ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 5 (2013)
PAGES 747-754

Technical Note

AN ASSESSMENT OF CLIMATIC DESIGN STRATEGY FOR LOW ENERGY RESIDENTIAL BUILDINGS IN HOT AND ARID CLIMATE

M. Arif Kamal*
Department of Architecture, Sharda University, Greater Noida, India

Received: 25 October 2012; **Accepted:** 24 February 2013

ABSTRACT

Buildings consume a lot of operational energy primarily due to its cooling requirements. Increasing consumption of energy has led to global warming resulting in ozone layer depletion. The key to conserve energy in buildings is to design buildings according to climate. Since most of the population in India is concentrated in hot and arid region, substantial amount of energy can be conserved using proper climatic design. In this paper basically three important climatic design strategies namely shading, thermal mass and courtyard and their significance in climatic control and conserving energy in residential buildings in hot and arid regions has been discussed.

Keywords: Climatic design; strategy; low energy; residential buildings; hot and arid climate.

1. INTRODUCTION

There has been a lot of reliance on energy-consuming technology in cooling and ventilation system to achieve thermal comfort in buildings especially in hot and dry region. The total amount of energy used in buildings during operation constitutes a significant part of the total amount of energy used in a country [1]. Housing forms the most common building type throughout the world. Over 15% of all savings in developing countries is invested in residential construction. The buildings use one third of all energy consumed in India and two third of all electricity. In India, the building sector represents about 33% of energy consumption with commercial and residential sector accounting for 8% and 25% respectively [2].

Increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion and subsequently having climate change. Since most of

* E-mail address of the corresponding author: architectarif@gmail.com (M. Arif Kamal)

the population is concentrated in hot and arid region of India, and housing sector comprising the major percentage of the building industry, a substantial amount of energy can be conserved. In this paper an attempt has been made to assess basically three important climatic design strategies namely shading, thermal mass and courtyard and their significance in climatic control and conserving energy in residential buildings in hot and arid regions.

2. RELATIONSHIP BETWEEN GLOBAL WARMING AND CLIMATE CHANGE

Researchers have proved that global warming and climate change are two interrelated phenomena. Hansen and others have shown that recent incidents of extreme weather in different parts of the world are almost certainly the result of global warming [3]. Fossil fuels are burned to produce the cooling energy demand, which causes green house gas emissions and hence global warming leading to climate change. By implementing energy reduction measures, we can reduce electricity demand and climate-altering emissions.

3. ENVIRONMENTAL EFFECTS CAUSED BY CLIMATE CHANGE

There are many environmental effect caused by global warming and ozone layer depletion and finally climate change. The average global temperature has risen by about 0.5° from the accumulation of anthropogenic greenhouse gases in the atmosphere during the past century or so. In India, climate variability is expected to lead to crop loss of 10 to 40 per cent and hundreds of billions of rupees in loss of revenue from agriculture with a 2° rise in average global temperatures [4]. According to Intergovernmental Panel on Climate Change (IPCC), some of the prominent environmental effect which are caused by climate change are [5]:

1. Unknown effects on food production
2. More extreme weather events
3. Unknown effects on ecosystems
4. Spread of disease to temperate climates
5. Submersion of land masses – 1 to 4 foot sea level rise
6. 140,000 deaths per year attributed to climate change

4. CHARACTERISTICS OF HOT AND ARID CLIMATE

Hot and arid climate normally occurs between latitudes 15º and 35º north and south of equator. In hot dry climates there is temperature inversion with large variation between day and night temperatures. Mean maximum air temperature for summer months is between 43 to 48º C and minimum is between 27 to 30º C While in winters mean maximum air temperature is between 24 to 30º C and minimum is between 17 to 22º C. The Precipitation is slightly low throughout the year from 300 to 600 mm per annum with maximum during the monsoon months. The sky conditions are normally clear with few clouds with a luminance of 1700 to 2500 cd/m^2. Solar radiation is direct and strong during the day, but the absence of clouds permit easy release of heat stored during the day time in the form of long wave radiation towards the night sky. Winds are usually local often caused by temperature inversion due to hot ground and cooler upper air resulting in local whirlwinds. Vegetation is sparse and difficult to maintain because of the lack of rain and low humidity. Figure 1 shows the various climatic zones in India.

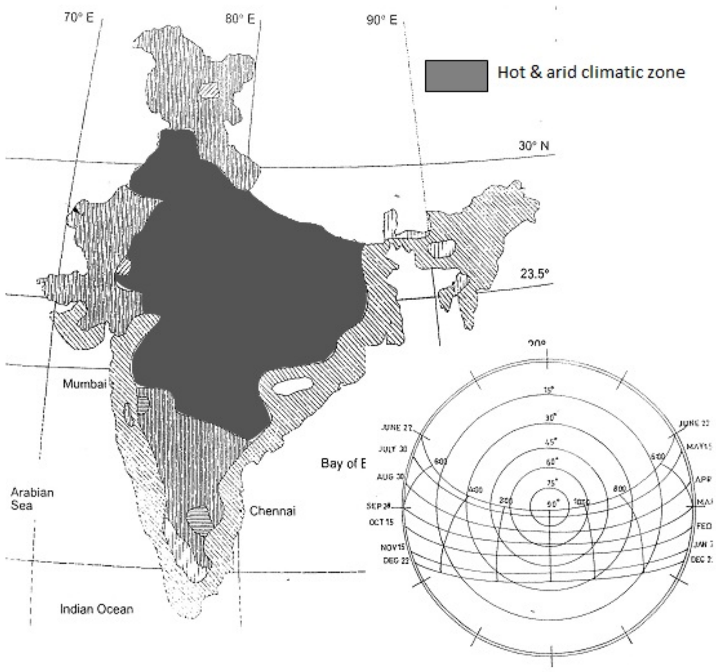

Figure 1: Various climatic zones of India and solar path diagram for Lat. 26°N (Source: Koenigsberger, Manual of Tropical Housing and Building Design)

5. CLIMATIC DESIGN STRATEGIES FOR RESIDENTIAL BUILDINGS IN HOT AND ARID REGION

Physiological uncomfortable conditions in arid climates are mainly caused by the extreme heat and dryness and to a lesser extent by sand and dust storms. Human thermal comfort is usually found when the mean skin temperature is maintained by various means below 33.9º C and above 31.1º C [6]. The design factors which affect the design of a residential building in hot arid climate include features like compact form, orientation, high thermal mass, shading the building, use of internal courtyards, small openings, evaporative cooling, use of reflective surfaces etc. Of all these factors shading of the building and openings, high thermal mass and having internal courtyards are the three most important climatic design determinants, which are discussed in the subsequent paragraphs.

6. EFFECTIVENESS OF THERMAL MASS IN HOT AND ARID CLIMATE

In hot and dry climates with a large diurnal range it is advantageous to use massive building elements. The effect of massive construction is to lower the maximum internal daytime temperature and to raise the minimum nighttime temperature while in lightweight construction; the internal temperatures follow closely the pattern of outdoor temperatures. The importance of heat storage increases with larger swings in outdoor temperature. Heat dissipation is then achieved overnight by exposing the building structure to the cooler night-time outdoor air. The classical use of thermal mass includes adobe or rammed earth houses. Its function is highly dependent on marked diurnal temperature variations. The wall predominantly acts to retard heat flow from the exterior to the interior during the day. The high volumetric heat capacity and thickness prevents heat from reaching the inner surface. When temperatures fall at night, the walls re-radiate the heat back into the night sky. In this application it is important for such walls to be massive to prevent the ingress of heat into the interior.

Hasan Fathy conducted tests on experimental buildings located at Cairo Building Research Centre, using different materials. The materials used were mud brick walls and roof 50 cm thick and prefabricated concrete panel walls and roof 10 cm thickness. The thermal performance of the two buildings over a 24 hour cycle was monitored. The air temperature fluctuation inside the mud brick model did not exceed 2°C during the 24 h period, varying from 21-23°C which is within the comfort zone. On the other hand, the maximum air temperature inside the prefabricated model reached 36°C, or 13°C higher than the mud brick model and 9°C higher than outdoor air temperature. The indoor temperature of the prefabricated concrete room is higher than the thermal comfort level most of the day [7]. Moore reported the temperatures in and around an adobe building. He observed that when average inside and outside temperatures are about equal, maximum interior temperature occurred at about 22:00 h (about 8 h after the outside peak). Furthermore, the outside temperature swing was about 24°C while the interior swing was about 6°C [8]. The effect of thermal mass on interior temperature is shown in Figure 2.

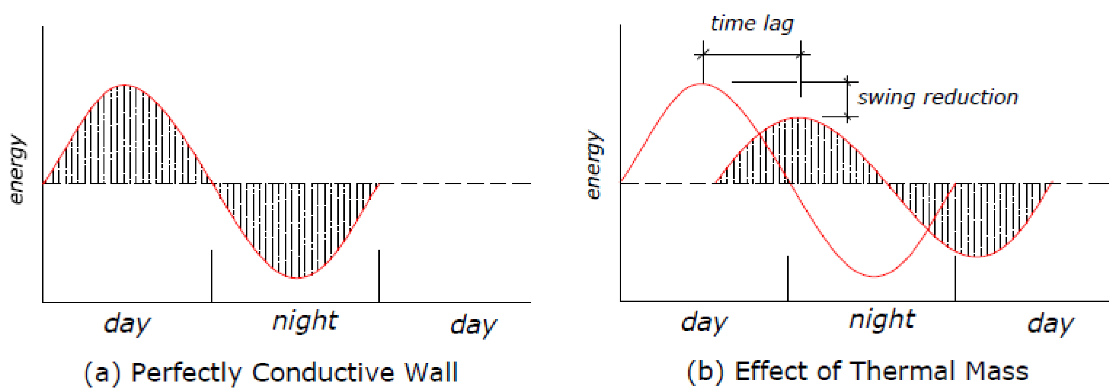

Figure 2: Effect of thermal mass on interior temperature

Table 1 shows the time lag and U value of different materials is shown in Table 1. Hence the buildings with large thermal mass with light coloured walls and reflective surfaces are suitable for climates which require heating in winter and cooling in summer and can reduce the energy needed considerably, Other than these passive cooling devices are also used to reduce the internal temperatures these are mainly of two types – Radiation cooling and cooling by evaporation. Active climate control using solar energy in building is by use of Air conditioners, Water heaters, Solar Collectors and Lighting powered by solar power by using Photovoltaic cells. These can be integrated in the building design on the roof and south and west walls and can reduce the energy demand by 2/3rd in a residential building in hot arid climate [10].

Table 1: Time lag values of different materials [9]

Material	Thickness	U-values	Time lag (Hours)
Brick	4	0.61	2 - 21/2
	8	0.41	5 - 21/2
	12	0.31	8 - 21/2
Concrete	4	0.85	2 - 21/2
	8	0.67	5
	12	0.55	8
Insulating Fibre Board	2	0.61	0.7
	4	0.09	0.3
Wood	½	0.68	0.2
	1	0.47	0.4
	2	0.30	1

7. RELEVANCE OF SHADING IN HOT AND DRY CLIMATE

The most effective method to cool a building in summer is to keep the heat from building up in the first place. The primary source of heat buildup (i.e., gain) is sunlight absorbed by the building through the roof, walls, and windows. Specific methods to prevent heat gain include reflecting heat (i.e., sunlight) away from the building, blocking the heat, removing built-up heat, and reducing or eliminating heat-generating sources in the building. The most important passive cooling strategy, regardless of mass, is shading. Shading is like putting a hat on the building. Shading is a simple method to block the sun before it can get into the building.

Kumar, Garg and Kaushik evaluated the performance of solar passive cooling techniques such as solar shading, insulation of building components and air exchange rate. In their study they found that a decrease in the indoor temperature by about 2.5°C to 4.5°C is noticed for solar shading. The analysis suggested that solar shading is quite useful to development of passive cooling system to maintain indoor room air temperature lower than the conventional building without shade [11]. Decisions on where and when to include shading can greatly affect the comfort level inside a closed space. Shading from the effects of direct solar radiation can be achieved in many ways:

- Shade provided by the effect of recesses in the external envelope of the building
- Shade provided by static or moveable external blinds or louvers
- Transient shading provided by the orientation of the building on one or more of its external walls
- Permanent or transient shading provided by the surrounding buildings, screens or vegetation.
- Shading of roofs by rolling reflective canvass, earthen pots, plant cover, vegetation etc.

Although shading of the whole building is beneficial, shading of the window is crucial. The total solar load consists of three components; direct, diffuse and reflected radiation To prevent passive solar heating, when it is not wanted, a window must always be shaded from the direct solar component and often so from the diffuse and reflected components.

Shading by Overhangs, Louvers and Awnings etc.

Well-designed sun control and shading devices, either as parts of a building or separately placed from a building facade, can dramatically reduce building peak heat gain and cooling requirements and improve the natural lighting quality of building interiors (Fig. 3). The design of effective shading devices will depend on the solar orientation of a particular building facade. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer. The shading devices can be classified as given below:

Movable opaque: Roller blind curtains, awnings etc. reduce solar gains but impede air movement and cut the view.

Louvers: They are adjustable or can be fixed. To a certain extent impede air movement and provide shade to the building from the solar radiation.

Fixed: Overhangs provide protection to the wall and opening against sun and rain.

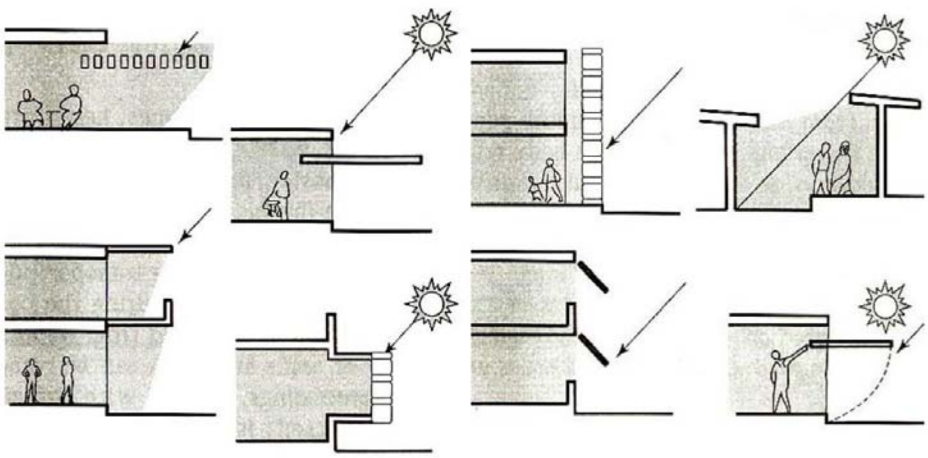

Figure 3: Different types of shading devices.

8. THE VALUE OF COURTYARD IN HOT AND ARID CLIMATE

Courtyard planning is a very suitable built form in hot and arid climate. Hence they are found in They are generally centrally located and are completely opened to the clear sky or partially shaded with overhangs in some of the cases. This also provides shaded spaces which results in reducing heat gain. The centrally placed courtyard provides light to all the spaces and also provides air movement due to induced ventilation through the openings on the walls facing the courtyard (Figure 4). For example, in hot-humid seasons, large courtyards provide good ventilation, especially when opening on to another courtyard or street such that cross ventilation is promoted. On the other hand, small courtyards provide more protection against hot, dusty winds in summers, especially in hot and arid climate.

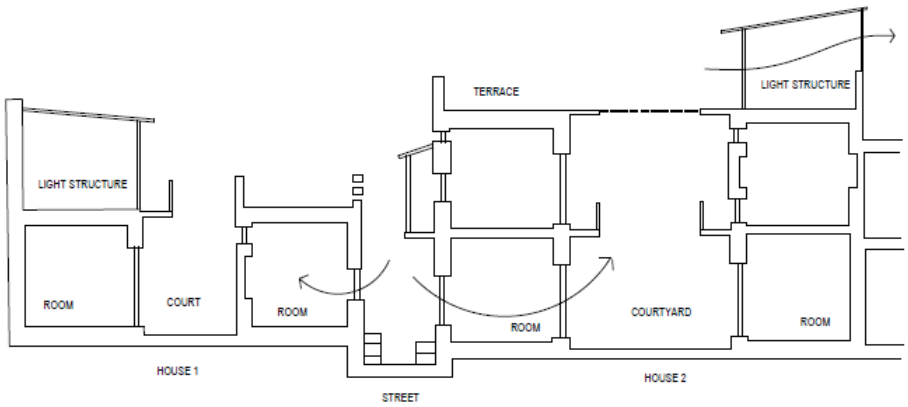

Figure 4: Thermal effect and air movement due to courtyard

The functioning of the courtyard during the 24-hour cycle can be subdivided into three phases. In the first phase, cool night air descends into the courtyard and into the surrounding rooms. The structure, as well as the furniture, are cooled and remain so until late afternoon. During the second phase, at midday, the sun strokes the courtyard floor directly. Some of the warm air begins to rise and also leaks out of the surrounding rooms. This induces convective currents, which may provide further comfort. At this phase the courtyard acts as a chimney and the outside air is at its peak temperature. The massive walls do not allow the external heat to penetrate immediately. The penetration is delayed and depends on the time lag of the walls. During the last phase, by late afternoon, the courtyard floor and the interior rooms become warmer. Most of the trapped cool air spills out by sunset. After sunset the air temperature falls rapidly as the courtyard begins to radiate rapidly to the clear night sky. Cool night air begins to descend into the courtyard, completing the cycle [12].

9. CONCLUSION

With the ever growing global concern for the use of energy and resources, architects have a greater responsibility to design buildings that are environmentally sustainable. With climate change, we are obliged to come back to systems and techniques which save energy and which don't need much capital. By implementing energy reduction measures, we can reduce electricity demand and climate-altering emissions. There are many simple ways in which, without recourse to new technologies and systems, buildings have been found to be much less wasteful than the overlit, overheated, overcooled, under insulated glass prisms that are today's commercial norm. However in modern times due the availability of electrical power to run active cooling systems, focus on use of these techniques had been forgotten. The techniques discussed in this paper minimize the climatic harshness in hot and arid climate and cool the building effectively and hence dramatically affect building energy performance. Incorporation of these three important passive techniques would certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental problems due to excessive consumption of energy and other natural resources and will evolve a built form, which will be more climate responsive, more energy efficient, more sustainable and more environmental friendly buildings of tomorrow.

REFERENCES

1. Winther BN, Hestnes AG. Solar versus green: the analysis of Norwegian row house. *Solar Energy*, **66**(1999) 387–93.
2. ECBC. *Energy Conservation Building Code*, Bureau of Energy Efficiency, New Delhi, 2011.
3. Hansen J, Sato M, Reudy R. Perception of climate change, *Proceedings of National Academy of Sciences*, USA, 2012.
4. Byravan S, Rajan S. *Warming signs for the economy*, The Hindu newspaper dated 22nd August 2012, New Delhi, 2012.
5. IPCC, Intergovernmental Panel on Climate Change, 2012, http://en.wikipedia.org/wiki/Intergovernmental_Panel_on_Climate_Change (accessed on 16 November 2012)
6. Koenigsberger. *Manual of Tropical Housing and Building Design*, Orient Longman, India, 1973.
7. Fathy H. *Natural Energy and Vernacular Architecture*, University of Chicago Press, Chicago, 1986.
8. Moore F. *Environmental Control Systems: Heating, Cooling, Lighting*, McGraw-Hill, USA, 1993.
9. CBRI. (1991) *Building Research Notes: Thermal Performance of Building Sections in Different Climate Zones* UDC: 699.-38, Central Building Research Institute, Roorkee, India, 1991.
10. Krishan A. *Climate Responsive Architecture: A Design Handbook for Energy Efficient Building*, Tata McGraw Hill, New Delhi, 2001.
11. Kumar R, Garg SN, Kaushik SC. Performance evaluation of multi-passive solar applications of a non air-conditioned building, *International Journal of Environmental Technology and Management*, No. 1, **5**(2005) 60–75.
12. Talib K. *Shelter in Saudi Arabia*, St. Martin Press. New York, 1984.