RESEARCH ARTICLE OPEN ACCESS

SUSTAINABLE BUILDINGS IN HOT AND DRY CLIMATE OF INDIA

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Abstract
The consumption of energy in the buildings is increasing as the development is taking at a very fast rate. No evidence is now required to prove that the present climate changes are directly linked to the human activities and also the concerns regarding exploitation of the fossil fuel have reached a level where the negative effect are having impact on the life of a common man. Passive Architecture involves blending conventional architectural principles with solar & wind energy and the inherent properties of building materials to ensure that the interiors remain warm in winter and cool in summer, thus creating a year-round comfortable environment. Various solar passive techniques have been studied in detail so that the undesirable impact in hot and dry climate could be mitigated. It is concluded that with the application of these techniques the building could be made comfortable with comparatively less use of energy.

Keywords: *sustainable design, orientation, building envelop, massive structure, courtyards, solar chimney, evaporative cooling, air tunnels, air flow*.

I. Introduction

India after China is having the second largest population of the world and is among the 10 fastest growing economies in the world and therefore our energy consumption is expected to continue increasing significantly. Increased energy consumption will lead to more greenhouse gas emissions with serious impacts on the global environment.

Environmental degradation and shortage of natural resources are serious issues that the country faces, and the rest of the world dreads. Taking these issues into account it is more of a necessity than a matter of choice that the urbanization process has to address environmental sustainability. [1]

Mainly the use of electricity has increased drastically to combat the undesirable impact of the climate. In commercial buildings, the annual energy consumption per square meter of the floor area is in excess of 200kWh with air-conditioning and lighting serving as the two most energy consuming end-use applications within a building. It is also estimated that 45% of the total final energy in India is consumed in the building sector.

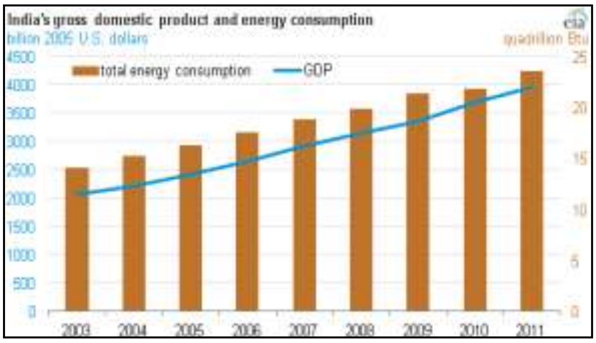


Image courtesy: http://www.eia.gov/todayinenergy

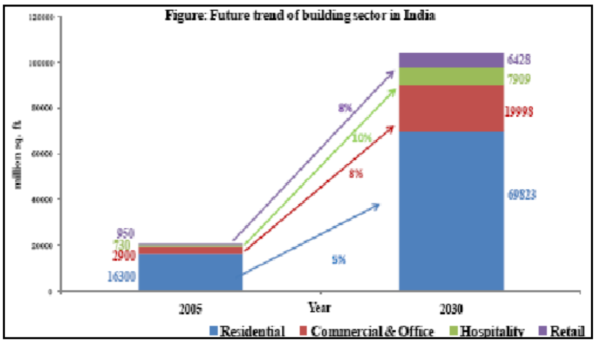


Image courtesy: Sanjay Seth 'Eenergy Efficiency Initiatives in Commercial Buildings'

Sustainable architecture posed a new challenge for Indian architecture. With the oil crisis of 1973, the Indian scientific community quickly responded to the issues of sustainable development heralded by the developed world. The emerging green architecture turned towards science and technology to provide solutions for environmental degradation. The western technology dependent solutions were adopted to solve India's environmental problems. In this approach energy efficiency was prioritized over all other concerns.

The analysis of the passive design features used to control the indoor environment inside the houses present a surprising fact that most of the passive design measures prescribed by the modern designers, energy conservationists, environmentalists and climatologists are already incorporated in these old structures. It is a very distressing fact that while evolving new environmentally friendly techniques and construction practices, we are ignoring the already existing legacy, which presents before most suitable of measures, perfected over the centuries of trial and error.

II.Need of sustainable design

No evidence is now required to prove that the present climate changes are directly linked to the human activities and also the concerns regarding exploitation of the fossil fuel have reached a level where the negative effect are having impact on the life of a common man. This resource intensive development model posed problems for a developing country like rising of costs, loss of productivity and disruption of economic activity etc. With the advancement of technology, the consumption of energy has increased and thus even technology is seen as a factor of environmental degradation. As we are aware that there is a limit to the natural resources available on earth we need to conserve these by judicially utilizing these. In the case of India reducing the consumption of energy may be linked to slowing down the development rate which surely may not be appreciated by many. It is need of the hour therefore to look into the aspects and methods which shall help to reduce the consumption of energy without hampering the development rate. It is therefore taken up in top priority by the Indian Government, although sustainable development in India is often misunderstood that such type (sustainable or energy efficient) construction is luxury and considered to be costly but the fact is not true as it is necessary to address this issue before it is too late and the costs of reversing the tends rise beyond control.

The results are significant as this issue is of particular relevance for developing countries such as India that are in the process of industrializing but are yet to confront the high costs of development. Both urbanization and suburban growth take a heavy toll on the environment and the lack of appropriate technologies and sustainable framework suggests that the architectural profession has failed to recognize the critical need for developing socially appropriate sustainable architectural practices for India.

Image courtesy: http://gupta9665.wordpress.com/ 2012/04/03/ learning-the-green-design-by-solid works certification/

There is an increasing demand for higher quality office buildings in India. Occupants and developers of the office building ask for a healthy and stimulating working environment. They also demand the buildings that create less environmental damage. The need for energy conservation and sustainable design in buildings is the main reason for this study. The commercial sector posted the highest economic growth rate and accounts for larger share of energy consumption in India. Double skin façades are getting ever-greater importance in building practice in modern building practice in the developed countries of the world. Providing comfortable environment to the building occupant is a major challenge for building designer in Hot and Dry regions.

III. Understanding built environment in hot and dry climate

Climate is an important aspect of life particularly in areas with hot and dry climate such as Jodhpur, where people face variety of problems related to climate especially in modern housing. Traditional built environment of Jodhpur is considered appropriate for both the climate as well as for social conditions. The modern architecture of international style which has dominated the new developments generally considered inappropriate, particularly because it was introduced without consideration for the local climate or for the cultural need of the population.

Traditional built environment in Jodhpur have evolved in response to climate, reducing the effect of hostile desert climate conditions. The main concern of the builders was to modify extremes of air temperature, and to protect the inhabitants from solar radiation and glare as well as from sand and dust. In hot and dry climate the most significant problems are those caused by solar radiation and UV rays. These can destroy surface finishes, above all coated surfaces of metal sections, metal sheeting and wood surfaces. The great temperature difference of 45^{o}C in summer and cold winter nights with temperature below freezing point, impose considerable strain on the construction and material in the form of swelling and contraction. Sand bearing winds have a damaging effect on the surface finishes, such as sand blasting surfaces. Although the choice of the building material is essentially determined by local availability, their economy, durability and suitability for the particular climate. The means of transporting materials from distant place of production is also an important factor. For many the acceptance of material is related to its status. Vernacular architecture of Hot and Dry Climate of Jodhpur has many passive design features. The coolness of the houses on a hot summer afternoon never fails to impress the visitor and makes one wonder how the indigenous builders could create such comfortable buildings without aid of modern scientific knowledge.

IV. Solar passive techniques to mitigate the undesirable impact in hot and dry climate

Passive Architecture involves blending conventional architectural principles with solar & wind energy and the inherent properties of building materials to ensure that the interiors remain warm in winter and cool in summer, thus creating a year-round comfortable environment. In passive building designs, the passive system is integrated into the building elements and materials. It should be understood that passive architectural design does not necessarily mean the elimination of standard mechanical systems. In recent designs however, passive systems coupled with high efficiency back-up systems greatly reduce the size of the traditional heating or cooling systems and reduce the amount of non-renewable fuels needed to maintain comfortable indoor temperatures.

4.1 Passive techniques and features

The first step to achieve passive cooling in a building is to reduce unnecessary thermal loads that might enter it. Usually, there are two types of thermal loads

1. Exterior loads due to the climate.
2. Internal loads due to people, appliances, cooking, bathing, lights etc.

Proper zoning of different components and local ventilation of major heat sources can reduce the overall impact of internally generated heat loads. [3]

4.2 Considerable factors to mitigate impact of heat loads:

1. Orientation and shape of building- Resist heat gain, Decrease exposed surface area
2. Insulation of building envelope-Increase thermal resistance
3. Massive structure - Increase thermal capacity (Time lag)
4. Air locks/ lobbies/balconies/verandahs- Increase buffer spaces
5. Weather stripping and scheduling air changes- Decrease air exchange rate (Ventilation during day-time)
6. External surfaces protected by overhangs Fins and trees- Increase shading
7. Pale color, glazed china mosaic tiles etc- Increase surface reflectivity
8. Provide windows/exhausts - Ventilation of appliances, Promote heat loss
9. Courtyards/wind towers/arrangement of openings - Increase air exchange rate, [2]

4.3 Urban Climate

The air temperatures in densely built urban areas are often higher than the temperatures of the surrounding countryside. This is due to rapid urbanization and industrialization. The term "urban heat island" refers to increased surface temperatures in some pockets of a city, caused by an ever changing microclimate. The difference between the maximum city temperature (measured at the city centre) and the surrounding countryside is the urban heat-island intensity. An urban heat island study was carried out in Pune, Mumbai, Kolkata, Delhi, Vishakhapatnam, Vijayawada, Bhopal and Chennai. It is seen that, the heat island intensity is greatest in Pune (about 10 °C) and lowest in Vishakhapatnam (about 0.6°C). In the metropolitan cities of Mumbai, New Delhi, Chennai and Kolkata, the corresponding values are 9.5, 6.0, 4.0 and 4.0^{o}C respectively. Clearly, the values are quite high. The density of the built environment and the extent of tree cover or vegetation primarily affect the heat-island intensity. Pollution and heat due to vehicular traffic, industrialization and human activities are other contributing factors

Normally, the central business district (CBD) or the centre of city experiences higher temperatures than the other parts. This is because the CBD mainly consists of concrete buildings and asphalted roads, which heat up very quickly due to radiation from the sun. Most of this heat is stored and released very slowly, sometimes even up to the night. This phenomenon does not allow the daily minimum temperature to become too low. Though it may be a welcome phenomenon in cold regions during winters, it makes life unbearable for people in the hot regions. Thus, in tropical climates, the provision of sufficient ventilation and spacing between buildings is required to allow the accumulated heat to escape to the atmosphere easily. [2]

Street patterns and urban blocks can be oriented and sized to incorporate concerns of light, sun, and shade according to the dictates of the climate. For example, the densely built areas produce, store and retain more heat than low-density areas. Thus, the temperature differential between urban areas and the surrounding countryside increases as the surrounding areas cool at night. As a result, cooler air from the surrounding countryside flows towards the centre. This kind of circulation is more pronounced on calm summer nights and can be utilized to flush dense areas of heat and pollutants. To achieve cool air movement, a belt of undeveloped and preferably vegetated land at the perimeter of the city, can be provided to serve as a cool air source. Radial street patterns can also be designed for facilitating movement of air from less dense to more dense areas.

A system of linear greenways or boulevards converging towards the city centre will help to maintain the movement of cool air. Provided the soil is adequately moist, a single isolated tree may transpire up to 400 liters of water per day. This transpiration together with the shading of solar radiation creates a cooler environment around the tree. On a hot summer day, the temperature can drop significantly under trees due to cool breezes produced by convective currents and by shading from direct sunlight. Planted areas can be as much as 5– 8^{o}c cooler than built-up areas due to a combination of evapotranspiration, reflection, shading, and storage of cold.

Local wind patterns are created when the warm air over a dense built up area rises, and is replaced by cooler air from vegetated areas. Having many evenly distributed small open spaces will produce a greater cooling effect than a few large parks. Studies suggest that for a city with a population of about one million, 10-20% of the city area should be covered by vegetation for effectively lowering local temperatures. As the vegetation cover in the city increases from 20 to 50%, the minimum air temperature decreases by 3-4^{o}c, and the maximum temperature decreases by about 5 ^{o}c.

The heat released from combustion of fuels and from human activities, adds to the ambient temperature of the city. Air pollution, caused mainly by emissions from vehicles and industries, reduces the long wave radiation back to the sky thereby making the nights are warmer. Global solar radiation during daytime is also reduced due to increased scattering and absorption by polluted air (this can be up to 10-20% in industrial cities). Pollution also affects visibility, rainfall and cloud cover. Effective land use to decongest cities, and the provision of proper vegetation would mitigate the effects of pollution. It is also important to use cleaner fuels and more efficient vehicles.

Meteorological studies and remote sensing by satellites can be used to ascertain drastic Changes in the climate, land use and tree cover patterns. Remote sensing can also be used to map hot and cool areas across a city by using GIS tools (Geographical Information System). Such mapping can help to reduce unplanned growth of a city, in preparing a proper land use plan, and to identify future vulnerable areas (those devoid of natural vegetation, parks and water bodies). These measures would certainly help in reducing urban heat island intensity.

4.4 Microclimate

The conditions for transfer of energy through the building fabric and for determining the thermal response of people are local and site-specific. These conditions are generally grouped under the term of 'microclimate', which includes wind, radiation, temperature, and humidity experienced around a building. A building by its very presence will change the microclimate by causing a bluff obstruction to the wind flow, and by casting shadows on the ground and on other buildings. A designer has to predict this variation and appropriately account for its effect in the design

The microclimate of a site is affected by the following factors:

- Landform
- Vegetation
- Water bodies
- Street width and orientation
- Open spaces and built form

An understanding of these factors greatly helps in the preparation of the site layout plan. For example, in a hot and dry climate, the building needs to be located close to a water body. The water body helps in increasing the humidity and lowering the temperature by evaporative cooling.

4.4.1 Landform

Landform represents the topography of a site. It may be flat, undulating or sloping. Major landforms affecting a site are mountains, valleys and plains. Depending on the macroclimate and season, some locations within a particular landform experience a better microclimate than others.

In valleys, the hot air (being lighter) rises while cooler air having higher density, settles into the depressions, resulting in a lower temperature at the bottom. Upward currents form on sunny slopes in the morning. By night, the airflow reverses because cold ground surfaces cool the surrounding air, making it heavier and causing it to flow down the valley. Moreover, the wind flow is higher along the direction of the valley than across it due to unrestricted movement. On mountain slopes, the air speed increases as it moves up the windward side, reaching a maximum at the crest and a minimum on the leeward side. The difference in air speed is caused due to the low pressure area developed on the leeward side.

Temperature also varies with elevation. The cooling rate is about 0.80C for every 100m of elevation. Air moving down the slope will thus be cooler than the air it replaces lower down, and vice versa. Further, the orientation of the slope also plays a part in determining the amount of solar radiation incident on the site. For example a south-facing slope will get more exposure than a north-facing one in the northern hemisphere. Studies conducted in Mardin, Turkey showed that building groups located on a south facing slope in the city needed approximately 50% less heat to maintain the same indoor temperature as buildings located on the plain land. Careful positioning of a building with respect to landform can thus help in achieving comfort.

4.4.2 Water bodies

Water bodies can be in the form of sea, lake, river, pond or fountains. Since water has a relatively high latent heat of vaporization, it absorbs a large amount of heat from the surrounding air for evaporation. The cooled air can then be introduced in the building. Evaporation of water also raises the humidity level. This is particularly useful in hot and dry climates. Since water has a high specific heat, it provides an ideal medium for storage of heat that can be used for heating purposes.

Large water bodies tend to reduce the difference between day and night temperatures because they act as heat sinks. Thus, sites near oceans and large lakes have less temperature variation between day and night, as well as between summer and winter as compared to inland sites. Also, the maximum temperature in summer is lower near water than on inland sites.

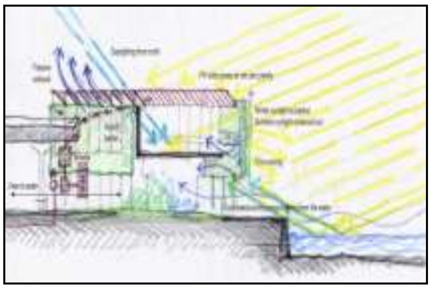


Image courtesy: archinspire.org/carbon-neutral-green-energy-building-design/

Evaporative cooling can help to maintain comfort in buildings in hot and dry climate. This feature was successfully adopted in vernacular architecture. For example, the Deegh palace in Bharatpur is surrounded by a water garden to cool the neighbourhood. Other examples include the Taj Mahal at Agra and the palace at Mandu. The evaporation rate of water in such an open spaces depends on the surface area of the water, the relative humidity of the air, and the water temperature.

4.4.3. Vegetation

Vegetation plays an important role in changing the climate of a city. It is also effective in controlling the microclimate. Plants, shrubs and trees cool the environment when they absorb radiation for photosynthesis. They are useful in shading a particular part of the structure and ground for reducing the heat gain and reflected radiation. By releasing moisture, they help raise the humidity level. Vegetation also creates different air flow patterns by causing minor pressure differences, and thus can be used to direct or divert the prevailing wind advantage.

Based on the requirement of a climate, an appropriate type of tree can be selected. Planting deciduous trees such as mulberry to shade east and west walls would prove beneficial in hot and dry zones. In summer, they provide shade from intense morning and evening sun, reduce glare, as well as cut off hot breezes. On the other hand, deciduous trees shed their leaves in winter and allow solar radiation to heat the building. The cooling effect of vegetation in hot and dry climates comes predominantly from evaporation, while in hot humid climates the shading effect is more significant.

Trees can be used as windbreaks to protect both buildings and outer areas such as lawns and patios from both hot and cold winds. The velocity reduction behind the windbreak depends on their height, density, cross-sectional shape, width, and length, the first two being the most important factors. When the wind does not blow perpendicular to the windbreak, the sheltered area is decreased.

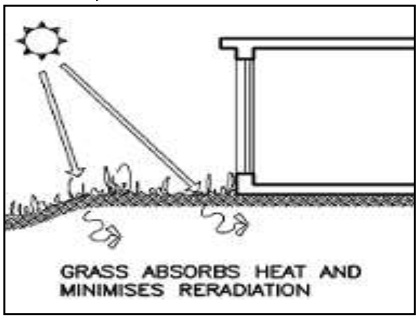


Image courtesy: http://miraresstudio.com/ludhiana_management_association.php

In cold climates, windbreaks can reduce the heat loss in buildings by reducing wind flow over the buildings, thereby reducing convection and infiltration losses. A single-row of high density trees in the form of a windbreak can reduce infiltration in a residence by about 60% when planted about four tree heights from the building. This corresponds to about 15% reduction in energy costs. Thus, trees can be effectively used to control the microclimate.

4.4.4. Street width and orientation

The amount of direct radiation received by a building and the street in an urban area is determined by the street width and its orientation. The buildings on one side of the street tend to cast a shadow on the street on the opposite building, by blocking the sun's radiation. Thus the width of the street can be relatively narrow or wide depending upon whether the solar radiation is desirable or not. For instance in Jaisalmer (hot and dry climate), most of the streets are narrow with buildings shading each other to reduce the solar radiation, and consequently the street
temperature and heat gain of buildings.

The orientation of the street is also useful for controlling airflow. Air movement in streets can be either an asset or a liability, depending on season and climate. The streets can be oriented parallel to prevailing wind direction for free airflow in warm climates. Smaller streets or pedestrian walkways may have number of turns (zigzags) to modulate wind speed. Wind is desirable in streets of hot climates to cool people and remove excess heat from the streets. It can also help in cross ventilation of buildings. This is important in humid climates, and at night in arid climates. In cold regions, wind increases heat losses of buildings due to infiltration. For regular organizations of buildings in an urban area, tall buildings on narrow streets yield the most wind protection, while shorter buildings on wider streets promote more air movement. When major streets are parallel to winds, the primary factors affecting the wind velocity are the width of streets and the frontal area (height and width) of windward building faces.

4.4.5 Open spaces and built form

The form of a building and the open spaces in its neighborhood affect the radiation falling on the building's surface and the airflow in and around it. Open spaces such as courtyards can be designed such that solar radiation incident on them during daytime can be reflected on to building façades for augmenting solar heat. This is desirable in cold climates, and it is possible if the surface finish of the courtyard is reflective in nature. Inside a courtyard, wind conditions are primarily dependent on the proportion between building height and courtyard width in the section along the wind flow line. Courtyards can also be designed to act as heat sinks. Grass and other vegetation in a courtyard can provide cooling due to evaporation and shading. Water sprayed on the courtyards would cause cooling effect due to evaporation. Consequently, the air temperature in the courtyard can be much lower compared to street or outdoor air temperatures in a hot and dry climate.

The air in open spaces shaded by surrounding buildings would be cooler and can be used to facilitate proper ventilation and promote heat loss through building envelope. Built forms can be so oriented that buildings cause mutual shading and thus reduce heat gain. For ensuring unobstructed airflow, taller structures can be planned towards the rear side of a building complex. Thus, open spaces and built form can be appropriately used to modulate the microclimate.

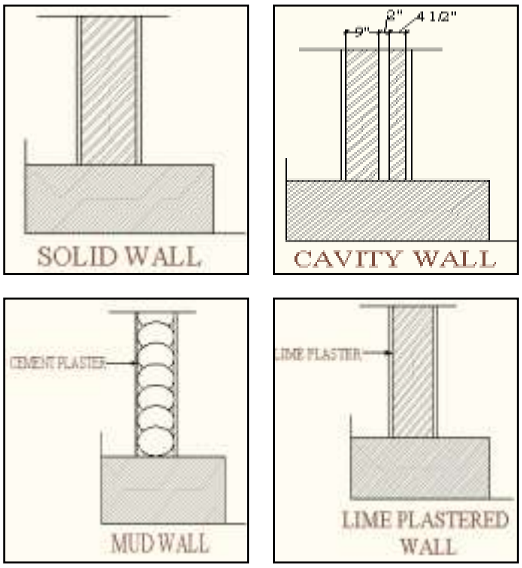
4.5 Various Methods to reduce heat gain in a building

- Building orientation
- Shading by neighboring buildings
- Shading by vegetation
- Reflecting surfaces
- Building surface cooling
- Roof ponds and garden
- Solar chimney
- Courtyard effect
- Air vent and wind tower
- Sensible and evaporative cooling
- Air cooling by tunnels
- Thermal storage

Image courtesy: http://www.rainharvest.co.za/ 2011/04/7-tips-on-sustainable-design/

Reduction of Solar and Convective Heat Import

The interaction of solar radiation by the building is the source of maximum heat gain inside the building space. The natural way to cool a building, therefore, is to minimize the incident solar radiation, proper orientation of the building, adequate layout with respect to the neighboring buildings and by using proper shading devices to help control the incident solar radiation on a building effectively. Good shading strategies help to save 10%-20% of energy for cooling.



Properly designed roof overhangs can provide adequate sun protection, especially for south facing surfaces. Vertical shading devices such as trees, trellises, trellised vines, shutters, shading screens awnings and exterior roll blinds are also effective. These options are recommended for east-facing and west-facing windows and walls. If ambient temperatures are higher than the room temperature, heat enters into the building by convection due to undesirable ventilation, which needs to be reduced to the minimum possible level. Adequate wind shelter and sealing of windows reduces the air infiltration and this requires proper planning and landscaping. [3]

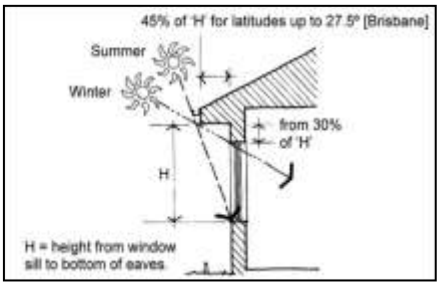


Image courtesy:http://www.yourhome.gov.au/passive-design/shading

4.5.1. Building orientation

Maximum solar radiation is interrupted by the roof (horizontal surface) followed by the east and west walls and then the north wall during the summer period, when the south oriented wall receives minimum radiation. It is therefore desirable that the building is oriented with the longest walls facing north and south, so that only short walls face east and west. Thus only the smallest wall areas are exposed to intense morning and evening sun.

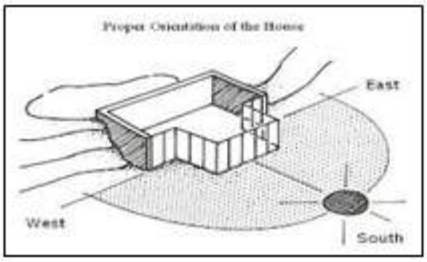


Image courtesy: http://www.techniki.eu/proper orientation/2007/4/18/proper-orientation-of-a-house.html

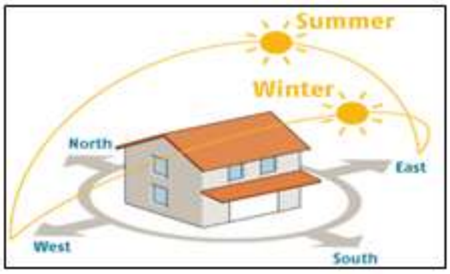


Image courtesy: http: //www.somfy architecture.com/ index.cfm?page=/buildings/home/bioclimatic facades

4.5.2. Shading by Neighboring Buildings

The buildings in a cluster can be spaced such that they shade each other mutually. The amount and effectiveness of the shading, however, depends on the type of building clusters. Martin and March (1972) have classified building clusters into three basic types, i.e., pavilions, streets and courts. Pavilions are isolated buildings, single or in clusters, surrounded by large open spaces. Street, long building blocks arranged in parallel rows, separated by actual streets in open spaces and courts are defined as open spaces surrounded by buildings on all sides.

Image courtesy: http:// ocw.mit.edu/courses/architecture/ 4-401-introduction-to-building-technology-spring-2006/

4.5.3. Shading by Vegetation.

Shading by trees and vegetation is a very effective method of cooling the ambient hot air and protecting the building from solar radiation. The solar radiation absorbed by the leaves is mainly utilized for photosynthesis and evaporative heat losses. A part of the solar radiation is stored as heat by the fluids in the plants or trees. The best place to plant shady trees is to be decided by observing which windows admit the most sunshine during peak hours in a single day in the hottest months. Usually east and west oriented windows and walls receive about 50% more Sunshine than the north and south oriented windows/walls. Trees should be planted at positions determined by lines from the centers of the windows on the west or east walls toward the position of the sun at the designated hour and date. On the south side only deciduous trees should be planted.

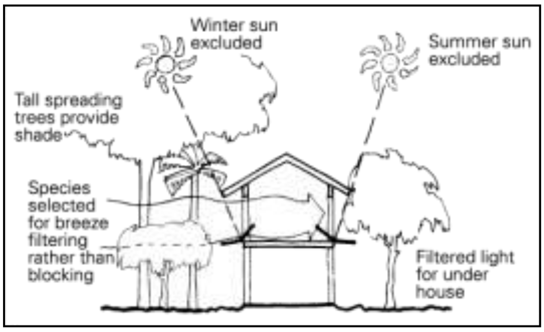
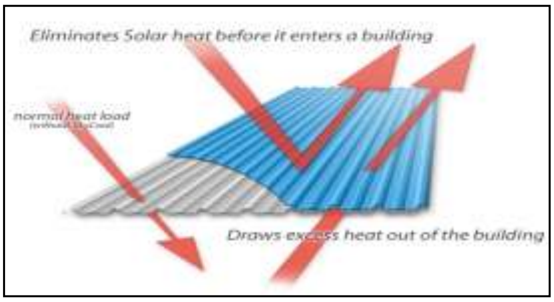


Image courtesy: http:// terrasolar.co.za/passive- solar-design/shading/

4.5.4 Reflecting Surfaces

If the external surfaces of the building are painted with such colors that reflect solar radiation (in order to have minimum absorption), but the emission in the long wave region is high, then the heat flux transmitted into the building is reduced considerably.



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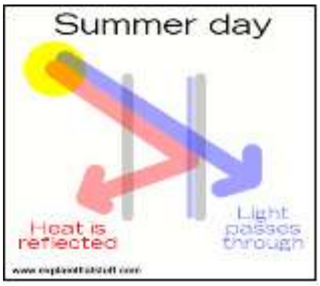


Image courtesy: http://www.explainthatstuff.com/how-low-e-heat-reflective-windows-work.html

4.5.5. Building Surface Cooling

Cooling of building surfaces by evaporation of water provides heat sink for the room air for dissipation of heat. Maintenance of water film over the surface of building element especially the roof brings down its temperature below the wet-bulb temperature of the ambient air even in the presence of solar radiation thus making the roof surface to act as a means of heat transmission from inside the building to the ambient air without increasing the humidity of the room air. Roof surface evaporative cooling consists of maintaining a uniform thin film of water on the roof terraces of buildings. This causes the roof temperature to achieve a much lower value than the other elements. The roof evaporation process can be very effective in hot and dry and also in warm and humid climate zones because of the incident solar radiation. The effect of roof surface cooling depends on the type of construction.

4.5.6. Roof Ponds and gardens

Water stored on the roof acts as a heat source and heat sinks both during winter and summer climatic conditions. The thermal resistance of the roof in this system is kept very small. In summer during the day, the reflecting insulation keeps the solar heat away from water, which keeps receiving heat through the roof from the space below it thereby cooling it. In the night, the insulation is removed and water, despite cooling the living space below, gets cooler on account of heat losses by evaporation, convection and radiation. Thus, the water regains its capacity to cool the living space. In winter, the insulation is removed during the day. Water and black surface of the roof absorb solar radiation; the living space continues to receive heat through the roof. During night water is covered with insulation to reduce heat loss.

4.5.7. Solar Chimney

A solar chimney utilizes the stack effect, as already described, but here the air is deliberately heated by solar radiation in order to create an exhaust effect. One should distinguish between the stack effect ventilation due to the building itself, and that due to a solar chimney. In the former case, one tries to keep the increment in the building temperature as small as possible (ventilation is being used for cooling) and hence the stack effect is weak. In the case of a solar chimney, there is no limit to the temperature increment within the chimney, since it is isolated from the used spaces. The chimney can therefore be designed to maximize solar gains and the ventilation effects. The parameters affecting the ventilation rates are:

- height between inlet and outlet;
- cross-sectional area of the inlet and the outlet;
- geometrical construction of the solar absorbing plate; And
- Inclination angle.

The use of solar chimneys is advisable for regions where very low wind speeds exist.

4.5.8. Courtyard Effect

Due to the incident solar radiation in the courtyard, the air in the courtyard becomes warmer and rises up. To replace it, cool air from the ground level flows through the louvered openings of the room, thus producing the air flow. During the night the process is reversed. As the warm roof surface gets cooled by convection and radiation, a stage is reached when its surface temperature equals the dry bulb temperature of the ambient air. If the roof surfaces are sloped towards an internal courtyard, the cooled air sinks into the court and enters the living space through the low level openings and leaves through higher level openings.

COURTYARD EFFECT (DAY)

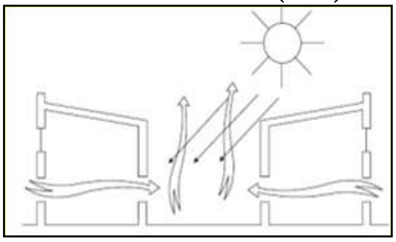


Image courtesy: Tropical climate responsiveness http://blog.deearth.com/

COURTYARD EFFECT (NIGHT)

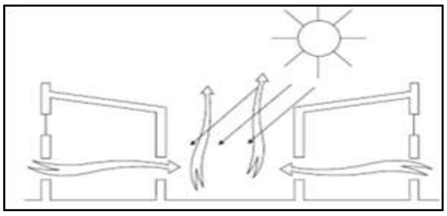


Image courtesy: Tropical climate responsiveness http://blog.deearth.com/

This concept can very well be applied in a warm and humid climate. It is necessary to ensure that the courtyard gets adequate radiation to produce a draft through the interior. Airflow inside the room can be maintained by a dual courtyard concept, where one courtyard is kept cool by shady trees vegetation and another courtyard to sun.

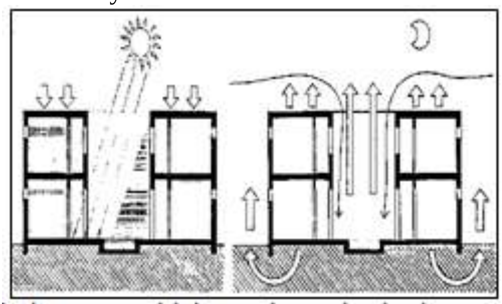


Image courtesy: (climate responsive building) http://www.nzdl.org

4.5.9. Air Vent or wind tower

A typical vent is a hole cut in the apex of a domed or cylindrical roof. Openings in the protective cap over the vent direct wind across it. When air flows over a curved surface, its velocity increases resulting in lowering of the pressure at the apex of the curved roof, thereby, inducing the hot air under the roof to flow out through the vent. In this way, air is kept circulating through the room under the roof. Air vents are usually placed over living rooms, often with a pool of water directly under the vent to cool the air, which is moving up to the vent, by evaporation.

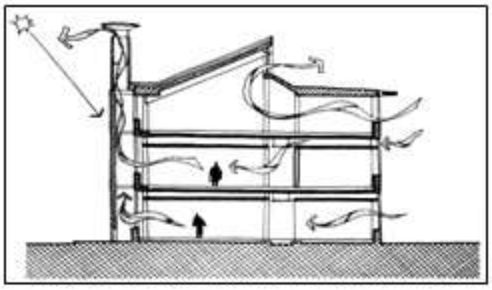
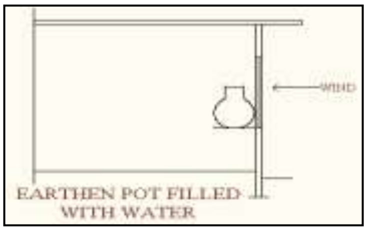


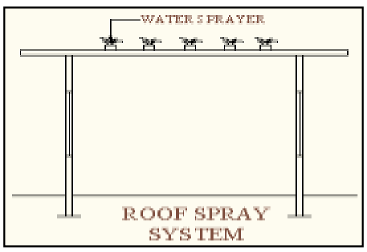
Image courtesy: Image from sun, wind, and light, by G.Z. brown and mark d ekay, published by Wiley

Air vents are employed in areas where dusty winds make wind towers impractical. It works well both in hot and dry zones and warm and humid zones unlike a wind tower which works only in hot and dry zones. It is most suited for single units which are just above frequently used livable space.

4.5.10. Sensible and Evaporative Cooling

The heat loss from air (on account of sensible cooling) results in a decreased air temperature, but no change in the water vapor content of the air. Air in the upper part of a wind tower is sensibly cooled. When water is introduced into a system, evaporative cooling occurs. Such cooling involves a change in both the water-vapor content and the temperature of the air. When unsaturated air comes in contact with water, some water is evaporated, thus lowering the temperature of the air and increasing its water-vapor content. A wind-tower system that cools air in an evaporative as well as sensible way is particularly effective.





4.5.11. Air Cooling by Tunnels

Temperature deep inside the earth remains nearly constant. Daily temperature variations hardly affect the earth’s temperature at a depth of more than one meter, while the seasonal variations of the ambient temperature are strongly dampened by the earth. The earth’s temperature up to a depth of 6 m to 8 m is influenced by the annual ambient temperature variations with a time delay of several months. It is seen that in Delhi the earth’s temperature at a depth of about 4 m in nearly constant at a level of about 23°C throughout the year. A tunnel in the form of pipes or otherwise will acquire the same temperature at its surface causing the ambient air ventilated through this tunnel to get cooled.

UNDERGROUND STREAM

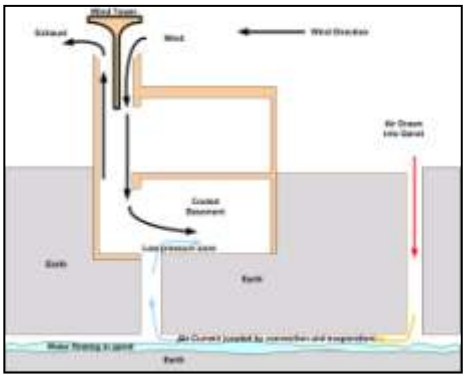


Image courtesy: http://www.solaripedia.com/13/205/2085/ wind_tower convection_illustration.html

WIND SCOOP

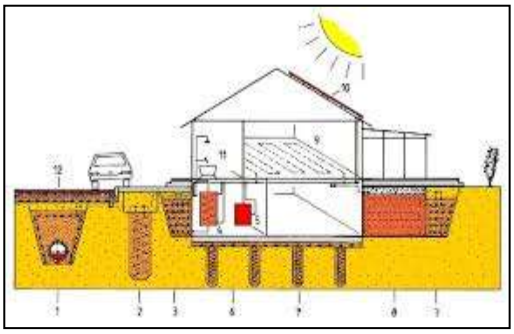


Image courtesy: http://www.pages.drexel.edu/~jm328/ AE390/A6/TheSystems.htm

4.5.12. Thermal Storage

Thermal capacity effects in the materials result in time delay as well as damping of the parameters in the environment. As a result temperature differences exist between the materials and the environment around them and this effect can be utilized for space cooling.

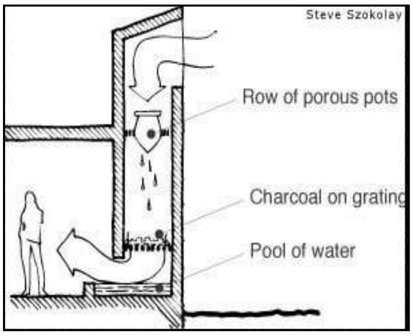


Image courtesy: http://orangedepotsystem.com/41233.html

4.6. Cooling and Heating Techniques using Thermal Mass

4.6.1. Building Elements

All building elements such as walls, roof and floor can be used for thermal storage. Creating a flow of fluid through the storage media can increase the efficiency of thermal storage. Additional thermal storage can be created by construction of rock bed storage.

4.6.2. Conventional Walls and Ceilings

Thermal storage efficiency of a building element depends on the heat storage capacity of various material layers of the building element, the order in which these layers are arranged and also on the fact whether the material is in the steady state or in the transient state. For example, a hanging acoustic ceiling of mineral wool below the roof acts as a lightweight building element for the thermal steady state conditions. During the transient state, however, the concrete room acts as a thermal storage system with appreciable time delay. A larger thermal storage capacity in any case leads to smoothening of the room temperature fluctuation and delays room temperature changes. The thermal performance of a building during the summer time is positively influenced by external as well as internal building elements.

4.6.3. Building Elements with Air Flow

The heat storage capacity of building elements can be increased by having some tubes in the massive ceiling and cooling it during the night by forcing air flow.

4.6.6. The Vary Therm Wall

Controlling the air movement in magnitude and direction gives rise to wall components with varying thermal resistance. Such a system can be used for mild winter heating and summer cooling for mixed climate as in Delhi. The external wall components are made of light material like aluminum or wood, while the internal component is made of brick (or concrete) wall. The flow of air is controlled into the room or to the ambient by providing proper vents in the interior wall. During the summer daytime, the wall provides effective air insulation and during the night the cool ambient air comes in contact with the warm brick wall and gets heated establishing a

natural flow of air. This air movement helps in quick removal of the heat flux. During winter, the vents are opened during the day into the room for supplying warm air and all vents are kept closed during the night time, thus providing an air insulation which minimizes heat losses to the ambient.
Vary therm wall deriving its name from the variable resistance can be operated in three modes:
 No flow of air in the gap thus effectively reducing the system to an air gap within the wall;
 Continuous flow of air into the room or to the atmosphere maintained by natural or forced convection; And
 No air flow during the day or night and creating airflow by opening the vents during night or day time depending on the weather conditions.

V. Conclusion

The purpose of the current study was to determine the main attributes of sustainability in the field of construction, and make a comprehensive definition of sustainability in this field. As conclusion, the model of sustainable building summarized.
By adopting operational practices that reduce energy and resource consumption in buildings, business and industry can green the building supply chain through market transformation. Incorporate solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation, and lighting. An energy-efficient building balances all aspects of energy use in a building – lighting, space-conditioning, and ventilation by providing an optimized mix of passive solar design strategies, energy efficient equipment, and renewable sources of energy.
By enacting sustainable building policies and applying integrated urban planning approaches, local governments can reduce infrastructure needs and costs. Finally, cities can foster change in consumption patterns and educate their residents on the benefits of sustainable buildings to ensure the long-term performance and benefits of sustainable buildings.
However, more research on this topic needs to be undertaken and practical solutions must be designed for developing countries.

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