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Effects of Solar Passive Architecture on Building Envelop

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ABSTRACT

In different parts of the world, man has found various solutions for protection against climatically unkind conditions through locally available materials. For example, in the hot and humid regions of Asia, Indonesia, Polynesia and Amazon, the roof was more important than the walls for modifying the indoor conditions. In fact the walls could be omitted altogether. Hence, lightweight structures of timber skeleton, wooden frames, thatched roofs and woven, lath and venture walling were used in such regions. On the other hand, in the mountainous cold forest regions in the North West U.S.A., Scandinavia and Himalayas, one found well-insulated timber houses.

In the case of vernacular architecture, the roof played a determining role in the general form and appearance. Flat roofs appeared in hot regions, vaulted roofs in hot and dry regions and inclined roofs in temperate-dry climates. Higher pitched roofs were used in wet-temperate and cooler places. Both domes and vaults were popular in the hot arid regions of the Middle East and Northern Africa, where low humidity leads to intense radiation exchange, and the variations between day and night temperatures are high. The logic here (probably deduced from centuries of experience) is that a hemispherical vault has about three times the surface area as the base of a square roof, so the solar radiation is diluted to that extent. Also, the cooling by radiation exchanges to the night sky is faster.

In the proto-historic period, community-based collective house forms evolved. Bio-climatic aspects such as orientation, house form, open spaces, etc. were well integrated in vernacular residential architecture.

KEYWORDS: *Building envelop, orientation, thermal storage, solar passive*

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1. INTRODUCTION

India experiences diverse climatic conditions which in turn have influenced the development of vernacular architecture in various regions. Control of the microclimate around the building was always an important aspect of indigenous designs. The urban forms ensured that individual buildings were not exposed to the sun. While planning a town, care was taken to orient the streets keeping the effects of sun and wind in mind. For example, towns in Gujarat and Rajasthan which experience hot and dry climate, had row-houses with common walls. These were tightly packed along the streets and plains to minimize the exposure to direct sun and hot winds. The front facades were further shaded with well-articulated balconies called "Jharokhas". Air inlets were usually located on the front facades where the air was relatively cooler since the streets and the lanes were well-shaded. Each house had an open courtyard which acted as an exhaust for warm air and provided enough natural light for the interior of the house. It has been recorded in the case of Jaisalmer, e.g., that the maximum temperature within the town was always lower than that recorded outside. Another important factor in building was the willingness and the ability of the user to organize his daily activity in space and time so that not all spaces required to be maintained at equal levels of comfort all the time. At any given time, the active use of the building could be restricted to the areas most comfortable at that time.

CLIMATE

Climate, the word is derived from Greek, word *KLIMA* and is defined by Oxford Dictionary as region with certain conditions of temperature, dryness, wind, light etc. A somewhat more scientific approach towards the definition is integration in time of physical states of the atmospheric environment, characteristics of a certain geographic location."

The 'climate' of a region is determined by the pattern of variations of several elements, when human comfort and building design are being considered are:

- Solar radiation
- Ambient air temperature
- Air humidity
- Precipitation
- Wind
- Sky conditions

2. SOLAR GEOMETRY

Sunlight falling on building raises indoor temperatures in two different ways when incident solar radiation (or isolation) fall on the external envelop of a building the energy is absorbed increases the surface temperatures which in turns causes heat to be conducted inward through walls and roof. But when solar radiation falls on window, almost all of the energy passed directly through the glass into the interior where it becomes trapped by a process called greenhouse effect. During cold weather this isolation is a variable free source of heat, but when interior temperatures are out of comfort range, it only adds to the occupant's discomfort.

Green House Effect

Glass, which allow virtually all the visible solar radiation striking its surface to pass through, will absorb most of the thermal (infrared or long wavelength) radiation it intercept this property of glass is highly desirable for use in collecting solar energy. Once sunlight is transmitted through glass. This process of trapping heat is commonly known as Green House Effect.

This does not imply that radiation losses from a space are eliminated although glass does not transmit thermal radiation; it absorbed this energy and then re-radiates and conducts it to the outside, but at the lower temperature of the glass surface.

From our daily experience we know that the sun appears to move across the sky from easterly to a westerly direction and that the path of this diurnal motion is longer is summer than in winter. Knowledge of sun's path in the sky on prerequisite for the calculation of solar radiation and in the design of solar control devices.

In order to design buildings, which precisely respond to direct radiation, the sun's position for any time of any day of the any year for any location throughout the world should be very clear in the designer's mind.

In fact the earth not only revolves around the sun every year, but it also rotates about its axis once in every 24 hour. One other important fact is that axis 0 the earth made 23o 27'angle to the plane in which it orbits the sun.

The earth is divided into 360 o longitudes & 180o latitudes that major latitudes is the diameter of earth and is known as equatorial line lie in Northern hemisphere. In order to understand sun so the sun motion is symmetrical about the equatorial line.

Summer & Winter Solstice

The earth orbits the sun, its axis at may remain tipped in the same direction, pointing towards Polaris, the distant "North" star. It means that at one point in the orbit the axis lean away from the sun and the opposite point half a year later, the axis is tipped towards the sun. These times are known as the winter solstice and summer solstice.

To develop the solar chart there should be a clear visual understanding of sun's movement across the skydome, two coordinates are needed to locate the position of sun in the sky which are called the attitude is the angle measured bet" the horizon and the position of sun above the horizon. The concentric circular / horizontal line on the chart represent attitude angles.

3. Building Orientation

Orientation refers to the location of a building with respect to the cardinal directions, i.e. North-South and East-West. Building orientation is an important parameter of design. In cold climates, the building needs to be oriented such the solar radiation is admitted to the maximum possible, while the reverse is true of hot regions. Similarly winds can be desirable or unwanted. Depending on the climate. Some time a compromise is required between these two orientations. It is seen that cooling load is the highest when the longer side of the building face East-West i.e. 0-180^{o} C. To decide on an optimum orientation, it is essential to have an idea of the sun's position and its movement pattern on a diurnal as well as seasonal basis.

Plan form

The planform of the building affects the amount of solar radiation received by the building and the airflow around it. Therefore it plays an important role in ventilation and heat loss or gain.

Wind when obstructed by a building creates pressure differences, i.e. positive pressure on the windward side and negative pressure on the leeward side. Consequently, a new airflow pattern is established around the building. Appropriate openings connecting high to low pressure areas provide effective ventilation.

The surface to volume ration determines the magnitudes of heat transfer in buildings. The larger the S/V ratio, the greater the heat gain/loss for a given volume of space. Conversely, a smaller S/V ratio will result in the reduction of heat gain/loss. For example, in cold climates it is preferable to have compact house form with minimum S/V ratio.

4. Building Envelope

The nature of the building envelope determines the amount of radiation and wind that will enter inside. It consists of the following elements.

- Roof
- Walls
- Fenestrations
- External color and texture
- Shading

A. **Roof:** Since roof receives a significant amount of Solar radiation, the type of roof plays an important role in modifying heat gain or loss, day lighting and ventilation. A massive roof as of reinforced cement concrete (RCC) tends to delay the transmission of heat into the interior when compared to lighter roofs such as asbestos cement sheet roofing. Sometimes inverted earthen pots with a layer of a earth also cover the roof over them. The earth and the inside the pots provide good insulation for resisting heat gain. A doubly pitched or curved roof provides a larger surface area for heat loss compared to a flat roof. Thus, the shape as well as the material both, has an effect on the performance of the roof. The roof can also be used advantageously for effective ventilation and day-lighting by incorporating vents and skylights respectively.

B. **Walls: -** Walls constitute a major part of the building envelope and receive a large amount of direct radiation. Depending on weather the need is for heating or cooling, variations in the thickness and material of the wall can be decided on. For example, it is estimated that more than 25% of the heat gain occurs due to conduction by walls in the warmer regions of India. Hence, control of heat gain through walls must be an important consideration for reducing the cooling loads. In the case of an air-conditioned building, a wall-type with a low U-value.

C. **Fenestration (openings):-** The patterns and configuration of openings such as window forms an important aspect of climatic design. These are provided for the purpose of heat gain, day-lighting and ventilation. Appropriate design of openings and shading devices help to keep out sun and wind or allow them in building. Ventilation lets in the fresh air and exhaust hot room air, resulting in cooling. An indoor speed of 1.5 - 2.0 m/s can cause comfort in warm and humid regions where the outdoor maximum air temperature dose not exceed 28 - 32^{o} C compared to out of the outdoor.

While deciding upon the position of a window, it is necessary to keep in mind the tendency of hot air to rise. Openings at higher levels would naturally aid inventing the hot air out. The size, shape and orientation of the windward side, permitting well cross-ventilation of interior space. Also, a small inlet as large outlet increases velocity and distribution of airflow through the room.

Natural light is introduced into the building through glazed openings, skylight, light shelves, clerestories, etc. Providing openable shutters and movable covers like curtains or Venetian blinds can control the extent of light and glare that enters. Besides, glazing of various tints or glazing with surface coatings can be used to control solar transmission, absorption and reflection characteristics. For example: the direct transmission of solar radiation through an absorbing glass can be reduced to as low as 45%. Coating the glass with a layer of reflective material usually makes reflective glass. Depending on whether the coating is on the outer or inner face of the glass, the reflectivity could vary.

It may be mentioned that window admit direct solar radiation and hence promote heat gain. This is desirable in cold climates, bit it is critical in overheated climates. The window size should be kept minimum in the Hot and Dry regions.

D. **External color and texture: -** The nature of the external surface finish determines the amount of heat absorbed or reflected but it. A smooth and light-colored. Surface reflects more heat and light; a rough textured surface causes self-shading and increases the area for re-radiation. White or lighter shades have higher emissivity, therefore are ideally used for reducing heat gain in warmer climates. Moreover, a heavy texture on these light-colored surfaces helps to reduce the glare. Dark colors absorb more radiation, which increases heat gain through the surface and can be used in cooler regions. It is seen that in all cities (Ahmedabad, Mumbai, Nagpur and Pune), a white painted surface outdoes all other colors in terms of lowering the room temperatures.

E. **Shading:-** Shading devices block the solar radiation incident on the exposed surfaces of a building, consequently reducing heat gain.

In the case of Hot and Dry regions, taller structures may be placed towards south. So as to shade other structures in a cluster. Walls can be shaded by the use of projections, balconies, fins, textured paints, vegetation, etc. openings can be shaded with appropriately sized chajjas, fins and awnings externally, and / or by using openable shutters and movable covers like curtains, Venetian blinds, etc. internally a schedule representation of the various types of shading devices.

Since the roof of the building receives the maximum amount of radiation shading it reduces the heat gain. Using movable canvas covers, plant cover, roof garden, etc can do this.

Advance solar passive techniques: - in addition to the simple features of solar passive architecture, there are a number of advance passive techniques that can be incorporated in buildings. A brief discussion of these techniques is as follows.

Direct Gain:-

Direct gain is a passive heating technique generally used in cold climates. It the most common, simple, cheap and effective approach. The basis principle of that sunlight is admitted into the living spaces, directly through openings or glazed windows, to heat the walls and floors and thereby the air inside. The requirements of a direct gain system are glazed windows and thermal storage. The glazed windows are generally located facing south to receive maximum sunlight during winter. They are generally double glazed with insulating curtains, to reduce heat loss during nighttime.

During the day, affected part of the house tends to get very hot, and hence, thermal storage mass is provided in the form of bare massive walls or floors of either masonry. Concrete or water-filled drums to arrest the increase in room temperature. The heat thus stored is released during night for space heating. It may be noted that carpets / curtai9ns should not be used to cover floors/walls used for storage purpose. Then, the heat flow into or out of the storage is prohibited. A suitable overhang may be provided for shading from the summer sun to avoid undesired heating.

Because of its simplicity and effectiveness, direct gain features are used extensively for heating purpose in cold climates. For example, clerestories used in a restaurant in a New Mexico, USA can maintain an indoor temperature of about 15^{o} C as compared to outside temperature of 1.0^{o}C.

Variations and Controls

Variations occur due to storage and glazing materials, and their locations in buildings. Thermal storage materials can be concrete, bricks, stone or water in containers. The thermal mass is typically located in the external or internal walls, floors, erected independent structures, etc. that receive direct sun.

Glazing materials may be glass indifferent layers and located in the wall or roof so that radiation falls directly on the thermal storage mass. Various forms of opening like clerestories can achieve direct gain. Skylight, greenhouses or glass curtain walls designed for the required heating. The color of internal surfaces also plays an important role in absorbing the radiation, as well as in the distribution of daylight. Darker colors absorb more heat than lighter shades as pointed out earlier. As far as the distribution of light is concerned, the lighter shades are preferred. Thus the storage surface should be of medium-dark colour, whereas lightweight materials should have colour to reflect sunlight on the masonry walls or floors.

The direct gain system with its large glazed area and storage facilities could result in undesirable winter losses and summer overheating. Various controls such as roof overhangs, shutters and reflectors can be used for decreasing or increasing the solar heat gain, exhaust and vents can be employed to cool the interior spaces through ventilation when the summer temperature rises.

Remarks:
While the main advantage of the direct gain approach is its simplicity and low cost, it causes large temperature swing because of large variations in the input of energy in the room. Strong directional daylighting, glare and ultraviolet degradation of the house material are some of the disadvantages of direct gain system. In spite of these facts, this is by far the most common system in the world since the approach is relatively simple and inexpensive.

5. Thermal Storage Wall:-

In this approach, a thermal storage wall is placed between the living space and the glazing. This prevents solar radiation from directly entering the living space; it is absorbed by the storage and then transferred into the living space. Such a feature is mainly used for heating buildings. Different types of storage walls are:

A. Trombe Wall

A trombe wall is a very solid wall with vents provided at both upper and lower parts, it is a massive thermal storage wall made of concrete. Masonry or composites of bricks, block and sand, usually located on the south side of a building to receive maximum solar radiation. The wall is painted black to increase its absorptive capacity and is place directly behind glazing with air gap between vents are provided fir air circulation.

Solar radiation is absorbed by the blackened surface and is stored as sensible heat in the wall. Air, in the space between the glazing and the wall gets heated up and enters the living room through the upper vents. Cool room air takes its place through the lower vents. Thus establishing a natural circulation pattern. A part of the absorbed heat is conducted through the wall and is transferred to the living space by convection and radiation. Thus, the living space gets heated up. During summer months, when the sun's altitude is high. The overhang on the all cuts off direct sunshine. Further, the Trombe wall can provide induced ventilation for summer cooling of the space. Here the heated air in the collector space flows out through exhaust vents at the top of the outer glazing, and air from outside enters the space through openings on the cooler side to replace the hot air . This continuous air movement cools the living space. It is noteworthy that in buildings with thermal storage walls, The indoor temperature can be maintained at about 15^{o} C while outside temperature is as low as 11^{o} C.

Generally, the thickness of storage wall is between 200-400mm; the air gap between the wall and the glazing is 50-150mm and the total area of each row vents is about 1% of the storage wall area.

Variation and controls
The distribution of heat into the living space can be almost immediate or delayed depending on air circulation. Furthermore, the delay can be varied depending on the thickness of the wall, and the time-lag property of the wall material.

If the vents are provided with dampers, the airflow can be controlled. Use of movable insulation in the form of a curtain, between the wall and the glazing provides another mode of control.

Materials which can store and release heat when they undergo a phase change between liquid and solid are called 'phase change materials' (PCM). They can be used as storage materials for thermal storage wall, as PCM have a greater ability to store and release heat when they undergo a phase change. Also for a given amount of heat storage, the phase change materials require less space than any sensible storage and are much lighter in weight.

They are therefore, convenient to make use of for retrofit of buildings.

Commonly used PCMS are hydrated and hydrocarbons. Of the hydrocarbons, paraffin wax has been very popular in building applications. Also used are (a) mixture of stearic acid, paraffin (80%) and mineral oil, and (b) sodium decahydrate. While hydrate salts are inexpensive and can store more heat than a hydrocarbon, their properties degrade with prolonged use; they are also corrosive. On the other hand, hydrocarbons are flammable and require careful handling.

B. Water Wall

Water wall are based on the same principle as that of the Trombe wall, except that they employ after as the thermal storage material. A water wall is a thermal storage wall made up of drums of water stacked up behind glazing. It is painted black externally to increase the absorption of radiation. The internal surface can be painted with any other color, and can be in contact with the interior space directly or separated by a thin concrete wall or insulating layer. Since storage in the water wall is a convective body of mass, the heat transfer is very rapid in comparison to the masonry wall.

Variations and control:
A large volume provides longer and greater storage capacity, while smaller units enable faster distribution. A variety of containers like tin cans, bottles, tubes, bins, barrels, drums etc., provide different heat-exchange surfaces to the storage mass ration.

Heat transfer through water wall is much faster than that of Trombe wall. So the control on distribution of heat is needed, if it is not immediately necessary for the building. This can be effected by using thin concrete layer or insulating layer or by providing air circulation through vents. The buildings, which work during the daytime, like schools or government offices benefit from the rapid heat, transfer in water wall. Using movable overhangs may prevent overheating during summer.

C. Solar chimney assisted passive heating device :

This is an example of passive heating system in which the thermal storage wall is separated from the glazing. This system can be identified as a modified Trombe wall, and be incorporated as part of the roof. The system consists of a solar chimney and a thermal storage unit. A solar chimney is essentially a collector panel with minimum thermal inertia on the south face of the building. It absorbs the incident solar radiation and heats up the air in the absorber glazing space. A well insulated collector limits the heat loss to the outside. The hot air forces itself into the living space through vents, and heats it up. Cooler air takes its place and the cycle is repeated. In addition to heating the space, heat can also be stored for later use bypassing the hot air through storage mass.

The storage is generally the inter structure of the building like an internal wall and/or a concrete ceiling which is not exposed to the outside. Thereby, the internal storage minimizes the heat loss to the outside. Besides, during evening and night hours, the well insulated collector serves as a thermal buffer between the house and the external atmosphere and eliminates the need for movable insulation.

Variations and controls:
Dampers can be used to control the airflow either to the storage unit or directly into the living space. The thermal storage may be suitable designed to realise a desired time lag for the distribution of heat to the living space. The potential of the system to induce ventilation for summer cooling can be realised by venting out the hot air and providing another opening for replacing the hot air by cool air from shaded or cooler area.

D. Transwall
Transwall is a thermal storage wall that is semitransparent in nature and is directly located behind the south facing glazing. It partly absorbs and partly transmits the solar radiation. The transmitted radiation causes direct heating and illumination of the living space. The absorbed heat is transferred to the living space at a later time. The heat loss through the glazing is low, as much of the heat is deposited at the center of the Transwall ensuring that its exterior surface does not become too hot. Thus the system combines the attractive features of both direct gain and Trombe wall system.

A Trombe wall has three main components:
1. Container made of parallel glass wall set in metal frame.
2. Thermal storage liquid , which is generally water.
3. A partially absorbing plate, set at the center of the Transwall, parallel to the glass walls.

These modules are stacked to from a wall on the south side of the building, located directly behind double-glazing. To prevent the growth of microorganisms in the storage, an inhibiting agent may be added.

Variations and Controls
The hydrostatic pressure exerted by the liquid dictates the dimensions of the storage module. Also important are the consideration of transportation, the method of installation, the ways of filling and draining the module, and attaching the modules to each other and integrating with the building.

Storage being a convective body of water, the transfer of heat is rapid. This can be regulated by providing baffles and adding a gelling compound. Baffles are transparent plates, which connect the module walls with the absorbing plate and prevent water movement. The geling compound increases the general flow resistance.

E. Thermal storage Roof / Roof pond / Skythern
A roof pond system works well both in summer as well as in winter. While it is mostly appropriate for cooling, for winter heating purpose it is better suited to lower latitudes with high winter sun.

In this system, a mass of water is stored on the roof of the building. During summer days, the pond is protected and insulated by an external, movable and reflective insulation. The insulation prevents solar radiation from reaching the water mass and keeps it cool. This cool water then absorbs heat from the rooms below and cools the air inside. At night the insulation is removed and the water cools by convection and radiation. The effectiveness of the roof pond may be gauged from the fact that an indoor temperature of 21^{o}C can be maintained when the outside temperature is as high as 35^{o} C.

In winter, the panel positions are reversed. During the day the insulation is removed so that heat is absorbed by water for heating the interior. During the night, the insulation cover reduces the heat loss. The effectiveness of the roof pond in winter in no less than in summer; indoor temperature can be maintained at about 21^{o} C while the outside is as low as - 11^{o} C.

Water in transparent bags /in waterproof structural metal/fiberglass tanks is kept on the roof, the depth ranging from 150 to 300 mm. The top of the container/bag needs to be transparent to solar radiation whereas it bottom (inside surface) should be made of dark color. If both sides of the container are transparent, the top surface of the roof needs to be blackened for absorbing solar radiation. A clear top and black bottom helps in minimizing temperature stratification in the pond water. Otherwise hot water at the top would lose its heat to the exterior, and the cold water at the bottom would inhibit the heat transfer to the interior of the building. The movable insulation is usually of 50.. Thick polyurethane foam reinforced with fiberglass strands and sandwiched between aluminum skins. The waterproofing layer of the roof should be such that the heat transfer from the pond to the interior is not inhibited. Radiation is responsible for the thermal interaction between the roof and living space. Therefore the ceiling of the room must not be very high, as the intensity of the radiation reduces with the height or distance. This technique is effective for one or two storied buildings.

Variations and Controls
Variations may be achieved by altering the ratios of heat transfer surfaces to thermal mass. The large the storage volume, the grater and longer the heat storage. Smaller containers provide greater heat exchange as the surface area increases, resulting in faster distribution. During winter, a transparent cover may be provided over the water bags leaving a gap. Air is blown through these gaps forming an insulation cover to reduce heat loss. During summer these gaps are flooded with water and the transparent cover is removed.

6. CONCLUSION

Passive Solar Design is a simple, highly effective (and cost-effective) method of making buildings more energy efficient by using natural systems to help keep them warm in the winter and cool in the summer. When all of the principles are applied correctly in a holistic way it leads to buildings that are full of light and sunshine in the winter, cool and shady in the summer and cost very little to operate throughout their lifespan.

A basic ability to understand passive design strategies in general including the approaches and benefits of using such strategies not only in the building design but also related to the urban context and human factors. The key to designing a passive building is to take advantage of the local climate (microclimate) and therefore, climate characteristics and classification can help with identifying approaches as early as site planning and analysis. Therefore, climate and comfort are the two fundamental measures in passive design that require attention. Passive design is a major part of environmental design and its approaches utilising several techniques and strategies that can be employed to achieve sustainable design also enhanced by patterns of biophilic design for improving health and well-being in the built environment.

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