

Climatic Responsive Energy Efficient Passive Techniques in Buildings

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The energy conscious traditional Indian way of life and architecture evolved out of the great timeless vedic philosophies, and hence, it was immutably appropriate to the very essence of life based on human knowledge, wisdom and vision of nature-man interaction. Thus, architecture in its nature based manifestations, and appropriateness, integrated to the life, has been most assiduously cultivated in India through ages. The energy conscious architectural heritage, thus, reached its pinnacle of perfection due to the sound principles embedded in man-nature spiritual and moral Indian values and honest dedication to the spatio-temporal creations. The ever alarming cost of energy in buildings enforces a statutory demand of energy conservation passive design techniques in buildings. Modern buildings reveal inadequate thermal performance and require mechanical devices to bring thermal comfort.

Keywords: Energy conservation measures; Passive techniques; Evaporative cooling

INTRODUCTION

The idea of using solar energy to heat and cool our buildings is not new. For centuries man has made use of sun's energy. In early days sun was used to temper the indoor climates. The earth's climate is dependent on solar energy. Earlier, man was aware of the advantages of finding a cave or placing wall openings in the direction of the sun's path to capture its warmth during winter days and the unique ability of certain materials to retain sun's warmth and release it later after the sun had set. Therefore, the designs, materials and orientation that exploited the natural energy flows around the inhabitants were chosen. Basic form and material were carefully refined to introduce solar heat or to keep out the sun as per requirement.

Man continually explored new avenues of harnessing solar energy for the service of mankind. It is only during the recent times that these essential principles of design set forth in the rich heritage of ancient architecture have been neglected. Despite the increased sophistication and reliability of solar powered devices, none of the early applications of solar energy survived competition with the emerging use of cheaper fossil fuels. Although solar energy was free and readily available, the capital investment was very high.

In recent years, interest in making use of energy from the sun has accelerated enormously. This problem is: how to convert the energy at reasonable cost into a reliable usable form for heating and cooling of buildings.

NEED FOR PASSIVE DESIGN

India has different climatic conditions ranging from extremely hot conditions to severely cold conditions. Energy

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availability is scarce and people have to protect themselves from these extremities of the climate in a natural way. Traditional architecture exhibits variety of building design suited to the respective climatic conditions. The month wise climatic data available for 233 stations spread over the whole country has been analysed by the CBRI, Roorkee. The various climatic zones thus determined have been delineated on the map of the country. The various stations have been categorised under one or the other climatic zone if their climate conformed for six or more months, otherwise it is placed under the 'composite' zone.

PASSIVE TECHNIQUES AND FEATURES

The first step to achieve passive cooling in a building is to reduce unnecessary thermal loads that might enter it. Usually, there are two types of thermal loads

- (1) Exterior loads due to the climate.

Table 1 Basic cooling strategies

Minimize External Load Due to Climate	Minimize Internal Heat Load	Removal of Heat	Provision of Additional Cooling
Reduction of penetration of direct sun	Reduction of casual gains	Ventilation	Earth contact buildings
Reduction of conduction of heat through walls/roofs			Evaporative cooling
Reduction of infiltration of outside hot air			Radiative cooling

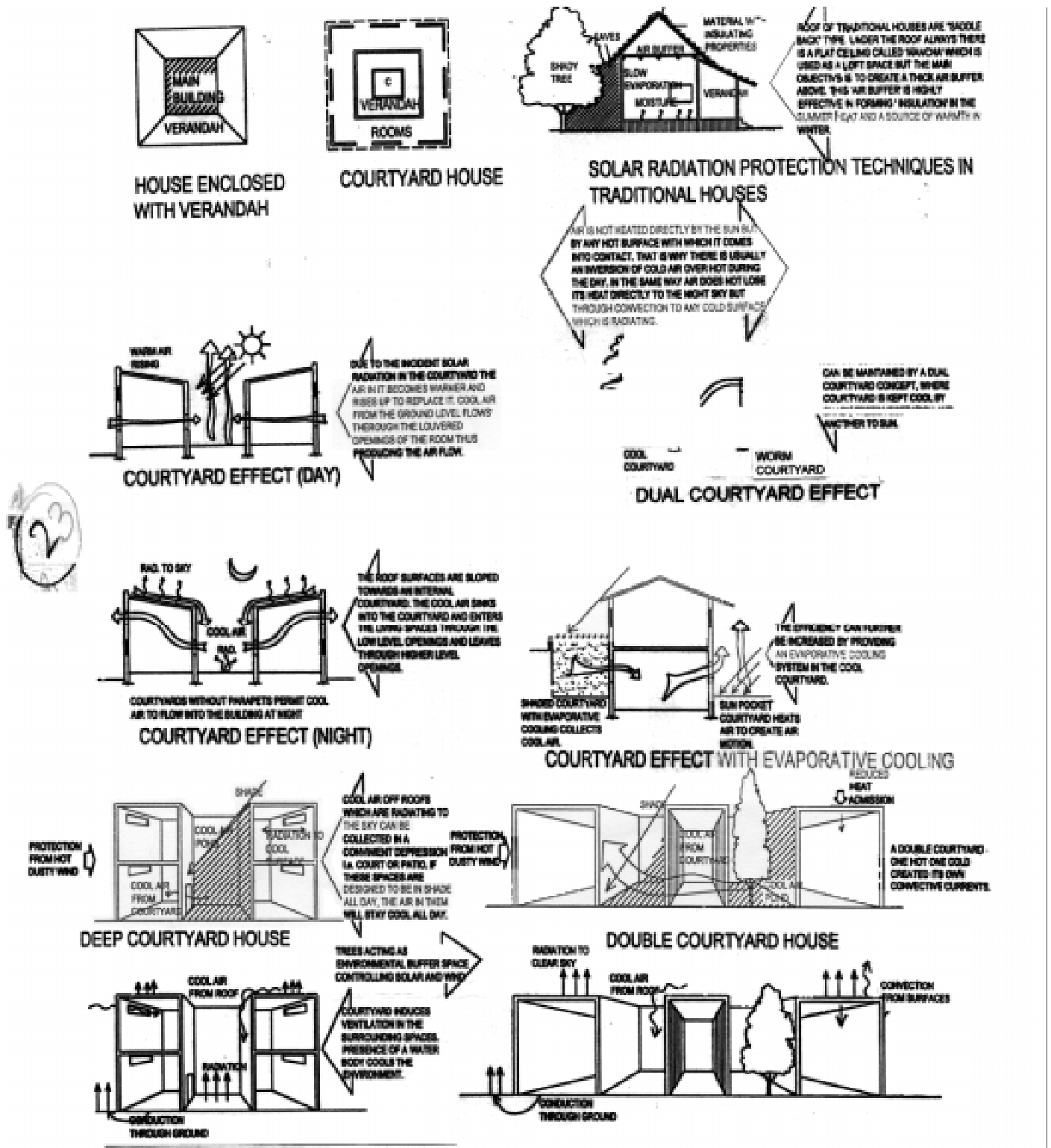


Figure 1 Passive techniques in practice

- (2) Internal loads due to people, appliances, cooking, bathing, lights etc.

Proper zoning of different components and local ventilation of major heat sources can reduce the overall impact of internally generated heat loads. Table 1, summarises the basic cooling strategies that can be considered in a building design.

Depending on the weather, the thermal load enters into a building in three major ways:

- (1) Penetration of direct beam sunlight.
- (2) Conduction of heat through walls, roofs etc.
- (3) Infiltration of outside air.

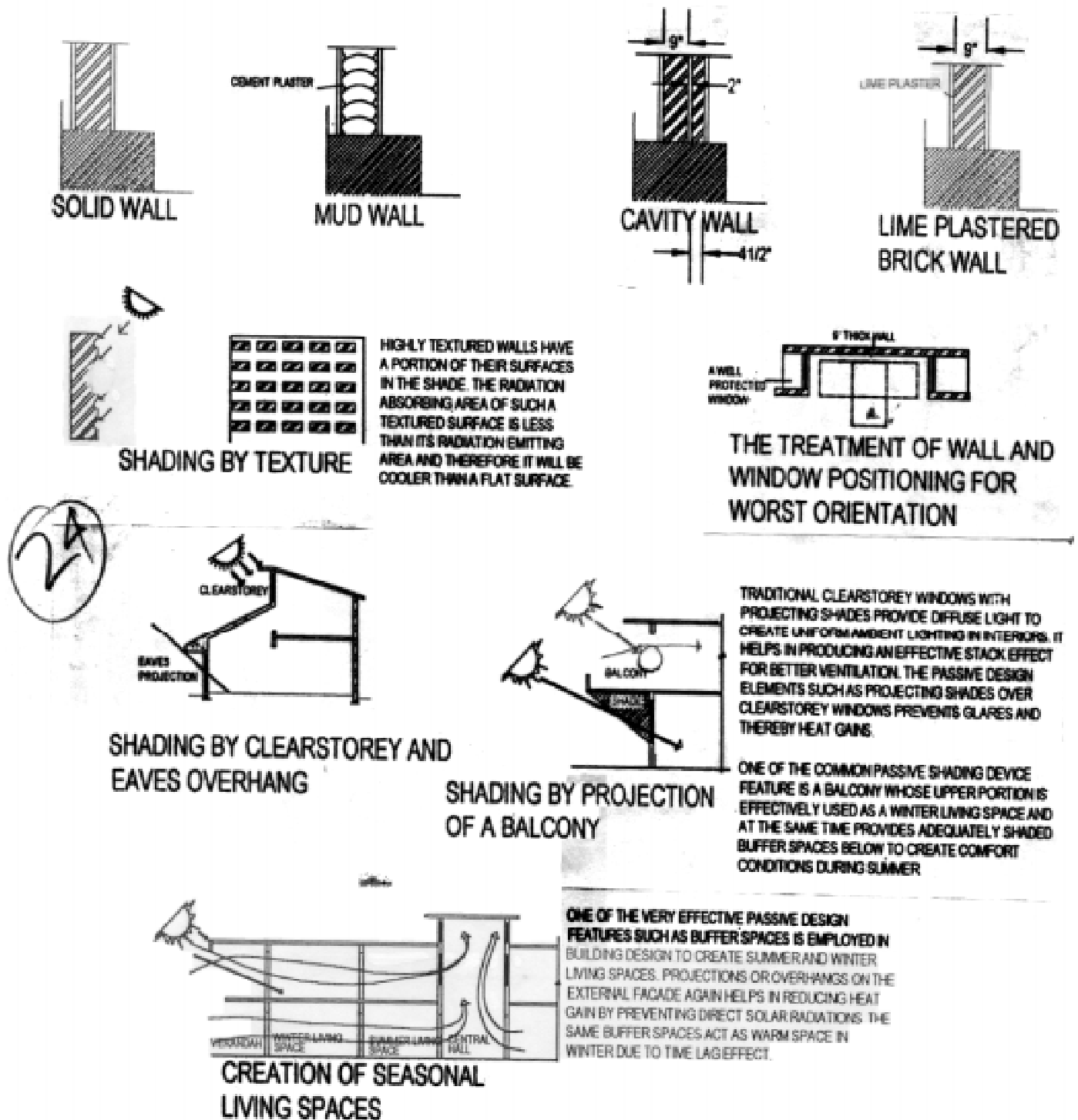


Figure 2 Heat gain prevention technique through commonly used passive shading device features such as : projections, balconies, buffer spaces etc

Any building design for warm climatic conditions would attempt to exclude any of the above major heat loads arising due to the prevailing ambient temperature and the intensity of solar radiation. Figure 1 shows the passive techniques in practice.

HEAT GAIN PREVENTION TECHNIQUES

Reduction of Solar and Convective Heat Import

The interaction of solar radiation by the building is the source of maximum heat gain inside the building space. The natural

way to cool a building, therefore, is to minimise the incident solar radiation, proper orientation of the building, adequate layout with respect to the neighbouring buildings and by using proper shading devices to help control the incident solar radiation on a building effectively. Good shading strategies help to save 10%-20% of energy for cooling. Properly designed roof overhangs can provide adequate sun protection, especially for south facing surfaces. Vertical shading devices such as trees, trellises, trellised vines, shutters, shading screens awnings and exterior roll blinds are also effective. These options are recommended for east-facing and west-facing windows and walls.

If ambient temperatures are higher than the room temperature, heat enters into the building by convection due to undesirable ventilation, which needs to be reduced to the minimum possible level. Adequate wind shelter and sealing of windows reduces the air infiltration and this requires proper planning and landscaping. Figure 2 shows some of the heat gain prevention techniques.

Orientation of Building

Maximum solar radiation is interrupted by the roof (horizontal surface) followed by the east and west walls and then the north wall during the summer period, when the south oriented wall receives minimum radiation. It is therefore desirable that the building is oriented with the longest walls facing north and south, so that only short walls face east and west. Thus only the smallest wall areas are exposed to intense morning and evening sun.

Shading by Neighbouring Buildings

The buildings in a cluster can be spaced such that they shade each other mutually. The amount and effectiveness of the shading, however, depends on the type of building clusters. Martin and March (1972) have classified building clusters into three basic types, *ie*, pavilions, streets and courts. Pavilions are isolated buildings, single or in clusters, surrounded by large open spaces. Street, long building blocks arranged in parallel rows, separated by actual streets in open spaces and courts are defined as open spaces surrounded by buildings on all sides.

Shading by Vegetation

Shading by trees and vegetation is a very effective method of cooling the ambient hot air and protecting the building from solar radiation. The solar radiation absorbed by the leaves is mainly utilized for photosynthesis and evaporative heat losses. A part of the solar radiation is stored as heat by the fluids in the plants or trees.

The best place to plant shady trees is to be decided by observing which windows admit the most sunshine during peak hours in a single day in the hottest months. Usually east and west oriented windows and walls receive about 50% more sunshine than the north and south oriented windows/walls. Trees should be planted at positions determined by lines from the centres of the windows on the west or east walls toward

the position of the sun at the designated hour and date. On the south side only deciduous trees should be planted.

Shading by Overhangs, Louvers and Textured Facade

The devices which provide shading to an opening can be classified into three types:

- (i) movable opaque, *eg*, roller blind, curtain etc can be highly effective in reducing solar gains but eliminates view and impedes air movement;
- (ii) louvers which may be adjustable or fixed affect view and air movement to some degree and provide security; and
- (iii) fixed overhangs: easy to attain on single storey buildings with overhanging roof. Also gives rain protection to walls and openings and has little or no effect on view and air movement.

Maximum solar radiation in summer is incident on the roof. It is, therefore, advisable to protect the roof from the sun as far as possible.

Shelter Against Hot Winds

Hot winds during summer in hot and dry climatic conditions are a source of large convective heat gain and a source of extreme thermal discomfort.

Wind shelter for a building can be provided by taking the advantage of the existing topography, such as an elevated landmass or by creating wind barriers in the form of trees, shrubs, fences or walls. Usually, an opaque barrier creates a turbulent flow of wind and one has to avoid the accumulation of heat from the sun-irradiated surfaces between the barrier and the surface.

ROOFING TECHNIQUES

A building can cope up with seasonal weather changes by tuning itself to the heat sources or heat sinks with which it is coupled. The heat sources should be at temperatures higher than the temperatures inside the building, whereas the heat sink must be at a lower temperature. Usual heat sources are sun or the earth, while the heat sinks are the ambient air, radiant sky and the earth. Figure 3 shows the traditional and modern roofing techniques.

Shading of Roof and Walls

Surface shading can be provided as an integral part of the building element or by the use of a separate cover. Highly textured walls have portions of their surfaces in the shade. 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 coefficient of convective heat transfer, which will permit the building to cool down faster at night when the ambient temperature is lower than the building temperature.

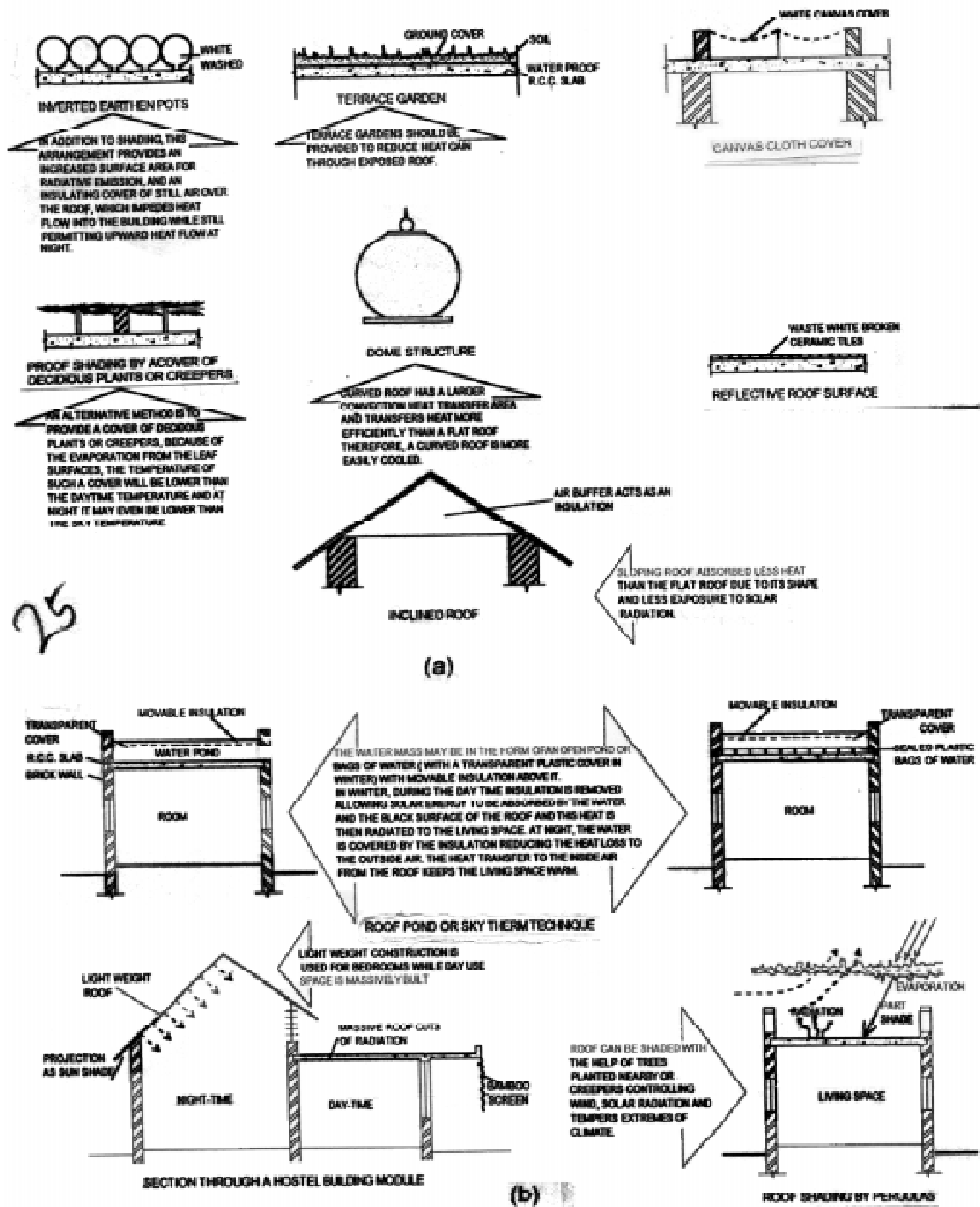


Figure 3 Roof techniques (a) traditional (b) modern

An alternative method is to provide a cover of deciduous plants or creepers. Because of the evaporation from the leaf surfaces, the temperature of such a cover will be lower than the daytime air temperature and at night it may even be lower than the sky temperature as in Figure 3.

In addition to shading, this arrangement provides an increased surface area for radiative emission, and an insulating cover of still air over the roof which impedes heat flow into the building, while still permitting upward heat flow at night. Although, the system of earthen pots is thermally efficient, the method suffers from practical difficulties because the roof is rendered unusable and its maintenance is difficult.

An effective roof-shading device is a removable canvas cover. This can be mounted close to the roof in the daytime and at night it can be rolled up to permit radiative cooling. The upper surface of the canvas should be painted white to minimize the amount of absorbed radiation by the canvas and the consequent conductive heat gain through it.

Reflecting Surfaces

If the external surfaces of the building are painted with such colours that reflect solar radiation (in order to have minimum absorption), but the emission in the long wave region is high, then the heat flux transmitted into the building is reduced considerably.

Building Surface Cooling

Cooling of building surfaces by evaporation of water provides heat sink for the room air for dissipation of heat. Maintenance of water film over the surface of building element especially the roof brings down its temperature below the wet-bulb temperature of the ambient air even in the presence of solar radiation thus making the roof surface to act as a means of heat transmission from inside the building to the ambient air without increasing the humidity of the room air.

Roof surface evaporative cooling consists of maintaining a uniform thin film of water on the roof terraces of buildings. This causes the roof temperature to achieve a much lower value than the other elements. The roof evaporation process can be very effective in hot and dry and also in warm and humid climate zones because of the incident solar radiation. The effect of roof surface cooling depends on the type of construction.

Roof Ponds

Water stored on the roof acts as a heat source and heat sink both during winter and summer climatic conditions. The thermal resistance of the roof in this system is kept very small. In summer during the day, the reflecting insulation keeps the solar heat away from water, which keeps receiving heat through the roof from the space below it thereby cooling it. In the night, the insulation is removed and water, despite cooling the living space below, gets cooler on account of heat losses by evaporation, convection and radiation. Thus, the water

regains its capacity to cool the living space. In winter, the insulation is removed during the day. Water and black surface of the roof absorb solar radiation; the living space continues to receive heat through the roof. During night water is covered with insulation to reduce heat losses.

VENTILATION TECHNIQUES

Windows

Windows play a dominant role in inducing indoor ventilation due to wind forces. Various parameters that affect ventilation are

- climate;
- wind direction;
- area of fenestration/location;
- size of inlet and outlet openings;
- volume of the room;
- shading devices;
- wire meshes/screens; and
- internal partitions

As in wind, two forces govern ventilation inside the building:

- (i) Air moves from high-pressure zone to a low-pressure zone if openings are made on the walls of the respective zones in a building.
- (ii) If the inlet and outlet are placed at different heights, air flows from the inlet to the outlet due to the density difference created by the upward movement of warm air.

Figure 4 shows different techniques for effective ventilation.

In order to attain sensible air movement, it is essential to provide cross-ventilation. Single sided ventilation allows air movement to a very shallow depth of the building. An alternative is to provide an exhaust for the air via a ridge terminal or chimney or an under floor supply of air to rooms on the leeward side of the building.

LIMITATION OF WINDOW VENTILATION

It may not always be possible to locate the openings in the windward direction due to reasons like site restriction, solar radiation, privacy etc. To some extent the limitations can be overcome by designing suitable wind deflectors.

Wind Tower

Principle

The hot ambient air enters the tower through the openings in the tower and is cooled when it comes in contact with the cool tower and thus becomes heavier and sinks down. When an inlet is provided to the rooms with an outlet on the other side there is a draft of cool air. After a whole day of heat exchange, the wind tower becomes warm in the evening.

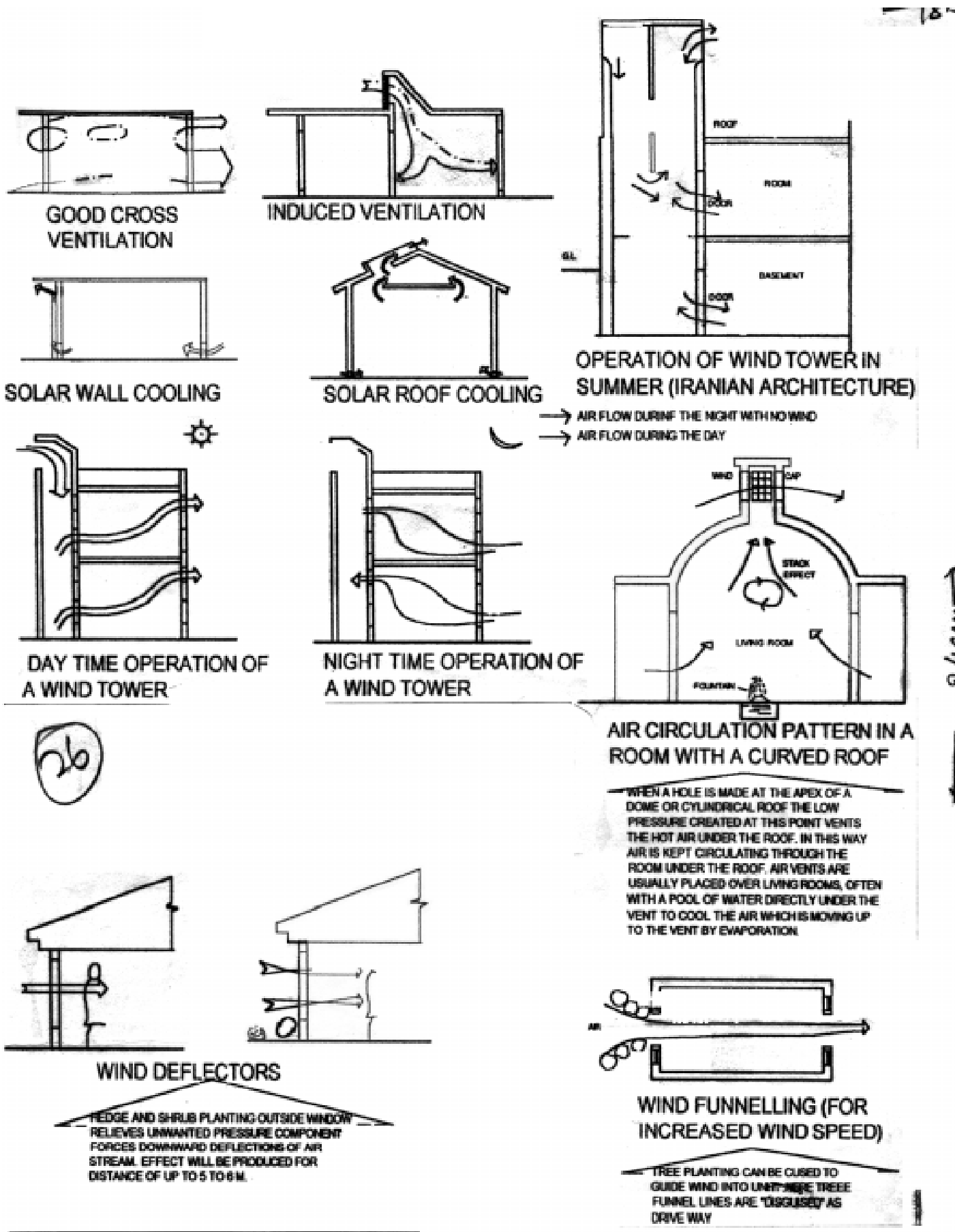


Figure 4 Ventilation techniques

During night the reverse happens, *ie*, the cooler ambient air comes in contact with the bottom of the tower through the rooms; it gets heated up by the warm surface of wind tower and begins to rise due to buoyancy, and thus an air flow is maintained in the reverse direction.

Application

This system can work very effectively in hot and dry types of climate, where daily variations in temperatures are high with high temperature during day time and low temperature during night time. As a result of clear sky conditions during the night, radiative losses are high. The openings of the wind tower are provided in the direction of the wind, and outlets on the leeward side take advantage of the pressure difference created by wind speed and direction. Normally, the outlets have thrice the area of the inlet for better efficiency. The inlet should be properly designed for uniform distribution.

Solar Chimney

A solar chimney utilizes the stack effect, as already described, but here the air is deliberately heated by solar radiation in order to create an exhaust effect. One should distinguish between the stack effect ventilation due to the building itself, and that due to a solar chimney. In the former case, one tries to keep the increment in the building temperature as small as possible (ventilation is being used for cooling) and hence the stack effect is weak. In the case of a solar chimney, there is no limit to the temperature increment within the chimney, since it is isolated from the used spaces. The chimney can therefore be designed to maximize solar gains and the ventilation effects. The parameters effecting the ventilation rates are

- height between inlet and outlet;
- cross-sectional area of the inlet and the outlet;
- geometrical construction of the solar absorbing plate; and
- inclination angle.

The use of solar chimneys is advisable for regions where very low wind speeds exist.

Courtyard Effect

Due to the incident solar radiation in the courtyard, the air in the courtyard becomes warmer and rises up. To replace it, cool air from the ground level flows through the louvered openings of the room, thus producing the air flow. During the night the process is reversed. As the warm roof surface gets cooled by convection and radiation, a stage is reached when its surface temperature equals the dry bulb temperature of the ambient air. If the roof surfaces are sloped towards an internal courtyard, the cooled air sinks into the court and enters the living space through the low level openings and leaves through higher level openings.

This concept can very well be applied in a warm and humid climate. It is necessary to ensure that the courtyard gets adequate radiation to produce a draft through the interior. An airflow inside the room can be maintained by a dual courtyard

concept, where one courtyard is kept cool by shady trees/vegetation and another courtyard to sun.

Air Vent

A typical vent is a hole cut in the apex of a domed or cylindrical roof. Openings in the protective cap over the vent direct wind across it. When air flows over a curved surface, its velocity increases resulting in lowering of the pressure at the apex of the curved roof, thereby, inducing the hot air under the roof to flow out through the vent. In this way, air is kept circulating through the room under the roof. Air vents are usually placed over living rooms, often with a pool of water directly under the vent to cool the air, which is moving up to the vent, by evaporation.

Air vents are employed in areas where dusty winds make wind towers impractical. It works well both in hot and dry zones and warm and humid zones unlike a wind tower which works only in hot and dry zones. It is most suited for single units which are just above frequently used liveable space.

COOLING TECHNIQUES

Sensible and Evaporative Cooling

The heat loss from air (on account of sensible cooling) results in a decreased air temperature, but no change in the water-vapour content of the air. Air in the upper part of a wind tower is sensibly cooled. When water is introduced into a system, evaporative cooling occurs. Such cooling involves a change in both the water-vapour content and the temperature of the air. When unsaturated air comes in contact with water, some water is evaporated, thus lowering the temperature of the air and increasing its water-vapour content. A wind-tower system that cools air evaporatively as well as sensibly is particularly effective. Figure 5 shows few of the commonly adopted cooling techniques.

Air Cooling by Tunnels

Temperature deep inside the earth remains nearly constant. Daily temperature variations hardly affect the earth's temperature at a depth of more than one meter, while the seasonal variations of the ambient temperature are strongly dampened by the earth. The earth's temperature upto a depth of 6 m to 8 m is influenced by the annual ambient temperature variations with a time delay of several months. It is seen that in Delhi the earth's temperature at a depth of about 4 m is nearly constant at a level of about 23°C throughout the year. A tunnel in the form of pipes or otherwise will acquire the same temperature at its surface causing the ambient air ventilated through this tunnel to get cooled.

Earth Cooling

Because of the thermal storage capacity of earth, the daily and even the annual temperature fluctuation keeps on decreasing with increasing depth below the ground surface. At a depth of 15 m, the earth has a constant temperature of 10°C. The level of water table plays an important role here. In summer and particularly during the day, the ground temperature is much

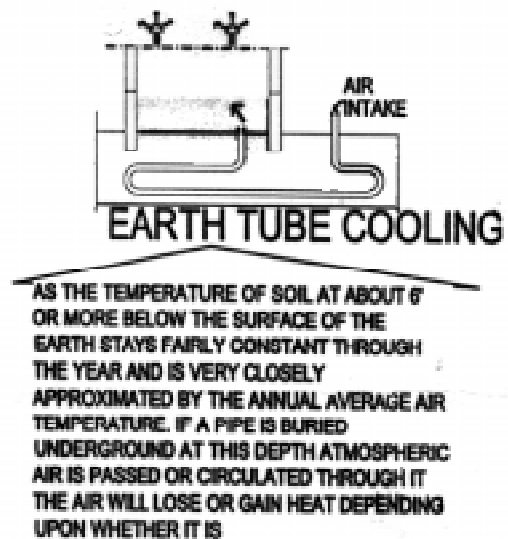
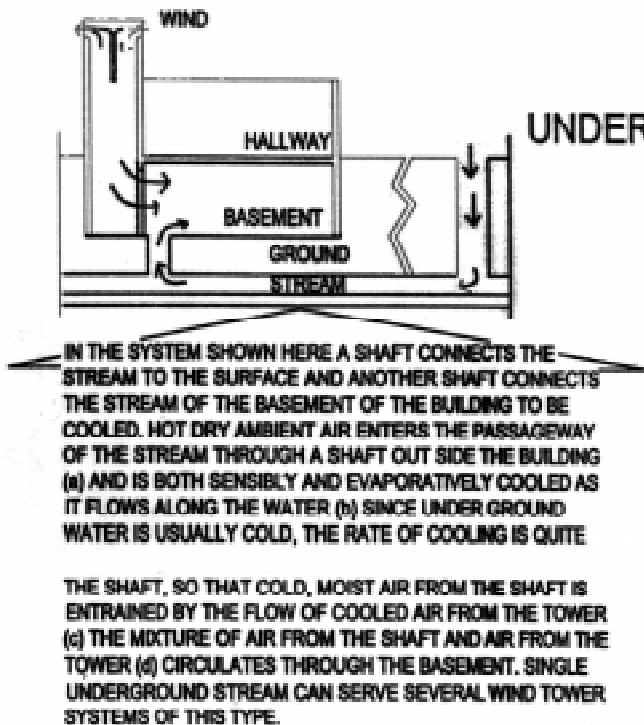
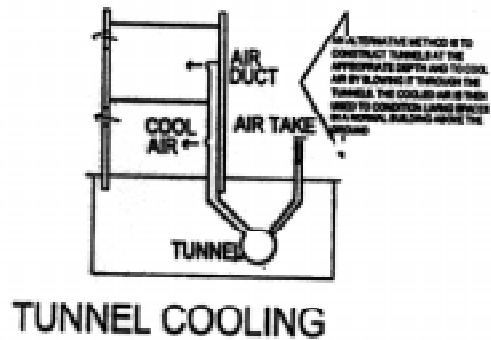
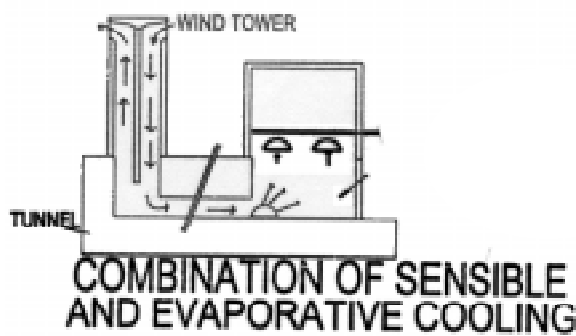
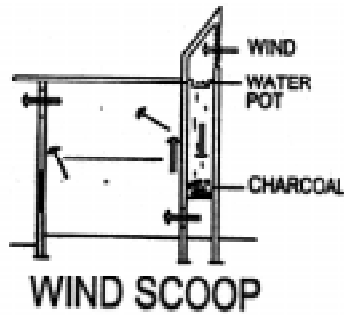
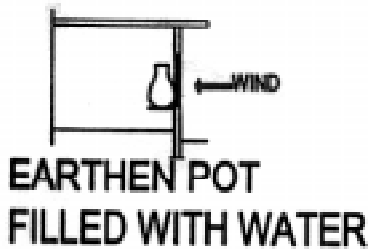


Figure 5 Cooling techniques (evaporative technique)

lower than the ambient air temperature. If a part of the building is earth bermed, the building loses heat to the earth particularly, if the insulation levels are low. The most ancient dwellings were often dug into the ground or covered with earth. Pit houses of North American Indians, Eskimo houses with sturdy timber roofs for supporting earth and a deep

covering of snow in winter, and the early Scandinavian farms are few examples of this principle.

Earth Tunnel Cooling

Benefits of ground temperature stabilisation for habitable rooms, food and wine stores have been known since

prehistoric times. There are many examples of underground vernacular buildings. The building may be coupled with the earth either by conduction, *ie*, where the building envelope is in contact with the deep earth by burying or berming. A third medium by which the earth could be coupled with the building is the earth air tunnel, where ventilation supply air is drawn into the building via insulated ducts buried deep into the earth.

Cooling and Heating Techniques using Thermal Mass

Thermal Storage

Thermal capacity effects in the materials result in time delay as well as damping of the parameters in the environment. As a result temperature differences exist between the materials and the environment around them and this effect can be utilized for space cooling.

Building Elements

All building elements such as walls, roof and floor can be used for thermal storage. Creating a flow of fluid through the storage media can increase the efficiency of thermal storage. Additional thermal storage can be created by construction of rock bed storage.

Conventional Walls and Ceilings

Thermal storage efficiency of a building element depends on the heat storage capacity of various material layers of the building element, the order in which these layers are arranged and also on the fact whether the material is in the steady state or in the transient state. For example, a hanging acoustic ceiling of mineral wool below the roof acts as a lightweight building element for the thermal steady state conditions. During the transient state, however, the concrete room acts as a thermal storage system with appreciable time delay. A larger thermal storage capacity in any case leads to smoothening of the room temperature fluctuation and delays room temperature changes. The thermal performance of a building during the summer time is positively influenced by external as well as internal building elements.

Building Elements with Air Flow

The heat storage capacity of building elements can be increased by having some tubes in the massive ceiling and cooling it during the night by forcing air flow.

The Vary Therm Wall

Controlling the air movement in magnitude and direction gives rise to wall components with varying thermal resistance. Such a system can be used for mild winter heating and summer cooling for mixed climate as in Delhi. The external wall components are made of light material like aluminium or wood, while the internal component is made of brick (or concrete) wall. The flow of air is controlled into the room or to the ambient by providing proper vents in the interior wall. During the summer daytime, the wall provides effective air

insulation and during the night the cool ambient air comes in contact with the warm brick wall and gets heated establishing a natural flow of air. This air movement helps in quick removal of the heat flux. During winter, the vents are opened during the day into the room for supplying warm air and all vents are kept closed during the night time, thus providing an air insulation which minimizes heat losses to the ambient.

Vary therm wall deriving its name from the variable resistance can be operated in three modes:

- (i) No flow of air in the gap thus effectively reducing the system to an air gap within the wall;
- (ii) Continuous flow of air into the room or to the atmosphere maintained by natural or forced convection; and
- (iii) No air flow during the day or night and creating an airflow by opening the vents during night or day time depending on the weather conditions.

CONCLUSION

The concept of 'Thermal mass' in buildings was used by ancestors. Today it is thought of as a means of conserving energy. The foregoing description of vernacular architecture if examined for recurrent forms, materials or life patterns may lead to newer ideas.

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