APPRAISAL OF TRADITIONAL BUILT FORM OF BIKANER: CLIMATIC DESIGN STRATEGIES AND SUSTAINABILITY

Mohammad Arif Kamal*
Architecture Section, Aligarh Muslim University, Aligarh, India

Abstract

The increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion. Therefore to reduce the emission of greenhouse gases, caused by fossil fuels to power the cooling requirement of the buildings, it has stimulated the interest towards exploring climate conscious architecture. The traditional houses of Bikaner, a town in India's desert region are climate responsive which have evolved from centuries of experience and observations of climate and nature. These buildings, therefore, can be studied as models of environmentally responsive and sustainable architecture. This paper evaluates specific traditional architecture of Bikaner and their response to climate, especially the natural cooling systems in hot and dry climate, which can be adapted to current architectural practice in the region, in order to optimize the relationship between site, building and climate. The methodology adopted in the research is through qualitative analysis. The objective of this paper is firstly to determine various climate responsive passive design features that have been employed in the traditional architecture of Bikaner, secondly how successful these features are in moderating the thermal environment in the traditional houses.

Keywords: Traditional, Built form, Bikaner, Climatic design, Sustainability.

Introduction

Natural and passive systems use non-mechanical methods to maintain a comfortable indoor temperature and are a key factor in mitigating the impact of buildings on the environment. The traditional architecture of the past is the best pointers in this regard and constitutes outstanding evidence of being climate responsive and energy conscious buildings. They display years of embodied experience built on the relationship between building and climate, implying a logical analysis, the consideration of appropriate principles, and a rational use of resources. The climate sensitive nature of sustainable design, as well as its awareness of regional environmental and material concerns, demands a fresh look at the issue of the traditional architecture as it pertains to the practice of sustainable building. The inherent and timeless knowledge of traditional architecture remains key to the future of responsible design and planning, providing an important foundation of design initiatives that will inspire eco-technological advancements that might one day alleviate our reliance upon energy abusive mechanical systems that have become dangerously universal. These buildings, therefore, can be studied as models of environmentally responsive and sustainable architecture.

* Corresponding Author: Mohammad Arif Kamal; E-mail- architectarif@gmail.com

Research Methodology

The objective of the research is to investigate and understand the natural cooling systems employed in the architecture of Bikaner. The study is carried out on the traditional architecture of Bikaner in India. A survey of residential Havelies more than 100 years old is carried out in the walled town of Bikaner. In this paper, a qualitative evaluation research method is used. The research methodology comprises of case studies, observation, data collection and mapping. The study identifies the need of sustainable built environment and why is it becoming necessary to switch to traditional architecture. The various passive techniques employed to achieve thermal comfort levels for habitation all the year round, especially the summer season have been studied in this paper. The analysis show that the natural and passive design systems provide comfortable indoor environment irrespective of the outdoor climatic variation.

Energy Consumption in Buildings

Buildings consume about 40% of energy use and carbon emissions in the world. It is evident that the total energy consumption of buildings especially for cooling purposes varies as a function of the quality of design and climatic conditions. Energy consumption is an important factor for today's living, the dependency on energy is primarily for achieving a comfortable life. Comfort achieved by the consumption of energy has its economic and environmental drawback. In hot climates, buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m2/year, while buildings of low quality environmental design may present loads up to 450 kWh/m2/year (Santamouris, 1998). 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 (ECBC, 2011). Researchers have proved that global warming and climate change are two interrelated phenomena. Fossil fuels are burned to produce the cooling energy, which causes greenhouse gas emissions and hence global warming leading to climate change. By implementing energy reduction measures, we can reduce electricity demand and climate-altering emissions.

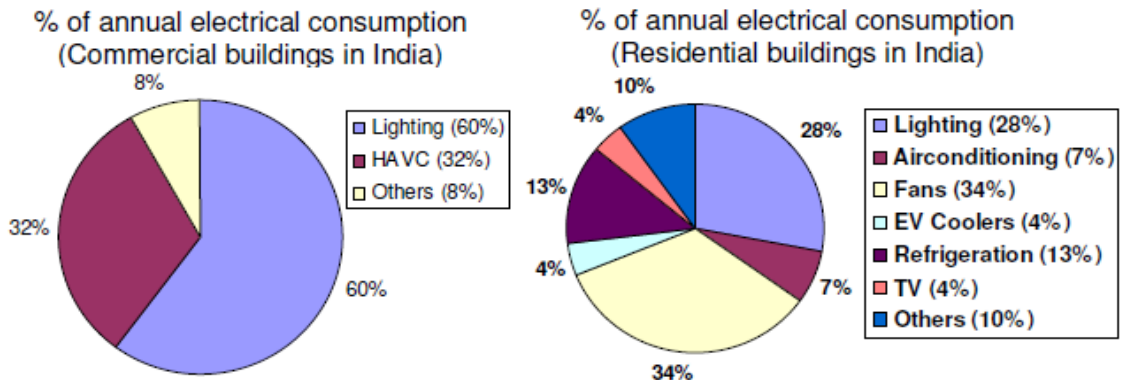

Figure 1: Energy consumption patterns in buildings in India

Environmental Sustainability in Architecture

Sustainability is a term used to describe the process undertaken to meet the needs of the present without compromising the ability of future generations to meet their own needs. Architectural sustainability is linked to the much quoted Brundtland commission report definition through an

emphasis on limits to the carrying capacity of the planet, and they pointed to the UK's Building Services Research and Information Association (BSRIA) definition of sustainable construction as 'the creation and management of healthy buildings based upon resource efficient and ecological principle' (Edward, 2001). With increasing population, the energy reserves are depleting at a very faster rate. The buildings need to be designed in a way that it consumes lesser energy produced from various conventional energy resources. In principle, sustainable buildings relate to the notion of climate-responsive design, which places emphasis upon natural energy sources with the aim of achieving building comfort through the interaction with the dynamic conditions of the building environment (Hyde, 2000). Sustainable architecture is an approach to design where building technology is integrated with the concept design and has the potential to reduce the need for high-tech systems and reduce the energy consumption of buildings.

Traditional Architecture and Climatic Design

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. In traditional architecture, an effort is made toward utilization of natural resources as much as possible. As the ancient structures are designed in such a way that there is no need of AC or cooler or fan for creating thermally comfortable environment. They have inbuilt feature for providing thermal comfort. The familiar elements of regional architectural styles i.e. verandahs, balconies, courtyards, air shafts, thick walls, high ceilings etc 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 traditional architecture (Maria, 2009). The traditional houses havelies of Bikaner region are typical examples of buildings adapted to the hot and dry climate. Traditional 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. During these times of environmental crisis and accelerated urban development, it seems logical for architects to practice sustainable ecological design (Bay, 2010).

Traditional Architecture and Sustainability

Sustainability is considering environmental, economic and social requirement all together while designing a building. Due to our present global crises such as population explosion, natural resource depletion, energy crisis, and ecological disaster, there is an urgent need to align development and the practice of architecture with the concept of sustainability. The traditional architecture supports a relationship of coexistence and balance between man, built form, and the environment that will be ultimately beneficial to the existence of all. All these aspects are already considered in traditional architecture, but now in modern structures the building regulation mostly focuses on environmental impact of building especially reducing the usage of fossil fuel. The steps are taken towards the reduction of CO_2 generation from construction of building to its daily use. Traditional architecture can be seen as ‘the essence of sustainability’, being constructed with local materials and the minimum waste of resources. The whole concept of sustainability encourages us to return back to, appreciate and analyze traditional architecture and its concept. Traditional architecture varies widely with the world’s vast spectrum of climate, terrain and culture. It contains inherent, unwritten information about how to optimize the energy performance of buildings at very low cost using local materials. Over the course of time, traditional dwellings have evolved to respond to challenges of climate, building materials and cultural expectations in a given place (Oliver, 2003). Traditionally designed buildings are also often considered as the predecessors of modern bioclimatic design (Coch, 1996).

Bikaner: The Study Context

Bikaner district is located in the northwestern part of Thar desert of Rajasthan and is encompassed between 28° 1' N to 73° 18' E. It was establised by Rao Bikaji (Fig. 2). Bikaner was founded in 1465 and has a geographical area of 30382.15 sq.km.. The walled city of Bikaner is a dense urban settlement with narrow, winding lanes and buildings featuring highly ornamental street facades. A wealthy merchant class that profited from the trade route was responsible for the opulently decorated courtyard houses, known as havelis, which characterize the historic center of the city. Constructed in red sandstone with elaborately detailed facades, they show various influences ranging from Rajput and Mughal styles to British colonial detailing. The architecture and urban form of the walled city are both a response to harsh hot and arid climate of the region and a celebration of its building tradition. The stone carved patterns enliven the urban facade with delicately carved stone jaalis (perforated screens), stone chajjas (overhangs), balconies, balustrades, gargoyles, jharokhas (projected windows) and thresholds. The urban form is even more striking through the characteristics of this landscape: verandahs for resting, balconies of varied designs supporting jaali and refined wood-worked doors. The havelis dates from the seventeenth to the early twentieth centuries. Now, these formerly grand homes had been subdivided, leading to their decay and overcrowding. (Bikaner, 2019)

Figure 2: Map of India, showing Bikaner

Climate of Bikaner: The climate of Bikaner is typical of a hot desert region. The two seasons predominate, summer and winter. The summer temperature is very hot and the day-time temperature can reach up to 50°C and down to 25°C at night. Similarly in winter the temperatures vary between 5°C-25°C. The diurnal range of temperatures is between 15°C and 20°C. Since the region is arid, there is very low relative humidity, especially during hot seasons. The relative humidity in summer can be less than 10% in the day. The average annual precipitation is less than 180mm with maximum during the monsoon months, but in some years there is no rainfall at all. During the summer months of May, June and July, the town is subjected to severe sand storms. The sky is mostly clear and solar radiation is intense throughout the year, the average solar radiation on a horizontal surface in June being 22.2 MJ/m2/day. The 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. Wind: During the summer months, wind velocity is usually high and there are severe dust storms during May and June.

Climatic Design of Traditional Built Form of Bikaner

The indigenous architecture of Bikaner evolved through the entire spectrum from individual building to settlement pattern; responds most appropriately to the climate in terms of spatial organization, construction techniques, material selection and use of passive design features. The traditional houses in Bikaner have employed some ingenious natural and passive features and techniques in order to maintain thermal comfort within the building, particularly during the summers. They are explained as followings:

Town Layout and Settlement Pattern: The fort contains the royal palace in addition to numerous common dwellings. Surrounded by protective fortifications, the houses and palaces were approached through narrow streets. The additions to the town included fortifications around the town and the construction of many beautiful residential buildings called 'Havelis'. A number of gates called Pols, define the entry points of the town. The famous havelis and the major residential area are located to the north of the bazaar. The settlement is compact, mostly planned around courtyards with respect to the climate and the need for social interactions (Fig. 3). The buildings are joined close to each other to form a dense cluster. The dense, compact settlement plan helps in reducing heat gain. It also allows mutual shading by buildings and thereby reduces the area of exposed surfaces.

Figure 3: Bikaner town is dense mass with compact planning

Street Configuration: The complex street pattern has a planned control over the microclimate. The houses open on to narrow streets through a hierarchy of spaces that become the interface between the street and the house. This help the buildings to shade one another as well as to shade the streets by the balcony and projections or by the buildings opposite, hence lowering the ambient air temperature surrounding the building envelope (Fig. 4). Generally the streets are narrow and surrounded with tall buildings providing good shade for long time on day time which is good for the hot dry climate. The effect of the street is mostly like a trench in which the maximum shade is achieved. In some places the buildings actually bridge across the streets. The contiguous construction ensures mutual shading by walls and other elements of the adjoining building. The general street orientation is South-East to North-West, which is at right angles to the prevailing summer winds. Hot dusty winds are thus kept out of the streets.

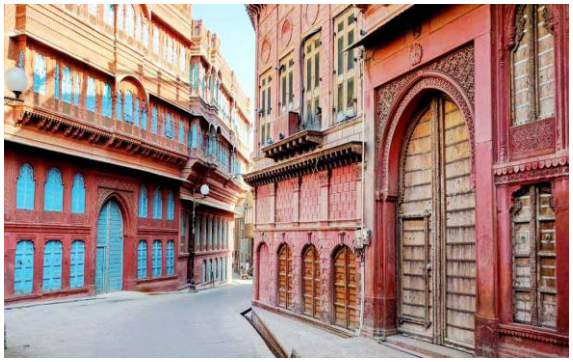

Figure 4: Narrow streets are shaded with the adjacent buildings

House Form: In almost all the traditional houses in Bikaner region, it is found that the hierarchy of space is clearly and categorically followed, which is evident in the houses selected for study. The arrangement of spaces reflecting the Bikaner heritage, their occupation, the family system and also their knowledge in building their houses with climate responsiveness are reflected in these houses (Fig. 5). These houses are essentially built with the understanding of the sun and air movement; and also they have clarity over the materials and the thermal behavior.

There are three or four storied houses, the courtyard is surrounded by rooms or verandahs on all sides. The uppermost storey comprises terraces enclosed by wind pavilions and high parapet walls. In some cases, the house is built around two courtyards. The typical house is

Figure 5: Entrance of a traditional house opening into the street

attached on its sides and at the back, leaving only a narrow facade with screened openings onto the street. To guard the privacy of the house, the ground floor rarely has any apertures toward the street other than the necessary entrance door. The entrance hall is a spacious room called *moda* and serves as both a transitional area leading to the courtyard and as a sitting room. From the courtyard, there are generally one or two steps leading up to a *chaupala* around which are grouped several rooms, one of which is used as a kitchen and the other as a storage room called as *ovra* (Fig. 6).

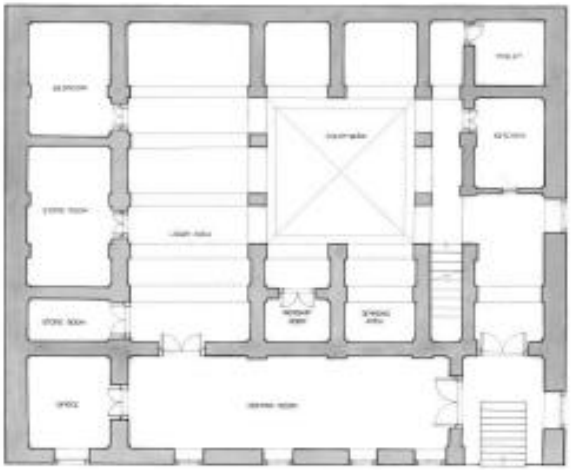

Figure 6: A typical layout of a traditional house of Bikaner

Courtyard Planning and Ventilation Strategies

Courtyard planning is a very suitable built form in hot and arid climate. They are generally centrally located and are completely opened to the clear sky or partially shaded with overhangs in some of the cases (Fig. 7). 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 (Fig. 8). Small courtyards provide more protection against hot, dusty winds in summers, especially in hot and arid climate. In addition to simple courtyards, very narrow vertical ducts and staircase shafts are used to deflect wind down into the house in Bikaner. Coupled with the high thermal inertia of the massive stone walls, such shafts temper air before it enters the living space in much the same way as happens in the Iranian wind towers (Bahadori, 1979).

Figure 7: Courtyard in traditional architecture of Bikaner

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 (Talib, 1984).

Figure 8: Verandah all around the courtyard in traditional haveli of Bikaner

Heavy Thermal Mass as Impediment to Climatic Extremes

The common building material used in Bikaner is stone of which there are two types. Light yellowish sandstone is used for walls, which are 0.45m or more in thickness. At upper floor level, where the building facade projects out, 50mm thick panels of limestone are used as wall elements. These are deeply carved in various geometrical patterns and from outside the building they give the appearance of latticework (jaali). Both the limestone used for carving and sandstone used for masonry are light in colour and provide a permanent natural finish (Fig. 9).

Figure 9: Thick walls in sandstone provides heavy thermal mass

There are two types of construction that are used for roofs and floors. The traditional method is to lay closely spaced timber beams and cover them with a layer of reed or grass matting and a thick layer (0.45 to 0.60m) of earth on top. In all cases the roof and floor are finished only with mud plaster. This presents no problem of water seepage, as there is little rainfall. Windows are generally small and are fitted with solid timber shutters. Doors are built with stone frames and fitted with thick timber shutters. In hot and dry climates with a large diurnal range it is advantageous to use massive building elements. Thick walls stores larger amount of heat due to large heat capacities and creates a larger time lag. This helps in keeping the inside cool during daytime when it is most inconvenient outside. The wall predominantly acts to retard heat flow from the exterior to the interior during the day. The high volumetric heat capacity and thickness

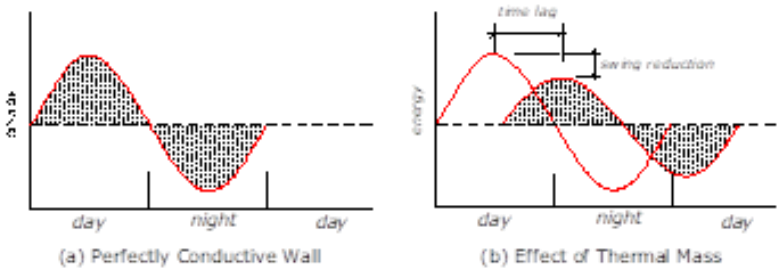

Figure 10: Effect of thermal mass on interior temperature

prevents heat from reaching the inner surface. When temperatures fall at night, the walls re-radiate the heat back into the night sky. In traditional houses of Bikaner, the walls have been protected from solar radiation; the main area of solar heat gain in buildings becomes the roof. The massive roof construction with 0.45m or more of earth ensures a very small decrement factor (0.162) and a large (24hour) time lag. The effect of thermal mass on interior temperature is shown in Fig. 10.

Openings and Jharokhas for Induced Ventilation

Since most time of the year, the climate is hot and dry with dusty winds, small openings are provided. These openings are opened during night time to allow convective cooling. During daytime the openings with thick wooden shutters are closed. All the openings are shaded with projections covered all around in the form of bay window with richly carved stone panels on the building facade. The whole system is known as Jharokha. Jharokhas are characteristic feature of vernacular architecture of Bikaner. Also, with the need for privacy for women, facades are characterized by small openings often in the form of Jharokhas (Fig. 11). They create suction effect to facilitate forced air movement from the exterior environment into the interiors of the building. This allows cooling of air by *venturi effect* phenomenon. In most of the buildings Jharokhas are provided on the upper floors.

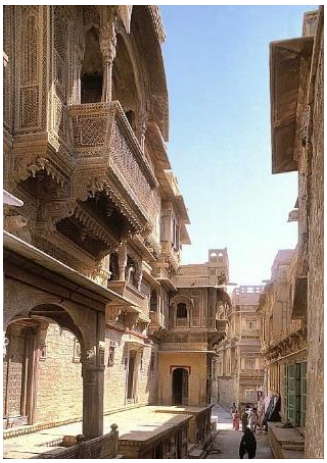

Figure 11: Jharokhas providing shade and inducing ventilation

Surface Finish and Texture

Textured surfaces are used in the exterior finish of the building facades, which are likely to be exposed to sun. The external surfaces of traditional buildings in Bikaner are generally of light colours sandstone that reflect solar radiation (in order to have minimum absorption). Light colored surface reduces the absorptivity of the wall surface, minimizing the effect of solar radiation on internal climate and tends to stabilize the internal temperature. The use of decorative carved surfaces is not governed by the need for sun control but also used for its decorative effect (Fig. 12).

Figure 12: Textured surface reduces solar absorption

Case Study: Kothari Haveli

Kothari haveli is one of the most beautiful havelies in Rajasthan. This haveli has excellent art collection (Fig. 13). On the ground floor there is workspace, kitchen, wooden room, a few rooms adjacent to the workspace. Bathroom on the first second floor are all new. The haveli is about 149 years old with a dwelling of five generations of the family which are mainly jewelers and bankers. The height of the haveli and the angled street along all the haveli enhanced the security aspects

of the place. The haveli was built by Prem Sukhdasji and Poonamji whose names are engraved on the haveli. The height of the haveli was for design as well as aesthetic purpose, moreover it also helped in boasting the glory of the owner. 'Dankhanas' was meant only for males and the females were restricted to views from jharokhas of the first floor and stay at the central courtyards. The dankhana has six pillars. Every pillar has a glass mirror with gold frame. This frame is engrossed with flowers mostly roses. The flowers and the leaves adore all walls of the diwankhnna. The diwankhana has paintings of gods and goddesses. Lord Ganesh and Laxmi and Parwati are the most prevalent among them. The haveli contain a number of paintings of Radha Krishan and Ram Sita also. The entire initial haveli was strictly built on the basis of vaastu for example-kitchen at south east, placement of water tank etc. The sunlight is minimum on the ground floor so as to avoid heat and in addition there was a limitation due to the areas nearby having havelis of similar height. Steps provided at the entrance are called 'Daasta' restricted the hasty movements which again dealt with the security of the haveli. Specifically the entire haveli was elevated from the ground level so as to restrict the view of outsiders into the house and the encroachment of animals (Fig. 14). Moreover the monitoring of the visitors was also convenient. Another significant feature in haveli is the number of floors below and above the ground were equal. During hot summers the area below becomes the main dwelling area due to being beneath the ground and consequently cooler and vice-versa.

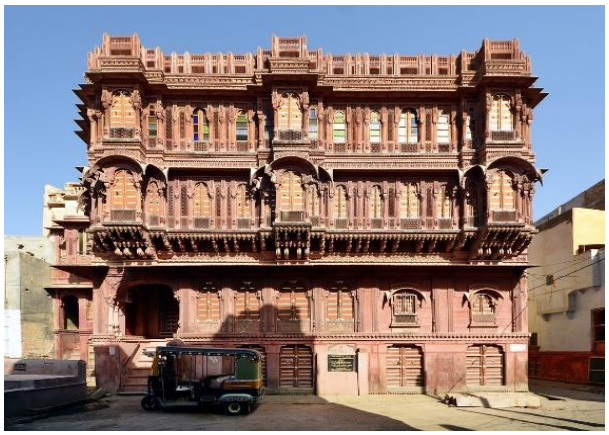

Figure 13: Front View of Kothari Haveli at Bikaner

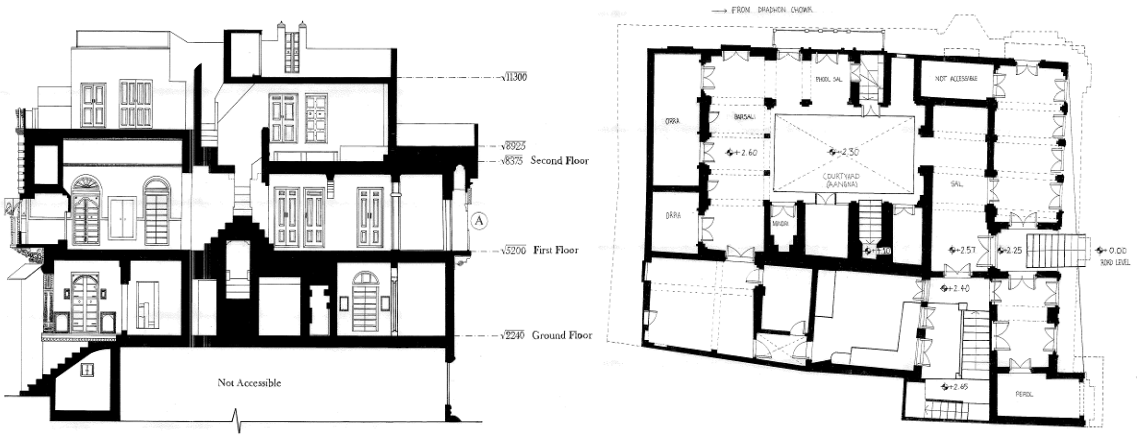

Figure 14: Ground floor plan and section of the Kothari Haveli at Bikaner

Conclusions

The traditional dwellings of Bikaner demonstrate an economical use of local building resources, and respond to climatic conditions using low-energy design principles that provide thermal comfort. The combination of engineering and architecture reveals an aesthetic quality which, instead of imposing on the environment, it emanates from it. The study has revealed that natural sources of energy, light and ventilation besides passive means have been adequately deployed in the Havelis for minimising dependence on active and mechanical means of energy. Thermal comfort has been achieved through design features like internal courtyards, orientation, thermal mass and solar gain. Havelis also highlights and showcase the construction methods and skills for

using locally available materials. 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. The Havelis of Bikaner have significant lesson to convey to the Architects, Engineers and other stakeholders engaged in the creating built environment, regarding achieving the goals of designing energy efficient building a and providing sustainable design solutions in their professional ventures.

The Traditional architecture of Bikaner can be defined as sustainable. The criteria that lead to the creation of such a sustainable traditional settlement are: 1) holistic consideration of negative environmental impacts that arise in the construction of buildings and their infrastructures; 2) design recommendations, which minimize the adverse environmental effects in building; 3) use of materials with low maintenance and energy efficiency; 4) selection of building materials that provide thermal comfort; 5) use of renewable and natural resources; 6) reduction of energy consumption by maximizing passive thermal comfort; 7) concern for integral quality: economic, social and environmental performance; 8) improvement of environmental quality; and 9) provision for comfortable living spaces [16]. Learning from the traditional wisdom can be a powerful tool for designing the buildings. Need for making present day built environment sustainable may well be served by using the principles of climate responsive designs options built in the traditional architecture. Incorporation of these sustainable design features and techniques especially in residential buildings will certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental problems due to excessive consumption of energy and will evolve a built form, which will be more climate responsive and more sustainable buildings of tomorrow.

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