

Passive Solar Design Primer

Passive solar design uses sunshine to heat and light homes and other buildings without mechanical or electrical devices. It is usually part of the design of the building itself, using certain materials and placement of windows or skylights. A successful passive solar building needs to be very well insulated in order to make best use of the sun's energy. The result is a quiet and comfortable space, free of drafts and cold spots. Passive solar design can also achieve summer cooling and ventilating by making use of convective air currents which are created by the natural tendency of hot air to rise.

In the winter when heating is required, the sun is low in the sky, which allows the heat to penetrate into windows on the south face of a structure. In the summer, south-facing windows can be shaded by an overhanging roof or awning to keep out the high hot summer sun. Because much of a building's heat is lost through its windows, the majority of windows in a passive solar building are located on the south wall.

Depending on the climate and the design, as much as 100 percent of a building's heating needs can be provided by the sun. In a climate such as Albuquerque, meeting 80 percent of a building's heating needs through sunlight is a realistic goal given a balanced design. Even if 50 percent or 30 percent is sun-generated, conventional heating bills are cut by that amount. Albuquerque's cold but sunny climate is a very favorable location for passive solar heating. Additionally, summer comfort can often be achieved without the need for air conditioning by employing shading and natural cooling techniques.

THE ADVANTAGES OF PASSIVE SOLAR DESIGN:

- High energy performance: lower energy bills all year round.
- Investment: independent from future rises in fuel costs, continues to save money long after initial cost recovery.
- Value: high owner satisfaction, high resale value.
- Atttractive living environment: large windows and views, sunny interiors, open floor plans.
- Low Maintenance: durable, reduced operation and repair.
- Unwavering comfort: quiet (no operating noise), warmer in winter, cooler in summer (even during a power failure).
- Environmentally friendly: clean, renewable energy doesn't contribute to global warming, acid rain or air pollution.

PASSIVE SOLAR DESIGN: The Tools

SOUTH FACING GLASS

South facing glass, also called **glazing**, is a key component of any passive solar system in the northern hemisphere. The system must include enough solar glazing for good performance in winter, but not so much that cooling performance in summer will be compromised. When the solar glazing is tilted, its winter effectiveness as a solar collector increases. However, tilted glazing can cause serious overheating in the summer if it is not shaded very carefully. Ordinary vertical glazing is easier to shade, less likely to overheat, less susceptible to damage and leaking, and so is almost always a better year-round solution. Even in the winter, with the sun low in the sky and reflecting off snow cover, vertical glazing can often offer energy performance just as effective as tilted.

THERMAL MASS

Almost all passive solar systems work in conjunction with **thermal mass**, or materials with a high capacity for absorbing and storing heat (e.g., brick, concrete masonry, concrete slab, tile, adobe, water). Thermal mass can be incorporated into a building design as floors, interior walls, fireplaces, or bancos. The sun does not need to hit these surfaces directly to store the heat, nor do these surfaces necessarily need to be a dark color. The thermal storage capabilities of a given material depend on the material's **thermal conductivity**, **specific heat** and density. Conductivity tends to increase with increasing density; generally, the higher the density of the material, the better. Effective materials for floors include painted, colored or acid-etched concrete, brick, quarry tile, and dark ceramic tile. When more mass is required, interior walls or interior masonry fireplaces can be incorporated into the design. Mass walls serve the dual functions of serving as structural elements or fire protection as well as for thermal storage. From an energy standpoint, it would be difficult to add too much thermal mass in a house. But thermal mass has a cost, and so adding too much mass just for thermal storage purposes can be unnecessarily expensive. As with all aspects of solar design planning, it is necessary to achieve a workable balance.

ORIENTATION

In order for passive solar systems to work effectively, care must be taken to ensure that the building is oriented to take advantage of year-round energy savings. The ideal orientation for solar glazing is within 5 degrees of true south. This orientation will provide maximum performance. Glazing oriented to within 15 degrees of true south will perform almost as well, and orientations up to 30 degrees off--although less effective--will still provide a substantial level of solar contribution. In Albuquerque, magnetic north as indicated on the compass is actually 13 degrees east of true north, and this **declination** should be corrected for when planning for orientation of south glazing. When glazing is oriented more than 15 degrees off true south, not only is winter solar performance reduced, but summer air conditioning loads also significantly increase, especially as the orientation goes west. The warmer the climate, the more east and west-facing glass will tend to cause overheating problems. In general, southeast orientations present less of a problem than southwest. In the ideal situation, the house should be oriented east-west and so have its longest wall facing south. But as a practical matter, if the house's short side has good southern exposure it will usually accommodate sufficient glazing for an effective passive solar system, provided that the heat can be transferred to the northern zones of the house.

SUNTEMPERING

Suntempering is the most basic of passive solar techniques, it is simply increasing the number of windows on the south side, without adding additional thermal mass apart from the framing, gypsum board, etc, that is normally part of a conventional house. In a conventional house, about 25 percent of the windows face south which amounts to about 3 percent of the house's total floor space. In a **suntempered** house, the percentage is increased to a maximum of about 7 percent. Energy savings are modest with this system, but suntempering is very low cost.

DIRECT GAIN

The most common passive solar system is called **direct gain**. Direct gain refers to the sunlight that enters a building through windows, warming the interior space. During the sunlight hours, this heat can be stored in thermal mass incorporated into floors or interior walls made of adobe, brick, concrete, stone, or water. The heat held by the thermal mass will continue to radiate into the space after the sun goes down. Designing a direct gain system includes calculating how much window area and how much thermal mass are required to provide the desired quantity of heat for the space. In general, total direct gain glass area should be at least 7 percent, but not exceed 12

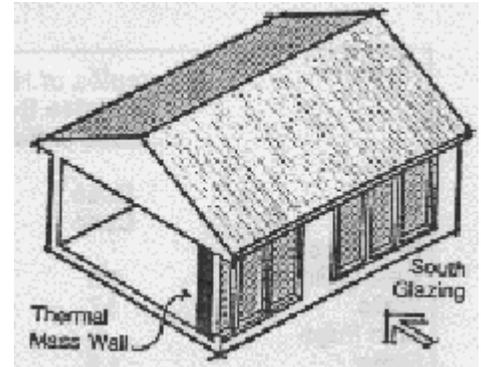
percent of the house's floor area. **Double glazing** is recommended for direct gain windows in Albuquerque. Night insulation, such as window shades, quilts or insulating drapes, improves **energy efficiency** dramatically.

THERMAL STORAGE WALLS

Trombe Wall

A **trombe wall** is a technique used to capture solar heat that was developed by French engineer Felix Trombe (Trombe rhymes with prom).

A portion of the south wall is constructed of thermal mass material such as adobe or poured concrete, then covered and sealed by a pane of glass positioned about two inches from its surface. Sunlight enters and the heat is then trapped by the glass, allowing it to be absorbed by the thermal mass wall. The heat then radiates into the interior of the room in the evening and nighttime hours. Trombe walls do not require ventilation, because the idea is not to circulate warm air, but to allow the wall itself to radiate heat. The masonry thermal storage wall should be solid, and there should be no openings or vents either to the outside or to the living space. Trombe walls perform better in summer (about 84 percent less heat gain) than a comparable area of direct glazing. Trombe walls can be combined with direct gain windows in the same wall, and furniture can be placed up against a trombe wall without changing its effectiveness. Trombe walls are particularly useful in a design where less window area in a room is desired, and nighttime comfort is sought, i.e., bedrooms and bathrooms. Double glazing is recommended for thermal storage walls, and the space between the glazing and the thermal mass should be 1-3 inches. In general, the effectiveness of the thermal storage wall will increase as the density of the material increases.



Water Walls

In **water walls**, water is held in light, rigid containers. Water provides about twice the heat storage per unit volume as masonry, so a smaller volume of mass can be used. Containers are shipped from manufacturers empty and are easily installed. At least 30 pounds (3.5 gallons) of water should be provided for each square foot of glazing. An indoor hot tub or a pool can also be used as a heat storing mass.

GREENHOUSES AND SUNSPACES

When built onto the south wall of a structure, a **solar greenhouse** or **sunspace** provides an insulating air cushion between the outside and inside of the building, lowering heating bills in the winter. Sunspaces are referred to as "isolated gain" passive solar systems because the sunlight is collected in an area which can be closed off from the rest of the house. During the day, the doors or windows between the sunspace and the house can be opened to circulate collected heat, and then closed at night, and the temperature in the sunspace allowed to drop. Thermal mass in the greenhouse/sunspace will also generate heat which can be moved into the building either mechanically or by designing the structure to encourage a convective air current.

Greenhouses generally have glass or plastic panels in the roof to allow light and heat for growing plants and early seed-starting. They are difficult to insulate in areas with very cold winters because often much heat is lost through the roof, but the tradeoff is an extended growing season.

Sunspaces usually have an insulated roof and full length windows on the south side. They are often more practical than greenhouses as living spaces, but will still provide an excellent environment for plants, and a more even temperature level throughout the year. Climate and desired use will dictate how a greenhouse or sunspace is designed for a particular application.

Ventilation, roof glass, and thermal mass are important design features that make either structure a valuable money-saving and comfort-enhancing addition to a home or design.

A rule of thumb for sunspaces is to incorporate 3 square feet of 4-inch thick thermal mass for each square foot of sunspace glazing. A good place for thermal mass in the sunspace is the flooring. The lower edge of the south-facing windows should be no more than 6 inches from the floor or the planter bed to make sure the mass in the floor receives sufficient direct sunlight. If the thermal mass is instead located in the common wall, it should be solid masonry approximately 4 to 8 inches thick, or a frame wall with masonry veneer. Windows on the east and west walls are useful for cross-ventilation but should be kept small (no more than 10 percent of the total sunspace area). Double glazing is recommended for sunspaces.

ENERGY CONSERVATION: Insulation, Infiltration and Non-Solar Glazing

Adding insulation to walls, floors, ceilings, roof and foundations improves their thermal **resistance (R-value)**, or resistance to heat flowing out of the house. Ensuring that the insulation is properly installed is very important to the house's overall energy performance. Sealing the house carefully to reduce air **infiltration** (air leakage) is also essential. Air will flow rapidly through cracks and crevices in the wall in the same way that water flows through the drain in a bathtub, so even a small opening can allow heat to bypass the insulation and lead to big energy losses. The tightness of a house is generally measured in the number of air exchanges per hour (ACH). A good, comfortable, energy efficient house will have approximately 0.35 to 0.50 air exchanges per hour under normal winter conditions. Increasing the tightness of the house beyond that may improve energy performance, but it may also create problems with indoor air quality, moisture build-up, and inadequately vented fireplaces and furnaces. Some kind of additional mechanical ventilation--for example, small fans, heat pump heat exchangers, integrated ventilation systems or air-to-air heat exchangers--is usually necessary to avoid such problems in houses with less than 0.35 ACH. Windows that are not south facing are considered non-solar glazing. Windows on the north side of a house in almost every climate lose significant heat energy and gain very little useful sunlight in the winter. East and west windows are likely to increase air conditioning needs unless heat gain is minimized with careful attention to shading. Of course, people want windows for reasons other than energy gain, so a good design will be a balance between efficiency and other benefits, such as views and bright living spaces. Some rules of thumb for non-solar glazing: triple-glazing (meaning three panes of glass) or low-e ("e" stands for **emissivity**) coating will reduce heat loss while allowing for light to enter; north facing windows should be small and have high insulation or R-value; east windows catch the morning sun and can cause potential overheating, therefore shading should be planned with care; west windows also have a high potential for overheating, tinted glass or low-e glass may be effective; and lastly, as many windows as possible should be kept operable for easy natural ventilation in summer.

INFILTRATION CHECK LIST:

- tighten seals around windows and doors, weatherstrip around all openings to outdoors
- caulk around all windows and doors before hanging drywall, seal plumbing & electrical conduit openings
- insulate behind wall outlets and/or plumbing lines in exterior walls
- caulk under headers and sills
- chink spaces between rough openings and millwork with insulation or fill with foam
- seal larger openings such as ducts into attics or crawlspaces with taped polyethylene covered with insulation
- locate continuous vapor retardants on the warmside of the insulation (building wrap, etc.)
- install dampers and/or glass doors on fireplaces; combined with outside combustion air intake
- install backdraft dampers on all exhaust fan openings
- caulk and seal the joint between the basement slab (or the slab on grade) and the basement wall
- remove wood grade stakes from slabs and seal
- cover and seal sump cracks
- close core voids in top of block foundation walls
- control concrete and masonry cracking
- employ proper radon mitigation techniques

BACK UP AND MECHANICAL SYSTEMS

The passive solar features in a house and the mechanical heating, ventilating and air conditioning systems (HVAC) will interact all year round so the most effective approach is to design the system as an integrated whole.

System Sizing

Mechanical systems are often oversized for the relatively low heating loads in well-insulated passive solar houses. Oversized systems will cost more in the first place, and will cycle on and off more often, wasting energy. The back-up systems in passive solar houses should be sized to provide 100 percent of the heating or cooling load on the design day, but no larger.

Night Setback

Clock thermostats for automatic night shutoff are usually very effective, but in passive solar systems with large amounts of thermal mass releasing heat during the night, night setback of the thermostat may not save very much energy.

Ducts for Air Heating Furnaces

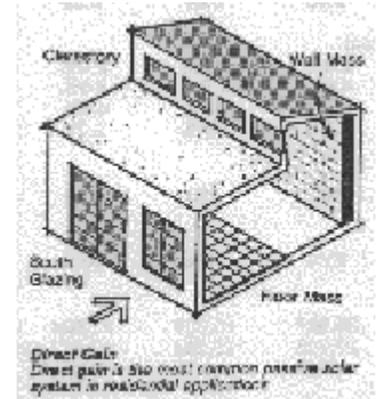
Both the supply and return ducts should be located within insulated areas, or be well-insulated if they run in cold areas of the house, and they should be well sealed at the joints.

INTERIOR SPACE PLANNING

Planning room layout by considering how the rooms will be used in different seasons, and at different times of the day, can save energy and increase comfort. In houses with passive solar features, the layout of rooms and interior zones is particularly important. A longer East-West axis will allow more rooms to face south. In general, living areas and other high-activity rooms should be located on the south side to benefit from the solar heat. The closets, storage areas, garage and other less-used rooms can act as buffers along the north side, but entryways should be located away from the wind. Clustering baths, kitchens and laundry rooms near the water heater will save the heat that would be lost from longer water lines. Another general principle is that an open floor plan will allow the collected solar heat to circulate freely through natural convection.

Other ideas include:

- orienting internal mass walls as north-south partitions that can be "charged" on both sides thus making maximum use of the mass.
- using an east-west partition wall for thermal mass, but avoid dividing the interior space into a north zone that may get too cold and south zone that may get too warm
- using thermal storage walls
- collecting the solar energy in one zone of the house and transporting it to another by fans, natural convection and/or an open floor plan
- providing south-facing clerestories to "charge" north zones.



SITE PLANNING FOR SOLAR ACCESS

The main objective of site planning for passive solar homes is to allow the south side as much unshaded exposure as possible during the winter months. A good design balances energy performance with other important factors such as, the slope of the site, the individual house plan, the direction of prevailing breezes for summer cooling, the views, the street lay out and so on. Ideally, the glazing on the house should be exposed to sunlight with no obstructions within an arc of 60 degrees on either side of true south, but reasonably good solar access will still be guaranteed if the glazing is unshaded within an arc of 45 degrees. Buildings, trees, or other obstructions should not be located so as to shade the south wall of solar buildings. At this latitude, no structures should be allowed within 10 feet of the south wall of a solar building; fences should be located beyond 10 feet; one story buildings should be located beyond 17 feet; and two story buildings should be located beyond 40 feet.

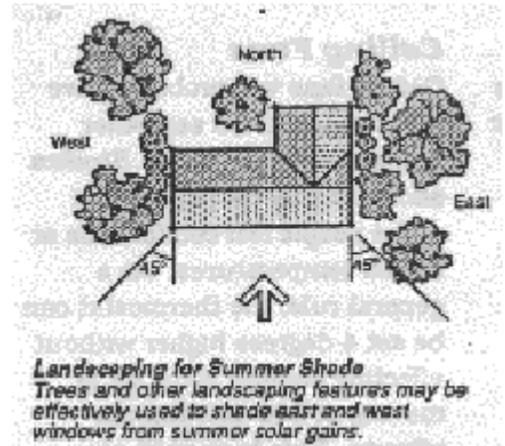
NATURAL COOLING GUIDELINES

"Natural cooling" refers to techniques which help a house stay cool in the summer but which require little to no energy. Such techniques help to reduce air conditioning, not replace it. Shading is particularly important in passive solar houses, because the same features that collect sunlight in winter will go right on collecting it in summer unless they are shaded and the house itself is designed to help cool itself. Thermal mass performs well year round, masonry materials can be effective in staying cool as well as storing heat in winter. If mass surfaces are exposed to cool night time temperatures, they will help the house stay cooler the next day. The additional insulation that increases winter performance will also work to improve summer performance by conserving the conditioned air inside the house. Some low-e windows and other glazes with high R-values can help shield against unwanted heat gain in summer.

SHADING: Landscaping, overhangs and shading devices

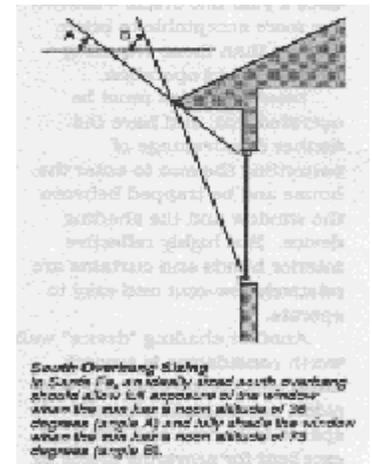
Landscaping

Trees and other landscaping features may be effectively used to shade east and west windows from summer solar gains. Trees on the southside, however, can all but eliminate passive solar performance, unless they are very close to the house and the lower branches can be removed to allow the winter sun to penetrate under the tree canopy. If a careful study of shading patterns is done before construction, it should be possible to accommodate the south-facing glazing while leaving in as many trees as possible. Other landscaping ideas for summer shade include: trellises on the east and west covered with vines; shrubbery or other plantings to shade paved areas; use of ground cover to prevent glare and heat absorption; trees, fences, or shrubbery planted so as to "channel" breezes into the house; and deciduous trees on the east and west sides of the house, to balance solar gains in all seasons.



Roof Overhangs

Fixed overhangs are an inexpensive feature and require no operation by the homeowner. They must be carefully designed, however. Otherwise, an overhang that blocks the summer sun may also block sun in the spring, when solar heating is desired. Likewise, an overhang sized for maximum solar gain in winter will allow solar gain in the fall on hot days. A combination of carefully sized overhangs on south windows and shading devices on the other windows usually allows for an effective solution. The following figure may be used to determine the optimum overhang size. In Santa Fe, an ideal overhang projection for a 4 foot high window would be 18 inches if the bottom of the overhang is 13 inches above the top of the window. For Albuquerque, strive to shade the window fully when the sun has a noon altitude angle of 65 degrees.



Shading Devices

External devices stop solar gain before the sun hits the building. These include awnings, solar screens, roll-down blinds, shutters and vertical louvers. They are adjustable and perform well, but require action by the homeowner to operate. Interior shading elements also require homeowner operation, and also permit the sun to enter the house and be trapped between the window and the shade. Reflective interior blinds and curtains are relatively low cost and are easy to operate. Another option in shading is a porch or carport, preferably located on the east or west sides.

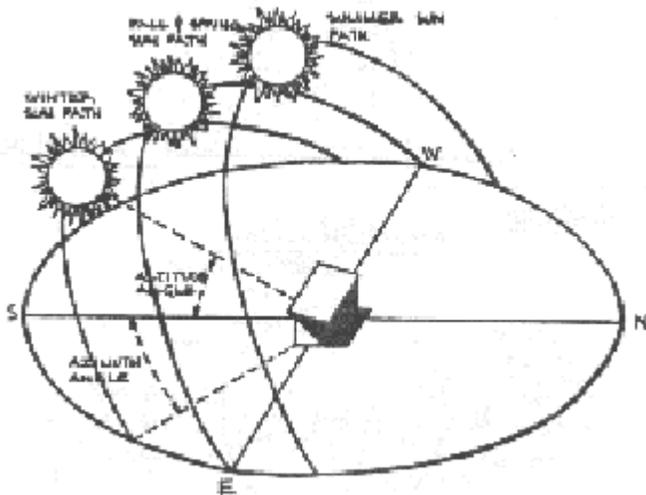
VENTILATION

When possible, the house should be positioned on the site to take advantage of prevailing winds. The prevailing winds direction is from the south during the summer. The free vent area (unobstructed openings like open windows) should be between 6 to 7.5 percent of total floor area, half located on the leeward and half on the windward side of the building. Ceiling fans will probably save more energy than any other single cooling strategy, since air movement can make people feel comfortable at higher temperatures. A whole house fan can also assist with ventilation, but is not very effective at cooling when the temperature is higher than 76 degrees F. Using a combination of the above cooling techniques will substantially reduce the need for air conditioning.

PASSIVE SOLAR DESIGN CHECKLIST

1. Is the house **oriented** to optimize both winter heating and summer cooling needs?
2. Does the house effectively incorporate sufficient **thermal mass**?
3. Does the house design include thorough **insulation** throughout?
4. Does the house design optimize **glazing** so as not to over or underheat?
5. Is the **backup heat system** appropriately sized?
6. Does the **interior design** maximize solar heating and cooling benefits?

SUNPATHS:



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