1.0 Introduction

The fundamental purpose of buildings is to provide man with a comfortable working and living space, protected from the extremes of climate. In these days of fuel crisis it is important that such comforts be provided with as little expenditure of energy as possible. Traditional architecture with hundreds of years of experience behind it, has evolved appropriate building methods for each type of climate. In most cases such buildings create a very comfortable living environment without any mechanical cooling or heating. In contrast with these, modern buildings provide a much lower degree of thermal comfort and many of these are not usable without mechanical cooling and heating. In India only a small percentage of population can afford the cost of air-conditioning, the majority lives in uncomfortable structures. The purpose of this paper is to suggest methods for ensuring thermal comfort in buildings by natural means. Many of the methods discussed below have been used in traditional buildings in India but there are some which are based on recent scientific research. Natural heating is not discussed here because the heating requirements in most parts of India are minimal.

Passive solar heating has been found to be popular in the U.S.A. and other countries because it can provide temperatures comparable to those provided by fuel based heating systems. In harsher climates solar heating reduces the need for conventional heating systems and thus saves large amount of energy. Natural cooling, on the other hand, can seldom provide the low temperatures that are possible with mechanical airconditioning . In some cases it is necessary to supplement natural cooling with conventional airconditioning.

2.00 Thermal Comfort

The physical condition that determines the feeling of warmth or cold by the human body is a combination of air temperature, mean radiant temperature, relative humidity and air velocity. Various authors have attempted to combine these four factors into a single index of comfort (e.g. the 'effective temperature scale' and the 'predicted four hours sweat rate ') but so far there is no standard reliable method to describe the relative comfort or discomfort that will result from combinations of these factors. The human response to the same physical condition varies from person to person. It depends upon the amount of clothing on the body and the nature of activity of a person which governs his metabolic rate. Psychological factors also modify the physiological response, but their influence is hard to determine.

The commonly accepted relationship between the four physical factors is as follows:

a) The effect of mean radiant temperature (M.R.T.) is similar to that of air temperature. One degree change of M.R.T. being equal to 0.75 deg change of air temperature.
b) In warm conditions, air movement is beneficial if the air temperature is lower than the skin temperature.
c) In humid conditions, air movement is essential for maintaining comfort.

3.00 Thermal Environment Within a Building

The effect upon the building of the outdoor climatic conditions viz. air temperature, solar radiation intensity, humidity (precipitation or evaporation), wind velocity and direction and clearness of sky, determines the internal environment. These outdoor conditions are constantly changing. At any given time, their effect on specific building elements depends upon the location and orientation of that element. In warm climate solar radiation is the most important cause of overheating of a building. The first natural cooling method therefore is to reduce the interception, absorption and in-ward transmission of solar radiation. Further, heat removal from the building can be effected by natural or induced ventilation, evaporation of water and use of desiccants and heat sinks.

3.10 Control of Solar Radiation Intercepted by the Building

The movement of sun and the variations in solar azimuth and altitude, diurnal and seasonal, are well described in several standard texts (Ref. 1) and are comprehensively depicted in the form of solar charts specified for each latitude. Through proper design of a building having due regard to solar geometry, the radiation intercepted by the building can be greatly reduced. Some of the important features of solar control through building orientation and form are mentioned here:

3.11 Solar Radiation and Building Form

It is well known that for a building with each of the four walls and the roof of equal area, the relative heat load due to direct solar radiation is as follows:

		ROOF		WALLS		
			North	South	East	West
Summer (June 22)	48-51%	48-51%	6-3%	0-2%	19-20%	19-20%
Winter (Dec. 21)	28-34%	28-34%	0	35-44%	14-15%	14-15%

Table 1 (for latitudes 17 deg N to 31 deg. N. Ref.2)

In addition to the direct radiation the building receives diffused and reflected radiation also. During the summer months in India the diffused radiation component is about one -third of the total radiation and during monsoons it is more than half of the total radiation. It is assumed that all walls receive equal diffused radiation while the roof receives nearly twice as much. The incidence of reflected radiation depends upon the nature of the surrounding surfaces and cannot be generalised.

From the foregoing it is clear that the north wall receives no direct radiation in winter but appreciable amounts in summer. The east and west walls receive equal amounts of radiation, more in summer than in winter. The south wall receives very little radiation in summer but the largest amount in winter. The roof receives large amounts of radiation in summer but much less in winter.

To reduce over all heat gain by the building in summer, the east and west walls should be kept as short as possible while the north and south walls can be longer. The roof needs special attention as it receives the maximum amount of solar radiation in summer.

3.12 Sun Protection (Shading)

All building elements need to be shaded from solar radiation in summer. But shading is vital for glazed areas of walls (windows) as the solar heat gain through glass is much greater than through opaque building elements. Direct solar radiation can be controlled through use of vertical, horizontal and inclined louvers (Ref. 1), movable screens, deciduous trees and plants. The effectiveness of sun shades is not equal for all orientations of walls and therefore glazed areas should be provided only in those positions where effective protection against the sun can be ensured. Protection against diffused and reflected radiation cannot be provided by any simple method. To reduce heat gain through glazed areas they should be kept to the minimum for good day light.

Shading against direct radiation is easiest to provide on the south wall. A horizontal projection of appropriate depth will exclude the summer sun (Fig. 1) while still permitting sun light in the building in winter.

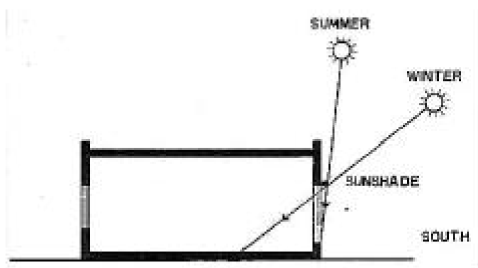

FIG. 1-SUMMER SUN PROTECTION

The east and west walls can be protected by a combination of horizontal and vertical louvers, or movable screens that may be used during the time the solar radiation is incident on the wall.

The north wall can be protected by vertical louvers. The roof can be shaded only by a horizontal cover (see 3.21) extending over the whole roof and projecting beyond it on the east, west and south sides.

3.20 Control of Outer Surface Temperature

The rate of heat flow through any building element is proportional to the temperature difference between the outer and the inner face. To reduce heat flow to the inside of the building, it is necessary to control the outer surface temperature. The heating of the building due to the effect of outdoor air temperatures and solar radiation is an intermittent process. At night when the air temperature is lower and there is no solar radiation, the building cools down both by convection and by radiation to the night sky. Ideally the building surface finish should be such that it would not absorb any solar radiation and would emit maximum possible long-wave radiation. The reflectivity of the surface for solar radiation and its emissivity at low temperature are therefore important properties of the material and the higher these properties the material possesses the greater its value. For some common building materials these properties are given below:-

MATERIAL	REFLECTIVITY (Solar Radiation)	EMISSIVITY (Low Temperature)
Polished Aluminium	0.80	0.05
Whitewash	0.70	0.90
Red Brick	0.40	0.90
Glass	0.08	0.90

Table 2

Whitewash with lower reflectivity than aluminium will stay cooler when exposed to solar radiation because of its very high emissivity. At night, whitewash, red brick and glass will attain lower surface temperatures than aluminium. However, aluminium will stay coolest if exposed to long-wave radiation. Generally, it can be stated that light coloured surfaces stay cooler than dark coloured. Roof surfaces, which are exposed to solar radiation for long hours in summer, should be painted white.

3.21 Surface shading can be provided as an integral part of the building element or it could be provided by a separate cover. Highly textured walls have a part of their surface in shade (Fig. 3). The radiation absorbing area of such a textured surface is less than its radiation emitting area and therefore it will be cooler than a flat surface. The increased surface area will also result in an increased co-efficient of convective heat transfer which will permit the building to cool down faster at night when the ambient air temperature is lower than the building temperature.

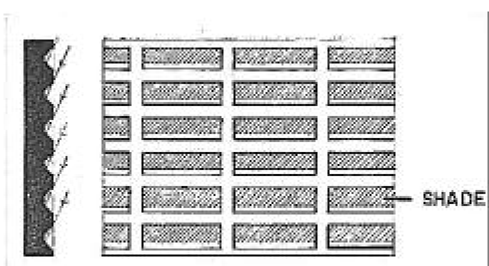

FIG. 3-SHADING BY TEXTURE

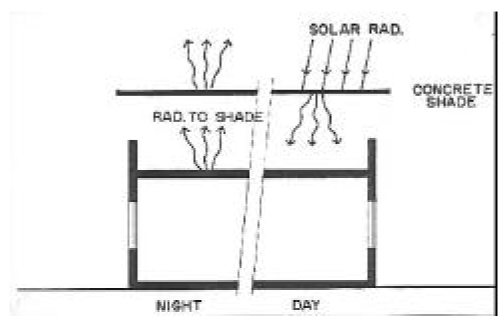

FIG. 4-ROOF SHADING

If external shading devices are used on the building surface, they should not interfere with night time cooling. This is particularly important for roof surfaces which are exposed to the cool night sky (see 3.52 below). A solid cover of concrete or galvanised iron sheets (Fig. 4) will shade the roof from solar radiation but it will not permit radiation to the night sky. An alternative method is to provide a cover of deciduous plants or creepers (Fig. 5). Because of evaporation from the leaf surfaces the temperature of such a cover will be lower than the day time air temperature and at night it may even be lower than the sky temperature. This will result in a very cool roof surface even if the day time shading is not 100%.

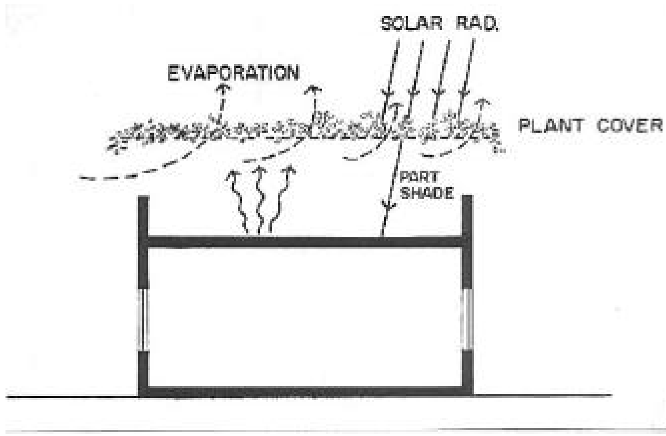

FIG. 5-ROOF SHADING BY VEGETATION

Another shading device used in some traditional buildings is the covering of the entire roof surface with small closely packed inverted earthen pots (Fig. 6). In addition to shading, such an arrangement provides increased surface area for radiation emission and insulative cover of still air over the roof which impedes heat flow into the building while still permitting upward heat flow at night. Although it is thermally efficient, this method suffers from practical difficulties as the roof is rendered unusable and is difficult to maintain.

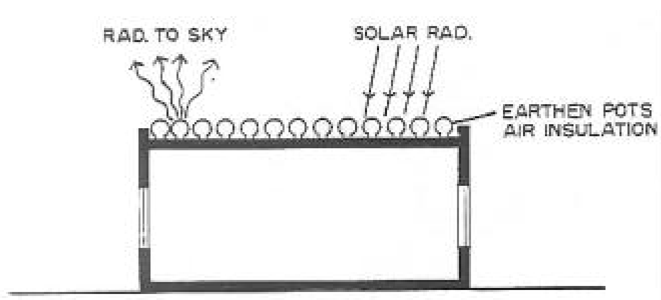

FIG. 6-ROOF SHADING BY POTS

An inexpensive and effective roof shading device is a removable canvas cover (Fig. 7). This can be mounted close to the roof in the day time and at night it can be rolled up to permit radiative cooling.

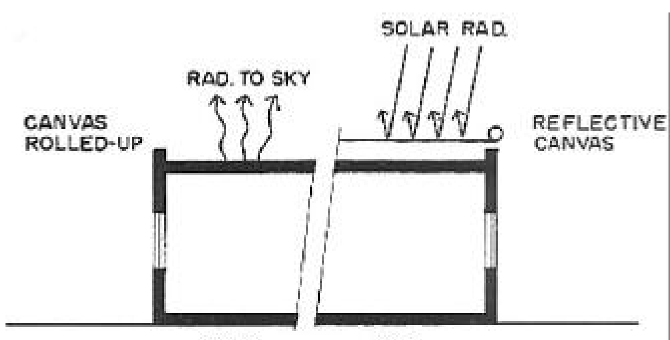

FIG. 7-REMOVABLE ROOF SHADE

The upper surface of the canvas should be painted white to reduce transmission of radiation through the material and to make it more durable. Surface temperatures can be controlled by evaporation of water also. This method is discussed in 3.53 below.

3.30 Control Of Internal Surface Temperature

Under steady-state conditions the heat flow through a building element is proportional to the thermal conductance (u-value) of the element. But under non-steady-state conditions which are found in buildings without mechanical cooling, apart from the u-value of the element its thermal capacity also determines the heat flow. Massive building elements with a large thermal capacity absorb large amounts of heat before they begin to transmit it to the interior. There is therefore a time-lag between the application of the highest external heat load and the time when the internal surface temperature reaches its peak value. The ratio between the temperature amplitudes of the internal and external surface is known as the decrement factor. Both the time-lag and the decrement factor are properties of building elements and not of materials. For building elements of massive construction the time-lag is larger and the decrement factor smaller than for a light weight element of the same u-value. The effect of massive construction is to lower the maximum day time temperature and to raise the minimum night time temperature (Fig. 8). In light weight construction, the internal temperatures follow closely the pattern of out door temperatures.

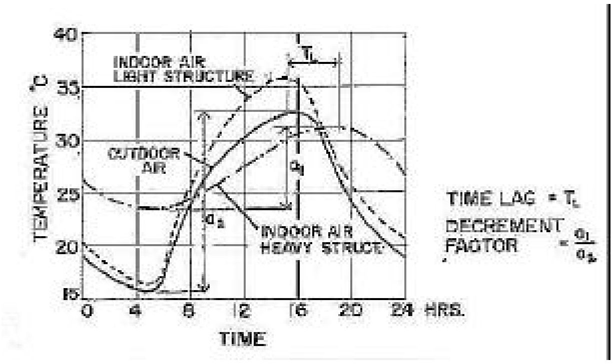

FIG. 8-EFFECT OF THERMAL CAPACITY

In warm climates it is advantageous to use massive building construction. The uncomfortable night time conditions in such structures can be modified by introducing additional ventilation into the building at night.

As no single material possesses all the structural and thermal characteristics desirable in a building element, combinations of materials with different properties are used to provide the necessary characteristics. For such a situation, the time lag and the decrement factor are determined not only by the thickness of various layers of material, but also by the order in which these layers are placed. Resistance insulation placed outside a brick wall will give substantially higher time-lag and lower decrement factor than if the same insulation was placed on the inner side of the wall.

High time-lag and low decrement factor are desirable only when there are large diurnal temperature variations. They serve no useful purpose in climates with small diurnal temperature changes. For composite climates a combination of light weight and heavy construction (see 4.2) is desirable.

Air cavities can be used in place of resistance insulation. By ventilating these cavities to the outside at certain times of the day or during a particular season, their resistance value can be decreased. In other words, air cavities can be employed to create wall or roof element with flexible u-value (Fig. 9). A similar effect is achieved by applying movable insulation (Fig. 10) to a fixed building element, although at much greater cost.

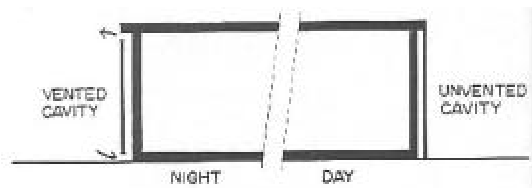

FIG. 9-VARIABLE INSULATION ON WALL

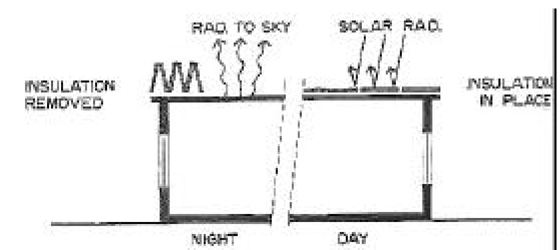

FIG. 10-VARIABLE INSULATION ON ROOF

Flexible u-value construction can be used for enhanced cooling of the building at night. The effect of such an arrangement on the in door temperature is shown in Fig. 11.

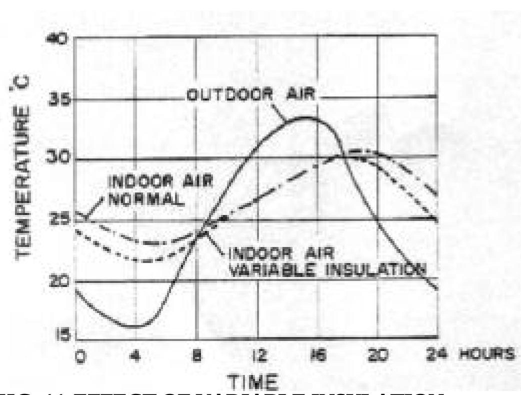

FIG. 11-EFFECT OF VARIABLE INSULATION

3.40 Control of Internal Heat Gain of the Building

If a building is fully insulated from the outdoor thermal environment, with normal use its internal temperature will rise because of the accumulation of heat from within the building. People, lights, machines, kitchen stoves and many such devices used in buildings produce heat. To prevent the accumulation of heat from individual sources like machines and kitchens, they should be thermally isolated from living areas and if possible they should be ventilated to the outside. Within the living and working areas, the heat produced from lights can be reduced by using more efficient luminaries and by proper daylighting of the building, as daylight (not direct sun light) has higher light to heat ratio than most artificial light sources.

3.50 Heat Removal From the Building

Sections 3.1 to 3.4 were methods of reducing heat gain by the building. Even with good building design some heat will reach the internal space and suitable methods have to be used for the removal of this heat to the outside. These methods can be broadly classified according to the principal means of heat transfer used i.e. convection, conduction, radiation or evaporation.

3.51 Convection

Ventilation and air movement control the convective heat flow from the building. Ventilation of living spaces is also necessary for removal of odours and gases produced by normal metabolic functions of the human body. Air movement relieves the heat stress imposed on the human body by humid conditions. During the periods when the out-door air temperature is lower than the in-door air temperature, ventilation will cause cooling of the interior. When the out-door air temperature is higher than the internal air temperature, ventilation must be kept to a minimum unless the air is cooled before it enters the living space.

Natural ventilation of the building results from differential wind forces on the various building surfaces and from thermal effects due to temperature difference between the outside and inside air. Factors such as surrounding landscape, location of other buildings, the building form, orientation with respect to wind direction, size and proportion of window openings and arrangement of internal partitions etc., affect the air flow within the building. These effects have been reported in detail by several authors (Ref. 3 & 4). Ventilation due to wind forces is of a higher order than due to thermal forces, but due to the intermittent nature of wind movement, such ventilation cannot be ensured at the most appropriate times. In densely built urban areas, the effect of wind is considerably less than in open country side or in sparsely built suburban areas. The rate of air flow due to thermal forces (Ref.4) is proportional to the difference of temperature between the inside and outside air, and the difference in the height of the outlet and the openings of the inlet. The maximum difference between the outlet and the inlet heights is generally determined by the height of the building, but in exceptional cases it is possible to increase this difference by building tall wind towers (Ref. 5). An increase in the internal air temperature over the external air temperature will cause greater ventilation, but the higher internal temperature will also result in thermal discomfort. (Fig. 12) shows an arrangement where an air cavity Is heated by solar radiation to induce ventilation. The living space is protected from the high temperatures in the cavity by a layer of insulation. If thermal storage can be provided, the system can ensure ventilation throughout the day.

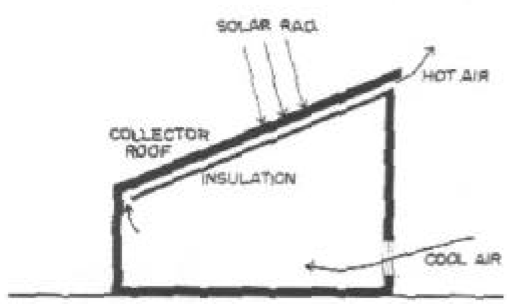

FIG. 12-SOLAR INDUCED VENTILATION

Differential heating of unequal sized courtyards by solar radiation causes air movement. This effect is commonly used in courtyard houses in densely built urban areas (see 4.1 and 4.2 below).

3.52 Conduction

Conductive heat loss in a building normally occurs through the floor. The diurnal variations in air temperature affect only the top layer of the soil (30 cm.) and even the seasonal variations of temperature are not felt below

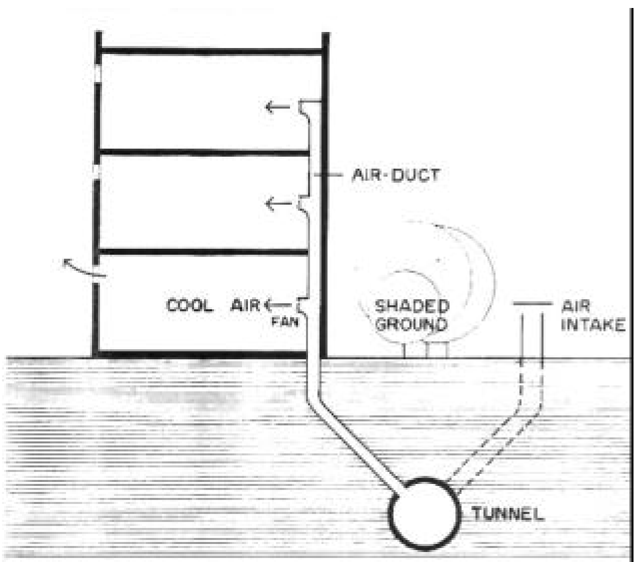

FIG. 13-TUNNEL COOLING

a few meters depth. The ground temperature a few meters below the surface remains constant throughout the year. The magnitude of this constant temperature depends upon the nature of the ground surface, the lowest temperatures resulting from a shaded and irrigated surface. For Delhi (India) this value has been determined (Ref. 6) at about 18 deg.C at 4 meters depth. If the building is constructed at this depth below the surface, it would be naturally cooled in summer and heated in winter. However, it is not practical to build every building at such a depth. An alternative method is to construct tunnels at the appropriate depth (Fig.13) and to cool air by drawing it through the tunnels. The cooled air is then blown into the living spaces in the building (Ref. 7).

An important design parameter for such tunnels is the total surface area of the tunnel across which the heat exchange takes place.

3.53 Radiation

During daytime, the building gains heat from solar radiation and the hot ambient air. This heat gets stored in the building envelope and after s-unset the outer surface of the building begins to cool down by convection to the outside air and by radiation to the sky. The radiative heat loss can be improved through the use of a coating that radiates efficiently at low temperatures. However, the atmosphere is opaque for long-wave radiation except for wavelengths between 8 to 13 /u, and much of the radiation from the building gets reflected back to it. A possible remedy would be the use of a selective radiation coating that radiates mostly between 8 to 13/U wavelengths. Unfortunately, such a coating is not available at present.

Vertical building elements such as walls are exposed to only a small part of the night sky and the radiative heat exchange between the building and the sky, takes place mainly through the roof. As the warm roof surface gets cold by convection and radiation, a stage is reached when its surface temperature equals dry bulb temperature of the ambient air. Further cooling by radiation continues as the night sky temperature is lower than the ambient air temperature.
The rate of this cooling process is slower because of the convective heat gained from the surrounding air. If the net heat exchange reduces the roof surface temperature to the wet bulb temperature of the surrounding air, condensation of the atmospheric moisture takes place on the roof and heat gain due to condensation limits any further cooling. Various methods of using the ambient air cooled by the roof, have been suggested by Givoni (Ref. 3 & 8).

If the roof surfaces are sloped towards an internal courtyard (Fig. 14), the cooled air sinks into the court and enters the living spaces through low level openings. A parapet wall is raised around the roof to prevent air mixing. However this method will not work in windy conditions.

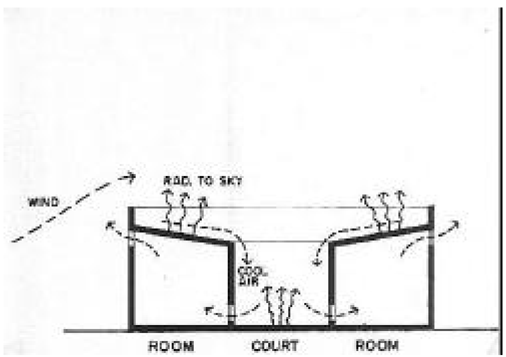

FIG. 14-RADIATIVE COOLING

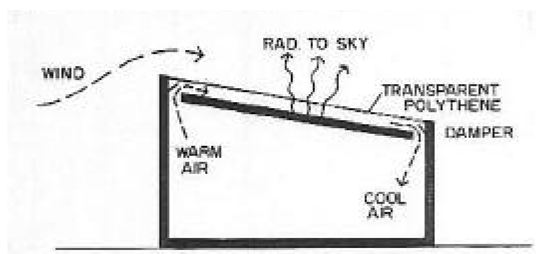

FIG. 15-RADIATIVE COOLING-THERMOSYPHON

The effect of wind movement and convective heat gain can be reduced by covering the roof with polythene which is transparent to long-wave radiation (Fig. 15). Inlet and outlet openings for air are provided in the roof itself. The major drawback of this method is the short life span of the polythene sheet.

An alternative method is to cover the roof with white painted corrugated iron sheeting (Fig. 16). Openings are provided in the roof for circulating air under the corrugated iron sheeting. During the day the openings are kept closed and no air circulation takes place. At night, air is circulated

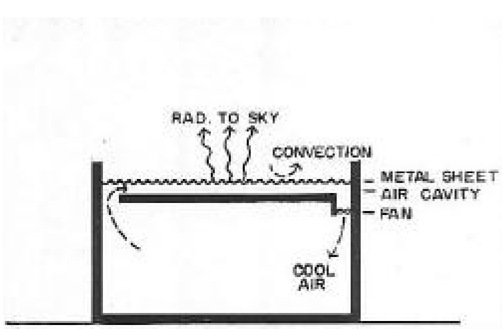

FIG. 16-RADIATIVE COOLING

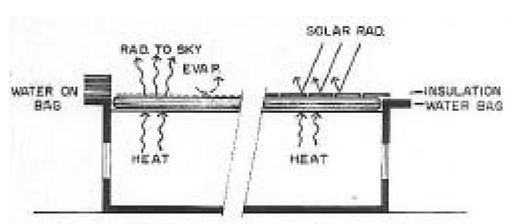

FIG. 17-SKYTHERM COOLING

under the sheets with the help of a blower and the cooled air is used in the living space. In this case the corrugated iron sheeting acts as the outer surface of the roof and cooling efficiency is limited due to convective heat gain from the outside air.

Hay has suggested the "Skytherm" system (Ref. 9) for night radiation cooling using a roof pond and movable insulation (Fig. 17). The surface of the pond is exposed at night and the water cooled by evaporation and radiation. During day time, the insulation covers the roof pond and prevents heat gain. The roof pond acts as a heat sink during the day and keeps the building cool. This is an expensive system and its cost can only be justified if it is also used for heating in winter. Equally effective cooling in summer can be achieved by simpler methods described below.

3.54 Evaporation

The most commonly used evaporative cooling system is the window unit air-cooler with evaporative pads, a fan and a pump. Central air cooling systems with a spray chamber and a blower are also used for larger buildings. To produce comfortable conditions both these systems require a high rate of air movement through the living space. In many work areas excessive humidity and air movement are not desirable and the Australian system (Fig. 18) with a rock-bed regenerator provides viable alternative for such areas. It uses two rock beds set side by side and separated by an air space in which a damper is located. Water sprays are mounted close to the inner surface of each rock bed, and two fans are used. The rock beds are cooled alternately by spraying water and letting it evaporate on the stones. While one rock bed is getting cooled, the other one (already cooled in the previous operation cycle) supplies cool air to the house. Very little moisture is thus added to the air entering the house as the rocks are almost dry before they are used to cool the incoming air in the next operating cycle. The humid air from the rock bed produced during its evaporation cycle, is vented to the outside.

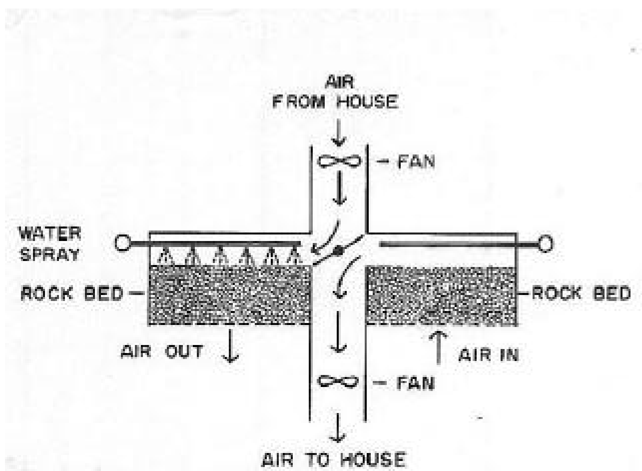

FIG. 18-ROCK-BED REGENERATIVE COOLER

Roof surface evaporation can be used to provide cooling for one or two storeyed buildings. Continuous evaporation from a thin film of water over the roof, lowers the temperature of the roof which in turn cools the living space below it. Solar radiation intensity and wind velocity over the roof, affect the rate of evaporation of water but not the temperature of the roof. For this method to be effective, the roof slab should be water proof and made as thin as possible.

One major problem, common to all the above mentioned evaporative cooling systems, is the low operating efficiency during the humid part of the summer. Conventional evaporative cooling cannot be used at all in regions where the humidity remains high throughout the year. A conceivable alternative for such regions is desiccant cooling. where the outside air is first dried by passing over a desiccant material like silica gel, and then cooled in the evaporator. Solar energy could be used for regenerating the spent desiccant material.

Desiccants were used as an integral part of the building in the Altenkirch House (Ref. 10) which was built in Israel in the fifties. This building was oriented with its long axis along the North-South direction. The hollow East and west walls (Fig. 19) were filled with a sorbent material which permitted air-flow through it. Vapor Aptiva coolers were placed on top of both walls and dampers were so arranged that air could flow through each wall from top to bottom or vice versa.

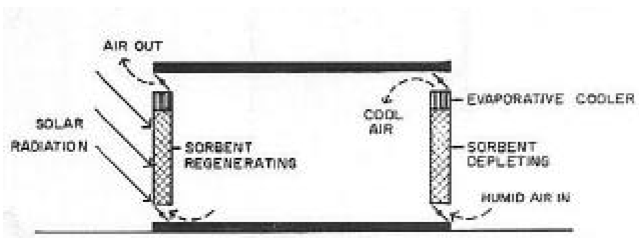

FIG. 19-ALTENKIRCH HOUSE

During the forenoon the sun would shine on the East wall and the humid outdoor air would first dry by circulation through the West wall and then cool in the evaporator. The cooled air which entered the living space from the top of the West wall would blow out through the East wall where it would carry away the moisture from the solar heated desiccant. During the afternoon, the air flow would reverse so that the regenerated desiccant in the East wall would be used for drying the air and the spent desiccant in the West wall be regenerated by solar heating. This is an interesting system of desiccant cooling which has not been developed after the initial experiment. The use of desiccant for natural cooling is limited by the non-availability of materials suitable for large scale application.

4.00 Traditional Cooling Systems

It was stated at the beginning of this paper that indigenous architecture has evolved suitable building styles for severe climates. It may now be added that traditional urban design provided the appropriate environment without which even the best building design could not have been wholly successful. Two examples of architecture and urban design suitable to the climate are presented below. One of these is from the hot and arid Tar desert (India) and the other is from the composite climate of the Indo-Gangetic Plain. A third example, not related to buildings, is the use of natural energies for ice making.

4.10 JAISALMER (Rajastan. India)

The best example of architecture of the hot and arid zone in India is Jaisalmer, a town built in the heart of the Thar desert. The geographical location of Jaisalmer is 26 deg. 55 min. North (lat.) and

70 deg. 55 min (long.), with a height above mean sea level of 241.66 meters. The day time temperatures in June reach upto 50 deg. C while the night temperatures in January are below the freezing point. Annual rainfall during the year is 120 to 150 mm, 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 climate demands protection from the scorching summer sun and sand storms on the one hand and very cold winter nights on the other. Humidity being low throughout the year, comfort could be easily provided by evaporative cooling, but this is not possible because water is very scarce in Jaisalmer. The only sources of water are the very deep wells and the Gharhisar tank on the outskirts of the town.

The layout of the town (Ref. 11) is the first defence against the harsh climate. The streets are narrow and shaded from the sun. The general street orientation (Fig. 20) 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. At many places, buildings overhang the streets on both sides, providing a cool shaded area almost like a tunnel. 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.

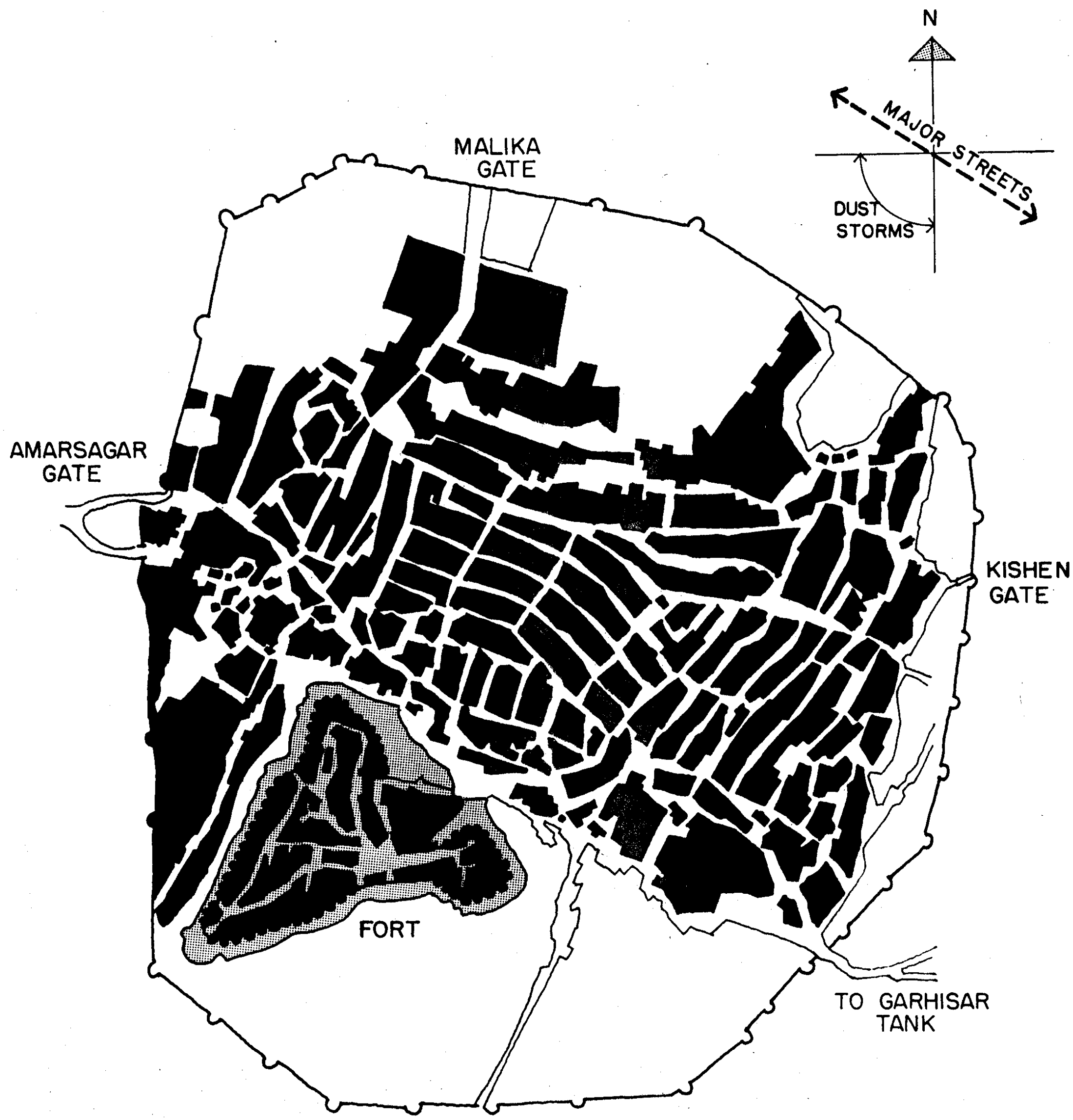

 FIG. 20- THE CITY OF JAISALMAR (RAJASTHAN, INDIA)

The main building material used for walls is light yellow coloured sand stone. Roofs are built of mud, supported on wooden beams covered with grass mat. In more recent construction, stone beams have been used as roof supports. The thickness of the roof varies from 45cms. to 90 cms., enough to dampen the effect of the diurnal temperature variations. There is no scientific study to compare the performance of the two kinds of roofing (i.e. stone slabs and wooden beams), but according to popular belief the wooden ceilings with grass mats stay cooler than stone ceilings. The wall surfaces are highly articulated (Fig. 21) with projecting balconies, sun shades and brackets, and each of these building elements is in turn intricately carved. Flat portions of stone walls are also decorated with deep carvings. The resulting overall building surface is designed to stay cool (see 3.21 above) even when it is exposed to the sun.

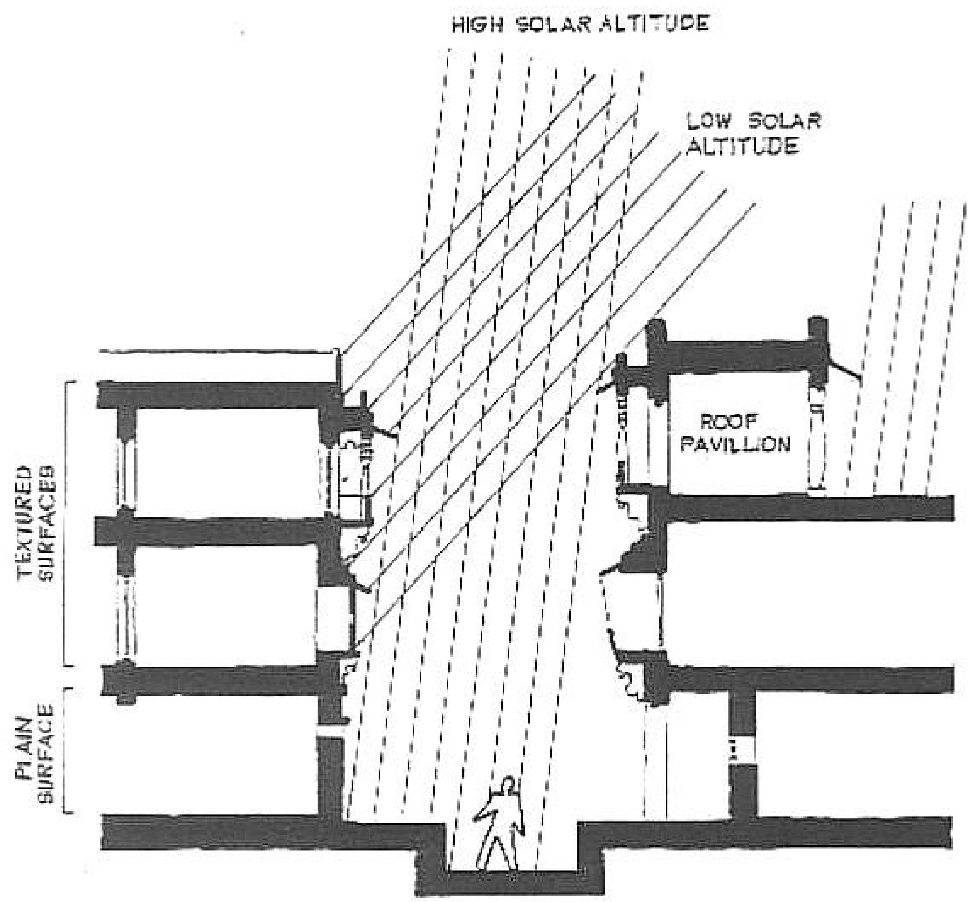

FIG. 21-TYPICAL STREET SECTION

According to the economic and social status of the house owners, there are three types of buildings. The poorest live in very small single storey houses built in mud. There is generally a small room and a verandah opening into a small courtyard enclosed by high walls. Usually a small basement is also built, but it is not ventilated and therefore used only as a store for valuables. The main living area of the house is the courtyard and verandah. The heavy roof and walls along with the courtyard ensure thermal comfort in the house.

The middle income house is a two or three storeyed structure with a completely enclosed courtyard. The deep and narrow building plot of land is surrounded on three sides by similar construction and on the fourth side by the narrow street. Therefore, solar heat gain through the walls is very little. The rooms built next to the street are cross ventilated through the courtyard. This may not be possible in the rooms built in the rear of the plot. Since window openings are small and the courtyard very deep, most rooms in these houses are poorly illuminated.

Architecturally the most interesting and the most comfortable thermally, are the "Havelis" (large courtyard houses) belonging to the rich. These are three or four storeyed structures with additional wind pavilions on the top floor. Each building is built around one or two courtyards with additional ventilation shafts provided at appropriate locations. Almost all the special thermal design features of these "Havelis" are incorporated in Nath Malji's Haveli described below.

Nath Malji's Haveli

This building (Fig.22) is planned around two courtyards, the one in the front is much smaller than the one in the rear. The front part of the building is three storeys high and has the main living quarters. The rear portion is two storey high and contains the ancillary accommodation. On either side of the main courtyard there is a small apartment built around a narrow vertical shaft. There is thus a variety of vertical ducts (courtyards) of different sizes.

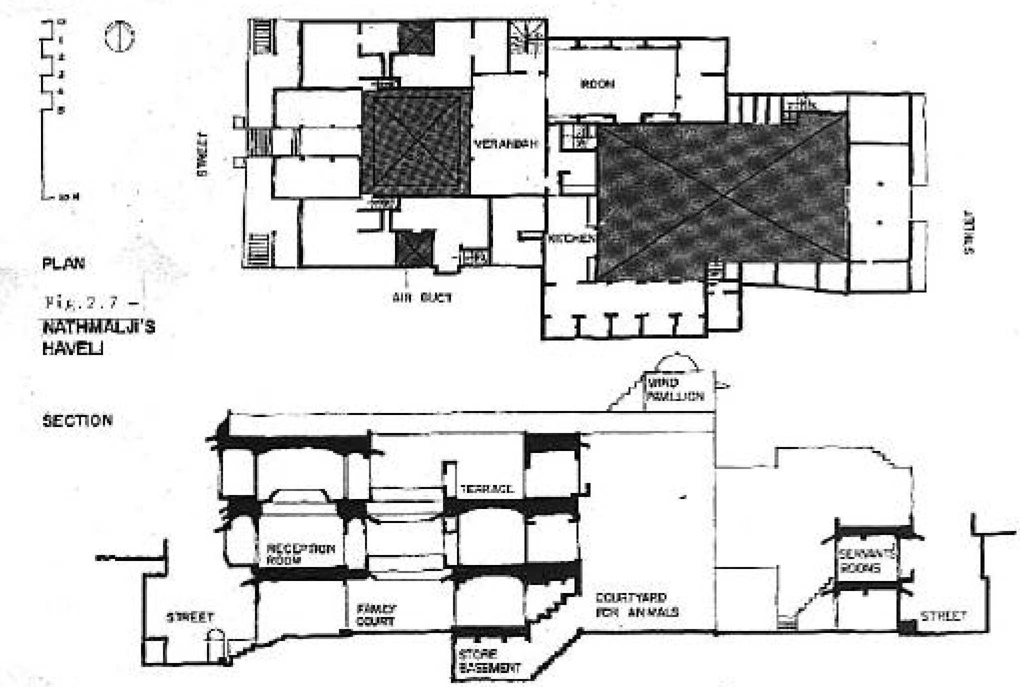

FIG. 22-PLAN NATHMALJI'S HAVELI SECTION

These provide light and ventilation for all the rooms. While the front receives some sunlight during the summer the rear courtyard is almost completely exposed to the sun. The street and the two narrow shafts are completely protected from the sun. This differential heating of the vertical ducts (Fig. 23) ensures a continuous air flow through the house. The two narrow shafts, being open on one side at the upper level of the building (Fig. 24), act as wind catchers as well.

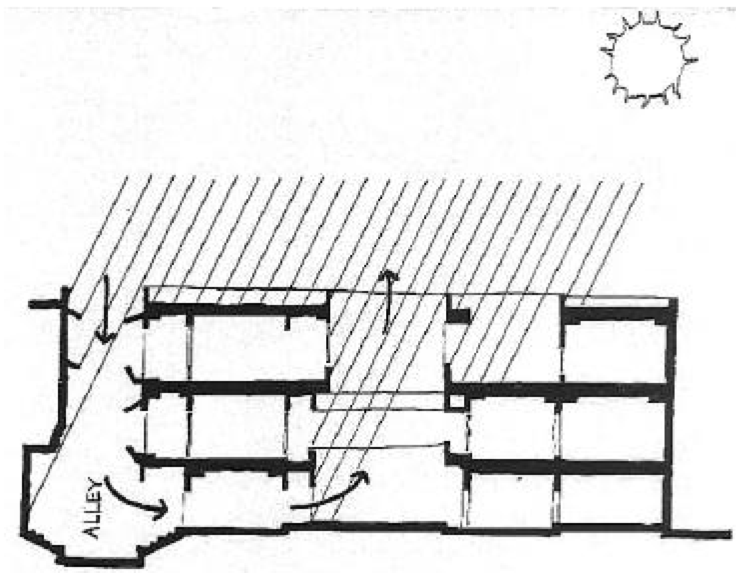

FIG. 23- COURTYARD EFFECT

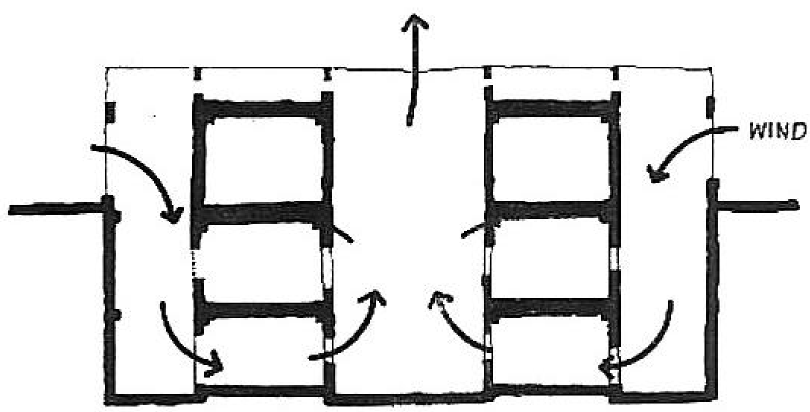

FIG. 24-AIR-SHAFTS OF NATHMALJI'S HAVELI

The drawing room of the family is located on the first floor above the entrance way. This richly decorated room is two storeys high. There are timber shuttered windows opening towards the street and a large number of small ventilation holes in the upper part of the room. Together, these openings ensure heat removal by ventilation.

As this building is taller than the surrounding buildings, parts of external walls are exposed to solar radiation. To avoid solar heat gain the walls are shaded with projections and carvings. The internal walls of the courtyard, which also receive some solar radiation, are treated in the same manner.

The total effect of this massive structure, the sun shades and the ventilation system is such that the family has not felt it necessary to install ceiling fans (air circulators) in the rooms, even though electricity is now available.

One type of ventilation device not found in the old buildings of Jaisalmer, but which has been installed in more recent constructions, is the roof top wind scoop (Fig. 25). In Jaisalmer, a cool breeze blows from the south in summer evenings, and the wind scoop is oriented to deflect this cool breeze into the house. A trap door is provided at the base of the wind scoop to keep out unwanted hot or dusty winds.

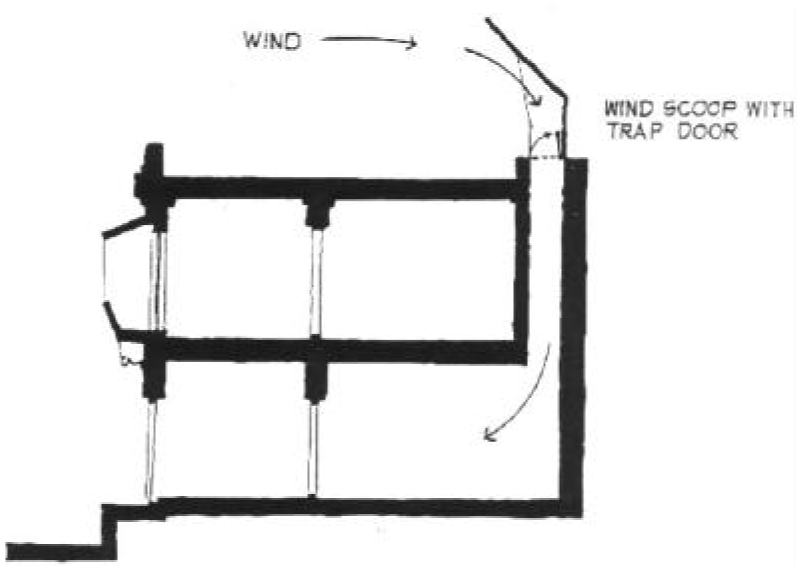

FIG. 25-UNIDIRECTIONAL WIND SCOOP (BUNG.)

4.20 Old Delhi (Shahjahanabad)

The geographical location of Old Delhi, known as Shahjahanabad during 17th and 18th centuries A.D., is 28 deg.53 min. North lat., 77 deg. 12 min. East long. with a height above mean sea level of 218 meters. The climate is characterised by a long dry summer followed by a warm humid monsoon season and a short dry winter with clear sky. The diurnal temperature variations are large (14 to 17 deg C) except during the rainy season. The summer daytime temperature exceeds 40 deg. C, while the lowest temperature during winter nights is around 5 deg. C.

Annual precipitation is 666 mms. and during the rainy season, the relative humidity varies from 60 - 80%. During the summer a hot wind "blows in the day and there are frequent dust storms in the evenings.

This composite climate is more difficult to design for than that of Jaisalmer, but the builders of Shahjahanabad did not have to worry about the shortage of water as the city is situated on the banks of the river Jamuna. Evaporative cooling was therefore used in many different ways.

The streets of the old city are narrow and the buildings tightly packed together, thus reducing solar heat gain to a minimum. The major streets which are wider, were lined with trees to provide shade for pedestrians. The shopping streets also had collonades on both sides. Almost continuous cover was provided in the narrower streets during summer by the use of cloth awnings.

The common building materials were bricks, lime, stone and timber. Roofs were built of mud supported on wooden beams and stone slabs or timber boarding. A layer of lime concrete was used on top of the mud roof for waterproofing. The walls were usually constructed in burnt bricks with lime plaster. A coat of lime wash was applied to all walls every year. This white wash keeps the walls cool by reflecting solar radiation (see 3.20 above).

Each of the smaller houses is two storeys high and built around a courtyard. Only small windows open towards the street, and light and ventilation for all rooms is derived mainly from the courtyard. Ventilation openings are provided in each room near the floor and also near the ceiling. In many cases the wall facing the courtyard was nothing more than a series of doors which could be opened up completely, as and when required.

The larger houses were built around two (sometimes three) courtyards of different sizes. The rooms between the two courtyards were provided with collapsible timber shutters on both sides. These shutters were opened up during the summer days and the room would thus become a wind pavilion, with air flowing continuously from one
court to the other.

The roof thickness in most cases is about 45 cm which is much less than in Jaisalmer. The house stays cool during the daytime but in the evening it is warmer than the outside atmosphere. The courtyard (normally roofed over with a metal grating) is also not fully exposed to the cool sky and therefore most people sleep out on the terrace in greater comfort. Water is sprinkled on the terrace to make it cool down faster.

An interesting feature of the houses in Old Delhi is the "Saiwaan". This is a light structure (Fig. 26) with timber walls and galvanized iron sheet roof. Mostly this a later addition at the top of the main building. This light structure cools down rapidly after sunset and during the monsoon months when it is not possible to sleep outdoors, because of rain. the "Saiwaan" provides a comfortable sleeping area.

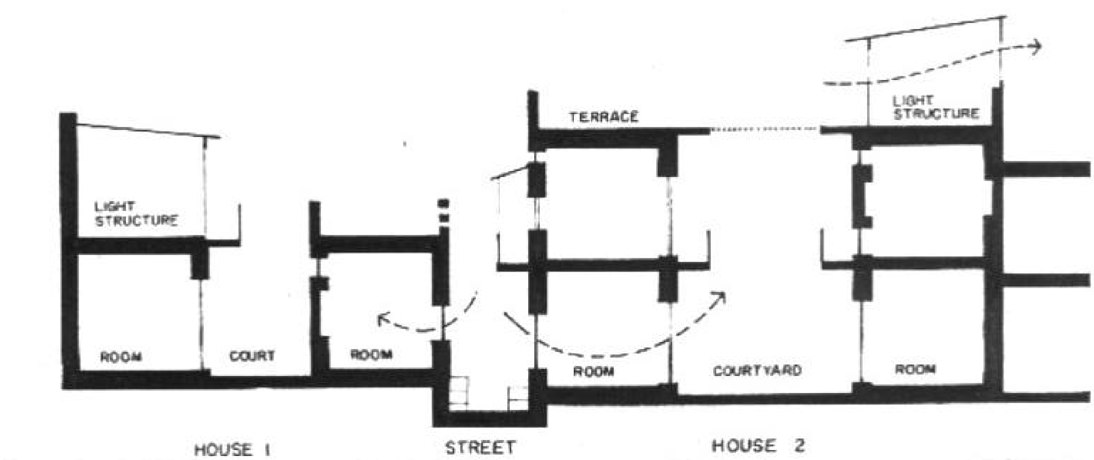

FIG. 26-TYPICAL SECTION THROUGH SHAHJAHANABAD HOUSE

The "Saiwaan" is made airy by the provision of large doors and windows.

During the extremely dry part of summer, additional cooling was provided with "Khas ki Tatti". These are screens made with a special grass, which were then hung outside the doors and windows and sprayed with water. With courtyard induced breeze, the evaporation of water from these screens brought down the temperature inside the room to a very comfortable level. Washing of floors is another method of evaporative cooling used commonly in Delhi even nowadays. Floors of verandahs and of courtyards are sprayed with water and then swept or mopped slowly to allow some of it to be absorbed by the flooring surface which acts as an absorbent material retaining some moisture which evaporates slowly thereby reducing the temperature in those areas.

Some houses in Old Delhi also have basements and unlike Jaisalmer, the basements in Old Delhi are lived in.
Thermal comfort was thus achieved in Old Delhi by use of narrow streets, a combination of light weight and heavy structures, reflective white wash on walls, small window openings, courtyards for solar induced ventilation and evaporative cooling.

4.30 Natural Ice Making

According to folklore, the King's throne in the Red Fort in Old Delhi was kept cool by keeping ice in a pool around it. This unsubstantiated story relates to the 17th century A.D. and makes one wonder how ice could have been manufactured in Old Delhi at that time.

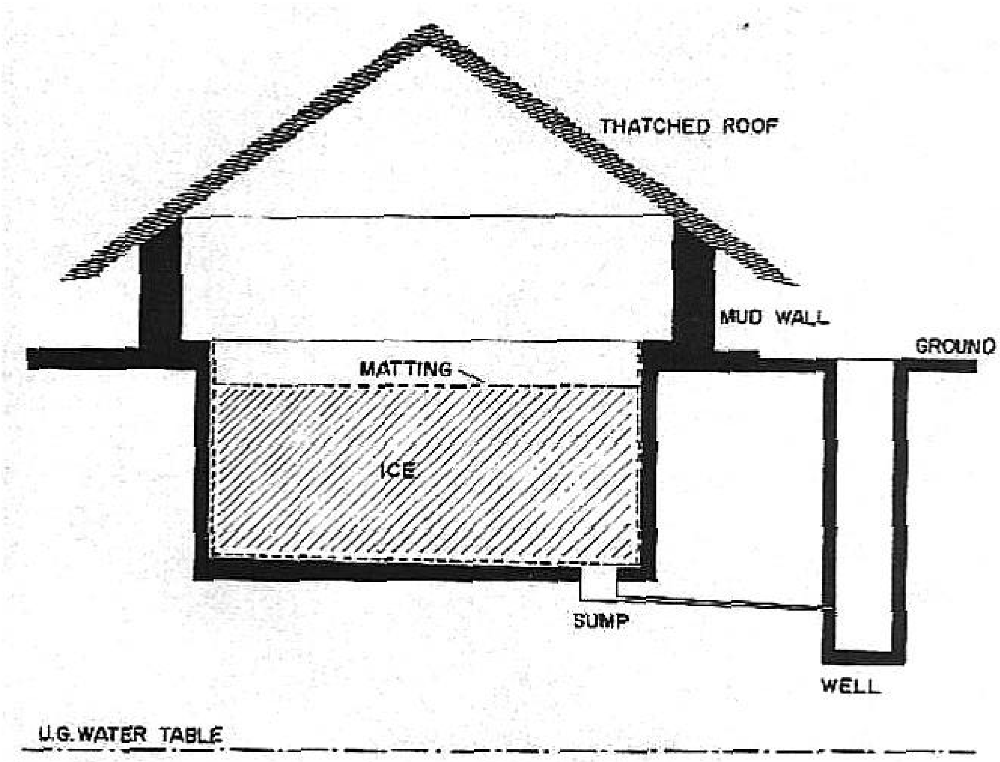

FIG. 27-ICE PIT (DELHI)

It is reported by several authors (Ref. 12) that during the 19th century, ice was manufactured in Old Delhi in winter and stored till the summer. The simple process involved cooling of water in a shallow metal pan at night by evaporation and by radiation to the night sky. The bottom of the pan was insulated by placing it upon a thick bed of blackish straw. The essential ambient conditions were, a clear sky, still atmosphere and air temperature less than 6 deg.C. A thin 4 cm. layer of ice would form by 3 a.m. with the right conditions and this ice was then stored (Fig. 27) in a large well-insulated pit. In the summer, small quantities of ice were taken out daily for distribution amongst the British officers. Ice manufactured during December to February was used during the summer months of May, June, July and August. Obviously this long storage was possible only because of the huge quantity of ice which was put in one pit.

Natural ice making was practiced in other towns in India as well. It was presumably discontinued when Delhi was linked by rail to Calcutta where American ice, used as ballast in ships, was off loaded. This ice was then transported to Delhi, Kanpur, Allahabad and other towns.

5.00 Conclusion

Many of the natural cooling methods described in this paper have been successfully utilised in traditional architecture in India. To a great extent the design of individual buildings depends upon the layout of the town and present day bye laws. New housing areas should be so planned that house builders can maximise the use of natural cooling methods.

The advent of electrical energy has raised the degree of thermal comfort in modern buildings to more than what was then acceptable in traditional buildings. If we have enough electrical energy available today to use air conditioners and make up the deficiency of building design and town planning, the advance can continue in the direction of total reliance on electrical energy. But there is no reason to believe that the source of this energy will be constantly abundant for ever. If the present trends of energy production and consumption continue, the day may not be far when we shall be compelled once again to look elsewhere.

We have to accept that the degree of comfort will continue to rise, and not remain at its present level in modern society. To reconcile this rise in demand with diminishing sources of energy is the task. To achieve more economical and better comfort standards than prevalent, the new scientific developments and available electrical energy have, in future, necessarily to be harnessed to traditional methods of design which are in harmony with nature.

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