Designing Buildings for Low Energy Footprint

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It is logical that a building's design will influence its energy consumption and the thermal comfort of its inhabitants. Design refers to passive design features of a building, that is – orientation, shading, thermal conductivity of materials, type of glazing, roof design and massing. These design factors influence the building's energy consumption for heating or cooling, ventilation and day-lighting. Unlike active elements such as fan, air conditioning or artificial lighting, they are part of the structure. They are passive features which use solar energy to provide thermal comfort to inhabitants by using principles of heat and energy flow in the immediate environment.

Optimum orientation of building, it is estimated, can reduce the cooling load by 30 – 40% (Y. P. Singh, Anoj Kr. Singh, 2004). Day-lighting is another major source of energy consumption in commercial buildings. Most offices in India use artificial light during the day, consuming up to 60% of total energy consumption. This amounts to immense wastage since working light level requirement in most offices varies from 200 – 300 Lux, which is only 2-3% of the design sky condition in India condition, which averages at 10,000 Lux (Arvind Krishan 2007).

Energy efficiency in buildings can be achieved by:

(i) Passive solar design of buildings

(ii) Use of renewable sources of energy

(iii) User-end measures in energy conservation

Use of renewable energy requires higher capital investments while the user-end measures cannot be regulated except with the use of energy conserving devices and equipments. Passive solar design of buildings achieves energy efficiency without any or substantial increase in capital investment. At the same time, it can make the building thermally comfortable. It is estimated that by some conservative estimates, the building sector world-wide could deliver emission reductions of 1.8 billion tonnes of C02. A more aggressive energy efficiency policy might deliver over two billion tonnes or close to three times the amount scheduled to be reduced under the Kyoto Protocol (Achim Steiner, UN Under-Secretary General and UNEP Executive Director, Oslo, March 2007/ SBCI report).

Passive solar design or the bioclimatic architecture has been an important field of study since the 1960s Victor Olgyay's research on finding a measure for human thermal comfort with the invention of the (temperature and relative humidity) bioclimatic chart. In fact, the practice of bioclimatic architecture dates back to the beginning of agriculture and society almost 10,000 years and is visible in vernacular architecture around the world which was dependent on passive design in the absence of active measures such as lights, fans and air conditioners.

Several passive design strategies such as the solar chimney, the trombe wall, the wind scoop, the malkaf, the courtyard, the wind tower, the earth air tunnel, etc. have been suggested to deal with different micro and macro climatic conditions.

Buildings have been designed to achieve thermal comfort with minimum energy input. Examples include the NMB Bank headquarters in Netherlands, the CII Green Building Center (a LEEDS Platinum rated building) and the IGP Complex, Gulbarga, Hyderabad among many others. However, specific design solutions for modern high rise residential buildings are deficient and where they exist, the relation between energy footprint and thermal comfort is not spelled nor quantified.

Building Physics:

"Architects seem to have a fear or lack of interest for all that is mathematical and lack an understanding of the basic laws of physics. The fact that this knowledge is presented in the way it is, makes it even more difficult to understand and even more improbable to influence his basic thinking." **–** Tombazis

Knowledge of building physics can not only be a vital tool and skill for an architect but can also enhance design and form. It includes the principles of heat and mass transfer in buildings, which is studied with respect to orientation, materials, massing, finishing, and so on. The first step in this subject is the analysis of climate under consideration.

Rudimentary climate analysis tools which are still in use include the sun dial, the solar path diagram, the wind rose and wind square diagram, Psychometric chart, Radiation square. Mahoney tables and bioclimatic charts are used to analyze data obtained from a meteorological department.

The instruments used to measure meteorological conditions include Stevenson's screen (to measure wet and dry bulb temperatures), thermograph and hydrograph (to measure temperature and relative humidity), rain gauge (to measure precipitation), anemograph and anemometer (to measure wind speed and wind direction), Sunshine recorder and pinoremeter (to measure the sunshine hours and the direct and diffuse radiation) and barometer (to measure atmospheric pressure).

Orientation:

Orientation affects the potential capture of prevailing wind and solar radiation for a building which are usually transmitted inside through the opening or fenestrations on the building envelope.

The Latitude of a place and the orientation of building determine the geometric relationship between a building and its environment - sun angles incident on the building in various seasons. The Cosine law states that greater the angle of radiation, greater the surface area its energy is spread over, lesser the intensity and heating capacity. While the 'Sol-air' orientation theory is considered where human stress is the objective measure of the solar impact; according to the theory, a building oriented to a particular axis receives maximum radiations during the under-heated period and minimum radiations during the over-heated period.

According to simulations conducted by Prof. Y. P. Singh (Dept. of Arch, MITS, Gwalior) and Anoj Kr. Singh (Research Associate, Dept. of Arch, MITS, Gwalior) in Jaipur, the amount of solar radiation per unit area on north and south facing walls is much less compared to that on the walls facing east and west. Hence for minimum solar heat gain by the building envelope, it is desirable that the longer axis of building should lie along east and west directions. When solar and winds are contradictory with respect to a building envelope, the building can be oriented within a range of 0 to 30^0 of prevailing wind direction to suit the solar angles without losing any beneficial aspect of breeze; buildings can be oriented at 450 to the incident wind for diminishing the solar heat gain without significantly affecting the air motion indoors.

Fenestration:

A building is an intrusion in a natural environment. Accordingly, it influences and is influenced by the existing natural environment. In their research paper on analyzing the effects of design parameters on thermal performance of buildings (in the context of composite climate), JIIA, December 2007, Ar. Rajeev Garg and Ar. Rajesh Jain of the Department of Architecture & Planning, Indian Institute of Technology, Rourkee, have simulated the model of a single room building. The base case is a building with four walls, no fenestrations and sunshades. The solar heat gain in this model has been compared with other models with similar dimensions but with additions of windows, sunshades, doors,etc. Thermal simulations were carried out for composite climate on May 30 for all the models oriented North. As the indoor temperatures were compared, it was found that the model with no fenestrations has the minimum heat gain as compared to the other three models. Shading the walls in addition to shading the openings, considerably reduces heat gain which is directly propotional to the number of fenestrations. Thus, fenestrations significantly contribute to solar heat gain and hence should be designed with discretion. Large openings on north and south facades are useful as they can be shaded with horizontal devices. While smaller opening are preferred on the east and west phases, since they require vertical shading.

Vernacular architecture provides the best examples of architecture elements employed for thermal comfort. The use of thick walls in the Bungas of Rajasthan provide a time lag for heat transfer, their round form minimizes heat gain per square meter of surface area; the different sizes and types of courtyards throughout India – from Rajasthan, Gujarat and Maharashtra to the Konkan belt upto Kerala – present a wide variation in courtyard design; in addition to providing privacy and an open to sky space, they also let in ample daylight and air circulation throughout the house. Hot and humid zones from Kerala, Maharashtra and Sri Lanka witness the absence of walls and the predominance of the roof as a design element. Different designs of the belvedere can be witnessed as it makes use of the prevailing breeze and the stack effect.

Passive design strategies include the direct and indirect heat gain for passive heating and cooling. Indirect gain includes use of Solar chimney, Trombe walls and water walls. Indirect cooling includes ventilation and stack effect and venture effect, belvedere, roof pond, earth air tunnel, courtyards and Malkaafs, wind scoops and wind towers.

The main objective of this approach to design is to achieve thermal comfort and to conserve energy

Thermal Comfort:

Thermal comfort can be defined as a mental state induced by physiological conditions in which a human being feels comfortable. For a long time, scientists around the world searched for a definition of thermal comfort and its variables. It was agreed that humans feel comfortable during particular seasons of the year and times of the day as compared to the rest and are, therefore, more productive at these times. This came to be called as 'the comfort zone'. The British department of Scientific and Industrial Research, headed by Drs. H.M. Vernon and T. Bedford arrived at certain conclusions in their experiments and investigations. Further C.E.P. Brooks showed that the British comfort zone lies between 58 to 70^0F; the comfort zone in the United States lies between 69 and 80^0 F; and in the tropics it is between 74 and 85^0F; with relative humidity between 30% and 70% (Brooks, Charles, Ernst, 1950).

The thermal comfort can differ with individuals, type of clothing, the nature of activity being carried on and the sex, as women and persons over 40 years, are found to have a thermal comfort temperature 1 degree higher than others.

The Olgyay brothers were the first to propose a bioclimatic chart. This chart was built up with two elements – the dry bulb temperature as ordinate and the relative humidity as abscissa. In the center of the chart is the comfort zone. On the whole, Olgyay's bioclimatic chart effectively demonstrates that climatic parameters are not independent. American scientists have tried to establish a physiological measurement, combining the effects of temperature, humidity and air movement. This was the effective temperature scale (ET) (Houghton F.C and Yaglou C.P., 1924). The Mahoney tables are commonly used to tabulate climatic data and categorize them according to the six climatic zones of India as shown in the figure.

The consideration of microclimatic conditions to a building's design is even more relevant than the macro climatic analysis. For example, the presence of tall structures may shade buildings and hinder the movement of wind, while the presence of paved surfaces may reflect and re-radiate heat. The presence of sea or water body creates a micro climatic condition known as land and sea breezes which cannot be ignored. Plant and grassy covers reduce temperatures by absorption of insolation and cooling by evaporation.