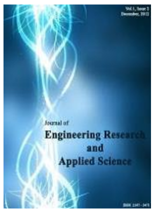
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 10 (1), June 2021, pp 1730-1740
ISSN 2147-3471 © 2021



Basic principles of passive solar heating for low carbon transition

K. Kaygusuz

Karadeniz Technical University, Chemistry, Trabzon, Turkey.

Accepted 12 May 2021

Abstract
The energy efficiency of buildings at residential sector can be greatly improved through the use of passive solar heating strategies. These strategies are universally applicable to new buildings of small to moderate size and are also applicable to many existing buildings that are suitable for retrofit. Three types of tools are provided. First, a general discussion of the basic concepts and principles of passive solar heating is presented to familiarize the reader with this technology. Second, a set of guidelines is presented for use during schematic design or for initial screening if an evaluation is being performed. These guidelines enable the user to quickly define a building that will perform in a cost-effective manner at the intended building site. Finally, a quantitative design-analysis procedure is presented that enables the user to obtain an accurate estimate of the auxiliary heating requirements of a particular passive solar design. This procedure may be used to refine a schematic design based on the guidelines already mentioned, or may be used to compare the merits of candidate designs in a proposal evaluation. The purpose of this paper is to provide the tools needed by professionals involved in building design and/or evaluation who wish to reduce the consumption of non-renewable energy resources for space heating and cooling.

Keywords: Solar energy, passive building, heating, low carbon economy, greenhouse gases.

1. Introduction

Passive solar heating is one of several design approaches collectively called passive solar design. When combined properly, these strategies can contribute to the heating, cooling, and daylighting of nearly any building. The types of buildings that benefit from the application of passive solar heating range from barracks to large maintenance facilities. Typically, passive solar heating involves [1-5]:

- 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.
- 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.

Passive solar heating systems do not have a high initial cost or long-term payback period, both of which are common with many active solar heating systems. Increased user comfort is another benefit to passive solar heating. If properly designed, passive solar buildings are bright and sunny and in tune with the nuances of climate and nature. As a result, there are fewer fluctuations in temperature, resulting in a higher degree of temperature stability and thermal comfort. By providing a delightful place to live and work, passive solar buildings can contribute to increased satisfaction and user productivity. In addition, passive solar design does not generate greenhouse gases and slows fossil fuel depletion [2-6].

There are a few considerations with passive solar design. First, to achieve the highest efficiency, the system needs to have maximum exposure to the sunlight. Second, the intensity of sunlight is intermittent, and the system can overload, which may adversely affect particular electrical appliances like air conditioners and computers. However, with the help of experienced passive solar designer architects and builders, passive solar design costs little more than conventional building design and saves money over the long term.

It is best to incorporate passive solar heating into a

[a] Corresponding author; kamilkaygusuz909@gmail.com

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. Passive solar heating strategies provide opportunities for daylighting and views to the outside through well-positioned windows. Window design is a critical factor for determining the effectiveness of passive solar heating. Passive solar features, such as additional south-facing windows, additional thermal mass, and roof overhangs, can easily pay for themselves. Overall, passive solar buildings are often less expensive when the lower annual energy and maintenance costs are factored in over the life of the building. This overview is intended to provide specific details for Turkish government building agencies considering passive solar heating technologies as part of a new construction project or major renovation.

2. Description of passive solar heating concept

Passive solar heating systems make use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating. A passive solar system does not require the use of mechanical equipment because the heat flow is by natural means, such as radiation, convection, and conductance, and the thermal storage is in the structure itself. A passive solar heating system is made up of the following key components, all of which must work together for the design to be successful (as shown in Figure 1 and 2):

- Aperture (Collector)
- Absorber
- Thermal mass
- Distribution
- Control.

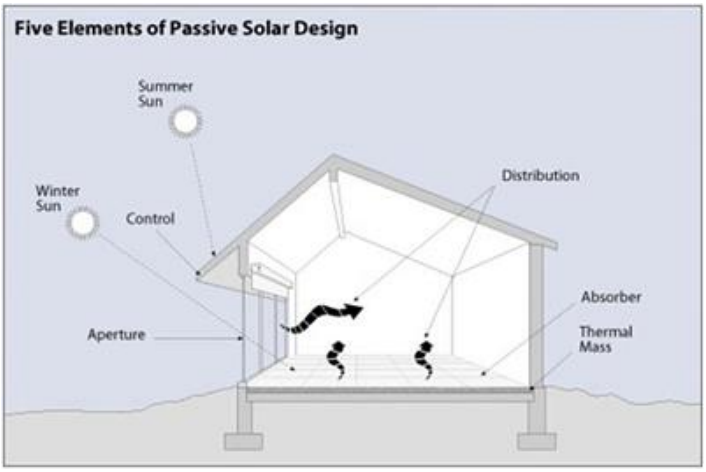


Figure 1. The five key elements of passive solar design [1].

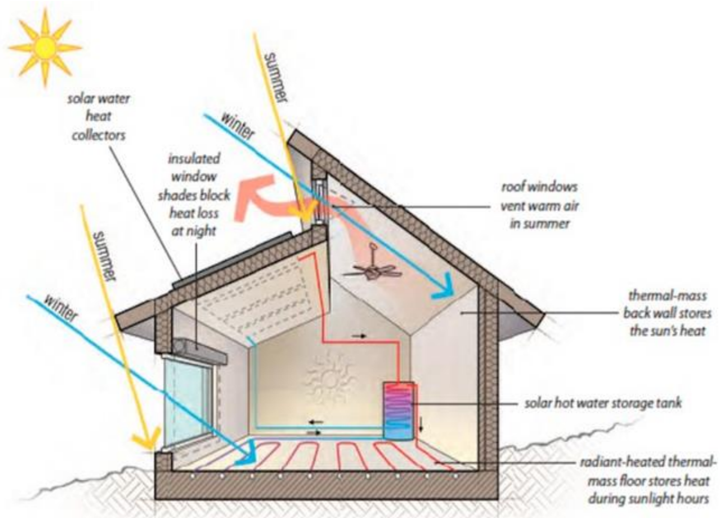


Figure 2 A Schematic overview of passive solar building concept.

In a passive solar heating system, the aperture (collector) is a large glass (window) area through which sunlight enters the building. Typically, the aperture(s) should face within 30° of true south and should not be shaded by other buildings or trees from 9 a.m. to 3 p.m. each day during the heating season. The hard, darkened surface of the storage element is known as the absorber. This surface could consist of a masonry wall, floor, or phase change material (PCM), or a water container sits in the direct path of sunlight. Sunlight then hits the surface and is absorbed as heat. The thermal mass is made up of materials that retain or store the heat produced by sunlight. The difference between the absorber and thermal mass, although they often form the same wall or floor, is that the absorber is an exposed surface, whereas thermal mass is the material below or behind that surface [7-9].

Distribution is the method by which solar heat circulates from the collection and storage points to different areas of the building. A strictly passive design will use the three natural heat transfer modes exclusively—conduction, convection, and radiation. In some applications, however, fans, ducts, and blowers may help with the distribution of heat through the building. Elements to help control under- and overheating of a passive solar heating system include roof overhangs, which can be used to shade the aperture area during summer months, electronic sensing devices, such as a differential thermostat that signals a fan to turn on, operable vents and dampers that allow or restrict heat flow, low-emissivity blinds, and awnings [1-3].

3. Passive solar design

Passive solar buildings are designed to let the heat into the building during the winter months, and block out the sun during hot summer days. This can be achieved by passive solar design elements such as shading, implementing large south-facing windows, and building materials that absorb and slowly release the sun's heat. On the other hand, incorporating shading concepts into your landscape design can help reduce the solar heat gain in the summer and reduce cooling costs. The leaves of deciduous trees or bushes located to the south of the building can help block out sunshine and unneeded heat in the summer. These trees lose their leaves in the winter, and allow an increase in the solar heat gain during the colder days. Incorporating overhangs, awnings, shutters and trellises into the building design can also provide shade [10-13].

3.1. General requirements

3.1.1 Basic concepts

The concepts introduced herein are limited to those that are further developed within the remainder of the design procedures. Thus, a comprehensive treatment is rejected in favor of one that is directed at areas of particular interest to our understanding is sufficient to warrant a quantitative treatment [1-13].

3.1.2. Direct gain heating

Direct gain buildings are passive solar heating systems in which sunlight is introduced directly to the living space through windows or other glazed apertures as indicated schematically in Figure 3. As with all passive solar systems, it is important that the apertures face south or near south in order to achieve high solar gains during the winter heating season and low solar gains during the summer cooling season [1, 2].

Thermal storage mass is essential to the performance and comfort of direct gain buildings. A building that has inadequate mass will overheat and require ventilation, which entails a loss of heat that might otherwise have been stored for night time use. Generally, it is desirable to employ structural mass as a storage medium in order to take advantage of the improved economics associated with multiple use. Insulation should always be placed on the outside of massive elements of the building shell rather than on the inside in order to reduce heat Losses without isolating the mass from the living space. Concrete floor slabs can contribute to the heat capacity of a building provided they are not isolated by carpets and cushioning pads. Heat losses from the slab can be limited by placing perimeter insulation on the outside of the foundation walls. If the structure is fairly light, the heat capacity can be effectively increased by placing water containers in the interior. A variety of attractive containers are available commercially [1,2].

An overhang, also illustrated in Figure 3, is used to shade the solar aperture from the high summer sun while permitting rays from the low winter sun to penetrate and warn the inside of the building. In climates having particularly warm and sunny summers, an overhang may not be sufficient to prevent significant aggravation of the summer cooling load. Sky diffuse and ground reflected radiation enter the living space despite the presence of an overhang and must be blocked by external covers or internal shades. Using movable insulation on direct gain apertures has the advantage of reducing night time heat losses during the winter-as well as eliminating unwanted solar gains during the summer [1].

Direct gain buildings involve less departure from conventional construction than other types of passive solar systems and are therefore cheaper and more readily accepted by most occupants. However, they are subject to overheating, glare, and fabric degradation if not carefully designed; these problems can be minimized by distributing the sunlight admitted to the building as uniformly as possible through appropriate window placement and the use of diffusive blinds or glazing materials. When properly designed for their location, direct gain buildings provide an effective means of reducing energy consumption for space heating without sacrifice of comfort or aesthetic values.

3.1.3. Daylighting

The daylight delivered to the interior of direct gain buildings is an additional resource that is available year-round. Pleasing uniform illumination can be achieved by using blinds that reflect sunlight toward white diffusive ceilings. The artificial lighting system in many buildings imposes a significant load on the cooling system that may be reduced by daylighting because the fraction of visible light in the solar spectrum is greater than the visible fraction of incandescent or fluorescent lighting [1, 2].

3.1.4. Radiant panels

Radiant panels are simple passive solar systems that are inexpensive and well suited as retrofits to metal buildings. A sketch of a radiant panel system is presented in Figure 3. Note that the solar aperture consists of one or more layers of glazing material placed over an uninsulated metal panel. The metal panel would ordinarily be a part of the building shell so that a retrofit is constructed by simply glazing an appropriate area on the south side of the structure. Any insulation or other poorly conducting material should be removed from the inner surface of the glazed portion of the metal panel to facilitate heat transfer to the interior [1]. Solar radiation is absorbed on the outer surface of the metal panel after passing through the glazing. The panel becomes hot and gives up heat to the interior by radiation and convection. Thermal mass must be included inside the building shell as with direct gain systems. Usually, only a concrete slab will be available before retrofitting a metal building and it may sometimes be necessary to add water containers to achieve the desired thermal capacitance. Radiant panels perform on a par with direct gain buildings and are likely to be less expensive when used as retrofits to metal buildings [1].

3.1.5. Thermosiphoning air panels

Thermosiphoning air panels (TAPs) are also appropriate for use on metal buildings either as retrofits or in new construction. Two configurations occur in practice and the first, which is referred to as a front-flow system, is illustrated in Figure 3. Again, there are one or more glazing layers over an absorbing metal surface but, in this case, the metal panel is insulated on the back side. Heat transfer to the interior occurs via circulation vents cut through the metal panel and its insulation at the upper and lower extremes. Solar radiation absorbed on the outer surface of the panel is converted to heat adjacent air which then rises due to buoyancy forces and passes through the upper vent into the living space. The warm air leaving the gap between the inner glazing and the absorber is replaced by cooler air from the building interior that enters through the lower vents. In this manner, a buoyancy driven loop is established and sustained as long as the temperature in the air gap exceeds that in the living space. Passive backdraft dampers or manually operated vent closures must be employed to prevent reverse circulation at night. Backdraft dampers are usually made of a lightweight plastic material suspended above a metal grid such that air flows freely in one direction but is blocked should the flow attempt to reverse.TAPs have thermal storage requirements similar to those of direct gain and radiant panel systems. Generally speaking, the best performance will be obtained from passive solar systems associated with high heat capacity structures. Although a backflow TAP performs slightly better than a comparable system in the front-flow configuration, the difference is not significant and construction costs should govern any choice between the two. Both TAP configurations outperform radiant panels and direct gain systems with comparable glazing and thermal storage mass. This performance edge is due to the low aperture conductance of TAPs, which can be insulated to arbitrary levels, thereby limiting night time heat loss [1, 2, 4, 6].

3.1.6. Thermal storage walls

A thermal storage wall is a passive solar heating system in which the primary thermal storage medium is placed directly behind the glazing of the solar aperture, as illustrated in Figure 5. The outer surface of the massive wall is painted a dark color or coated with a selective surface to promote absorption of solar radiation. Solar radiation absorbed on the outer surface of the wall is converted to heat and conducted to the inner surface where it is radiated and convected to the living space. Heat transfer to the living space is sometimes augmented by the addition of circulation vents placed at the top and bottom of the mass wall. These vents function in the same manner as the vents in a TAP system except that only a portion of the solar heat delivered by the system passes through the vents [1, 2]. A thermal storage wall provides an effective buffer between outside ambient conditions and the building interior; night time heat losses are reduced during the cold winter months, and during the summer, unwanted heat gains are limited. This moderating effect generally enables thermal storage walls to outperform direct gain systems. There are many types of thermal storage walls distinguished by the type of storage medium employed. The options included in the design procedures are reviewed in the following subsections [1, 2]:

- *Trombe wall.* A Trombe wall is a thermal storage wall that employs solid, high density masonry as the primary thermal storage medium. Appropriate thicknesses range from 15 to 45 cm depending on the solar availability at the building site (see Figure 3). Sunny climates require relatively thicker walls due to the increased thermal storage requirements. The wall may be vented or unvented. A vented wall is slightly more efficient and provides a quicker warm up in the morning but may overheat buildings containing little secondary thermal storage mass in the living space.
- *Concrete block wall.* Ordinarily, a thermal storage wall would not be constructed of concrete building blocks, because solid masonry walls have a higher heat capacity and yield better performance. However, concrete block buildings are very common in the Navy and offer many excellent opportunities for passive solar retrofits. The south facing wall of a concrete block building can be converted to a thermal storage wall by simply painting the block a dark color and covering it with one or more layers of glazing. Walls receiving this treatment yield a net heat gain to the building that usually covers the retrofit costs rather quickly. The relatively low heat capacity of concrete block walls is offset somewhat by the large amount of secondary thermal storage mass usually available in these buildings. Concrete floor slabs and massive partitions between zones help prevent overheating and otherwise improve the performance of concrete block thermal storage walls. Concrete block thermal storage walls may also be introduced during the construction of new buildings. For new construction, however, it is advisable to take advantage of the superior performance of solid masonry walls by filling the cores of the block in the thermal storage wall with mortar as it is erected. This process is inexpensive and the resulting performance increment covers the increased cost. The design procedures developed herein are applicable to 8-inch concrete block thermal storage walls with filled or unfilled cores.
- *Water wall.* As the name implies, water walls are thermal storage walls that use containers of water placed directly behind the aperture glazing as the thermal storage medium. The advantage over masonry walls is that water has a volumetric heat capacity about twice that of high-density concrete; it is therefore possible to achieve the same heat capacity available in a Trombe wall while using only half the space. Furthermore, a water wall can be effective at much higher heat capacities than a Trombe wall because natural convection within the container leads to nearly isothermal condition that utilizes all of the water regardless of the wall thickness. The high thermal storage capacity of water walls makes them especially appropriate in climates that have a lot of sunshine.
- *Sunspaces.* There are many possible configurations for a sunspace but all of them share certain basic characteristics; a representative schematic is presented in Figure 3. Sunlight enters the sunspace through south facing glazing that may be vertical or inclined or a combination of the two and is absorbed primarily on mass surfaces within the enclosure; the mass may be masonry or water in appropriate containers and is generally located along the north wall and in the floor. The massive elements provide thermal storage that moderates the temperature in the enclosure and the rate of heat delivery to the living space located behind the north wall.

Operable windows and circulation vents in the north wall provide for heat transfer by thermal convection from the sunspace to the living space. The north wall may be an insulated stud wall placed behind containers of water or a masonry wall through which some of the heat in the sunspace is delivered to the building interior by thermal conduction as occurs in a Trombe wall. A sunspace may be semi-enclosed by the main structure such that only the south facing aperture is exposed to ambient air, or may be simply attached to the main structure along the north wall of the sunroom, leaving the end walls exposed.

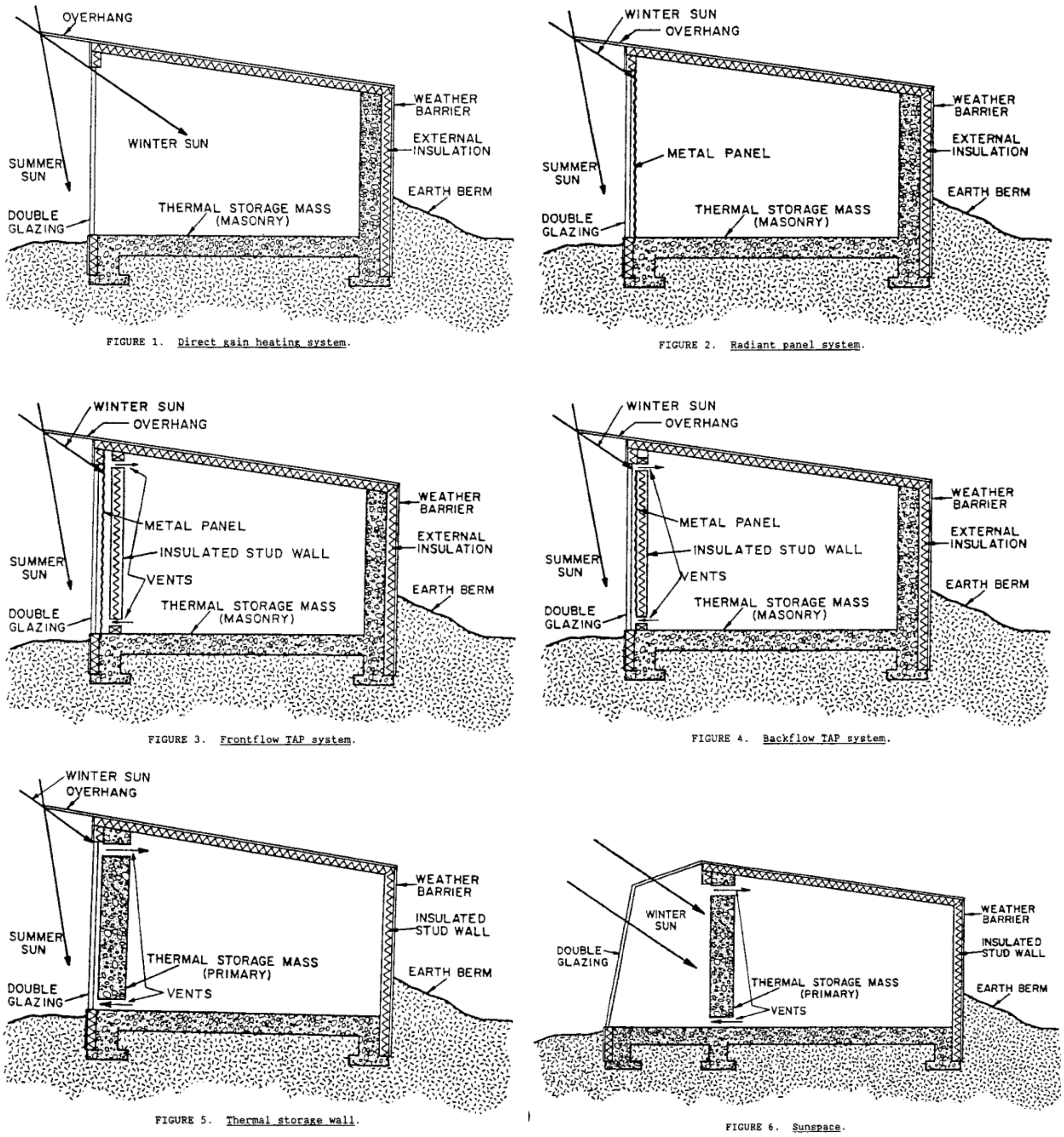


Figure 3. A schematic overview of the passive solar concepts [1, 2].

Effective thermal mass materials, like concrete, or stone floor slabs, have high specific heat capacities, as well as high density. It is ideally placed within the building where it is exposed to winter sunlight but insulated from heat loss. The material is warmed passively by the sun and releases the thermal energy into the interior during the night. On the other hand, the most important characteristic of passive solar design is that it is holistic, and relies on the integration of a building's architecture, materials selection, and mechanical systems to reduce heating and cooling loads. It is also important to consider local climate conditions, such as temperature, solar radiation, and wind, when creating climate-responsive, energy conserving structures that can be powered with renewable energy sources [1, 2, 3, 4].

In climates that are appropriate for passive solar heating, large south-facing windows are used, as they have the most sun exposure in all seasons. Although passive solar heating systems do not require mechanical equipment for operation, fans or blowers may 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. This typically includes 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.

4. Skin-load and internal-load dominated

There are two main uses for passive solar heating: skin-load dominated buildings in cold and temperate climates, and internal-load dominated buildings in warm climates. 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 [1-13].

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. 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
- Downsizing heating, ventilating, and air conditioning (HVAC) equipment.

Internal-load dominated buildings such as educational facilities, 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 [1].

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
- Incorporating adequate shading devices.

5. Types and costs of technology

There are four generic passive solar heating approaches for skin-load dominated buildings: (1) sun-tempered, (2) direct gain, (3) indirect gain, and (4) isolated gain (Figure 4).

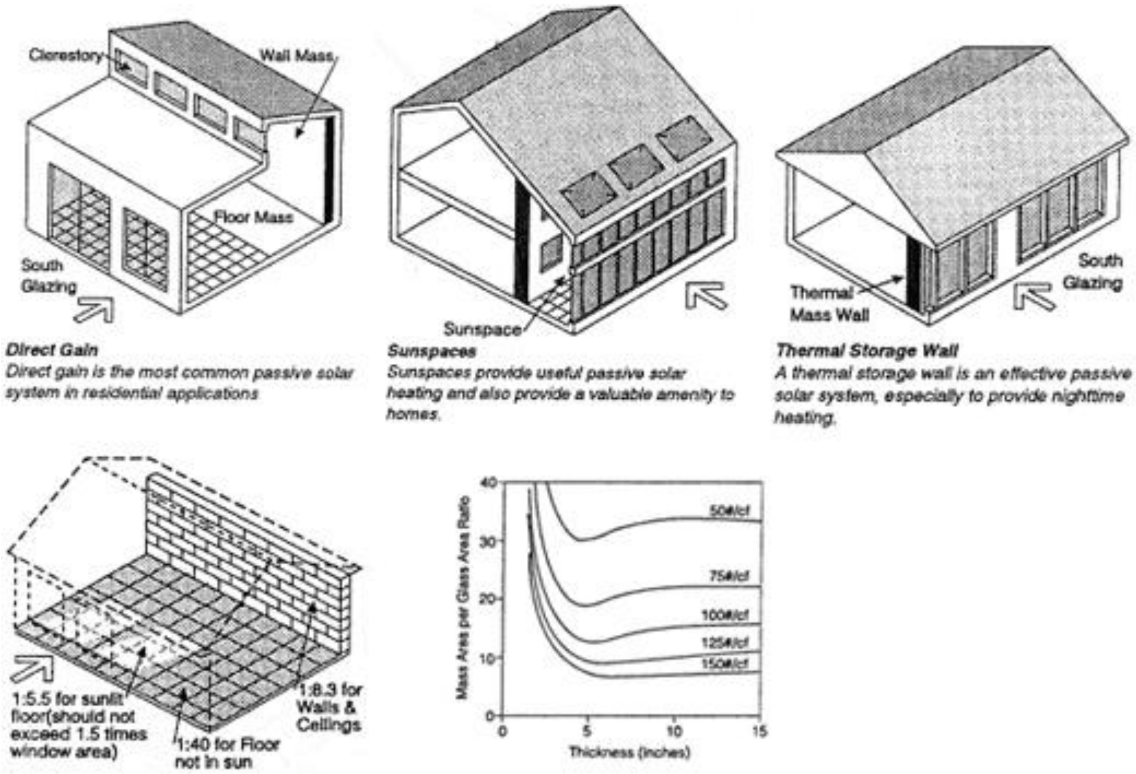


Figure 4. The four approaches for passive solar heating in skin-load dominated buildings [2].

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 facade with a south glass equal to about 3% of 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. 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 [1, 2].

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. 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.

5.1. Economics

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 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 [1, 2, 3, 4].

With the help of experienced passive solar designer architects and builders, passive solar design costs little more than conventional building design and saves money over the long term. However, in areas where experienced solar architects and builders are not available, construction costs can run higher than for conventional buildings, and mistakes can be made in the choice of building materials, especially window glass. For example, passive solar homes are often built using glass that rejects solar energy. Unfortunately, this is a costly mistake. The right glass choice depends on the climate and on which side of the building (east, west, north, or south) the glass is installed. During the summer or in consistently warm climates, daylighting could actually increase energy use in a building by adding to its air-conditioning load.

5.2. Resource availability

In climates with clear skies during the winter heating season and where alternative heating sources are relatively expensive, passive solar heating will tend to work the best and be the most economical option. A good passive solar site is one that will allow its solar surfaces to face true south with a minimal amount of shading in the solar access zone. Facing solar surfaces to the south is not enough to ensure their performance; the area to the south must be clear of obstructions that could block the sun from reaching them. In the winter, there should be no significant blockage between 9 a.m. and 3 p.m. solar time.

Obstructions directly to the south of the building need to be located at a distance of at least 1.7 times their height away from the surface to avoid shading the building in winter. Obstructions located along the 45° lines east or west of south need to be at least 3.5 times their height away from the building to avoid shading. It is important to remember that the sun is lower in the sky and casts longer shadows in winter. Therefore, even if the site is unshaded in summer, it may not remain that way in winter.

6. Design considerations

Pay careful attention when constructing a durable, energy-conserving building envelope. Address orientation issues during site planning. To the maximum extent possible, reduce glass on the east and west sides and protect openings from prevailing winter winds. Establish 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 building to ensure thermal integrity. Consider requiring blower-door tests of model homes to demonstrate air-tightness and minimize duct losses. Specify windows and glazing that have low thermal transmittance values (U values) while admitting adequate levels of incoming solar radiation. The amount of glazing will depend on building type and climate. 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. From the overhang use summer (B) and winter (A) sun angles to calculate optimum overhang design (Figure 5).

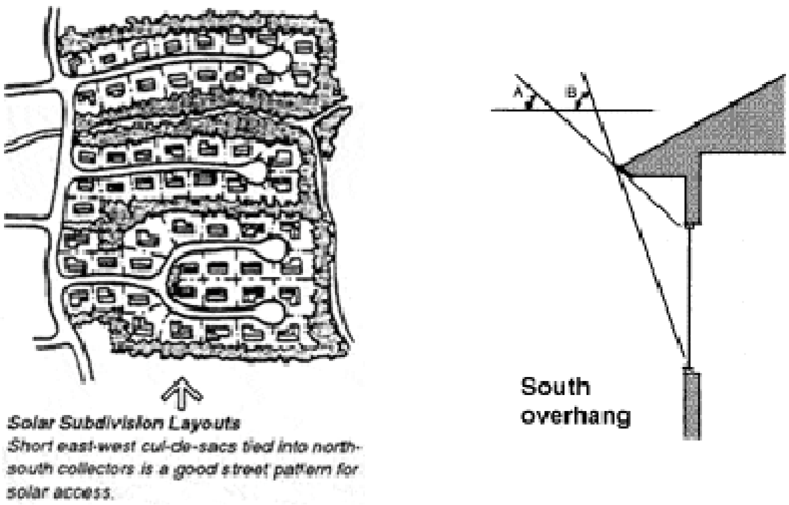


Figure 5. Solar subdivision layouts and south overhang angles [1, 2].

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. 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 [1-5].

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 with a quality of light that is suitable to its function. Elongate the building (if possible) along the east-west axis to maximize the south-facing elevation and the number of south-facing windows that can be incorporated. Plan active living or working areas on the south side of the building and less frequently used spaces, such as storage and bathrooms, on the north side. Keep south-facing windows to within 20° of either side of true south.

Improve building performance by employing either high-performance, low-e glazing or nighttime, moveable insulation to reduce heat loss from glass at night. 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. Include overhangs or other devices, such as trellises or deciduous trees, for shading in summer. 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 Council of American Building Official's Model Energy Code [1-3].

Select an auxiliary (HVAC) system that complements the passive solar heating effect. Resist the urge to oversize the system by applying "rules of thumb." 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. 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.

7. Conclusions

Passive solar heating is the most cost-effective method to heat buildings. In most locations, the amount of solar energy that falls on the roof of a house is more than the total energy consumed within the house. In passive solar architecture, much of this wasted heat can be captured without adding substantially to the cost of the structure. A passive solar and energy efficient design can reduce the monthly operational costs of any home. Because heating and cooling require the most energy in most homes, reducing heating and cooling requirements via a passive design can generate large monthly savings, typically from 50 to 70%.

Most buildings are designed with a HVAC system using forced air or water (furnace, boiler, radiant floor, etc.). In passive building designs, the HVAC system is integrated into the building design elements and materials: the windows, walls, floors, and roof are all used as the heat collecting, storing, releasing, and distributing system. Passive solar does not necessarily mean the elimination of standard mechanical systems, although high efficiency back-up heating systems greatly reduce the size of the traditional heating systems and reduce the amount of non-renewable fuels needed to maintain comfortable indoor temperatures, even in the coldest climates.

Acknowledgement: The author acknowledged to the Turkish Academy of Science (TÜBA).

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