Energy efficiency in architecture: An overview of design concepts and architectural interventions

Buildings, as they are designed and used today, contribute to serious environmental problems because of excessive consumption of energy and other natural resources. The close connection between energy use in buildings and environmental damage arises because energy intensive solutions sought to construct a building & meet its demands for heating, cooling, ventilation & lighting cause severe depletion of invaluable environmental resources.

However, buildings can be designed to meet occupant's need for thermal and visual comfort at reduced levels energy & resources consumption. Energy resource efficiency in new constructions can be effected by adopting an integrated approach to building design. The primary steps in this approach would be to:

- *Incorporate solar passive techniques in a building design to minimise load on conventional systems (heating, cooling, ventilation and lighting)* Passive systems provide thermal and visual comfort by using natural energy sources and sinks e.g. solar radiation, outside air, sky, wet surfaces, vegetation, internal gains etc. Energy flows in these systems are by natural means such as by radiation, conduction, convection with minimal or no use of mechanical means. The solar passive systems thus, vary from one climate to the other e.g. in a cold climate an architects' aim would be design a building in such a way that solar gains are maximised, but in a hot climate his primary aim would be to reduce solar gains, maximise natural ventilation and so on.
- *Design energy-efficient lighting and HVAC systems (heating, ventilation and air-conditioning)* Once the passive solar architectural concepts are applied to a design, the load on conventional systems (HVAC and lighting) is reduced. Further, energy conservation is possible by judicious design of the artificial lighting and HVAC system using energy efficient equipments, controls and operation strategies.
- *Use renewable energy systems (solar photovoltaic systems/ solar water heating systems) to meet a part of building load* The pressure on the earth's non-renewable resources can be alleviated by judicious use of earth's renewable resources i.e. solar energy. Use solar energy for meeting electrical needs for a building can further reduce consumption of conventional forms of energy.
- *Use low energy materials and methods of construction and reduce transportation energy* An architect also should aim at efficient structural design, reduction of use of high energy building material (glass, steel etc.) and transportation energy and use of low energy buildings materials.

Thus in brief, an energy efficient building balances all aspects of energy use in a building: lighting, space-conditioning and ventilation, by providing an optimised mix of passive solar design strategies, energy-efficient equipments and renewable sources of energy. Use of materials with low embodied energy also form a major component in energy-efficient building design.

The book covers 44 case studies on energy and resource efficient architectural projects in India". Each project highlights the energy efficiency measures, e.g. passive solar interventions, energy-efficient systems, buildings materials with low embodied energy, adopted by several architects in their respective projects.

The projects have been classified climate-wise. The thermal performance of a selected number of buildings have also been presented. The incremental costs for incorporation of energy efficiency measures to buildings have been highlighted wherever such data was available.

This chapter briefly elaborates the passive architectural techniques that have been adopted by the architects and draws examples from projects which have been covered in the book.

Architects can achieve energy efficiency in the buildings they design by studying the macro-and micro-climate of the site, applying bioclimatic architectural principles to combat the adverse conditions, and taking advantage of the desirable conditions. Some common design elements that directly or indirectly affects thermal comfort conditions and thereby the energy consumption in a building are

(a) landscaping,
(b) ratio of built form to open spaces,
(c) location of water bodies,
(d) orientation,
(e) planform, and
(f) building envelope and fenestration.

However, in extreme climatic conditions, one cannot achieve comfortable indoor conditions by these design considerations only. There are certain tested and established concepts which, if applied to a design in such climatic conditions, are able to largely satisfy the thermal comfort criteria. These are classified as advanced passive solar techniques. The two broad categories of advanced concepts are,

1. Passive heating concepts (direct gain system, indirect gain system, sunspaces, etc.) and
2. Passive cooling concepts (evaporative cooling, ventilation, wind tower, earth-air tunnel, etc.).

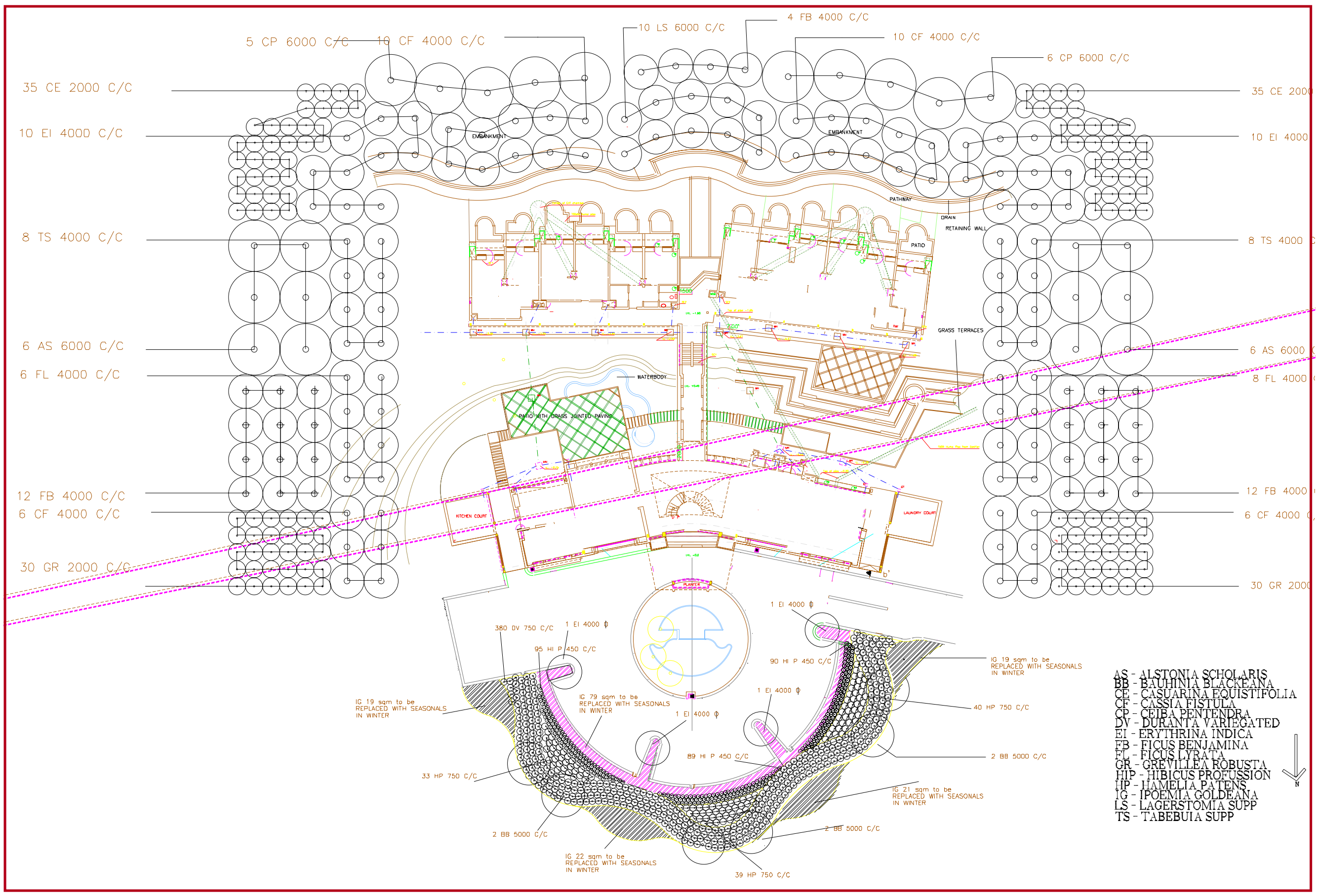
The commonly considered design elements for achieving lower energy consumption in a building are as follows.

Landscaping

Landscaping is an important element in altering the microclimate of a place. Proper landscaping reduces direct sun from striking and heating up of building surfaces. It prevents reflected light carrying heat into a building from the ground or other surfaces. Landscaping creates different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference. Additionally, the shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling. Properly designed roof gardens help to reduce heat loads in a building. A study shows that the ambient air under a tree adjacent to the wall is about 2 °C to 2.5 °C lower than that for unshaded areas, which reduces heat gain by conduction (www.greenbuilder.com).

Trees are the primary elements of an energy-conserving landscape. Climatic requirements govern the type of trees to be planted. Planting deciduous trees on the southern side of a building is beneficial in a composite climate. Deciduous plants such as mulberry or Champa cut off direct sun during summer, and as these trees shed leaves in winter, they allow the sun to heat the buildings in winter.

This landscaping strategy has been adopted to shade the southern side of the RETREAT building of TERI.



The RETREAT building has deciduous trees on the south side to cut off summer gains. These trees shed leaves during winter so that winter solar gains are not cut off. Wind breaks are provided in the north and north-east to protect from the winter winds.

Building form /surface-to-volume ratio

The volume of space inside a building that needs to be heated or cooled and its relationship with the area of the envelope enclosing the volume affects the thermal performance of the building. This parameter, known as the S/V (surface-to-volume) ratio, is determined by the building form. For any given building volume, the more compact the shape, the less wasteful it is in gaining/losing heat. Hence, in hot, dry, regions and cold climates, buildings are compact in form with a low S/V ratio to reduce heat gain and losses respectively. Also, the building form determines the airflow pattern a round the building, directly affecting its ventilation. The depth of a building also determines the requirements for artificial lighting - greater more the depth, higher the need for artificial lighting.

A view of the WALMI building. The flowing form overlooks a waterbody which has been used to advantage for modification of the micro climate

Location of water bodies

Water is a very good modifier of microclimate. It takes up a large amount of heat in evaporation and causes significant cooling especially in a hot and dry climate. On the other hand, in humid climates, water should be avoided as it adds to humidity.

Water has been used very effectively as a modifier of microclimate in the WALMI building complex at Bhopal.

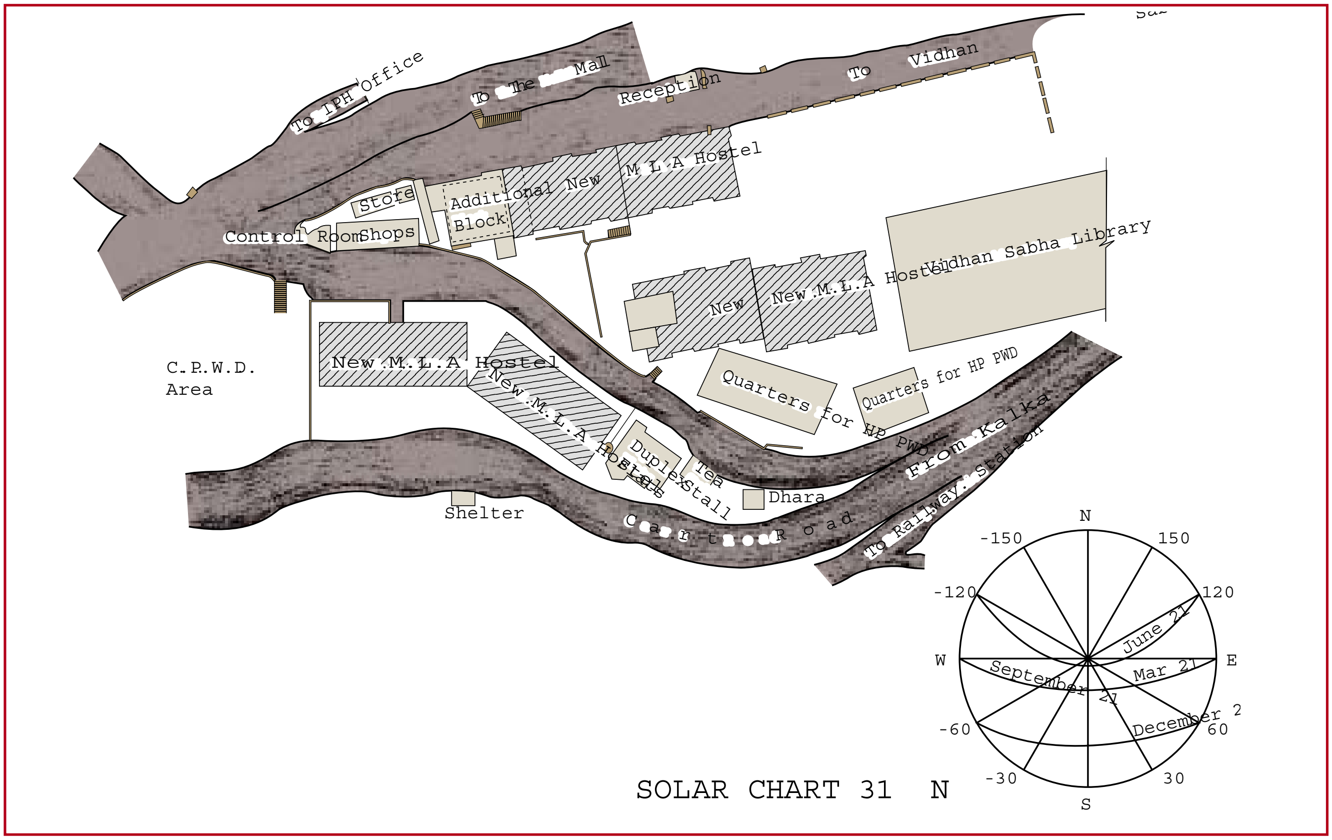
Orientation

Building orientation is a significant design consideration, mainly with regard to solar radiation and wind.

In predominantly cold regions, buildings should be oriented to maximize solar gain; the reverse is advisable for hot regions. In regions where seasonal changes are very pronounced, both the situations may arise periodically. For a cold climate, an orientation slightly east of south is favoured (especially 15° east of south), as this exposes the unit to more morning than afternoon sun and enables the house to begin to heat during the day.

This has been amply demonstrated in the MLA hostel building at Shimla.

Similarly, wind can be desirable or undesirable. Quite often, a compromise is required between sun and wind orientations. With careful design, shading and deflecting devices can be incorporated to exclude the sun or redirect it into the building, just as wind can be diverted or directed to the extend desired.



The building blocks in the MLA hostel, Shimla, located in the cold and cloudy zone, are oriented due south ±15° for direct solar gain. They are spaced apart so as to eliminate shadows of one building over the other, even for the longer winter shadows. It was proposed that all bedrooms be south facing to avail of the benefit of south exposure

Building envelope and fenestration

The building envelope and its components are key determinants of the amount of heat gain and loss and wind that enters inside. The primary elements affecting the performance of a building envelope are

(a) Materials and construction techniques,
(b) Roof,
(c) Walls,
(d) Fenestration and shading, and
(e) Finishes.

Materials and construction techniques

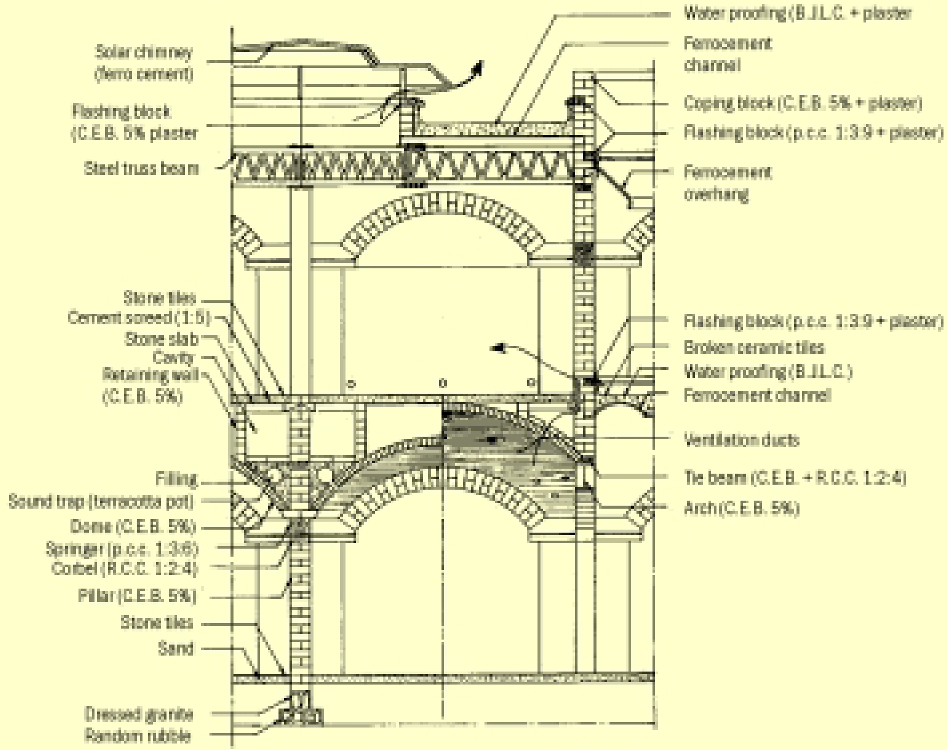
Material with low embodied energy

Choice of building materials is very important in reducing the energy contents of buildings. Reducing the strain on conventional energy can be achieved by low-energy buildings with low-energy materials, efficient structural design, reducing the quantities of high-energy building materials and transportation energy.

The choice of materials also helps to maximize indoor comfort.

Use of materials and components with low embodied energy has been demonstrated in various buildings in the Auroville region of Pondicherry.

The visitor's centre at Auroville uses innovative materials and construction techniques to reduce embodied energy of the building and attain the desired comfort conditions conducive to the warm, humid climate of Pondicherry.



Sectional details showing use of alternative construction techniques. Ferrocement solar chimney and ventilation duct in corbelled arch demonstrates use of passive solar ventilation techniques.

Table 1 The energy contents of commonly used building materials are as follows

Building	Elements/materials	KWh/cum (in situ)
Cement concrete	1:5:10	402
Lime concrete with brick ballast	1:4:8	1522 (80% in brick)
Brick masonry	1:5	676
Brick masonry	1:4	709
Random rubble masonry	1:4	267
Stabilized mud with 6% lime		197
Stabilized mud with 10% lime		320
RCC roof (10 cm)		174/m2
Stone slabs in RCC joists		132/m2
Cement plaster	1:4	20.65/m2
Cement plaster	1:6	15.09/m2
Lime surkhi	1:4	11.05/m2

Source Energy contents of building materials for India: paper by Dr C L Gupta. Green Architecture festival, Nasik, February 1994; data Courtesy Sanjay P, Rakesh Ahuja. Geeta V

Thermal insulation

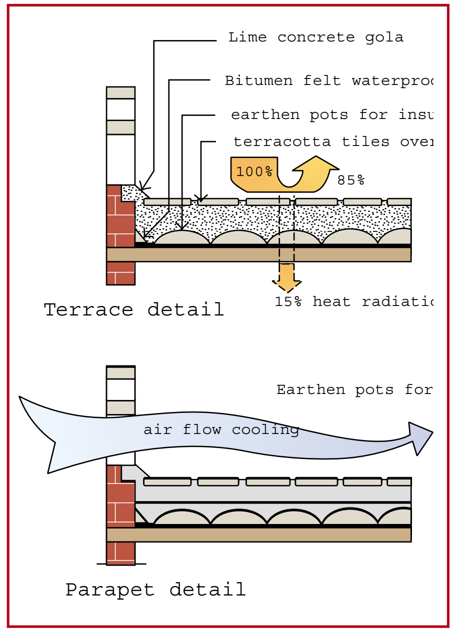
Insulation is of great value when a building requires mechanical heating or cooling and helps reduce the space-conditioning loads. Location of insulation and its optimum thickness are very important. In hot climates, insulation is placed on the outer face (facing exterior) of the wall so that thermal mass of the wall is weakly coupled with the external source and strongly coupled with the interior.

Use of 40 mm thick expanded polystyrene insulation on walls and vermiculite concrete insulation on the roof has brought down space-conditioning loads of the RETREAT building by about 15%.

Roof

The roof receives significant solar radiation and plays an important role in heat gain/losses, daylighting, and ventilation.

Depending on the climatic needs proper roof treatment is very essential. In a hot region, the roof should have enough insulating properties to minimize heat gains. Some roof protection methods are as follows



Roof details showing use of earthen pots for roof insulation

Broken China mosaic can be used as top most layer in roof for reflection of incident radiation

- A cover of deciduous plants or creepers can be provided. Evaporation from leaf surfaces will keep the rooms cool.
- The entire roof surface can be covered with inverted earthen pots. It is also an insulating cover of still air over the roof.
- A removable cover is an effective roof-shading device. This can be mounted close to the roof in the day and can be rolled up to permit radiative cooling at night.
  The upper surface of the canvas should be painted white to minimize the radiation absorbed by the canvas and consequent conductive heat gain through it.
- Effective roof insulation can be provided by using vermiculite concrete. This has been used in the RETREAT building at Gual Pahari (near New Delhi) and has reduced roof conduction by 60%.

The skylight on the roof of West Bengal Renewable Energy Development Agency office building provides natural light for inner office spaces and is connected to the office spaces for inducing ventilation by stack effect

The roof can also be used advantageously for effective ventilation and daylighting by incorporating vents and skylights. This has been demonstrated effectively in the recently constructed office building of the WBREDA (West Bengal Renewable Energy Development Agency) at Calcutta.

Walls

Walls are a major part of the building envelope and receive large amounts of solar radiation. The heat storage capacity and heat conduction property of walls are key to meeting desired thermal comfort conditions. The wall thickness, material, and finishes can be chosen based on the heating and cooling needs of the building.

Appropriate thermal insulation and air cavities in walls reduce heat transmission into the building, which is the primary aim in a hot region.

Air cavities

Air cavities within walls or an attic space in the roof ceiling combination reduce the solar heat gain factor, thereby reducing space-conditioning loads. The performance improves if the void is ventilated. Heat is transmitted through the air cavity by convection and radiation. A cavity represent a resistance that is not proportional to its thickness. For a thickness >20 mm, the resistance to heat flow remains nearly constant. Ventilated air does not reduce radiative heat transfer from roof to ceiling. The radiative component of heat transfer may be reduced by using low emissivity or high reflective coating (e.g. aluminium foil) on either surface facing the cavity. With aluminium foil attached to the top of ceiling, the resistance for downward heat flow increase to about 0.7 m2k/w, compared to 0.21m2/k in the absence of the foil.

Fenestration and shading

Of all the elements in the building envelope, windows and other glazed areas are most vulnerable to heat gain or losses. Proper location, sizing, and detailing of windows and shading form an important part of bioclimatic design as they help to keep the sun and wind out of a building or allow them when needed.

The location of openings for ventilation is determined by prevalent wind direction. Openings at higher levels naturally aid in venting out hot air. Size, shape and orientation of openings moderate air velocity and flow in the room; a small inlet and large outlet increase velocity and distribution of airflow through the room. When possible, the house should be so positioned on the site that takes it advantage of prevailing winds. The prevailing wind direction is from the south/ south-east during summer. The recommendations in IS:3362-1977 Code of practices for natural ventilation of residential buildings (first revision) should be satisfied in the design of windows for lighting and ventilation. There should be sufficient air motion in hot humid and warm humid climate. In such areas, fans are essential to provide comfortable air motion indoors. Fenestrations having 15 to 20% of floor area are found adequate for both ventilation and daylighting in hot and dry, and hot and humid regions.

Natural light is also admitted into a building through glazed openings. Thus, fenestration design is primarily governed by requirements of heat gain and loss, ventilation and daylighting. The important components of a window that govern these are the glazing systems and shading devices.

Glazing systems

Before recent innovations in glass, films, and coatings, a typical residential window with one or two layers of glazing allowed roughly 75-85% of the solar energy to enter a building. Internal shading devices such as curtains or blinds could reflect back some of that energy outside the building. Most of the energy, primarily heat-remained inside, which affected the thermal comfort. The weak thermal characteristics of windows became a prime target for research and development in an attempt to control the indoor temperature of buildings.

A detailed write-up on energy efficient glazing system is provided in **Appendix ???.**

Windows admit direct solar radiation and hence promote heat gain. This is desirable in cold climates, but is critical in overheated climates. The window size should be kept minimum in hot and dry regions. For example, in Ahmedabad, if glazing is taken as 10% instead of 20% of the floor area, then number of uncomfortable hours in a year can be reduced by as much as 35% (J K Nayak, et al).

Shading devices

Heat gain through windows is determined by the overall heat loss coefficient U-value (W/m2K) and the solar energy gain factor, and is much higher as compared to that through solid wall. Shading devices for windows and walls thus moderate heat gains into the building. In a low-rise residential building in Ahmedabad (hot and dry climate), shading a window by a horizontal 0.76-m deep chhaja can reduce the maximum room temperature by up to 4.6 °C (from 47.7 to 43.1 °C). Moreover, the number of uncomfortable hours in a year with temperatures exceeding 30 °C can be reduced by 14% (J K Nayak, et al).

Shading devices are of various types:

1. Moveable opaque (roller blind, curtains, etc): These can be highly effective in reducing solar gains but eliminate view and impede air movement.
2. Louvres: May be adjustable or fixed. These affect view and air movement to some degree.
3. Fixed overhangs.

Relative advantages and disadvantages of these shading devices have been enumerated as follows.

Moveable blinds or curtains

- Block the transmission of solar radiation through glazed windows, especially on the east and west walls
- In hot and dry climates, when ambient air is hotter than room air, they help to reduce convective heat gain.
- In warm, humid climates, where airflow is desirable, they impede ventilation.
- For air-conditioned buildings, where the flow of outside air is to be blocked, they can reduce cooling load.

Overhangs and louvres

- Block that part of the sky through which the sun passes.
- Overhangs on south-oriented windows provide effective shading from the high-altitude sun.
- An extended roof shades the entire north or south wall from the noon sun.

The office building for the West Bengal Pollution Control Board is a landmark of energy and resource conscious architecture in this region. Efficient planning and carefully designed shading devices, fenestration design and efficient lighting design has brought about 40% energy savings over a conventional building of similar size and function. This picture shows the east facade with inclined louvers to cut off solar gains.

- East and west openings need much bigger overhangs, which may not be possible and can be achieved by porticos, or verandas, on these sides or by specially designed louvres to suit the building requirements.

The scientific design of fenestration and shading devices in the West Bengal Pollution Control Board building has brought down the projected energy consumption substantially (TERI. 1996).

Finishes

The external finish of a surface determines the amount of heat absorbed or relected by it. For example, a smooth and light colour surface reflects more light and heat in comparison to a dark colour surface. Lighter colour surfaces have higher emissivity and should be ideally used for warm climate.

Advanced passive heating techniques

Advanced passive heating techniques are used by architects in building design to achieve thermal comfort conditions in cold climate.

Passive solar heating systems can be broadly classified as:

1. Direct gain systems
2. Indirect gain systems

Direct gain

Direct gain is the most common passive solar system. In this system, sunlight enters rooms through windows, warming the interior space. The glazing system is generally located on the southern side to receive maximum sunlight during winter (in the northern hemisphere). The glazing system is usually double-glazed, with insulating curtains to reduce heat loss during night. South-facing glass admits solar energy into the building, where it strikes thermal storage materials such as floors or walls made of adobe, brick, concrete, stone, or water. The direct gain system uses 60-75% of the sun's energy striking the windows. The interior thermal mass tempers the intensity of heat during the day by absorbing heat. At night, the thermal mass radiates heat into the living space, thus warming the spaces.

The direct gain system of the Bhowali house.
The picture highlights the fully glazed walls for the dayuse rooms from inside. ▼

Direct gain can be achieved by various forms of openings such as clerestories, skylight windows, etc. designed for the required heating.

Direct gain systems have been used for day-use rooms by architect Sanjay Prakash in the residence for Mohini Mullick at Bhowali. The user is extremely satisfied with the thermal performance of the direct gain system in this residence.

Direct gain systems have some limitations. They cause large temperature savings (typically 10 °C) because of large variations in input of solar energy. Strong sunlight, glare, and ultraviolet degradation of the house material are some disadvantages of direct gain systems. However, being relatively simple to construct and inexpensive, they are by far the most common systems used world wide.

Indirect gain system

In an indirect gain system, thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space. The indirect gain system uses 30-45% of the sun's energy striking the glass adjoining the thermal mass. Some commonly used indirect gain systems are as follows.

Trombe wall

A trombe wall is a thermally massive wall with vents provided at the top and bottom. It may be made of concrete, masonry, adobe, and is usually located on the southern side (in the northern hemisphere) of a building in order to maximize solar gains. The outer surface of the wall is usually painted black for maximizing absorption and the wall is directly placed behind glazing with an air gap in between.

Solar radiation is absorbed by the wall during the day and stored as sensible heat. The air in the space between the glazing and the wall gets heated up and enters the living spaces by convection through the vents. Cool air from the rooms replaces this air, thus setting up a convection current. The vents are closed during night, and heat stored in the wall during the day heats up the living space by conduction and radiation.

Trombe walls have been extensively used in the cold regions of Leh. Various forms of Trombe walls have been tried and tested in the Ledeg hostel at Leh (refer to the chapter on the 'Ledeg Trainees Hostel for their advantages).

It is noteworthy that in buildings with thermal storage walls, indoor temperature can be maintained at about 15 oC when the outside temperature is as low as -11 oC (Mazria E. 1979).

Generally, thickness of the storage wall is between 200 mm and 450 mm, the air gap between the wall and glazing is 50-150mm, and the total area of each row of vent is about 1% of the storage wall area (Levy M E, Evans D, and Gardstein C. 1983).

The trombe wall should be adequately shaded for reducing summer gains.

Water wall

Water walls are based on the same principle as that for trombe walls, except that they employ water as the thermal storage material. A water wall is a thermal storage wall made up of drums of water stacked up behind glazing. It is usually painted black to increase heat absorption. It is more effective in reducing temperature swings, but the time lag is less.

Heat transfer through water walls is much faster than that for trombe walls. Therefore, distribution of heat needs to be controlled if it is not immediately required for heating the building. Buildings that work during the daytime, such as schools and offices, benefit from the rapid heat transfer in the water wall.

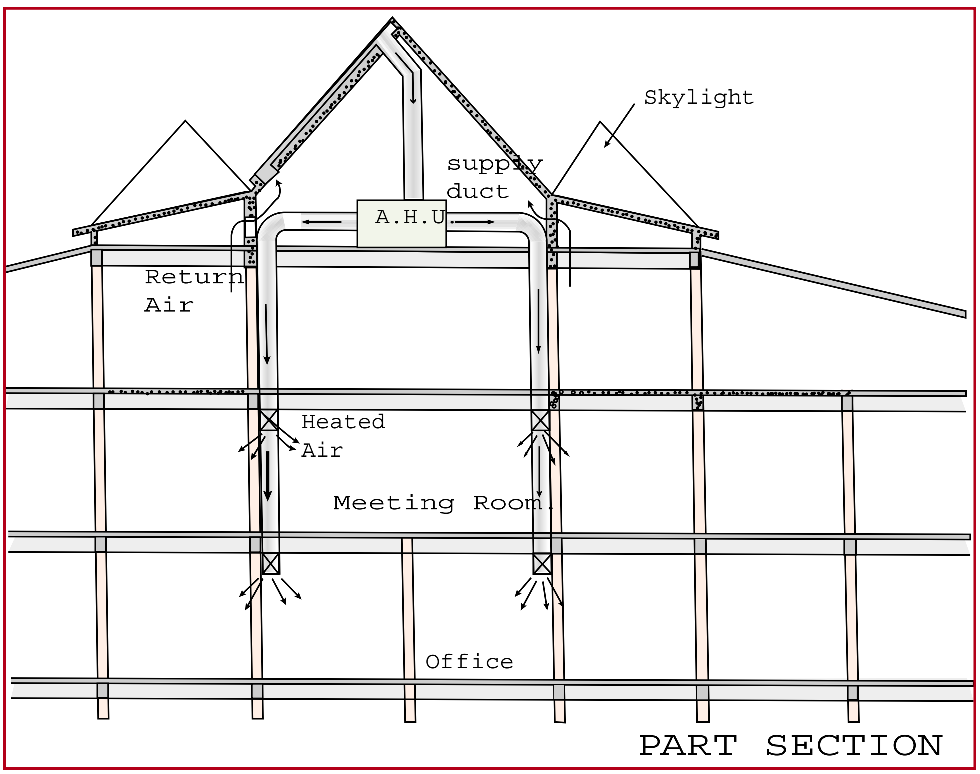
Overheating during summer may be prevented by using suitable shading devices.

Roof-based air heating system

In this technique, incident solar radiation is trapped by the roof and is used for heating interior spaces.

In the Northern Hemisphere, the system usually consists of an inclined south-facing glazing and a north-sloping insulated surface on the roof. Between the roof and the insulation, an air pocket is formed, which is heated by solar radiation. A moveable insulation can be used to reduce heat loss through glazed panes during nights. There can be variations in the detailing of the roof air heating systems. In the Himachal Pradesh State Cooperative Bank building, the south glazing is in the form of solar collectors warming the air and a blower fan circulating the air to the interior spaces.

Roof based air heating system for winter heating in Himachal Pradesh State Cooperative Bank Building.



Sun spaces

A sun space or solarium is the combination of direct and indirect gain systems. The solar radiation heats up the sun space directly, which in turn heats up the living space (separated from the sun space by a mass wall) by convection and conduction through the mass wall. In the northern hemisphere, the basic requirements of buildings heated by sun space are (a) a glazed south-facing collector space attached yet separated from the building and (b) living space separated from the sun space by a thermal storage wall. Sunspaces may be used as winter gardens adjacent to the living space. The Himurja building in Shimla has well desgined solariam as integral part of south wall to maximise solar gain.

Advanced passive cooling techniques

Before the turn of the century, buildings were designed to take advantage of daily temperature variations, convective breeze, shading, evaporative cooling, and radiation cooling. However, with a thoughtless imitation of the west, these concepts took a back seat and buildings became energy guzzlers. Today, with high energy costs and growing environmental concerns, many of these simpler techniques are once again becoming attractive. Passive cooling systems rely on natural heat-sinks to remove heat from the building. They derive cooling directly from evaporation, convection and radiation without using any intermediate electrical devices. All passive cooling strategies rely on daily changes in temperature and relative humidity. The applicability of each system depends on the climatic conditions.

The relatively simple techniques that can be adopted to provide natural cooling in the building have been elaborated earlier. These are

Reduction of solar and connective heat import by

- orientation of building
- shading by adjoining building
- landscaping
- window shading devices
- surface finishes

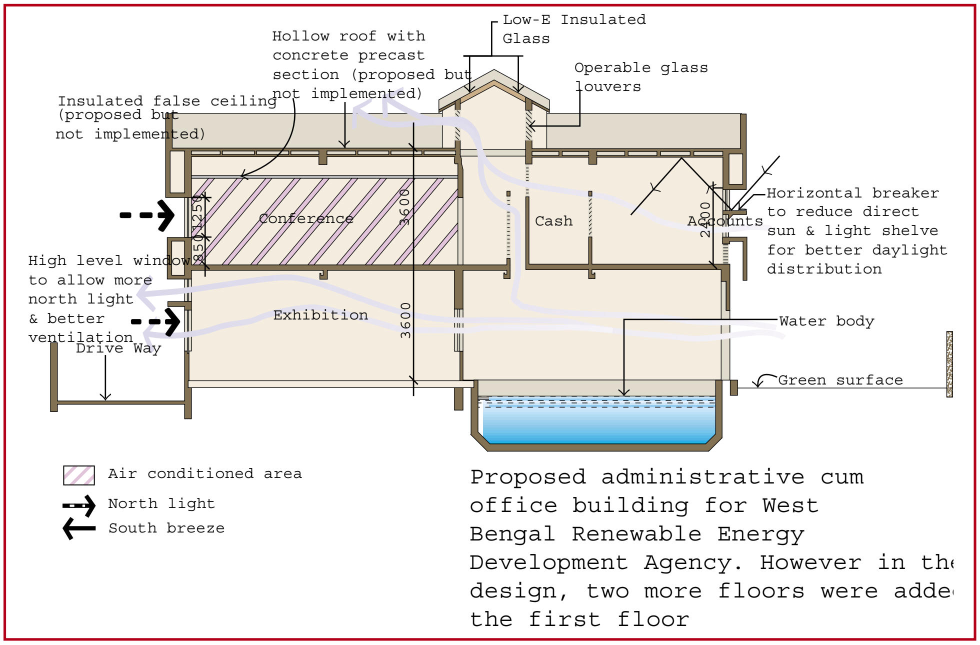
Reduction of heat transmission in the building by

- thermal insulation
- air cavities

These design strategies reduce heat gains to internal spaces. This section briefly elaborates the passive techniques that aid heat loss from the building by convection, radiation, evaporation, or by using storage capacity of surrounding spaces, e.g. earth berming.

Ventilation

Outdoor breezes create air movement through the house interior by the 'push-pull' effect of positive air pressure on the windward side and negative pressure (suction) on the leeward side. Good natural ventilation requires locating openings in opposite pressure zones. Also, designers often choose to enhance natural ventilation using tall spaces called stacks in buildings. With openings near the top of stacks, warm air can escape whereas cooler air enters the building from openings near the ground. Ventilation by creating stacks has been effectively used in the WBREDA office building in Calcutta. Located in a warm humid climate, induced ventilation was a primary design strategy for this building.



Section of the WBREDA office building showing ventilation strategies

Innovative ventilation strategies by use of building integrated solar chimneys have been used in Sudha and Atam Kumar's residence in the composite climate of New Delhi.

The windows, as discussed earlier, play a dominant role in inducing indoor ventilation due to wind forces. Other passive cooling techniques that induce indoor natural ventilation and are used by architects to achieve passive cooling are as follows.

Picture showing building integrated solar chimney in Sudha and Atam Kumar's residence at New Delhi for effective ventilation especially during humid season. The inset shows a close view of the chimney top

Airvent

A typical vent is a cut-out in the apex of a domed or cylindrical roof. The openings in the protective cap over the vent direct wind loss 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. The hot air under the roof flows out through the vent. 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 by evaporation.

The special form of domes restricts use to the top floor only. Acoustic concentration often occurs in this type of ceiling.

Wind tower in Jodhpur Hostel to catch favourable cool wind from south-west for passive cooling

Wind tower

In a wind tower, the hot ambient air enters the tower through the openings in the tower, gets cooled, and thus becomes heavier and sinks down. The inlet and outlet of rooms induce cool air movement. In the presence of wind, air is cooled more effectively and flows faster down the tower and into the living area. After a whole day of air exchanges, the tower becomes warm in the evenings. During the night, cooler ambient air comes in contact with the bottom of the tower through the rooms. The tower walls absorb heat during the daytime and release it at night,warming the cool night air in the tower. Warm air moves up, creating an upward draft, and draws cool night air through the doors and windows into the building. The system works effectively in hot and dry climates where diurnal variations are high. The Jodhpur hostel designed by Dr Vinod Gupta uses wind tower for summer cooling.

A wind tower works well for individual units not for multi-storeyed apartments. In dense urban areas, the wind tower has to be long enough to be able to catch enough air. Also protection from driving rain is difficult.

Courtyard effects

Due to incident solar radiation in a courtyard, the air gets warmer and rises. Cool air from the ground level flows through the louvred openings of rooms surrounding a courtyard, thus producing air flow.

At night, the warm roof surfaces get cooled by convection and radiation. If this heat exchange reduces roof surfaces temperature to WBT of air, condensation of atmospheric moisture occurs on the roof and the gain due to condensation limits further cooling.

If the roof surfaces are sloped towards the internal courtyard, the cooled air sinks into the court and enters the living space through low-level openings, gets warmed up, and leaves through higher-level openings.

However, care should be taken that the courtyard does not receive intense solar radiation, which would lead to conduction and radiation heat gains into the building. Intensve solar radiation in the courtyard also produces immense glare.

Earth air tunnels

Daily and annual temperature fluctuations decrease with the increase in depth below the ground surface. At a depth of about 4 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to the annual average temperature of the place. A tunnel in the form of a pipe or otherwise embedded at a depth of about 4 m below the ground, will acquire the same temperature as the surrounding earth at its surface and therefore the ambient air ventilated though this tunnel will get cooled in summer and warmed in winter and this air can be used for cooling in summer and heating in winter.

Earth air tunnel has been used in the composite climate of Gurgaon in the RETREAT building. The living quarters (the south block of the RETREAT) are maintained at comfortable temperatures (approximately between 20 °C and 30 °C) round the year by the earth air tunnel system, supplemented, whenever required, with a system of absorption chillers powered by LPG during monsoons and with an air washer during dry summer. However, the cooler air underground needs to be circulated in the living space. Each room in the South Block has a 'solar chimney'; warm air rises and escapes through the chimney, which creates an air current for the cooler air from the underground tunnels to replace the warm air. Two blowers installed in the tunnels speed up the process. The same mechanism supplies warm air from the tunnel during winter (for details please refer to chapter on 'RETREAT')

Evaporative cooling

Evaporative cooling lowers indoor air temperature by evaporating water. It is effective in hot-dry climate where the atmospheric humidity is low. In evaporative cooling, the sensible heat of air is used to evaporate water, thereby cooling the air, which in turn cools the living space of the building. Increase in contact between water and air increases rate of evaporation.

The presence of a water body such as a pond, lake, sea etc. near the building or a fountain in a courtyard can provide a cooling effect. The most commonly used system is a desert cooler, which comprises of water, evaporative pads, a fan, and pump.

Evaporative cooling has been tried as a roof-top installation solar energy centre, Gurgaon. However, the system has now become defunct due to poor water supply in the area.

Passive downdraught cooling

It is a evaporative cooling that has been used for many centuries in parts of the Middle East, notably Iran and Turky. In this system, wind catchers guide outside air over water-filled pots, inducing evaporation and causing a significant drop in temperature before the air enters the interior. Such wind catchers become primary elements of the architectural form also. Passive downdraught evaporative cooling is particularly effective in hot dry climates. It has been used to effectively cool the Torrent Research Centre in Ahmedabad.

Passive downdraught cooling has been successfully used at Torrent Research Centre, Ahmedabad. The wind catchers for the system are the predominant architectural elements in this building

This books contains 44 case studies of energy and resource efficient architecture which have used one or a combination of the above concepts and techniques. In addition to the above many of the projects have adopted innovative daylighting strategies. use of energy efficient lighting and space-conditioning strategies are primary strengths of some buildings.

In the present era of growing environmental concerns, these case studies would inspire an architect to design and create a better tommorrow.

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