ENERGY IMPACT IN SOLAR PASSIVE BUILDING

A Strategic Energy Conservation

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Abstract: The current development patterns prevalent in the world are having a negative impact on our environment. It is imperative to conserve what resources remain by utilizing them in as judicious a way as possible. The current problem, climate change, which has been increasingly threatening has reached a point that could have disastrous consequences in future. Passive solar heating and cooling represents an important strategy for displacing traditional energy sources in buildings. Passive solar techniques make use of the steady supply of solar energy by means of building designs that carefully balance their energy requirements with the building's site and window orientation. The term passive indicates that no additional mechanical equipment is used, other than the normal building elements. 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. All solar gains are brought in through windows. All passive techniques use building elements such as walls, windows, floors and roofs, in addition to exterior building elements and landscaping, to control heat generated by solar radiation. Solar heating designs collect and store thermal energy from direct sunlight. Passive cooling minimizes the effects of solar radiation through shading or generating airflows with convection ventilation. The benefits of using passive solar techniques include simplicity, price and the design elegance of fulfilling one's needs with materials at hand.

Keywords: passive design, energy conservation, natural ventilation, day lighting, solar energy

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I. Introduction

Buildings form a major component of today's world. The construction sector poses a major challenge to the environment. Globally, buildings are responsible for at least 40% of energy use. An estimated 42% of global water consumption and 50% of global consumption of raw materials is consumed by buildings. In addition, Building activities contribute an estimated 50% of world's air pollution, 42% of its greenhouse gases, 50% of all water pollution, 48% of all solid wastes and 50% of all chlorofluorocarbons (CFC) to the environment. As a design approach, passive solar design can take many forms. It can be integrated to greater or lesser degrees in a building. Key considerations regarding passive design are determined by the characteristics of the building site. The most effective designs are based on specific understanding of a building site's wind patterns, terrain, vegetation, solar exposure and other factors often requiring professional architectural services. However, a basic understanding of these issues can have a significant effect on the energy performance of a building.

At macro level, extensive urbanization is leading to uncontrolled 'heat island' effect. Vegetation and tree cover give way to urban areas with large expanses of pavements, buildings and thus eliminating cooling provided by vegetation through both shade evapotranspiration. This contributed to formation of ground level ozone, which is detrimental to human health. Moreover, this also increases demand for air conditioning. Increased air conditioning demands increased generation of electricity which again contributes to the emission of green house gases. The sun plays a major role in designing of buildings. All traditional buildings around the world have been suitably adapted to the local climate which in turn primarily governed by the sun. Design principles, in most of the traditional buildings, revolve around the position of the sun during a given time of the year. Passive solar systems use the energy from the sun to heat, cool, and illuminate buildings. Two broad categories of solar concepts: (1) those that use the energy from the sun to directly or indirectly impact the thermal needs (heating and cooling energy use) of the building, and (2) those that use the energy from the sun to directly impact the lighting needs of the building. Solar systems that heat or cool the building will be called solar thermal systems; ones that light the building will be called day lighting systems.

II. Solar Passive Architecture

Solar passive architecture adopts principles which are a direct adaptation of traditional architecture of various regions. These principles have been refined over centuries and are known as energy efficient. A solar passive building when coupled with optional water and waste recycling strategies, adoption of low embodied energy materials and renewable energy technologies can yield a building as close to the sustainable model as possible. Green rating for integrated habitat assessment (GRIHA) attempts to mainstream these features in order to enrich the country not only with environmentally friendly green buildings but also aesthetically rich building. GRIHA understands the importance of these traditional principles of design and encourages architect to adopt them while designing the building.

There are various levels at which green buildings can adopt solar passive design techniques. The interventions begin from site planning and landscape design and proceed towards the building envelope and interior design of the building. Criteria 4, 13 and 14 of GRIHA rating system emphasize upon adoption of solar passive principles in building design. Criterion 4 encourages incorporation of existing site features in building design, one of which is building orientation. The criterion 13 of the GRIHA rating places great emphasis on solar passive design of buildings. The objective of criteria 13 is “To apply solar passive measures, including day lighting, in order to reduce the demand on conventional energy for space conditioning and lighting systems in buildings”. This particular criterion also has a direct impact on criteria 14 which measures the reduction in energy demand of a building. Buildings designed on solar passive principles tend to consume much less energy compared to conventional buildings.

A. Orientation

Orienting the building correctly to the local sun path is one of the first and foremost interventions towards designing a solar passive building. By ensuring that the building is correctly oriented (as shown in fig. 1), one ensures that there is no excess heat gain and helps in positioning the windows to allow for maximum daylight penetration in the building. After the building is appropriately oriented, external landscape can further assist in reducing the heat gains into the building. In composite climates, such as warm and humid climate, hot and dry climate, the heat gain from east and west sides is quite crucial. The northern facades in composite climate do not require any shading from the sun. The east and west facades get sun at quite low angles, this result in harsh light levels as well as high heat gains. Thus it is recommended for composite climates, to completely cut off the sun on the eastern and western sides. On the south side, the sun can be easily cut off during summer by designing appropriate shading devices and during winter, the sun is low in the sky which allows it to penetrate deeper into the building, thereby heating the internal spaces and reduced the need for mechanical heating devices. This forms part of the criteria-4 of the GRIHA rating which requires incorporating existing site features into the building.

Landscape design around the building helps in reducing the energy requirement of any given building. As in case of composite climates, planting evergreen trees on the eastern and western sides of a building will ensure that it is appropriately shaded throughout the year and gains minimum heat from these two sides. On the southern side, deciduous trees on the south facade are that these trees shed their leaves during winter and retain them during summer. Thus they help shade the building during summer and allow sun ray to penetrate through during the winter. After the building is oriented correctly on site, the next important intervention is the design of the building envelope, shading devices and internal layouts. The maximum amount of sunlight and heat enters a building through its glazed area. In regions where one wants to prevent sunlight from entering the building, the glazed area of the facade is minimized while in colder regions, allowing the sunlight to enter the building reduces demand mechanical heating and thus in such regions, the glazed area of the façade is increased. The windows are also the source of natural light and ventilation for a building. Having insufficient windows would result in increased dependence on artificial lighting systems as the amount of natural daylight entering into a building would get reduced. Thus, the glazed area of the facades has to be balanced with the amount of day lighting entering into the building.

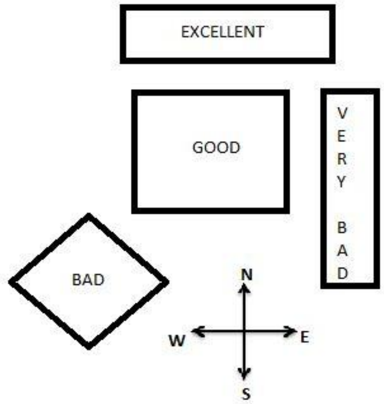

Figure 1. Building orientations with directions

B. Passive Solar Heating Systems

Passive solar system often categorized by the relationship between the solar system and the building, that is, whether or not the solar system is part of a room being heated, part of the building, or totally separate from the building. Using this reasoning, there are three categories of passive solar heating systems :(1) Direct gain systems, (2) Indirect gain systems and (3) Isolated gain systems. Direct sunlight brings with it light as well as heat components while the indirect or diffused sunlight bring sufficient light while reducing the amount of heat gain getting transferred into the building (shown in fig. 2),. In cold climatic region direct sun light is desirable. In order to prevent direct sunlight entering into a building, appropriate shading devices and optimum window areas must be designed. The shading devices are designed such that they cutoff direct sunlight from entering the building while simultaneously permitting maximum natural diffused daylight inside the building. This reduces the heat gain inside the building while reducing the need for artificial lighting (shown in fig. 3).

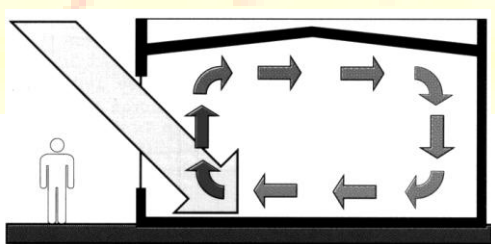

Figure 2: Direct Gain (DG) Schematic

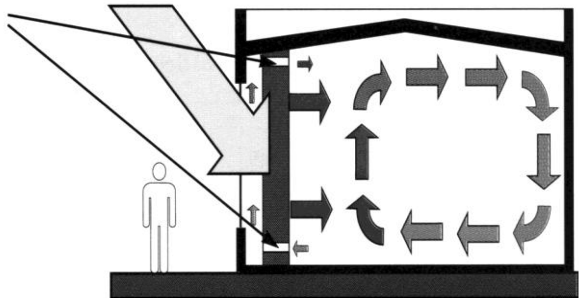

Figure 3: Indirect Gain (IND) Schematic

The internal layouts of a building can also be designed in response to local sun path. This can be done by organizing the service areas within a building towards the direction which needs to have a thermal buffer. A thermal buffer acts as a space between outside and inside a building and leads to reduce heat transfer. Thus in composite climate, having toilets and staircases on the west side of a building would ensure that extreme heat from the west does not enter into the living spaces. Such interventions affect a reduction in the amount of energy required to cool the living areas like bedrooms, living room etc. Adopting these various solar passive design features can lead to a reduction in operational energy requirement by up to 15%. An energy efficient building design leads to minimum negative environmental impact of building and helps in the reducing dependence on conventional sources of energy. Moreover, an integrated approach leads to the most effective and energy efficient building design. The basic principles of energy efficient building design are outlined below:

- Climate responsive building or solar passive building design guidelines to minimize load on conventional energy demand.
- Optimization of electro-mechanical (lighting and HVAC) systems to reduce energy consumption.
- Use of renewable energy systems (solar photo voltaic system and solar water heating systems) for generation of green energy.

Currently, the construction sector design prefers building with glass walls. The building designs do not respond to macro or micro climate parameters. The windows do not have shading devices to reduce direct sunlight, improper designed openings force building occupants to close the blinds even during the day, and turn on artificial lights. This substantially increases the heat gain inside the building. Such buildings require utilization of energy-intensive mechanical systems for providing visual and thermal comfort to the occupants.

III. Elements of Passive Solar Building

Every passive solar building includes five distinct elements: the aperture (or collector), the absorber, thermal mass, the distribution, and the control (shown in fig. 4 below.)

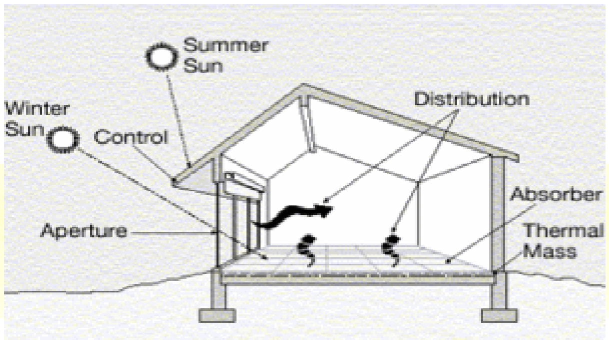

Figure 4: Elements of passive solar building

A. Collection

Passive heating concepts use heat from the sun to offset winter heating needs. The collection subsystem may include windows, skylights, or some other type of solar aperture. The purpose of collection subsystem is to allow sunlight into the building to heat the space and, if appropriate, to heat the storage mass. The storage subsystem usually includes parts of the floor or interior walls of the building. The aperture(s) should face within 30 degrees 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.

B. Storage

The purpose of the storage subsystem is to store the collected solar heat until it is needed by the occupants in the building. In most cases, heat is collected during the daytime and used at night. Stored energy is released from the storage mass and distributed throughout the building to offset heating energy use. Storage elements signifies such as masonry wall, floor, or partition (phase change material), or any other material in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.

C. Distribution

Distribution is accomplished by arranging the functional spaces of the building such that those that need heat are closest to the storage subsystem. The size and shape of the solar apertures (collection subsystem) affects the quantity of heating energy available to offset auxiliary heating energy needs. The size of the storage subsystem affects the quantity of heat stored and the time delay between initial collection and final use of energy. The size, shape, and location of rooms in the building, impact the optimum distribution of the heat throughout the building. Heat distribution is accomplished by a combination of radiation and convection. Heat is radiated from the storage subsystem into the rooms being heated after the collected solar energy has passed through the storage system. Heat is convicted through the air, warming it, and thereby warming the people in the room.

d. *Control*

Roof overhangs can be used to shade the aperture area during summer months. Other elements that control under – and/or overheating include: electronics 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. In many passive buildings, the control mechanisms are manual; that is, people control the building. A balance between the size, shape, and location of each subsystem must be achieved to ensure optimal system performance and efficiency.

IV. Impact of Window Transmittance

Most of us are aware that windows provide us with natural light, ventilation, and a view. But windows still remain the least understood building design component, even though many home owners place much importance on the functioning and energy efficiency of their windows. Windows transmit not only sunlight but also both indoor heat and solar heat through the building envelope. They may account for major heat losses in winter as well as major solar heat gains in summer. A windows heat transmittance is measured by U-factor. A small U-factor provides more insulating value than a larger one. With today's technology, a window is considered energy efficient if its U-factor is less than 0.40. Glass's transmittance is measured by solar heat gain coefficient (SHGC), which is a decimal number less than one. Passive solar heating requires a high SHGC quite often passive solar homes are built using glass that rejects solar energy (low SHGC). This can be a costly mistake. When selecting the glass, here are some general rules of thumb that you can follow:

- East- and west – facing glass should have a low SHGC(less than 0.40).
- South-facing glass should have a high SHGC if the house has a proper overhang.

- The SHGC makes little difference on the north façade. Because most windows get low U-values by adding low-e coatings.

In heating climates, reduce the window area on north-east and west-facing walls, while still allowing for adequate daylight. Effective south facing windows require a high solar heat gain coefficient (SHGC) usually 0.60 or higher to maximize heat gain, a low U-factor (0.35 or less) to reduce conductive heat transfer and a high visible transmittance (VT) for good visible light transfer. SHGC refers to the portion of incident sunlight admitted through a window, and U-factor indicates the heat loss rate for the window assembly.

V. Passive Design Strategies

Some of the passive design strategies adopted to optimize building design that controls heat gain and allows maximum natural light are as follows.

- Optimum orientation
- Internal space arrangement(thermal buffer zone/buffer space)
- Allocation of building openings
- Sizing of openings(limitation of window-wall-ratio and skylight-roof-ratio)
- Appropriate shading design(façade shading and fenestration shading)
- Adequate day lighting(optimum day lighted area and daylight factor)

A. Optimum orientation

Optimum orientation of buildings helps in reducing the total incident solar radiation on their surfaces. This forms the initial step of climate-responsive building design. The best orientation from a solar radiation point of view requires that the building, as a whole, should receive maximum solar radiation in winter and minimum in summer. For practical evaluation, it is necessary to know the duration of sunshine, and hourly solar intensity on various external surfaces during representative days of the seasons.

B. Internal Space Arrangement (thermal buffer zone)

As the western and eastern facades receive maximum insulation, all spaces adjoining the facades will have maximum heat gain. Therefore, from the perspective of occupant comfort, it is recommended to design the internal layout of the building in such a way that most of the living/regularly occupied spaces are placed along the northern or southern facades and away from the eastern and western facades. The less functional spaces such as storage ands service areas like toilets, staircases , and so on should be allocated along critical orientations lie west, east, south-west and southeast.

C. Allocation of building openings

In order to further reduce the heat gain in buildings, openings should be located on the facades with the least amount of insulation. Thus, it is always recommended to provide maximum openings along the northern and southern facades and avoid openings on the eastern and western facades to allow maximum daylight and minimum solar radiation inside the building.

D. Sizing of opening

Glazing allows shortwave infrared radiation emitted by the sun to pass through, but is almost opaque to long wave radiation emitted by objects in the room. The consequence is that once the radiant heat has entered through a window, it is trapped inside the building, a phenomenon called the 'green house effect'. Hence the heat gain in the buildings can be reduced by limiting the glazing area. Windows typically, have a higher conductance coefficient than the rest of the building envelope so that buildings with high glazing areas will have greater heat gain, as compared to similar buildings with lesser glazing area. Therefore GRIHA has limited the glazing area especially for the hot regions of India in terms of window-to-wall ratio (WWR) and skylight-roof-ratio (SRR).

E. Appropriate shading design

Two strategies can be adopted, to reduce the insulation and heat gain, namely façade design and fenestration shading.

1) **Façade Shading:** In order to block direct solar radiation at source, that is before it heats up the building surface. If the critical surfaces can be shaded externally, then the cooling load of the building can be reduced drastically (shown in fig. 5). In the orientation analysis, it has been observed that maximum incident heat gain occurs through the roof,

followed by walls to the west and east. Therefore, these facades need appropriate shading devices that can cut incident radiation throughout summer. The western and eastern walls of buildings are subject to very low angle solar radiation due to lower altitude position of the sun, with respect to the wall surface. Therefore these walls are difficult to shade with horizontal shading devices and these facades require complete vertical shading or vertical screening. There are various types of façade-shading strategies, which can be incorporated in building design such as the following.

1. Roof pergola
2. Space frame/tensile structure
3. Green wall
4. Wall/windows pergola
5. False wall/jaalis
6. Plantation on east and west sides.

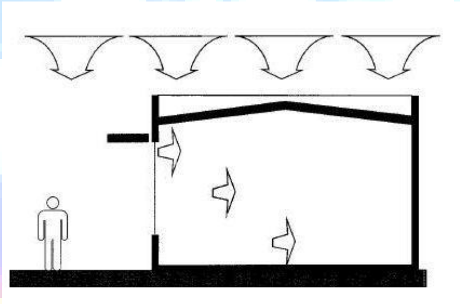

Figure 5: Facade shading

2) **Fenestration shading:** The openings/fenestrations are the prime source of heat gain in the building envelope. Therefore, if façade shading is not possible, then it becomes important to shade the exposed fenestrations of the building from direct solar exposure. Use of external shading devises is the most effective way to prevent unwanted heat gain during summer. However, the shading devices need to be optimized as per the solar angle, so that the shading device can keep the summer sunlight out and allow the winter sunshine in. The shading devices can be broadly categorized under the following.

1. Horizontal type
2. Vertical type

Horizontal fenestration: Horizontal fenestration is of three types such as skylight, monitor, and saw tooth. The day lighted area under various horizontal fenestrations extends beyond the dimensions of the aperture of the top opening on the working plane as demonstrated in figures.6.1, 6.2, and 6.3 below.

Vertical fenestration: The day lighted area under vertical fenestrations extends to the floor plate perpendicular to the side aperture, as demonstrated in figure.7.

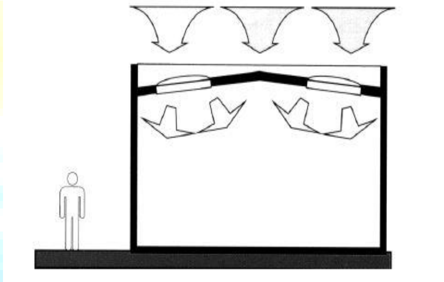

Figure 6.1: Skylight Schematic

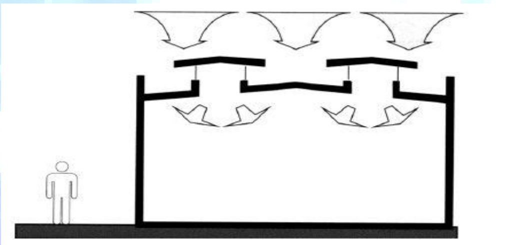

Figure 6.2: Monitor Aperture Schematic

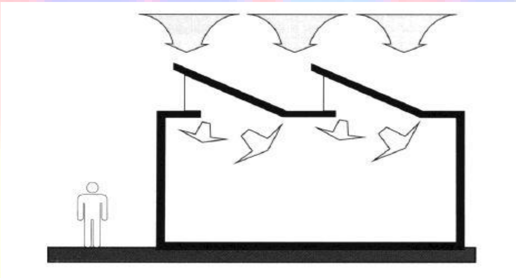

Figure 6.3: Sawtooth Aperture Schematic

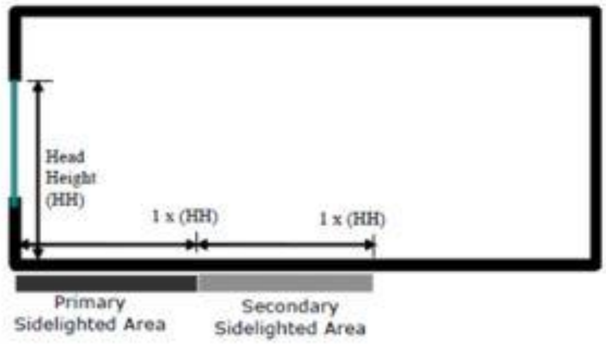

Figure 7: Vertical Fenestration Schematic

F. Adequate day lighting

Daylight is a natural source of light, which meets all the requirements of good lighting while enhancing user efficiency and productivity. Day light is available in plenty under clear sky conditions and can be used for satisfactory indoor illumination during the day. By proper design of windows in terms of their orientation, size and shape one can eliminate the use of artificial lighting in most buildings during daytime. Building spaces with poor daylight availability and spaces with night time usage can be provided with supplementary artificial lighting as per requirement. Therefore, adequate shading devices are recommended not only for thermal comfort but also for visual comfort. The major daylight design parameters (as per GRIHA) are as follows.

1. Defined day lighted area/daylight zone
2. Defined living area
3. Recommended daylight factor(DF)
4. Fixed design sky condition

1) **Daylight factor:** Daylight factor (DF) is the amount of available daylight inside a building with respect to the outside luminance. DF is designed as the percentage ratio of the daylight luminance at an indoor point on the working plane to the simultaneous outdoor luminance on a horizontal plane due to whole of the sky vault, excluding the direct sunlight. For the clear design sky, the DF is a percentage fraction of outdoor luminance.

2) **Design sky condition:** The basis of day lighting design adopted for the Indian standards is the clear design sky, which is representative of the prevalent sky condition in India and ensures adequate daylight for most of the working hours. The clear design sky basis holds good for any building orientation, and ensures adequate daylight indoors for about 90% of the daylight working hours. The outdoor design sky luminance varies for different climatic regions of the country. The recommended design sky luminance for different climatic zones is as follows.

1. Cold climate – 6800 lux
2. Composite climate – 8000 lux
3. Warm-humid – 9000 lux
4. Temperate – 9000 lux
5. Hot dry – 10500 lux

VI. CONCLUSION

In solar passive building design, architects and engineers primarily focus on utilization of solar-energy and wind for free heating, cooling, ventilating, and lighting indoor spaces. Solar passive design can substantially reduce end energy use in buildings. It can cut down or even eliminate the use of mechanical cooling and heating systems, and the use of daytime artificial lighting. The principles of passive solar design are compatible with diverse architectural styles and building techniques. During the comprehensive planning process, it may be enough that passive solar heating and/or cooling, and/or day lighting, are appropriate in a building. When more detailed analysis is needed during the design process, it can be done from the above procedures and Passive solar building design is often a foundational element of a cost-effective zero energy building. Although a ZEB uses multiple passive solar building design concepts, led to the following conclusions:

- Harvest solar heat by proper building orientation with respect to the site and annual solar path.
- Keep that heat in the building by proper air sealing and insulation (quality envelope).
- Store the heat (level temperature variations in both seasons) with properly designed interior thermal mass.

- Use efficient backup heat for long overcast spells and imperfect designs.

Passive solar is best for buildings that have low internal heat gains and in which direct solar gain is directed to absorbent thermal mass. A more recent trend is the development of Building—Integrated Photo voltaic (BIPVs). The PV cells are in corporate into a building element. Currently there is much development in PV roofing, PV shading elements. By following such a construction approach one may also develop an effective passive solar building.

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