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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

UNIT – 1– CLIMATE: FACTORS AND CLASSIFICATION – SARA1303

GLOBAL CLIMATIC FACTORS

- Solar radiation quality
- Solar radiation quantity
- Tilt of the earth axis
- Radiation at earth surface
- The earths thermal balance
- Winds – thermal forces

Solar Radiation quality and quantity:

The earth receives all its energy from the sun ***nm=10^{-9} m*

Ultra Violet (290 – 380 nm)
Visible (380 – 700 nm)
Infra-red (700 – 2300 nm)

The Spectral energy distribution varies with ALTITUDE (Filtering effect – shorter wavelength absorbed by atmosphere)

The intensity of radiation reaching the upper surface of the atmosphere is taken as **SOLAR CONSTANT: 1395 W/m^2**

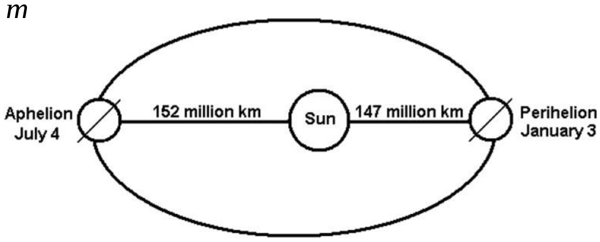


Fig. 1 : Earth's elliptical orbit

Tilt of the earth axis:

The plane of the ecliptic is the plane of the Earth's orbit around the sun. The Earth's axis is titled by 231/2 ^{0} from the perpendicular to the plane of the elliptic.

In the other words it makes an angle of 231/2 ^{0} with the plane of elliptic as shown in the Figure 2.

The axis of rotation remains pointing in the same direction as it revolves around the Sun. As a result, the earth's axis of rotation remains parallel to its position at any other time as it orbits the sun, a property called **Parallelism of Axes.**

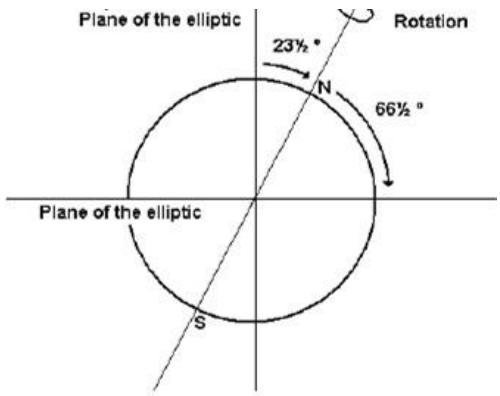


Fig. 2 : Earth's elliptical orbit

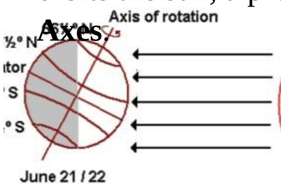


Fig. 3 : Summer Solstice

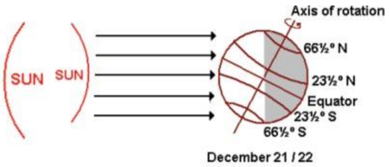
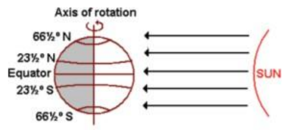


Fig. 4 : Winter Solstice

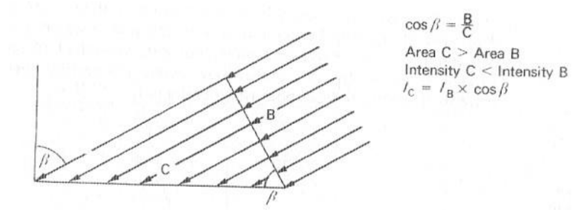


Septermber 22 / 23 and March 21 / 22

Fig. 5 : Autumnal and Spring Equinox

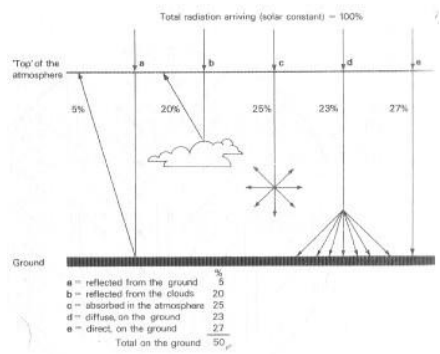
Radiation at earth surface:

The COSINE LAW – The intensity of TILTED SURFACE equals the normal intensity times the cosine of the angle of INCIDENCE



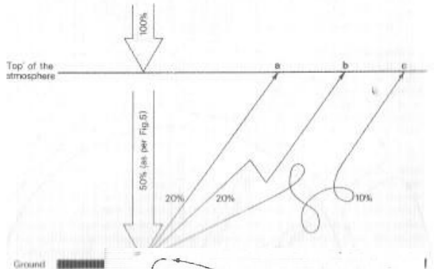
The SOLAR DEPLETION – The Absorption of radiation by ozone, Vapours, Dust particles

The lower the solar altitude angle, the longer the path of radiation thus a smaller part reaches the earth surface. The duration of SUN SHINE –The length of daylight period.



THE EARTH's THERMAL BALANCE

The total amount of HEAT ABSORBED by the earths surface is balanced by the corresponding heat loss – **without this cooling, the thermal balance of the earth could not be maintained.**



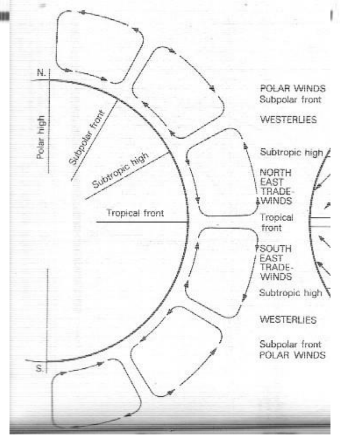
The earth surface losses heat by
Radiation Evaporation Convection

WINDS – Thermal Forces :

Winds are convection currents in the atmosphere, tending to even out the differential heating of various zones

At maximum heating zones (between Tropic of cancer and Capricorn) the air is heated by hot surface and flows of a higher level towards colder regions.

Part of the air having cooled down at high level descends to the surface in the sub tropic region



TRADE WINDS – The atmosphere rotates with earth. As it is light and behaves like fluid held against the earth surface only by gravity and friction it has a tendency to lag behind earth rotation There is a slippage between the earth and the atmosphere caused by **CORIOLIS FORCE**

North easterly winds - north of equator and South easterlies - south of equator

Mid latitude westerlies –

Around 30 N & S there are two bands of continually high barometric pressure. Wind in these region are light and variable

30 – 60 N and S strong westerly wind prevails.

The total Angular Momentum of earth is constant. If it is reduced at the equator by easterlies.

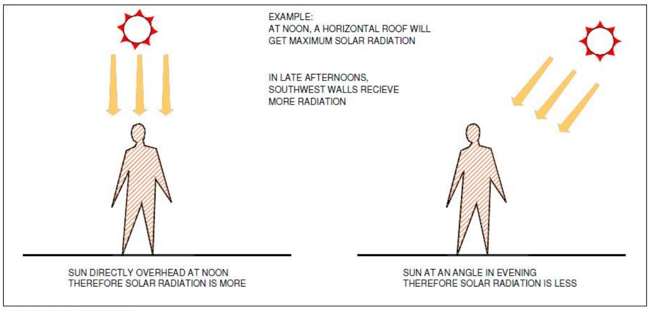
Polar winds –

Further towards the poles from latitudes 60 N and south, the air flow patterns come under the influence of thermal forces similar to equator.

COMPONENTS OF CLIMATE:

- SOLAR RADIATION
- AMBIENT TEMPERATURE
- AIR HUMIDITY
- PRECIPITATION
- SKY CONDITION
- WIND

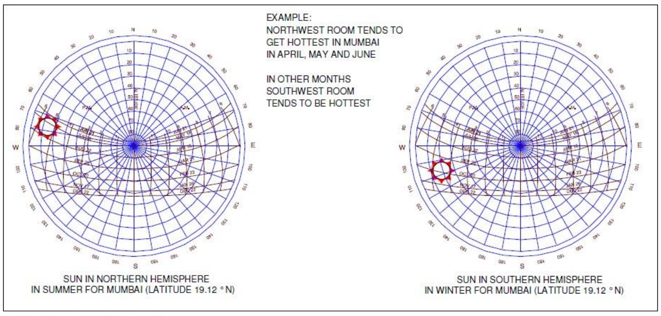
Solar Radiation: Solar radiation is the radiant energy received from the sun. It is the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square metre (W/m^2). The radiation incident on a surface varies from moment to moment depending on its geographic location (latitude and longitude of the place), orientation, season, time of d ay and atmospheric conditions (Fig.).



EFFECT OF TIME

Solar radiation is the most important weather variable that determines whether a place experiences high temperatures or is predominantly cold.

The instruments used for measuring of solar radiation are the **pyranometer and the pyrheliometer**. The duration of sunshine is measured using a sunshine recorder.



EFFECT OF SEASON

Ambient Temperature:

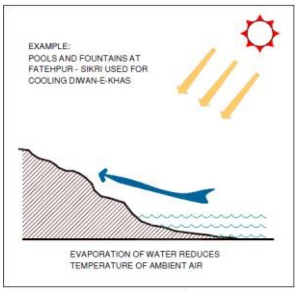
The temperature of air in a shaded (but well ventilated) enclosure is known as the **AMBIENT TEMPERATURE**

It is generally expressed in degree Celsius (ºC). Temperature at a given site depends on wind as well as local factors such as shading, presence of water body, sunny condition, etc.

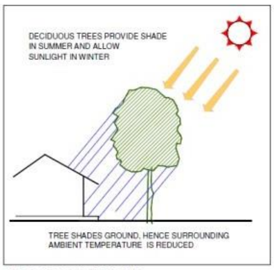
The dry bulb Temperature (DBT) is the value taken in shade using a simple Mercury thermometer kept in a Stevenson’s screen can measure ambient temperature.

The average is taken between each day's maximum and minimum and then the average of the 30 days' average is found (and possibly as many years' average for the same month).To give an indication of diurnal variations, data's can be supplemented by monthly mean maxima and minima. (Monthly mean maximum is the average of 30 days' maximum temperatures.) These will establish the monthly mean range of temperatures. It may be useful to indicate the highest and lowest temperatures ever recorded for each month, i.e. the monthly extreme maxima and minima, to establish the monthly extreme range of temperatures.

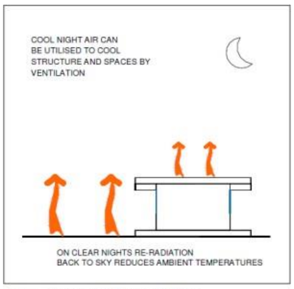
It is important to know the monthly mean maxima and minima, monthly extreme maxima and



EFFECT OF WATER BODY



EFFECT OF SHADING



EFFECT OF SKY CONDITION

minima

The **dry-bulb temperature** (DBT) is the **temperature** of air measured by

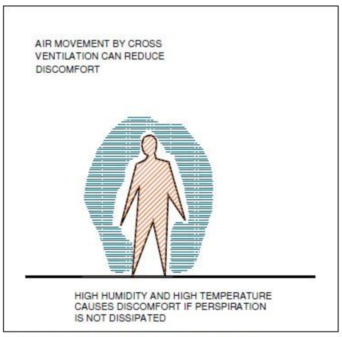
a **thermometer** freely exposed to the air, but shielded from radiation and moisture.

Humidity

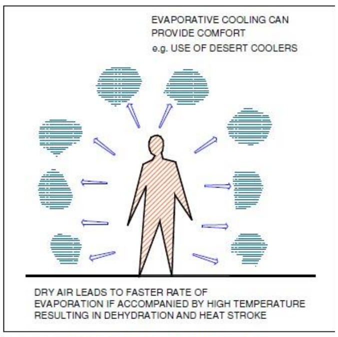
The humidity of air can be described as absolute humidity (AH), i.e. the amount of moisture actually present in unit mass or unit volume of air, in terms of gramme per kilogramme (g/kg) or gramme per cubic metre (g/m3).

The relative humidity (RH) is, however, a much more useful form of expression, as it gives a direct indication of evaporation potential. The amount of moisture the air can hold (the saturation-point humidity: SH) depends on its temperature. Relative humidity is the ratio of the actual amount of moisture present, to the amount of moisture the air could hold at the given temperature – expressed as a percentage. RH = (AH/SH) X 100
Humidity is usually measured with the wet-and-dry-bulb hygrometer.

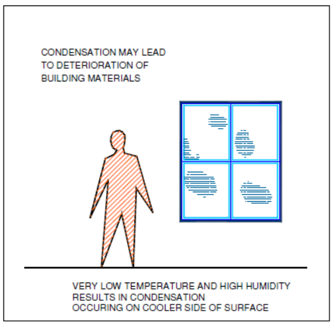
<u>This consists of two ordinary mercury thermometers mounted side by side.The first one measures the air (dry-bulb) temperature (DBT). The bulb of the second one is covered with a gauze or wick and is kept wet. Moisture evaporating gives a cooling effect, thus the reading of the wet-bulb</u>



EFFECT OF HIGH TEMPERATURE AND HIGH HUMIDITY



EFFECT OF HIGH TEMPERATURE AND LOW HUMIDITY

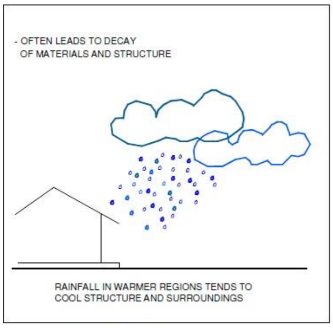


EFFECT OF LOW TEMPERATURE AND HIGH HUMIDITY temperature (WBT) will be less than the DBT. As in dry air the evaporation is faster, the cooling is more pronounced and the difference between the two readings (the 'wet-bulb depression') is greater. In case of 100% RH the two readings will be identical, as there is no evaporation. The rate of evaporation, thus the wet-bulb depression, is a function of the relative humidity.

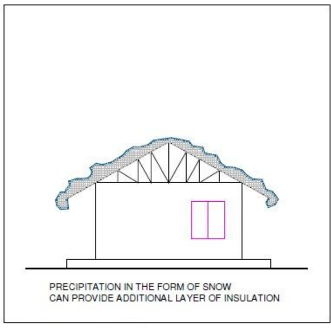
Precipitation:

Precipitation is a collective term used for rain, snow, dew etc.It is measured in RAIN GAUGES and expressed in mm/day. The maximum rainfall data will help in predicting flood and for the design of drainage system.

Driving rain is the product of annual rainfall (m) and the average wind velocity (m/s). Thus the unit of driving rain index is (m^2/s).



EFFECT OF RAINFALL



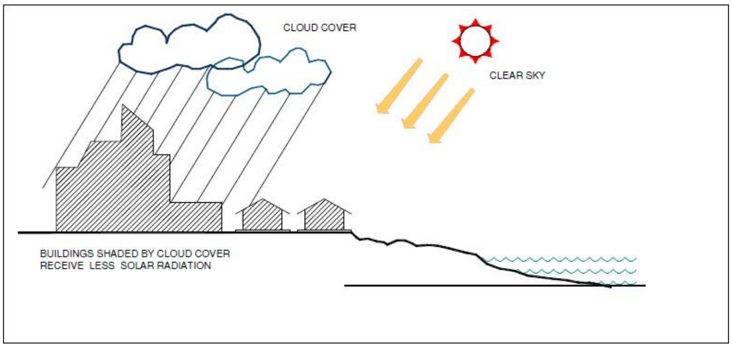
EFFECT OF SNOW

The exposure is moderate at 3-7 m^2/s and sever above 7 m^2/s.

Sky condition:

Sky condition generally refers to the extent of cloud cover in the sky or the duration of sunshine. Under clear sky conditions, the intensity of solar radiation increases; whereas it reduces in monsoon due to cloud cover.

The re-radiation losses from the external surfaces of buildings increase when facing clear skies than covered skies. The measurement of sky cover is expressed in oktas. For example, 3 oktas means that 3/8th of the visible sky is covered by clouds.

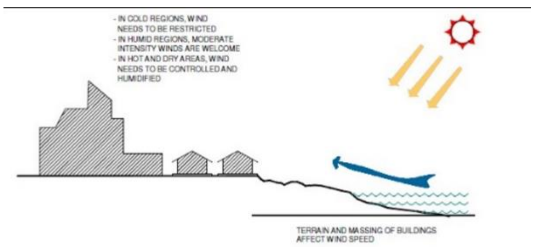


<u>Wind :</u>

Wind velocity is measured by propeller ANEMOMETER. Measurements are taken in urban areas between 10 – 20 m ht. The direction of wind are 8 or 16 category – the unit is m/s.

Wind is the movement of air due to a difference in atmospheric pressure, caused by differential heating of land and water mass on the earth's surface by solar radiation and rotation of earth.

It is a major design consideration for architects because it affects indoor comfort conditions by influencing the convective heat exchanges of a building envelope, as well as causing air infiltration into the building.



Solar radiation

The amount of solar radiation may be influenced by local factors three ways:

- The intensity on a theoretical horizontal plane above the ground is affected by local variation in the transparency of the atmosphere. Atmospheric pollution, smoke, smog or dust and local cloud formation can produce substantial reductions.
- The intensity on the actual ground surface is influenced by the slope and orientation of the site.
- The daily amount of radiation may also be influenced the slope.

Special characteristics

- Thunder-storms are macroclimate phenomena, but local topography can influence their path, their intensity and even their frequency.
- Dust and sand-storms are influenced by local factors , both by ground surface providing sand and dust to be carried by the wind, and by topography in funnelling or diverting the wind or by causing local eddies.

Vegetation

- Although considered as an effect of climate, vegetation can play a major role in site climate
- Trees and vegetation form an intermediate layer between the earth's surface and the atmosphere.
- The moderating effect can be referred with respect to air temperature, humidity, radiation and air movement.

Impact of rainfall in the design of buildings

In regions having high rainfall, a pitched roof will most often be used. In regions having driving rainfall and where ventilation is important, one of the most difficult problems which a designer must attempt to solve is to provide large openings, but at the same time give protection from driving rain, insects, smells and noise, without radically reducing air movement.
Broad eaves can be provided to shade the walls and openings, provide protection from driving rain and sky glare and permit the openings to be kept open most of the time.

Large projecting eaves and wide verandas are needed in the warm-humid season in the out-door living areas, to reduce sky glare, keep out the rain and provide shade.

louvers and other sun breaks used to protect openings during the hot-dry period, are also advantageous in the rainy season, serving as protection against rain.

Rain protection and special protective measures are needed if rain is frequent and heavy - such as deep verandas, wide overhangs and covered passages.

With heavy rainfall occurring even in one month of the year, special provisions for roof drainage will be necessary.

Thermal Comfort

- Our life cycle comprises activity, fatigue and recovery.
- Recovery is essential to counter balance against mental and physical fatigue through recreation, rest and sleep.
- This can be affected by unfavorable climatic conditions and the resulting stress on body and mind causes discomfort, loss of efficiency and breakdown of

health.

- **Thermal comfort is the condition of mind that expresses satisfaction with thermal environment and is assessed by subjective evaluation. (ANSI/ASHRAE Standard 55)**
- The task of the designer is **to create the best possible indoor climate or even the environment for the users** as they judge the quality of design based on physical and emotional point of view.
- Thermal comfort is considered to be a necessary component of workplace contentment and production.
- The thermal comfort has to be satisfied in spaces where people will spend most of their lives. For e.g. Schools are the buildings where children spend most of their active day time.
- Thermal discomfort in school buildings can create unsatisfactory conditions for both teachers and students which is disturbing for them, reducing their working productivity, attention and performance in studies.

Climate change is the most serious threat we face. Its consequences will remain unpredictable.

The future will bring warmer and wetter winters, hotter and drier summers, rising sea levels, more flooding and other extreme weather. Because of the delayed effects from greenhouse gas emissions, we are locked into significant climate change, regardless of any emission reductions that we may secure now.
Global warming is likely to be the greatest threat of the 21st century.

the Earth is warming up at a steady pace. The reason for this is the increase in human- caused greenhouse gases, which has led to health, ecological and humanitarian crises.

Two degrees may sound like a small amount, but it's an unusual event in our planet's recent history. Earth's climate record, preserved in tree rings, ice cores, and coral reefs, shows that the global average temperature is stable over oftime. Furthermore, small changes in temperaturecorrespond to enormous changes in the environment.

CLASSIFICATION OF CLIMATE

- KOPPEN CLIMATE CLASSIFICATION SYSTEM
- ATKINSON CLIMATE CLASSIFICATION
- CHARACTERISTICS OF TROPICAL CLIMATE

PARAMETERS AFFECTING CLIMATE ZONES

Latitude
Altitude
Low and high pressure zones
Global wind patterns
Proximity to oceans and large seas
Ocean currents

Latitude zones :

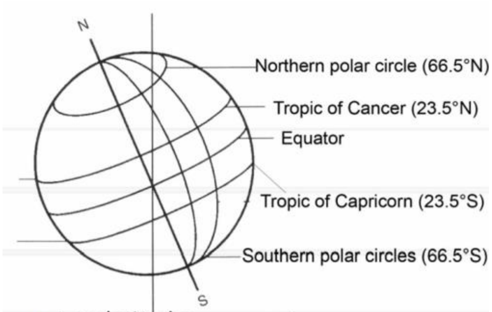
Latitude is defined as a measurement of distance in degrees north and south of the equator

The word latitude is derived from the Latin word,“latus”,meaning “wide.”

There are 90 degrees of latitude from the equator to each of the poles, north and south.

Latitude lines are parallel, that is they are the same

These lines are sometimes referred to as parallels



- Low latitudes: 0-30°N/S
- **Mid-latitudes: 30°N/S-60°N/S**
- **High latitudes:>60°N/S**

KOPPEN CLIMATE CLASSIFICATION SYSTEM

Koppen has classified the climate into 5 types.

- A CLIMATES _ TROPICAL WARM AND WET
- B CLIMATES _ DRY OR ARID
- C CLIMATES _ SEA OR MARITIME
- D CLIMATES _ CONTINENTAL
- E CLIMATES _ POLAR

I. A CLIMATES _ TROPICAL WARM AND WET

- Near equator the sun is at high angle and its low pressure area. Often it rains and warm around.
- Avearge temperature per month at least 18 ºc.

II. B CLIMATES _ DRY OR ARID

- Away from equator its warm, dry and desert type and these are high pressure areas.
- Maximum 400 mm precipitation.

III. C CLIMATES _ SEA OR MARITIME

Colder than 18 ºc in coldest month but warmer than -3 degrees.

IV. D CLIMATES _ CONTINENTAL

- Coldest month colder than -3 degrees on average.

V. E CLIMATES _ POLAR

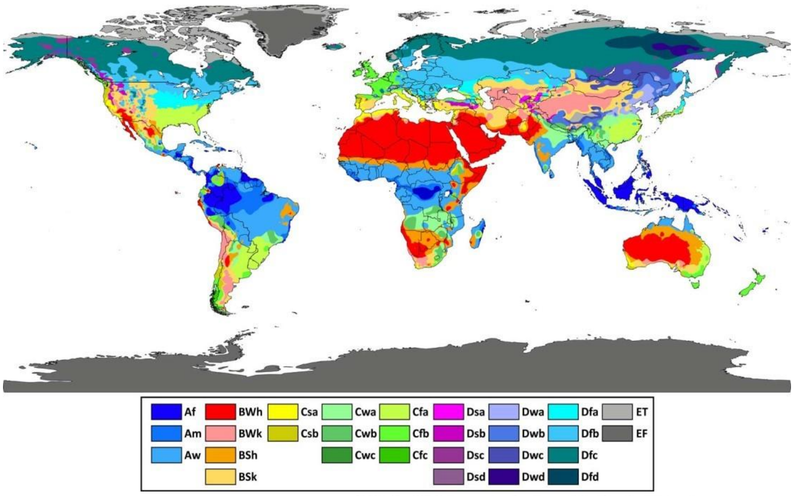
- Warmer month is on average colder than 10 ºc.

Sub Climates

Ef _ Always frost, only snow, nothing grows, **Et** _ Tundra, no trees

Bs _ Semi-arid, 200-400mm precipitation, **Bw** _ Desert, maximum 200mm precipitation

Af _ Year round precipitation, **Aw** _ Winter drought, **As** _ Summer drought.



Climatic Groups According to Koeppen

Group	*Characteristics*
A - Tropical	Average temperature of the coldest month is 18° C or higher
B - Dry Climates	Potential evaporation exceeds precipitation
C - Warm Temperate	The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3°C but below 18°C
D - Cold Snow Forest Climates	The average temperature of the coldest month is minus 3° C or below
E - Cold Climates	Average temperature for all months is below 10° C
H - High Land	Cold due to elevation

Atkinson classification, which has 4 major climate types

Cold

Temperate

Hot dry

Warm humid.

Apart from this, another climate type is added, which is a Composite.

Composite-a location does not have a regular climate pattern, or a similar pattern for more than 2 months,

- it may be too cold in winter, too hot in summer.
- Sometimes, it is too rainy as warm humid climates.
- 2 to 3 months the climate pattern or characteristic, of that location keeps changing.

City like Hydrabad, Delhi ,lucknow, Nagpur are the examples for composite climate

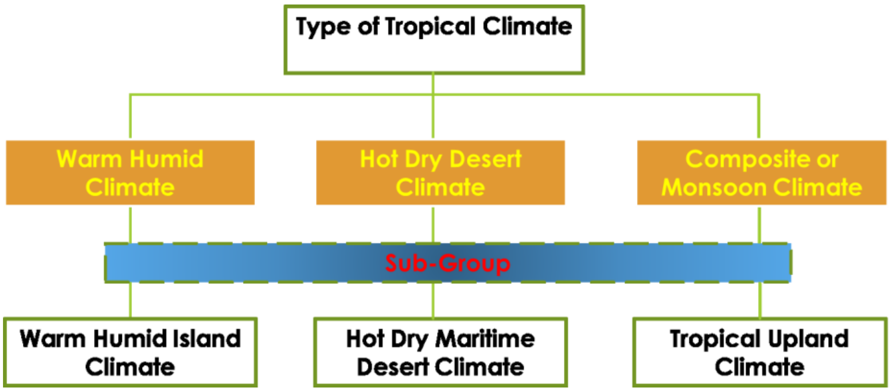
The classification given below was suggested by G A Atkinson in 1953.

The basis of this classification is given by the two atmospheric factors which dominantly influence human comfort:Air temperature,Humidity.

The main criterion is: what **extremes** of these **two factors** are likely to **cause discomfort**.

Accordingly the tropical regions of earth are divided into three, major climatic zones and three subgroups:

Tropical Climate and its Types



Characteristics of Tropical Climate

A tropical climate is a kind of climate typically in the tropics

- Defined as non-arid climate in which all 12 months have mean temperature above 64.4 °F (18.0 °C)
- Cover the largest area of earth (20% of land surface and 43% of ocean surface) - the home to almost half of the world 's population
- South Florida, The Caribbean, Central Africa, Coastal India, Southeast Asia, North Queensland, Hawaii, Central America, or most of Brazil.
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Warm humid island climate Islands within the equatorial belt and in the trade wind zone belong to this **climate** type. **Humidity** levels are usually very high all year round.

Hot Dry Maritime Desert Climate

These climates occur in two belts at latitudes between approximately 15 and 30° north and south of the Equator.There are two seasons: a **hot** one and somewhat **cooler one**. Air temperature, i.e. DBT, in the shade reaches a day-time mean maximum of about 38°C, but in the cool season it remains between 21 and 26°C.

Tropical Upland Climate

These climates usually occur in large land masses near the tropics of Cancer and Capricorn, which are sufficiently far from the Equator to experience marked seasonal changes in solar radiation and wind direction.

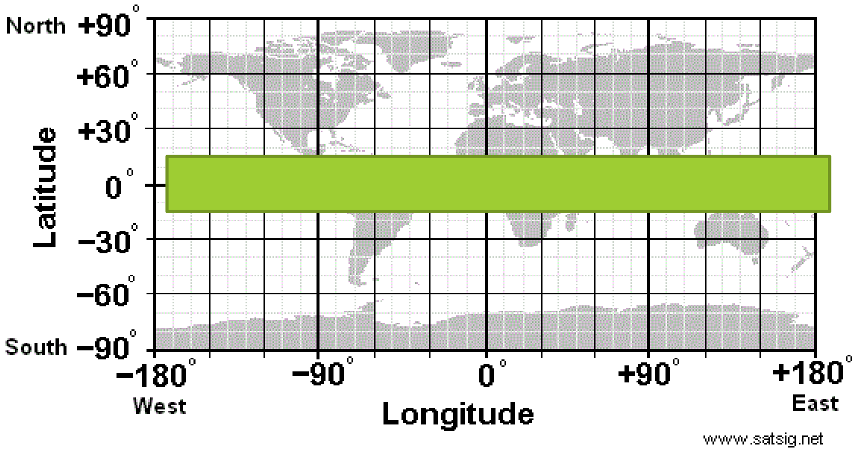
monthly mean temperatures above **18 °C (64 °F)** in every month of the year and a dry season.

Tropical monsoon climates is the intermediate **climate** between the wet Af (or **tropical** rainforest **climate**) and the drier Aw (or **tropical** savanna **climate**).

Warm-humid climates are found in a belt near the **Equator extending to about 15°N and S.** Examples of cities in this zone: Lagos, Dar-es-Salam, Mombasa, Colombo, Singapore, Jakarta, Quito and Pernambuco.

Southern parts of India

There is very **little seasonal variation throughout the year**, the only punctuation being that of periods with more or less rain and the occurrence of gusty winds and electric storms.



Air temperature :DBT, in the shade reaches a mean maximum **during the day of between 27 and 32 °C,** but occasionally it may exceed the latter value. At night the mean minimum varies **between 21 and 27 °C.** Both the diurnal and annual ranges of temperature are quite narrow.

Humidity :RH, **remains high,** at **about 75% for most of the time, but it may vary from 55 to almost 100%.**Vapour pressure is steady in the region of **2500 to 3000 N/m2**.

Precipitation : It is high throughout the year, generally **becoming more intense for several consecutive months**. Annual rainfall can vary from 2000 to 5000 mm and may exceed 500 mm in one month, the wettest month. During severe storms rain may fall at the rate of 100 mm/h for short periods.

Sky conditions: It is **fairly Cloudy throughout the year. Cloud cover varies between 60 and 90%.** Skies can be bright, a luminance of 7000 cd/m2 or even more when it is thinly overcast, or when the sun illuminates white cumulus clouds without itself being obscured. When heavily overcast, the sky is dull, 850 cd/m2 or less.

Solar radiation:partly reflected and partly scattered by the cloud blanket or the high vapour content of the atmosphere, therefore the radiation reaching the ground is diffuse, but strong, and can cause painful sky glare. Cloud and vapor content also prevents or reduces outgoing radiation from the earth and sea to the night sky, thus the accumulated heat is not readily dissipated.

Wind velocities: Typically low, **calm periods are frequent, but strong winds can occur during rain squalls**. Gusts of 30 m/s have been reported. **There are usually one or two dominant directions.**

Special characteristics:high humidity accelerates mould and algal growth, rusting and **rotting.Organic building materials tend to decay rapidly. Mosquitoes and other insects abound**. The thunder-storms are accompanied by frequent air-to- air electrical discharges.

Vegetation: Vegetation **grows quickly** due to **frequent rains and high temperatures and it is difficult to control**. The red or brown laterite soils are generally poor for agriculture. Plant-supporting organic substances and mineral salts are dissolved and washed away by rain-water. **The subsoil water table is usually high** and the ground may be waterlogged. Little light is reflected from the ground.

Warm-humid island climate

Islands within the equatorial belt and in the trade-winds zone belong to this climate type. Typical examples are the Caribbeans,the Philippines and other island groups in the Pacific Ocean.

Hot-dry desert climate

These climates occur in two belts at latitudes between approximately 15 and 30° north and south of the Equator. Examples of settlements in this zone: Baghdad, Alice Springs, and Phoenix.

Two marked seasons occur: **a hot and a somewhat cooler period.**

Air temperature:DBT, in the shade rises quickly after sunrise to a day-time **mean maximum** of **43 to 49 °C**. The ever-recorded maximum temperature of 58 °C was measured in Libya in 1922. During the **cool season the mean maximum temperature ranges from 27 to 32 °C.** Night-time mean minima are between 24 and 30°C in the hot season and between 10 and 18°C in the cool season. **The diurnal range is very great: 17 to 22 degC.**

Humidity:the RH, varies from **10 to 55%,** as the wet-bulb depression is large (rapid evaporation). The vapour pressure is normally between **750 and 1 500 N/m2**

Precipitation: It is slight and variable throughout the year, from **50 to 155 mm** per annum. Flash-storms may occur over limited areas with as much as **50 mm rain** in a few hours, but some regions **may not have any rain for several years.**

Sky conditions: Sky conditions are **normally clear.** Clouds are few due to the low humidity of the air. The sky is usually dark blue, with a luminance **of 1700 to 2500 cd/m2** ,and further darkened during dust or sand-storms to 850 cd/m2 or even less. Towards the end of the hot period, dust suspended in the air may create a white haze, with a luminance of 3500 to 10000 cd/m2 , which produces a diffuse light and a painful glare.

Solar radiation: is **direct and strong during the day,** but the absence of cloud permits easy release of the heat stored during the day-time in the form of l**ong-wave radiation towards the cold night sky.** Diffuse radiation is only present during dust haze periods.

Wind velocities: Winds are usually local. The heating of air over the hot ground causes a temperature inversion, and as the lower warm air mass breaks through the higher cooler air, local whirlwinds are often created. **Winds are hot, carrying dust and sand – and often develop into dust-storms**

Special characteristics:during certain **months dust and sand-storms may be frequent**. The high day-time temperatures and **rapid cooling at- night** may cause materials to crack and break up.

Vegetation: Vegetation is **sparse and difficult to maintain because of the lack of rain and low humidities.** The soil is usually dusty and very dry. Strong sunlight illuminating a highly reflective light coloured and dry ground can create a luminance of 20000 to 25000 cd/m2 . Soils dry quickly after rain and would generally be fertile if irrigated. The **subsoil water-table is very low.**

Hot-dry maritime desert climate

Maritime desert climates occur in the same latitude belts as the hot-dry desert climates, where the sea adjoins a large land mass. These are regarded to be amongst the most unfavourable climates of the earth. Typical examples are Kuwait, Antofagasta and Karachi. There are **two seasons: a hot one and somewhat cooler one.**

Composite or monsoon climate

These climates usually occur in large land **masses near the tropics of Cancer and Capricorn, which are sufficiently far from the Equator to experience marked seasonal** changes in solar radiation and wind direction.

Examples of cities with composite climates: Lahore, Mandalay, Asuncion, Kano and **New Delhi.**

Two seasons occur normally. Approximately **two-thirds of the year is hot-dry and the other third is warm-humid.** Localities further north and south often have a third season, best described as cool-dry.

Air temperature, i.e. DBT

seasons	*hot-dry*	*warm-humid*	*cool-dry*
Day-time mean max.	32–43°C	27–32°C	up to 27°C
Night-time mean min.	21–27°C	24–27°C	4–10°C
Diurnal mean range	11–22 degC	3–6 degC	11–22 degC

Humidity: the RH, is low throughout the dry periods at **20 to 55%,** with a vapour pressure of 1300 to 1 600 N/m2 . During the wet period it rises to 55 to 95%, with a vapour pressure of 2000 to 2500 N/m2

Precipitation: the monsoon rains are intense and prolonged; occasionally **25 to 38 mm can fall in an hour.** Annual rainfall varies from 500 to 1300 mm with 200 to 250 mm in the wettest month. **There is little or no rain during the dry seasons.**

Solar radiation: Solar radiation **alternates between conditions found in the warm-humid and the hot-dry desert climates.**

Wind velocities : Winds are **hot and dusty during the dry period.** Directional changes in the **prevailing winds at the beginning of the warm-humid season bring rain-clouds and humid air from the sea**. Monsoon winds are fairly strong and steady.

Special characteristics :seasonal changes in relative humidity cause rapid weakening of building materials. Dust and sand-storms may occur. Termites are common. **Occasional condensation problems.**

Vegetation : is sparse – characteristic of a hot-dry region – **with brown and red barren ground, changes rapidly and dramatically with the rain**. The landscape becomes green and fertile within a few days. **Plants grow quickly. In the cooler period vegetation covers the ground, but diminishes**

as the temperature rises. The soil is damp during the rains but it dries out quickly. There is a risk of soil erosion during monsoons. In the dry season strong ground glare may be experienced.

The composite climate displays the characteristics of hot and dry, warm and humid, as well as cold climate. Designs here are guide by longer prevailing climatic condition. This zone covers the central part of India – cities like New Delhi, Chandigarh, Kanpur and Allahabad.

TROPICAL UPLAND CLIMATE

Mountainous regions and plateau more than **900 to 1 200 m above** sea-level experience such climates, between the two 20°C isotherms.

Examples of cities in such regions: **Addis Ababa, Bogota, Mexico City and Nairobi.**

Seasonal variations are small in upland climates near the Equator, but when further away from the Equator, the seasons follow those of the nearby lowlands.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

UNIT – 2– VENTILATION AND DAYLIGHTING – SARA1303

VENTILATION

FUNCTIONS OF VENTILATION

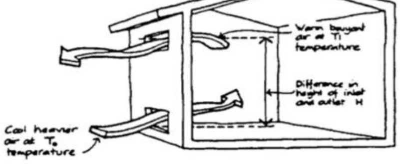
- It has three distinctly different functions:
    - supply of fresh air
    - convective cooling
    - physiological cooling
- There is a radical difference in the form of provisions for 1 and 2 and for 3: therefore, the first two functions will be considered as ‘ventilation’ but the last function is considered separately as ‘air movement’

SUPPLY OF FRESH AIR

- The requirements of fresh air supply are governed by the type of occupancy, number and activity of the occupants and by the nature of any processes carried out in the space
- For natural ventilation usually certain limited solutions are prescribed and not the expected performance. The provision of ‘permanent ventilators’, i.e. of openings which cannot be closed, may be compulsory. These may be grilles or ‘air bricks’ built into a wall, or may be incorporated with windows. The size of open-able windows may be stipulated in relation to the floor area or the volume of the room.
- The aim of all these rules is to ensure ventilation, but the rigid application of such rules may often be inadequate. To ensure a satisfactory performance of the principles involved must be clearly understood.

CONVECTIVE COOLING

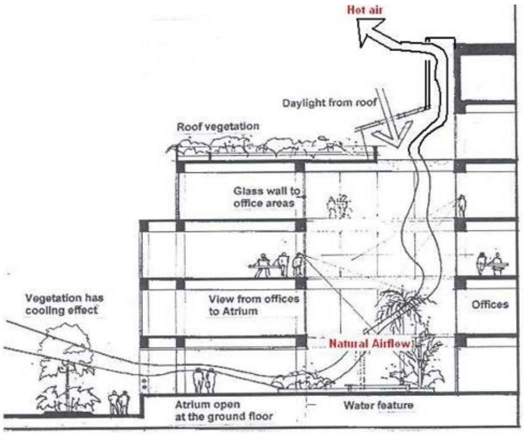
- The exchange of indoor air with fresh out-door air can provide cooling, if the out-door air is at a lower temperature than the indoor air. The moving air acts as a heat carrying medium.
- A situation where this convective cooling is a practical proposition, can arise in moderate or cold climates, when the internal heat gain is causing a temperature increase, but also in warm climates, when the internal heat gain or solar heat gain through windows would raise the indoor temperature even higher than the out-door air temperature.

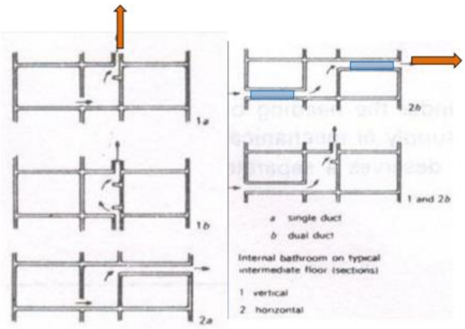


FUNCTIONS OF VENTILATION

- Ventilation i.e. both the supply of fresh air and convective cooling, involves the movement of air at a relatively slow rate. The motive force can be either thermal or dynamic (wind).
- The stack effects relies on thermal forces, set up by density difference (caused by temperature differences) between the indoor and out-door air. It can occur through an open window (when the air is still): the warmer and lighter indoor air will flow out at the top and the cooler, denser out-door air will flow in at the bottom.

- Special provision can be made for it in the form of ventilating shafts. The higher the shaft and the larger the cross- sectional area will have the greater temperature difference: the greater the motive force therefore, the more air will be moved.





Ventilation duct arrangements

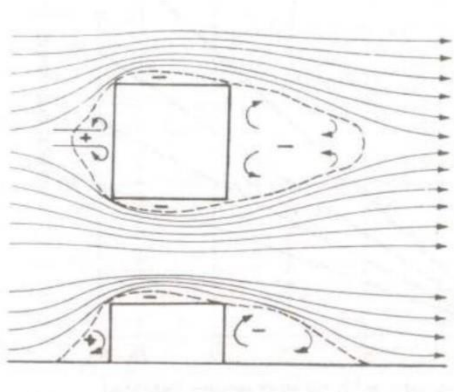
. **Figure above-** shows some duct arrangements for multistory buildings, with vertical or horizontal single or double duct systems.

PHYSIOLOGICAL COOLING

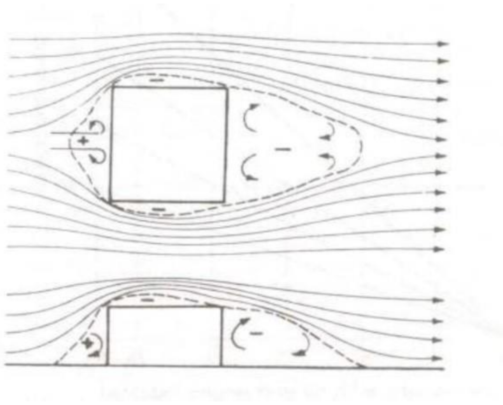
- The movement of air passing the skin surface accelerates heat dissipation in two ways
  - increasing convective heat loss
  - Accelerating evaporation
- In very low humidities (below 30%) this cooling effect is not great, as there is an unrestricted evaporation even with very light air movement. In high humidities (above 85%) the cooling effect is restricted by the high vapour pressure preventing evaporation greater velocities (above 1.5 to 2 m/s) will have some effect.
- It is most significant in medium humidities (35 to 60%). Cooling by air movement is most needed where there are no other forms of heat dissipation available, when the air is as warm as the skin and the surrounding surfaces are also at a similar temperature.

WIND SHADOW

- Air – although light – has a mass (around 1.2 kg/m3), and as it moves, has a momentum, which is the product of its mass and its velocity(kg m/s). When moving air strikes an obstacle such as a building this will slow down the air flow, but the air flow will exert a pressure on the obstructing surface. This pressure is proportionate to the air velocity, as expressed by the equation
  - $Pw = 0.612 \times v^2$
- Where Pw = wind pressure in N/m2, V = wind velocity in m/s (the constant is Ns^2/m^4)
- The slowing down process effects a roughly wedge-shaped mass of air on the windward side of the building, which in turn diverts the rest of the air flow upwards and sideways. A separation layer is formed between the stagnant air and the building on the one hand and the laminar air flow on the other hand.



The laminar air flow itself may be accelerated at the obstacle, as the area available for the flow is narrowed down by the obstacle. As shown in the fig.



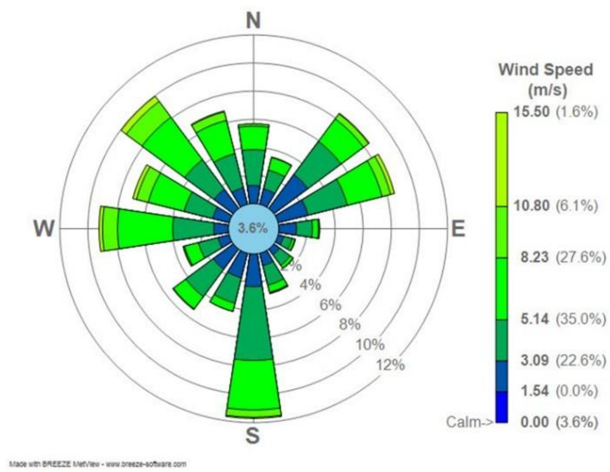
- At the separation layer, due to friction, the upper surface of the stagnant air is moved forward, thus a turbulence or vortex is developed. Due to its momentum, the laminar air flow tends to maintain a straight path after it has been diverted, therefore it will take some time to return to the ground surface after the obstacle, to occupy all the available 'cross-section'. Thus a stagnant mass of air is also formed on the leeward side, but this is at a reduced pressure. In fact, this is not quite stagnant: a vortex is formed, the movement is light and variable and is often referred to as **'WIND SHADOW'.**

WIND PRESSURE

Consequently, vortexes are formed wherever the laminar flow is separated from the surfaces of solid bodies. On the windward side such vortexes are at an increased pressure and on the leeward side at a reduced pressure. If the building has an opening facing a high pressure zone and another facing a low pressure zone, air movement will be generated through the building.

THE WIND ROSE

- Wind speed frequency diagrams do not provide information on the direction that the wind is blowing. This is often done by a graph called a "wind rose."
- A wind rose is a polar plot giving the direction, magnitude, and cube of the magnitude of the wind. The data is usually averaged over a year. In some cases, shorter time periods, such as months, may be appropriate.



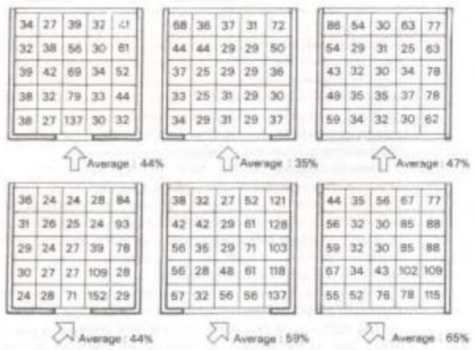
AIR FLOW THROUGH BUILDINGS

- As no satisfactory and complete theory is available, air flow patterns can only be predicted on

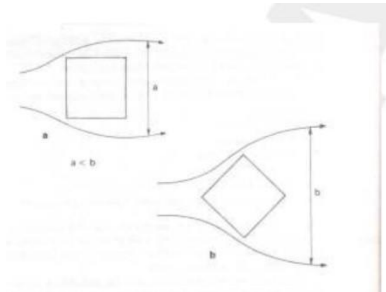
the basis of empirical
rules derived from measurements in actual buildings or in wind tunnel studies.

- On the basis of such experimental observations the following factors can be isolated which affect the indoor air flow (both patterns and velocities) :
    - Orientation
    - External features
    - Cross-ventilation
    - Position of openings
    - Size of openings
    - Controls of openings

ORIENTATION



- The greatest pressure on the windward side of a building is generated when the elevation is at right angles to the wind direction, so it seems to be obvious that the greatest indoor air velocity will be achieved in this case. A wind incidence of 45⁰ would reduce the pressure by 50%.
- Thus the designer must ascertain the prevailing wind direction from wind frequency charts of wind rose and must orientate his building in such a way that the largest openings are facing the wind direction.
- It has, however, been found that a wind incidence at 45⁰ would increase the average indoor air velocity and would provide a better distribution of indoor air movement.



Effect of direction on width of wind shadow

- It often happens that the optimum solar orientation and the optimum orientation for wind do not coincide. In equatorial regions a north-south orientation would be preferable for sun exclusion but most often the wind is predominantly easterly.
- The usefulness of the above findings is obvious for such a situation – it may resolve the contradictory requirements.

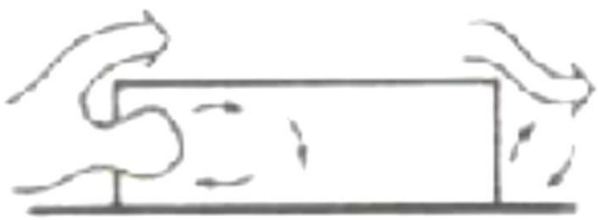
EXTERNAL FEATURES

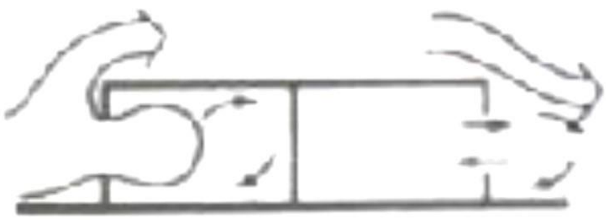
- Wind shadows created by obstructions upwind, should be avoided in positioning the building on the site and in positioning the openings in the building. The wind velocity gradient is made steeper by an uneven surface, such as scattered buildings, walls fences, trees or scrub – but even with a moderate velocity gradient, such as over smooth and open ground, a low building can never obtain air velocities similar to a taller one.

- For this reason (or to avoid specific obstructions) the building is often elevated on stilts. External features of the building itself can strongly influence the pressure build-up. For example, if the air flow is at 45º to an elevation, a wing-wall at the downwind end or a projecting wing of an L-shaped building can more than double the positive pressure created.
- A similar '**funnelling'** effect can be created by upward projecting eaves. Any extension of the elevational area facing the wind will increase the pressure build-up. If a gap between two buildings is closed by a solid wall, a similar effect will be produced.
- The air velocity between free-standing trunks of trees with large crowns can be increased quite substantially due to similar reasons. The opposite of the above means will produce a reduction of pressures: if a wing wall or the projecting wing of an L-shaped building is upwind from the opening considered, the pressure is reduced or even a negative pressure may be created in the front of the window.

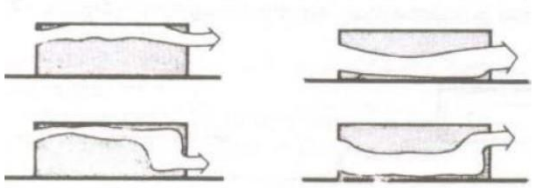
CROSS VENTILATION

- Figure shows that in the absence of an outlet opening or with a full partition there can be no effective air movement through building even in case of strong winds. With a windward opening and no outlet, a pressure similar to that in front of the building will be built up indoors, which can make condition even worse, increasing discomfort.
- In some cases oscillating pressure changes, known as 'buffeting' can also occur. The latter may also be produced by an opening on the leeward side only, with no inlet. Air flow loses much of its kinetic energy each time it is diverted around or over an obstacle.
- Several right angle bends, such as internal walls or furniture within a room can effectively stop a low velocity air flow . Where internal partitions are unavoidable, some air flow can be ensured if partition screens are used, clear of the floor and the ceiling.

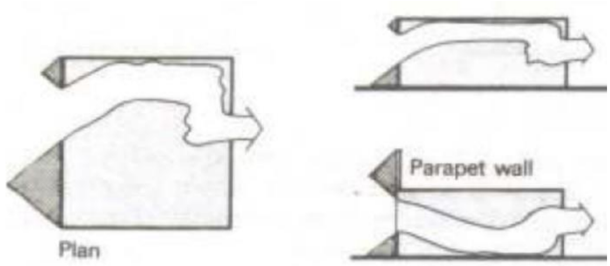




POSITION OF OPENINGS



- The relative magnitude of pressure build-up in front of the solid areas of the elevation (which in turn depends on the size and position of openings) will, in fact, govern the direction of the indoor air stream and this will be independent of the outlet opening position.



- Figure shows that Larger solid surface creates a larger pressure build-up and this pushes the air stream in an opposite direction, both in plan and in section.
  To be effective, the air movement must be directed at the body surface. In building terms this means that air movement must be ensured through the space mostly used by the occupants: through the 'living zone' (up to 2m high).
- As the figure shows If the opening at the inlet side is at high level, regardless of the outlet opening position, the air flow will take place near the ceiling and in the living zone.
- As a result of this, in a two storey building the air flow on the ground floor may be satisfactory but on the upper floor it may be directed against the ceiling. One possible remedy is an increased roof parapet wall.

<u>SIZE OF OPENINGS</u>

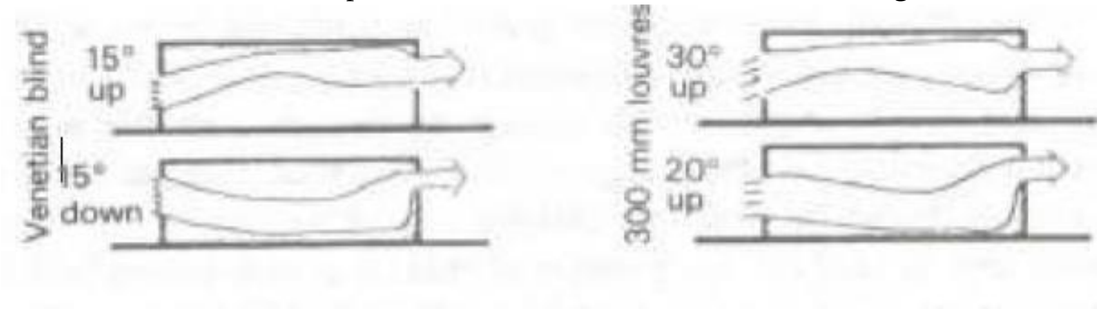
- With an given elevational area – a given total wind force(pressure x area) – the largest air velocity will be obtained through a small inlet opening with a large outlet.
- This is partly due to the total force acting on a small area, forcing air through the opening at a high pressure and partly due to the 'venturi effect': in the broadening funnel (the imaginary funnel connecting the small inlet to the large outlet) the sideways expansion of the air jet further accelerates the particles.
- Such an arrangement may be useful if the air stream is to be directed (as it were focused) at a given part of the room. When the inlet opening is large, the air velocity through it will be less, but the total rate of air flow (volume of air passing in unit time) will be higher.
- Such an arrangement may be useful if the air stream is to be directed (as it were focused) at a given part of the room. When the inlet opening is large, the air velocity through it will be less, but the total rate of air flow (volume of air passing in unit time) will be higher.

<u>CONTROLS OF OPENINGS</u>

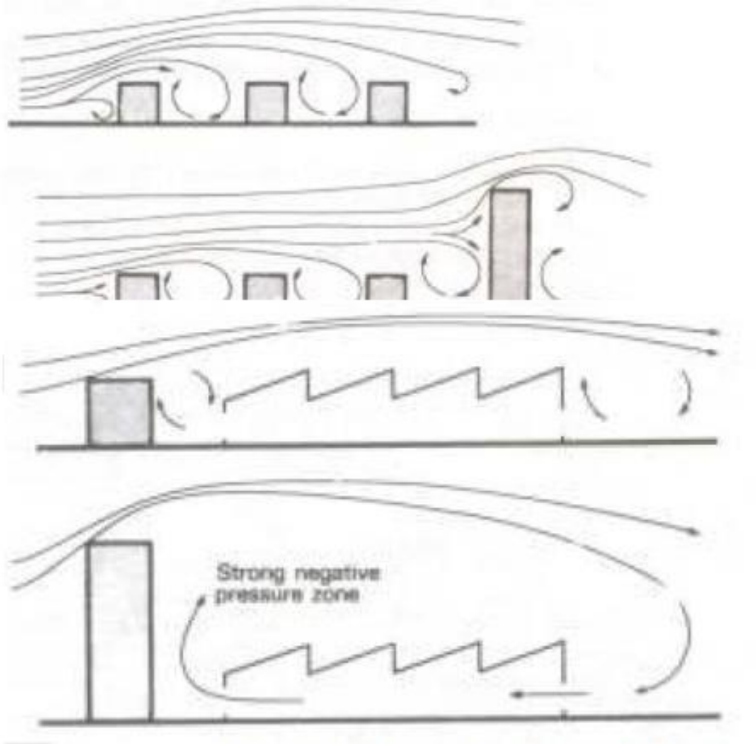
- **Sashes, canopies, louvers and other elements controlling the openings, also influence the indoor air flow pattern.**
- Sashes can divert the air flow upwards. Only a casement or reversible pivot sash will channel it downwards into the living zone.

Effect of sashes

Canopies can eliminate the effect of pressure build-up above the window, thus the pressure below the window will direct the air flow upwards. A gap left between the building face and the canopy would ensure a downward pressure, thus a flow directed into the living zone.



Effect of louvres



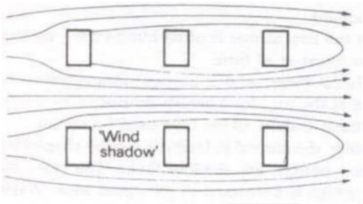
Reverse flow behind a tall block

AIR FLOW AROUND BUILDINGS

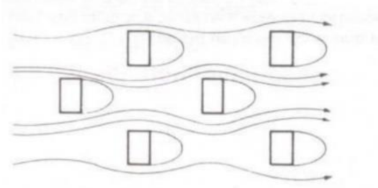
- When the architect's task is the design of more than one building, a cluster of buildings or a whole settlement, especially in a warm climate, in deciding the layout, provision for air movement must be one of the most important considerations. After a careful analysis of site climatic conditions a design hypothesis may be produced on the basis of general information derived from experimental findings, such as those described below.
  If there are tall blocks in mixed developments air stream separates on the face of a tall block, part of it moving up and over the roof part of it down, to form a large vortex leading to a very high pressure build-up. An increased velocity is found at ground level at the sides of the tall block. This could serve a useful purpose in hot climates, although if the tall block is not fully closed but is permeable to wind, these effects may be reduced.
- If a low building is located in the wind shadow of a tall block, the increase in height of the obstructing block will increase the air flow through the low building in a

direction opposite of that wind. The lower (return-) wing of a large vortex would pass through the building

- If single storey buildings are placed in rows in a grid-iron pattern, stagnant air zones leeward from the first row will overlap the second row.
- A spacing of six times the building height is necessary to ensure adequate air movement for the second row.
- In a similar setting, if the buildings are staggered in a checker-board pattern, the flow field is much more uniform, stagnant air zones are almost eliminated.



Air flow grid-iron layout

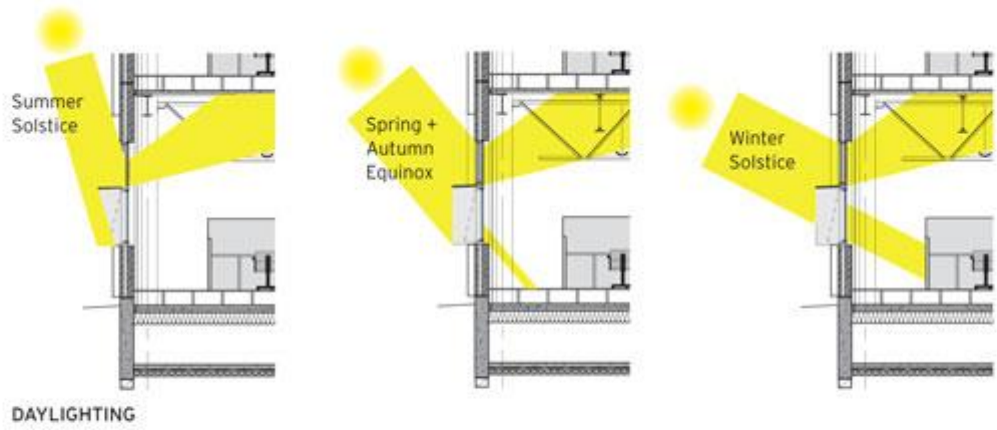

Air flow checker-board layout

DAYLIGHTING

Light is a form of energy manifesting itself as electromagnetic radiation such as radio waves, radar, microwaves, infrared and ultraviolet radiation and X-rays.
The only difference between the several forms of radiation is in their wavelength. Radiation with a wavelength between 400 to 700 nanometres forms the visible part of the electromagnetic spectrum, and is therefore referred to as light.
The eye interprets the different wavelengths within this range as colours – moving from red, through orange, green, blue to violet as wavelength decreases. Beyond red is infrared radiation, which is invisible to the eye but detected as heat.
At wavelengths beyond the violet end of the visible spectrum there's ultraviolet radiation that is also invisible to the eye, although exposure to it can damage the eye and the skin (as in sunburn).
Light is a part of electromagnetic spectrum; it is a visible portion this is the only thing human eye can see.

DAYLIGHTING

- If the **building envelope** is thought of as a **barrier between the internal, controlled environment** and the **external, perhaps undesirable conditions**, it must be realised that it should be a **selective barrier, or rather a filter,** which excludes the unwanted influences whilst admits those which are desirable. One such desirable effect is **daylight.**
- Perhaps the most important communication channel of man with his environment is vision. The eye is stimulated by light reflected from objects, thus light is a prerequisite of seeing.
- Light can be produced artificially (e.g. electric light), but if it is available – as it were 'free of charge' – it should be utilized.



Importance of day lighting

- **The two primary reasons for using daylight** to meet the illumination requirements of an architectural space are the **psychological benefits** and the **energy savings benefits**.
- Good day lighting has been shown to improve the overall satisfaction and wellbeing of building occupants.

Energy saving benefits

- Day lighting, with proper electric lighting controls, can result in significant energy savings by reducing electric lighting loads and associated cooling loads.
- In addition, with proper solar control, solar gains during cooling load periods can be mitigated and solar gains during heating load periods can be utilized, reducing the energy requirements of both cooling and heating a space.

Psychological benefits

- A number of research studies have shown a variety of benefits of day lighting in different building types and functions, like:
- improved retail sales in big stores,
- increased worker productivity and reduced absenteeism in office buildings,
- improved student educational performance in schools,
- And improved patient recovery times in hospitals.
- Exposure to daylight has also been shown to improve general health and circadian rhythm.
- These psychological benefits can easily justify any extra design effort or added expense associated with introducing controlled daylight into buildings.

Characteristics of light : transmission, reflection, diffusion, glare

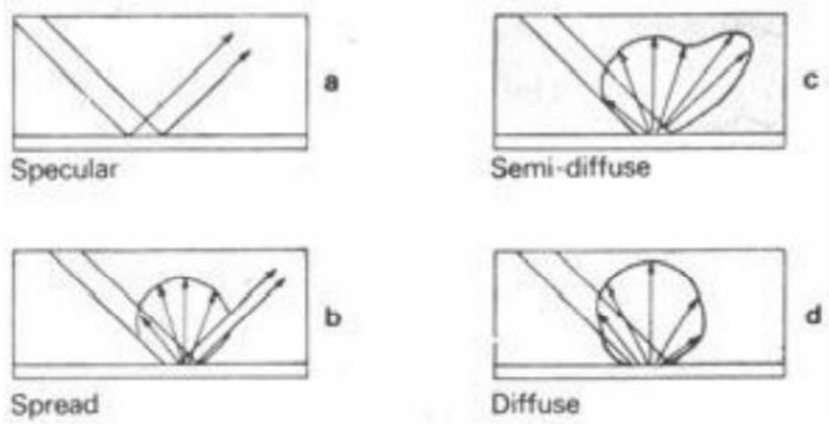
- **TRANSMISSION:** Some materials when exposed to light, transmit a large part of it - these are referred to as **'transparent'.**
- Others, the 'opaque' materials, block the passage of light. Behind an opaque object there will be no light (no direct light), i.e. it will cast a shadow.

- The term **'translucent'** is applied to materials which transmit a part of the incident light, but break its straight passage, scatter it in all directions, creating 'diffuse' light.
- Light incident on an object can be distributed three ways: **reflected, absorbed and transmitted.**

Reflection

- If parallel rays of incident light remain parallel after reflection from a surface, the surface is a 'plane mirror' and of 'specular reflection'.-The rules of geometrical optics apply to such surfaces: the angle of reflection is the same as the angle of incidence.

- Light reflected from a matt surface will be diffused .Most often a mixture of the two kinds of reflections will occur, termed as 'semi-diffuse' or 'spread' reflection.



ABSORPTION

If the material's surface is not entirely reflecting or the material is not a perfect transmitter, part of the light will be absorbed. It 'disappears' and is basically converted into heat. **The percentage of light absorbed by a surface (i.e. absorbance) depends on both the angle of incidence, and on the wavelength.**

Wood is opaque to visible light. Some materials are opaque to some frequencies of light, but transparent to others. Glass is opaque to ultraviolet radiation below a certain wavelength, but transparent to visible light.

Glare is an important factor affecting the quality of lighting.

Glare: Bright light which interferes with visual perception is called glare. An overly bright area in our field of vision reduces our ability to perceive for visual information.

Different Types of Glare caused by a bright object directly in our field of vision is called direct glare.

Glossy or polished surfaces, which reflect the image of a bright object, produce reflected glare.

According to the way glare is produced, it can be divided into **direct glare** and **indirect glare**.

GLARE may also be caused by a saturation effect, even without any contrast, when the average luminance exceeds about 25000 cd/m2 .

According to the senses of the human body, glare can be divided into **discomfort glare**(in a less severe case) and **disability glare** (in a severe situation).

Uncomfortable glare will cause **visually unpleasant** and **uncomfortable feeling**;

disability glare is the glare that can temporarily or even permanently **reduce a person's visual function**.

Sources of light

The ultimate source of daylight is, of course, the sun, but the light arriving at the earth from the sun may be partly diffused by the atmosphere and the locally prevailing atmospheric conditions will determine how this light will reach a building.

the Design Sky illuminance levels in different latitudes. The Design Sky illuminance levels "represent the horizontal illuminance value of the time between the hours of 9am and 5pm at least for 85 % of the time.

In India -National codes suggests around 8000 lux as design sky illuminance.

Daylighting requires illumination from exterior environment. The first step is to determine

the light levels outside the building.
Daylight comes from not just direct sunlight but also from illumination from the sky on overcast days.

The daylight factor concept

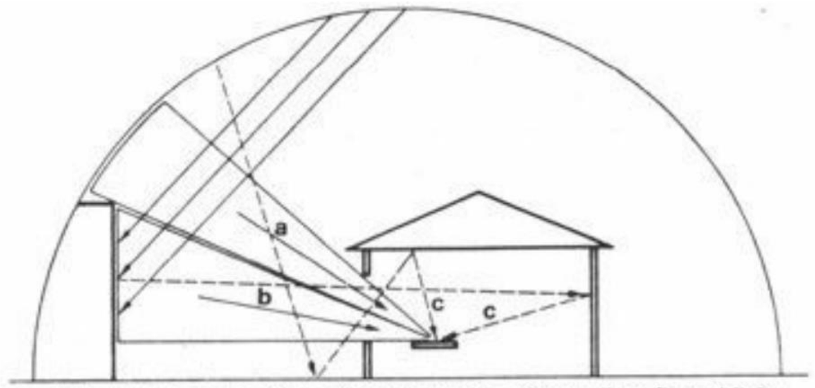
Due to the variability of out-door lighting levels it is difficult to calculate interior lighting levels. However, in a given building, at a certain point, the ratio of the illumination to the simultaneous out-door illumination can be taken as constant.
This constant ratio, expressed as a percentage, is the daylight factor (DF):

DF =Ei /Eo × 100 (%)

where Ei = illumination indoors, at the point taken
Eo = illumination out-doors from an unobstructed sky hemisphere

Apart from the **direct component - design sky illuminants.**

a. diffused or skylight, through a window or opening **(sky component)**
b. **externally reflected light** (by the ground or other buildings), through the same windows
c. **internally reflected light from walls,** ceiling or other internal surfaces.
d. **direct sunlight,** along a straight path from the sun, through a window to the given point
e. sky component (SC)
f. externally reflected component (ERC)
g. internally reflected component (IRC)
h. **Thus: DF = SC +ERC +IRC**



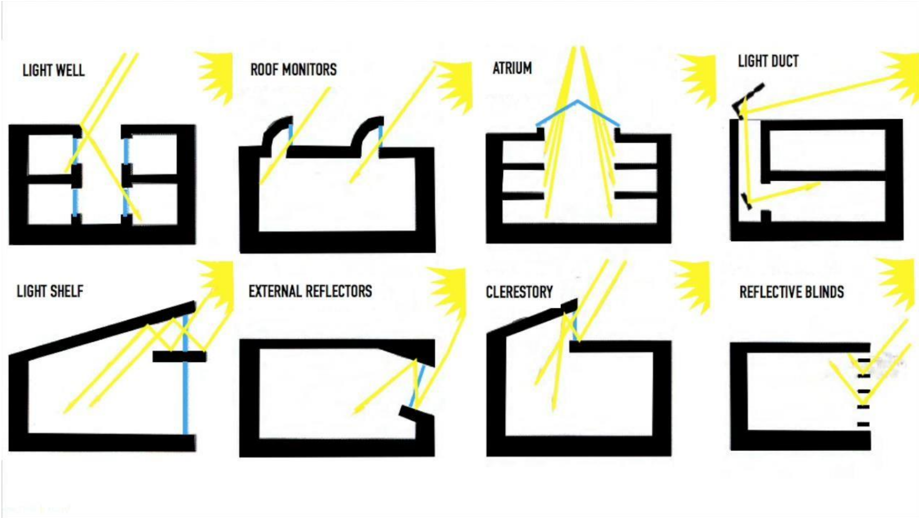
a = skylight , b = externally reflected light c = internally reflected light

The magnitude of each of these components depends on the following **design variables:**

a. **SC** - the area of sky visible from the point considered and its average altitude angle (i.e. the luminance of sky at that angle), therefore: window size and position in relation to the point, thickness of window frame members, quality of glass and its cleanness, any external obstructions.
b. **ERC** - the area of external surfaces visible from the point considered and the reflectance of these surfaces.
c. **IRC** - the size of room, the ratio of wall, etc., surfaces in relation to window area and the reflectance of these indoor surfaces.

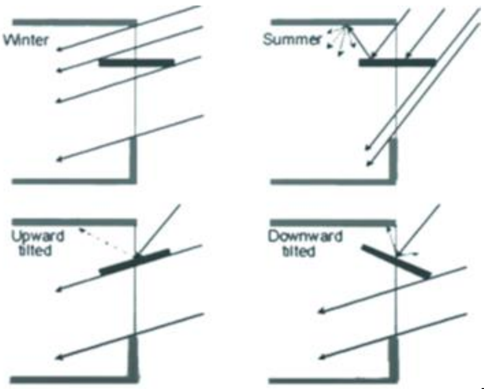
Basic principles of effective daylight design

- Site Orientation
- Building Form
- Glazing ratio
- Glazing Specification
- Roof lighting
- Monitor lighting
- Clearstory windows



LIGHT SHELF

Specific harnessing systems with which are strategies- To improve or enhance the amount of daylight available light which is entering the building.



Light shelf- very commonly used it can be active it can be passive.

Light Shelf- conventional and optically treated light shelves available.

- **Working principle:** split the whole glazing or window area in to two
- the **first part it caters to the peripheral areas directly then,**
- it can be also attached and used as **shading system it shades this particular glazing area from direct sunlight it improves the energy performance of your window**
- **additional advantage-** If the top surface is reflective it will get direct light reflected back and then it will re -reflected to the interior parts of it.

optically treated : for example, different times of the day winter sun versus summer sun.

- winter sun is very low get light directly.
- in summer sun is very high it gets reflected on the surface and caters into the interior parts.
- some of these things are also adjustable. It can be upward or downward tilted depending

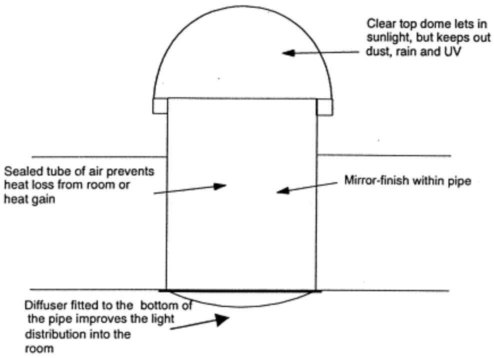
on the requirement.

- it can also incorporate specific **manual or automatic tilting facility ,**so as to adjust the amount of lighting which is required in a particular space it works in a simple principle it can extend into the building.

Daylight harvesting systems

LIGHT PIPES- which are typically day light harvesting system.

They will typically cultivate or harvest daylight on the roof top or any outside surface on they will transport it to the interiors of your building.



<u>three components</u>

1.receiving element

2.transitional portion which will have to have good reflecting surfaces. So, that in the light is simply reflected the losses are less.

3.final internal component which acts as your light source.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

UNIT – 3– SOLAR CHARTS AND SHADING DEVICES – SARA1303

Unit 3: SOLAR CHARTS AND SHADING DEVICES

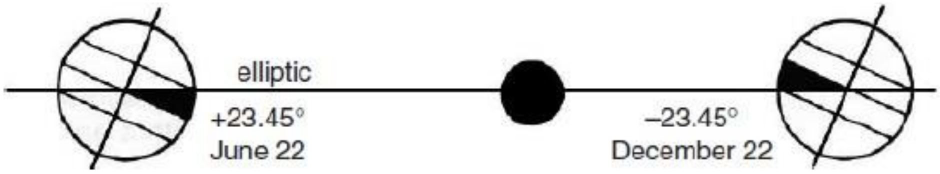
The climate of earth is driven by the energy input from the sun. For designers there are two essential aspects to understand:

- The apparent movement of the sun (the solar geometry) and
- The energy flows from the sun and how to handle it (exclude it or make use of it).

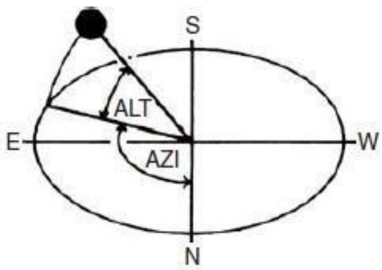
The earth moves around the sun on a slightly elliptical orbit. At its maximum **(aphelion)** the earth– sun distance is 152 million km and at its minimum **(perihelion)** 147 million km.

The earth's axis is not normal to the plane of its orbit, but tilted by 23.5◦. Consequently, the angle between the earth's equatorial plane and the earth–sun line varies during the year. This angle is known as the declination (DEC) and varies as follows:

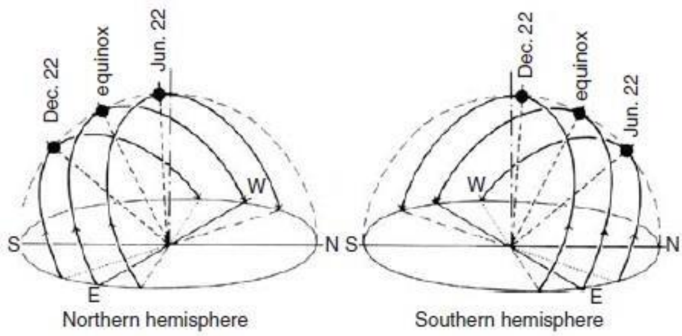
• +23.45◦ on June 22 (Northern solstice)
• 0 on March 21 and Sept. 22 (Equinox dates)
• −23.45◦ on December 22 (Southern solstice)



The sun's position can be determined by two angles
– Altitude (ALT): measured upwards from the horizon, 90◦ being the zenith
– Azimuth (AZI): measured in the horizontal plane from north (0◦), through east (90◦), south (180◦) and west (270◦) to north (360◦).



The sun has the highest orbit and will appear to be on the zenith at noon on June 22 along the Tropic of Cancer (LAT=+23.45^0) and along the Tropic of Capricorn (LAT = −23.45^0)



on December 22.

Sun Path Diagrams

There are several ways of showing the 3-D sky hemisphere on a 2-D circular diagram. The sun's path on a given date would then be plotted on this representation of the sky hemisphere as sun- path line.

In the USA the equidistant representation is used, which is not a projection method, but a set of radial coordinates with evenly spaced altitude circles on which the sun-paths are plotted.

The orthographic (or parallel) projection is the method used in technical drafting. The figure below shows how points of the hemisphere (shown at 15^0 altitude increments) would be projected onto the horizon plane, giving the positions of the corresponding altitude circles on the horizon plane. Note that the altitude circles (of equal increments) are spaced very close together near the horizon and are widely spaced nearer the zenith. Consequently, such a graph would give a rather poor resolution for low solar positions.

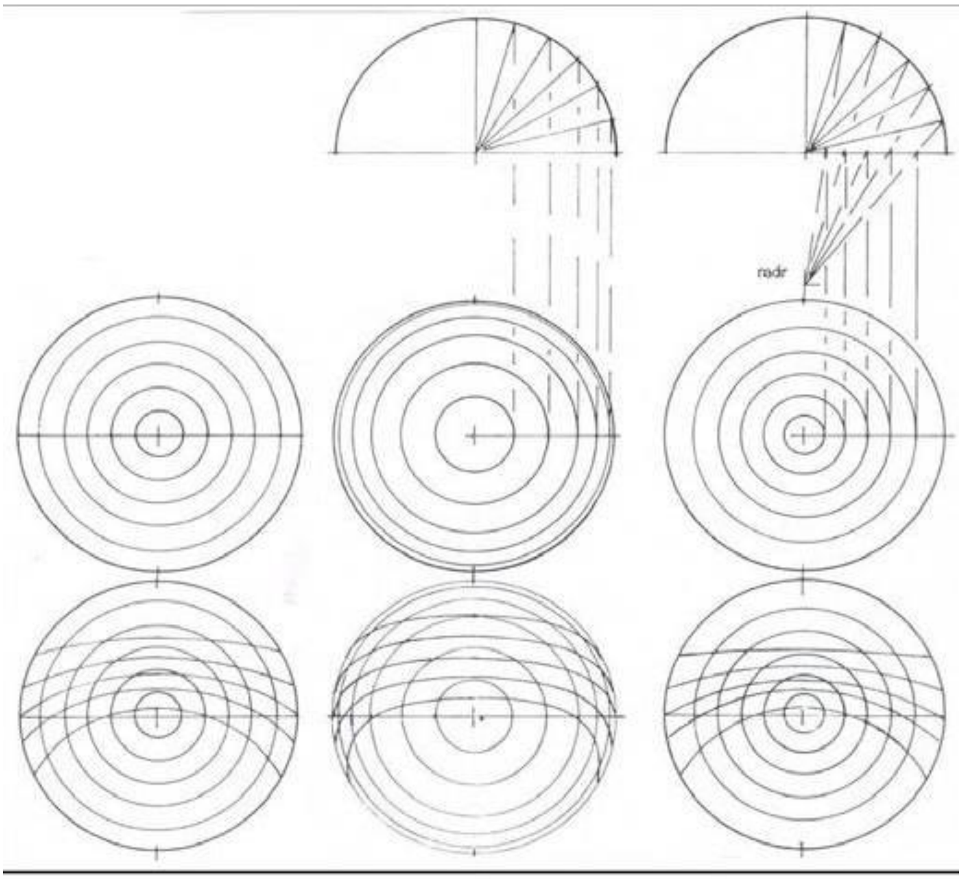
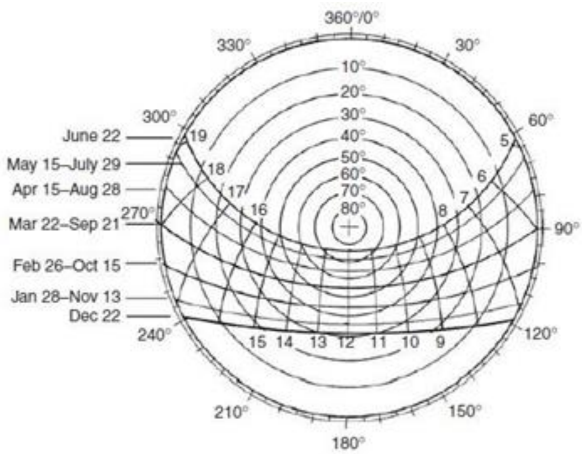


Fig.13 Equidistant chart Fig.14 Orthographic projection Fig.15 Stereographic projection

Sun-path diagrams or solar charts are the simplest practical tools for depicting the sun’s apparent movement. The sky hemisphere is represented by a circle (the horizon). Azimuth angles (i.e. the direction of the sun) are given along the perimeter and altitude angles (from the horizon up) are shown by a series of concentric circles, 90° (the zenith) being the center.



A stereographic sun-path diagram for latitude 36°.

The sun-path lines are plotted on this chart for a given latitude for the solstice days, for the equinoxes. For an equatorial location (LAT = 0°) the diagram will be symmetrical

about the equinox sun path, which is a straight line; for higher latitudes the sun-path lines will shift away from the equator. For a polar position the sun paths will be concentric circles (or rather an up and down spiral) for half the year, the equinox path being the horizon circle, and for the other half of the year the sun will be below the horizon.
The shifting of sun-paths with geographical latitudes is illustrated in the Figure. The date-lines (sun-path lines) are intersected by hour lines. The vertical line at the center is noon. Note that on equinox dates the sun rises at due east at 06:00 and sets at due west at 18:00 h. As an example a complete sun-path diagram for latitude 36◦ is given as Figure.

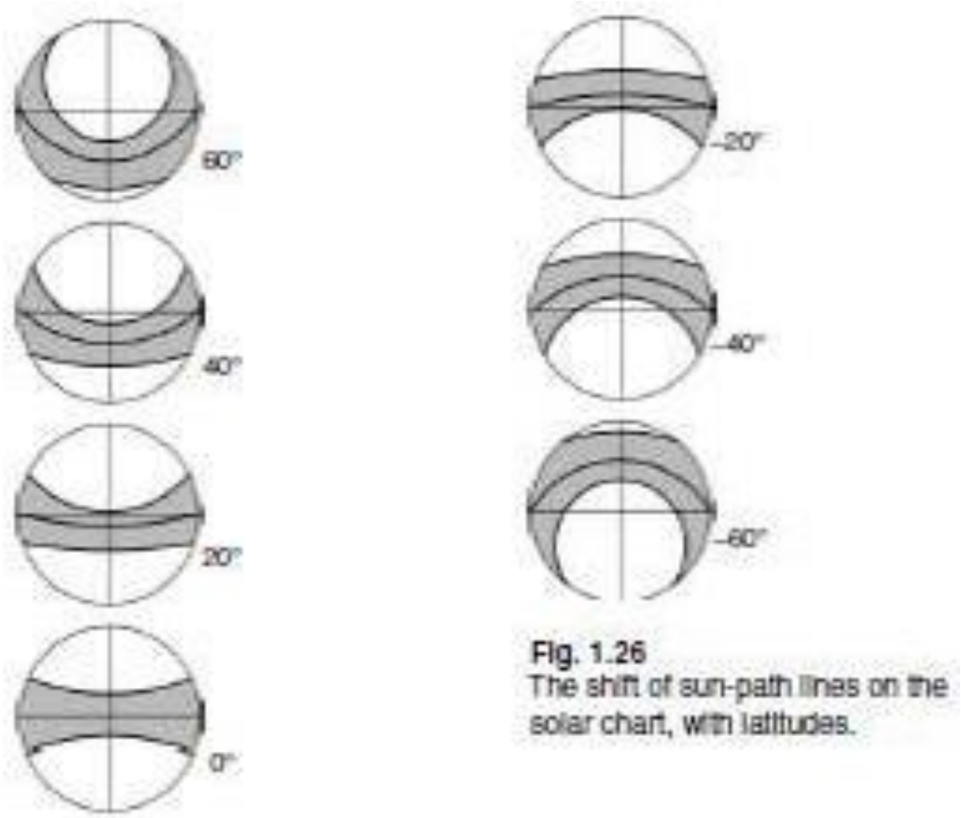
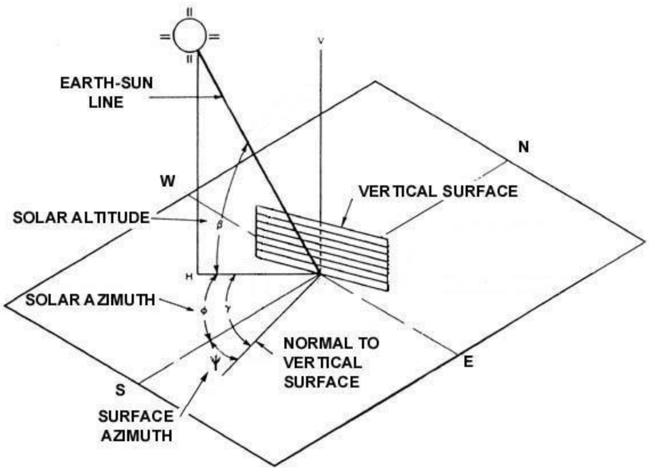


Fig. 1.26
The shift of sun-path lines on the solar chart, with latitudes.

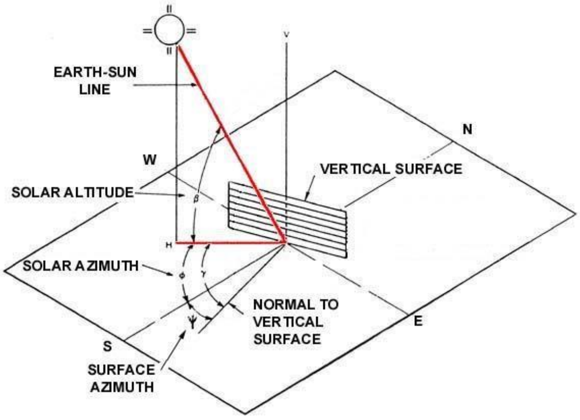
SOLAR ANGLES



Describe the sun position relative to a vertical surface

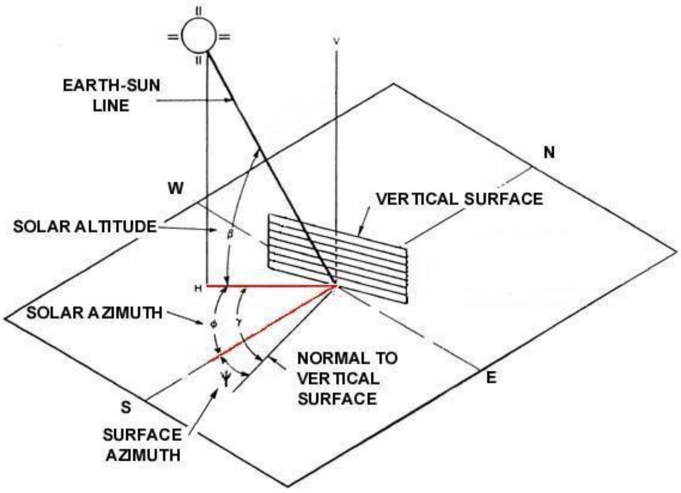
Solar Altitude: β (beta)

Vertical angle to sun position



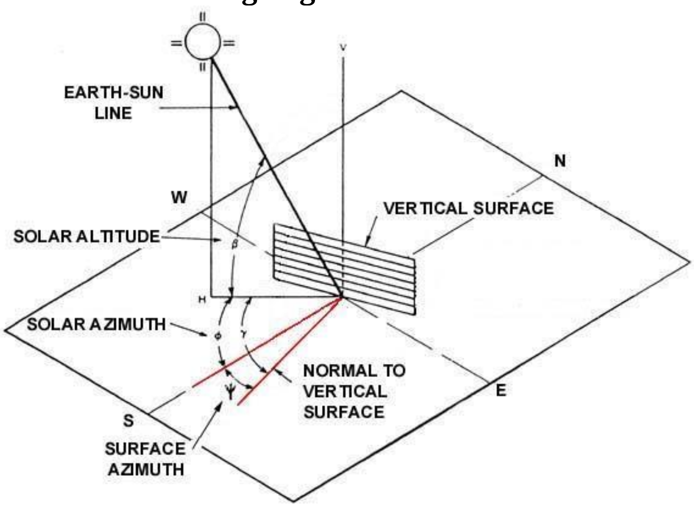
Solar Azimuth: Φ (phi)

Horizontal bearing angle from south

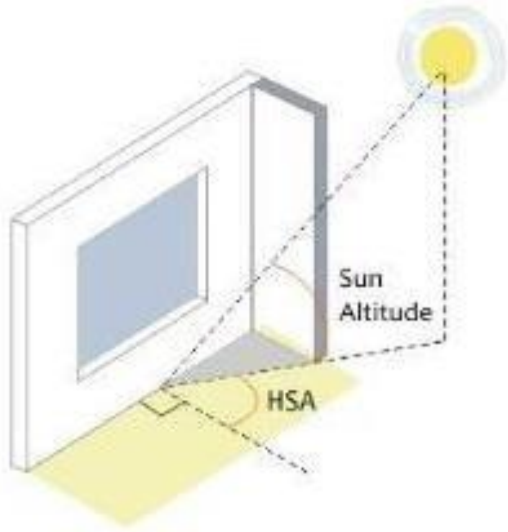


Surface Azimuth: Ψ (psi)

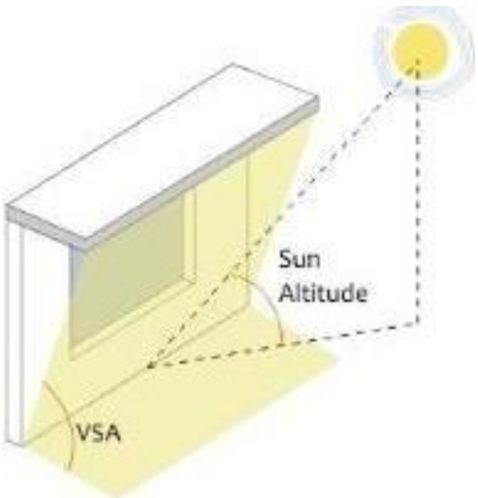
Surface horizontal bearing angle from south



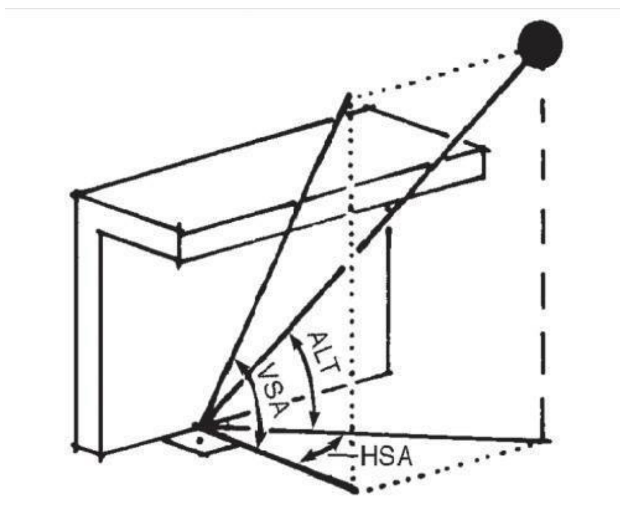
HSA (Horizontal Shadow Angle) – For vertical shading device.



HSA = SOLAR AZIMUTH – SURFACE/WALL AZIMUTH



COS (VSA) = COS (HSA) X COS (SOLAR ALTITUDE)



Vertical Shadow Angle (VSA)

Example:

Find the sun's position in an equatorial location at 15.00 hours on 22 December:

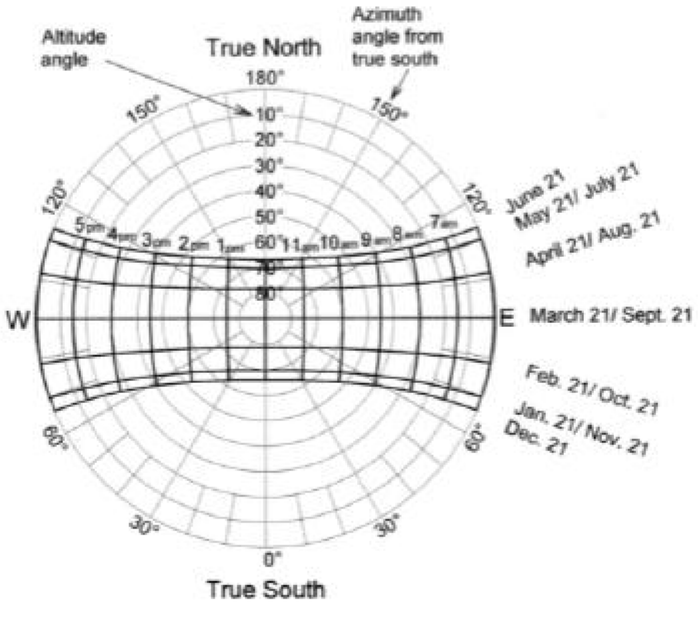
a. select the chart marked latitude 0^0

b. select the 22 December date line

c. select the 15.00 hour line and mark its intersection with the date line

d. read off from the concentric circles the altitude angle - 400

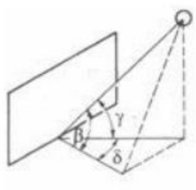
e. lay a straight-edge from the center of the chart through the marked time point to the perimeter scale and read off the azimuth angle - 239^0



Sun Path Diagram, 0° Latitude

Angle of incidence

From these two angles the sun's position in relation to the wall surface of any orientation (thus the angle of incidence) can be established. The horizontal component of the angle of incidence (δ) will be the difference between the solar azimuth and the wall azimuth. If, for the above example, the wall is facing west (270°): $\delta = 270 - 239 = 31°$ The vertical component is the same as the solar altitude angle itself (γ). The angle of incidence (β), i.e. the angle between a line perpendicular to the wall and the sun's direction, can be found by the 'spherical cosine equation'.



$\cos\beta = \cos\delta \times \cos\gamma$

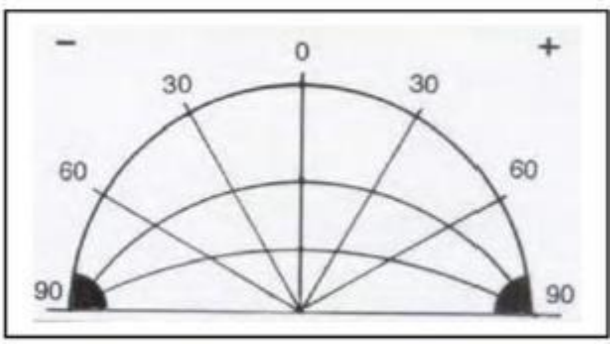
The angle of incidence $\cos\beta = \cos\delta \times \cos\gamma$

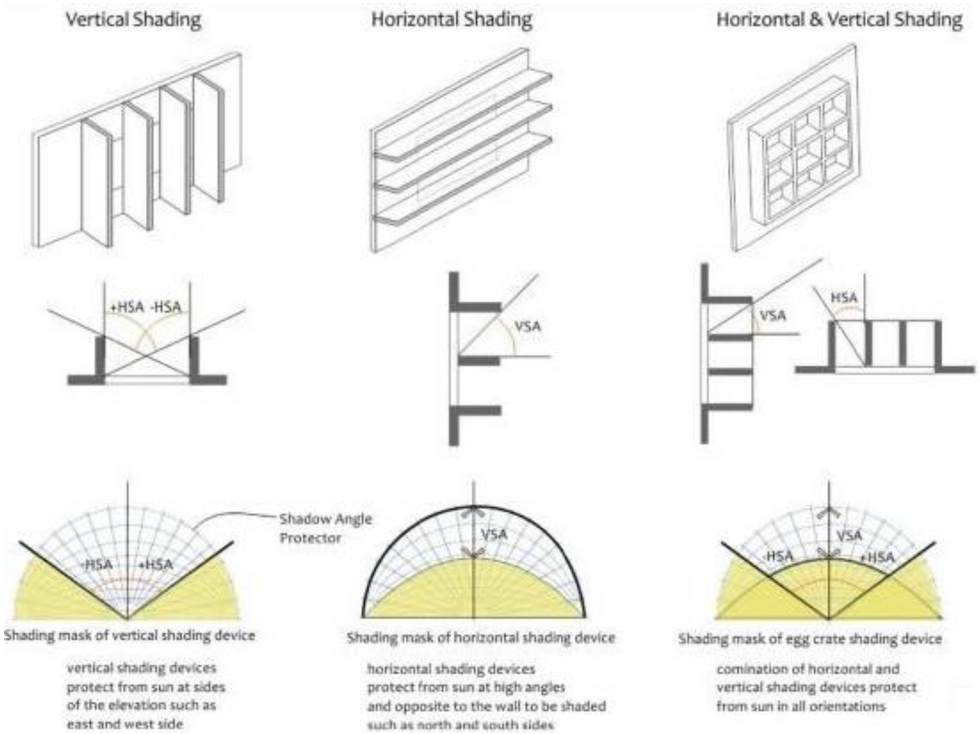
cos β = cos 31° × cos 40° = 0.8572 × 0.7660 = 0.6566 β = 49°

This angle of incidence will be required both for selecting the appropriate solar gain factor in heat gain calculations through windows and for calculating the incident radiation on an opaque surface, e.g. when the sol-air temperature is to be established.

The intensity of radiation measured on a plane normal to the direction of radiation must be multiplied by the cosine of this angle of incidence.

SHADOW MASK AND SHADOW ANGLE PROTRACTOR





Design of Vertical shading device

1. Connect the edge of the device to the opposite corner of the window, this gives the shading line
2. Superimpose the protractor on that corner
   - Plot the HSA on the protractor.
   - Repeat same for the other window corner
3. Superimpose the protractor on sun path diagram

4. Time-points (dates and hours) covered by the shaded region will be in shade

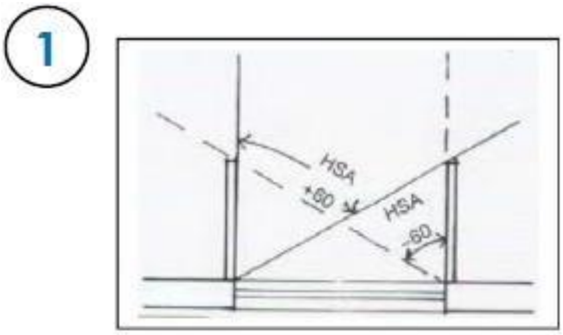


Fig.34 HSA of a pair of vertical fins

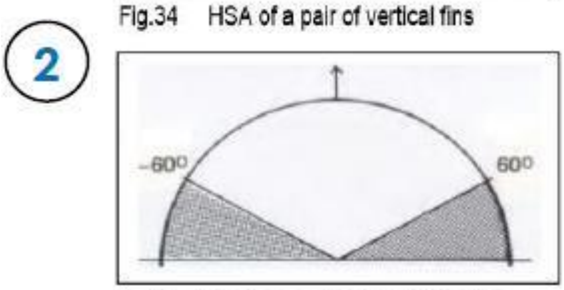
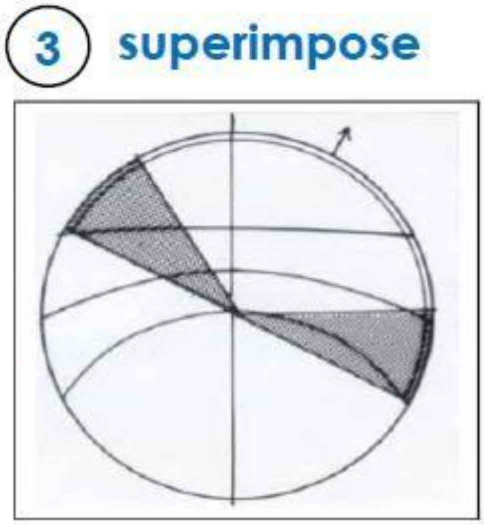


Fig.35 Shading mask of the vertical fins



g.36 as 35, superimposed on sun-path diagram

Design of Horizontal shading device

1. Connect the edge of the device to the opposite corner of the window, this gives the shading line

2. Superimpose the protractor on that corner

•Plot the VSA on the protractor.

•Repeat same for the other window corner

3. Superimpose the protractor on sun path diagram

4. Time-points (dates and hours) covered by the shaded region will be in shade

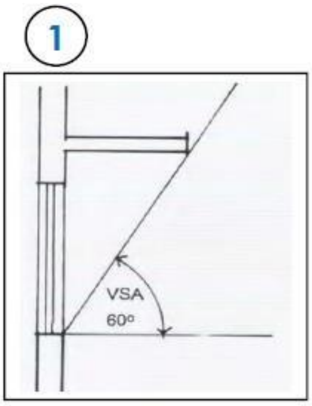


Fig.37 VSA of a horizontal device

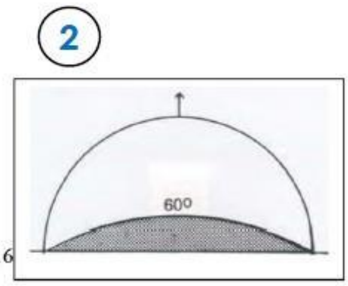
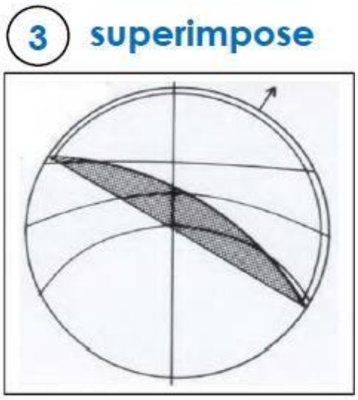
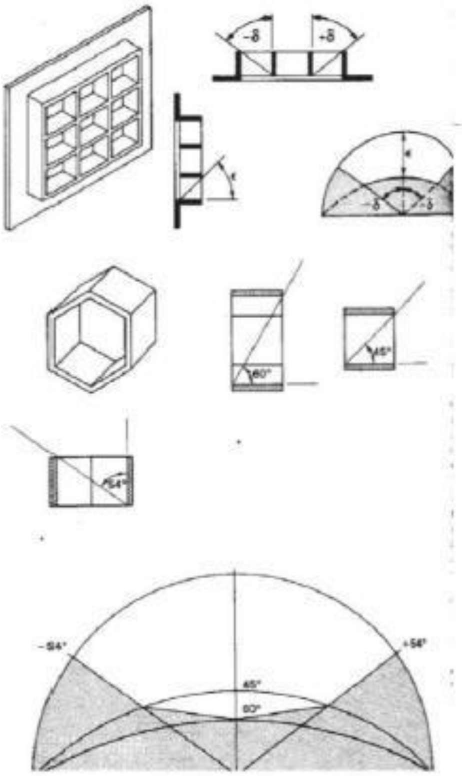


Fig.38 Shading mask of this device

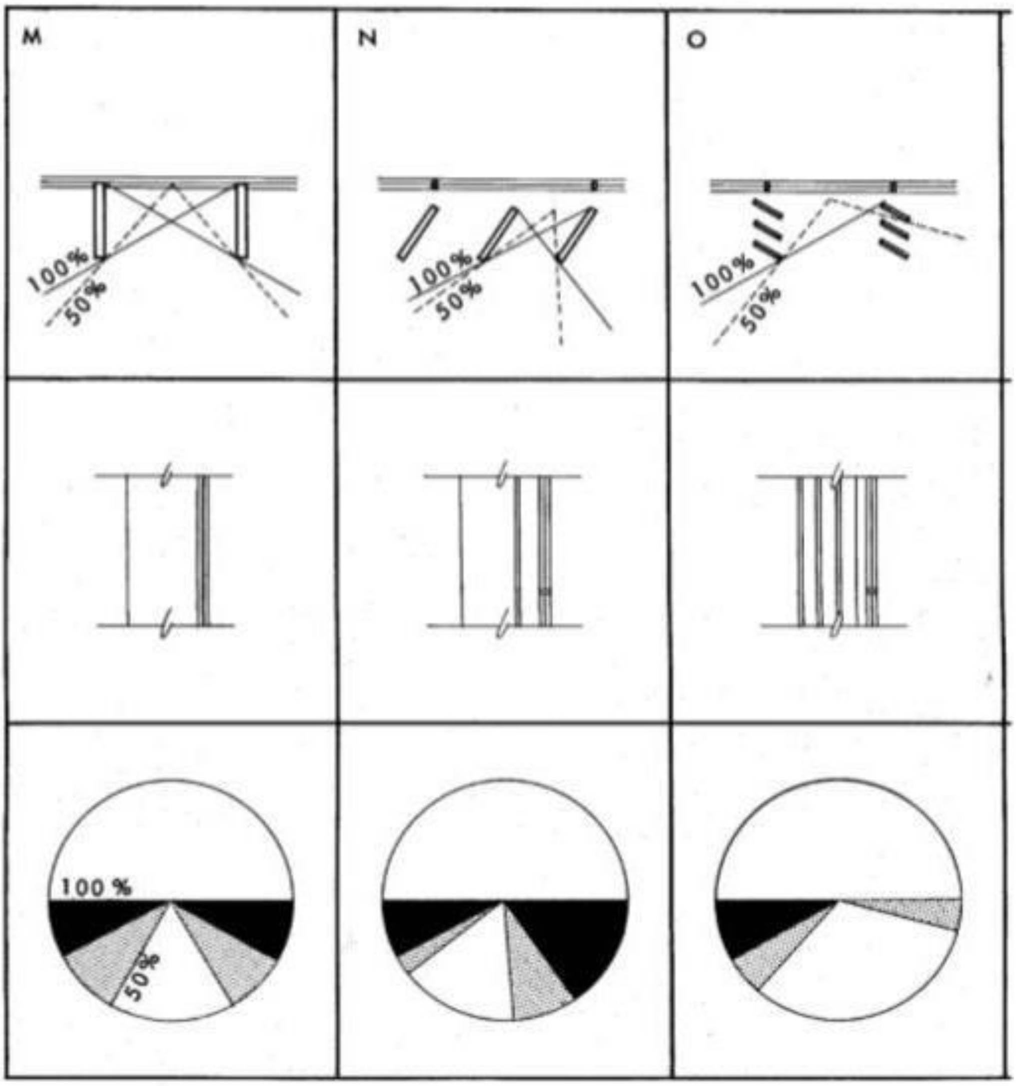


Egg-crate shading device



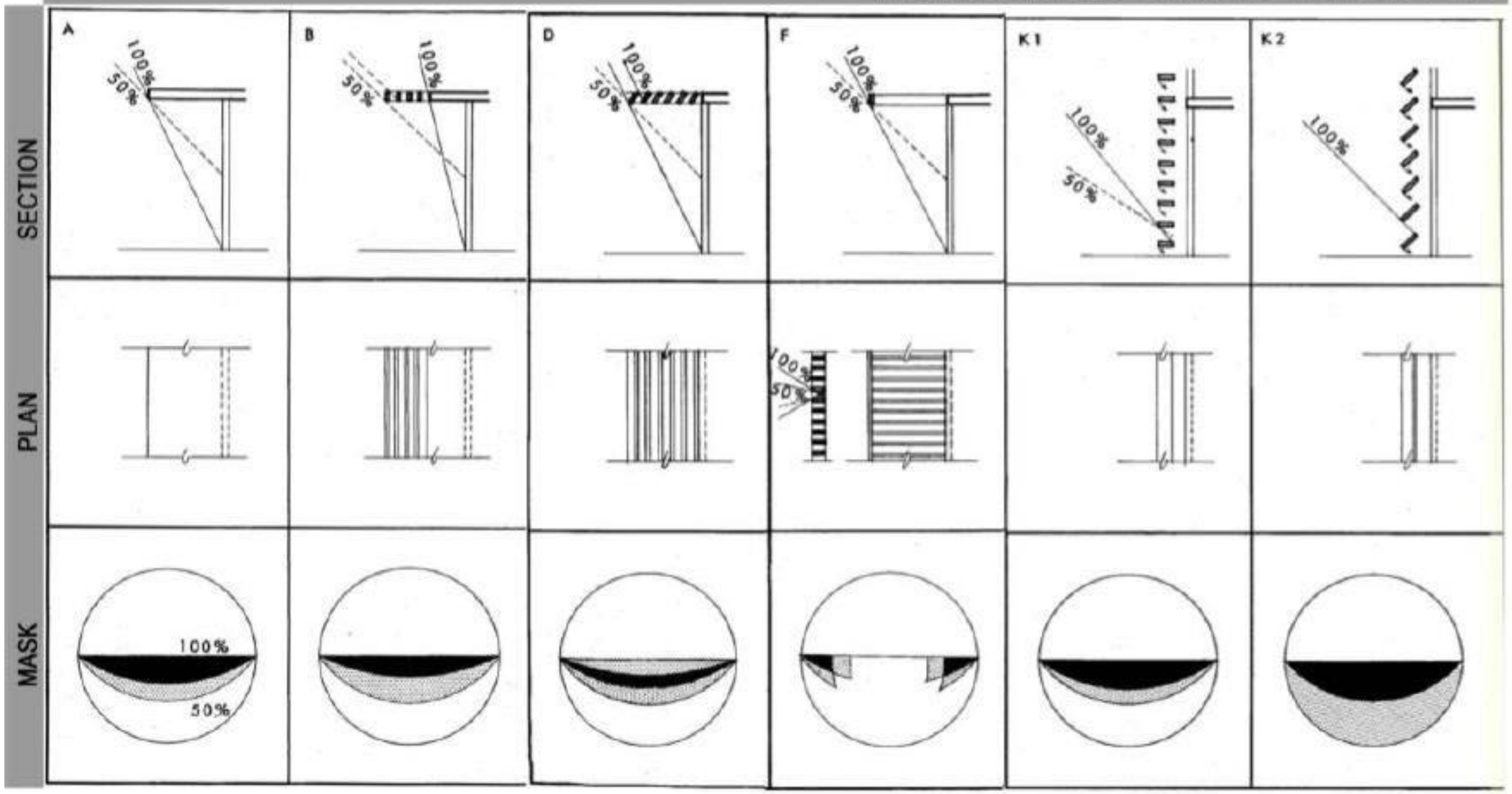
TYPES OF SHADING DEVICES –THEIR DIFFERENT SHADING MASKS
(FOR EXISTING STRUCTURES)

VERTICAL SHADING DEVICES



179. M. Solid vertical fin with 100% and 50% radial mask. N. Vertical fin oblique to wall will result in an asymmetrical mask. O. With vertically louvered fins masks can be designed which give 100% shading only to one side.

HORIZONTAL SHADING DEVICES



176. A. Solid horizontal overhang with 100% and 50% segmental mask.

B. Overhang partially solid, partially louvered.

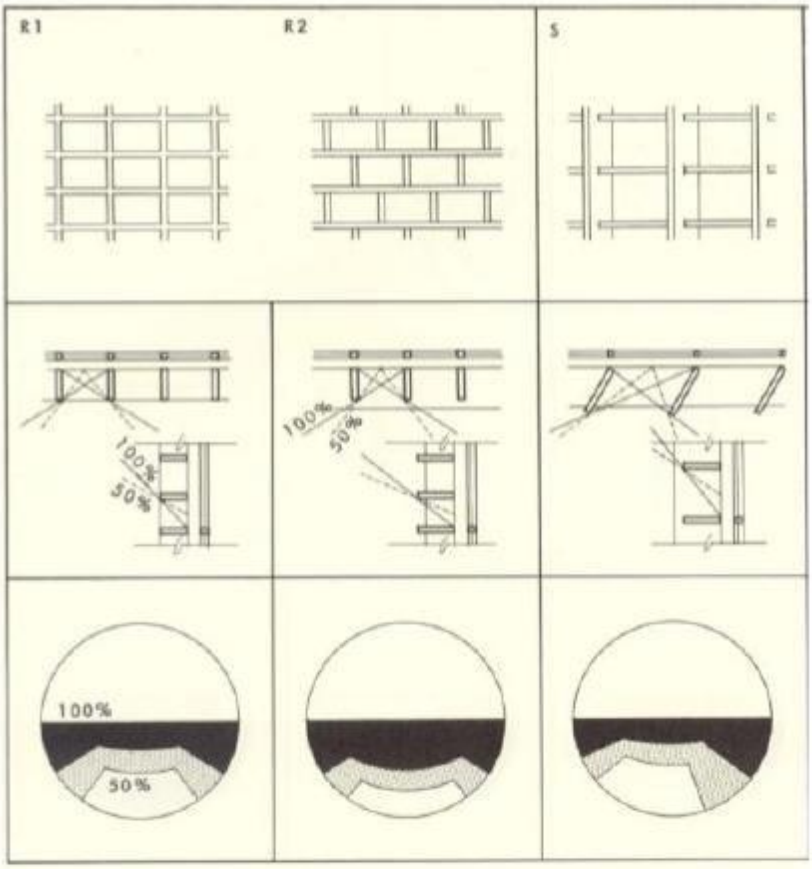
177. D. Tilted louvers parallel to wall let in some sunrays at high altitudes, as shown in mask.

F. Overhangs with louvers perpendicular to wall will cut out sunrays from the sides.

K1. Movable horizontal louvers change their mask characteristics according to their positioning.

K2. The same device as shown before in horizontal positioning is tilted in 45° angle.

EGGCRATE SHADING DEVICES



180. Eggcrate types are combinations of horizontal and vertical types and therefore their mask is a superimposed diagram of the two masks. As type "A," a solid horizontal overhang combined with type "M," a solid vertical type gives type "R." R_1 and R_2 could have the same mask, depending on their horizontal and vertical measurements. S. Solid eggcrate with slanting vertical fins results in an asymmetrical mask.

<u>Design of solar shading devices</u>

1. CALCULATE OVERHEATED PERIOD AND

2. DESIGN SHADOW ANGLES FOR THAT PERIOD

<u>PROCEDURE TO CALCULATE OVER HEATED PERIOD</u>

1. Calculate the minimum and maximum Effective Temperatures (E.T.) for all the months of the year.

2. Calculate the upper and lower values of Comfort zone for the particular location.

3. Take the chart provided for calculating hourly temperatures.

4. Mark the comfort zone as a band and shade it using a light colour.

5. Mark the minimum E.T. and maximum E.T. values for January and join them with a straight line.

6. Repeat stage 5 for all the months of the year.

7. Note down the months whose minimum E.T. value is less than the comfort zone value.

8. Mark the point of intersection of the line connecting minimum E.T. and maximum

E.T. of these particular months, with the lower limit of the comfort zone.

9. From these intersection points project lines vertically upwards and downwards until they intersect with the time lines at the top and bottom.

10. Note down the time of heating or cooling in a table for these particular months.

Procedure for marking the overheated period on sun path diagram

11. Take the sun-path diagram corresponding to the latitude of the particular location and orientit such that the north direction faces up and south faces down.
12. Mark these times of heating or cooling on the sun-path diagram for the first six months i.e. January to june.
13. Join these time values to obtain the overheated period. Shade this over-heated period using a light colour.
14. Repeat stages 12 and 13 for the next six months i.e. July to December.

Calculating HSA and VSA to shade the overheated period

15. Take the shadow-angle protractor. Place it on the sun-path diagram aligning the center of the base of the protractor to the center of the sun-path diagram, such that zero degrees on the semi- circular perimeter scale faces north.
16. Note down the values of the horizontal and vertical shadow angles which would be sufficient to cover the over-heated period.
17. Repeat stages 15 and 16 for all the four principal directions.

When a building elevation is considered from the point of view of shading, it will be represented in plan by a line crossing the center point of the solar chart. Any part of the over-heated period behind this line can be ignored: when the sun is in these positions, it will not strike the elevation considered.

The design of a suitable shading device is basically the finding of a shading mask which overlaps the over-heated period with as close as fit as possible. Many combinations of vertical and horizontal shading devices may achieve the same purpose. Minor compromises may be acceptable, i.e. for short periods the sun may be pe1mitted to enter, if this results in substantial economies.

Once the necessary shadow angles have been established, the design of the actual form of the shading devices will be a simple task and should be handled together with other considerations namely structural, aesthetic, and day-lighting and air-movement.

CALCULATING OVERHEATED PERIOD

CALCULATE EFFECTIVE TEMPERATURE FOR EACH MONTH

CALCULATE THERMAL COMFORT RANGE

SUPERIMPOSE BOTH ON MONTHWISE TEMPERATURE CHART

FIND MONTHWISE H, O, C PERIODS (HEATED, OPTIMUM, COLD)

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

UNIT – 4- DESIGN WITH CLIMATE – SARA1303

DESIGN WITH CLIMATE

There are various factors that affect the building design. The most important is the climate control as this involves maintaining comfortable conditions inside the building. The Thermal discomfort of people

1. Results in lower productivity and psychological stress.

2. Increases the energy costs of maintaining comfort conditions.

Passive design aspects should be considered at the planning and design stage.

DIFFERENT CLIMATES IN INDIA

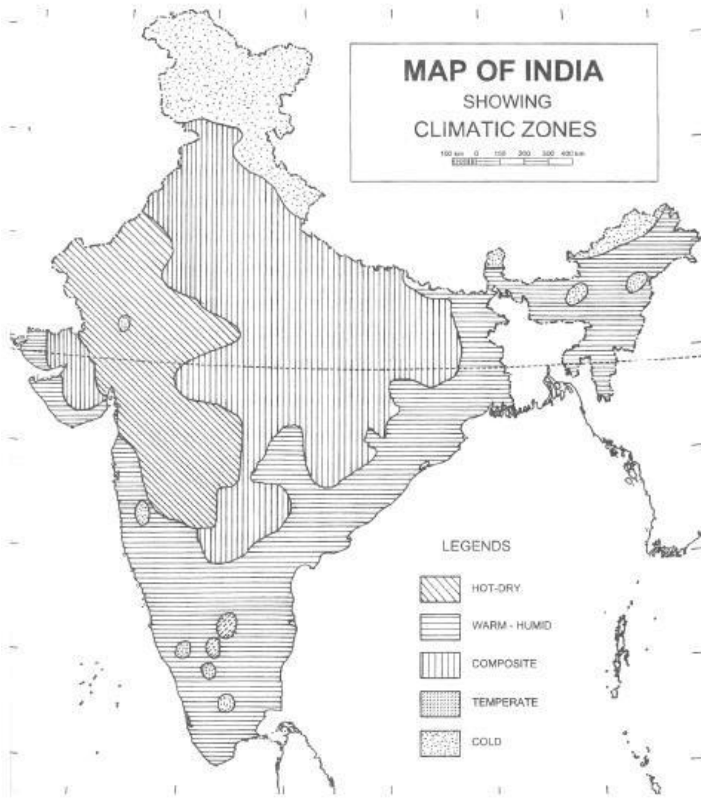


Fig. 2.13b Climatic zones of India [9]

- Hot And Dry Climate
- Warm And Humid Climate
- Cold Climate
- Composite Climate
- Temperate Climate

CHARACTERISTICS OF HOT AND DRY CLIMATE

The characteristics features of hot dry climate are that it is hot during summer; cool to very cold during winter and warm humid and monsoon season. This zone lies in western and the central part of India; Jaisalmer, Jodhpur and Sholapur.

- Maximum day- time air temperatures : 27 – 45deg C
- Night-time air temperatures : as low as 22 deg C
- Relative Humidity : moderately low up to 20%

It is desirable to keep the heat out and if possible increase the humidity level. Heavy massive structures with thick walls and roof are preferred. Building axis should fall east-west to minimize heat gains through walls in summer and Maximize the same in winter by the southern facing walls.

Design objectives for Hot and Dry Climate

RESIST HEAT GAIN BY:

a. Decreasing the exposed surface
b. Increasing the thermal resistance
c. Increasing the thermal capacity
d. Increasing the buffer spaces
e. Decreasing the air-exchange rate during daytime.
f. Increasing the shading
g. Increase surface reflectivity

PROMOTE HEAT LOSS BY:

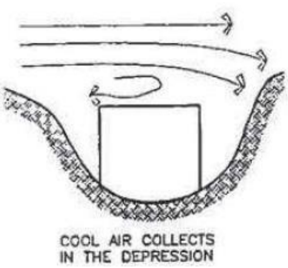
a. Ventilation of appliances
b. Increasing the air exchange rate during cooler parts of the day or nighttime.
c. Evaporative cooling

Design strategies

- Site level – Landforms, Water bodies, street width and orientation, Open spaces and built form relationship.
- Building Envelope design – Roof, Walls, Fenestrations, Surface finishes
- Day lighting

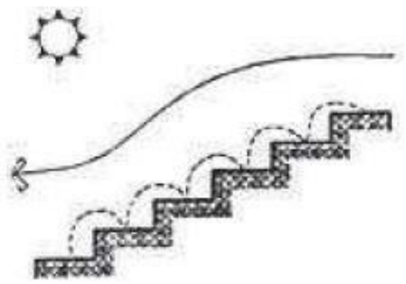
SITE: Landforms

Regions in this zone are generally flat and hence the surrounding areas tend to heat up uniformly. In case of an undulating site, the building can be located on a north facing slope which receives lower solar radiation. To reduce the effect of hot dusty winds, the leeward side of slope is better. In case of ventilation, building in a depression is preferable as cool air tends to sink in valleys.

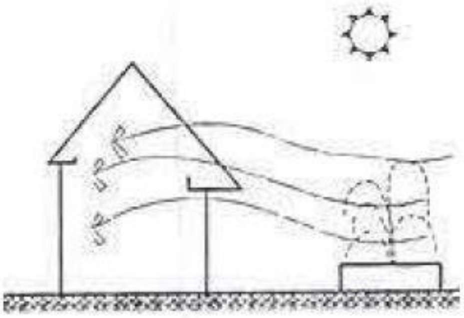


Water bodies

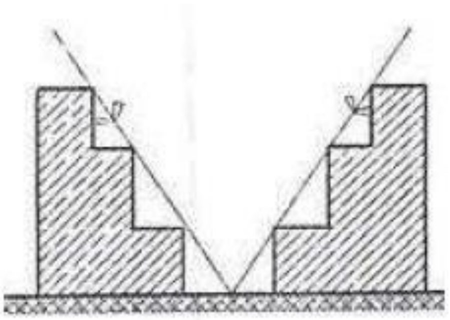
Water bodies such as ponds and lakes can be used for evaporative cooling as well as heat sinks for reducing the thermal heat gain. Hot air blowing over water gets cooled which can then be allowed to enter the building.



WATER CASCADE HELPS EVAPORATIVE COOLING



FOUNTAIN AIDS IN EVAPORATIVE COOLING

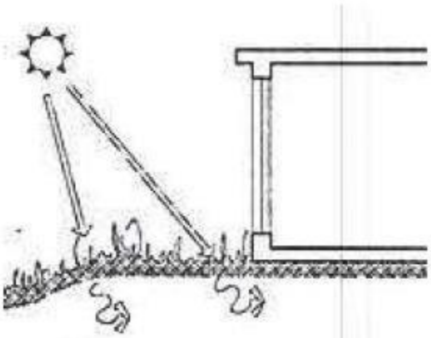


SMALL WIDTH TO HEIGHT RATIO CUTS OFF SUN AND LIGHT

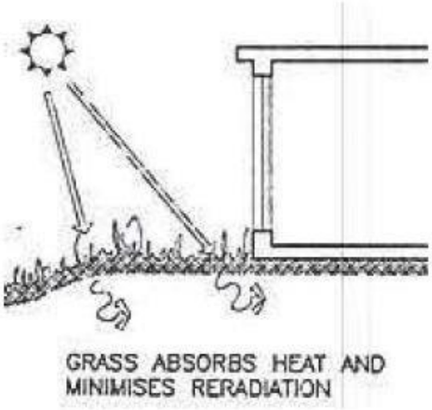
Street width and Orientation

Streets must be narrow so that they can encourage mutual shading of buildings. Streets to be oriented in the north-south direction to block solar radiation.

Open Spaces and Built form :Open spaces such as courtyards and atriums are beneficial as they promote ventilation. In addition they can also be provided with ponds and fountains for evaporative cooling. Courtyards act as heat sinks during day and radiate the heat back to the atmosphere during the night. Grass can be provided as groundcover to absorb solar radiation and help in the evaporative cooling. Building below the ground (e.g. earth berming) can help in lowering the temperature and also deflect hot summer winds.

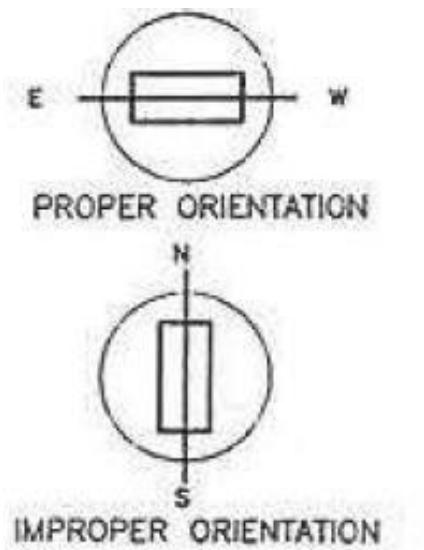


GRASS ABSORBS HEAT AND MINIMISES RERADIATION



Form and Planning

Building should be enclosed, compactly planned and essentially inward looking. Surfaces exposed to the sun should be reduced as much as possible. Site conditions permitting, the larger dimensions of a building should preferably face north-south, as these elevations receive the lowest heat loads from solar radiation. The worst orientation is the west. Non-habitable rooms can be effectively used as thermal barriers and can be placed on the east



and west end of the walls.

Shading of roofs, walls and outdoor spaces are critical. Projecting roofs, verandahs, shading devices, trees and utilization of surrounding walls and buildings are the techniques used to reduce the solar radiation. By aligning building close to each other, especially if east and west walls are placed close to each other, mutual shading will decrease the heat gains on external walls. Cross ventilation must be ensured at night as ambient temperatures during this period are low.

Building Envelope: Roof

The most critical part of the building is the roof design. In locations near the equator the roof receives the greatest amount of solar radiation, thus the highest heat load. The diurnal temperatures are large and the ambient night temperatures are about 10deg C lower than the daytime values. These areas receive cool breeze. Massive flat roofs with reinforced cement concrete slab is recommended. Or thatch is preferred for Sloped roof. External insulation of mud phuska (roofing materials is mud plaster with straw as its reinforcement) with inverted earthen pots is suitable (filler slab). Evaporative cooling of roof surface and night time radiative cooling can be employed.

Walls

In buildings, walls and glazing account for most of the heat transfer. It is estimated that walls and windows account for more than 80% of the annual cooling load of a conditioned building. The control of heat gain through walls by shading is an important consideration for reducing the room temperatures. To achieve this, walls must be constructed of heavy materials with a large thermal capacity. (e.g.) 22.5cm thick brick walls can be used. Cavity walls, hollow block, etc., can also be used. The air cavity can be filled with loose insulating materials to improve the thermal performance. Precast concrete panels, hollow blocks and lightweight cellular concrete blocks can also be used.

Fenestrations

In these climates, minimizing the window area can definitely lead to lower indoor temperatures. Larger windows should be provided in north as it receives lower radiation. All openings should be protected from the sun by the use of external shading devices such as chajjas and fins. Heat dissipation through the inside surfaces should be assisted during the night by adequate ventilation. Fenestrations having 15-20% of floor area should be used for ventilation and day lighting.

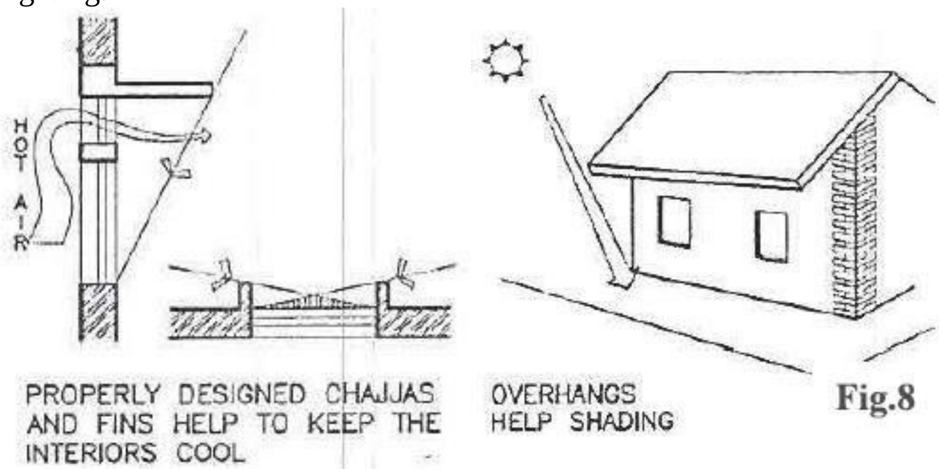
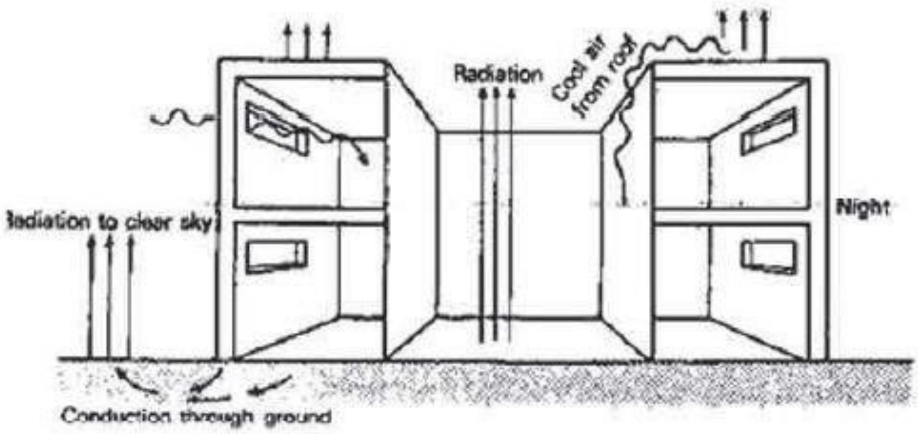


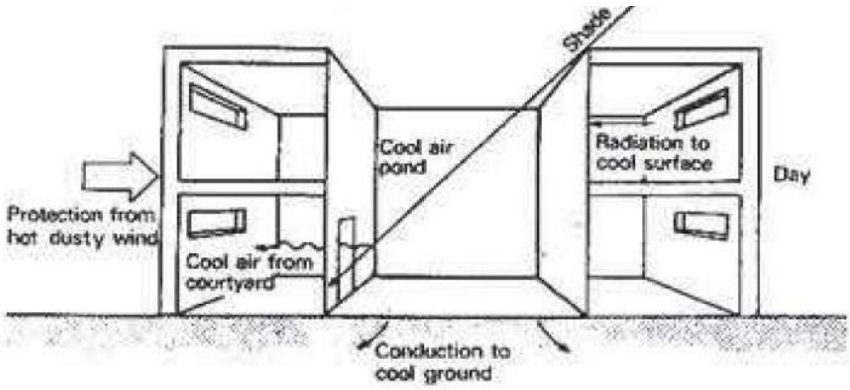
Fig.8

Thus the design of openings is governed by two requirements:

1. During the day the absence of openings would be most desirable or at least openings as small as possible, located high on the walls.
2. During the night the openings should be large enough to provide adequate ventilation for the dissipation of heat emitted by the walls and roof.



A solution satisfying both requirements is the use of large openings, with massive shutters, with a high thermal resistance, e.g., heavy shutters made of wood. If these are kept closed during day, the heat inflow is retarded, and if opened at night, the heat dissipation is not obstructed. A courtyard house with room opening into the courtyard would be a suitable solution in these climates.

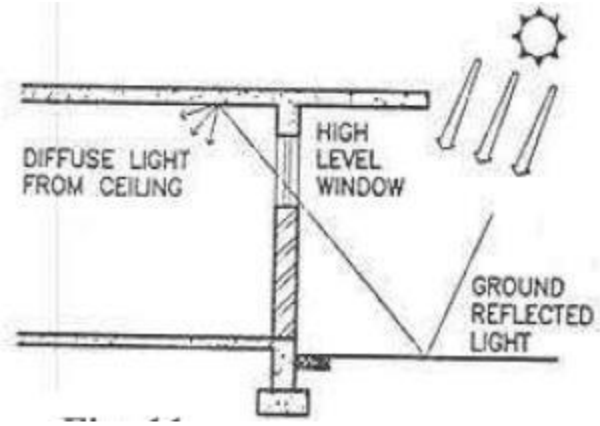


Surface Finishes

Finishes used can also affect heat absorption to a greater extent. Darker shades should be avoided for surfaces exposed to direct solar radiation. Light colored or shiny external surfaces will reflect a large part of the incident solar radiation, thus mush less heat will actually enter the building fabric. The surface of the roof can have undulations (broken tiles). This helps in reflecting the sunlight back to the atmosphere and hence the heat gain of the building is reduced.

Day lighting

In hot dry climate, there is direct sunlight from clear skies. Direct sunlight is not preferred for day lighting because of glare and overheating. Therefore, externally reflected light (the light reflected from ground and other building surfaces) and internally reflected light is the most convenient form of day lighting. A small window is located at a high level (with sill above eye level) for ensuring adequate diffuse lighting.



Recommendations

The winters in this region are uncomfortable cold. Hence, the windows should be designed such that they encourage direct gain during these colder seasons. Deciduous trees can be used to shade the building during summer and admit sunlight during winter. The well-insulated and very thick walls give good thermal performance. Glazing should be kept to a minimum and well-shaded, as found in traditional architecture. Indoor plants can be provided near the window, as they help in evaporative cooling and absorbing solar radiation. Outdoor sleeping areas are good for summer nights. Use of ceiling fans is most desirable. Desert coolers can be used in summer.

OBJECTIVES	PHYSICAL MANIFESTATION
1)Resist heat gain	
• Decrease exposed surface area	Orientation and shape of building
• Increase thermal resistance	Insulation of building envelope
• Increase thermal capacity (Time lag)	Massive structure
• Increase buffer spaces	Air locks/ lobbies/balconies/verandahs
• Decrease air exchange rate (ventilation during day-time)	Weather stripping and scheduling air changes
• Increase shading	External surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles etc.
2)Promote heat loss	
• Ventilation of appliances	Provide windows/ exhausts
• Increase air exchange rate (Ventilation during night-time)	Courtyards/ wind towers/ arrangement of openings
• Increase humidity levels	Trees, water ponds, evaporative cooling

Example: Solar Passive Hostel, Jodhpur

CHARACTERISTICS OF WARM AND HUMID CLIMATE

The characteristics of Warm and Humid climate are the hot, sticky conditions and the continual presence of dampness. Some cities that fall under this zone are Mumbai, Chennai and Kolkata.

- Maximum day- time air temperatures : 21 – 32deg C (with little diurnal variations)
- Relative Humidity : Ranges between 70% to 90%

Cross ventilation is the most desirable and essential. Protection from direct solar radiation should be ensured by shading.

Design objectives for Warm and Humid Climate

RESIST HEAT GAIN BY:

a. Decreasing exposed surface area
b. Increasing thermal resistance
c. Increasing buffer spaces.
d. Increasing shading
e. Increasing reflectivity

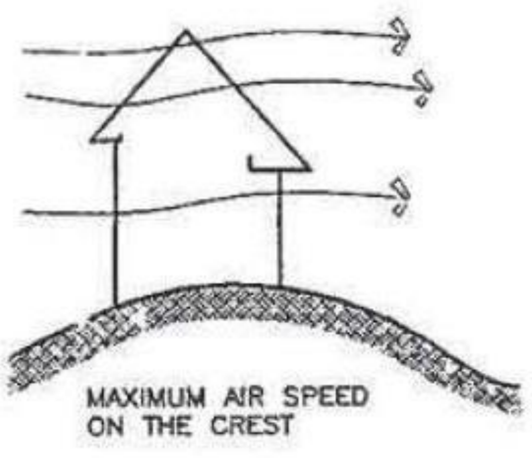
PROMOTE HEAT LOSS BY:

a. Ventilation of appliances
b. Increasing air exchange rate (ventilation) throughout day
c. Decreasing humidity levels

SITE

Landforms:

In case of sloped sites building should be located on the windward side or crest to take advantage of cool breezes.

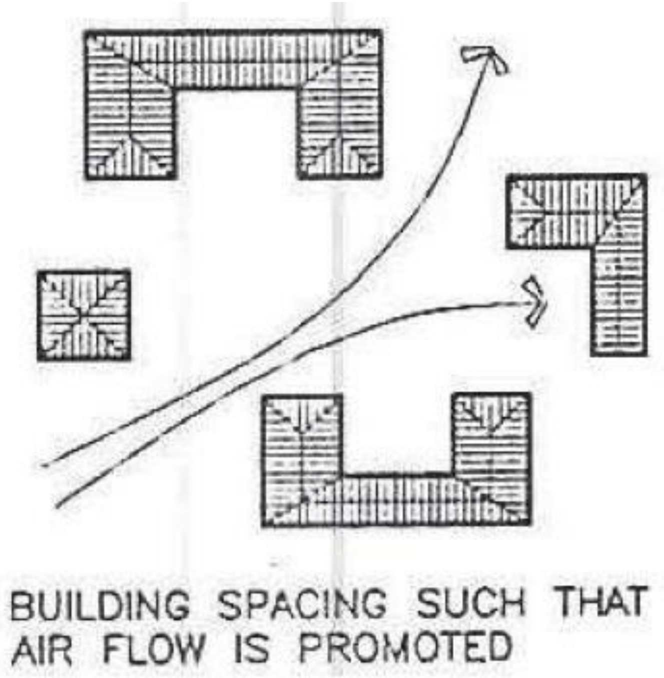


Water bodies:

Since the humidity is high in this zone provision of water bodies in the design is not preferred.

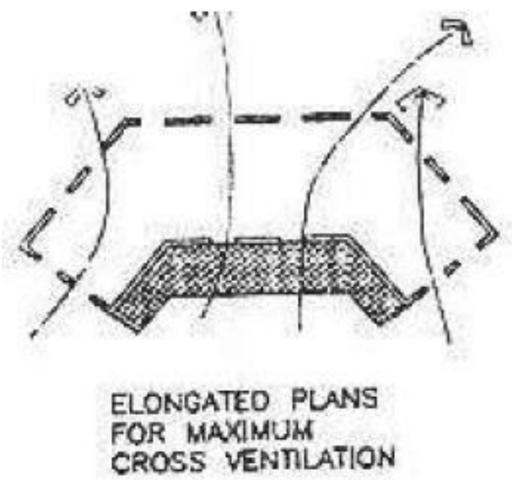
Open Spaces and Built form

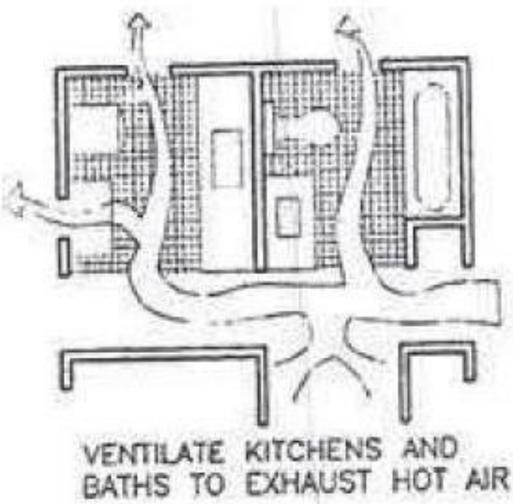
Buildings should be spread out with large open spaces for unrestricted air movement. In cities, buildings on stilts can promote ventilation and cause cooling at ground.



Street width and orientation
Major streets should be oriented parallel to or within 45 degrees of the prevailing wind direction to encourage ventilation. A north-south orientation is ideal from the point of view of blocking solar radiation.

Form and Planning
The buildings have to be opened out to breezes and oriented to catch available air movement. Buildings have elongated plans, with a single row of rooms to allow cross ventilation. Rooms may be accessible from open verandahs or galleries, which also provide shading. Doors and window openings should be as large as possible allowing a free passage of air.





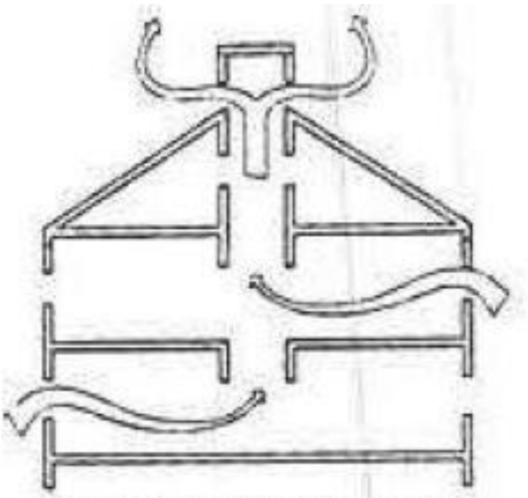
Produced Heat from kitchen areas and moisture from toilets must be ventilated and separated from the rest of the structure. Since the daytime temperatures are not very high, semi-open spaces such as balconies, verandahs and porches can be used advantageously for daytime activities. Such spaces also give protection from rainfall. In multistoried buildings a central courtyard can be provided with vents at higher level to draw away the rising hot air (Stack effect).

Building Envelope

Reliable to construct buildings of low thermal capacity materials, using light weight construction.

Roof:

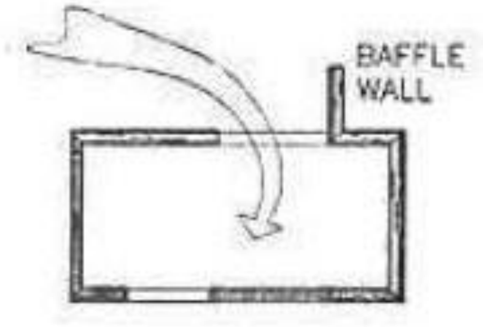
It can be a reflective upper surface or a double roof construction, with roof space ventilated - a ceiling with its upper surface reflective will have a good resistive insulation. Vents at



the roof top effectively induce ventilation and draw hot-air out.

Walls

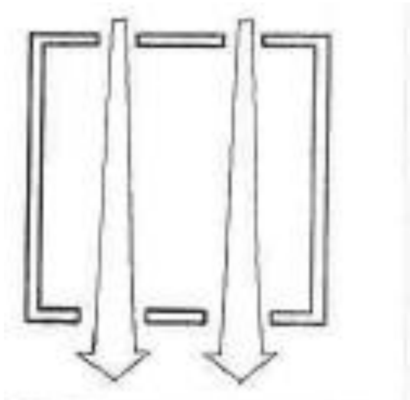
For solid vertical walls insulation is not necessary if they are shaded. If the walls are exposed to solar radiation (such as gable walls), good insulation needs to be provided. Reflective qualities on the outer surface of such unshaded walls will also be helpful. The walls need to be designed to promote air movement. Baffle walls, both inside and outside the building can help to divert the flow of wind inside. They should be protected from the prevailing heavy rainfall. The exposed brick walls and mud plastered walls work very well by absorbing the humidity and helping the building to breathe.



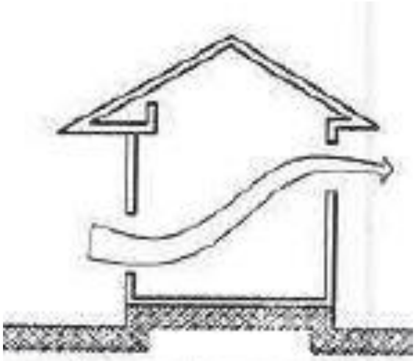
BAFFLE WALLS HELP
TO DIVERT AIR FLOW

Fenestration

Openings must be placed suitably in relation to the prevailing breezes to permit natural air flow through the internal spaces at the body level. The openings should be large and operable. Fixed windows should be avoided. Venetian blinds or louvers can be used to shelter the room from sun and rain`s as well as direct the air movement to the living zone. Openings of a comparatively smaller size can be provided on the windward.



OUTLET LARGER THAN INLET



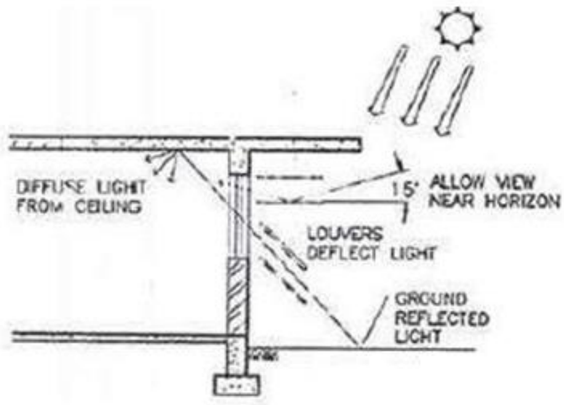
INLET AT LOWER LEVEL AND
OUTLET AT HIGHER LEVEL

Surface finishes

Dark colors should be avoided and light colors to be preferred for external surfaces that are exposed to direct solar radiation. The external surface of the roof can be of broken glazed tiles. These reduce heat gain of the buildings.

Day lighting

Direct sunlight is not desirable for thermal reasons. The sky is bright enough to provide sufficient light, but it may cause glare. Louvers which reflect daylight from the ground and a white-colored ceiling are effective.

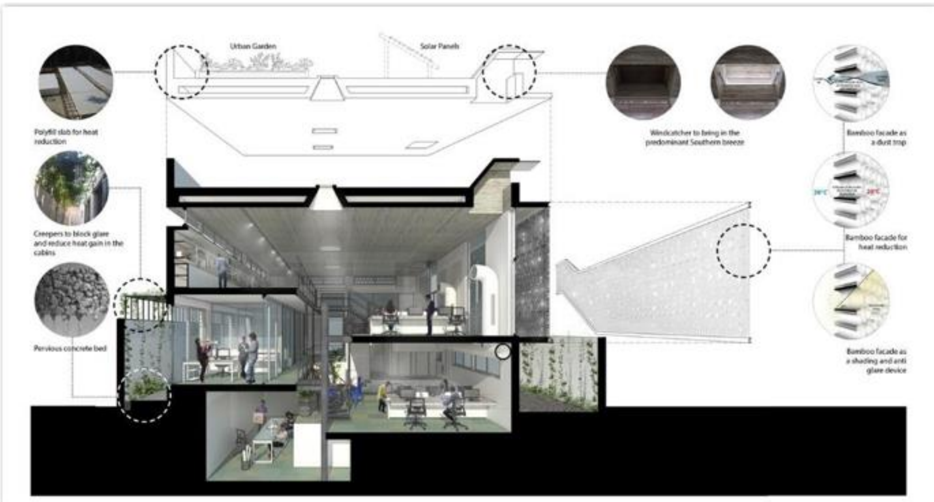


Recommendations

Building should be oriented along E-W or NE-SW axis to reduce solar heat gains by walls and improve wind movements. Ceiling fans are effective in reducing the level of discomfort in this type of climate. Careful waterproofing and drainage of water are essential.

OBJECTIVES	PHYSICAL MANIFESTATION
1)Resist heat gain	
• Decrease exposed surface area	Orientation and shape of building
• Increase thermal resistance	Roof insulation and wall insulation. Reflective surface of roof.
• Increase buffer spaces	Balconies and verandahs
• Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2)Promote heat loss	
• Ventilation of appliances	Provide windows/ exhausts
• Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
• Decrease humidity levels	Dehumidifiers/ desiccant cooling

Example: KSM Architecture Studio, Chennai



CHARACTERISTICS OF COLD CLIMATE

This region experiences very cold winters. Hence, trapping and using the sun's heat whenever available, is of prime concern in building design. E.g., Darjeeling, Mussoorie, Shilong, Ooty, Shimla etc.

- Mean Daily dry bulb temperature : 6 deg c or less during December and January.
- Altitude : 1200m above M.S.L

Design objectives for Cold Climate

RESIST HEAT GAIN BY:

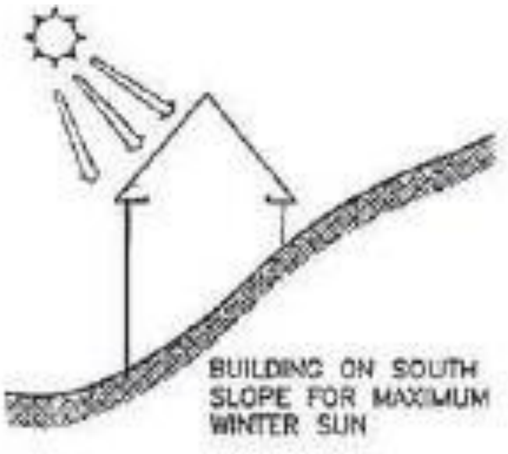
a. Decreasing the exposed surface area
b. Increasing the thermal resistance
c. Increasing the thermal capacity
d. Increasing the buffer spaces
e. Decreasing the air exchange rate

PROMOTE HEAT LOSS BY:

a. Avoiding excessive shading
b. Utilizing the heat from appliances
c. Trapping the heat of the sun.

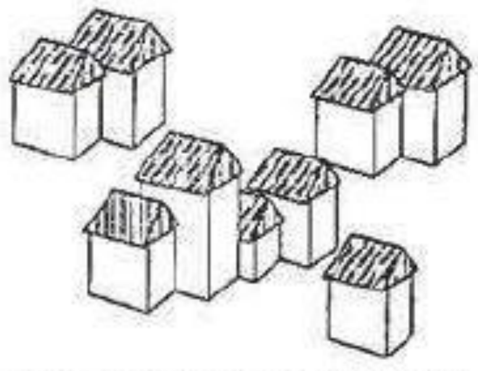
SITE: Landform

In cold climates, heat gain is desirable. Hence, buildings should be located on the south slope of a hill or mountain for better access to solar radiation. At the same time, the exposure to cold winds can be minimized by locating the building on the leeward side. With the help of natural barriers, protection from cold winds are possible.

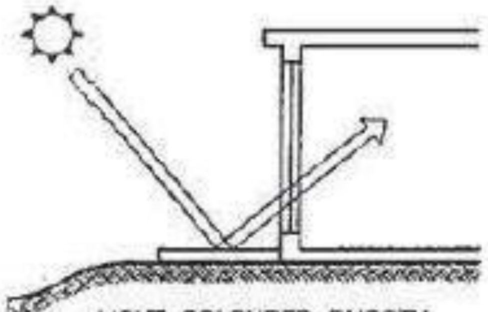


Open spaces and built forms

Buildings in cold climates should be clustered together to minimize the exposure to cold winds. Open spaces must allow maximum south sun (Solarium or sun spaces). Pavement and immediate surrounding should be treated with a hard and reflective surface for reflecting solar radiation on to the building.



CLUSTERED BUILDINGS SHARING WALLS TO REDUCE EXPOSURE TO COLD WINDS



LIGHT COLOURED SMOOTH PAVING REFLECTS LIGHT AND HEAT

Street width and Orientation

The street should be wide enough to ensure that the buildings on one side do not shade those on the other side (i.e. solar access should be ensured).

Form and Planning

In these climates, the buildings must be compact. This is because the lower the surface area, the lower the heat loss from the building. Windows should preferably face south to encourage direct heat gain. The north side of the building should be well insulated. Living areas can be located on the southern side while utility areas such as stores can be on the northern side. Air-lock lobbies at the entrance and exit points of the building, reduce heat loss. The heat generated by appliances in rooms such as kitchens may be recycled to heat the other parts of the building.

Building Envelope: Roof

False ceiling are a regular roof feature of houses in cold climates. Internal insulation such as polyurethane foam (PUF), thermocol, wood wool, etc., can be used. An aluminum foil is generally used between the insulation layer and the roof to reduce heat loss to the exterior. A sufficiently sloping roof enables quick drainage of rain water and snow. A solar air collector can be incorporated on the south facing slope of the roof and hot air from it can be used for space heating purpose. Skylights on the roofs admit heat as well as light in winters.

Walls

Walls should be low 'U' value to resist heat loss. The south facing walls (exposed to solar radiation) could be of high thermal capacity (such as trombe wall) to store day time heat for later use. The walls should be insulated internally. The insulation should have sufficient vapourbarrier (such as two coats of bitumen, polyethylene sheet 300 – 600 gauge or aluminium foil) on the warm side to avoid condensation. Hollow and light weight concrete blocks are also quite suitable. On the windward or north side, a cavity wall type of construction may be adopted.

Fenestration

Windows upto 25% floor area may be provided. It is advisable to have maximum window area on the southern side of the building to facilitate direct heat gain. Windows should be sealed and preferably double glazed. Double glazing helps to avoid heat losses during winter nights.

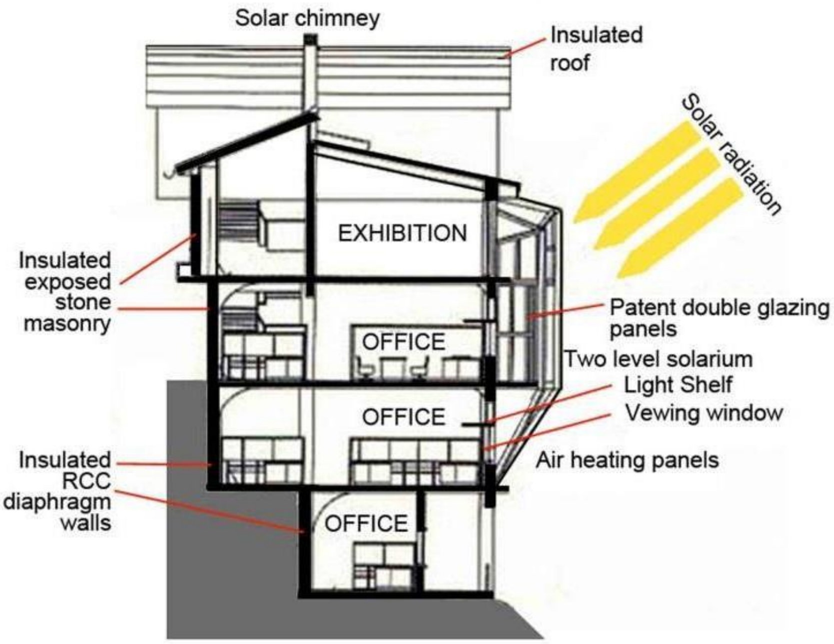
Surface Finishes

The external surfaces of the walls should be dark in color having high absorptivity to facilitate heat gains.

Day lighting

From a physical as well as psychological point of view, an excess of day lighting is advantageous in this region. The over-lighting leads to an increased sense of well-being. Hence, windows must have minimum shading.

OBJECTIVES	PHYSICAL MANIFESTATION
1)Resist heat loss	
• Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	Roof insulation, wall insulation and double glazing
• Increase thermal capacity (Time lag)	Thicker walls
• Increase buffer spaces	Air locks/ Lobbies
• Decrease air exchange rate	Weather stripping
• Increase surface absorptivity	Darker colours
2)Promote heat gain	
• Reduce shading	Walls and glass surfaces
• Utilise heat from appliances	
• Trapping heat	Sun spaces/ green houses/ Trombe walls etc.



Section demonstrating various passive solar features integrated into the building enverlope

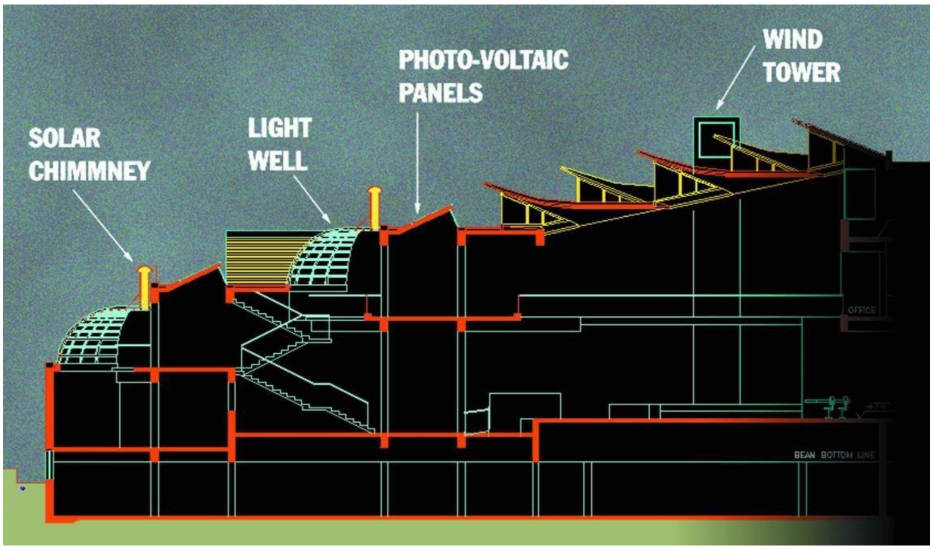
Himurja Office Building, Shimla

CHARACTERISTICS OF COMPOSITE CLIMATE

The composite climate displays the characteristics of hot and dry, warm and humid, as well as cold climate. Designs here are guide by longer prevailing climatic condition. This zone covers the central part of India – cities like New Delhi, Chandigarh, Kanpur and Allahabad. The duration of 'uncomfortable' period in each season has to be compared to derive an order of priorities. In India most of the design decisions will pertain to cooling. In composite climates, natural lighting varies greatly due to overcast and clear sky conditions. The day lighting needs to be controlled such that maximum illumination is provided in winter and minimum in summer. Movable shading devices are preferred for this purpose.

OBJECTIVES	PHYSICAL MANIFESTATION
1)Resist heat gain in summer and Resist heat loss in winter	
• Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
• Increase thermal resistance	Roof insulation and wall insulation
• Increase thermal capacity (Time lag)	Thicker walls
• Increase buffer spaces	Air locks/ Balconies
• Decrease air exchange rate	Weather stripping
• Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
• Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
2)Promote heat loss in summer/ monsoon	
• Ventilation of appliances	Provide exhausts
• Increase air exchange rate (Ventilation)	Courtyards/ wind towers/ arrangement of openings
• Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
• Decrease humidity in monsoon	Dehumidifiers/ desiccant cooling

PEDA Solar Passive complex, Chandigarh



Universal Guidelines

For a climatically responsive design of buildings in any climate zone, the sun path (to identify the desirable or undesirable radiation), the predominant winds, topography, vegetation, building envelope, day lighting factors are to be considered. In addition to the above the relative humidity and the precipitation of a particular location is analyzed and the design is developed.

PASSIVE DESIGN STRATEGIES

PASSIVE COOLING

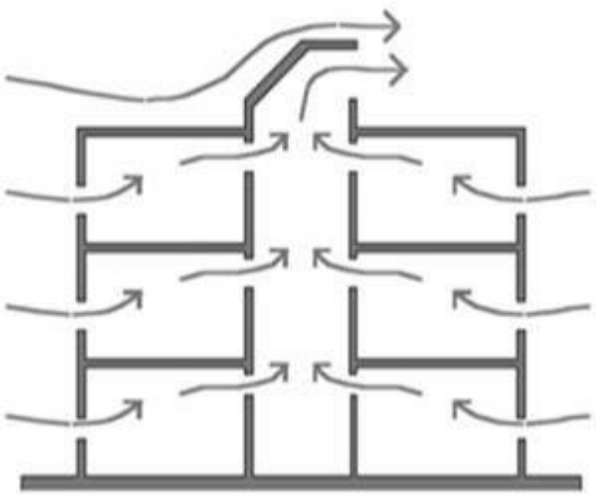
- Ventilation cooling
- Cross ventilation
- Wind tower
- Induced Ventilation
- Evaporative cooling
- Roof Surface Evaporative Cooling (RSEC)
- Passive down draft Evaporative Cooling

The underlying principle of passive cooling is to prevent heat from entering the building, or remove heat once it has entered. The various concepts discussed are ventilation cooling, evaporative cooling, nocturnal radiation cooling, desiccant cooling and earth coupling.

Ventilation Cooling

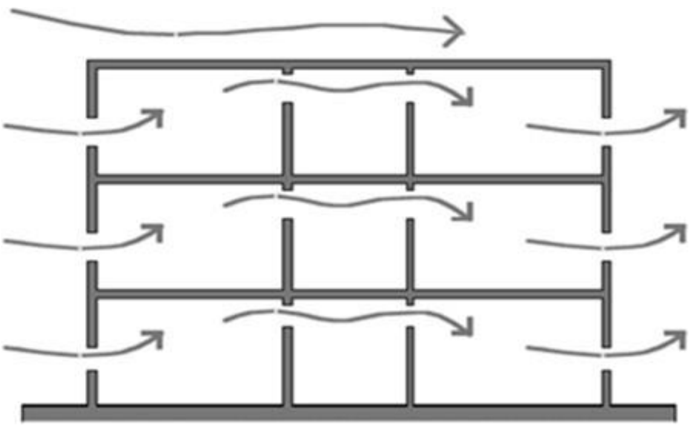
Ventilation is generally defined as there placement of stale air by fresh air. It also provides cooling by air movement. Ventilation as the supply of outside air to the interior for air motion and replacement of vitiated air. An indoor air speed of 1.5 - 2.0 m/s can cause comfort in warm and humid regions where the outdoor maximum air temperature does not exceed 28–32^{o}C.

A faulty design resulting in inadequate ventilation will result in higher energy consumption in the building for creating comfortable indoor conditions. In hot environments, evaporation is the most important process of heat loss from the human body for achieving thermal comfort. As the air around the body becomes nearly saturated due to humidity, it becomes more difficult to evaporate perspiration and a sense of discomfort is felt. In such circumstances, even a slight movement of air near the body gives relief. The air movement indoors is mainly due to **stack effect.**



Cross ventilation

The available wind velocity in a room with a single window on the wind ward side is about 10% of the outdoor velocity at points up to a distance of one-sixth of room width from the window. Beyond this, the velocity decreases rapidly and hardly any air movement is produced in the leeward end of the room. Therefore, it is better to provide two windows on adjacent or opposite walls to improve ventilation.



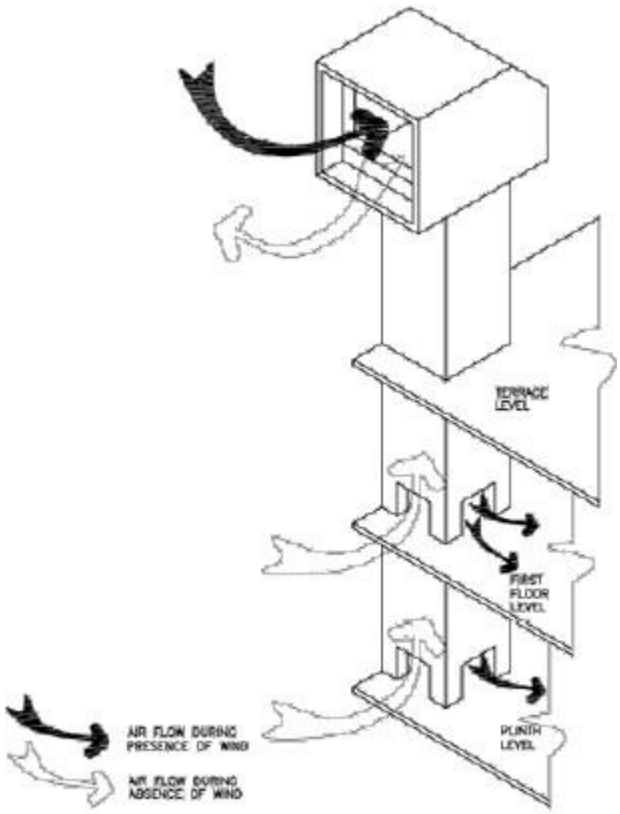


Fig. 3.25 Working principle of a wind tower

Wind tower

Wind tower is generally used in hot and dry climates for cooling purposes. The tower is meant to “catch” the wind at higher elevations and direct it into the living space. The tower may have only one opening facing the wind, if wind is predominantly in one direction, or may have openings in all directions in locations with variable wind directions.

A prerequisite for using a wind tower is that the site should experience winds with a fairly good and consistent speed. A wind tower operates in various ways according to the time of day and the presence or absence of wind. The **cardinal principle** of its operation lies in changing the temperature and there by the density of the air in and around the tower. The difference in density creates a draft, pulling air either upwards or downwards through the tower.

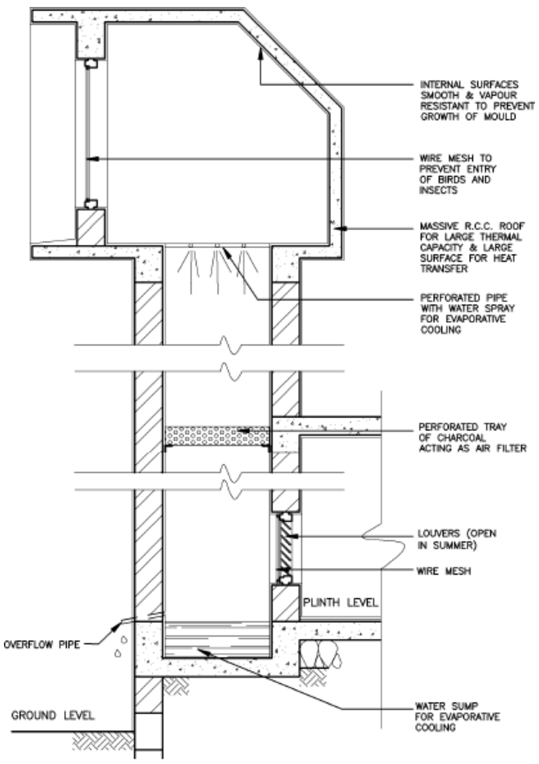


Fig. 3.26 Detail of a wind tower

Induced Ventilation

Passive cooling by induced ventilation can be very effective in hot and humid climates as well as hot and dry climates. This method involves the heating of air inside are stricted area through solar radiation, thus creating a temperature difference and causing air movements. The draft causes hot air to rise and escape to the ambient, drawing in cooler air and there by causing cooling. In effect, a solar chimney is created to cause continuous air circulation.

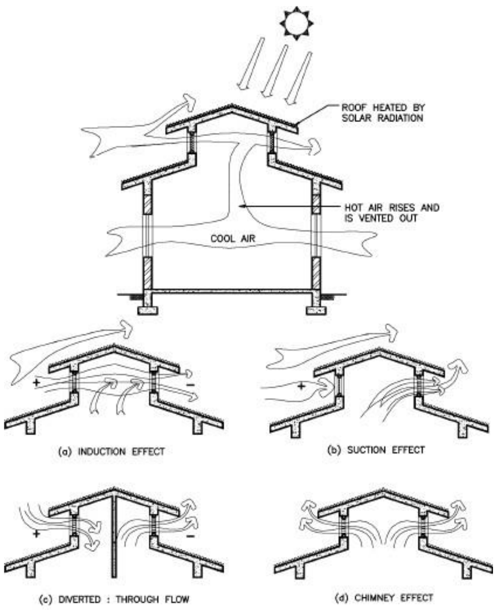


Fig. 3.27 Induced ventilation: principle and variations

Evaporative cooling

Evaporative cooling is a passive cooling technique in which outdoor air is cooled by evaporating water before it is introduced in the building. The presence of a water body such as a pond, lake or sea near the building, or a fountain in the courtyard can provide a cooling effect.

Roof Surface Evaporative Cooling (RSEC)

In a tropical country like India, the solar radiation incident on roofs is very high in summer, leading to overheating of rooms below them. Roof surfaces can be effectively and in expensively cooled by spraying water over suitable water-retentive materials (e.g., gunny bags) spread over the roof surface. As the water evaporates, it draws most of the required latent heat from the surface, thus lowering its temperature and reducing heat gain.

Passive down draft Evaporative Cooling

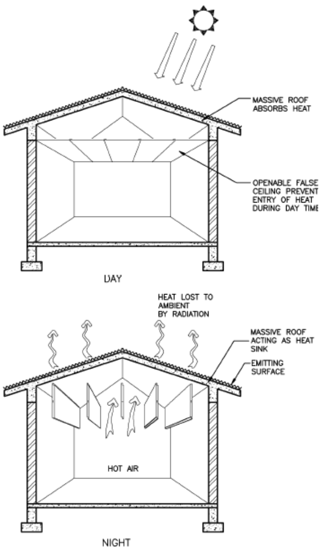


Fig. 3.30 Nocturnal radiation cooling: working principle

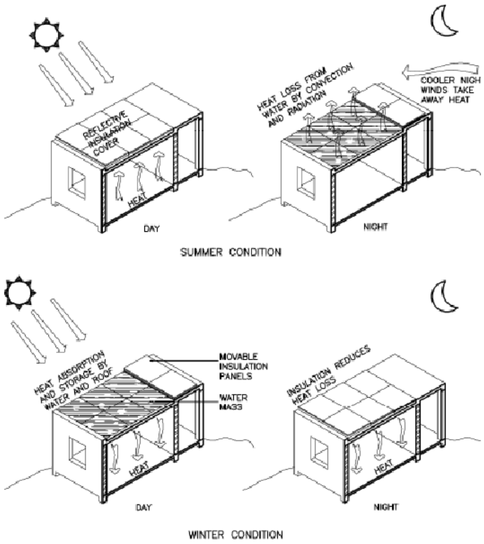


Fig. 3.31 Working principle of a roof pond

PASSIVE HEATING

- Direct Gain
- Indirect Gain
- Roof top collectors
- Isolated Gain
- Solarium (Attached Green House / Sunspace)

Direct Gain

Direct gain is a passive heating technique that is generally used in cold climates. It is the simplest approach and is therefore widely used. In this technique, sunlight is admitted into the living spaces directly through openings or glazed windows. The sunlight heats the walls and floors, which then store and transmit the heat to the indoor environment. The main requirements of a direct gain system are large glazed windows to receive maximum solar radiation and thermal storage mass.

Thus a direct gain system has the following components:
(a) Glazing –to transmit and trap the incoming solar radiation,
(b) Thermal mass –to store heat for night-time use,
(c) Insulation –to reduce losses at night,
(d) Ventilation –for summer time cooling,
(e) Shading –to reduce overheating in summer.

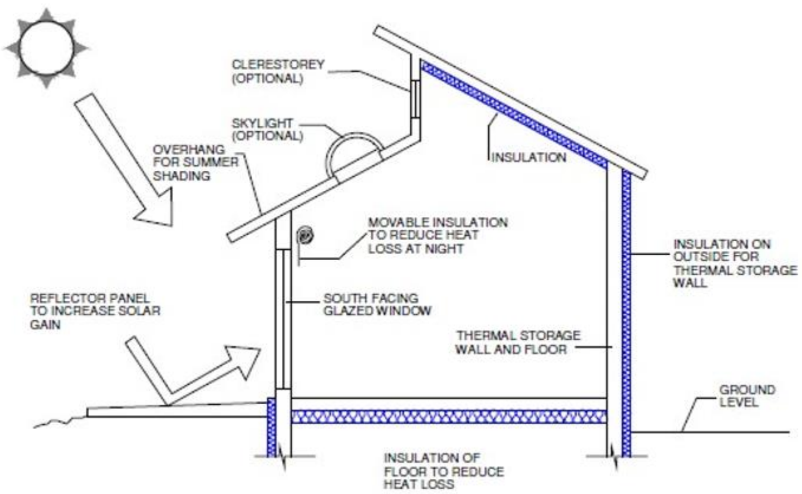


Fig. 3.12 Components of a direct gain system

Glazed windows

Principal function of a glazed window in a direct gain approach is to admit and trap solar energy so that it can be absorbed and stored by elements within the space. Window must face south in the northern hemisphere as it receives maximum solar radiation in this direction. To avoid excessive heat gain in the cooling season and to increase overall system performance, some provision should

be made for shading the windows. Common external shading devices are overhangs (fixed or adjustable), trellises, awnings, louvers (horizontal or vertical, fixed or adjustable), and wing walls.

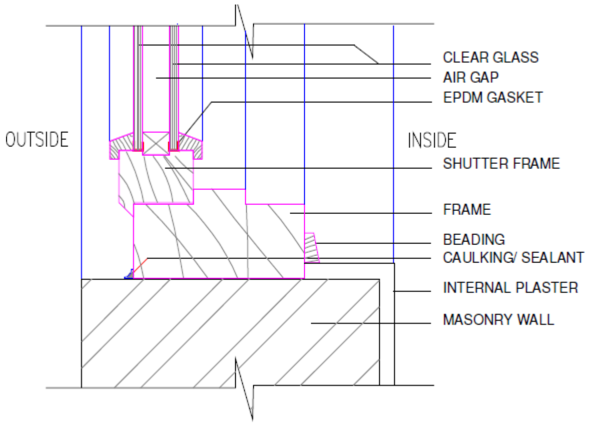


Fig. 3.13 Details of a double glazed window

Willem House, Architect: Jean Cosse. Using highly glazed south facing façades increases the solar heat gains which this building receives.

Interior view showing the exposed concrete soffits and the fin shaped up stand posts. Source: Christian Richters

Thermal Storage Mass

Solar energy can be stored in the floor, walls, ceiling, and / or furnishings of the living space if these components have sufficient capacity to absorb and store heat for use at night. Thermal storage materials can be concrete, bricks, stone or water in containers. Darker colors absorb more heat than lighter colors. Heat losses can also be controlled by providing insulation on the storage mass. Insulating the interior surface of a storage wall effectively nullifies any thermal storage capability of the wall.

Thermal storage wall

- Trombe wall
- Water wall

Thermal storage wall systems are designed primarily for space heating purposes. In this approach, a wall is placed between the living space and the glazing such that it receives maximum solar radiation. The collection, absorption, storage and control of solar energy occur outside.

A Trombe wall is a thermal storage wall made of materials having high heat storage capacity such as concrete, bricks or composites of bricks, block and sand. The external surface of the wall is painted black to increase its absorptivity and is placed directly behind the glazing with an air gap in between. In an unvented wall, the stored heat slowly migrates to the interior, where it heats the adjacent living space. The hotter the air in the airspace, the greater is the heat loss. This heat loss can be reduced by venting the storage wall at the top and bottom. Such units are called as ‘vented Trombe walls’.

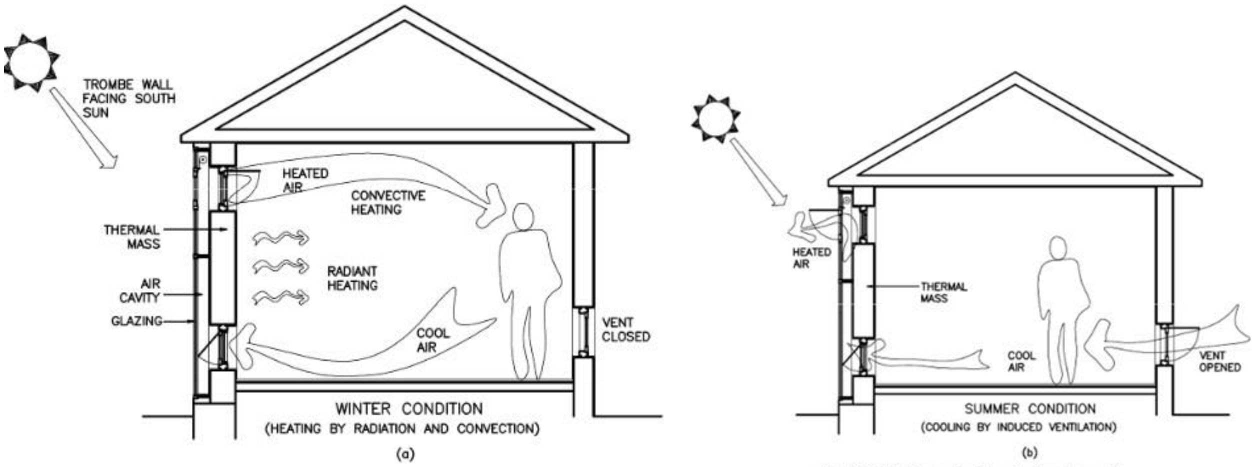


Fig. 3.14 Working principle of a Trombe wall

The air, in the space between the glazing and the wall gets warmed up and enters the living room through the upper vents. Cool room air takes its place through the lower vents, thus establishing a natural circulation pattern **(thermo circulation)** that needs no mechanical means for moving the air. Glare, and the problem of ultra violet degradation of materials is eliminated as compared to the direct gain system. During summer months, the Trombe wall can provide induced ventilation for summer cooling of the space as shown in figure. Here, the heated air in the collector space flows out through exhaust vents at the top of the outer glazing, and air from outside enters the space through openings on the cooler side to replace the hot air. This continuous air movement cools the living space.

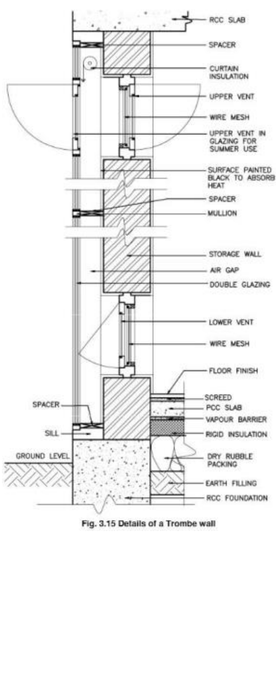


Fig. 3.15 Details of a Trombe wall

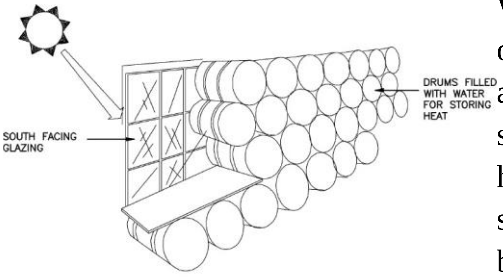


Fig. 3.16 Water wall

Water walls are based on the same principle as that of the Trombe wall, except that they employ water as the thermal storage material. Water walls can store more heat than concrete walls because of the higher specific heat. A water wall is a thermal storage wall made up of drums of water stacked up behind glazing. Buildings like schools or government offices which work during the day, benefit from the rapid heat transfer in water walls. To reduce heat losses, the glazing of the water wall is usually covered with insulation at night. Overheating during summer may be prevented by using movable overhangs.

Sun spaces are essentially used for passive heating in cold climates. This approach integrates the direct gain and thermal storage concepts. Solar radiation admitted directly into the sun space heats up the air, which by convection and conduction through the mass wall reaches the living space. A solarium essentially consists of a sun space or a greenhouse constructed on the south side (in the northern hemisphere) of the building with a thick mass wall linking the two. The sun space can be used as a sit-out during day as it allows solar radiation but keeps out the surrounding cool air. At night, it acts as a buffer

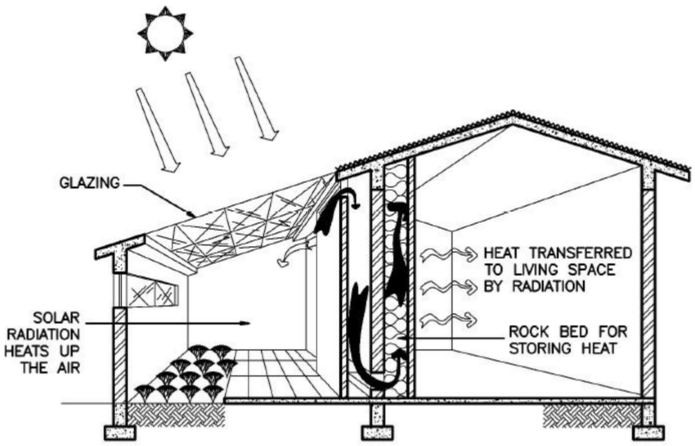


Fig. 3.23 Working principle of a solarium

space.

Passive strategies in different climate zones of India

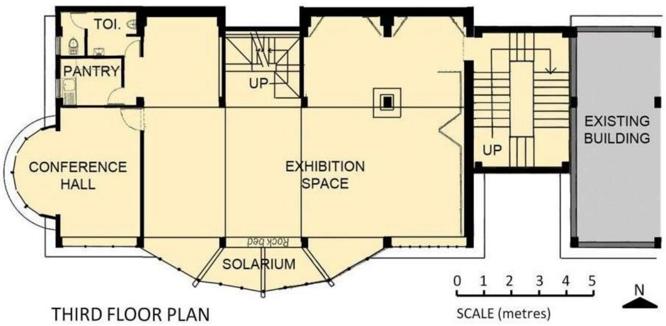
Passive Design Strategies for Cold Climate	
Trombe walls	Indirect solar gain
Solarium	Air lock to prevent heat loss
Heat capturing wall panels	Thermal mass
Sun spaces	Glass covered atrium / central spaces
Solar wall, Direct solar gain in rooms	Design according to the site slopes
Solar heat collector based ventilation / thermal system	Orientation of the building

Maximum openings on positioned in order to bring in more heat	Geothermal heating / cooling

Himurja Office building, Shimla

Architect: Arvind Krishan and Kunal Jain

The Himurja building is a multistoried office located on a sharply sloping site. This office is a 4 storied building of built up area 635 sq.m terraced with an existing building.

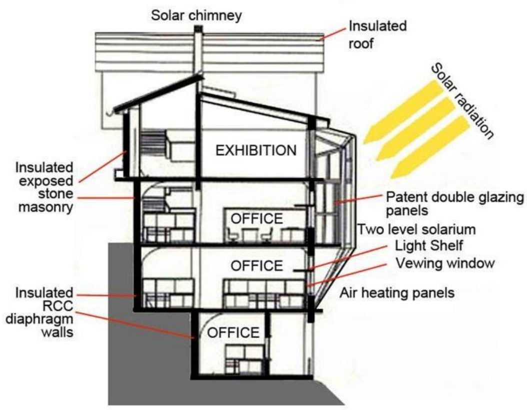


Floor plan of the Himurja Office building

Himurja Office Building, Shimla

The building is set into the slope of the site and the orientation provides maximum exposure to the south side. The Thermal strategies includes coupling the ground and first floor with the earth prevents heat loss to a great extent. With most openings on the south and west facades, the building maximizes solar gain.

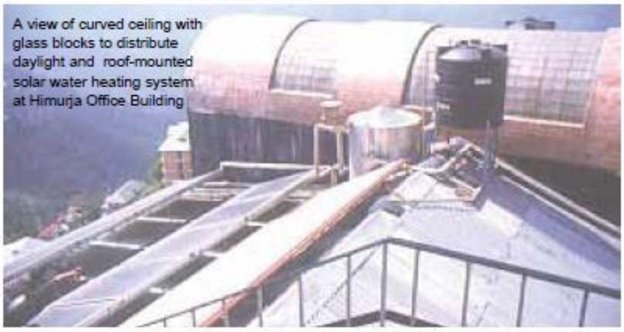
The plan of the building and its three dimensional form allow maximum penetration of sun maximizing both solar heat gain and day light. The judiciously designed thermal mass absorbs and provides heat in the spaces throughout the day. Air heating panels designed as an integral part of the southern wall panels provide effective heat gain. Distribution of heat gain in the entire building is achieved through a connective loop.



Section demonstrating various passive solar features integrated into the building envelope

Ventilation - To optimize ventilation during summer, the connective loop is coupled with solar chimneys designed as an integral part of the roof.

A closer view of the solarium at Himurja Office Building



A view of curved ceiling with glass blocks to distribute daylight and roof-mounted solar water heating system at Himurja Office Building

A solarium (sunspace) is built as an integral part of the southern wall maximizing heat gain. Distribution of daylight in spaces is achieved through careful integration of window and light

shelves. Light reflected off the light shelves is distributed into the deep plan of the building by designing a ceiling profile that provides effective reflectivity. Good Insulation of 5mm thick glass wool in RCC diaphragm walls prevents heat loss. Infiltration losses are minimized through weather-proofed hard plastic windows. Double glazing helps control heat loss from glazing without creating any internal condensation. Renewable energy systems by providing the photovoltaic system of 1.5kWp meets the energy demand for lighting whenever required. Roof- mounted solar water heater system (1000 litre per day) has been used in the building. The water is circulated through radiators for space heating especially in the northern spaces.

Passive Strategies @ Himurja Office building

- Design according to the site slope
- Orientation of the building
- Day lighting - light shelves, solarium
- Thermo-syphoning heating panels
- Double-glazed windows
- Thermal mass
- Insulated roof
- Indirect solar gain
- Design according to the site slope, Orientation of the building, Day-lighting features, light shelves, solarium, thermo-syphoning heating panels, double-glazed windows, Thermal mass, Insulated roof, Indirect solar gain, and Renewable energy systems of solar water heating, and solar photovoltaic lighting features.
- This building does not require any auxiliary heating in winters.
- The monitoring of building shows the inside temperatures as 18 °C to 28 °C with ambient temperature variation from 9 °C to 15 °C.

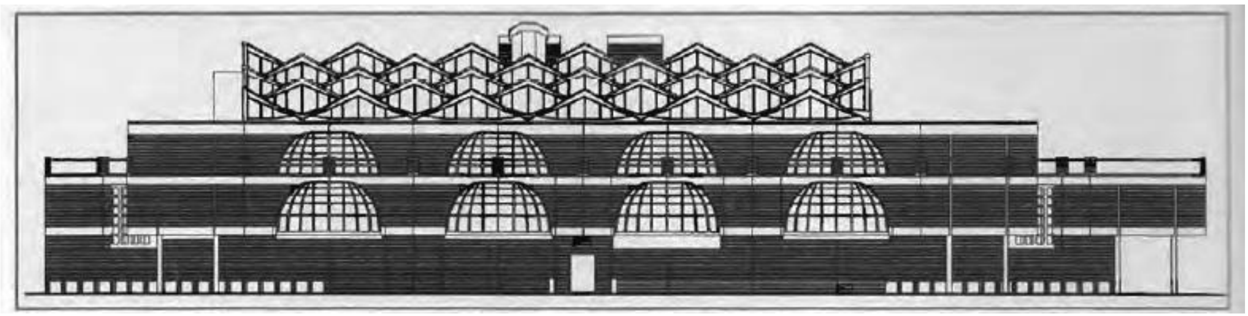
Passive Design Strategies for Composite Climate	
Solar Chimney / Wind Tower	**Terrace Garden / Green Roof**
Courtyards	Roof insulation using clay pots (mutkas)
Waterbodies for evaporation	Design according to site slopes
Building / Site planning to increase cross ventilation (layout of windows in the rooms and building for wind flow)	Internal distribution of spaces to be carried out such that buffer spaces like store rooms, staircases, toilets etc. are located on the eastern and western facades
Earth berming	Light shelves
Thermal mass to reduce heat gain / loss	Geothermal cooling/heating
Dense vegetation cover to moderate micro-climate	Cool roofs in the form of terrace gardens/ roof ponds etc. (high reflective paint finish would not be accepted here)
Cavity walls	Ventilators

PEDA Solar Passive complex, Chandigarh

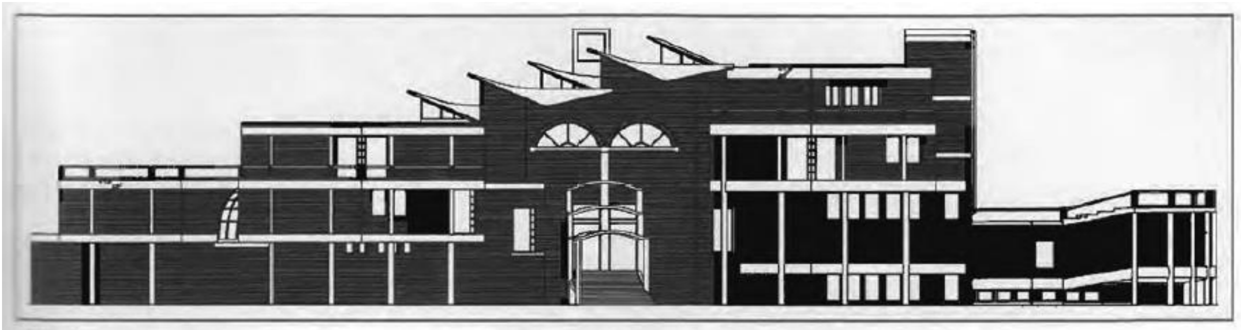
Architect: Arvind Krishan

Punjab Energy Development Agency (PEDA), Chandigarh is a state nodal agency responsible for development of new & renewable energy and non-conventional energy in the state of Punjab. **PEDA**–Solar Passive Complex, Chandigarh is a unique and successful model of Energy Efficient Solar Building, designed on solar passive architecture.

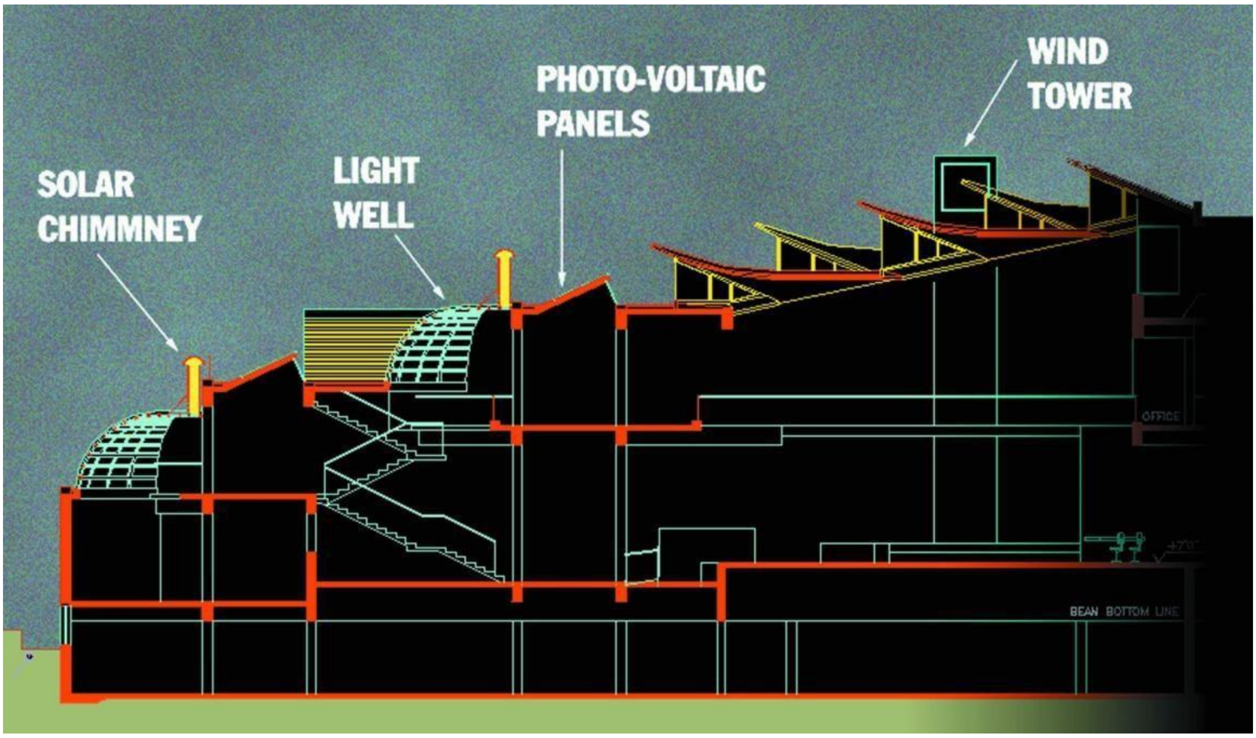
The site area of this complex is 1.49 acre (268ft. x 243 ft.) and the total covered area is 68,224 Sq.Ft. including 23,200 Sq.Ft. Basement. This building has a 3 Dimensional form responding to solar geometry i.e., minimizing solar heat gain in hot dry period and maximizing solar heat gain in cold period. Overlapping floors at different levels in space floating in a large volume of air, with interpenetrating large vertical cut-outs enclosed within an envelope. These are integrated with light wells and solar activated naturally ventilating, domical structures.



South elevation showing domical roofs and vertical roof glazing systems for daylight integration and ventilation



Interconnected volumes of space to enable passive space conditioning of entire volume of building



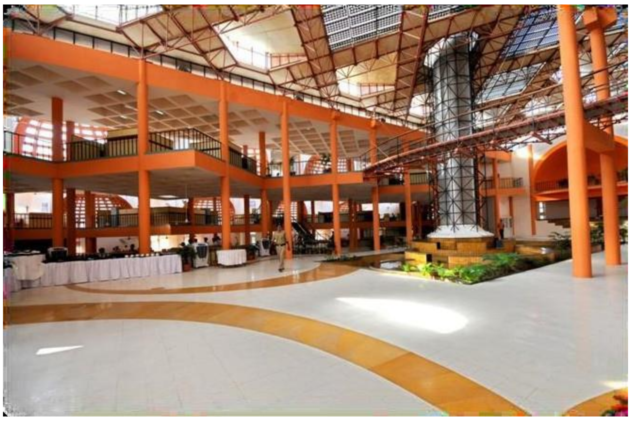
Passive strategies adopted at PEDA

Daylight Harvesting:

On the south western facade, dome shaped concrete structures have horizontal and vertical intersecting fins with glass fixed in the voids to allow natural light with reduced glare. These allow indirect light to enter the building in summers and direct sunshine in winters. The atrium is covered by a lightweight shell roofing of 10 cm of high-density EPS (extruded polystyrene) sandwiched between high-grade FRP (fibre-reinforced plastic) sheets and reinforced with steel; specifically angled to allow sun in winters and block in summers.

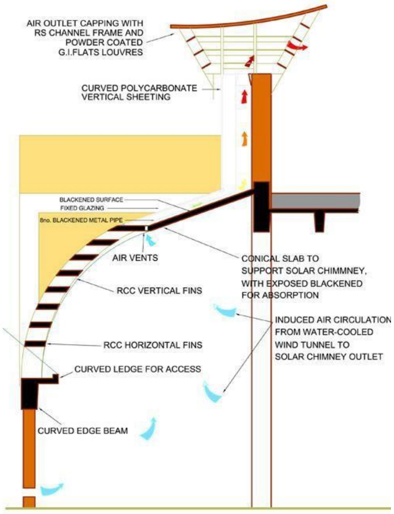

Maintaining thermal comfort:

The envelope attenuates the outside ambient conditions and the large volume of air is naturally conditioned by controlling solar access in response to the climatic swings during summer and winters. The large volume of air is cooled during the hot period by a wind tower, integrated into the building design, and in cold period this volume of air is heated by solar penetration through the roof glazing generating a convective loop.The thermal mass of the floor slabs helps attenuate the diurnals swings.



Light Vaults _ the vertical cut outs in the floating slabs are integrated with light vaults and solar activated naturally ventilating, domical structures in the south to admit day light without glare and heat.

Wind Tower coupled with Solar Chimneys_ The wind tower centrally placed coupled with solar chimneys on the domical structures for scientific direct & indirect cooling and scientific drafting of used air.



Water Bodies: The water bodies with waterfalls and fountains have been placed in the central atrium of the complex for cooling of whole the complex in the hot and dry period.

Cavity Walls: The complex is a single envelope made up of its outer walls as double skin walls having 2” cavity in between. The cavity walls facing south and west are filled with further insulation material for efficient thermal effect.

Floating Slab System

The system of floating and overlapping slab with interpenetrating vertical cut outs allow free and quick movement of natural air reducing any suffocating effect.

Shell Roofing on Central Atrium:
The Central atrium of the complex having main entrance, reception, water bodies, cafeteria and sitting place for visitors constructed with hyperbolic shell roof to admit daylight without glare and heat coupled with defused lighting through glass to glass solar panels. The roof is supported with very light weight space frame structure.

Insulated Roofing:
All the roofs have been insulated with double insulation system to avoid penetration of heat from the roof.

Solar Power Plant: 25Kwp building integrated solar photovoltaic power plant has been set up to meet the basic requirement of electricity in the complex

Passive Strategies @ PEDA Office Complex

- Appropriate building design
- Orientation
- Evaporative cooling towers – Wind tower with Solar Chimney
- Water bodies
- Day lighting – Light vault, Central Atrium
- Insulated Roofing
- Good thermal mass – Cavity walls, Floating slabs
- Evaporative cooling towers work best with open floor plans that permit the air to circulate throughout the building without any obstacles.
- Good thermal mass of the building helps the building to perform in extreme

conditions (Cavity walls).

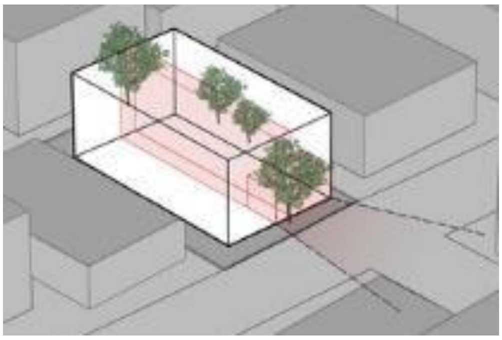
- Appropriate building design and orientation having properly placed building elements reduced or minimize the solar gain in summer.
- Elements like light Vault, Solar chimney, hyperbolic parabolized atrium roof help to minimize the solar gain.

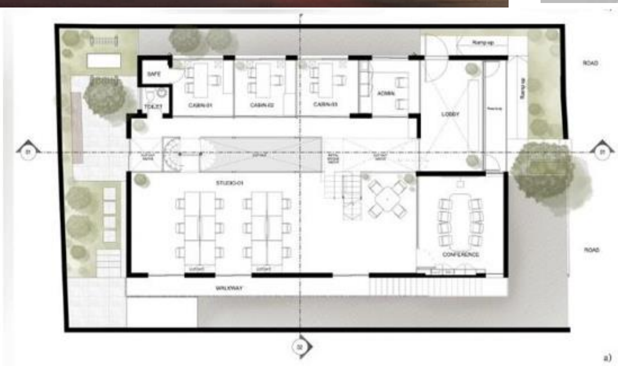
Passive Design Strategies for Warm and Humid Climate	
Building/Site planning to increase cross ventilation (layout of windows in the rooms and building for wind flow).	Internal distribution of spaces to be carried out such that buffer spaces like store rooms, staircases, toilets etc. are located on the eastern and western facades.
Earth berming	Solar Chimneys, Ventilators
Terrace gardens / Green roofs	Thermal mass

<u>KSM Architecture Studio, Chennai</u>

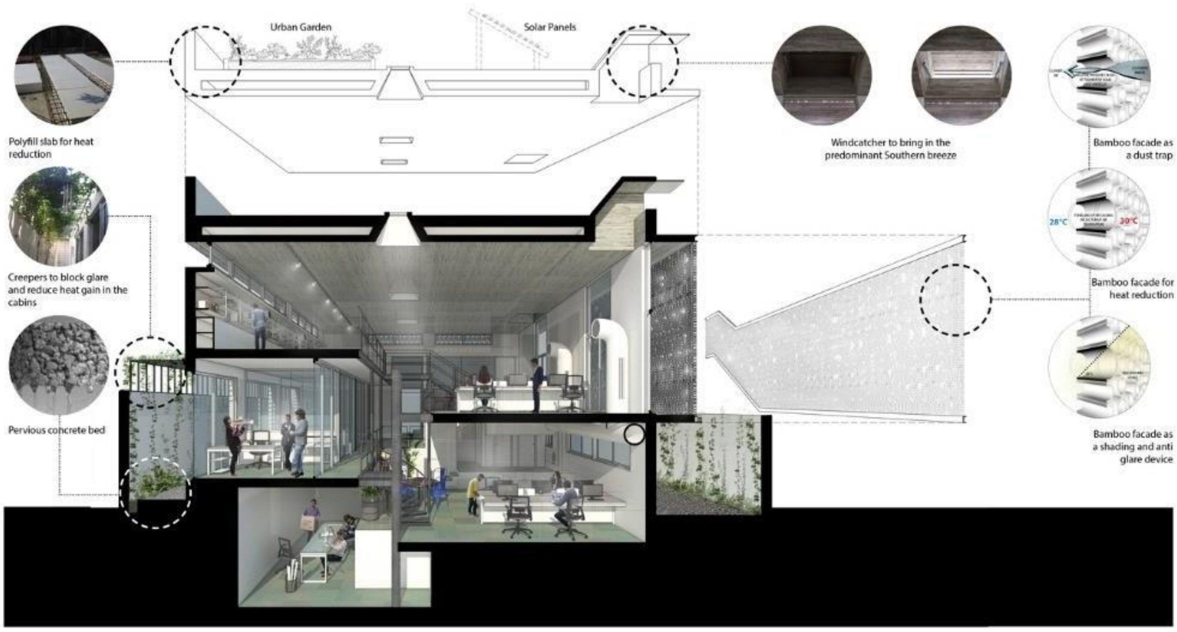
Architect: Sriram Ganapathi

KSM Architecture Studio embodies the design beliefs and principles of the practice that has been about environmentally friendly and climate sensitive and relevant architecture. The entire studio is covered by a roof spanning 10.70m that envelops the different functions as one single volume. The building was envisaged as a simple two storied structure _ a container.



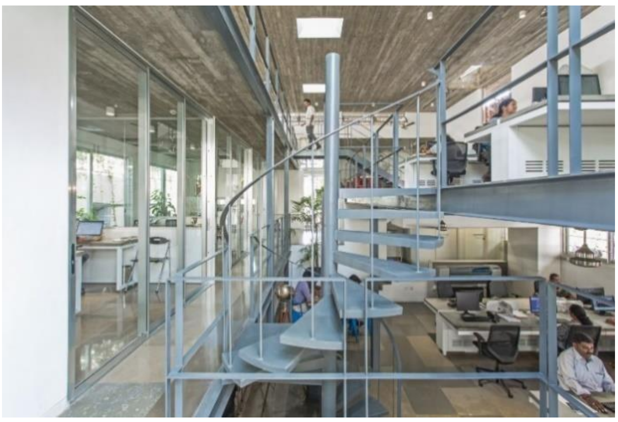


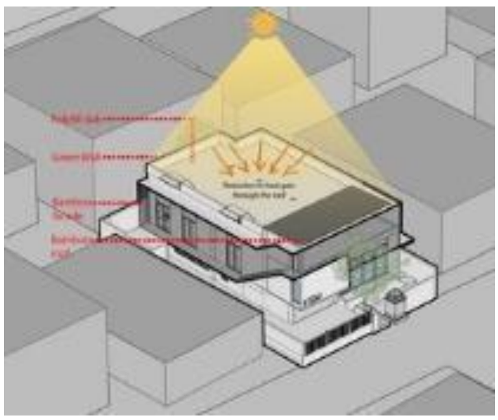
Five different levels are created on either side of a central void space acting as a contiguous link with the street in both a visual and sensory manner. The five levels house the principal designers, the architecture and the engineering studio, library, a workshop. In addition to these, a cafeteria on the terrace level. The roof contributes for more than 60% of the heat gain. Chennai has a constant southern breeze at velocities of around 1.5 m/s almost all year round.



The Building Envelope

The building has a self-sustaining 'skin'. The 10.70m clear width of the studio is spanned with 450mm deep concrete rib beams at 1.0m spacing. The roof is insulated with 250mm thick high- density polystyrene blocks sandwiched between two 100mm thick concrete slabs. The eastern and southern facades are covered by a curtain of sliced bamboo culms of 60mm length, strung together along a steel rod.





The Bamboo façade serves three purposes

- It cuts the glare from the morning and afternoon sun into the workspaces
- Brings in the prevailing southern breeze into the workspaces and also acts as a dust trap
- Brings down the temperature by a significant amount in the interior spaces.

A layer of high solar reflective index tiles cover the roof in addition to the poly fill slab which further reduce heat gain. Three skylights, 300mm square, are set in trapezoidal steel cones in the roof slab bringing in diffused light into the studio. A verandah like cafeteria with an inclined bamboo roof runs along the eastern edge of the building. It shades and directs the cool sea breeze through top-hung openings at the roof level into the studio. Two motorized wind catchers are placed close to the roof on the southern side with flaps that open out perpendicular to the wall and help draw in the ambient breeze into the interiors.

Passive Strategies @ KSM Architecture Studio

- Climate responsive building
- Open plan with 5 levels
- Building envelope
- Roof insulation
- Thermal mass
- Skylight
- Light shelves
- Wind catchers
- Green wall
- Terrace gardens
- Cross ventilation

- Locally available materials
- Climate responsive building, Open plan with 5 levels, Building envelope, Roof insulation, Thermal mass, Skylight, Light shelves, Wind catchers, Green wall, Terrace gardens, Cross ventilation, Locally available materials.
- All these envelopes together result in keeping the indoor temperature within 25-30°C whereas the outdoor temperature is between 35 - 42°C

DESIGN STRATEGIES FOR WALLS, ROOFS AND FLOORS

BUILDING SKIN THICKNESS

Humans can survive only if their deep-body temperature is around 35-40^{0}C (w i t h skin temperatures of 31 -34^{0}C), but people live in places where the air temperature can be high as 50^{0}C or as low as -50^{0}C. This is only possible because of the three sets of adjustment / protection mechanisms available: thermo regulation of the body itself,clothing and shelters (buildings).

The proportion of annual heating load that can be supplied by the sun results from a balance between the amounts of solar radiation collected, the building's rate of heat loss, and the amount of heat that can be stored in thermal mass during the day for use at night. The amount of heat loss is a function of the insulating qualities of the building skin [SKIN THICKNESS] and the severity of the climate.

The building envelope is physical separator between the exterior and the interior of the building and fenestration systems.

- **OPAQUE COMPONENTS** include walls, roofs, slabs on grade (in touch with ground), basement walls, and opaque doors.

- **FENESTRATION SYSTEMS** include windows, skylights, ventilators, and doors that are more than one- half glazed.

- **THE ENVELOPE** protects the building's interior and occupants from the weather conditions and shields them from other external factors e.g. noise, air pollution, etc.

This strategy recommends insulation thickness, depending on climate and building type, which creates greater or lesser conductive loads on the envelope. More insulation is needed in skin-loaded buildings and in cold climates. There are three basic strategies for placing thermal insulation

- The insulation may be contained within the skin cavity.
- The insulation can be applied to the surface of the skin.
- The insulation and structure are integrated, with no framing.

Insulation levels for skin load dominated, passively cooled buildings are based on maintaining a temperature difference between the inside and the outside and on reducing solar heat gain. Cooling strategies like cross ventilation and stack ventilation are used, the inside temperature is slightly

higher than the outside, so insulation is not needed to reduce the heat flow. If walls and roofs are protected from solar gain by full shading insulation levels can be significantly reduced.

Assessing the thermal performance of the building envelope involves three considerations:

- The quantity of heat transferred through the walls, windows and other elements of building envelope – the conductive heats transfer.
- The quantity of heat needed to bring the temperature of the outdoor air to that of the indoor air.
- The air-leakage characteristics or air exchange rate, the differences on the inner surfaces of the building envelope – the mold and mildew control points.

Heat transfer through the Building Envelope

Heat transfer through envelope components is complex and dynamic. The direction and magnitude of heat flow are affected by solar gains from the sun, outdoor temperature, indoor temperature, and exposed surface area. Building envelope components have three important characteristics that affect their thermal performance: their U-factor or thermal resistance; their thermal mass or ability to store heat, measured as heat capacity (HC); their exterior surface condition/finish (for example, are they light in color to reflect the sun or dark to absorb solar heat?).

R-values & U-values

U-factor takes account of the overall construction assembly, the R-value is a material property, like density, specific heat, and conductance. A larger R-value has greater thermal resistance, or more insulating potential, than a smaller R-value. (Of course, the opposite is true with U-factors- the lower the better.) R-values are widely recognized in the building industry and are used to describe insulation effectiveness. The insulation R-value does not describe the overall performance of the complete assembly, however it only describes the thermal resistance of the insulation material. U-factor, not R-value, is what matters and the U-factor is affected by many factors other than the thermal resistance of the insulation material.

The components of the envelope, which include walls, windows, doors, roofs, etc., have different effects on heat exchange, whereby heat gain through unshaded windows and roofs, represent the largest proportion of the total amount of heat gain of the building.

Different types and thicknesses of walls might improve the thermal resistance of the building envelope beside the lower U value a shorter heating period is obtained. The thermal capacity of the envelope in a hot climate helps reduce the thermal temperature instability of the inner environment and delays the heat from reaching peak level.

Heat/Moisture Losses	Walls	Roof	Window
Minimise conduction losses	Use insulation with low U-value	Use insulation with low U-value	Use mamerial with low U-value
Minimise convection losses & Moisture penetration	Reduce air leakage & use vapor barrier	Reduce air leakage & use vapor barrier	Use prefabricated window and seal the joints between windows and walls
Minimise Radiation Losses	Use light coloured coating with high reflectance	Use light coloured coating with high reflectance	Use glazing with low SHGC

Fig 2: ECBC Compliant Design Strategy for a Building *(Source: Energy Conservation Building Code User Guide, BEE, ECO-III)*

Envelopes for Climate Types

HOT AND DRY CLIMATE ZONE	
Thermal Requirements	**Physical Manifestation**
Reduce Heat Gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Insulation of building envelope
Increase thermal capacity (Time lag)	Massive structure
Increase buffer spaces	Air locks/lobbies/balconies/verandahs
Decrease air exchange rate (ventilation during day-time)	Smaller windows openings, night ventilation
Increase shading	External surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale colour, glazed china mosaic tiles etc.
Reduce solar heat gain	Use glazing with lower SHGC and provide shading for windows. Minimize glazing in East and West
Promote Heat Loss	
Increase air exchange rate (Ventilation during night-time)	Courtyards/wind towers/arrangement of openings
Increase humidity levels	Trees, water ponds, evaporative cooling

.

WARM AND HUMID CLIMATE ZONE	
Thermal Requirements	**Physical Manifestation**
Reduce Heat Gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Roof insulation and wall insulation
	Reflective surface of roof
Increase buffer spaces	Balconies and verandas
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale color, glazed china mosaic tiles, etc.
Reduce solar heat gain	Use glazing with lower SHGC and provide shading for windows. Minimize glazing in East and West
Promote Heat Loss	
Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
Decrease humidity levels	Dehumidifiers/desiccant cooling

COLD (Cloudy/Sunny) CLIMATE ZONE	
Thermal Requirements	**Physical Manifestation**
Reduce Heat Loss	
Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
Increase thermal resistance	Roof insulation, wall insulation and double glazing
Increase thermal capacity (Time lag)	Thicker walls
Increase buffer spaces	Air locks/Lobbies
Decrease air exchange rate	Weather stripping and reducing air leakage
Increase surface absorptive	Darker colours
Promote Heat Gain	
Reduce shading	Walls and glass surfaces
Trapping heat	Sun spaces/green houses/Trombe walls etc.

COMPOSITE CLIMATE ZONE	
Thermal Requirements	**Physical Manifestation**
Reduce Heat Gain in Summer and Reduce Heat Loss in Winter	
Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
Increase thermal resistance	Roof insulation and wall insulation
Increase thermal capacity (Time lag)	Thicker walls
Increase buffer spaces	Air locks/Balconies
Decrease air exchange rate	Weather stripping
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale color, glazed china mosaic tiles, etc.
Reduce solar heat gain	Use glazing with lower SHGC and provide shading for windows. Minimize glazing in East and West
Promote Heat Loss in Summer/Monsoon	
Increase air exchange rate (Ventilation)	Courtyards/wind towers/arrangement of openings
Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
Decrease humidity in monsoon	Dehumidifiers/desiccant cooling

Thermal Mass

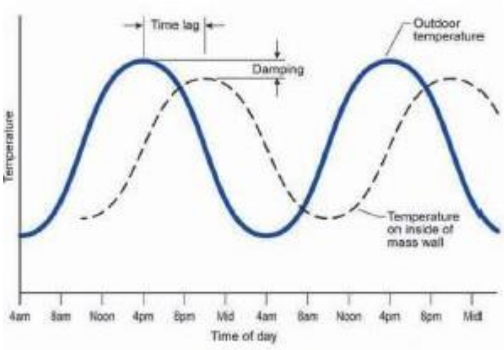


Figure E-2: Time Lag and Damping Effects of Thermal Mass

Mass is another important characteristic that affects the thermal performance of construction assemblies. Heavy walls, roofs, and floors have more thermal mass than light ones. Thermal mass both delays and dampens heat transfer. The time lag between peak outdoor temperature and Interior heat transfer. Is between four and twelve hours depending on the heat capacity of the construction and other characteristics.

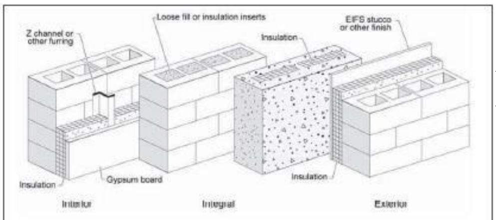


Figure E-3: Mass Wall Constructions

The impact of thermal mass is greater in climates where there is a large temperature difference between night and day (such as mountain and desert climates). Thermal mass has far less impact when outdoor conditions are steadily hot or cold.