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Passive Techniques for Achieving Thermal Comfort in the Vernacular Dwellings of Bikaner

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ABSTRACT: Vernacular architecture based on bioclimatic concepts was developed and used through the centuries by many civilizations across the world. Different civilizations have produced their own architectural styles based on the local conditions. Bikaner is a non basin settlement in the hot and dry climatic region of india. The vernacular architecture of the bikaner haveli's has provided a comfortable shelter against the harsh climatic conditions of the region. However, it has not been studied in the quantitative evaluation method. This study is carried out on the vernacular buildings of bikaner, india. A survey of residential haveli's, more than 100 years old was carried out in the walled town of bikaner. The objective of the investigation was to understand the passive environmental control systems of vernacular architecture of bikaner to achieve thermal comfort. The results show that the natural and passive design systems provide comfortable indoor environment irrespective of the outdoor climatic conditions.

Keywords: Passive techniques, Thermal Comfort, Vernacular Architecture, Hot & Dry region, Bioclimatic architecture.

I. THERMAL COMFORT

Thermal comfort research in recent years has been driven by a need for energy efficiency in the building sector without compromising long term health and wellbeing of its occupants. Various models of thermal comfort has been developed by researchers. Traditionally our buildings have been regarded as our third skin, clothing the second, while the biological skin is considered the first. These 3 skins help us maintain the deep body temperature at around 37 degree Celsius around the year in any geographical location. Thermal comfort of the body is of utmost importance as it affects the working of the individual and also the health.

A. Comfort and Built Environment

Built environment has direct effect on human's satisfaction and well-being. Building's response to inhabitant's physical and psychological needs is essential to give them a sense of self worth, safety, and privacy. In spite of all these, it is necessary for a healthy environment to delight, uplift the sprits, relax or provide contact with nature (Sassi, 2006). Therefore for attaining the physical satisfaction, the human body should be in a comfort level that achieving this depends on the accommodation of building design with the outdoor climate. Accordingly climate is one of the most important factors, which can have an effect on human comfort. Hence due to differences of climate in different part of the world, each region needs its designs and constructions techniques in its building that can provide human comfort. However in recent years, by the development of technology, most of the new building are designed in such a manner that for any thermal needs they rely on the mechanical devices.

Human health and comfort have been perceived as the most important parameters during evaluations of indoor environments. Developing countries are limited by extreme environmental conditions, out- dated construction techniques and scarce financial resources and therefore struggle to adopt costly technologies aimed at achieving improved interior environments (S Kumar). Any analysis of the role of energy in architecture is faced with serious limitations due to the lack of such studies in the architectural literature. An awareness of these limitations will enable one to understand why architects have paid little attention to the inter- action between form and energy and a bioclimatic focus in contemporary architecture (Coch, 1998).

II. VERNACULAR ARCHITECTURE

Understanding of the traditional architecture in terms of heat, humidity, air movement and light with respect to the physical environment provides vital lessons for the present design endeavours. The familiar elements of regional architectural styles – Verandahs, balconies, courtyards, shutters and such are created to use the sun for warmth and light and to create shade and breeze for cooling. Climatic design lessons can be learned and inspiration can be sought by observation of the long tradition of vernacular architecture (Maria, 2009). Building energy consumption in India is the highest among all Asia Pacific Partnership countries (S Bin, 2008). On the other hand, the vernacular houses/ havelie's of Bikaner region are typical examples of buildings adapted to the hot and dry climate.

Fig. 1. Typical Haveli.

Vernacular architecture is in a developmental process intended to reclaim the architectural values of protection against the severities of the exterior climate in accordance with the objective of minimal consumption (to near-zero if possible). We can high-light, for example the new emerging vernacular of self-built urban settlements in Brazil (LC Labaki, 1998). During these times of environmental crisis and accelerated urban development, it seems logical for architects to practice sustainable ecological design (Bay, 2010). Bioclimatic adjustments basically comprise three directions: energy, human health/wellbeing and sustainability (Metallinou, 2006). To apply bioclimatic architecture, it is necessary to consider the various climate levels of the building's location, including the general climate, the meso climate and the climate near the building defined by the nearby elements or microclimate (N Gaitani, 2007). The next step would include the architectural skin, which requires account- ing for the temperature, relative humidity, solar radiation and albedo, as well as the wind speed and direction, as the elements to consider when striving for comfortable conditions (Cañas I, 2004). Human thermal comfort can be defined as a condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 2013) such that the person would prefer neither warmer non cooler surround-ings (Fanger, 1970). Comfort can also be defined as the optimal thermal condition in which the least extra effort is required to maintain the human body's thermal balance. Various environmental factors (air temperature, surrounding surface temperatures, air humidity and air velocity) and psychosocial factors (clothing, activities, age and sex) affect human comfort (Callejon-Ferre AJ, 2011). Different bioclimatic diagrams are used as tools with which to determine comfort levels. The most widely used include the diagram developed by Victor Olgyay (Olgyay V, 1963) to determine exterior comfort as well as diagrams for interior comfort, including the thermal comfort index (or effective temperature), which can be calculated using the relative humidity and interior temperature values and has been adopted by ASHRAE (Freire RZ, 2008). Some of the intervals for the external comfort parameter values that interact to determine thermal comfort are shown in the bioclimatic diagrams and include an ambient air temperature between 18 and 26 1C, a mean radiant temperature on building surfaces between 18 and 26 1C, an air velocity between 0 and 2m/s and a relative humidity between 40% and 65%.

III. CLIMATE OF BIKANER

A. Climatic Classification

Climatic Zone	Mean Monthly Maximun Temprature ˚C	Mean Monthly Relative Humidity %
Hot -Dry	Above 30	Below 55
Warm-Humid	Above 30, Above 25	Above 55, Above 75
Temperate	Between 25-30	Below 75
Cold	Below 25	All Values
Composite	This applies, when six months or more do not fall within any of the above categories	

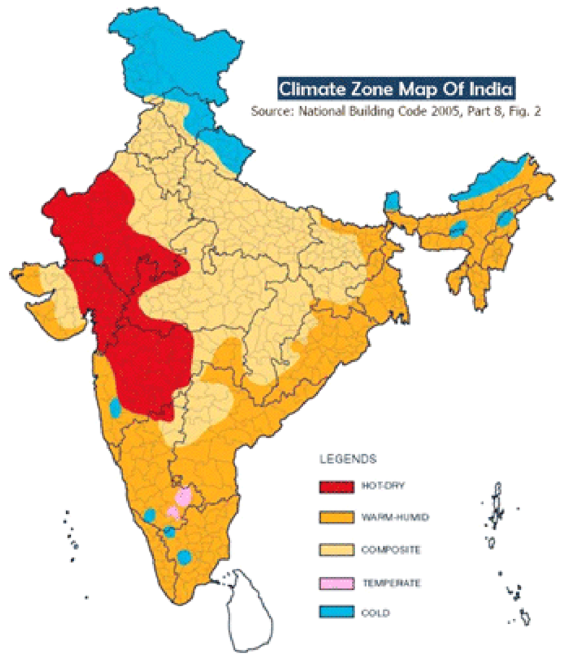

Fig. 2. Climatic Zones in India.

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. 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 Fig. 2.

IV. COMFORT REQUIREMENTS OF HOT-DRY

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 Roorkee1, 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

$$TSI = 0.745\, t_a + 0.308\, t_w - 2\, v + 0.841$$

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.

V. PASSIVE TECHNIQUES

What vernacular and traditional architecture has achieved through trial through the years inherently provides the aesthetic qualities, the climatic adaptability and the economic feasibility that today's sensitive architects search for. Indigenous urban and rural fabric and individual building structures demonstrate endlessly such ingenuities of past architecture. Climatic control commences with community planning on the urban scale. It initiates through the way buildings agglomerate and shelter each other from heat, the way serpentine like streets denounce the harsh sun and pull the cool breeze through while keeping dust and glare out.

A. 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.

B. Orientation of Building

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.

C. 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, ie, 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.

D. Shelter against Hot Winds

Hot winds during summer in hot and dry climatic conditions are a source of large convective heat gain and a source of extreme thermal discomfort. Wind shelter for a building can be provided by taking the advantage of the existing topography, such as an elevated landmass or by creating wind barriers in the form of trees, shrubs, fences or walls. Usually, an opaque barrier creates a turbulent flow of wind and one has to avoid the accumulation of heat from the sun-irradiated surfaces between the barrier and the surface.

Fig. 3. Shaded Streets.

Fig. 3a. Overhanging upper floors.

Fig. 3b. Mutual Shading.

Table 1: Requirement for building form in relation to climate (Central Building Research Institute, 1991).

Climate	Element and requirement	Purpose
Hot & Dry Climate	Minimize South Walls and West walls	To reduce heat gain
	Minimize surface area	To reduce heat gain and loss
	Minimize Building depth	Increase thermal capacity
	Minimize Windows on wall	Control ventilation, heat gain and light.

VI. ROLE OF THERMAL MASS IN HOT ARID CLIMATE

In hot arid climates with a large diurnal range it is advantageous to use massive building elements. The effect of massive masonry construction provides heat storage within the building structure due to its thermal capacity, which helps contain indoor temperature fluctuations and acts as interim heat sink. The classical use of thermal mass includes adobe or rammed earth houses. 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 (Fathy, 1996). Moore reported the temperatures in and around an adobe building. It indicated that when the average inside and outside temperatures are about equal, the 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 (Moore, 1993). The effect of thermal mass on interior temperature is shown in Fig. 5.

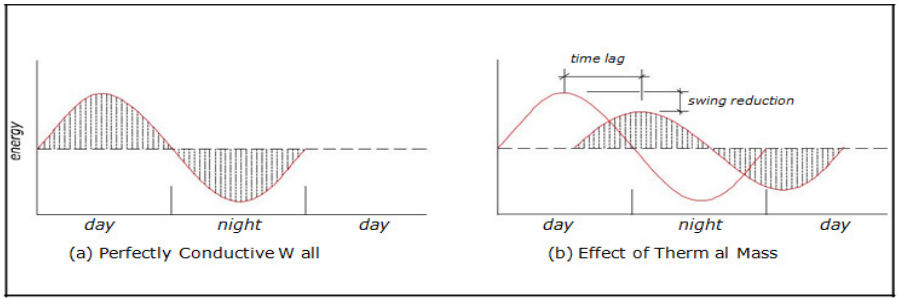

Fig. 4. Effect of thermal mass on interior temperature (Moore, 1993).

Table 2: Time Lag Values of different Materials (Central Building Research Institute, 1991).

Material	Thickness	U-Value	Time Lag (Hours)
Brick	4	0.61	2 - 2 1/2
	8	0.41	5 – 2 ½
	12	0.31	8 – 2 ½
Concrete	4	0.85	2 – 2 ½
	8	0.67	5
	12	0.55	8
Insulating Fiber Board	2	0.61	0.7
	4	0.09	0.3
Wood	1/2	0.68	0.2
	1	0.47	0.4
	2	0.30	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 (Krishan, 2001).

Effectiveness Of Courtyard: Courtyard built form is a very suitable form for hot arid regions. That is why they are generally found in traditional architecture in hot arid climate. They are mostly centrally located and are completely opened to the clear sky or partially shaded with overhangs in some of the cases. They also provide shaded spaces which results in reducing heat gain. Small courtyards provide more protection against hot, dusty winds in hot arid climate in summers.

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.

VII. CONSULUSION

This paper has reviewed the passive techniques applied in Bikaner to achieve thermal comfort. The vernacular housing have efficiently been with standing the harsh climate for so many years. The indigenous principles are decoded and can be applied to any settlement in the hot and dry zone. Understanding the potential of passive techniques will greatly help in reducing the dependence on energy for achieving thermal comfort.

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