# Natural Cooling Systems of Jaisalmer

Vinod Gupta

Assistant Professor of Architecture, School of Planning and Architecture, New Delhi 110002, India.

*The natural cooling systems used at Jaisalmer include:*

1. *Dense clustering of buildings.*
2. *Sun control through orientation and structural projections.*
3. *Cooling of sunlit surfaces by use of fins.*
4. *Massive construction for roofs and walls.*
5. *Courtyards and other air ducts for ventilation.*

*The effectiveness of each of these cooling methods has been evaluated by temperature observations and this will be reported in a subsequent paper.*

## INTRODUCTION

In the absence of the corrupting influence of water and electricity supply, mechanised transport and modern building technology, the builders of the medieval Indian town of Jaisalmer have done a remarkable job of creating an urban environment that is in tune with nature and provides for more than just the basic needs of the inhabitants. Situated in the heart of the Thar Desert, Jaisalmer is famous for its richly carved building facades (Fig.1). Less known perhaps is the fact that the town and buildings in it overcome the problem

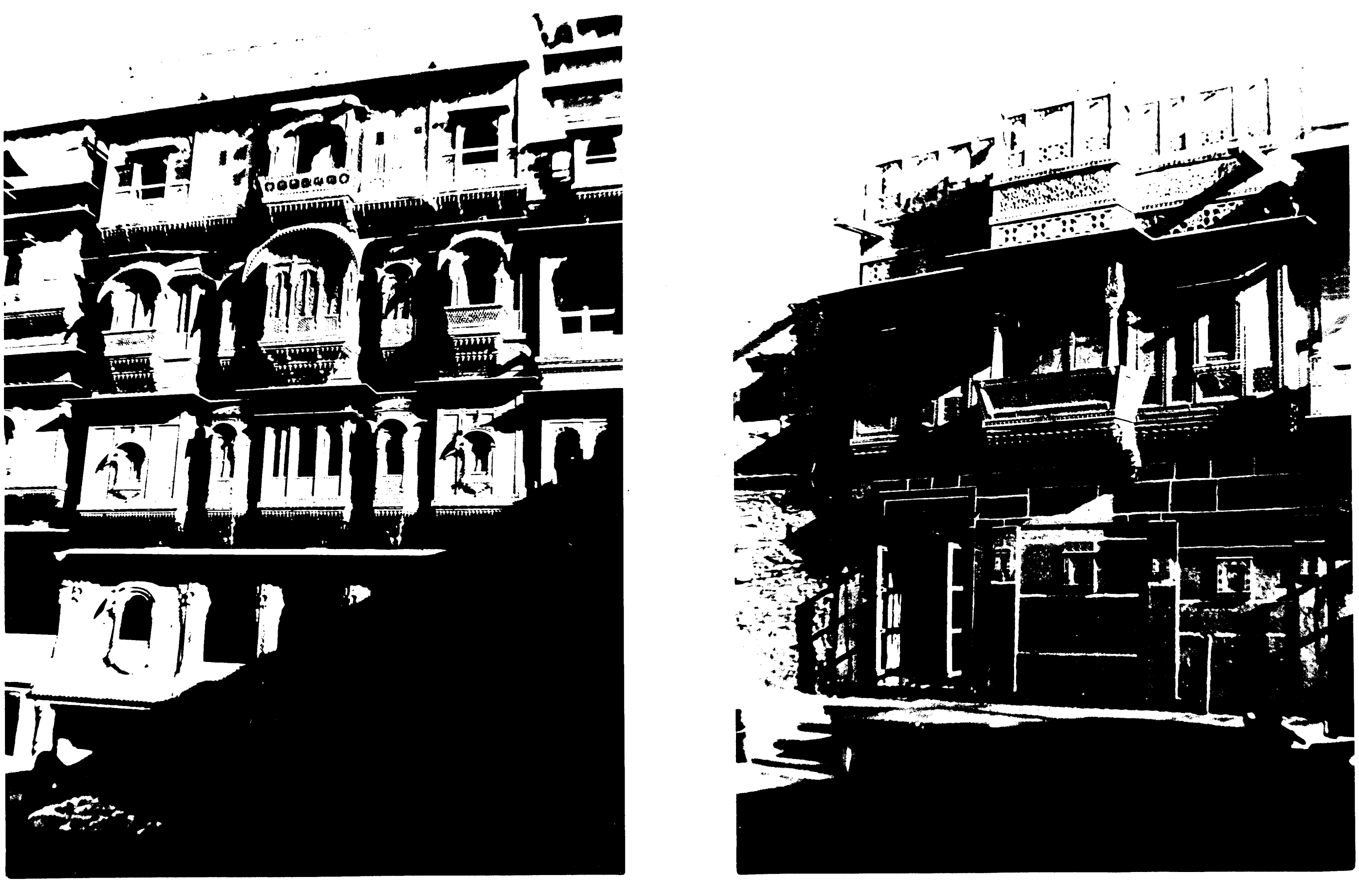


*Fig. 1. Two richly carved building facades in Jaisalmer.*

of the severe desert summer by special passive design features. The aim of the present study is firstly to determine what these features are, secondly to determine how successful these features are in moderating the thermal environment, and thirdly to find ways and means of applying the underlying principles in the design of modern buildings and urban complexes.

The town of Jaisalmer is situated at 26°55'N latitude and 75°55'E longitude, 241.7m above mean sea level. It was founded in the year 1156 A.D. by Maharwal Jaisal Singh who was looking for a more secure location for the state capital which was located at Ludorva about 15km away from Jaisalmer.

The climate of Jaisalmer (Fig.2) is typical of a hot desert region. There is scanty and unreliable rainfall (average annual precipitation being less than 200mm). Two seasons predominate, summer and winter. In summer the day-time temperature can reach up to 45°C and down to 25°C at night. Similarly in winter the temperatures vary between 25°C and 5°C. The diurnal range of temperatures is between 15°C and 20°C. Relative humidity in summer can be less than 10% in the day, although the mean monthly values given in Figure 2 show only a minimum of 30%. 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. During the summer months, wind velocity is usually high and there are severe dust storms during May and June.

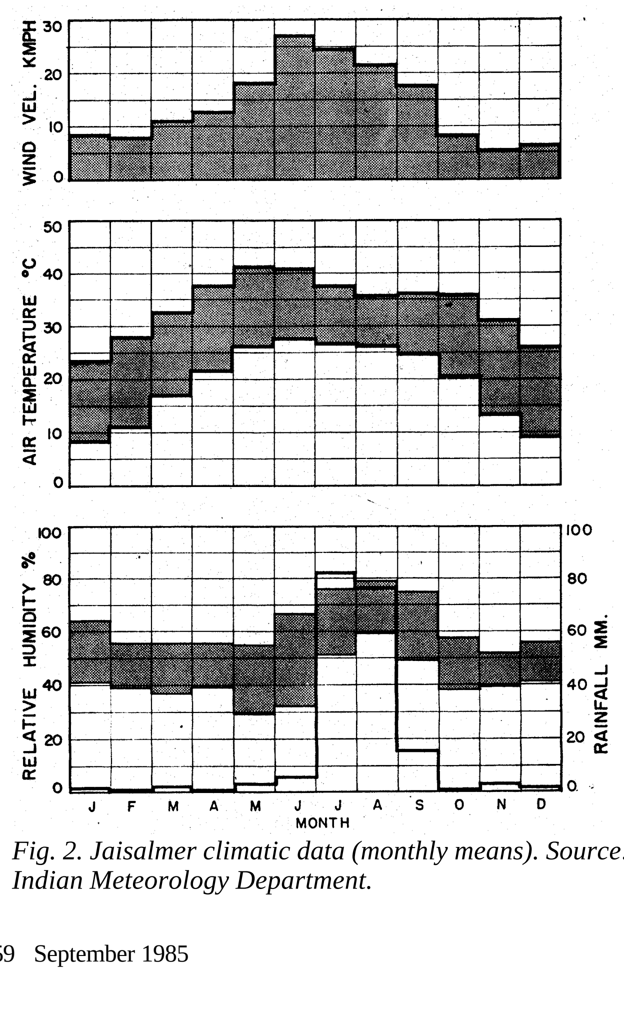



*Fig. 2. Jaisalmer climatic data (monthly means). Source: Indian Meteorology Department.*

The landscape of the surrounding region is flat, rocky and barren, relieved by sparse scrubby weeds, but no trees. In certain areas (notably "Sam") around Jaisalmer, there are shifting sand dunes. Water is the most scarce and valuable resource. In time of the frequent drought, there is no water available for tens of kilometers. Several kinds of light coloured limestone and sandstone are available in the area.

## TOWN LAYOUT

It is in this context that Jaisal Singh founded his fort on one of the hilly outcrops of the Aravalli range, called "Trikut" because of its triangular plan. One major reason for selection of this site was the availability of sub-surface water. The fort was built on the hilltop, generally following its triangular geometry.

Surrounded by protective fortifications, the houses and palaces were approached through narrow streets. Unlike other Indian forts, which are characterised by strong rectilinear geometry and open spaces, this one had few community open spaces. With influx of population from the surrounding areas, the fort was in time completely built up and further expansion of the settlement took place at the foot of the hill. The construction of the town was started in 1725 A.D. (Agarwala, 1979). For various socio-cultural reasons, the town plan of Jaisalmer developed in the form of "padas" based on clan or profession and this division persists till today. During the years 1750 to 1850 A.D. additions to the town included fortifications around the town and the construction of many beautiful residential buildings called "Havelis". The most famous of these are Nathmaiji's haveli, Salim Singh's haveli and the five havelis belonging to Patuas. The town plan of Jaisalmer is not entirely dissimilar to that of older Indian cities like Delhi. Relieved from the limiting geometry of the triangular hill on which the fort is built, the town is more interesting from the point of view of climatic adaptation and the present work is devoted to the study of this part of Jaisalmer.

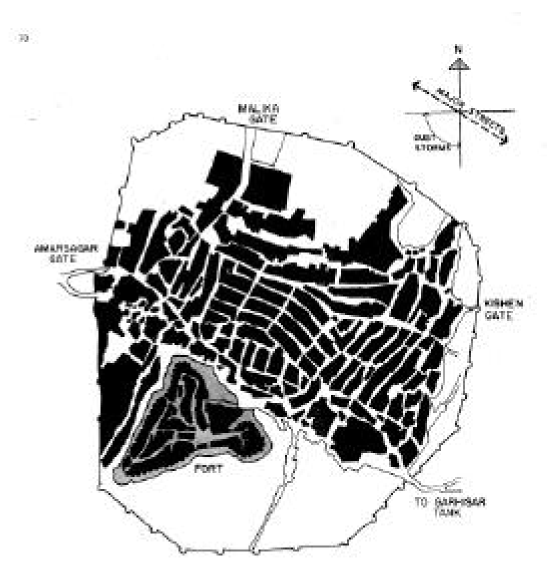
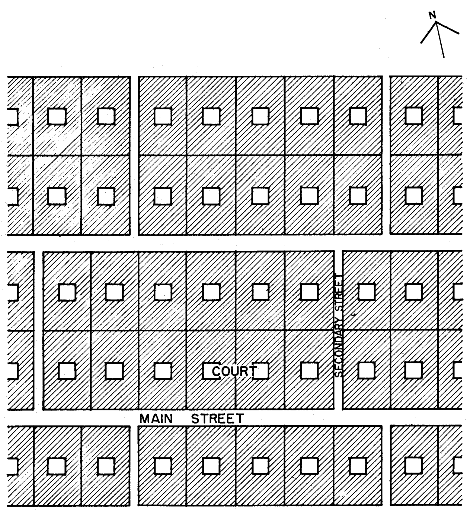



*Fig. 3. Plan of Jaisalmer Town.*

A 5 to 6 metre high wall surrounds Jaisalmer town (Fig.3). A number of gates called Prols, define the entry points of the town. There is one major bazaar, which connects the Amar Sagar Prol at the eastern end to the Garhisar Prol on the western side of the town. The famous havelis and the major residential area are located to the north of the bazaar. Figure 4 shows an enlarged and simplified plan of this area.

There are major streets oriented almost E-W and minor streets at right angles to these. The famous decorative house-fronts (Fig.1) are located mainly on the E-W streets, which are relatively wider, the height of the buildings being one to two times the width of the street. The N-S streets, on the other hand, are only about one-fourth the height of the buildings on the sides. Nevertheless an impression exists in architectural circles (Ghosh, 1968: Grover, 1967) that the streets of Jaisalmer are unusually narrow with overhanging balconies at upper levels. There is only one lane near the Patua havelis which fits this description and all other streets are relatively wider and without any substantial overhangs.




HOUSE FORM

Depending upon the socio-economic status of the inhabitant, there are three types of houses in Jaisalmer. The simplest town house (Fig. 5) consists of a single room, a verandah and a courtyard. Larger houses of this type have another verandah over the entrance and some houses have an additional room on one side of the courtyard. Three single-storey structures are owned by the poorest people and have been built in the peripheral areas of the town.
The second type of house (Fig. 6) belongs to the middle-income people. A two or three-storey structure, this house type can be considered the typical house of Jaisalmer. It is similar to the first house type in plan, with the only difference that additional rooms and small enclosed terraces are located at the upper floors. The front part of the first floor has a balcony projecting onto the street.

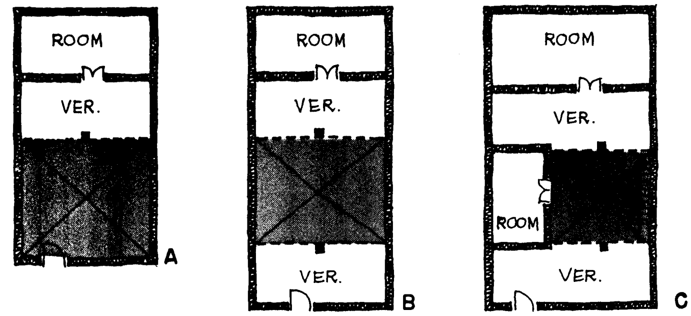



*Fig. 5. Small houses in Jaisalmer*

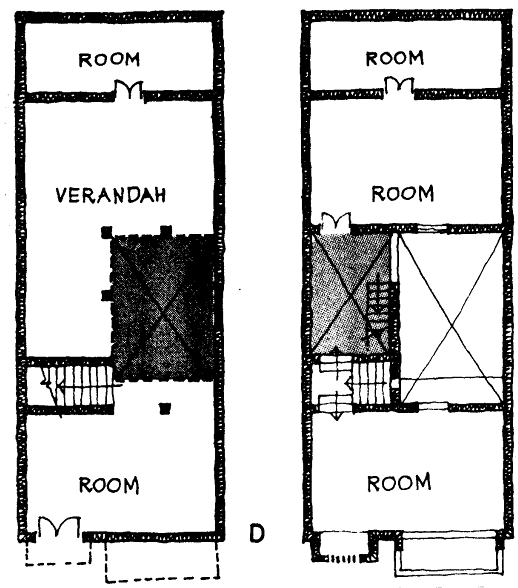



*Fig. 6. Middle-income houses in Jaisalmer*

The most complex and interesting residential buildings in Jaisalmer are the havelis (Fig.7) built by the rich merchants or courtiers. In these four or five-storied houses, the courtyard is surrounded by rooms or verandahs on all sides. There are underground rooms as well, sometimes at two levels one below the other. The uppermost storey comprises terraces enclosed by wind pavillions and high parapet walls. In some cases, the house is built around two courtyards.

BUILDING CONSTRUCTION
The common building material used in Jaisalmer is stone of which there are two types. Light yellowish sandstone is used for walls, which are 0.45m or more in thickness. In better quality construction the stone is dressed and joints made accurately without any mortar. The individual stones are held together by stone keys cut into the blocks themselves or by iron cramps. In poorer people's houses the stone is undressed and the walls are built in mud mortar and finished with mud plaster. 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 (jali). Both the limestone used for carving and sandstone used for masonry are light in colour and provide a permanent natural finish.

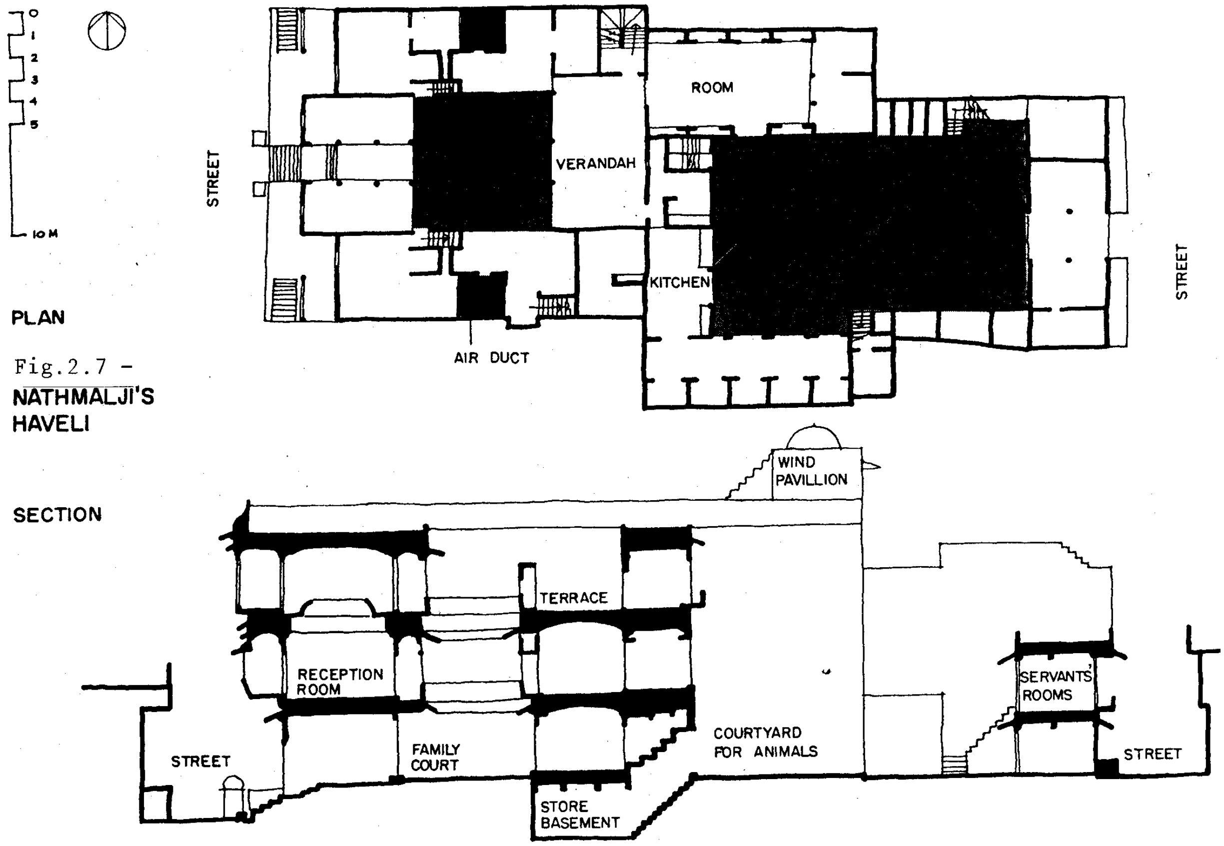



*Fig. 7. Nathmalji's "haveli"*

Two types of construction are used for roofs and floors. The traditional method is to lay closely spaced timber beams (Fig. 8) and cover them with a layer of reed or grass matting and a thick layer (0.45 to 0.60m) of earth on top. Because of the difficulty of finding timber in the desert, in some later houses the timber stone slabs have replaced beams. 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.

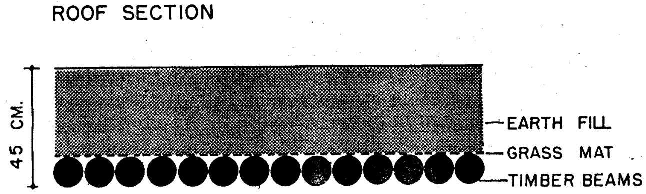



*Fig. 8. Construction of the roof of Nathmalji's Haveli*

Windows are generally small and are fitted with solid timber shutters. Because of the need for privacy, the use of windows was limited to upper floors only and it is only in recent construction that windows have been built at the street level. Doors are built with stone frames and fitted with thick timber shutters.

NATURAL COOLING SYSTEMS

Layout

In Jaisalmer, the layout of the town is the first defence against the harsh climate. Even though the major streets are not particularly narrow, the street orientation of WNW-ESE ensures that the building facades are either shaded by the balcony and sunshade projections (for high solar altitude and south facing facades) or by the buildings opposite.
Considering (for simplicity) an E-W street orientation, in summer the sun would be shining on the south facade from 9.30am to 2.30pm. The corresponding solar altitudes during this time are 54° to 86° and even small horizontal projections are sufficient to shade the south-facing building (Fig. 9). The north face of the building receives solar radiation before 8 am and after 4pm with solar altitude being less than 35°. At this time the building opposite shades the northern facade even if the street is relatively wide.
For streets oriented N-S, the summer sun shines on the east facade till 11.30am and the west facade after 12.30pm. The solar altitude during these periods varies from 0° to 79°, With a narrow street, the building facades would be shaded before 10.30am and after 1.30pm (Fig.10), Thus, solar radiation would be incident on the E-W facades for no more than an hour each which is taken care of by the massive wall construction.

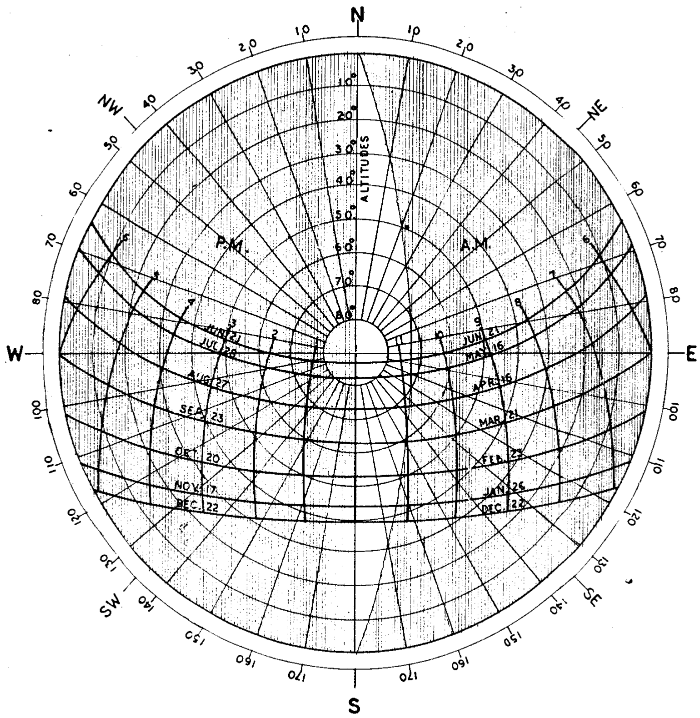



*Fig. 9. Shading mask for the small horizontal projections for a south-facing wall in a relatively wide street.*

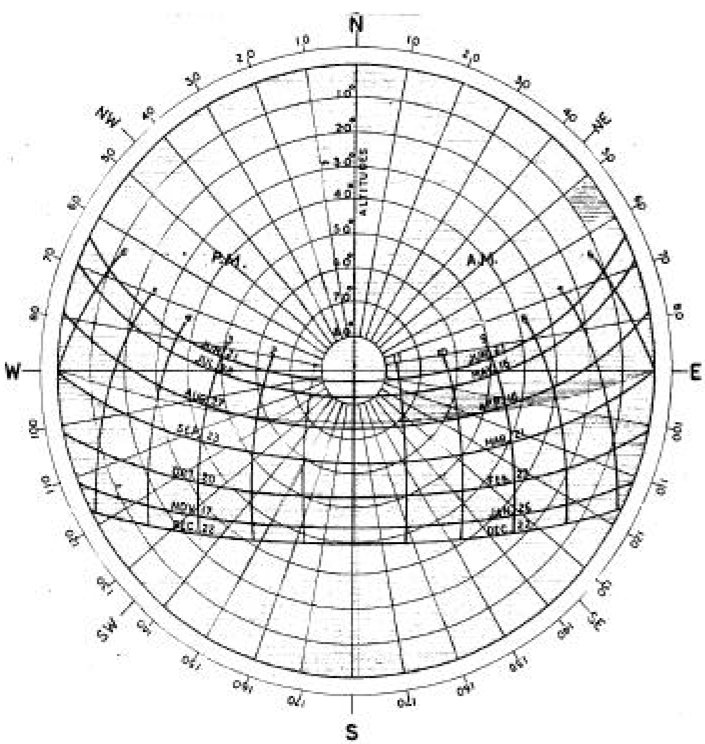



*Fig. 10. Shading mask for an eastern wall in a narrow street. The shading mask for a western wall is similar.*

## Texture

An interesting feature of Jaisalmer is the use of texture. This happens at three different levels of organisation. At the town scale the buildings are of unequal heights with wind pavilions and high parapet walls creating an uneven skyline and shading each other in the process (Fig. II). At the second level, the building facades have a large number of projections like sunshades and balconies (Fig.12). At the smallest level, the flat parts of the building facades are deeply carved (Fig. 13), creating finned surfaces. Such uneven structures and surfaces can be considered extended surfaces.

The use of such surfaces always results in increased convective heat transfer to air and such surfaces are normally used in engineering applications where a higher rate of heat transfer is desirable. In cold climates, extended surfaces cause increased heat loss from buildings (Thakur, 1982) and are not desirable. But in a hot climate, where the major heat source is the sun, solar exposed extended surfaces will be cooler than plain surfaces. In the evening, when the ambient air-cools down, the extended surface will also cool down faster than a plain surface. However, an extended surface that is shaded all the time will warm up faster than a plain surface under similar conditions. It is in this context, that it is important to know where an extended surface is useful. In Jaisalmer textured surfaces are used only in the upper part of building facades, which are likely to be exposed to sun. Plain walls are used in the lower part of north and south facades and over the full height of east and west facades, which are shaded, almost all day. Obviously the use of decorative carved surfaces is not governed by the need for sun control only and in a town there are bound to be exceptions where the carved surface is used in completely shaded locations only for its decorative effect. It may be pointed out that the cooling effect of surface texture is useful only for thin walls. Because of their thermal load levelling characteristics, thick walls of materials like brick, stone or mud are capable of reducing heat gain due to solar radiation, even without surface texture. In Jaisalmer, the walls with texture are only 50mm thick while the massive walls are 450mm to 600mm thick.

Finned surfaces, of course, can be used in other ways also, for example, Beville and Brandt (1968) have used a finned surface as a heat trap in solar collectors also. Using very long specularly reflective fins, they managed to increase the absorptivity of the absorber and reduce its emissivity. However, even with such fins they have reported a lower absorber temperature than could be achieved without the fins. The improved efficiency of the collector was mainly due to the improved heat transfer between the absorber and the incoming air. This same effect is beneficial in keeping sun-exposed building surfaces cool.

## Uneven Building Form

An uneven building form can also influence radiative heat loss from the building to the sky. In most calculations of heat loss from walls, the radiative component is usually neglected because it is assumed that walls will "see" other walls at the same temperature and, therefore, the magnitude of radiative heat loss will be extremely small.

This assumption is not justifiable in all situations and the increased wall area of an uneven building mass radiates a greater amount of heat to the sky and consequently it stays cooler than a more compact mass. Thus it is to be expected that the uneven built form of Jaisalmer with large wall areas helps in keeping the building cool.

VENTILATION

At higher temperatures, human thermal comfort can be provided only by ensuring air movement in the built space. Natural air movement through a building is caused either by wind or by temperature differences between interior and exterior. When buildings are tightly clustered together, it is generally difficult to let winds into the house and air movement due to temperature differentials is usually too sluggish to cause any comfort unless it is augmented by special design features. Another ventilation problem relates to the temperature of ambient air during daytime. Before outside air passes through a living space, its temperature must be reduced, or else its cooling effect on the human skin is nullified by convective heat gain due to its high temperature. During summer when there are strong surface winds, sand gets blown along the ground and can enter buildings unless precautions are taken against this nuisance. There are also regional dust storms where sand and dust can get into buildings. Successful ventilation design calls for ensuring adequate air movement through the building and pre-treating the air to lower its temperature and to reduce its dust particle content.

*Fig. 11. The uneven built form of Jaisalmer and the highly articulated street facades.*

In Jaisalmer buildings, a number of interconnected vertical shafts are used for ventilation. The courtyard effect (Koenigsberger, 1971) is well known and used in almost all hot-dry climates. In addition to the simple courtyards, very narrow vertical ducts and staircase shafts are used to deflect wind down into the house in Jaisalmer (Fig.14). 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).

In some recently constructed houses wind scoops and suitably located air ducts are also used to channel wind into the building. But these are not found in the older buildings and their origin can be traced to migrants from Sind where this sort of device is very popular (Rudofsky, 1964). The overall effect of these ventilation systems is such that there is substantial air flow through the house, and this air flow is maximum when the indoor air temperature and ventilation by outdoor air is most desirable.

While there is little that can be done to eliminate dust due to regional dust storms, the problem of wind-blown sand is effectively settled by the 5 to 6 metre high wall around the town. Within the town most surfaces are paved, reducing the chance of dust being raised.

Selective ventilation (i.e. ventilation only during the cooler periods of the day) can help in structural cooling of a massive building, leading to lower indoor temperatures during the day. Surprisingly enough selective ventilation is not practised in Jaisalmer and ventilation apertures are kept open throughout the day. This is understandable, as people are concerned with thermal comfort and not temperature. At temperatures less than 35°C a slow current of air will always provide better comfort than a slightly lower temperature with no air movement (Givoni, 1967). In the absence of mechanical ventilation devices, even warmer outdoor air is welcome. However, in winter when there is no special need for air movement, window apertures are opened during the day and kept shut at night.

As 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. It is interesting to note that with such a construction the ceiling, the roof surface and the ambient air reach their peak temperature at about the same time. This is contrary to the modern belief (Givoni, 1969; Koenigsberger, 1971; Van Straaten, 1968) that time lag should be such as to cause the highest internal surface temperature at night when the effect of the increase in mean radiant temperature can be offset by the lower temperature of ventilation air. But the 24-hour time lag is also accompanied by a greater reduction in the incoming heat flux. The peak indoor temperatures occur at a time when people are better prepared for them. High internal temperatures are unbearable at night but they can be easily tolerated during daytime.

Almost all houses in Jaisalmer have a basement; but these rooms were designed to be used only as strong rooms for valuables. The temperature underground remains almost constant throughout the year due to the absence of any heat load and due to rapid decay of the ambient temperature wave in soil. But in Jaisalmer in no case are such rooms ventilated or lighted, as they are not used as living space. Some of the benefits of sub-surface construction are, however, available in the lower floor of the taller buildings, which stay much cooler than the upper floors of the same buildings.

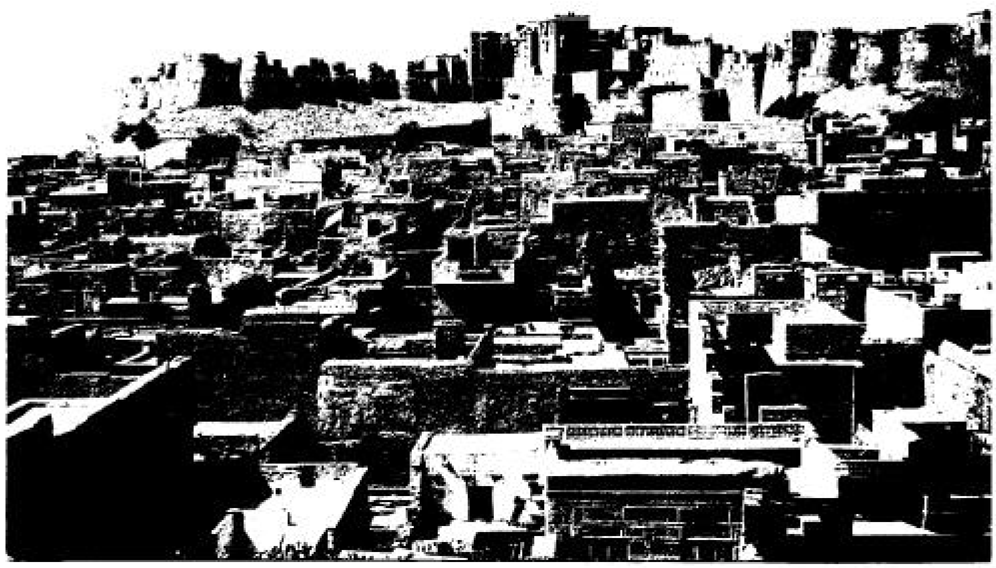


*Fig. 12. The natural cooling systems of Jaisalmer.*

Water is a precious commodity in Jaisalmer, and since all the water for domestic use had to be carried to the house from the Garhisar tank outside the town by womenfolk, the common people never used any form of evaporative space cooling. But there are a few places, in the palace and in one Patua Haveli, where fountains and cascades have been installed. From the small size of cisterns feeding these fountains it is clear that their use must have been limited to some special occasions.

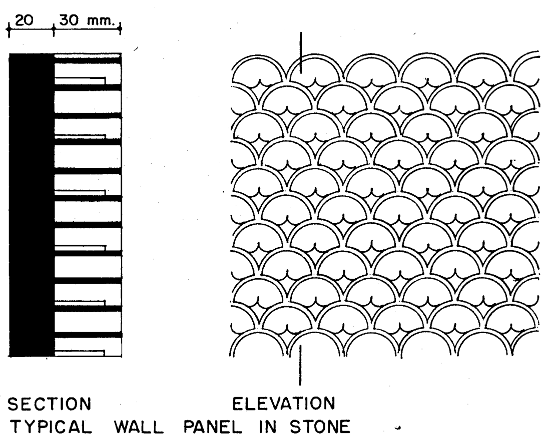



*Fig. 13. Details of carved panel*

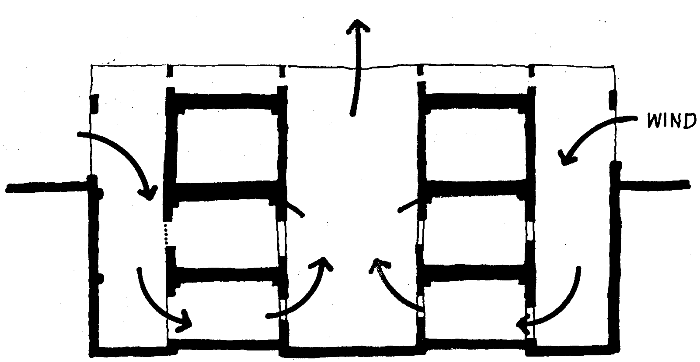



*Fig. 14. Air ducts of Nathmal's haveli*

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