, it is difficult to achieve. In all but the most favorable climates, some form of backup heat is required.

To prevent overheating in the winter, passive solar homes require thermal mass inside the structure. Mass absorbs and releases heat into rooms at night, helping to minimize temperature swings. In passive solar homes in which south-facing glass is less than 7 percent of the total square footage, no additional thermal mass is required. Incidental mass—mass in the structure, such as drywall, framing, and furniture—is usually sufficient. If solar glazing exceeds 7 percent, additional thermal mass is required.

A proper glass-to-mass ratio, for example, protects against unbearably hot room temperatures. High performance windows that have a high solar heat gain coefficient (greater than 0.5) reduce unwanted heat gain, heat loss, and leakage. For most climates, double- or triple-pane, argon-gas-filled window assemblies with warm edges (thermal spacers that reduce heat conduction through the frame) are advised.

Too much glass can cause huge temperature swings. Homes tend to overheat during the day, even in the winter, and get too cold at night, because windows lose considerable amounts of heat.

Blunder #4, Inadequate Overhangs

Many early passive solar homes and some more recent structures feature huge, two-story glass walls. I've visited three breathtaking examples lately. But after extolling the virtues of their homes, the owners all confided that they wouldn't build a home this way again. Why? One of the problems is that two-story, south-facing glass walls can lead to overheating in the winter.

Overheating also occurs in these homes during the swing seasons—the late spring and early fall—because of a lack of sufficient exterior overhangs. In the designs I've studied, the upper levels of glass are frequently protected by an overhang, but the lower levels are not. The result is that too much sunlight enters from the intermediate-angled sun.

In a single-story home with sufficient overhangs, sunlight penetration is controlled quite naturally. In the fall, as the sun angle decreases, sunlight begins to penetrate south-facing glass, but just deep enough to provide the small amount of heat generally required for comfort. In a two-story glass wall, the unshaded lower-tier glazing lets in more sunlight than is needed. Unless the lower story has been protected with an overhang or sufficient mass has been provided to absorb the excess heat, overheating is practically guaranteed. In a two-story glass wall, sunlight can even enter the lower windows during the summer months, greatly increasing the cooling load.

Nighttime heat loss can also be significant with this design. And huge expanses of glass are rather difficult to cover with window shades. Even if you can install shades, the second-story ones are often difficult to access and operate. As a result, many homeowners leave their glass walls unprotected in the winter, and suffer the consequences—discomfort and high heating bills.

The overhangs in this house provide adequate shading for the upstairs, but the ground floor bakes in the summer sun.

Blunder #5, Angled Glass

The rationale for sloped glass is that it permits maximum sunlight penetration during the winter months. With the glass set perpendicular to incident sunlight on the shortest day of the year, the house achieves maximum solar gain. Reflection of light rays, which occurs in vertical glass, is minimized.

Angled glass is one of those design ideas proffered by those seeking 100 percent or near 100 percent passive solar heating—and it is also valuable when trying to grow year-round in planters located along the south side of a house. If you don't provide angled glass for plants, you'll need skylights. Plants don't grow well behind vertical glass, especially in the summer when the sun cuts a steep arc in the sky.

Although angled glass has its benefits, the problems it creates are significant. Any time a window assembly is off-vertical, it is likely to eventually leak, especially if it is exposed to extreme temperature swings. Unshaded, tilted glass permits unwanted solar gain during the swing seasons and the summer, increasing cooling loads. Angled glass is not easy to shade—it is not conducive to overhangs and it is difficult to fit with internal shades. One of the only options you'll have is external shades, which are inconvenient and unappealing aesthetically.

Sloped glazing is hard to shade, often allowing too much heat gain in some seasons.

To beat the stratification of heat in his great room, Don...well, poor Don.

Blunder #6, Underinsulation

Insulation and reducing air leakage are the other keystones of successful passive solar design and passive cooling. Modern solar architects and builders pay close attention to them, and achieve levels that greatly reduce the heating and cooling loads of homes and other buildings.

Although windows perform admirably as solar collectors, the best-built, airtight, energy-efficient windows still permit massive amounts of heat to escape at night or on cold, cloudy days. In the winter, the period of solar gain is far shorter than the period of heat loss. In all homes, especially passive solar structures, insulated shades, and internal shutters are all well worth the investment. They insulate cold window surfaces that suck heat from a house, and may even diminish air infiltration around windows.

Insulate the ceilings, walls, floors, and foundation well, paying special attention to foundations and concrete floors that collect and store thermal mass—you won't want to lose this heat to the earth. Although many municipalities and counties have upgraded their insulation standards, most are still woefully inadequate. I recommend insulation levels 30 percent greater than the International Code Council's Model Energy Code.

Blunder #7, Inadequate Thermal Mass

In my second home, the thermal storage wall seemed to be the only feature the builder got right. But, as I soon found out, it too had some problems. Like many early Trombe wall designs, this one had been built with vents to move hot air from the space between the glass and the mass wall to the living space. In a vented thermal storage wall, hot air moves upward by convection, creating a thermosiphon effect, and ensures some daytime heating from a structure that otherwise provides mostly nighttime heat.

Unfortunately, we found that the Trombe wall had the opposite effect. After the sun stopped heating the thermal storage wall, a reverse thermosiphon was established, pulling warm air from the room. We solved this problem by permanently inserting foam blocks into the openings to block the flow of air. (Operable louvres were another possible solution, but daytime heating was not something this house needed.) My thermal storage wall worked perfectly from that day on.

Thermal mass is vital to the success of a passive solar home. It prevents overheating and reduces temperature swings at night by radiating stored heat into the room when the interior air temperature falls below the surface temperature of the mass. Any material that has the capacity to store heat can serve as thermal mass.

In most passive solar homes, thermal mass consists of masonry building materials such as poured concrete and concrete block walls, or earthen materials such as adobe floors and walls or rammed earth walls. Even plaster over a straw bale wall can serve as thermal mass. For effective thermal storage, the mass needs to be about 3 inches (7.6 cm) thick. Besides providing enough thermal mass, successful passive solar design means situating the mass properly to absorb and collect solar radiation.

Blunder #8, Poor Ventilation

A couple of years after we moved into our second house, during the house's fifth year of existence, the shingles on the roof began to buckle. When I examined the problem, I found that the roof decking and insulation were soaking wet. The builder had failed to install a vapor barrier and a roof venting system. As a result, water vapor from the home's interior had been migrating through the ceiling and insulation, condensing on the decking, and then dripping onto the insulation, dramatically reducing its effectiveness.

To solve the problem, I installed soffit vents and a ridge vent, and replaced all of the wet insulation. Vents allow air to circulate over the insulation, drawing off moisture that migrates through the ceiling. The retrofit cost several thousand dollars.

The lesson here is that controlling indoor moisture levels is crucial. Exhausting moist air at the sources with dryer vents, and kitchen and bathroom exhaust fans, and ventilating roof cavities can stop moisture problems at their source. Installing vapor barriers on the warm side of the insulation (interior side in heating-dominated climates) in walls and ceilings also will help reduce moisture problems. Applying latex paint to drywall also helps to reduce its permeability to vapor. The combination of the two can be quite effective.

What About Attached Sunspaces?

Attached sunspaces, while aesthetically pleasing, often prove to be a waste of space, and generally add little, if any, usable living space to a home. In the winter during the day, they're often drenched with sunlight and unusable, unless shaded. At night, sunspaces tend to be very cold and uncomfortable.

If they're designed with a considerable amount of roof glass, they'll end up baking in the sun and will require shading. It's also often difficult to transfer heat from a sunspace into a home during the winter. In my experience, direct gain systems and thermal storage walls work better for heating interior space. They also provide much more useful floor space than an attached sunspace.

Blunder #9, High Ceilings

Aesthetically speaking, I have to admit that part of my second home's appeal was its dramatic 20-foot (6 m) vaulted ceilings. But from a passive solar design performance standpoint, they were a nightmare. The vaulted ceilings permitted hot air to rise and dissipate through the skylights and the roof. At night, the lovely passive solar house that cooked us during the day, chilled us.

Although the builder had anticipated the problem of rising hot air and had installed two fans in wall plenums (metal ducts leading from the ceiling to the lower level) to distribute heat to the house's lower level, the fans were undersized and ineffective. I replaced them with larger models, but they barely made a dent in the problem. A ceiling fan we installed didn't help much either.

When designing a passive solar home, never lose track of the fact that hot air rises, and that moving hot air downward is extremely difficult. In most climates, high-ceilinged, passive solar homes are a poor design. You can install large, powerful fans, but they can be noisy and are often unable to move the volume of air that is needed to ensure comfort. They'll also require additional energy to operate, negating the chief goal of passive solar design—to use as little energy as possible.

High ceilings also mean there's a greater volume of air to heat in the house, and the more volume, the greater the heating load. The greater the temperature differences between the air at ceiling level and the outside air, the greater the heat loss through the ceiling. In this house, ironically, the high ceilings probably made the structure a bit more livable during winter days. Without them, the living room and dining room would have surely been much hotter. But there are other ways of ensuring comfortable temperature that don't spawn secondary problems.

Blunder #10, Sun Drenching

In many early passive solar homes, living spaces were often drenched in sunlight during much of the heating season. Although these designs provided plenty of heat, rooms were so brightly illuminated that they often became unusable during the daylight hours. Excess sunlight can produce glare that can make TV or computer monitor viewing difficult, uncomfortable, or even impossible. Sunlight can bleach carpets and furniture, too. Many a disappointed homeowner has turned to heavy window shades to block the sun, a measure that dramatically cuts down on solar gain.

Fortunately, some simple design strategies can ensure solar gain while producing sun-sheltered spaces. Planters, hallways, partition walls, entryways, and other design features may all be used to create sun-free zones. Sunlight can also be directed into interior stairs where a brightly lit interior meets little, if any, objection. Trombe walls are extremely effective in reducing sun drenching. Clerestory windows can be used to deliver sunlight to back walls of a room.

Future Passive Solar Design

Despite past problems, passive solar heating is moving forward on much more solid footing. Although there is more to be learned, the new generation of informational resources delivers considerably more science and engineering to the task. New resources are available to assist you in the design of energy-efficient, passively conditioned homes. Publications such as *Home Power* and *Solar Today*, and computer software like Energy-10 are just a few of the dozens of resources aimed at helping architects and builders develop cost-effective, energy-efficient, low-impact passive solar buildings.

Access

Dan Chiras, Sustainable Systems Design, 9124 Armadillo Trail, Evergreen, CO 80439 • 303-674-9688 • danchiras@msn.com • www.danchiras.com

The Solar House Daniel Chiras, 2002, Paperback, 288 pages, ISBN 1-931498-16-4, US$29.95 from Chelsea Green Publishing, PO Box 428, White River Junction, VT 05001 • 800-639-4099 or 802-295-6300 • Fax: 802-295-6444 • info@chelseagreen.com • www.chelseagreen.com

Sustainable Buildings Industries Council, 1331 H St. NW, Suite 1000, Washington, DC 20005 • 202-628-7400 • Fax: 202-393-5043 • sbic@sbicouncil.org • www.sbicouncil.org • Energy-10 software