You don't need airconditioners to cool your home

VINOD GUPTA

Traditional architecture does it well. Even rich families living in the heart of the desert cool their homes naturally

WHY CAN'T OUR buildings be better designed, so that one can be comfortable without airconditioners, desert coolers and fans? Why can't we design offices so that there is no need for electric lights during the day time at least?

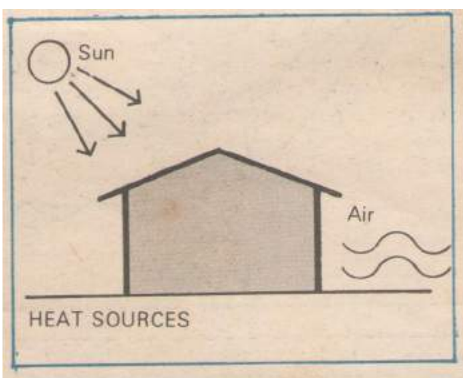
The primary purpose of buildings is to provide a sheltered and secure space for human activities. They are also to provide protection against the extremes of climate. Our traditional buildings serve these purposes in a variety of ways without using electricity. Under the present conditions it is all the more necessary that the modern buildings also provide this shelter with the least expenditure of energy. The reasons for the inability of modern architecture to provide a reasonable degree of thermal comfort are complex and only some of them are design-oriented. Others are related to changes in lifestyle and an increase in our expectancy of thermal comfort.

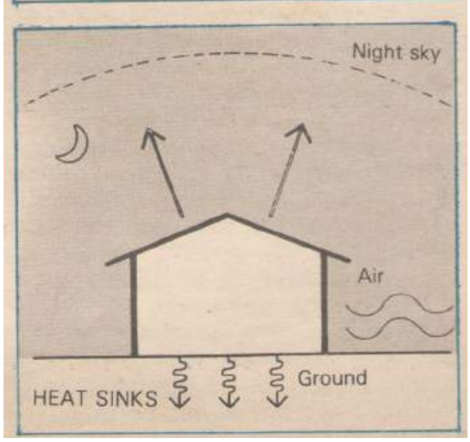
People within a building are surrounded by what we call "the internal environment". In airconditioned buildings, this internal environment is controlled but in other buildings it is influenced by the external environment and its effects on the outer surfaces of the building. These surfaces act as a filter between the external and internal environments. How well it works depends upon how it is constructed and how it is used.

Internal environment and thermal comfort

Contrary to popular belief it is not just the air temperature that determines personal comfort. The human body converts food into energy and produces a great deal of heat which cannot be used for bodily functions; this is called waste heat. A person lying down produces as much waste heat as a 100 Watt bulb, while a person engaged in strenuous exercise can produce the equivalent of a one-kW electric heater. The excess heat has to leave the body continuously and this can happen by convection from the skin to air, by radiation from skin to the surrounding surfaces and by evaporation to the air. The evaporative heat loss is a continuous process and it takes place on the skin as well as inside lungs.

Convective heat loss can take place only if the surrounding air is cooler than 31 ° C and radiative heat loss occurs when the surrounding surfaces are at an average temperature lower than 31 ° C. Evaporation proceeds irrespective of temperature so long as the air is not saturated with moisture; that is, the relative humidity is less than 100 per cent. The body loses heat by convection and evaporation to the air immediately in contact with the skin: we are enveloped by a layer of warm air. Unless this warm humid layer is removed by air circulation further heat loss from the body stops. For effective heat removal, therefore, four factors are important: low air temperature (less than 28O C); low surface temperature of walls, roof, floor, etc (also less than 28O C); humidity; and air movement. When the air and surface temperatures exceed these limits, cooling can still be ensured by low humidity and a higher rate of air circulation. Thus in dry conditions higher air temperatures are not as uncomfortable as in humid conditions.





Since outdoor conditions influence the conditions indoors, climatic adaptation of the building is important. In most of northern and central India summers are dry and there is a large difference between the day and night temperatures. When the monsoons arrive, the air temperature falls but relative humidity increases. In the coastal regions, summers are humid and the difference between day and night temperatures is less than 8O C Very different strategies are needed to tackle these two conditions: the hot and dry and the hot and humid summers.

Corresponding to the four environmental conditions that govern human comfort, there are four external environmental parameters: air temperature, relative humidity, solar insolation and wind.

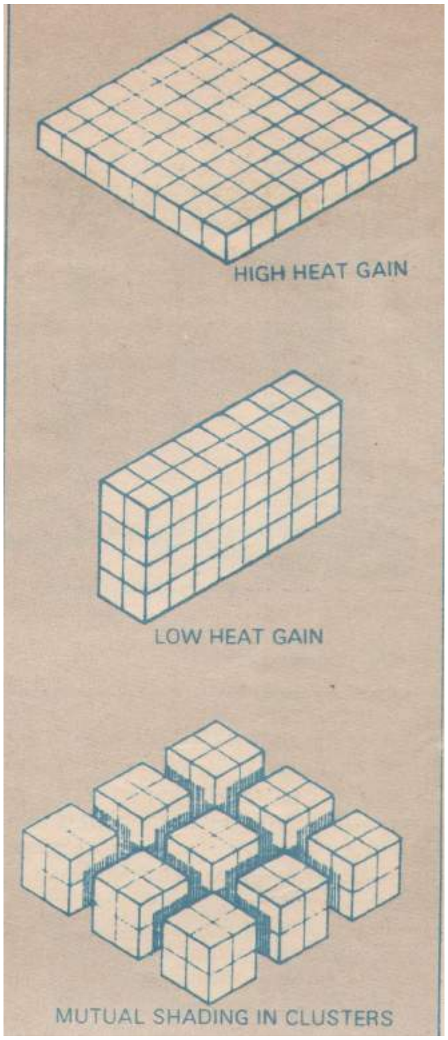
How buildings heat up

The opaque elements like walls and roofs, and the transparent elements like windows react differently; heat enters the building through both. Externally, there are two main sources of heat, the Sun and the wind. Under clear sky conditions up to 80 per cent of the solar radiation incident on a building can arrive from the direction of the Sun while the rest is reflected from dust in the atmosphere and from nearby buildings, trees and ground. This is diffuse radiation and its direction is not fixed. Under an overcast sky, nearly all the radiation is diffuse. The relative proportion of direct and diffuse radiation is important because shading against direct radiation is easier to organise than shading against diffuse radiation. Even seemingly shaded building surfaces are subject to diffuse radiation.

During the day, as air temperature rises, the external building surfaces begin to warm up. Solar radiation incident on an opaque surface raises its temperature above the air temperature. For white surfaces this elevation of surface temperature is minimum, but for dark surfaces it can be as much as 20O C. Gradually the heat seeps in through the wall or roof and some of it reaches the interior of the building. If the wall or roof is well insulated, less heat will reach the interior; in thick walls of heavy materials like brick or stone, heat takes a longer time to get there. Light-weight concrete, rock wool, fibre-glass blanket, thermocole and even thatch, are all in-Sulative materials while brick, concrete, stone are high-heat-capacity materials. A wall or roof made of a combination of an insulating material on the outside and a high-heat-capacity material on the inside can ensure a reduction in heat flow and a high time-lag.

Heat flow through glass windows is almost instantaneous. Solar radiation passes through ordinary glass almost totally and heats up the building interior. Even if the glass is shaded by louvres and sunshades, diffuse radiation will still pass through it. In addition to this, because of its thinness, has practically no insulation value and heat from the outside air is easily conducted into the building. Sealed double glazing, which has been introduced in the Indian market recently, has better insulation properties.

Hot outdoor air entering the buildings can heat up the interior. Air enters the building not only through open doors and windows but even through cracks between the frames and shutters when the doors and windows are closed.



Buildings also generate heat internally. People, machines, cooking, lighting and even fans and refrigerators add heat to the interior. Even if the building is perfectly insulated against outside conditions, the internally generated heat is enough to cause discomfort. It is therefore necessary to remove heat from the building.

How buildings cool

Just as outdoor factors can heat the building, they can also cool it. The principal cooling sources, called heat sinks, are the sky, the ground and the outdoor air. The building can be cooled by outdoor air whenever the air is cool, that is mainly at night. During the day, when the air is hot, the building can be cooled by evaporation of water on the external surface. But this is obviously not possible in humid areas. Atmospheric moisture reduces the radiant cooling of horizontal surfaces (roofs) exposed to the night sky and the only heat sink which is operative in humid conditions is the ground, which conducts heat away from the building. Because of its very large heat capacity, the ground heats up and cools down slowly and its temperature stays more or less even.

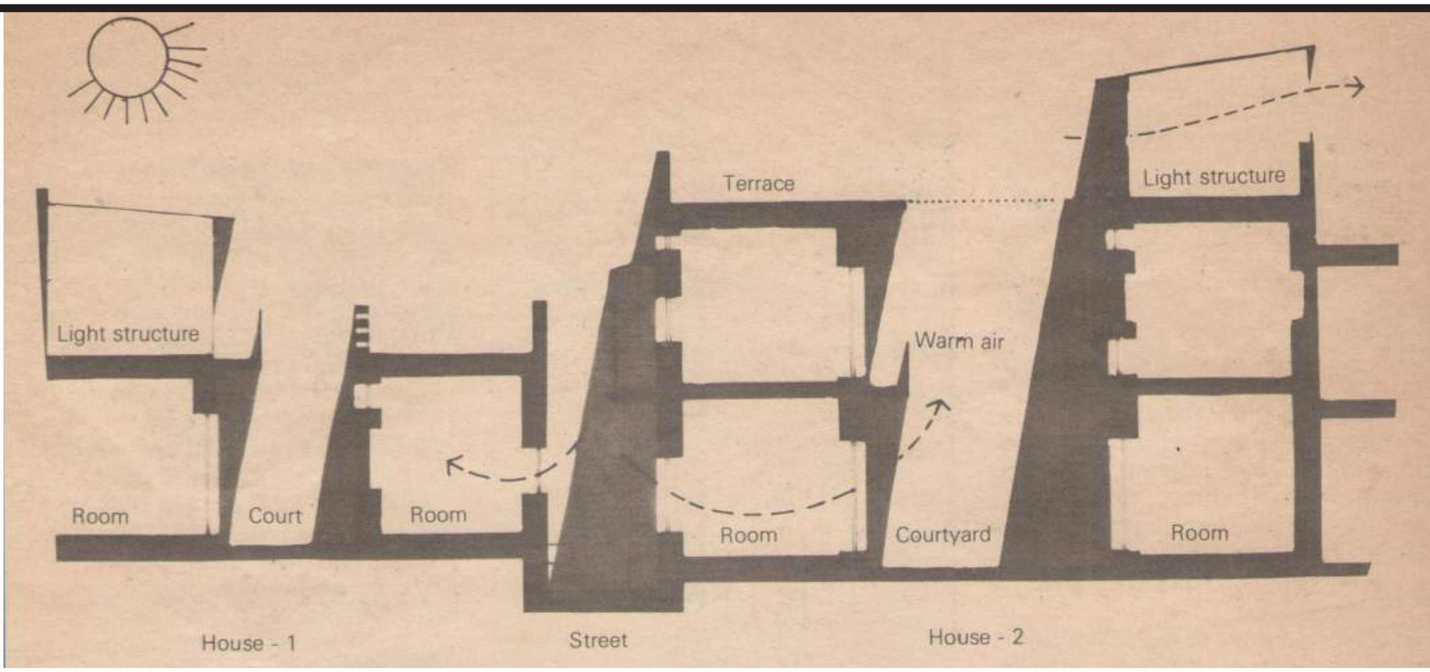
Naturally cooled buildings

There are of course some limitations on how cool the building can be and this depends upon the climate. A good indicator of the severity of the problem is the average daily outdoor air temperature in shade. The need for mechanical airconditioning can be totally eliminated if this temperature is 28O C or less and even in hotter weather tolerable thermal conditions can be achieved by good design by:

- minimising the solar heat load on the building through orientation, suitable building form, light coloured exteriors and sunshading devices for windows and roof;
- minimising the inward heat flow through walls and roofs by insulation and through windows by stopping ventilation during daytime;
- providing appropriate heat capacity in the structure — large in dry climates and small in humid climates;
- providing means for rapid heat loss from the interior of the building during the cooler hours of the day; and
- minimising the internal heat gain from machines, lighting, etc.

We can now discuss these in somewhat greater detail. Most of India lies between the latitudes 9 O N and 35 O N. Between these latitudes the surface that receives the maximum solar radiation in summer is the roof, followed by the east and west walls. The north and south walls are less exposed. Because all the five surfaces in a building (four walls and the roof) do not receive equal amount of solar heat, the overall building form should be such that it is least exposed to the Sun. This usually happens when the building has relatively longer north and south walls and shorter east and west walls. For single-storey buildings, the roof area is comparatively large; buildings with four or more floors are preferable to single-storey buildings.

Building clusters as opposed to single isolated buildings have the additional advantage that they can shade one another. This mutual shading can be used to maximum advantage when the streets between buildings are narrow and when buildings are built around courtyards. Of course this type of dense layout may not be most suitable for places where a high rate of



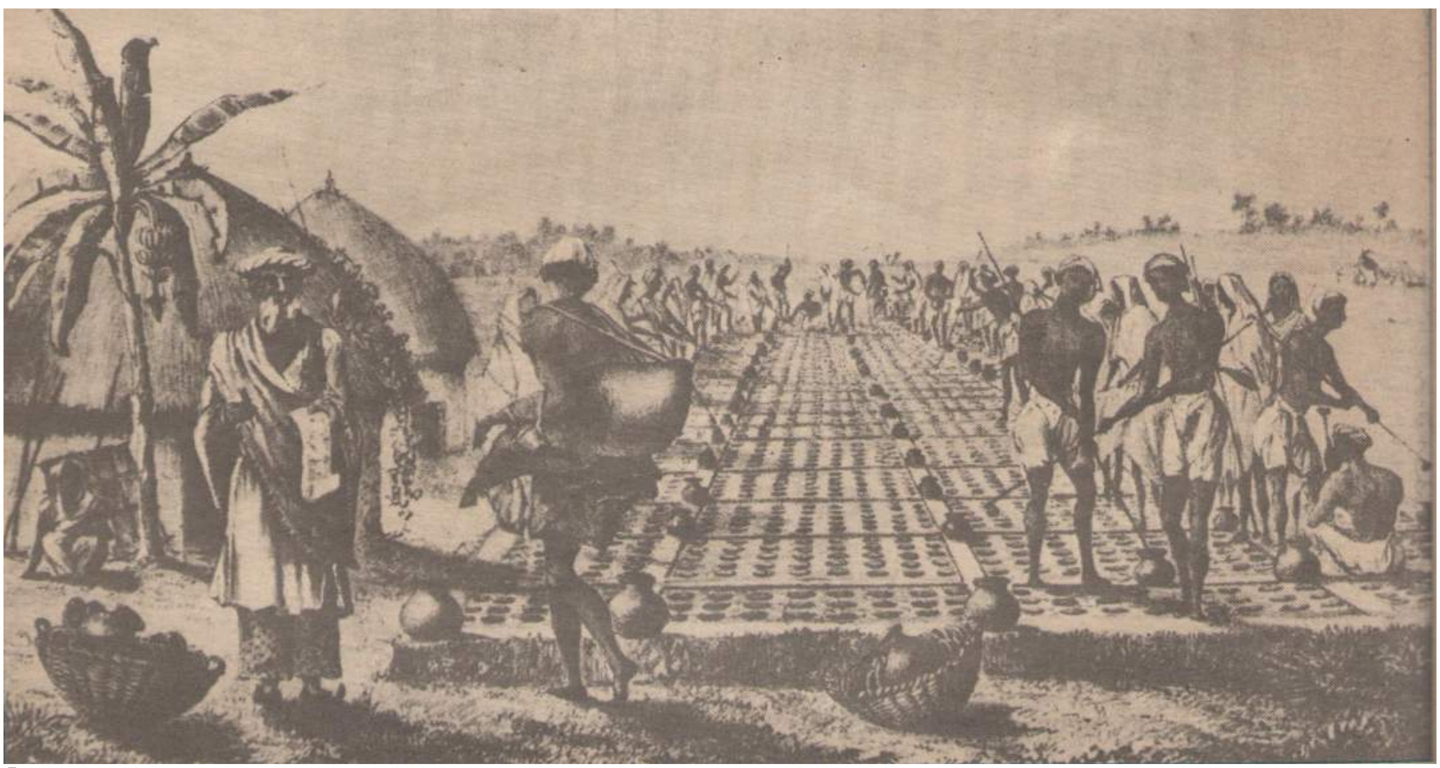
TYPICAL SECTION THROUGH SHAHJAHANABAD HOUSES (daytime)

natural ventilation is desirable. An individual builder has little control over any of these factors because building byelaws and town planning regulations decide the layout, the orientation, and even the building form. The only way out is to resort to other methods of solar radiation control.

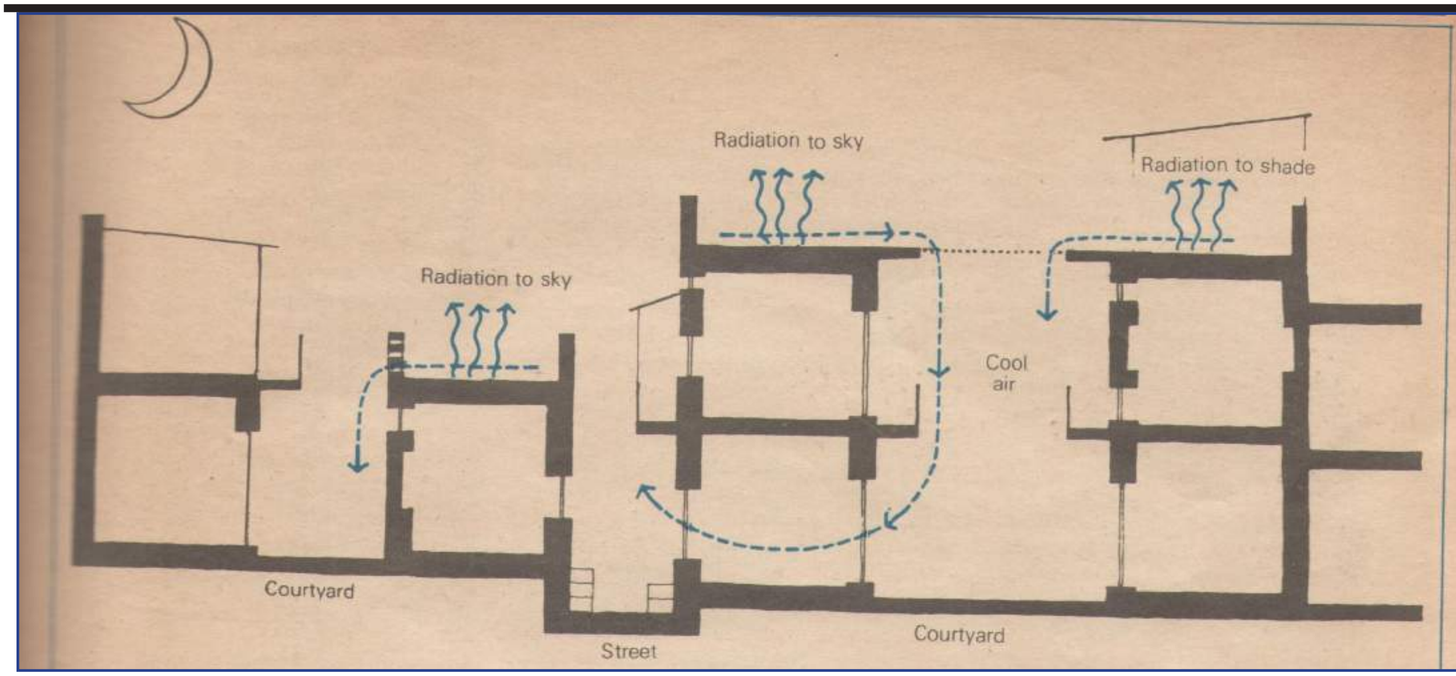
The fraction of solar heat absorbed by a building determines how much of it will reach indoors through the opaque surfaces of the building. White wash reflects 90 per cent of solar heat while a red brick surface can reflect no more than 30 per cent. A light coloured finish to the building exterior is therefore useful to keep out the heat. Painting the roof with a light colour is a problem because it gets dirty in no time. The best solution is to finish the roof with a layer of white glazed tiles. Shading the roof is even more effective but it is also more difficult to organise.

Shading windows is a must. This is done easily by having horizontal projections above the window on the south side and by vertical projections on the sides of north facing windows.

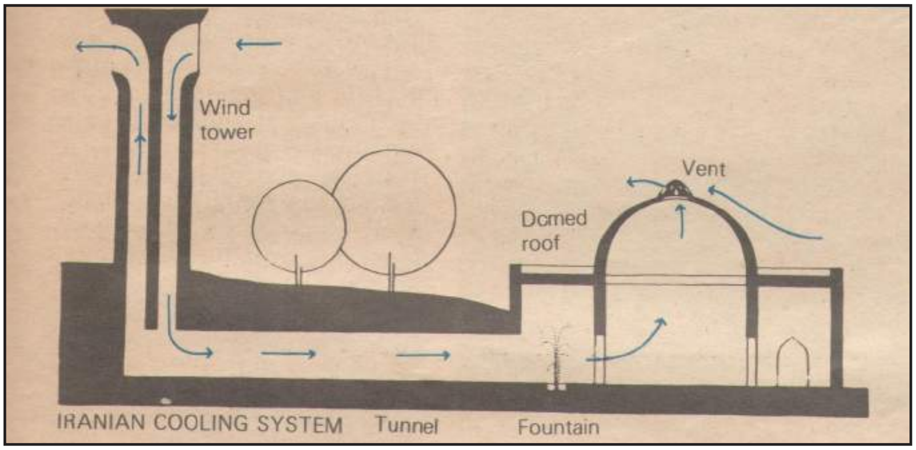
East and west facing windows are very difficult to shade because the 'Sun strikes them even from a low angle. Traditional methods like rolled down bamboo screens (chiks), louvred shutters of timber and fixed perforated terra-cota screens (jalis) are still the most effective methods. Curtains and other internal shades offer poorer protection than external shades. Because



Ice pits



TYPICAL SECTION THROUGH SHAHJAHANABAD HOUSES (night time)



ones, do not prevent heat from getting into the building. The best internal shades are again those which are highly reflective, which means they should be light coloured. Insulating the walls prevents heat-gain in the interior. For structural reasons, byelaws prescribe 23 cm as the minimum thickness of external walls, but in multistorey buildings, where structural supports are provided by concrete beams and columns, the walls are only 12 cm thick. In such cases, additional insulation can be provided externally by lightweight concrete blocks, or on the inside by panels of any insulating material. Cavity walls constructed with two layers of brickwork separated by a 5 cm — wide air-gap provide effective insulation, but they are difficult to construct. But wherever they are used, their effectiveness can be further improved by ventilating the cavity through holes left at the bottom and top of the wall. Such holes must be screened with fine wire-mesh to keep out insects and birds.

Insulating the roof is even more important than insulating the walls. The traditional method of embedding small earthen pitchers in the roof material is both cheap and effective. Modern materials like foam concrete or polyurethane foam are easier to install and more reliable. The absence of roof insulation is one of the most serious design deficiencies of modern construction. Ironically, this has been made possible by improvements in the strength of structural materials, which enable construction of roofs only 10 cm thick.

But insulation is a double-edged weapon: while it keeps outside heat out during daytime, it also interferes with the cooling of the building at night. The best insulation therefore is that which can be removed at night to permit heat to flow out of the building freely. This can be achieved by special types of constructions such as hinged or sliding insulating panels on the roof.

Ventilation control is more of an operational problem than a design problem. To prevent hot air from entering the building, windows must be shut during the day and kept open at night, to allow cooling. While this is

The greenhouse effect

BECAUSE GLASS lets in light and enables us to see the view outside, its use has been on the increase. It has the peculiar property of being transparent to solar radiation but opaque to the thermal radiation emitted by objects at room temperature. Thus the radiant heat flow through glass is. only one way and it acts as a heat trap. In cold regions, glass is used for building greenhouses because it can ensure high internal temperatures. The “greenhouse effect” which is beneficial in cold climates is most unwelcome in hot climates. New types of glass can transmit less solar radiation either because the outer surface is made reflective or because it is made absorptive. Tinted glass which falls in the latter category is” less effective than the mirrorised glass of the reflective type. The same effect can also be achieved by applying specially coated plastic films to the glass.

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Natural ice-making — the power of radiant cooling

ACCORDING TO folklore, the king's throne in the Red Fort in Delhi was kept cool by keeping ice in a pool around it. If this story is true, one wonders how ice could have been manufactured in Delhi in 17th century AD.

Fanny Parks provides a clue to this mystery in "Wanderings of a Pilgrim in Search of the Picturesque. Accor-ding to her, in the 19th century ice was manufactured in Delhi in winter and stored till the summer. The simple process involved cooling water in a shallow metal pan at night by evaporation and by radiation. The bottom of the pan was insulated from the ground 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°C. With the right condi-tions, a 4 cm-thick layer of ice could form by about 3 am and this was then stored in a large, well- insulated pit. Ice manufactured during December to February was distributed daily to the British officers in May, June, July and August. This long storage period was possible only because of the huge quantity of ice which was put in one pit.

Natural ice-making was practised 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 offloaded. This ice was then transported to Delhi, Kanpur, Allahabad and other towns.

Compared to these smallscale ice-making efforts in India, Iranians had very large natural ice-making plants. They made shallow ponds and pro-tected them from the Sun and wind by erecting very tall walls on their south side. During winter nights when the sky was clear and cloudless, the ponds were filled with water which was left to freeze. The ice made in the ponds during the night was cut into pieces the next day and transferred to the deep underground storage pit for use the next summer. The opera-tion of these natural ice-makers has been stopped because of health reasons, but many of these massive structures still exist in Iran.

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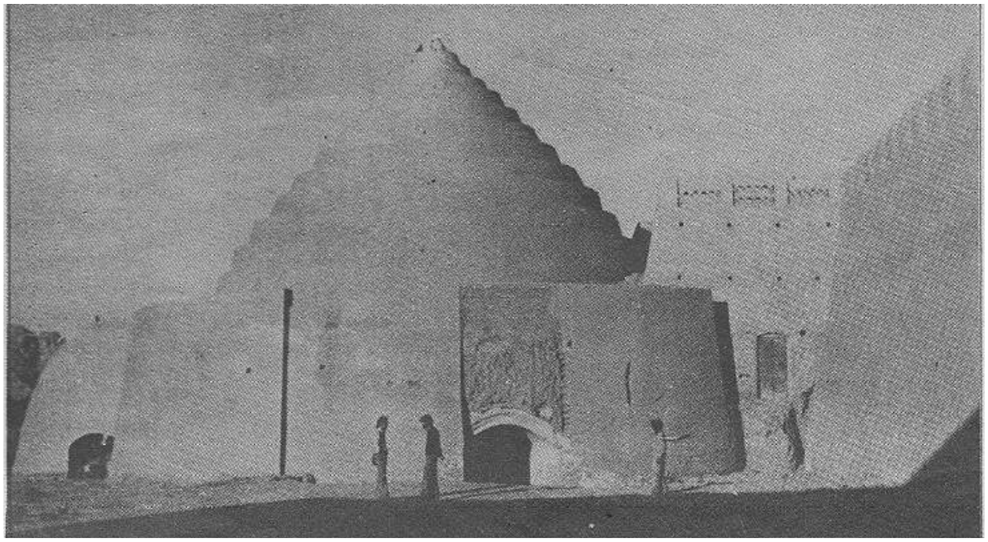


The storage pit and walls of a neutral ice maker in Kerman.

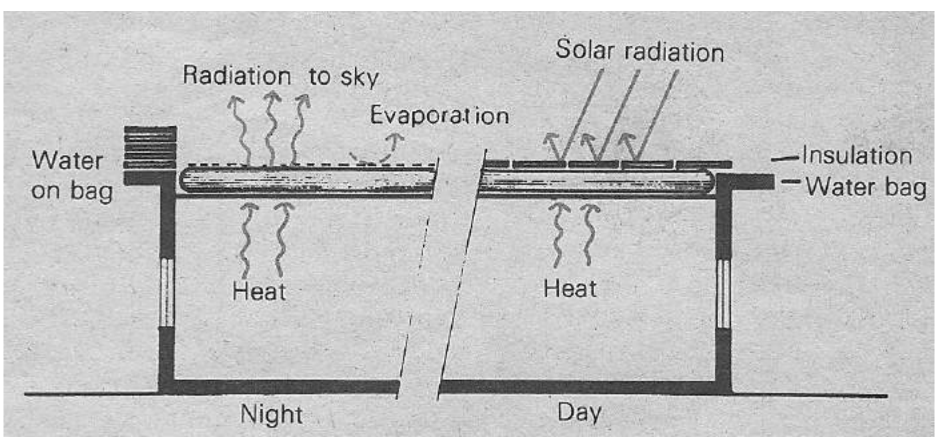
simple enough to organise in a house, it creates problems of security and management in offices, educational buildings, etc, unless special types of windows with hinged slats of glass, metal or timber are used.

Traditional construction combines many of these ideas into a single design concept. A courtyard house of northern India is an example of this. The building is protected against solar radiation by other buildings around it. Uneven heating of the courtyard and street causes thermal air currents to be set up, which ventilate the house. At night, the radiative cooling of roof surface causes the air immediately in contact with the roof to cool down. This cooler and heavier air flows down and cools the house. During. the day, the outdoor air is hot and therefore lighter and it cannot displace the cooler and denser air in the building.

The people of Iran have used wind towers and underground tunnels for cooling buildings. The tall towers (more than 30 m high) can catch dust free wind from higher levels, and bring it down into the house. Sometimes the wind is drawn through a tunnel which cools it, and through a fountain which further cools and humidifies it. In all cases, the tower walls are very thick and have a large heat capacity. These walls absorb heat during the hot day and warm the uncomfortably cold nighttime air.

Landscaping of open spaces around buildings plays an important part in keeping buildings cool. The Mughal gardens found in many places in India and in other countries cool the air around buildings by evaporation of water from plants, trees, grass, fountains and water cascades. The Red Fort in Delhi has a highly developed system of waterways and fountains not only in the gardens but in the buildings as well. The Amber Fort near Jaipur combines garden courts with wind effects for cooling. For special occasions, this fort even has a "floating" pleasure garden.

By now one might think that it is alright for the nawabs to build fine palaces but how does modern science and technology enable a common man to build a comfortable house? So far as scientific principles of good building design are concerned, our fore-fathers displayed a better grasp and appreciation of these than we do day. The major technological developments however enable us today to



SKYTHERM COOLING

Use a wide variety of materials which can do more with less. Electricity has enabled us to extract a better perfor--mance from the traditional systems. Computer simulation techniques enable us to predict the behaviour of diverse buildings built with new materials and therefore help to design better. There have been a few com-pletely new developments as well (not including the conventional aircondi-tioning) which are worth looking at.

The first of these, called the Sky-therm system, was originally developed in India by an American scientist. In its basic version, the system depends upon allowing the building roof to night by sky radiation and water evaporation and then to insulate it against solar heat gain the next day. By providing adequate heat capacity in the roof it is possible to store sufficient "coolth" in it and keep the building cool throughout the day. Although a thick concrete or earth roof will give adequate heat capacity the best results are obtained with a thin metal roof and a 15 cm thick water bag above it. For insulation, sliding shutters of foam plastic are us-ed during the day. These shutters can be moved twice a day manually or with automatic mechanical systems. For single-storey buildings, this system can provide good thermal comfort where night skies are clear.

A method that promises to be useful in humid regions, where evaporative cooling does not work, is "dessiccant cooling". Essentially, this involves drying of the humid outside air by passing it through a water ab-sorbent material and then cooling the air by water evaporation. The difficulty is of drying the spent sorbent material for re-use. This problem was solved in the experimental Altenkirch House in Israel in the fifties by use of solar energy. This building was oriented with its long axis along the north-south direc-tion. The long hollow east and west walls were filled with a sorbent material which allowed airflow through it. Evaporative 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. During the forenoon, the Sun shone on the east wall and the humid outdoor air would first dry by circulation through the west wall, cool in the evaporator, pass through the living space and exit through the east wall, carrying away moisture from the Sun-heated sorbent material. During afternoons the air flow was reversed so that air was dried by the sorbent in the east wall, cooled by the evaporator and then it passed through the Sun-heated west wall regenerating the sorbent in the process. It was thus possible to regenerate the dessiccant material without any external heat source. Further development of dessiccant materials is required before such systems can become commercially available.

No single cooling method is adequate in dealing with real-life situations because buildings have many other functional and aesthetic requirements. A few examples of some modern buildings will help illustrate the possible design alternatives. Take for example, the Delhi hostel. Here the need is not only summer cooling but also winter heating. Summers in Delhi are very dry but they are follow-ed by the monsoon when it is hot and humid. To reduce the solar heat load on this building it is constructed as a two-storeyed long block facing north-south directions. All windows have been shaded to eliminate direct sunlight in summer and the roof is to be shaded with a cover of vegetation. The building exterior is to be painted white and the roof finished with white glazed tiles. A special cavity wall has been provided on the east and west faces. The lower floor of the building is designed as a semi-basement for bet-ter earth contact and cooling. A sprinkler system is to be installed on the rooftop for evaporative cooling.

Special openings have been provided on the north-side of the building (the daytime summer winds come from the north) with a system of wet grass mats to humidify the living space in summer. One additional feature is the introduction of solid timber window shutters behind the glass. These shutters will reduce daytime heat gain in summer and nighttime heat loss in winter. With these special design features it is expected that the building will stay comfortably cool through summer and monsoons.

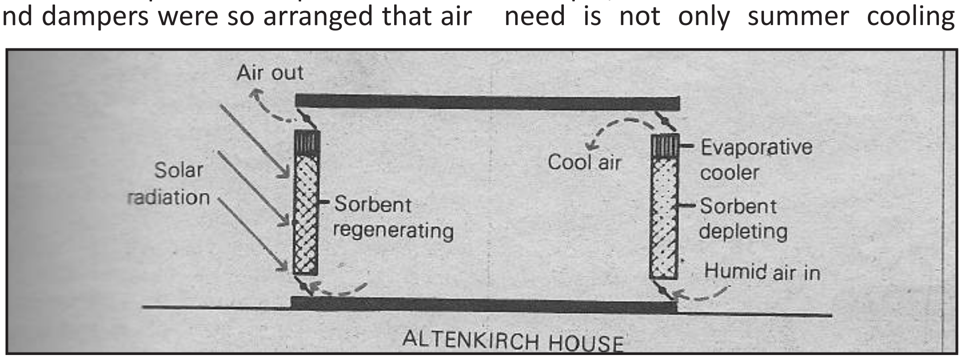
A building with similar requirements for Jodhpur has a completely different design. Winter heating is less of a problem in Jodhpur than in Delhi and Jodhpur has stronger winds. Evaporative cooling can be used only on a small scale because of the shortage of water. This building has been designed around a courtyard and it also faces the north-south direction.

Living in flats

APARTMENTS IN multistorey buildings are becoming the most common type of dwelling in con-gested cities. As a building form, the multistorey block is suited to avoiding excessive solar heat gain provided the building is properly oriented with respect to the Sun and the windows are well shaded. But there are difficulties in keeping them at comfortable temperatures. These buildings are unable to utilise the heat sinks effectively. All flats in tall buildings cannot make use of night sky radiation and Earth contact and therefore the only operative heat sink is the air outside. Such buildings must then be designed to make the maximum use of available winds, particularly in the cooler time of the day.

In the coastal regions, a land-to-sea night breeze is available but in areas deeper inland, the days are more windy than the nights. Day winds are hot and they can be allowed to enter the building only after pretreatment. This can be done by in-stalling porous grass mats kept wet, on the windward-side windows; in tall buildings this can eliminate the use of fans or pumps. If the building had a high enough heat capacity, it will feel cool even at night. In the hot humid coastal areas, in case wind cannot generate sufficient air flow through the building, it is a good idea to in-stall an exhaust fan to suck outdoor air into the building.

In all cases, some improvement in thermal conditions is possible by ensuring adequate external sunshading (non internal curtains or blinds) by us-ing reflective films on the windows, by painting the exterior in a light col-our and by making sure that the kit-chen is ventilated to the outside so that heat from cooking does not find its way into the living space. VG



Solar airconditioning

OF ALL the uses of solar energy, the one which sounds most tantalising is solar airconditioning. This is because unlike many other applications of solar energy, solar airconditioning is needed most when there is plenty of solar radiation available.

In a normal airconditioning plant a gas is first liquefied by compressing it, using electricity as fuel, and then the liquid is evaporated, causing cooling of the evaporator coils from which it absorbs its latent heat of evaporation.

A solar airconditioning plant uses the "vapour absorption" system. In this a gas like ammonia, which gets readily absorbed in water, is used. During the absorption process, the water gets cooled and can in turn be used for cooling air. After all the ammonia has been absorbed, the water-ammonia liquid is separated by heating it with solar energy which causes the gas to be driven out of the water. The absorption cycle can then be repeated again to get the desired cooling. The solar energy is collected through the use of flat-plate solar collectors which can be mounted either on the roof of a building or on the ground.

Calculations show that in places like Delhi or Hyderabad, with the present state of this technology, the area of solar collectors required is 1.0 to 1.5 times the floor area of the building to be airconditioned. Also, a standby airconditioning plant is xequired for hot and cloudy weather. Because of these limitations, solar airconditioning cannot be used in multistorey buildings. The necessary roof area will not be available in these.

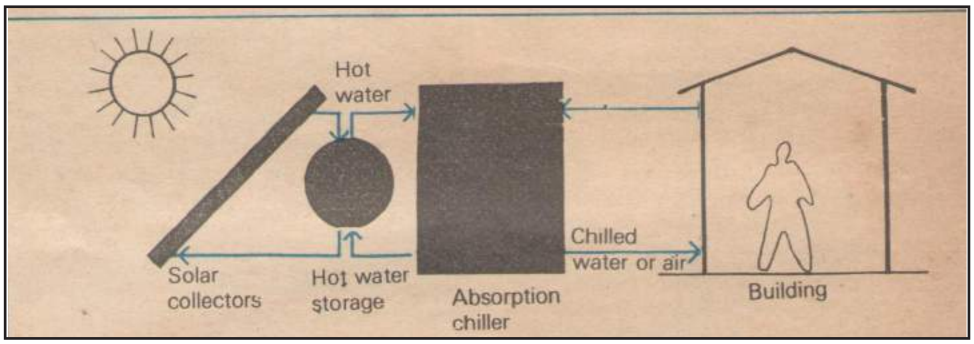
An alternative is to delink the energy collection system from the building. This can be done by the use of a solar energy biomass biogas system. Biomass or plant matter can be grown in any place, stored and then used to generate biogas which can be burnt for regenerating the working fluid in the vapour absorption system. Such a system will be more reliable and use up less land area for energy collection than a flat plate collector because plants can collect energy throughout the year and this energy can be easily stored for use.

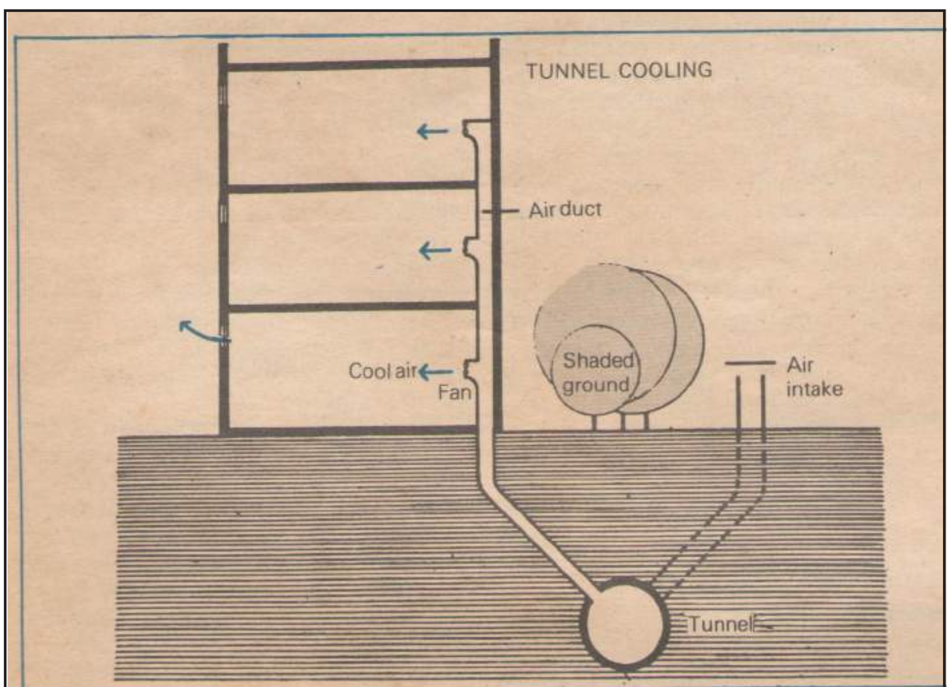
Solar airconditioning systems are at the experimental stage in India but they have been successfully used in Japan and the USA. **VG**

The building layout is such that only toilets and kitchenettes come on the east and west sides which are prone to overheating.

As in the Delhi hostel, the lower floor is a semi-basement and all windows have been protected with proper sunshades. The roof is thick and massive to provide the necessary insulation and heat capacity. The major cooling system is a tall wind tower which brings air into all the rooms in the building. Because of massive walls with a large heat capacity, the tower cools the wind before it enters the building, further air-cooling being provided by a simple evaporative cooling system in the tower. Tall kitchen flues facing away from the wind direction help induce a draught in the building. The windows in this building are designed for light and view-but not for ventilation which is ensured by the tower. This separation of ventilation and lighting enables the use of winds from the otherwise unfavourable south-west direction.

These two are single, isolated buildings, but how does one deal with a large complex of buildings. A design for a computer research centre in





Hyderabad with its diverse needs required several different natural cooling strategies. There were laboratories and offices for day use, hostel bedrooms for night use and computer rooms for day and night use. In this case, the climate demands no heating at all in winter and, for a low building, orientation assumes secondary importance. Cooling is needed for the dry summer and for the humid monsoon season.

The basic strategy for the office and laboratory areas was to organise them around large courtyards with plenty of vegetation and water. Outside the building, earth was piled up high against the walls to reduce heat gain and to promote cooling by conduction. The roof was shaded with a vegetation cover and, as in the case of Delhi hostel, a sprinkler system provided for roof surface evaporative cooling. All windows were shaded

Traditional buildings and natural cooling

ONE OF the best examples of Climate-adapted architecture and town planning in the hot arid zone in India is Jaisalmer— the Rajasthan town from the 13th century, famous for its richly carved "havelis". In this part of the Thar desert day temperatures in June reach up to 50 O C and have been known to drop below freezing point in winter. The normal rainfall during the year is 120 to 150 mm, but in some wears there is no rain at all. During the summer months of May, June and July, the town is hit by sandstorms. The climate demands protection from the scorching summer sun and sandstorms on the one hand and the freezing winter nights on the other. Humidity being low throughout the year, comfort could be easily provided by evaporative cooling, provided water could be had, but water is scarce in summer.

Planning for the summer started with the layout of the town itself. The streets are narrow and buildings shade one another from the Sun. They are oriented in such a way that they do not come In the way of the hot and dusty summer winds. The contiguous construction of buildings ensures mutual shading of walls.

The main building material used for walls is yellowish limestone which is a good reflector of sunlight. Roofs are built of mud, supported on wooden beams and covered with a grass mat. The total thickness of roofs varies from 45 to 60 cm, enough to dampen the effect of the very large temperature changes from day to night. The wall surfaces are highly articulated with projecting balconies, sunshades and brackets and each of these building elements is in turn intricately carved. Flat portions of walls are also decorated with deep carvings. The resulting overall building surface is designed to shade itself against the Sun and thus stay cool.

Each house, whether single-storey or multistorey, is arranged around a courtyard. Usually a small basement is also there, but it is not ventilated and therefore used only as a storehouse. The main living areas in the house are the courtyard and verandah around it.

The most interesting and comfortable buildings are the "havelis" 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 ventilation shafts provided at appropriate locations.

How does such a system ensure summer comfort? First of all, each

Yellow limestone is a good reflector of sunligjht

Buildings shade one another across narrow streets

building has very little wall area exposed to the Sun. The main heat load is from the roof and that is well insulated. The massive structure warms up very slowly so that a near constant temperature is maintained within the buildings. Since ventilation by hot air is not desirable, courtyards ensure air flow through the building only when the outdoor air is cool. Before the air enters the building it passes through the narrow streets or air ducts and gets cooled down. Courtyards also cooled air into the help bring building at night from the radiantly cooled rooftops.

The total effect of the massive structure, the sunshades and the ventilation system is such that during day time the indoor air temperature is IOOC less than outdoors. Even rich families in Jaisalmer have not found it necessary to install ceiling fans in their houses, even though electricity is now available.

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Courtyards bring cooled air into the building

Building types and their responses

DIFFERENT TYPES of buildings respond differently to the natural heat sinks and sources. A look at some of the more extreme architectural types will help illustrate these responses. Many factory buildings and even some homes are built like tin boxes, that is their external walls and roofs are extremely thin with hardly any insulation or heat capacity. Such buildings heat and cool very quickly because of their low heat capacity. When the Sun shines on such buildings their surfaces become much hotter than the outside air and the solar heat passes indoors, raising the internal air temperature as well as the mean radiant temperature. During the day, such tin boxes become more uncomfortable than the outdoors, but at night they cool down easily and the indoor temperatures are less than outdoors. Only buildings, or parts of buildings which are used exclusively at night should be made like this.

A contrast to the tinbox building is a large thermos bottle. This has lightweight construction with no heat capacity but extremely good insulation. Such a structure is capable of keeping the outdoor heat out and indoor heat in and can be comfortable if no solar heat enters through the windows and no heat is generated indoors—an improbable situation. Consider what happens when a thick building made of heavy materials is subjected to fluctuating outdoor conditions. In contrast to the tin box or the thermos bottle, actual temperatures inside a heavy building will be less severe than the outdoor temperature because the material will slowly store heat during the day and release it slowly to both the inside and the outside of the building at night. In extreme examples like the Egyptian pyramids or caves, not only does the temperature remain more or less constant during the day but it can also be constant throughout the year. In the hot dry conditions of northern. India heavy buildings are built traditionally because they alone can provide comfort in such a climate.

Heavy buildings are not needed or even useful in all climates. In the high humidity conditions of the coastal regions or during the monsoon even in otherwise dry areas of north and central India, the temperature difference between night and day is not very much and the flywheel effect of massive construction is not needed. Because of the presence of atmospheric moisture the night sky heat sink is not operative. The only cooling possible is by air movement across the body of the building occupants. This calls for a building with a well-designed roof for maximum shade and no walls at all— essentially a chicken coop. This has the potential of maximising the beneficial effect of wind and minimising the effect of solar heat.

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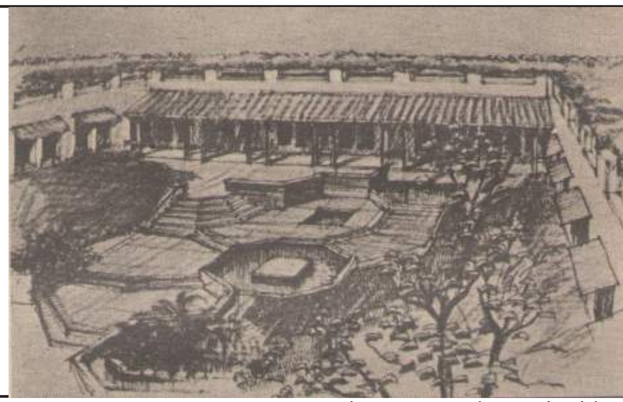
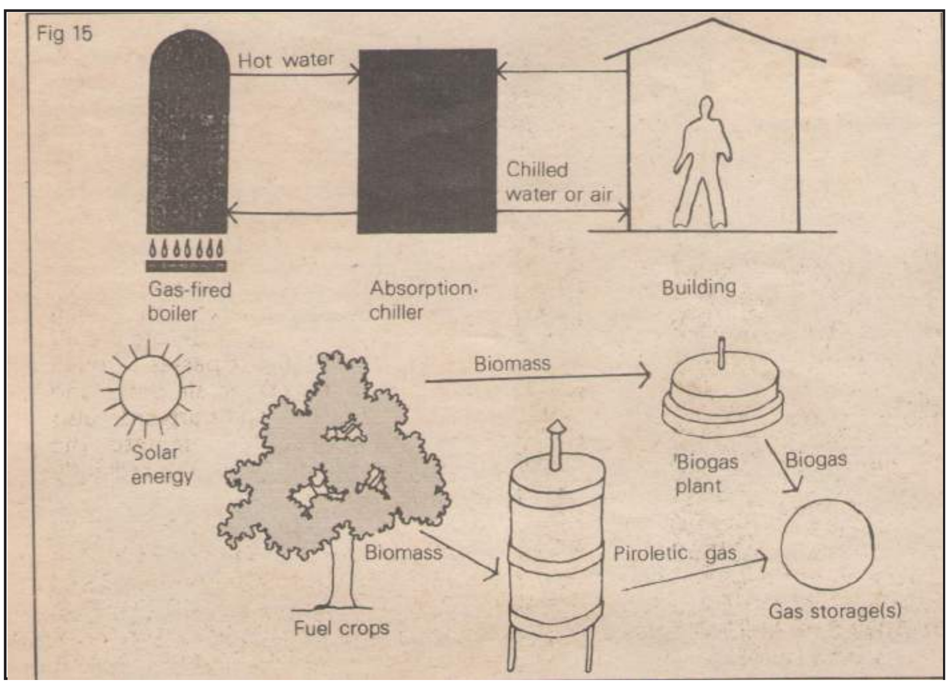
against direct sunshine. A solar air-conditioning system (see box p 24)based upon biomass grown on the site was proposed for cooling the computer rooms where natural cooling would not be adequate.

The trainees hostel was designed with a day-use space of massive construction and bedrooms for night use with very light terra-cota tile roofing and timber walls. The bedrooms were ventilated with very large windows of adjustable timber slats which could be closed up during the day and opened

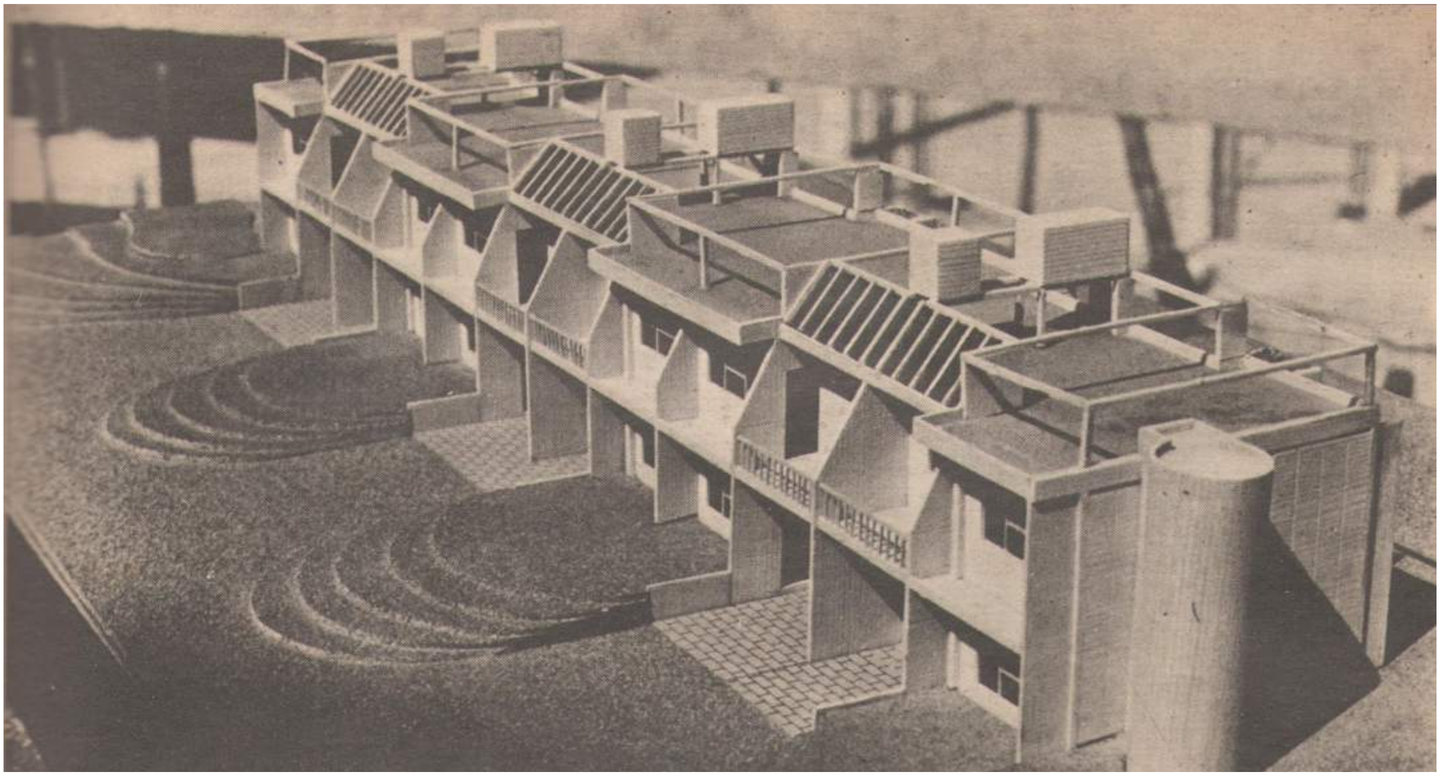


The projected CMC building in Hyderabad



out at night. In some of the Other spaces for casual use, a double-tile roof with water circulation on the lower layer of tiles was proposed. The upper layer of tiles, in this case, shades the lower layer and conserves water.

Another building worth mentioning here is a hospital designed and built by American missionaries in Mathura. While some of the design features, such as large inadequately shaded windows and the use of red brick for external finish, are questionable, the basic cooling system is very interesting. The hospital is spread over a large area and buildings are two or three storeys high. A network of underground tunnels connects all the buildings. Fresh air is drawn through the tunnels where it gets cooled and then supplied to all rooms in the hospital. This system not only provides summer cooling but winter heating as well. It points the way to a method

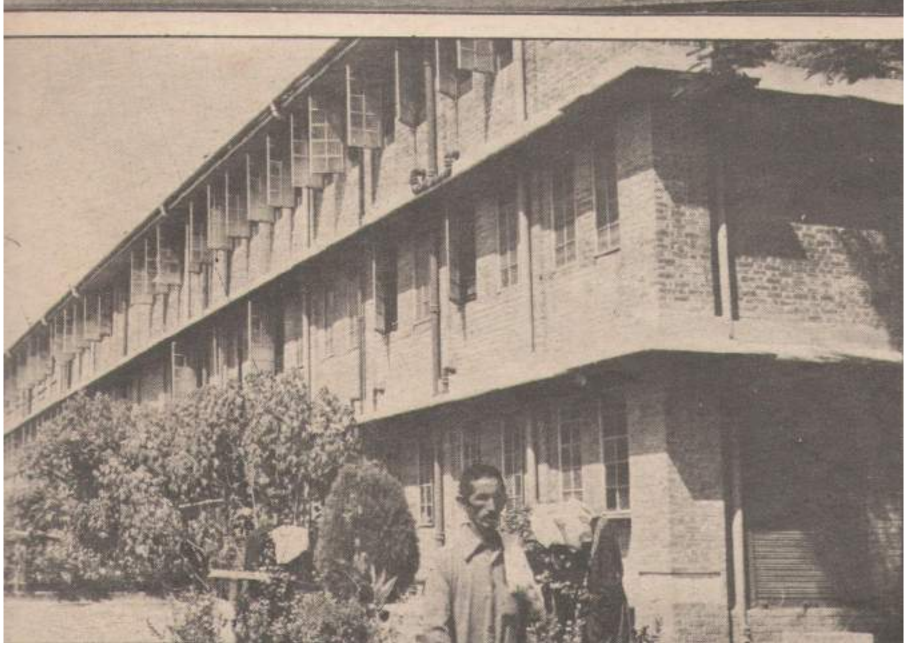


The Delhi hostel

The Jodhpur hostel

that can be useful in multistorey buildings even in hot humid climates where evaporative cooling does not work. Unfortunately, the system has not been used because of periodic flooding of tunnels and the security problems in that area. Recent commissioning of one test section of the tunnel provided air in the rooms at 27 ° C—a comfortable temperature.

How effective are these cooling measures? Three of the buildings described have not yet been constructed but the first two have been extensively studied with the help of computers. The indications are that they will be substantially more comfortable than other similar normally constructed buildings. A word of caution may be added here. In extremely hot climates, natural cooling should not be confused with mechanical airconditioning as we know it. After all one does not compare a train (which can be used by everyone) to a jumbo-jet (which is accessible to few people only) even though both will take us places.



The Mathura hospital

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