National Institute of BUILDING SCIENCES
WBDG WHOLE BUILDING DESIGN GUIDE
The Gateway to Up-To-Date Information on Integrated 'Whole Building' Design Techniques and Technologies

RESOURCE PAGE

Passive Solar Heating

by Judy Fosdick
Tierra Concrete Homes
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Introduction

Passive solar heating is just one strategy in a group of design approaches collectively called passive solar design. When combined properly, these strategies can contribute to the heating, cooling, and daylighting of nearly any building.

Passive solar heating in particular makes use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating. It does not require the use of mechanical equipment because the heat flow is by natural means (radiation, convection, and conductance) and the thermal storage is in the structure itself. Also, passive solar heating strategies provide opportunities for daylighting and views to the outdoor through well-positioned windows.

It is best to incorporate passive solar heating into a building during the initial design. The whole building approach evaluates it in the context of building envelope design (particularly for windows), daylighting, and heating and cooling systems. Window design, especially glazing choices, is a critical factor for determining the effectiveness of passive solar heating. Passive solar systems do not have a high initial cost or long-term payback period, both of which are common with many active solar heating systems.

In heating climates, large south-facing windows are used, as these have the most exposure to the sun in all seasons. Although passive solar heating systems do not require mechanical equipment for operation, this does not mean that fans or blowers may not, or should not, be used to assist the natural flow of thermal energy. The passive systems assisted by mechanical devices are referred to as "hybrid" heating systems.

Passive solar systems utilize basic concepts incorporated into the architectural design of the building. They usually consist of: buildings with rectangular floor plans, elongated on an east-west axis; a glazed south-facing wall; a thermal storage media exposed to the solar radiation which penetrates the south-facing glazing; overhangs or other shading devices which sufficiently shade the south-facing glazing from the summer sun; and windows on the east and west walls, and preferably none on the north walls.

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Description

Passive Solar Design

The most important characteristic of passive solar design is that it is holistic (it relies on the integration of a building's architecture, materials selection, and mechanical systems to reduce heating and cooling loads). It takes into consideration local climate conditions, such as temperature, solar radiation and wind, to create climate-responsive, energy conserving structures that can be powered with renewable energy sources. Some benefits of passive solar designed buildings include:

- Increased User Comfort: Properly designed, passive solar buildings are bright and sunny and in tune with the nuances of climate and nature. Mass reduces temperature swings and produces a high degree of temperature stability and thermal comfort.
- Increased User Productivity: Delightful places to live and work, passive solar buildings can contribute to increased satisfaction and productivity.
- Reduced Emissions: By relying on solar energy, a renewable, non-polluting energy source, passive solar design does not generate greenhouse gases and slows fossil fuel depletion.

For small, skin-load dominated buildings in cold and temperate climates, passive solar design often involves using solar energy to provide space heating. For other kinds of structures, such as internal-load dominated buildings in warm climates, responsible passive solar design is more likely to emphasize cooling avoidance using shading devices, high performance glazing and daylighting.

In a skin-load dominated structure, energy consumption is primarily dictated by the influence of the exterior climate on a building's envelope, or "skin." Examples of typical skin-load dominated buildings include barracks and other low-rise housing, small warehouses, or small retail facilities. By contrast, internal-load dominated buildings such as schools, offices, or large retail complexes often consume the majority of their energy to provide interior lighting and to provide cooling to counteract the heat given off by people, plug-loads (such as computers), fixtures, and other internal sources. Such buildings can require cooling year-round. Note, however, that less solar radiation enters a well-shaded south window in the summer than a similarly shaded window on the north, east, or west side of the building.

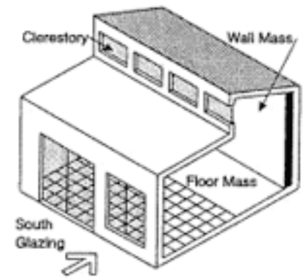
Depending on climate, the passive solar design of skin-load dominated buildings might include:

- orienting more windows to the south,
- shading to avoid summer sun,
- incorporating thermally massive construction materials,
- providing properly sized and installed insulation and,
- downsizing HVAC equipment.

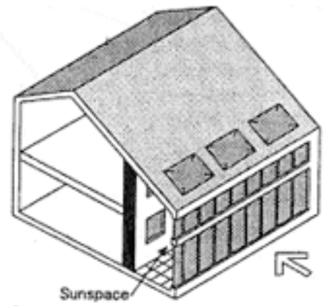
Depending on climate, the passive solar design of internal-load dominated buildings might include:

- daylighting work spaces with properly oriented and controlled windows,
- specifying high-performance glazing that reduce heat gain while admitting visible light,
- selecting high-efficiency HVAC systems and,
- incorporating adequate shading devices.

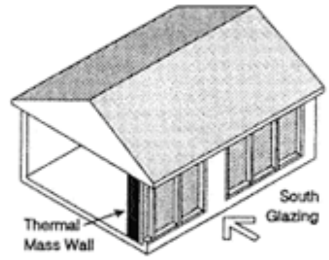
The following information focuses primarily on the Passive Solar Heating of skin-load dominated structures in temperate and cold climates.



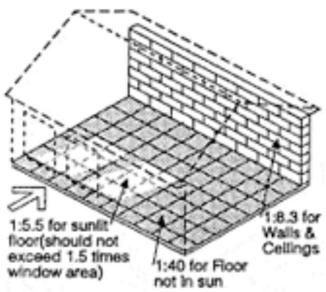
Direct Gain
Direct gain is the most common passive solar system in residential applications

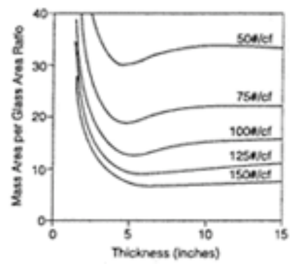


Sunspaces
Sunspaces provide useful passive solar heating and also provide a valuable amenity to homes.



Thermal Storage Wall
A thermal storage wall is an effective passive solar system, especially to provide nighttime heating.





Passive Solar Heating Fundamentals

Typically, Passive Solar Heating involves:

- the collection of solar energy through properly-oriented, south-facing windows,
- the storage of this energy in "thermal mass," comprised of building materials with high heat capacity such as concrete slabs, brick walls, or tile floors, and
- the natural distribution of the stored solar energy back to the living space, when required, through the mechanisms of natural convection and radiation,
- window specifications to allow higher solar heat gain coefficient in south glazing.

Modest levels of passive solar heating, also called sun-tempering, can reduce building auxiliary heating requirements from 5% to 25% at little or no incremental first cost and should be implemented for all small buildings in temperate and cold climates. More aggressive passive solar heated buildings can reduce heating energy use by from 25 to 75% compared to a typical structure while remaining cost-effective on a life-cycle basis. This approach should be considered for many small buildings in temperate and cold climates.

The idea of passive solar heating is simple, but applying it effectively requires attention to the details of design and construction. There are four generic passive solar heating approaches: sun-tempered, direct gain, indirect gain, and isolated gain.

a. Sun-tempering is achieved through modest increases in south-facing windows. A tract builder's house typically has about one quarter of its windows on each façade with a south glass equal to about 3% the house's total floor area. Depending on the climate, a sun-tempered house or barracks might increase this percentage to between 5 and 7%. In this case, no thermal mass needs to be added to the basic design (the "free mass" of gypsum wallboard and furnishings is sufficient to store the additional solar heat.)
b. Direct gain is the most basic form of passive solar heating. Sunlight admitted through south-facing glazing (in the Northern hemisphere) enters the space to be heated, and is stored in a thermal mass incorporated into the floor or interior walls. Depending on climate, the total direct gain glass should not exceed about 12% of the house's floor area. Beyond that, problems with glare or fading of fabrics are likely to occur, and it becomes more difficult to provide enough thermal mass for year-round comfort.
c. An indirect gain passive solar heating system (also called a trombe wall or a thermal storage wall) is a

south-facing glazed wall, usually built of heavy masonry, but sometimes using containers of water or phase change materials. Sunlight is absorbed into the wall and it heats up slowly during the day. Then as it cools gradually during the night, it releases its stored heat over a relatively long period of time indirectly into the space.

d. Isolated gain, or sunspace, passive heating collects the sunlight in an area that can be closed off from the rest of the building. The doors or windows between the sunspace and the building are opened during the day to circulate collected heat, and then closed at night, allowing the temperature in the sunspace to drop. Small circulating fans may also be used to move heat into adjacent rooms.
e. Exterior concrete walls insulated on the outside to protect the concrete from weather are now available. The concrete should be exposed on the inside to exchange heat with the room air.

It is important to incorporate adequate thermal mass in buildings that attempt to achieve a high percentage of passive solar heating.

a. When possible, the area of thermal mass should be six times the area of the accompanying glazing. Somewhat less thermal mass is necessary in a climate with foggy or rainy winters.
b. Place the mass effectively by ensuring that it is directly heated by the sun or is spread in thin layers throughout rooms in which there is a large quantity of solar collection.
c. The color of the mass surface is less important than originally thought; "natural" colors (e.g. colors in the 0.5 to 0.7 absorption range) are quite effective.
d. Thermal storage may be incorporated in floors or walls consisting of concrete, masonry, or tile. Generally, walls should remain light colored to reflect light and enhance the space.

Sizing of glass areas, insulation values, shading, and mass will depend on climate. Higher solar savings contributions will require greater amounts of glazing and mass. Be aware that the relationship between glass area and mass is not linear. For example, a doubling of glass area may require a tripling of effective thermal mass.)

Design of Passive Solar Heated Buildings

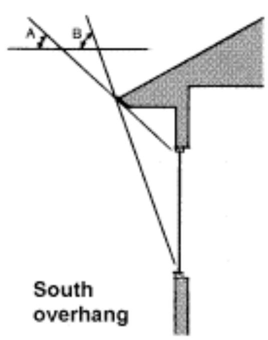
The following are general recommendations that should be followed in the design of passive solar heated buildings.

1. Passive solar heating will tend to work best, and be most economical, in climates with clear skies during the winter heating season and where alternative heating sources are relatively expensive.
2. Use passive solar heating strategies only when they are appropriate. Passive solar heating works better in smaller buildings where the envelope design controls the energy demand.
3. Careful attention should be paid to constructing a durable, energy-conserving building envelope.
4. Address orientation issues during site planning. To the maximum extent possible, reduce east and west glass and protect openings from prevailing winter winds.
5. Specify an air-tight seal around windows, doors, and electrical outlets on exterior walls. Employ entry vestibules; and keep any ductwork within the insulated envelope of the house to ensure thermal integrity. Consider requiring blower-door tests of model homes to demonstration air-tightness and minimal duct losses.
6. Specify windows and glazing that have low thermal transmittance values (U values) while admitting adequate levels of incoming solar radiation (higher Solar Heat Gain Coefficient). Data sources such as the National Fenestration Rating Council "Certified Products Directory" should be consulted for tested performance values. The amount of glazing will depend on building type and climate.
7. Ensure that the south glass in a passive solar building does not contribute to increased summer cooling. In many areas, shading in summer is just as critical as admitting solar gain in winter. Use your summer (B) and winter (A) sun angles to calculate optimum overhang design.
8. Avoid overheating. In hot climates, buildings with large glass areas can overheat. Be sure to minimize east- and west-facing windows and size shading devices properly. For large buildings with high internal heat gains, passive solar heat gain is a liability, because it increases cooling costs more than the amount

saved in space heating.

9. Design for natural ventilation in summer with operable windows designed for cross ventilation. Ceiling fans or heat recovery ventilators offer additional air movement. In climates with large diurnal temperature swings, opening windows at night will release heat to the cool night air and closing the windows on hot days will keep the building cool naturally.
10. Provide natural light to every room. Some of the most attractive passive solar heated buildings incorporate elements of both direct and indirect gain. This can provide each space a quality of light suitable to its function.
11. If possible, elongate the building along the east-west axis to maximize the south-facing elevation and the number of south-facing windows that can be incorporated.
12. Plan active living or working areas on the south and less frequently used spaces, such as storage and bathrooms, on the north. Keep south-facing windows to within 20° of either side of true south.
13. Improve building performance by employing either high-performance, low-e glazing or nighttime, moveable insulation to reduce heat loss from glass at night.
14. Locate obstructions, such as landscaping or fences, so that full exposure to the sun is available to south windows from 9 A.M. to 3 P.M. for maximum solar gain in winter.
15. Include overhangs or other devices, such as trellises or deciduous trees, for shading in summer.
16. Reduce air infiltration and provide adequate insulation levels in walls, roofs, and floors. As a starting point for determining appropriate insulation levels, check minimum levels in the CABO Model Energy Code.
17. Select an auxiliary HVAC system that complements the passive solar heating effect. Resist the urge to oversize the system by applying "rules of thumb."
18. Make sure there is adequate quantity of thermal mass. In passive solar heated buildings with high solar contributions, it can be difficult to provide adequate quantities of effective thermal mass.
19. Design to avoid sun glare. Room and furniture layouts need to be planned to avoid glare from the sun on equipment such as computers and televisions.

Solar Subdivision Layouts
Short east-west cul-de-sacs tied into north-south collectors is a good street pattern for solar access.



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Application

Among the primary types of buildings that can benefit from the application of passive solar heating principles are:

- barracks and other low-rise housing in temperate and cold climates (locations that experience above 2,000 degree days annually),
- small PX facilities (less than 10,000 square feet),
- warehouses, and
- maintenance facilities.

Case Study

McKay Center - University of Wisconsin Arboretum, Madison, WI

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Relevant Codes and Standards

- *AF Passive Solar Handbook, Volume I: Introduction to Passive Solar Concepts*
- Energy Policy Act of 2005 (PDF 1.9 MB, 550 pgs)
- *UFC 3-440-03N Design: Passive Solar Buildings*

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Additional Resources

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PRODUCTS AND SYSTEMS

Building Envelope Design Guide: Cast-in-Place Concrete Wall Systems, Masonry Wall Systems

- *Federal Green Construction Guide for Specifiers*
  03 30 00 (03300) Cast-In-Place Concrete
  03 40 00 (03300) Precast Concrete
  04 20 00 (04200) Unit Masonry

Publications

- *Designing Low-Energy Buildings with Energy-10 Software Integrating Daylighting, Energy Efficient Equipment, and Passive Solar Design in Commercial Institutional and Residential Buildings* available from SBIC.
- *E Source Electronic Encyclopedia* Rocky Mountain Institute. Available from E Source (see especially Chapter 5: Space Heating)
- *Passive Solar Design Strategies: Guidelines for Home Building* available from SBIC.
- *Passive Solar Design in Architecture*—University of Hong Kong
- *Passive Solar Design Strategies: Guidelines for Home Building* available from SBIC.
- *The Passive Solar Home Book* by Mazria, Edward. Available from Rodale Press, Emmaus, PA. (out of print)
- Proceedings of the National Passive Solar Conferences. American Solar Energy Society (ASES).
- *Sustainable Building Sourcebook*, Passive Solar Guidelines

Training Sessions

- Current FEMP renewables workshops
- SBIC workshops. These workshops teach the use of Energy-10 software using a hands-on, computer-based format.

Building Evaluations and Case Studies

- Evaluations of the performance of a number of passive solar heated buildings are available through the U.S. Department of Energy Exemplary Building Program. A description of the projects for building energy analysis is available through the National Renewable Energy Laboratory (NREL). (NREL, Public Affairs Office; 1617 Cole Boulevard, Golden, Colorado 80401)
- Solar Today magazine, published monthly by the American Solar Energy Society (ASES) has an ongoing program of case study publication. Many projects include passive solar heating (ASES, 2400 Central Avenue,

Suite G-1 Boulder, CO 80301).

Analysis Tools

- To analyze the performance of small residential-type, skin-load dominated passive solar heated buildings, use: *Guidelines for Home Building with BuilderGuide software*. This is a simple computer software tool (in a Windows format) for evaluating the solar savings fraction of a building design. The program is available from the Sustainable Buildings Industry Council (SBIC).
- To analyze the performance of small residential, institutional, and commercial passive solar heated buildings (with one or two thermal zones), use: *Passive Solar Design Strategies: Guidelines for Home Building & ENERGY-10 software*. The solar heating performance of simple commercial buildings of up to approximately 10,000 square feet can be evaluated using the Strategies and the ENERGY-10 hourly simulation program.
- To analyze the performance of large, internal-load dominated, commercial and institutional buildings, see: *DOE 2.1e (or latest)*. The solar heating performance of larger and more complex buildings requires the use of a more powerful computer program. Multi-zone programs developed by the government (Department of Energy) such as DOE2.1 and EnergyPlus are available from the Simulation Research Group, Lawrence Berkeley National Laboratory.

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