Climatic Design for Energy Efficiency in Buildings

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Necessity and benefits of designing buildings with energy efficiency considerations having been incorporated right from the planning stage have been discussed. Climatic classification map of India has been included for identification of the climate of the building site in question. The requirements of thermal comfort for various climatic zones have been defined. Method of selection of suitable architectural features like plan form, orientation, location and size of fenestration, shading devices, treatment of building envelop etc, which on incorporation in design of buildings would provide thermal comfort with minimum consumption of energy. Simple guidelines for design of buildings, which would function in conformity with climate, are also presented in the paper.

Keywords: Thermal comfort; Energy efficiency; Tropical summer index (TSI)

INTRODUCTION

Provision of thermal comfort in buildings is an important consideration in the design of buildings for efficiency and well being of occupants. Two well known methods for creating comfortable environment in the interior of buildings include adoption of the use of electrically operated mechanical devices, such as, air conditioners, heaters, blowers, etc, and natural systems based on judicious utilization of solar and wind energy. Though the earlier one is more dependable, the estimated electricity consumption on account of heating, ventilating and air conditioning, lighting and water heating is about 30% that constitutes a significant proportion of the total electricity consumption in the country. In the present energy scenario in India where gap between demand and supply of electrical energy is continuously increasing, the escalation in cost of power and associated environmental concerns have created awareness about efficient use of energy in every walk of life. Since, building sector is a major consumer of electricity, it is imperative to evolve building designs that would utilize solar and wind energy to the fullest possible extent for ameliorating thermal environment indoors. The Bureau of Energy Efficiency constituted by the Government of India in March, 2002, has identified ‘Energy Efficiency in Buildings and Establishments’ and ‘Energy Conservation Building Codes’ as the thrust areas of its action plan. The focus of these areas is directed towards improving energy efficiency in existing buildings and development of codes so that new buildings be designed and built with energy efficiency considerations having been incorporated right from the planning stage. This is a testimony to the fact that necessity for design of functional and energy efficient buildings has been very well recognized and efforts are needed to design buildings that would function in conformity with climate and not against it. Accomplishment of the aforesaid objective involves three steps (i) identification of the climate at the building site in question; (ii) determination of the comfort requirements of the relevant climate; and (iii) selection of appropriate architectural features including space planning, orientation, location and size of fenestration, shading devices, treatment of building envelope etc. Extensive studies covering the aforesaid aspects have been carried out at Central Building Research Institute, Roorkee and else where also.

CLIMATIC CLASSIFICATION

Classification of climate in respect of building design means zoning the country into regions in such a way that the difference of climate from region to region are reflected in the building design, warranting some special provision for each region. Based on this criteria, there are five major climatic zones, (i) hot-dry; (ii) warm-humid; (iii) cold; (iv) temperate; and (v) composite.

<table>
<thead>
<tr>
<th>Climatic Zone</th>
<th>Mean Monthly Maximum Temperature, °C</th>
<th>Mean Monthly Relative Humidity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-Dry</td>
<td>above 30</td>
<td>below 55</td>
</tr>
<tr>
<td>Warm-Humid</td>
<td>above 30</td>
<td>above 55</td>
</tr>
<tr>
<td></td>
<td>above 25</td>
<td>above 75</td>
</tr>
<tr>
<td>Temperate</td>
<td>between 25-30</td>
<td>below 75</td>
</tr>
<tr>
<td>Cold</td>
<td>below 25</td>
<td>all values</td>
</tr>
<tr>
<td>Composite</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

A given station is categorized under a particular zone if its climate conforms to that zone for six or more months, otherwise it falls under the composite zone. A map of India depicting various climatic zones is shown in Figure 1. For example, in Jaipur, it is cold in January, Temperate during February, November, December, hot-dry during March to June and October and warm-humid in July to September.
Since, none of the climate persists for six months or more, the stations fall in composite climate zone.

**COMFORT REQUIREMENTS OF HOT-DRY AND WARM-HUMID CLIMATE**

Comfort conditions depend upon air temperature, relative humidity, wind speed, as well as on clothing, acclimatisation, age, sex, and type of activity of the people. Based on exhaustive studies carried out on thermal comfort at CBRI Roorkee, a tropical summer index (TSI) representing the combined effect of temperature, relative humidity and wind speed was evolved. The TSI is defined as the temperature of calm air, at 50% relative humidity which imparts same thermal sensation as the given environment. Mathematically, TSI is expressed as

\[
\text{TSI} = 0.745t_a + 0.308t_w - 2v + 0.841
\]

where \(t_a\), dry bulb (globe) temperature, °C; \(t_w\), wet bulb temperature °C; \(v\), air speed in m/sec.

The thermal comfort usually lies between TSI values of 25°C and 30°C with maximum per cent of people being comfortable at 27.5°C. On lower side, the coolness of environment is tolerable between 19°C and 25°C (TSI) and below 19°C (TSI) it is too cold. This clearly indicates that for achieving comfortable environment indoors, heating upto 19°C is necessary in winter, whereas steps need to be taken to achieve indoor conditions conforming to TSI values around 27.5°C in summer. Therefore, in hot-dry climate, emphasis is laid on adopting design techniques that contribute towards reduction in indoor air temperature or globe temperature and provision of adequate night ventilation. On the other hand, provision of ample air motion is an important requirement of building design in warm-humid climate.

**DESIGN CONSIDERATIONS FOR ENERGY EFFICIENCY IN BUILDINGS**

Energy efficiency in buildings broadly implies three aspects; (i) obviating wastage in energy due to unwanted and non-judicious use of electrically operated gadgets; (ii) development of energy efficient appliances; and (iii) optimum utilization of non-conventional sources of energy through judicious planning and design of buildings. The aspects (i) and (ii) concern with the design, installation and operation of electrical appliances whereas aspect (iii) is related to incorporation of appropriate passive features at the initial design stage of the buildings. Several theoretical and experimental studies have demonstrated the usefulness of these techniques in respect of ameliorating thermal environment indoors. In context with cooling of buildings in hot-dry and warm-humid climates, the passive techniques mainly aim towards reduction in heat penetration through building envelope and provision of fenestration for inducing desired natural ventilation indoors.

**Reduction in Heat Penetration through Building Envelope**

Solar radiation incident on building envelope is the main source of heat responsible for raising the temperature of exterior surface of the envelope and also for creating temperature gradient across the thickness of the envelope. As a result, heat is conducted indoors thereby causing a rise in the interior surface temperature. Hence, reduction in the temperature of exterior surface is necessary for keeping the indoor surface temperature at a low value. Transparent window facing sun also permits direct entry of sun. This also contributes to the rise in the interior surface temperature. Hence, control of direct entry of sun through windows is an essential requirement for preventing the rise in interior surface temperature. Based on these considerations, various methods have been evolved for curtailment of heat flow through building envelope.

**Optimum Orientation**

It is well known that the amount of daily solar radiation incident per unit area on N and S facing walls is much less as compared to that on the walls facing other directions. Hence, for minimum solar heat gain by the building envelope, it is desired that the longer axis of building should lie along East-West direction. Further, the effect of orientation of a building on heat penetration through envelope also depends on the aspect ratio, i.e., length/breadth of the building. For a building with square plan, i.e., aspect ratio 1:1 and glass area equally distributed on all the four walls, the effect of orientation is nil, while for a rectangular building with aspect ratio 2:1, the fabric load is reduced by 30% due to change in orientation from worst to best.

**Shading of Windows**

Louvers, overhangs or awnings provided on windows help
control direct entry of sun into the room especially during summer months. Optimum dimensions of the louver depend on the duration of sunshine on the window facade. Windows of the same dimensions but oriented differently should have different dimensions of louvers to be effective. A simple box type louver\(^3\) may be suitable on an eastern facade, a slightly more complicated vertical and horizontal louver system on the southern facade and an egg crate type on the western facade. The northern facade receives only very early morning or late afternoon sunshine and hence no elaborate systems are needed and only rain shade is sufficient. It is reported\(^4\) that overhang with optimum dimensions can produce cooling load reduction of 12.7% in summer without causing any sufficient change in sunshine hours received in winter. It is worth mentioning that an overshadowing of the windows must be avoided as it reduces availability of daylight indoors, which in turn results in increased consumption of energy for artificial lighting.

**Exterior Surface Solar Reflectance**

Surface colour of the external wall affects both the percentage of solar radiation absorbed by the external surface and also the long wave radiation emission. Hence, the heat flux transmitted into the building is considerably reduced when external surface is painted with a colour with minimum absorption of solar radiation and high emission in long wave region. Such data\(^2\) for a few materials are given in Table 1. Simulation studies\(^6\) conducted at Lawrence Berkley Laboratory USA indicate that by changing the overall albedo of a city from an existing value of about 0.2 to a white washed of 0.4 may result in saving of electrical energy by 40% to 50%.

**Roof and Wall Insulation**

Provision of insulation on walls and roof of a building increases their thermal resistance and curtails conductive heat flow through the building envelope. Recommended thicknesses of some of the insulating materials for roofs of unconditioned and conditioned buildings are given in Table 2. Introduction of air cavity in a wall also increases its thermal resistance. Studies\(^7\) on estimation of thermal properties of such a wall revealed that the overall heat transmission coefficient \(U\) value of a 27.5 cm brick cavity wall (11.25 cm brick + 5.0 cm air gap + 11.25 cm brick) is 1.63 W/m\(^2\) K while that of a 22.5 cm solid brick wall with 1.25 cm cement plaster on both the side \(U\) value is 2.26 W/m\(^2\) K. Here, it is worth emphasizing that the thermal performance of the above cavity wall is slightly better than that of a 35 cm solid brick wall.

**Energy Efficient Windows**

Window is a critical component in the design of energy efficient buildings. The most effective way of window design to conserve energy is by optimising the window size and location. Windows on East and West facades should be avoided as these are the worst orientations from the heat gain point of view. In air conditioned buildings, windows are considerably less insulating than other parts of the envelope of the structure. It is observed that for a single glazed window system the \(U\) value is 5.22 W/m\(^2\) K which is less than the desired value. The \(U\) value is considerably less (3 W/m\(^2\) K) for a window system consisting of a double glazing with an air gap of 12 mm-18 mm. Adoption of such a system reduces heat gain by at least 10%.

**GUIDELINES FOR INDUCEMENT OF AIR MOTION INDOORS**\(^8\)

1. For achieving maximum benefit from natural wind, buildings need not necessarily be oriented perpendicular to the prevailing outdoor wind; these may be oriented at any convenient angle between 0° and 30° without losing any beneficial aspect of breeze. If the prevailing wind is from East or West, buildings can be oriented at 45° to the incident wind for diminishing the solar heat gain without significantly affecting the air motion indoors.

2. Atleast one window should be provided on windward wall and the other on leeward wall.

3. Maximum air movement at a particular plane is achieved by keeping the sill height at 85% of the height of the plane.

4. In rooms of normal size having identical windows on opposite walls, the average indoor air speed increases rapidly by increasing the width of window up to about 2/3 of the wall width; beyond that the increase

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**Table 1 Reflectivity and emissivity of different coatings**

<table>
<thead>
<tr>
<th>Material</th>
<th>Reflectivity (Solar Radiation)</th>
<th>Emissivity (Long wave Radiation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum foil bright</td>
<td>0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>Aluminum paint</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>White wash new</td>
<td>0.88</td>
<td>0.90</td>
</tr>
<tr>
<td>Grey colour light</td>
<td>0.60</td>
<td>0.90</td>
</tr>
<tr>
<td>Grey colour dark</td>
<td>0.30</td>
<td>0.90</td>
</tr>
<tr>
<td>Red brick</td>
<td>0.40</td>
<td>0.90</td>
</tr>
<tr>
<td>Glass</td>
<td>0.08</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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**Table 2 Recommended thickness of insulation for roof**

<table>
<thead>
<tr>
<th>Insulating Material</th>
<th>Density (\text{kg/m}^3) Min</th>
<th>Density (\text{kg/m}^3) Max</th>
<th>Thermal Conductivity (W/mK)</th>
<th>Thickness in cm for Unconditioned Buildings</th>
<th>Thickness in cm for Conditioned Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular concrete</td>
<td>450</td>
<td>600</td>
<td>0.081</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Foam concrete</td>
<td>320</td>
<td>400</td>
<td>0.070</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Light weight bricks</td>
<td>400</td>
<td>450</td>
<td>0.081</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Thermocole</td>
<td>16</td>
<td>20</td>
<td>0.041</td>
<td>2.5</td>
<td>10.0</td>
</tr>
</tbody>
</table>
is in much smaller proportion than the increase of the window width (Figure 2(a)).

5. The average indoor wind speed in the working zone is maximum when window height is 1.1 m. Further increase in window height promotes air motion at the top level of window, but does not contribute additional benefits as regards air motion in the occupancy zone in buildings.

6. For a total fenestration area (inlet plus outlet) of 20% to 30% of floor area, the average indoor wind velocity is around 27% of outdoor velocity. Further increase in window size increases the velocity but not in the same proportion. In fact, even under ideal conditions the maximum average indoor wind velocity does not exceed 40% of the outdoor velocity (Figure 2(b)).

7. In regions having fairly constant wind direction, the size of the inlet should be kept within 30% to 50% of the total area of fenestration and building should be oriented perpendicular to the incident wind. Since, inlets smaller than outlets are more sensitive to change in wind direction, openings of equal sizes are preferred in the regions having frequent changes in wind direction.

8. In case of room with only one wall exposed to outside, provision of two windows is preferred to that of a single window.

9. Windows located diagonally opposite to each other, with the windward window near the upstream corner, give better performance than other window arrangements for most of the building orientations.

10. Horizontal louver, i.e., a sunshade, atop a window deflects the incident wind upward and reduces air motion in the zone of occupancy. A horizontal slot between the wall and horizontal louver prevents upward deflection of air in the interior of rooms. Provision of L type louver increases the air motion in the room provided that the vertical projection does not obstruct the incident wind (Figures 3(a) and 3(b)).
11. Provision of horizontal sashes inclined at an angle of 45° in the appropriate direction helps to promote the air motion inside rooms. Sashes projecting outward are more effective than those projecting inwards.

12. Air movement at working plane 0.4 m above the floor can be enhanced by 30% using a pelmet type wind deflector (Figure 4).

13. Roof overhangs help air motion in the working zone inside buildings.

14. Verandah open on three sides is preferable since it causes an increase in the room air motion for most of the orientations of building with respect to the incident wind.

15. A partition placed parallel to the incident wind, has little influence on the pattern of air flow but when located perpendicular to the main flow, the same partition creates a wind shadow. Provision of a partition with spacing of 0.3 m underneath, helps augmenting air motion near floor level in the leeward compartment of wide span buildings.

16. Air motion in a building unit having windows tangential to the incident wind is accelerated when another unit is located at end-on position on downstream side (Figures 5(a) and 5(b)).

17. Air motion in two wings oriented parallel to the prevailing breeze is promoted by connecting them with a block on the downstream side (Figures 6(a) and 6(b)).

18. Air motion in a building is not affected by constructing another building of equal or smaller height on the leeward side, but it is slightly reduced if the leeward building is taller than the windward block (Figures 7(a), 7(b) and 7(c)).

19. Air motion in a shielded building is less than that in an unobstructed building. To minimise the shielding effect, the distance between the two rows should be about 8 H for semidetached houses and 10 H for a long rows of houses. However, the shielding effect is diminished by raising the height of the shielded building.

20. Hedges and shrubs deflect the air away from the inlet openings and cause a reduction in air motion indoors. These elements should not be planted at a distance less than 8 m from the building because the induced air motion is reduced to minimum in that case. However,
21. Trees with large foliage mass having trunk bare of branches up to the top level of window, deflect the outdoor wind downward and promote air motion in the occupancy zone inside the buildings.

22. Ventilation conditions indoors can be ameliorated by constructing buildings on earth mound having a slant surface with a slope of $10^\circ$ on upstream side.

23. A non-conventional system of ventilation, commonly called as wind tower, helps to induce air motion in rooms devoid of windows on two exposed walls. The wind tower consists of a vertical wind carrying shaft with a wind scooping attachment atop thereof. On its vertical sides, the shaft is provided with several openings, which connect the tower to the different rooms intended to be ventilated. Openings in rooms are also provided on walls other than the one facing the tower. Such an arrangement of openings facilitates cross ventilation in the rooms. The impingement of wind on the face of the tower causes development of positive pressure thereon. As the wind flows around the building, separation of flow takes place at the windward edges and negative pressure is created over all the leeward faces of the building. Thus, a pressure difference exists between the tower inlet and openings.
located on the leeward side of the rooms. Consequently, flow of wind occurs from tower inlet to the room openings. In the process, the wind entering through the wind tower sweeps the room area and finally exits through the room opening thereby ventilating the room (Figure 9).

CONCLUSION
Design techniques for cooling of buildings have been described. It has been established that adoption of some simple passive features like optimum orientation, adequate shading of windows, reflective coatings on exterior surfaces, greenery cover over the building, roof and wall insulation, energy efficient window system, judicious provision of windows for ample natural ventilation etc results in significant saving in the energy consumed while creating comfortable environment indoors.

REFERENCES
7. 'Thermal Data of Building Fabrics and its Application in Building Design.' Building Digest, CBRI, no 52, Roorkee.