

Passive Solar Design of Buildings – A Case Study

Sanjiv Kumar* and Manjeet Bansal**

*Department of Civil Engineering, GZS College of Engineering & Technology,
Bathinda, India, sanjiv_aggarwal@rediffmail.com

**Department of Civil Engineering, GZS College of Engineering & Technology,
Bathinda, India, push_kar5@yahoo.com

ABSTRACT

Passive solar technologies are means of using sunlight for useful energy without use of active mechanical systems, as contrasted to active solar techniques. The scientific basis for passive solar building design has been developed from a combination of climatology, thermodynamics, particularly heat transfer, and human thermal comfort. Specific attention is directed to the site and location of the dwelling, the prevailing climate, design and construction, solar orientation, placement of glazing-and-shading elements, and incorporation of thermal mass. The Solar Passive Complex of Punjab Energy Development Agency (PEDA), at Chandigarh, India is a unique and successful model of energy efficient solar building, designed on solar passive architecture. More than 90% reduction in lighting consumption, and more than 50% saving in overall energy consumption has been achieved in this complex, which thus provides a clean and pollution free work environment.

Keywords: solar, building, architecture, energy, environment.

1 INTRODUCTION

Passive solar technologies are means of using sunlight for useful energy without use of active mechanical systems, as contrasted to active solar techniques. Such technologies convert sunlight into usable heat in the form of water, air, thermal mass; cause air-movement for ventilating, or future use, with little use of other energy sources. Passive cooling is the use of the same design principles to reduce summer cooling requirements. Technologies that use a significant amount of conventional energy to power pumps or fans are active solar technologies. 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, 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. Low-grade energy needs, such as space and water heating, have

proven, over time, to be better applications for passive use of solar energy.

2 PASSIVE SOLAR DESIGN OF BUILDINGS

Passive solar design refers to the use of the sun's energy for the heating and cooling of living spaces. In this approach, the building itself or some element of it takes advantage of natural energy characteristics in materials and air created by exposure to the sun. Passive systems are simple, have few moving parts, and require minimal maintenance and require no mechanical systems. Operable windows, thermal mass, and thermal chimneys are common elements found in passive design. Operable windows are simply windows that can be opened. Thermal mass refers to materials such as masonry and water that can store heat energy for extended time. Thermal mass will prevent rapid temperature fluctuations. Thermal chimneys create or reinforce the effect hot air rising to induce air movement for cooling purposes. Wing walls are vertical exterior wall partitions placed perpendicular to adjoining windows to enhance ventilation through windows.

The scientific basis for passive solar building design has been developed from a combination of climatology, thermodynamics, particularly heat transfer, and human thermal comfort. Specific attention is directed to the site and location of the dwelling, the prevailing climate, design and construction, solar orientation, placement of glazing-and-shading elements, and incorporation of thermal mass. While these considerations may be directed to any building, achieving an ideal solution requires careful integration of these principles. Modern refinements through computer modeling and application of other technology can achieve significant energy savings without necessarily sacrificing functionality or aesthetics.

3 ELEMENTS OF PASSIVE SOLAR DESIGN

Passive solar buildings range from those heated almost entirely by the sun to those with south-facing windows that provide some fraction of the heating load. The difference between a passive solar building and a conventional building is its design, and the key is designing a passive

solar building to take the best advantage of the local climate. Elements of design include window location and glazing type, insulation, air sealing, thermal mass, shading, and sometimes, auxiliary heat. Passive solar design techniques can be most easily applied to new buildings. However, existing buildings can also be adapted or retrofitted to passively collect and store solar heat. In some ways, every building is a passive solar building because it has windows, but designing a building to work in its climate is the basis for these techniques. Every passive solar building includes five distinct elements: the aperture, absorber, thermal mass, the distribution and the control, as shown in Figure 1 [1].

3.1 Aperture (Collector)

This is the 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.

3.2 Absorber

This is the hard, darkened surface of the storage element. This surface, which could be masonry wall, floor, or partition (phase change material), or a water container, sits in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.

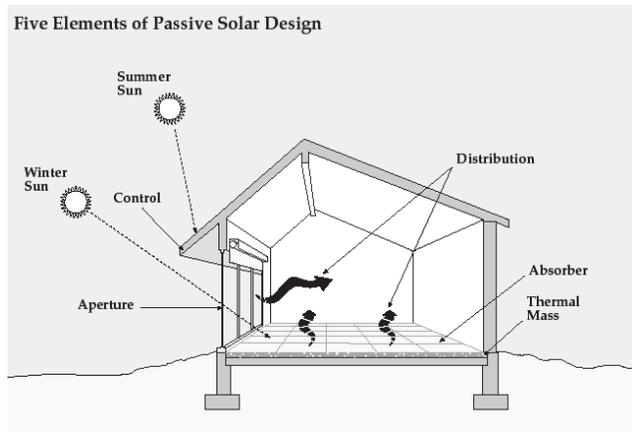


Figure 1: Five Elements of Passive Solar Design

3.3 Thermal Mass

These are the 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 storage is the material below or behind that surface. The thermal mass must be insulated from the outside temperature, otherwise the collected solar heat can drain away rapidly, especially when thermal mass is directly

connected to the ground, or in contact with outside air whose temperature is lower than the desired temperature of the mass.

3.4 Distribution

This 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, i.e., conduction, convection and radiation exclusively. In some applications, however, fans, ducts and blowers may help with the distribution of heat through the building.

3.5 Control

The roof overhangs can be used to shade the aperture area during summer months. Other elements that control under and/or overheating include: 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 sunshades.

4 BASIC TYPES OF PASSIVE SOLAR DESIGN

There are three basic types of passive solar design, i.e., direct gain, indirect gain and isolated gain that differ in how the above five elements of design are incorporated. Each performs a separate function, but all five must work together for the system to be successful [2].

4.1 Direct Gain

Direct gain is the simplest passive design technique. In this system, the actual living space is a solar collector, heat absorber and distribution system. South facing glass admits solar energy into the house where it strikes directly and indirectly thermal mass materials in the house such as masonry floors and walls as shown in Figure 2. The direct gain system will utilize 60 – 75% of the sun's energy striking the windows. In this system, the thermal mass floors and walls are functional parts of the house. It is also possible to use water containers inside the house to store heat. However, it is more difficult to integrate water storage containers in the design of the house. The thermal mass will temper the intensity of the heat during the day by absorbing the heat. At night, the thermal mass radiates heat into the living space.

The amount of passive solar fraction depends on the area of glazing and the amount of thermal mass. The glazing area determines how much solar heat can be collected. And the amount of thermal mass determines how much of that heat can be stored. It is possible to undersize the thermal mass, which results in the house overheating.

There is a diminishing return on over sizing thermal mass, but excess mass will not hurt the performance. The ideal ratio of thermal mass to glazing varies according to the climate.

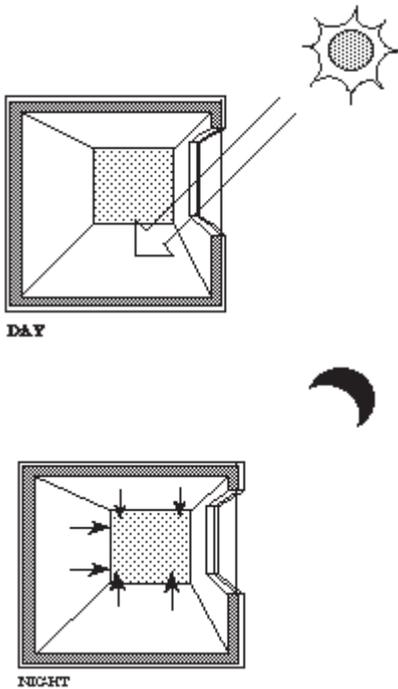


Figure 2: Direct Gain System

4.2 Indirect Gain – Trombe Wall

An indirect-gain passive solar building has its thermal storage between the south-facing windows and the living spaces. Using a Trombe wall as shown in Figure 3 is the most common indirect-gain approach.

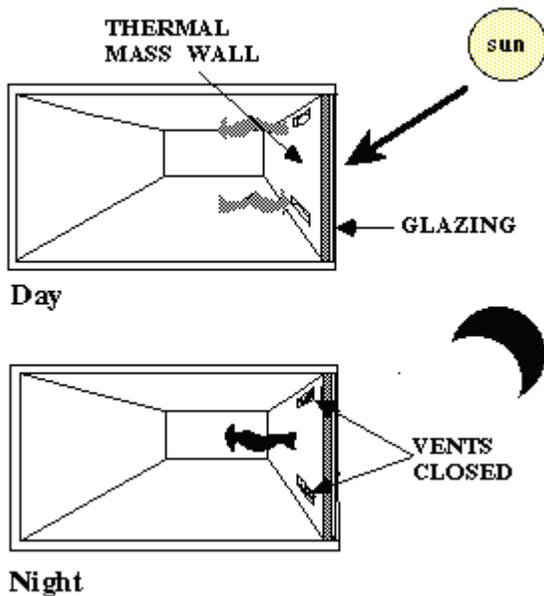


Figure 3: Trombe Wall or Thermal Mass Wall

The wall consists of an 8 inch to a 16 inch-thick masonry wall on the south side of a house. A single or double layer of glass is mounted about 1 inch or less in front of the wall's surface. Solar heat is absorbed by the wall's dark colored outside surface and stored in the wall's mass, where it radiates into the living space. The Trombe wall distributes or releases heat into the building over a period of several hours. Solar heat migrates through the wall, reaching its rear surface in the late afternoon or early evening. When the indoor temperature falls below that of the wall's surface, heat begins to radiate and transfer into the room. For example, heat travels through a masonry wall at an average rate of 1 hour per inch. Therefore, the heat absorbed on the outside of an 8-inch thick concrete wall at noon will enter the interior living space around 8 p.m.

4.3 Isolated Gain – Sunspace

A sunspace is also known as a solar room or solarium. It is a versatile approach to passive solar heating. A sunspace can be built as part of a new building or as an addition to an existing one. The simplest and most reliable sunspace design is to install vertical windows with no overhead glazing. Sunspaces may experience high heat gain and high heat loss through their abundance of glazing. The temperature variations caused by the heat losses and gains can be moderated by thermal mass and low-emissivity windows. The thermal mass that can be used include a masonry floor, a masonry wall bordering the house or water containers. The distribution of heat to the house can be accomplished through ceiling and floor level vents, windows, doors or fans. Most builders also separate the sunspace from the building with doors and/or windows so that the comfort inside the house isn't overly affected by the sunspace's temperature variations.

Sunspaces may often be called and look a lot like greenhouses. However, a greenhouse is designed to grow plants while a sunspace is designed to provide heat and aesthetics to a building. Many elements of a greenhouse design, such as overhead and sloped glazing, which are optimised for growing plants, are counterproductive to an efficient sunspace. Moisture related fungus and decay, insects and dust inherent to gardening in a greenhouse are not especially compatible with a comfortable and healthy living space. Also, to avoid overheating, it is difficult to shade sloped glass, while vertical glass can be shaded with a right-sized overhang.

5 PEDDA SOLAR PASSIVE COMPLEX

The Solar Passive Complex of Punjab Energy Development Agency (PEDA), at Chandigarh, India is a unique and successful model of an energy efficient solar building, which has been designed on solar passive architecture, with a total covered area 68,224 sq.ft. including 23,200 sq.ft. basement [3]. It is the centre of

excellence for solar buildings, minimizing conventional lighting load in the office building, efficient movement of natural air, light vaults, wind tower coupled with solar chimney, Water bodies, designed landscape horticulture and energy conservation activities. The main aims & objectives of this complex are to demonstrate the Solar Passive Architecture concepts, to educate architects, engineers & builders for replication of concepts, and to generate awareness among general public, teachers, students of school and colleges. The building has the following salient design features:

Orientation: Solar Passive Complex has been developed in response to solar geometry i.e. minimizing solar heat gain in cold period. The building envelope attenuates the outside ambient conditions and the large volume of air is naturally conditioned by controlling solar access in response to the climatic swings.

Solar Power Plant: 25Kwp building integrated solar photovoltaic power plant has been set up to meet the basic requirement of electricity in the complex.

Unique Shell Roofing on Central Atrium: The central atrium of the complex having main entrance, reception, water bodies, cafeteria and sitting place for visitors constructed with hyperbolic shell roof to admit daylight without glare and heat coupled with defused lighting through glass to glass solar panels. The roof is supported with very light weight space frame structure.

Water Bodies: The water bodies with waterfalls and fountains have been placed in the central atrium of the complex for cooling of whole the complex in the hot and dry period.

Light Vaults: The vertical cutouts in the floating slabs are integrated with light vaults and solar activated naturally ventilating, domical structures in the south to admit day light without glare and heat.

Cavity Walls: The complex is a single envelope made up of its outer walls as double skin walls having 2" cavity in between. The cavity walls facing south and west are filled with further insulation material for efficient thermal effect.

Unique Floating Slab System: The system of floating and overlapping slab with interpenetrating vertical cutouts allow free and quick movement of natural air reducing any suffocating effect.

Landscape Horticulture: The space around the building inside and outside of boundary wall and a big lawn in the south has been designed with trees, shrubs and grass. The big trees along the boundary wall acts as a curtain to minimize air pollution, sound pollution and filter/cool the entry of air.

Wind Tower Coupled with Solar Chimneys: The wind tower centrally placed coupled with solar chimneys on the domical structures for scientific direct & indirect cooling and scientific drafting of used air.

Insulated Roofing: All the roofs have been insulated with double insulation system to avoid penetration of heat from the roof.

Auditorium: A unique auditorium scientifically designed to control heat penetration, light & sound distribution is placed in the north under the shade of main building.

Big Exhibition Centre: The complex is having a proper designed exhibition centre for display of renewable & non-conventional energy devices / equipments.

Unique Workstations: Scientifically designed and fully equipped unique workstations have been made for the employees having comfortable environment, good ergonomics with sufficient natural light and air.

6 CONCLUSIONS

The basic natural processes that are used in passive solar energy are the thermal energy flows associated with radiation, conduction, and natural convection. These basic responses to solar heat lead to design elements, material choices and placements that can provide heating and cooling effects in a building. Key aspects of passive design include appropriate solar orientation, the use of thermal mass, and appropriate ventilation and window placement. Passive design is practiced throughout the world and has been shown to produce buildings with low energy costs, reduced maintenance, and superior comfort. In the PEDAs Passive Solar Complex in Chandigarh, more than 90% reduction in lighting consumption, and more than 50% saving in overall energy consumption has been achieved, which thus provides a clean and pollution free work environment. This building heralds the beginning of the energy efficiency movement in the non-domestic buildings such as offices, educational institutions and factories in India.

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