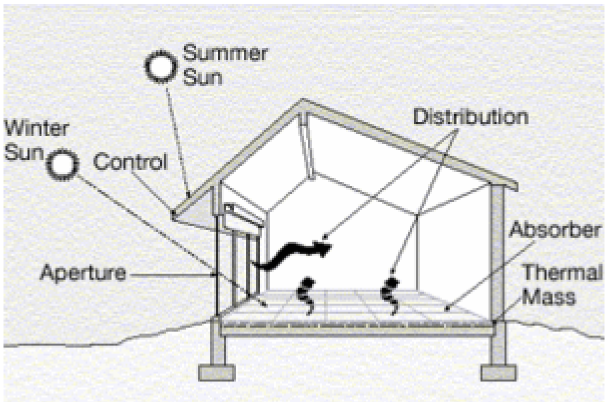
Passive solar building design

In **passive solar building design**, windows, walls, and floors are made to collect, store, and distribute **solar energy in** the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active **solar heating** systems, it doesn't involve the use of mechanical and electrical devices.

The key to designing a passive solar building is to best take advantage of the local **climate**. Elements to be considered include window placement and glazing type, **thermal insulation, thermal mass**, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".



Passive energy gain

Passive solar technologies use **sunlight** without active mechanical systems (as contrasted to **active solar**). Such technologies convert sunlight into usable heat (water, air, thermal mass), cause air-movement for **ventilating**, or future use, with little use of other energy sources. A common example is **a solarium** on the **equator**-side of a building. **Passive cooling** is the use of the same design principles to reduce summer cooling requirements.

Some passive systems use a small amount of conventional energy to control dampers, shutters, night insulation, and other devices that enhance solar energy collection, storage, use, and reduce undesirable **heat transfer**.

Passive solar technologies include direct and indirect **solar gain** for space heating, **solar water heating** systems based on the thermo siphon or geyser pump, use of **thermal mass** and **phase-change materials** for slowing indoor air temperature swings, **solar cookers**, the **solar chimney** for enhancing natural ventilation, and **earth sheltering**.

More widely, passive solar technologies include the **solar furnace** and **solar forge**, but these typically require some external energy for aligning their concentrating mirrors or receivers, and historically have not proven to be practical or cost effective for widespread use. 'Low-grade' energy needs, such as space and water heating, have proven, over time, to be better applications for passive use of solar energy.

Convective heat transfer

Convective heat transfer can be beneficial or detrimental. Uncontrolled air infiltration from poor **weatherization** / weather-stripping / draft-proofing can contribute up to ٤٠% of heat loss during winter,[1] however strategic placement of operable windows or vents can enhance convection, cross-ventilation, and summer cooling when the outside air is of a comfortable temperature and **relative humidity**.[Filtered **energy recovery ventilation** systems may be useful to eliminate undesirable humidity, dust, pollen, and microorganisms in unfiltered ventilation air.

Natural convection causing rising warm air and falling cooler air can result in an uneven stratification of heat. This may cause uncomfortable variations in temperature in the upper and lower conditioned space, serve as a method of venting hot air, or be designed in as a natural-convection air-flow loop for passive solar heat distribution and temperature equalization. Natural human cooling by perspiration and evaporation may be facilitated through natural or forced convective air movement by fans, but ceiling fans can disturb the stratified insulating air layers at the top of a room, and accelerate heat transfer from a hot attic, or through nearby windows. In addition, high relative humidity inhibits evaporative cooling by humans.

Radiative heat transfer

The main source of heat transfer is radiant energy, and the primary source is the sun. Solar radiation occurs predominantly through the roof and windows (but also through walls). Thermal radiation moves from a warmer surface to a cooler one. Roofs receive the majority of the solar radiation delivered to a house. A cool roof, or green roof in addition to a radiant barrier can help prevent your attic from becoming hotter than the peak summer outdoor air temperature (see albedo, absorptive, emissivity, and reflectivity).

Windows are a ready and predictable site for thermal radiation. Energy from radiation can move into a window in the day time, and out of the same window at night. Radiation uses photons to transmit electromagnetic waves through a vacuum, or translucent medium. Solar heat gain can be significant even on cold clear days. Solar heat gain through windows can be reduced by insulated glazing, shading, and orientation. Windows are particularly difficult to insulate compared to roof and walls. Convective heat transfer through and around window coverings also degrade its insulation properties.[When shading windows, external shading is more effective at reducing heat gain than internal window coverings.[

Western and eastern sun can provide warmth and lighting, but are vulnerable to overheating in summer if not shaded. In contrast, the low midday sun readily admits light and warmth during the winter, but can be easily shaded with appropriate length overhangs or angled louvers during summer. The amount of radiant heat received is related to the location latitude, altitude, cloud cover, and seasonal / hourly angle of incidence (**see** Sun path and Lambert's cosine law).

Another passive solar design principle is that thermal energy can be stored in certain building materials and released again when heat gain eases to stabilize diurnal(day/night) temperature variations. The complex interaction of thermodynamic principles can be counterintuitive for first-time designers. Precise computer modeling can help avoid costly construction experiments.

Site specific considerations during design

- Latitude, sun path, and insulation (sunshine)
- Seasonal variations in solar gain e.g. cooling or heating degree days, solar **insulation,** humidity
- Diurnal variations in temperature
- Micro-climate details related to breezes, humidity, vegetation and land contour
- Obstructions / Over-shadowing - to solar gain or local cross-winds

Design elements for residential buildings in temperate climates

- Placement of room-types, internal doors & walls, & equipment in the house.
- Orienting the building to face the equator (or a few degrees to the East to capture the morning sun)[Y]
- Extending the building dimension along the east/west axis

- Adequately sizing windows to face the midday sun in the winter, and be shaded in the summer.
- Minimizing windows on other sides, especially western windows
- Erecting correctly sized, latitude-specific roof overhangs,[or shading elements (shrubbery, trees, trellises, fences, shutters, etc.)
- Using the appropriate amount and type of **insulation** including radiant barriers and bulk insulation to minimize seasonal excessive heat gain or loss
- Using **thermal mass** to store excess solar energy during the winter day (which is then re-radiated during the night)

The precise amount of equator-facing glass and thermal mass should be based on careful consideration of latitude, altitude, climatic conditions, and heating/cooling **degree day** requirements.

Factors that can degrade thermal performance:

- Deviation from ideal orientation and north/south/east/west aspect ratio
- Excessive glass area ('over-glazing') resulting in overheating (also resulting in glare and fading of soft furnishings) and heat loss when ambient air temperatures fall
- Installing glazing where solar gain during the day and thermal losses during the night cannot be controlled easily e.g. West-facing, angled glazing, skylights[
- Thermal losses through non-insulated or unprotected glazing
- Lack of adequate shading during seasonal periods of high solar gain (especially on the West wall)
- Incorrect application of **thermal mass** to modulate daily temperature variations
- Open staircases leading to unequal distribution of warm air between upper and lower floors as warm air rises
- High building surface area to volume - Too many corners
- Inadequate **weatherization** leading to high air infiltration
- Lack of, or incorrectly installed**, radiant barriers** during the hot season. (See also **cool roof** and **green roof**)
- **Insulation materials** that are not matched to the main mode of heat transfer (e.g. undesirable convective/conductive/radiant **heat transfer**)

Efficiency and economics of passive solar heating

Technically, PSH is highly efficient. Direct-gain systems can utilize (i.e. convert into "useful" heat) ٦٥-٧٠% of the energy of solar radiation that strikes the aperture or collector. To put this in perspective relative to another energy conversion process, the **photosynthetic efficiency** theoretical limit is around ١١%.

Passive solar fraction (PSF) is the percentage of the required heat load met by PSH and hence represents potential reduction in heating costs. RET Screen International has reported a PSF of ٢٠-٥٠%. Within the field of **sustainability**, energy conservation even of the order of ١٥% is considered substantial.

Other sources report the following PSFs:

- ٥-٢٥% for modest systems

- ٤٠% for "highly optimized" systems
- Up to ٧٥% for "very intense" systems

In favorable climates such as the southwest United States, highly optimized systems can exceed ٧٥% PSF

Key passive solar building design concepts

There are six primary passive solar energy configurations:

- direct **solar gain**
- indirect solar gain
- isolated solar gain
- heat storage
- insulation and glazing
- **passive cooling**

Direct solar gain

Direct gain attempts to control the amount of direct **solar radiation** reaching the living space. This direct solar gain is a critical part of passive solar house designation as it imparts to a direct gain.

The cost effectiveness of these configurations are currently being investigated in great detail and are demonstrating promising results.[١٩]

Indirect solar gain

Indirect gain attempts to control solar radiation reaching an area adjacent but not part of the living space. Heat enters the building through windows and is captured and stored in **thermal mass** (e.g. water tank, masonry wall) and slowly transmitted indirectly to the building through **conduction** and **convection**. Efficiency can suffer from slow response (thermal lag) and heat losses at night. Other issues include the cost of **insulated glazing** and developing effective systems to redistribute heat throughout the living area.

Isolated solar gain

Isolated gain involves utilizing solar energy to passively move heat from or to the living space using a fluid, such as water or air by natural convection or forced **convection**. Heat gain can occur through a sunspace, **solarium** or solar closet. These areas may also be employed usefully as a greenhouse or drying cabinet. An equator-side sun room may have its exterior windows higher than the windows between the sun room and the interior living space, to allow the low winter sun to penetrate to the cold side of adjacent rooms. Glass placement and overhangs prevent solar gain during the summer**.** **Earth cooling tubes** or other **passive cooling** techniques can keep a solarium cool in the summer.

Measures should be taken to reduce heat loss at night e.g. window coverings or movable window insulation

Examples:

- **Thermo siphon**
- **Barra system**

- **Double envelope house**
- Thermal buffer zone[
- **Solar space heating** system
- **Solar chimney**

Heat storage

The sun doesn't shine all the time. Heat storage, or **thermal mass** keeps the building warm when the sun can't heat it.

In diurnal solar houses, the storage is designed for one or a few days. The usual method is a custom-constructed thermal mass. These include a **Trobe**, a ventilated concrete floor, a cistern, water wall or roof pond.

In subarctic areas, or areas that have long terms without solar gain (e.g. weeks of freezing fog), purpose-built thermal mass is very expensive. Don Stephens pioneered an experimental technique to use the ground as thermal mass large enough for annualized heat storage. His designs run an isolated thermo siphon ٣m under a house, and insulate the ground with a ٦m waterproof skirt.

Insulation

Thermal insulation or super insulation (type, placement and amount) reduces unwanted leakage of heat. Some passive buildings are actually **constructed of insulation**.

Special glazing systems and window coverings

*Main articles: **Insulated glazing** and **Window covering***

The effectiveness of direct **solar gain** systems is significantly enhanced by insulative (e.g. **double glazing**), spectrally selective glazing (**low-e**), or movable window insulation (window quilts, bifold interior insulation shutters, shades, etc.).[٢٢]

Generally, Equator-facing windows should not employ glazing coatings that inhibit solar gain.

There is extensive use of super-insulated windows in the **German** **Passive House** standard. Selection of different spectrally selective window coating depends on the ratio of heating versus cooling **degree days** for the design location.

Glazing selection

Equator-facing glass

The requirement for vertical equator-facing glass is different from the other three sides of a building. **Reflective window coatings** and multiple panes of glass can reduce useful solar gain. However, direct-gain systems are more dependent on **double or triple glazing** to reduce heat loss. Indirect-gain and isolated-gain configurations may still be able to function effectively with only single-pane glazing. Nevertheless, the optimal cost-effective solution is both location and system dependent.

Roof-angle glass / Skylights

Skylights admit harsh direct overhead sunlight and glare[٢٣] either horizontally (a flat roof) or pitched at the same angle as the roof slope. In some cases, horizontal skylights are used with reflectors to increase the intensity of solar radiation (and harsh glare), depending on the roof **angle of incidence**. When the winter sun is low on the horizon, most solar radiation reflects off of roof angled glass (the **angle of incidence** is nearly parallel to roof-angled glass morning and afternoon). When the summer sun is high, it is nearly perpendicular to roof-angled glass, which maximizes solar gain at the wrong time of year, and acts like a solar furnace. Skylights should be covered and well-insulated to reduce **natural convection** (warm air rising) heat loss on cold winter nights, and intense solar heat gain during hot spring/summer/fall days.

The equator-facing side of a building is south in the northern hemisphere, and north in the southern hemisphere. Skylights on roofs that face away from the equator provide mostly-indirect illumination, except for summer days when the sun rises on the non-equator side of the building (depending on **latitude**). Skylights on east-facing roofs provide maximum direct light and solar heat gain in the summer morning. West-facing skylights provide afternoon sunlight and heat gain during the hottest part of the day.

Some skylights have expensive glazing that partially reduces summer solar heat gain, while still allowing some visible light transmission. However, if visible light can pass through it, so can some radiant heat gain (they are both **electromagnetic radiation** waves.

You can partially reduce some of the unwanted roof-angled-glazing summer solar heat gain by installing a skylight in the shade of **deciduous** (leaf-shedding) trees, or by adding a movable insulated opaque window covering on the inside or outside of the skylight. This would eliminate the daylight benefit in the summer. If tree limbs hang over a roof, they will increase problems with leaves in rain gutters, possibly cause roof-damaging ice dams, shorten roof life, and provide an easier path for pests to enter your attic. Leaves and twigs on skylights are unappealing, difficult to clean, and can increase the glazing breakage risk in wind storms.

"Saw tooth roof glazing" with vertical-glass-only can bring some of the passive solar building design benefits into the core of a commercial or industrial building, without the need for any roof-angled glass or skylights.

Skylights provide daylight. The only view they provide is essentially straight up in most applications. Well-insulated **light tubes** can bring daylight into northern rooms, without using a skylight. A passive-solar greenhouse provides abundant daylight for the equator-side of the building.

Infrared thermograph color thermal imaging cameras (used in formal **energy audits**) can quickly document the negative thermal impact of roof-angled glass or a skylight on a cold winter night or hot summer day.

The U.S. Department of Energy states: "vertical glazing is the overall best option for sunspaces." Roof-angled glass and sidewall glass are not recommended for passive solar sunspaces.

The U.S. DOE explains drawbacks to roof-angled glazing: Glass and plastic have little structural strength. When installed vertically, glass (or plastic) bears its own weight because only a small area (the top edge of the glazing) is subject to gravity. As the glass tilts off the vertical axis, however, an increased area (now the sloped cross-section) of the glazing has to bear the force of gravity. Glass is also brittle; it does not flex much before breaking. To counteract this, you usually must increase the thickness of the glazing or increase the number of structural supports to hold the glazing. Both increase overall cost, and the latter will reduce the amount of solar gain into the sunspace.

Another common problem with sloped glazing is its increased exposure to the weather. It is difficult to maintain a good seal on roof-angled glass in intense sunlight. Hail, sleet, snow, and wind may cause material failure. For occupant safety, regulatory agencies usually require sloped glass to be made of safety glass, laminated, or a combination thereof, which reduce solar gain potential. Most of the roof-angled glass on the Crowned Plaza Hotel Orlando Airport sunspace was destroyed in a single windstorm. Roof-angled glass increases construction cost, and can increase insurance premiums. Vertical glass is less susceptible to weather damage than roof-angled glass.

It is difficult to control solar heat gain in a sunspace with sloped glazing during the summer and even during the middle of a mild and sunny winter day. Skylights are the antithesis of **zero energy building** Passive Solar Cooling in climates with an air conditioning requirement.

Angle of incident radiation

The amount of solar gain transmitted through glass is also affected by the angle of the incident **solar radiation**. **Sunlight** striking glass within ٢٠ degrees of **perpendicular** is mostly transmitted through the glass, whereas sunlight at more than ٣٥ degrees from perpendicular is mostly **reflected**

All of these factors can be modeled more precisely with a photographic **light meter** and a **heliodon** or **optical bench**, which can quantify the ratio of **reflectivity** to **transmissivity**, based on **angle of incidence**.

Alternatively, **passive solar** computer software can determine the impact of **sun path**, and cooling-and-heating **degree days** on **energy** performance. Regional climatic conditions are often available from local weather services.

Operable shading and insulation devices

A design with too much equator-facing glass can result in excessive winter, spring, or fall day heating, uncomfortably bright living spaces at certain times of the year, and excessive heat transfer on winter nights and summer days.

Although the sun is at the same altitude ٦-weeks before and after the solstice, the heating and cooling requirements before and after the solstice are significantly different. Heat storage on the Earth's surface causes "thermal lag." Variable cloud cover influences solar gain potential. This means that latitude-specific fixed window overhangs, while important, are not a complete seasonal solar gain control solution.

Control mechanisms (such as manual-or-motorized interior insulated drapes, shutters, exterior roll-down shade screens, or retractable awnings) can compensate for differences caused by thermal lag or cloud cover, and help control daily / hourly solar gain requirement variations.

Home automation systems that monitor temperature, sunlight, time of day, and room occupancy can precisely control motorized window-shading-and-insulation devices.

Exterior colors reflecting - absorbing

Materials and colors can be chosen to reflect or absorb **solar thermal energy**. Using information on a **Color** for **electromagnetic radiation** to determine its radiation properties of reflection or absorption can assist the choices.

See Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory: **"Cool Colors"**

Landscaping and gardens

Energy-efficient landscaping materials for careful passive solar choices include hard cape building material and "soft cape" **plants**. The use of **landscape design** principles for selection of **trees**, **hedges**, and **trellis**-**pergola** features with **vines**; all can be used to create summer shading. For winter solar gain it is desirable to use deciduous plants that drop their leaves in the autumn gives year round passive solar benefits. Non-deciduous **evergreen** **shrubs** and trees can be **windbreaks**, at variable heights and distances, to create protection and shelter from winter **wind chill**. **Xeriscaping** with 'mature size appropriate' **native species** of-and **drought tolerant plants**, **drip irrigation**, mulching, and **organic gardening** practices reduce or eliminate the need for energy-and-water-intensive **irrigation**, gas powered garden equipment, and reduces **landscape lighting** the landfill waste footprint. Solar powered and fountain pumps, and covered **swimming pools** and **plunge pools** with **solar water heaters** can reduce the impact of such amenities.

- **Sustainable gardening**
- **Sustainable landscaping**
- **Sustainable landscape architecture**

Other passive solar principles

Passive solar lighting

Passive solar lighting techniques enhance taking advantage of **natural** **illumination** for interiors, and so reduce reliance on artificial lighting systems.

This can be achieved by careful building design, orientation, and placement of window sections to collect light. Other creative solutions involve the use of reflecting surfaces to admit daylight into the interior of a building. Window sections should be adequately sized, and to avoid **over-illumination** can be shielded with a **Brise_soleil, awnings**, well placed trees, glass coatings, and other passive and active devices.

Another major issue for many **window** systems is that they can be potentially vulnerable sites of excessive thermal gain or heat loss. Whilst high mounted **clerestory** window and traditional **skylights** can introduce daylight in poorly oriented sections of a building, unwanted heat transfer may be hard to control. Thus, energy that is saved by reducing artificial lighting is often more than offset by the energy required for operating **HVAC** systems to maintain **thermal comfort.**

Various methods can be employed to address this including but not limited to **window coverings, insulated glazing** and novel materials such as aero gel semi-transparent insulation, **optical fiber** embedded in walls or roof, **or hybrid solar lighting at Oak Ridge National Laboratory**.

Interior reflecting

Reflecting elements, from active and **passive day lighting** collectors, such as **light shelves**, lighter wall and floor colors, **mirrored** wall sections, interior walls with upper glass panels, and clear or translucent glassed hinged doors and **sliding glass doors** take the captured light and passively reflect it further inside. The light can be from passive windows or skylights and solar **light tubes** or from **active day lighting** sources. In traditional **Japanese architecture** the Shoji sliding panel doors, with translucent Wash screens, are an original precedent. **International style, Modernist** and **Mid-century modern** **architecture** were earlier innovators of this passive penetration and reflection in industrial, commercial, and residential applications

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