B.ARCH (6th SEMESTER)

BAR 608 – THEORY OF SUSTAINABLE ARCHITECTURE

PASSIVE SOLAR BUILDING DESIGN

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Introduction to Passive Solar System

- What is the meaning of this word “Passive” ?
- What is “Passive solar design”?

The term "passive" implies that energy-consuming mechanical components like HVAC, pumps, fans etc. are not used.

- Passive solar design refers to the use of the sun’s energy for the heating and cooling of living spaces. In this approach, the building itself or some element of it takes advantage of natural energy characteristics in materials and air created by exposure to the sun.
- Passive systems are simple, have few moving parts, and require minimal maintenance and require no mechanical systems.

Passive Solar Design (Rule Of Thumb)

- The building should be elongated on an east-west axis.
- The building's south face should receive sunlight between the hours of 9:00 A.M. and 3:00 P.M. (sun time) during the heating season.
- Interior spaces requiring the most light and heating and cooling should be along the south face of the building. Less used spaces should be located on the north.
- An open floor plan optimizes passive system operation.
- Use shading to prevent summer sun entering the interior. Sun Angles can help you figure the overhang calculations.

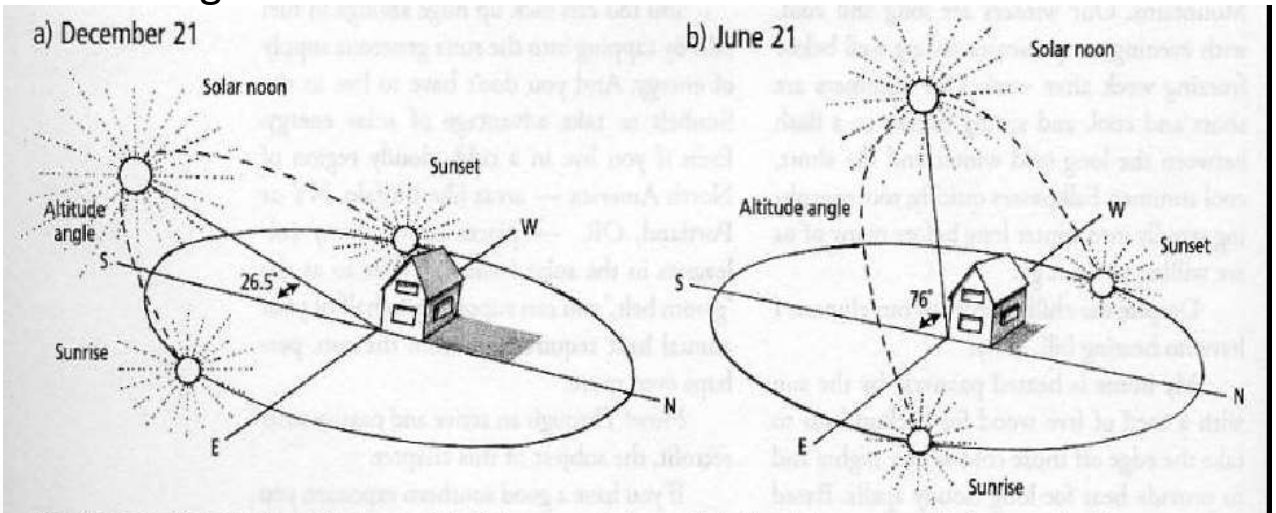


Fig. 4-1: In a passive solar home, the low-angled winter sun penetrates south-facing windows to heat the home. During the summer, the high-angled sun shines on the roofs of houses, reducing heat gain.

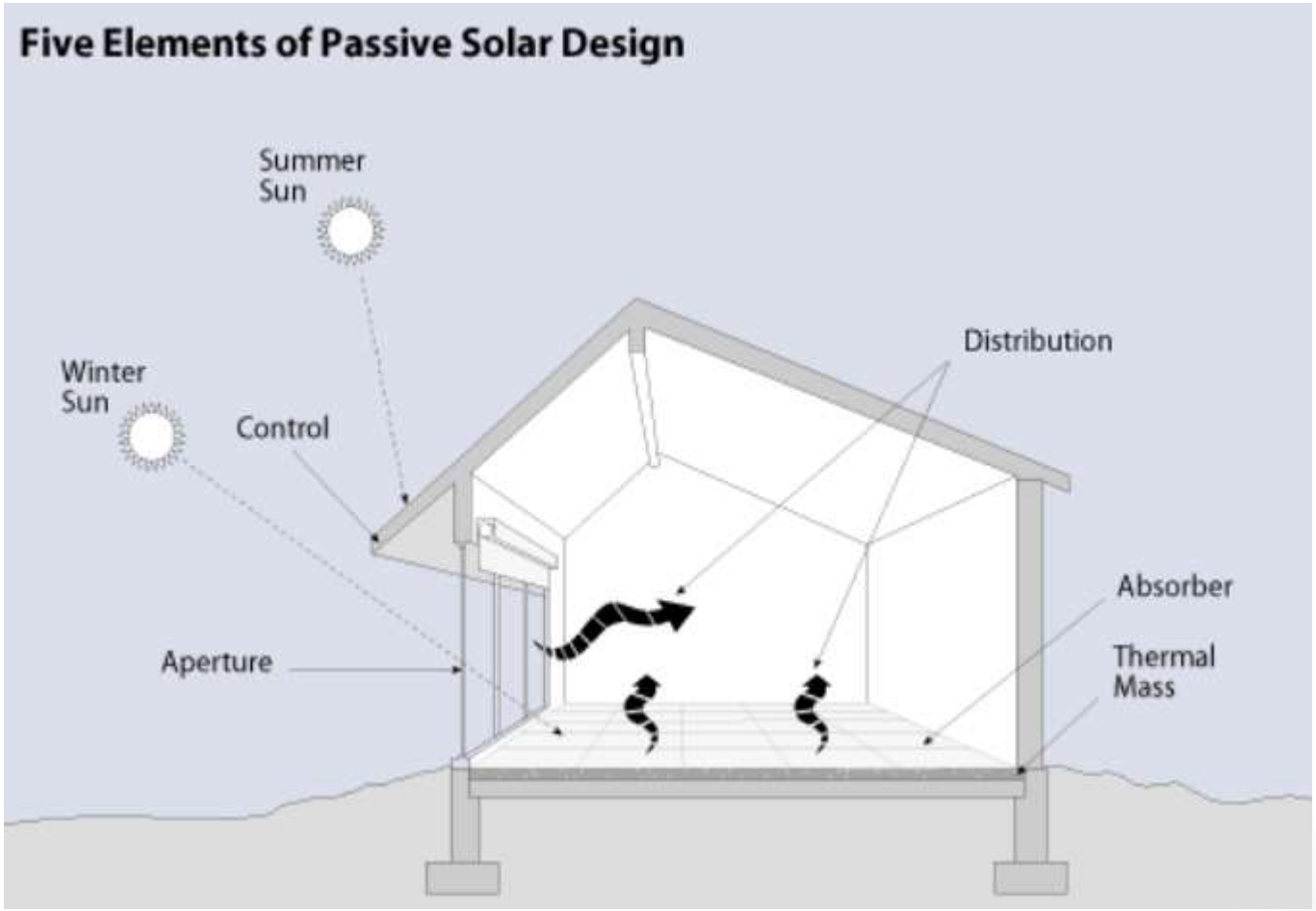
- Passive solar energy is an excellent idea to heat,cool and lightning the living room based on the structure of our buildings.
- Passive solar energy is used to distribute heat or cool through wise selection of building materials.
- Passive solar energy will provide inexpensive sustainable alternatives for heating and cooling of home.
- Passive solar system is used to “collect, store and distribute thermal energy”-by means of conduction, convection and radiation.
- Decrease the amount of money that we spend on energy.
- The exploitation and misuse of natural resources rapidly depleting the Non-renewable energy resources.
- Passive solar energy buildings considerably reduces the usage of Non-renewable energy resources.

Why Passive?

- Passive meets the minimum requirements.
- Active produce the green house gases such as (CO2).
- Active solar energy is expensive and more equipments are need for installation.

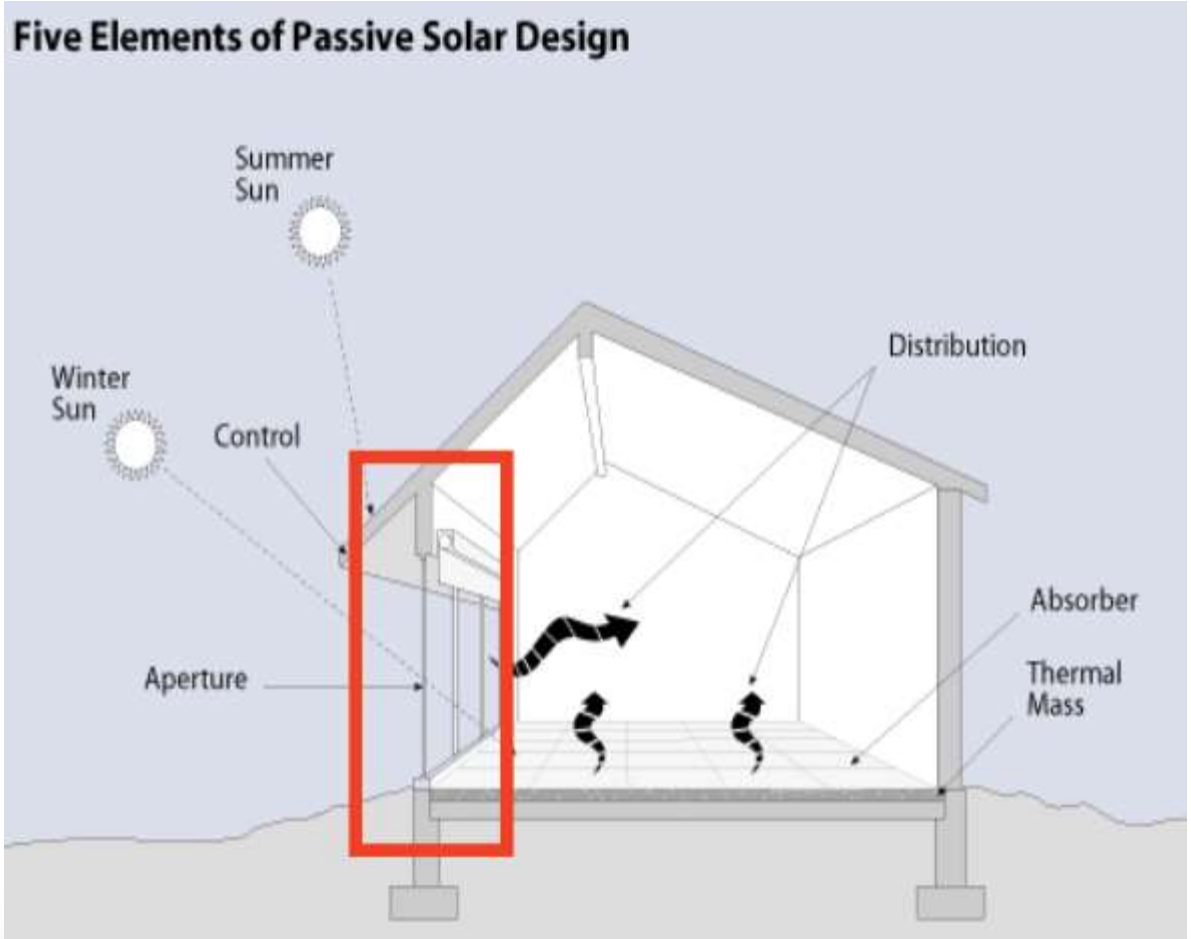
Passive Solar Design Basics

- Aperture/Collector
- Absorber
- Thermal mass
- Distribution
- Control



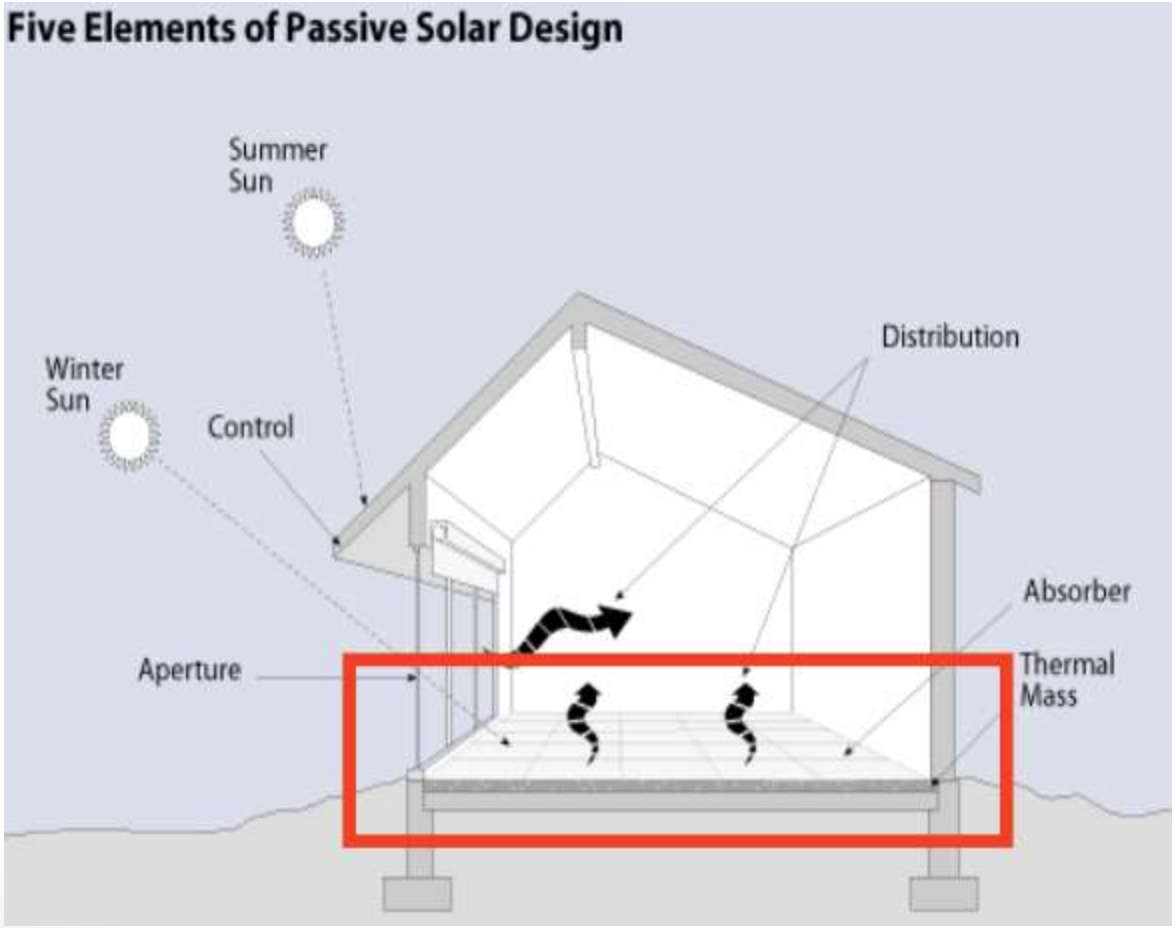
Aperture/Collector

The large glass area through which sunlight enters the building. The aperture(s) should face within 30 degrees of true south and should not be shaded by other buildings or trees from 9a.m. to 3p.m. daily during the heating season.



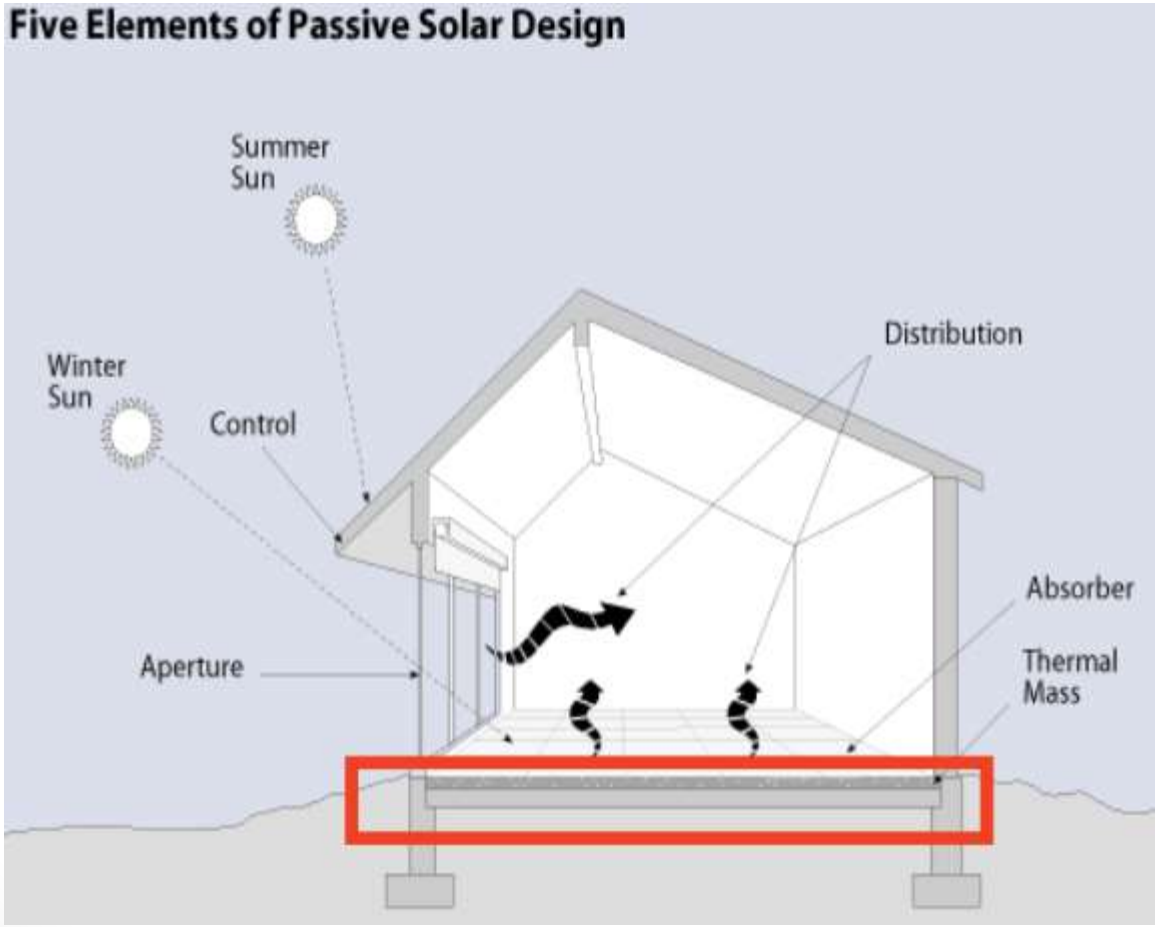
Absorber

The hard, darkened surface of the storage element. The surface, which could be a masonry wall, floor, or water container, sits in the direct path of sunlight. Sunlight hitting the surface is absorbed as heat.



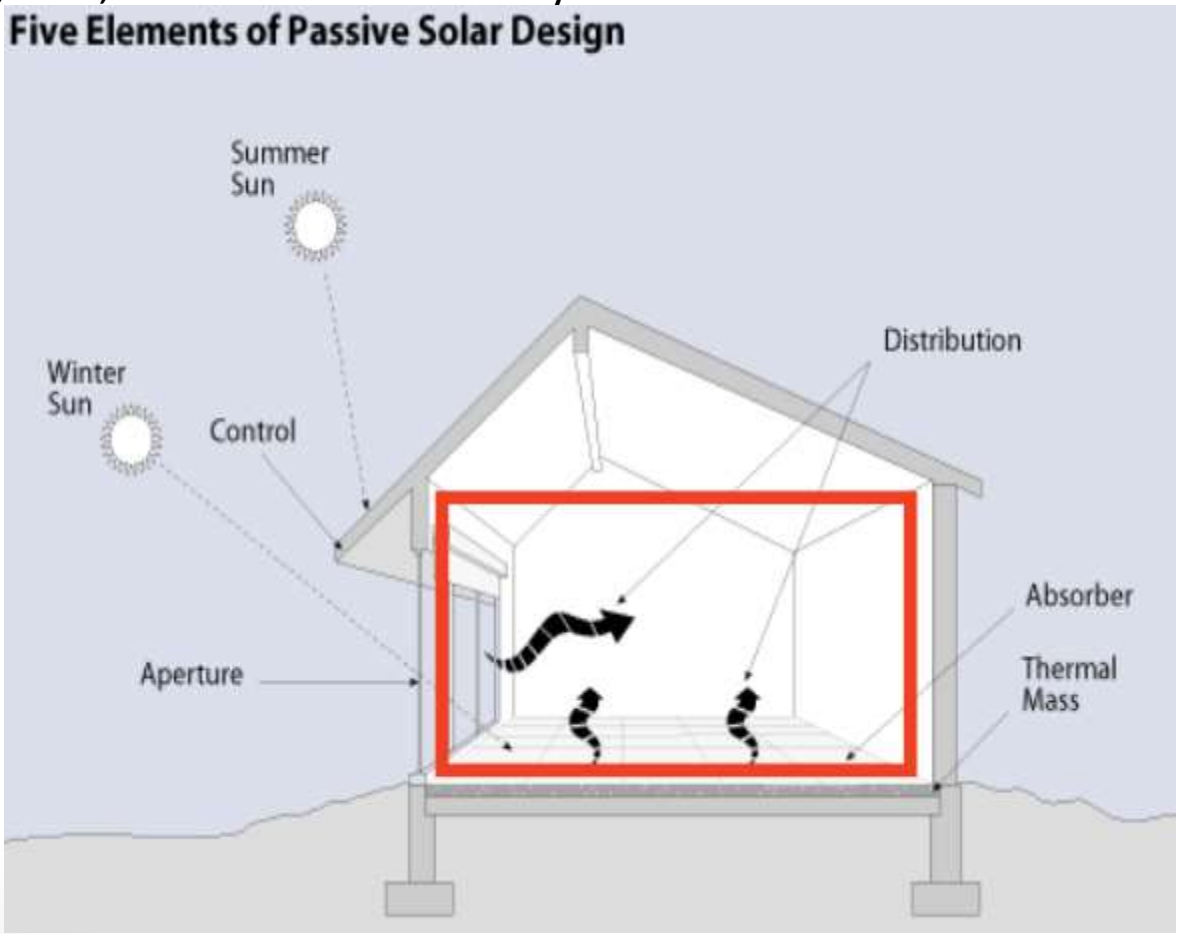
Thermal mass

Materials that retain or store the heat produced by sunlight. While the absorber is an exposed surface, the thermal mass is the material below and behind this surface.



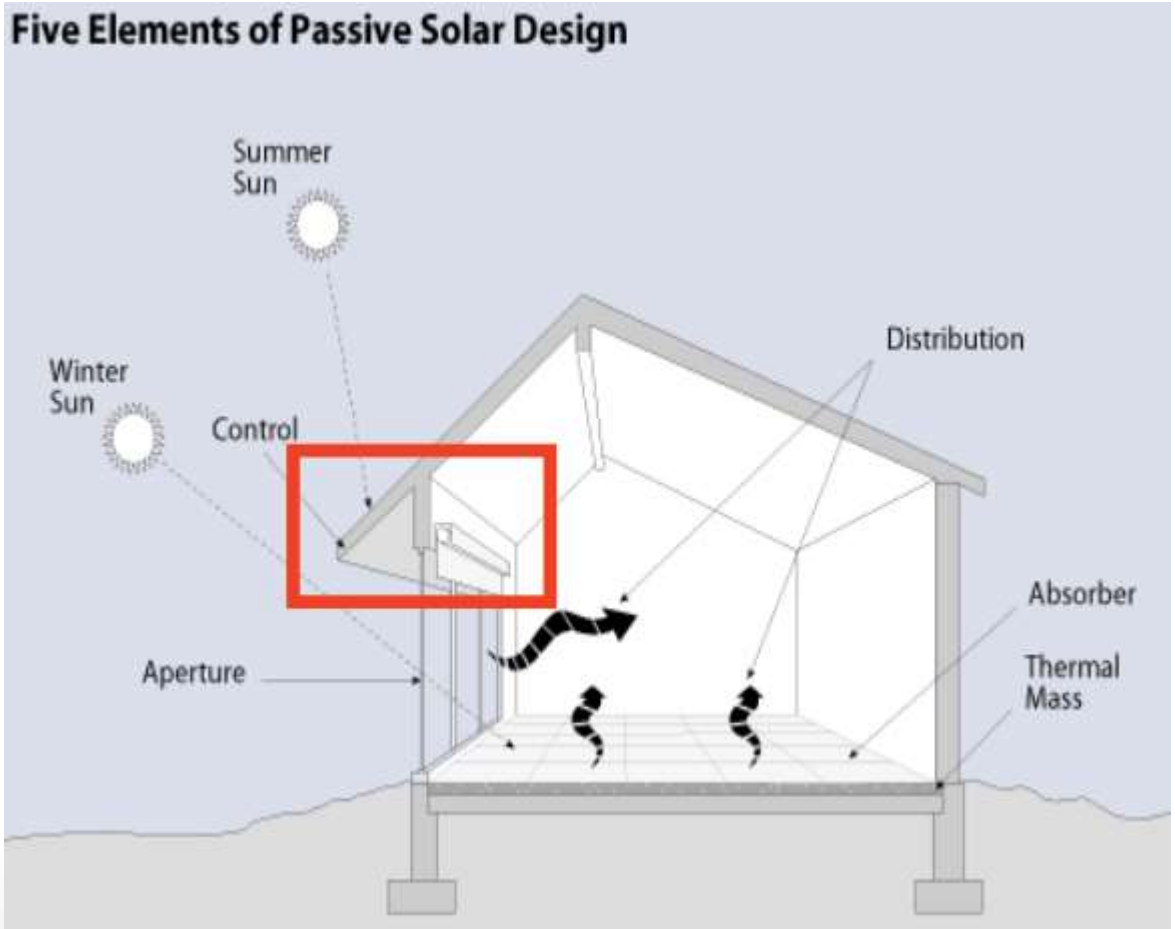
Distribution

Method by which solar heat circulates from the collection and storage points to different areas of the house. A strictly passive design will use the three natural heat transfer modes conduction, convection and radiation exclusively. In some applications, fans, ducts and blowers may be used to distribute the heat through the house.



Control

Roof overhangs can be used to shade the aperture area during summer months. Other elements that control under and/or overheating include electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; and awnings



Passive Solar Heating

- Passive solar heating happens when sunlight strikes an object and that object absorbs the heat.
- Effective when the windows are oriented correctly,
- Perfect orientation is south.
- By installing high performance windows with insulated frames, multiple glazing, low-e-coatings we may reduce the heat loss by 50 to 75 percent.

Passive Solar Heating

- The goal of all passive solar heating systems is to capture the sun's heat within the building's material and release that heat during periods when the sun is not shining.

Primary elements of passive solar heating are :

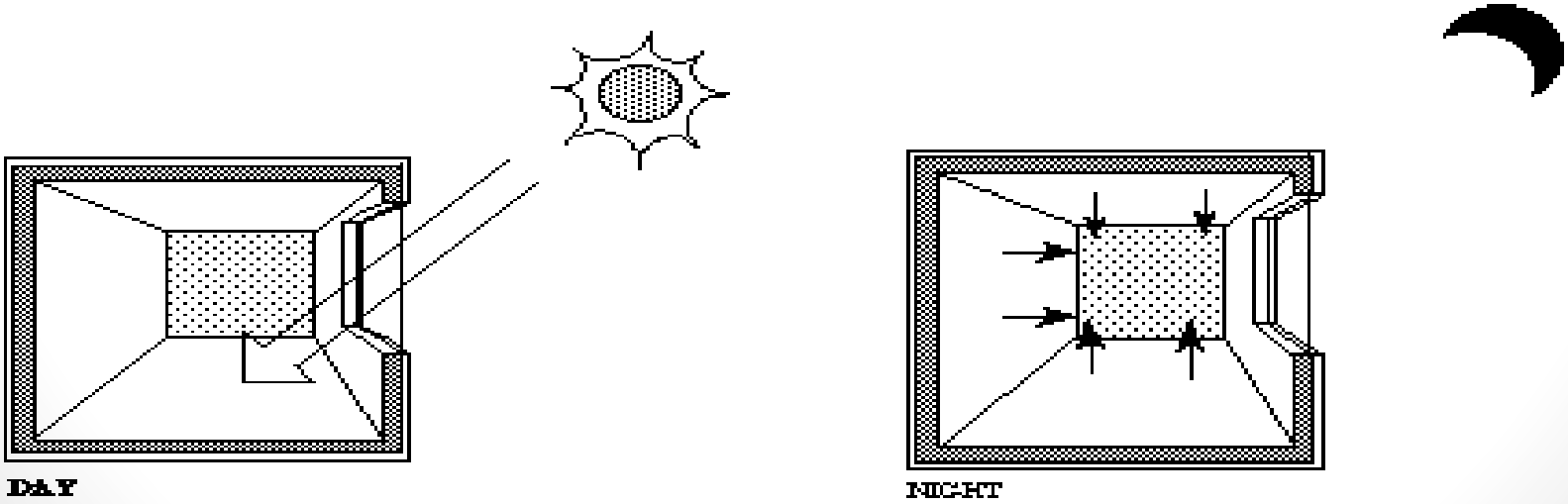
- Thermal mass to absorb, store, and distribute heat.
- South-facing windows are designed to let the sun's heat in while insulating against the cold.
- Open floor plans allow more sun inside.

There are 3 main methods of passive solar heating:

- *Direct gain*
- *Indirect gain*
- *Isolated gain*

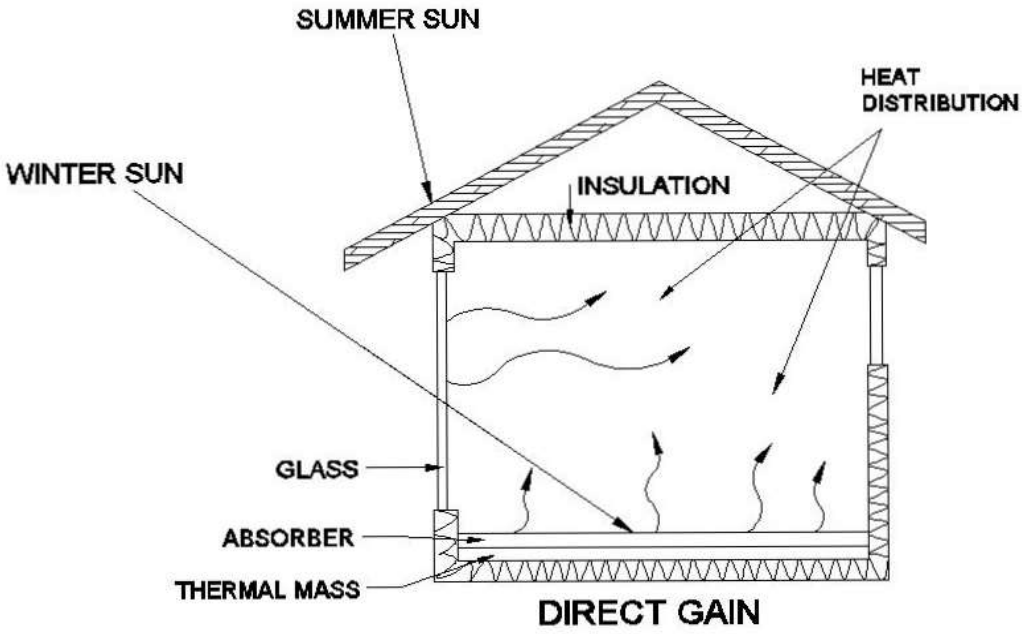
Direct Gain

The actual living space is a solar collector, heat absorber and distribution system. South facing glass admits solar energy into the house where it strikes masonry floors and walls, which absorb and store the solar heat, which is radiated back out into the room at night. These thermal mass materials are typically dark in color in order to absorb as much heat as possible.



Direct Gain

- Direct gain method is the simplest method where the space of the building is directly heated by sunlight.
- Living space work as solar collector, heat absorber and distribution system.
- South-facing windows.



Indirect Gain

Thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space by conduction. The indirect gain system will utilize 30-45% of the sun's energy striking the glass adjoining the thermal mass.

The most common indirect gain systems is a Trombe wall. The thermal mass, a 6-18 inch thick masonry wall, is located immediately behind south facing glass of single or double layer, which is mounted about 1 inch or less in front of the wall's surface. Solar heat is absorbed by the wall's dark-colored outside surface and stored in the wall's mass, where it radiates into the living space. Solar heat migrates through the wall, reaching its rear surface in the late afternoon or early evening. When the indoor temperature falls below that of the wall's surface, heat is radiated into the room.

Indirect Gain

- For indirect gain,sunlight is often received by a south facing wall,and as air moves internal space the heat moves through the living room.
- Sunspace

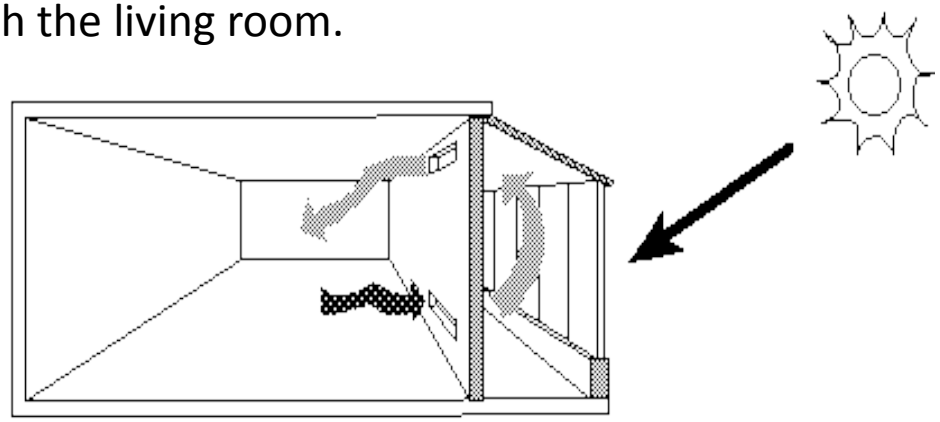
Main functions of sunspaces

Main considerations

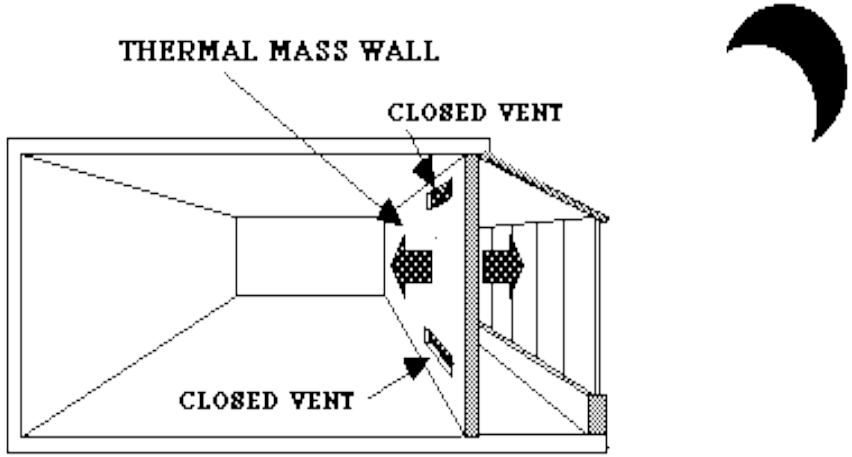
a. *Siting*

b. *Heat Distribution*

c. *Glazing*

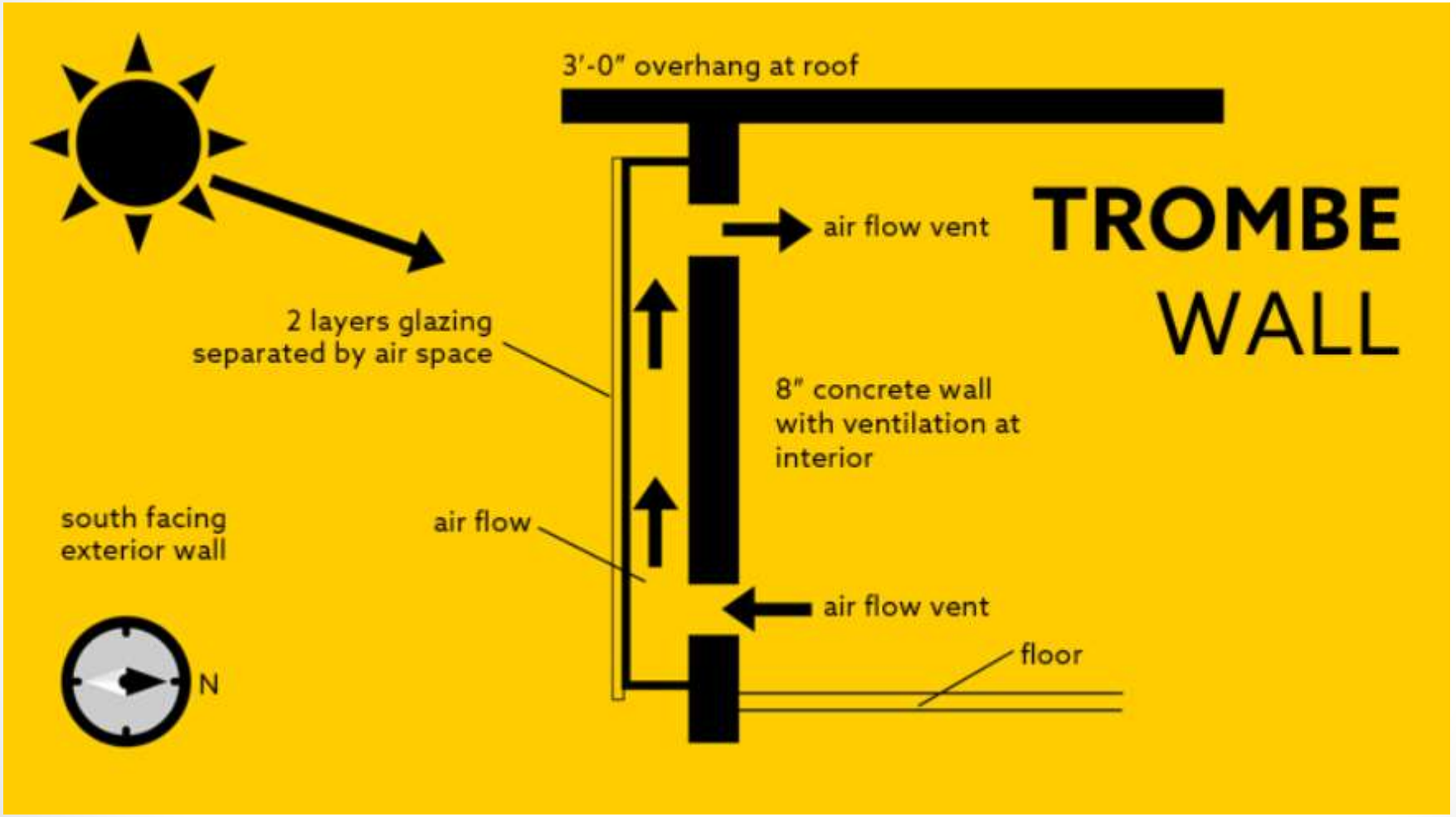


DAY



NIGHT

Indirect Gain



Indirect Gain

The main aspects of Trombe wall are:

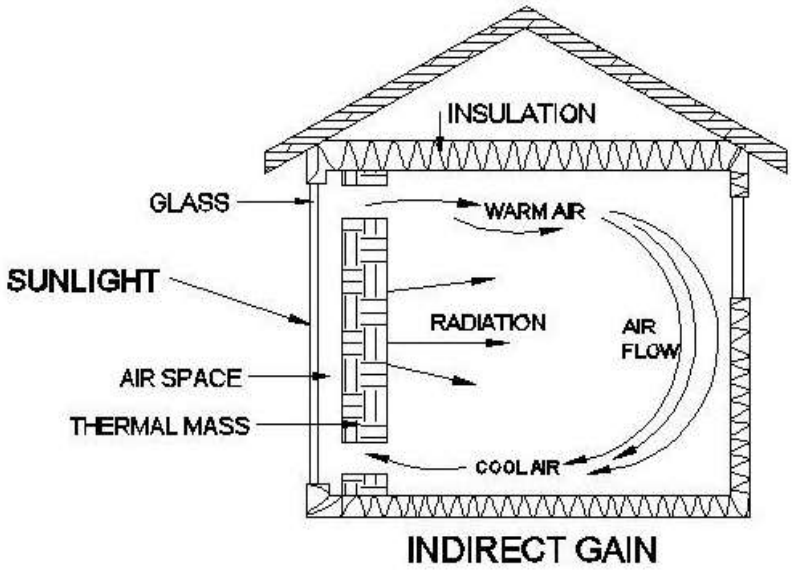
I. Glazing

II. Air gap between glazing and thermal wall

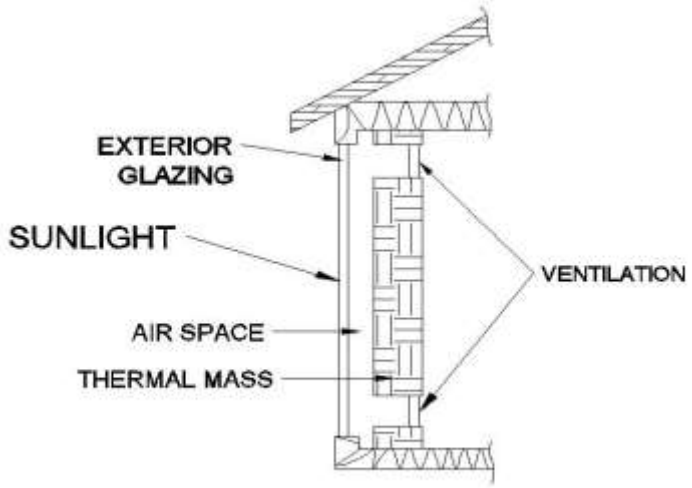
III. Mass or thermal storage

IV. vents (in some thermal storage walls)

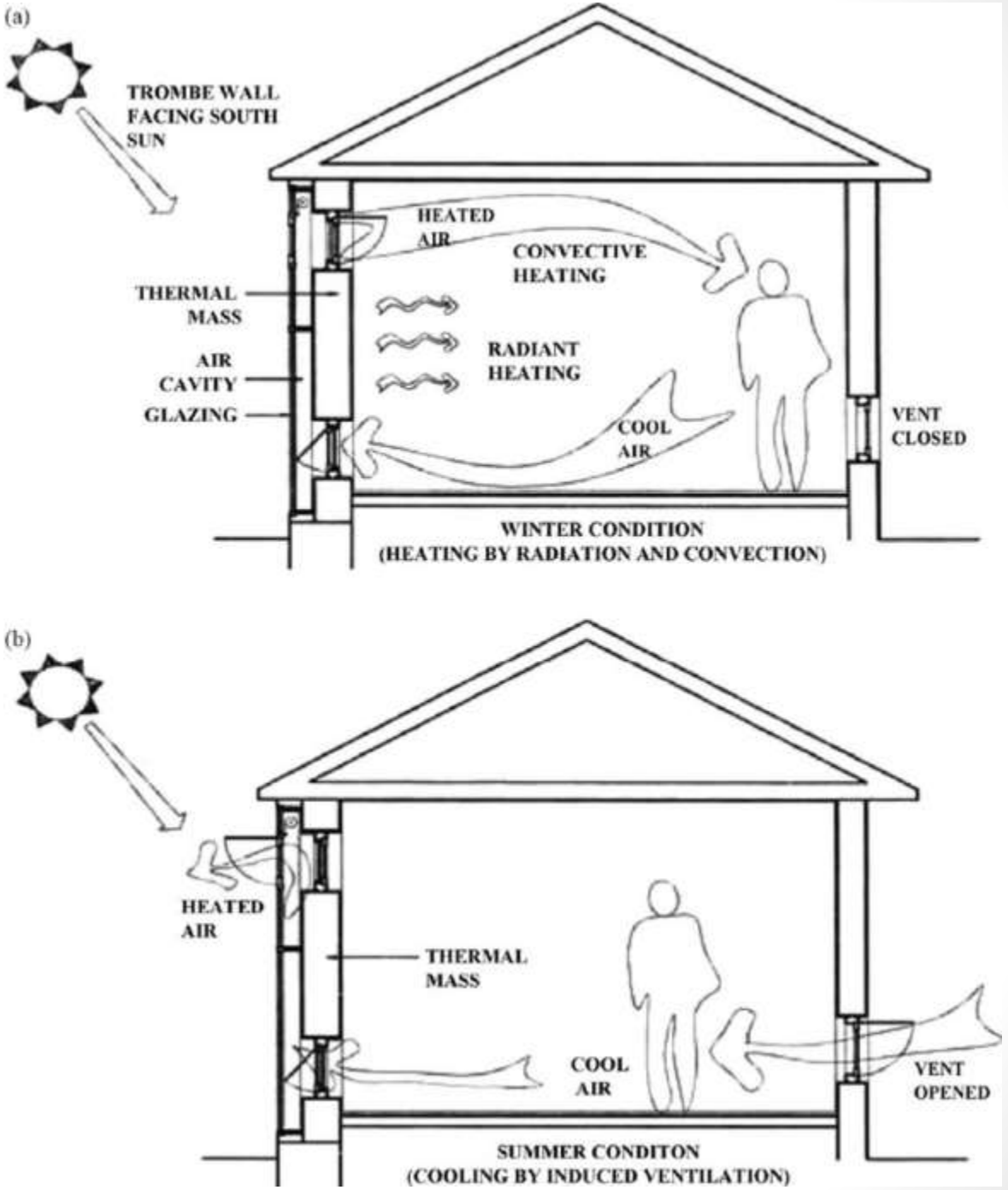
V. roof overhang (especially in warm climates).



INDIRECT GAIN



Trombe wall


(a)
TROMBE WALL
FACING SOUTH
SUN
HEATED
AIR
CONVECTIVE
HEATING
THERMAL
MASS
AIR
CAVITY
GLAZING
RADIANT
HEATING
COOL
AIR
VENT
CLOSED
WINTER CONDITION
(HEATING BY RADIATION AND CONVECTION)
(b)
HEATED
AIR
THERMAL
MASS
COOL
AIR
VENT
OPENED
SUMMER CONDITON
(COOLING BY INDUCED VENTILATION)

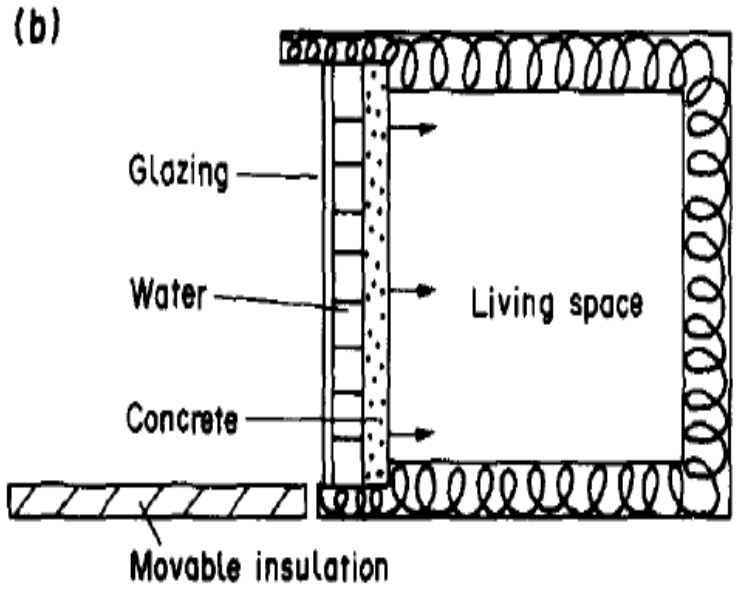
Trombe wall

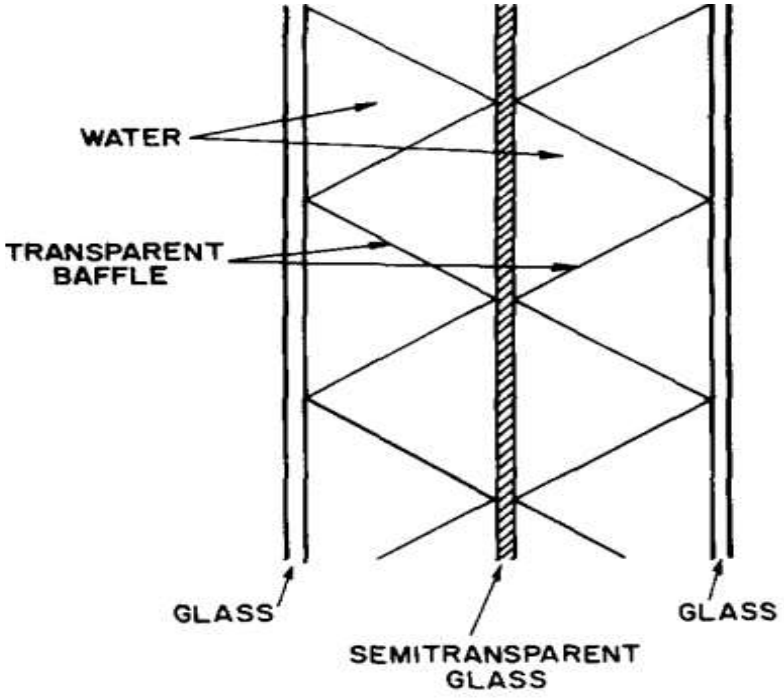
Thermal walls can be categorized into three types:

Trombe wall: Those utilizing a massive wall to store heat

Water wall: Those utilizing a water to store heat

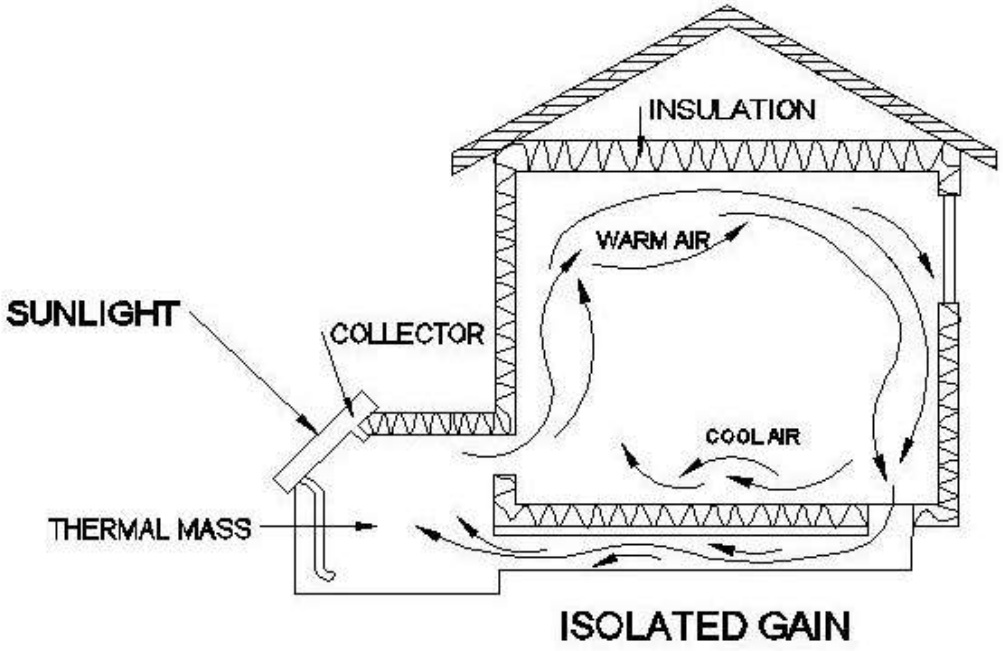
Trans wall: Those utilizing water for storage along with transparent absorber to facilitate visual comfort





Isolated Gain

- Isolated gain method contains solar collection,thermal storage that are separated from actual living space.
- Thermal mass place between sun and space.
- Use of flat plat collectors.



Passive Cooling

- Buildings are designed to retain cooling and drew the heat air away.
- The shading device is fixed and this was achieved by natural vegetation and using special glazing in windows.
- The shading device can reduce solar gains up to 90%.
- It rely on natural heat-sinks to remove heat from the building. They derive cooling directly from evaporation, convection, and radiation without using any intermediate electrical devices.
- All passive cooling strategies rely on daily changes in temperature and relative humidity.
- The applicability of each system depends on the climatic conditions.
- These design strategies reduce heat gains to internal spaces.

- Passive cooling systems are least expensive means of cooling a home which maximizes the efficiency of the building envelope without any use of mechanical devices.

The primary focus of passive cooling is:

- Slow heat transfer into the house.
- Remove unwanted heat from the building.

Various passive technologies that can be adopted in the various climatic zones in India are as follow:

- *Shading system*
- *Ventilation*
- *Solar chimney*
- *Thermal mass*
- *Wind towers*
- *Evaporative cooling system*
- *Courtyard effect*
- *Passive down draught cooling.*
- *Lattice screen (jaali)*
- *Earth air tunnel*

Shading

•Solar control is a critical requirement for both cooling-load dominated and passively solar-heated buildings.
•The most effective method of cooling a building is to shade windows, walls and roof of building from direct solar radiation.

•Heavily insulated walls and roofs need less shading.

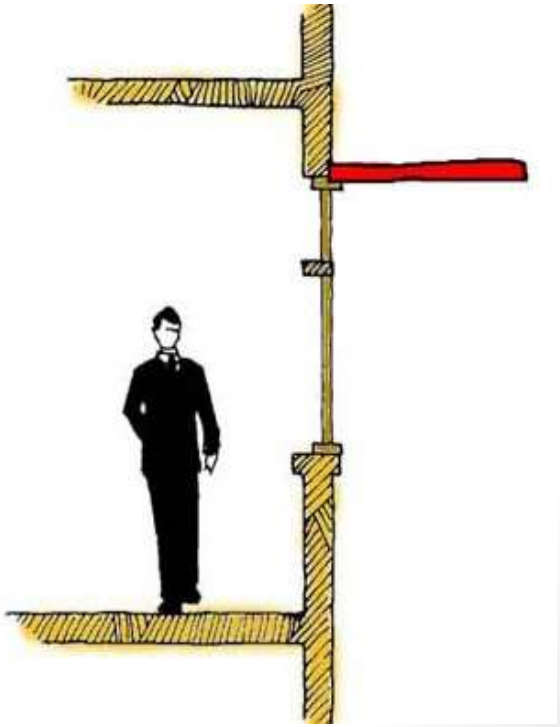
•Can use overhangs on outside facade of the building.

Each project should be evaluated depending on its relative cooling needs:

•Extend the overhang beyond the sides of the window to prevent solar gain from the side.

•Use slatted or louvered shades to allow more daylight to enter, while shading windows from direct sunlight.

•Reduce solar heat gain by recessing windows into the wall.



Shading system

- The most effective method of cooling a building is to shade windows, walls and roof of building from direct solar radiation.
- There are two types of shading system:
- *External Shading*
- *Internal Shading*

External shading

These method used in external shading:

- *Eaves*
- *Awnings*
- *Screens and shutters*
- *Louvers*
- *Verandahs*
- *Pergolas*
- *Trees and shrubs*

Different kinds of shading

Retractable Awnings

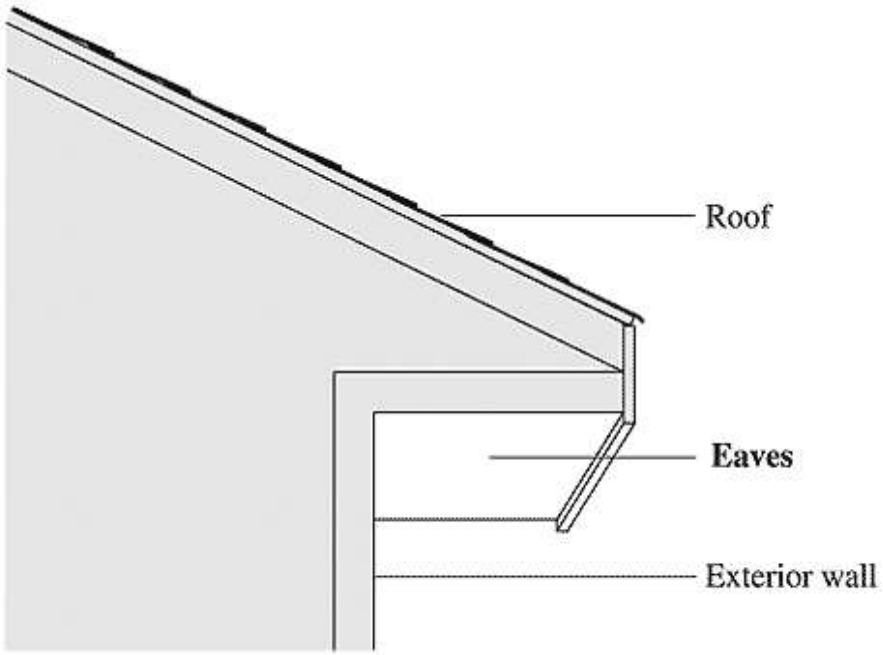
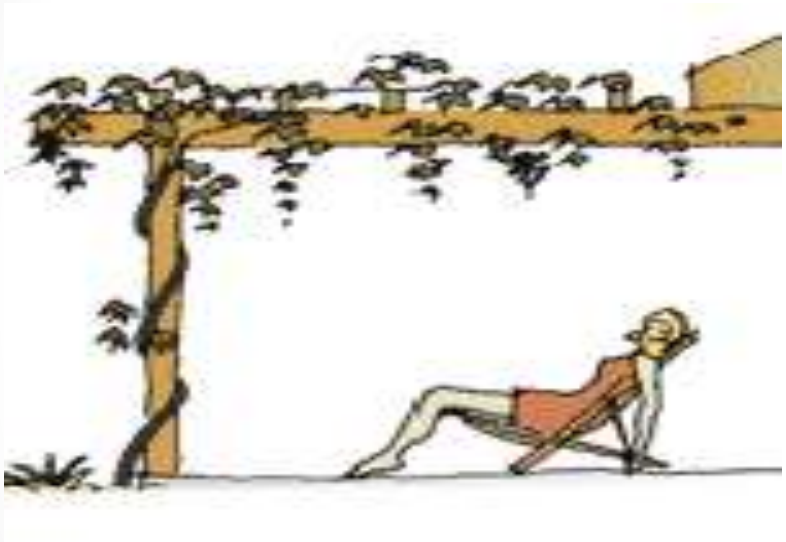
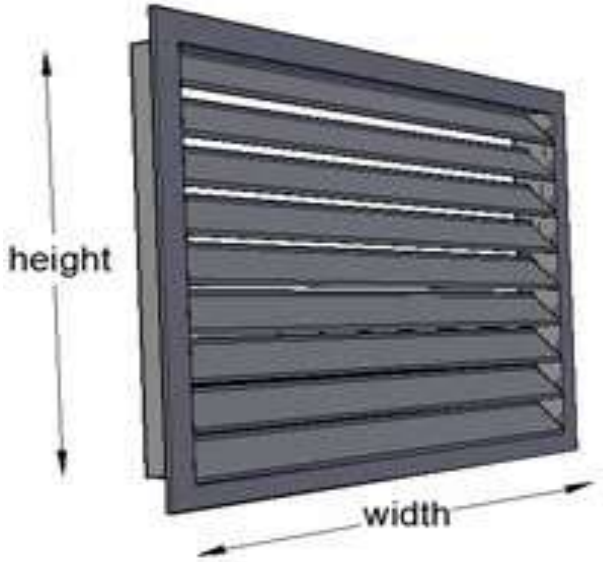


FIG. 59. EAVES

Different kinds of shading

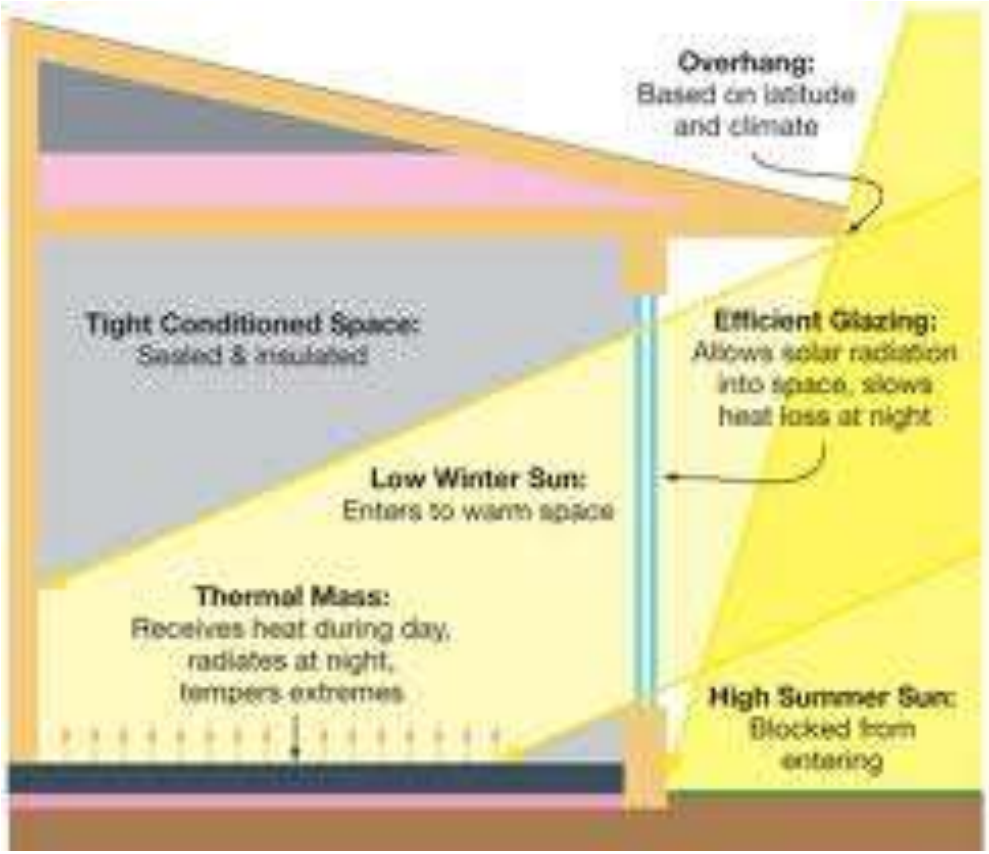


Shade From Pergola



Louvers

Overhang is use for shading

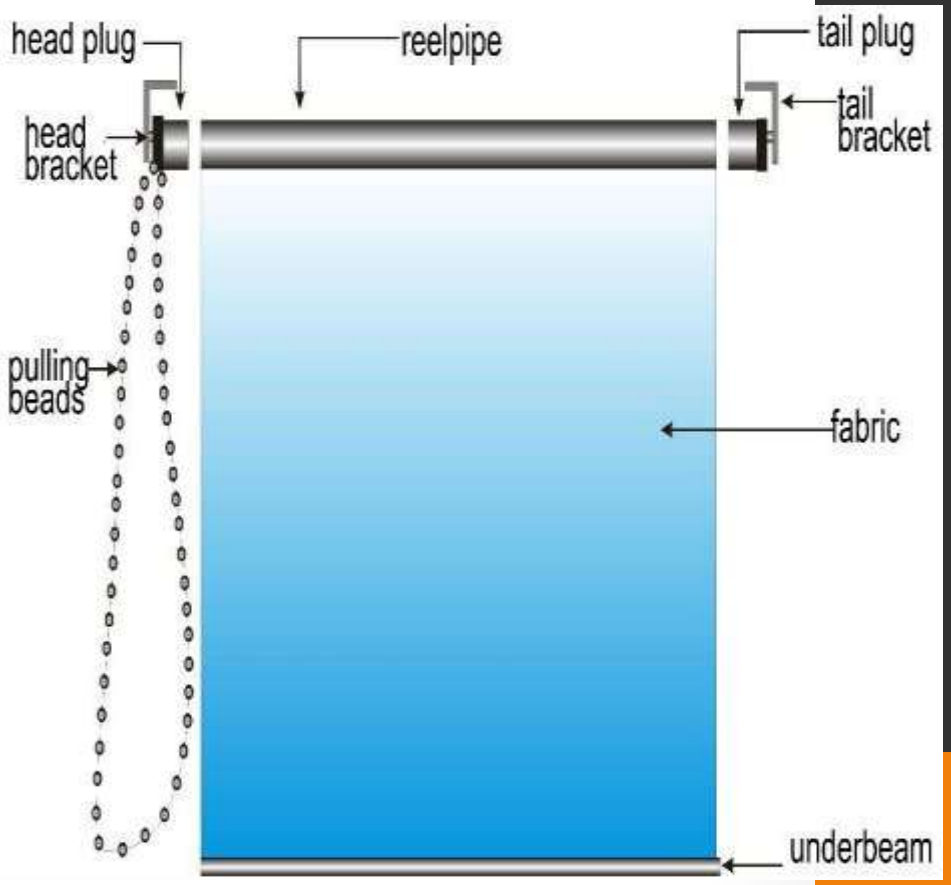


Internal shading

- Internal shading can be provided using curtains and blinds.

Internal shading can be a useful device when:

- The sun penetrates for only a short time heat build-up will not be major problem.
- Windows can he sun be left open adjacent to them.
- It is required to reduce glare.



Ventilation

- The mechanical system or equipment used to circulate air or to replace stale air with fresh air.
- Passive ventilation is when air is exchanged in a building through openings in the building envelope using the stack and wind pressures.

Ventilation in buildings has three main purposes:

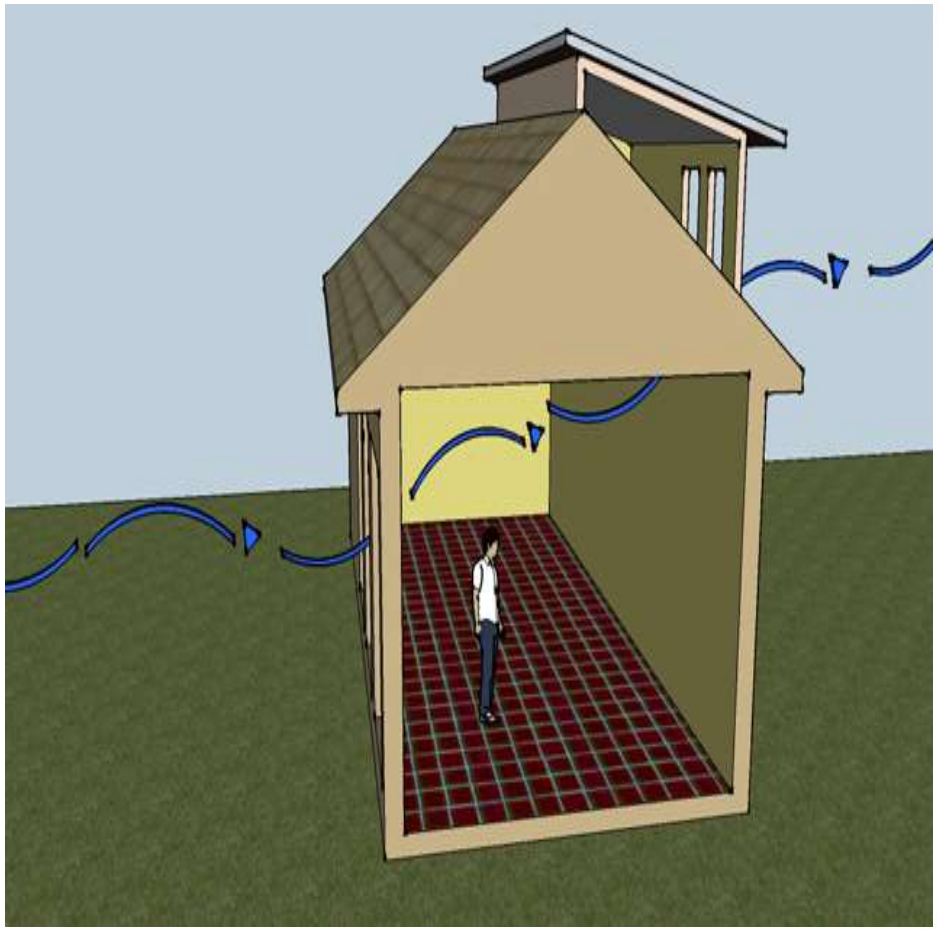
1. To maintain a minimum air quality
2. To remove heat (or other pollutant)
3. To provide perceptible air movement to enhance thermal comfort

Natural Ventilation

- Stack Ventilation
- Cross Ventilation
- Night Ventilation

Stack Ventilation

- In stack ventilation cool air is pulled throughout the home while warmer air rises above the cool air to exit through an opening near the top of the structure.
- Stack ventilation is where air is driven through the building by vertical pressure differences developed by thermal buoyancy. The warm air inside the building is less dense than cooler air outside, and thus will try to escape from openings high up in the building envelope; cooler denser air will enter openings lower down. The process will continue if the air entering the building is continuously heated, typically by casual or solar gains.



Stack Ventilation

When to use stack ventilation?

- Stack ventilation, can operate when no wind pressure is available. A building can be designed to induce its own ventilation by duplicating the temperature stratifications that are the source of wind itself.
- It must be born in mind that the stack effect can only take place when the average temperature in the stack is greater than the outside air.

What to remember when using Stack Ventilation?

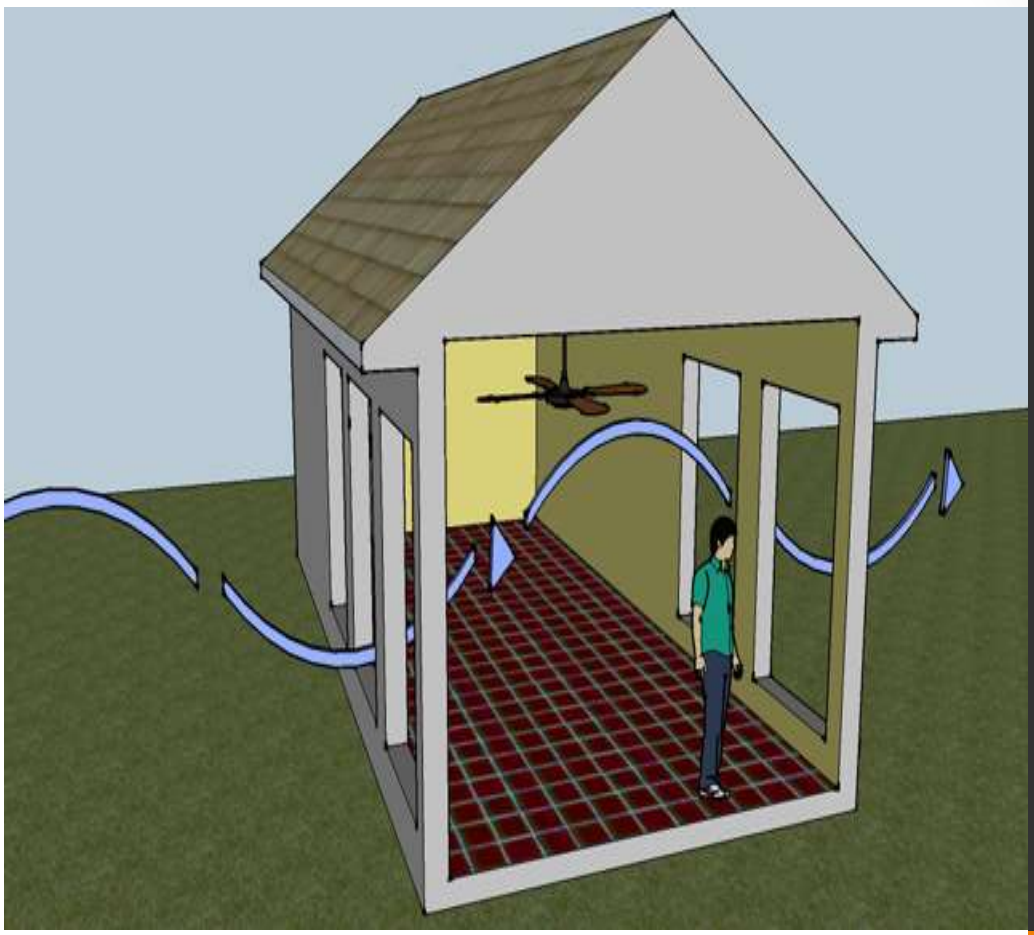
- Typically the stack effect is quite weak, and therefore openings and ducts must be large, to minimize resistance.
- The pressure difference within the stack varies with height resulting in diminishing air flows from spaces opening on to the stack, as their height above ground floor increases.
- In tall spaces (multi-room height) the temperature of the air may be hotter in the upper zone. This is referred to as **stratification**. For a given average temperature, this means that there is a cooler zone at the bottom, which is good news if this is the only occupied space. However it means that rooms facing the upper zone may experience unwanted heat gains, as well as reduced stack effect due to their smaller stack height.

Disadvantage

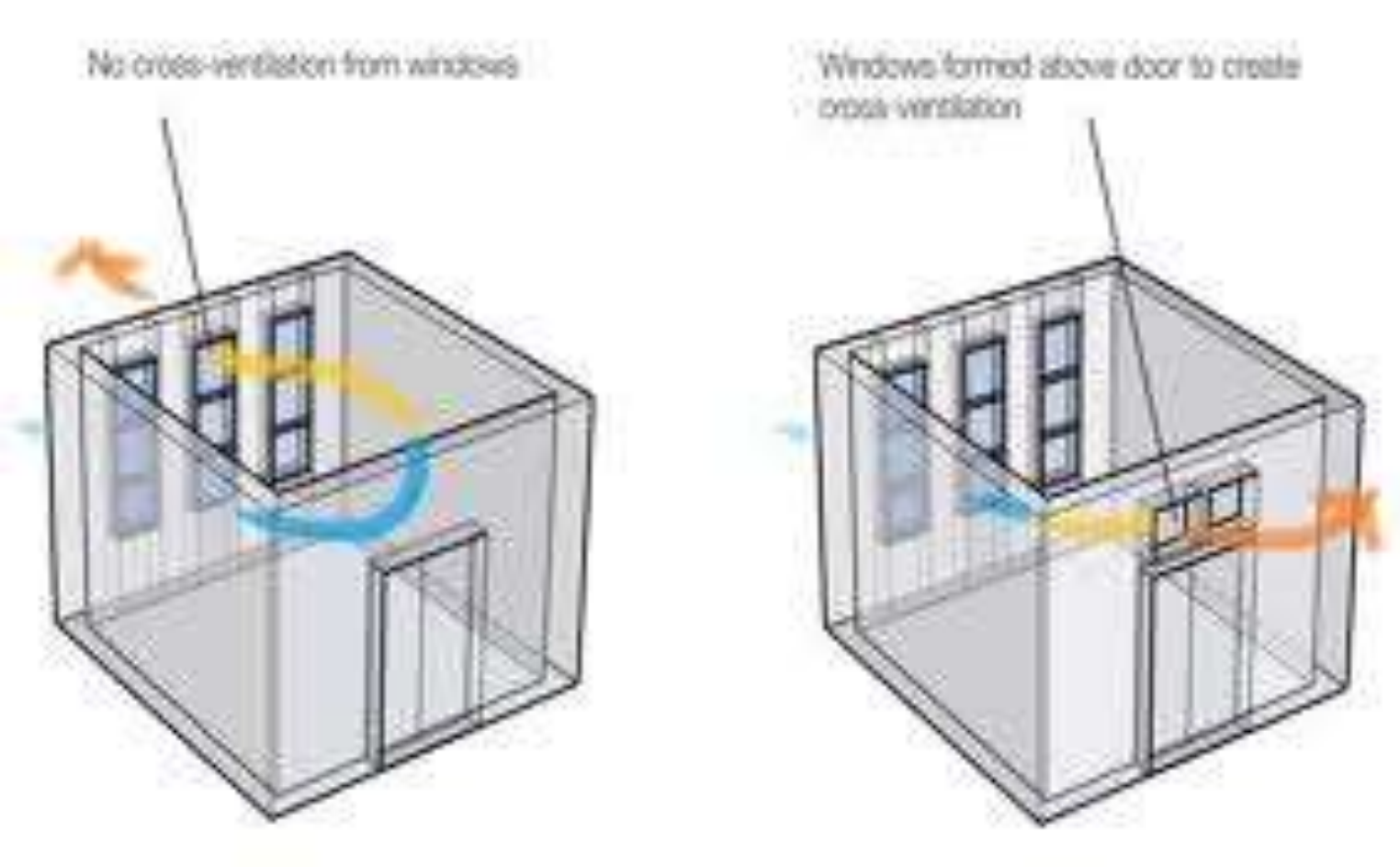
- Due to the weakness of the driving pressures generated by thermal buoyancy, openings have to be large and unobstructed. This means that they will readily transmit noise. Noise attenuating techniques, often used in ductwork of mechanical systems, involve labyrinthine pathways, lined with acoustic absorber. This principle can be applied here but has to be on a large scale in order to cause a minimum flow resistance.

Cross-Ventilation

- cross-ventilation strategies place air inlets on the windward side and air outlets on the leeward side of the home.
- Wind-induced ventilation uses pressures generated on the building by the wind, to drive air through openings in the building. It is most commonly realised as cross-ventilation, where air enters on one side of the building, and leaves on the opposite side, but can also drive single sided ventilation, and vertical ventilation flows.



Cross-Ventilation



What to remember when using Cross Ventilation?

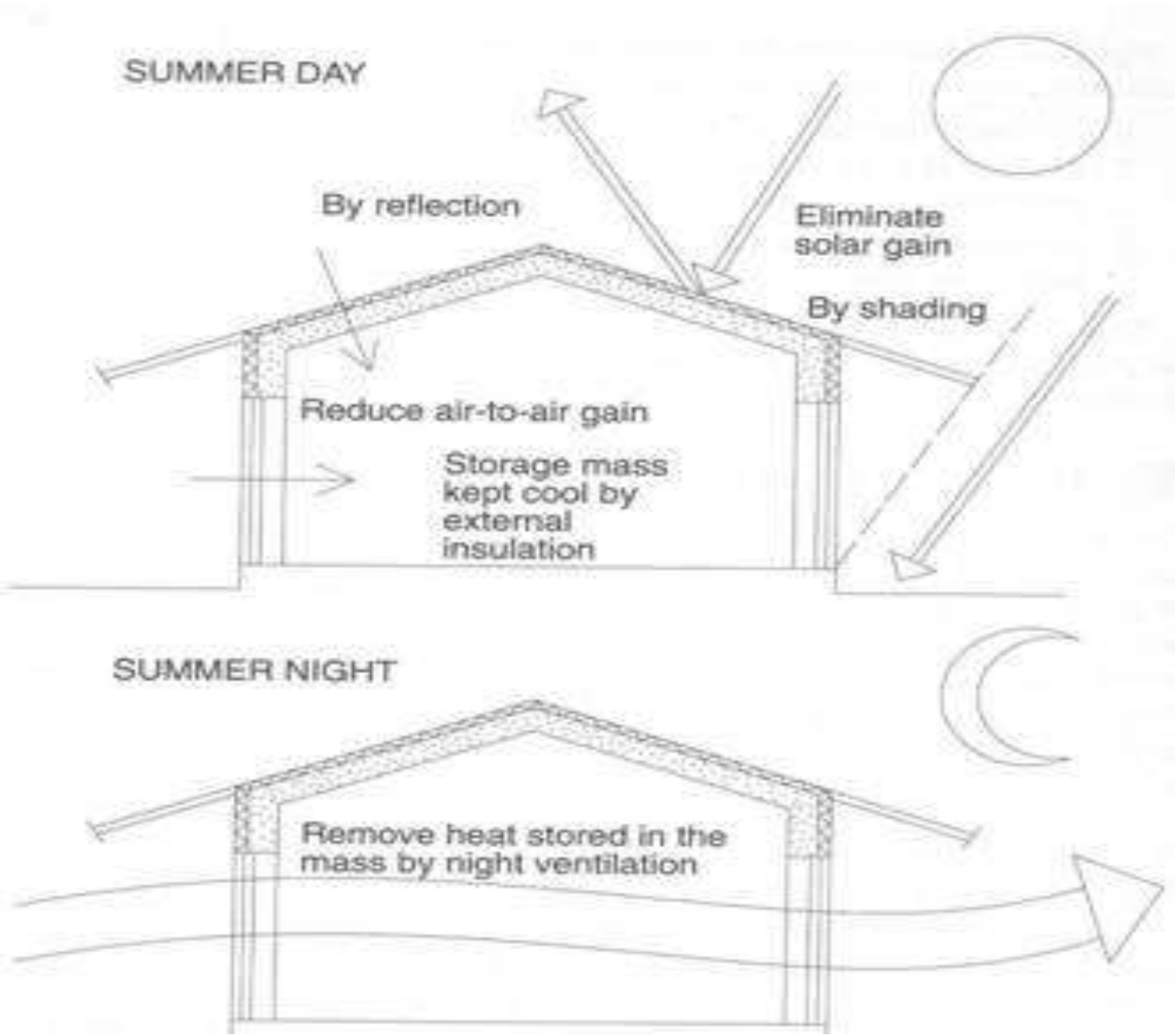
- Wind speed and direction is very variable. Openings must be controllable to cover the wide range of required ventilation rates and the wide range of wind speeds.
- As with stack ventilation, the internal flow path inside the building must be considered.
- For cross-ventilation, bear in mind that the leeward space will have air that has picked up heat or pollution from the windward space. This may limit the depth of plan for cross-ventilation.

Disadvantage

- As with stack ventilation, the requirement for large openings may present problems with noise control. Also, the need to provide flow paths within the building may conflict with acoustic separation between internal spaces. However, the provision of by-pass ducts can help reduce this.

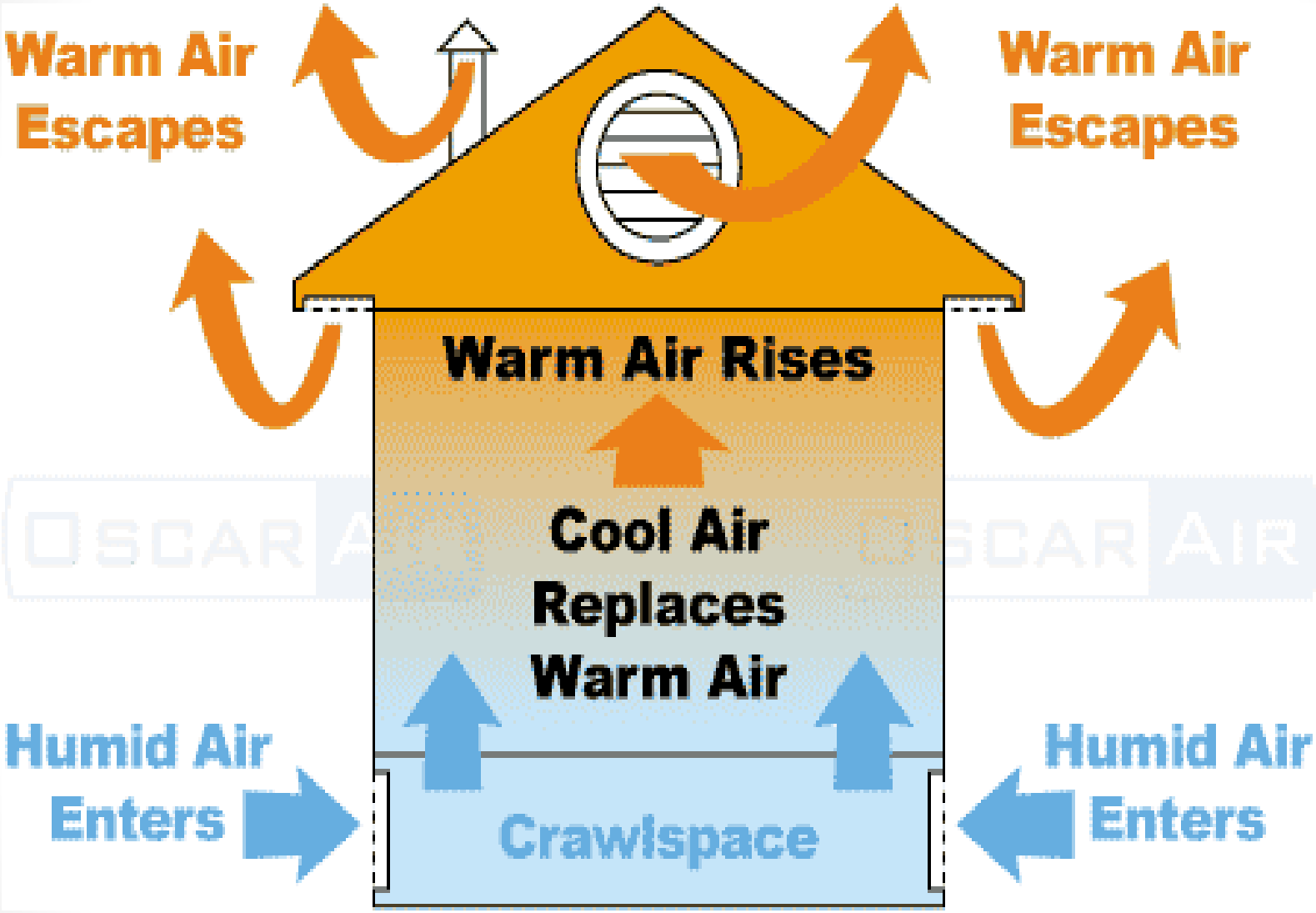
Night Ventilation

- Night ventilation is the use of the cold night air to cool down the structure of a building so that it can absorb heat gains in the daytime. This reduces the daytime temperature rise.
- An overheating prevention strategy which uses little or no fossil energy, and together with other passive strategies such as natural ventilation and shading , can avoid the use of air-conditioning. This saves energy (and CO2 emissions), and once set-up would require lower maintenance than mechanical systems.


SUMMER DAY
By reflection
Eliminate
solar gain
By shading
Reduce air-to-air gain
Storage mass
kept cool by
external
insulation
SUMMER NIGHT
Remove heat stored in the
mass by night ventilation

Solar Chimney Effect

- The most effective application of this natural law (stack effect) is a "thermal chimney," a solar-exposed enclosure tall enough to generate maximum air flow and massive enough to retain heat and power the system into the evening hours.


Warm Air Escapes
Warm Air Escapes
Warm Air Rises
Cool Air Replaces Warm Air
Humid Air Enters
Humid Air Enters
Crawlspace

Thermal Mass

- A material that has thermal mass is one that has the capacity to absorb, store and release the sun's heat energy.
- The best way to cool a building is to build with thick stone or masonry.
- Thermal mass is measured in terms of 'Volumetric heat capacity'.
- Thermal mass properties of some material are presented in table below:

Material	Conductivity W/m K	Vol. heat capacity kJ/m3K
Water	1.9	4186
Cast concrete	1.4	2300
Granite	2.1	2154
Brick	0.72	1360

Thermal Mass

Thick walls provides thermal insulation.

JDT Islam campus, Calicut

Vaults at nalanda international school, vadodara

Part of domical roof is always shaded.

Outer surface shades the wall itself.

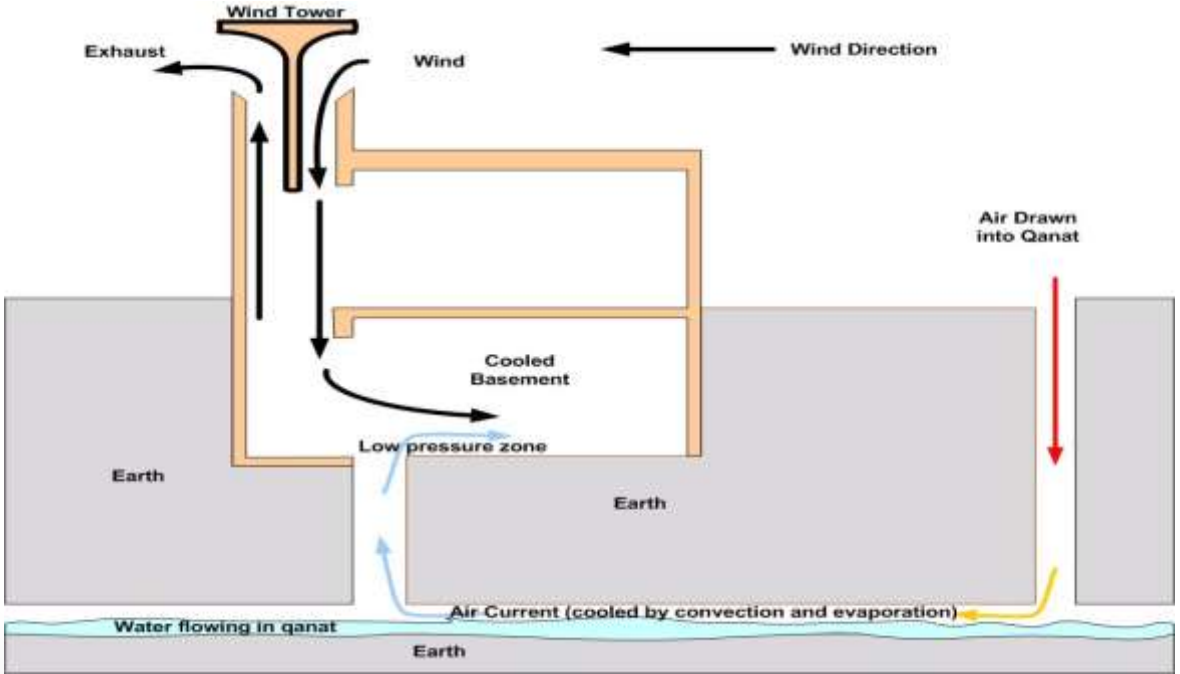
Arched ceiling helps to cool internal space of the roof.

•When the outer temperature is lowered at night, the high emissive property of the walls allows cooling down the wall surfaces rapidly.

•Flat roofs get more radiations while vaulted and domed roofs prevent the absorption of heat of the summer's vertical sun.

Wind Towers

- In a wind tower, the hot air enters the tower through the openings in the tower, gets cooled, and thus becomes heavier and sinks down.
- The inlet and outlet of rooms induce cool air movement.
- In the presence of wind, air is cooled more effectively and flows faster down the tower and into the living area.
- After a whole day of air exchanges, the tower becomes warm in the evenings.
- During the night, cooler ambient air comes in contact with the bottom of the tower through the rooms.



•The tower walls absorb heat during daytime and release it at night, warming the cool night air in the tower.

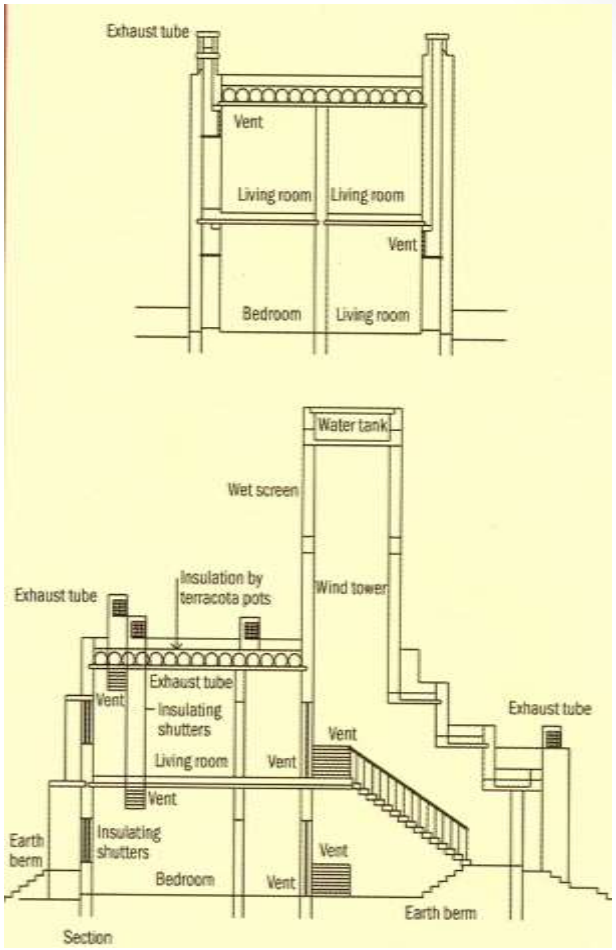
• Warm air moves up, creating an upward draft, and draws cool night air through the doors and windows into the building.

•The system works effectively in hot and dry climates where fluctuations are high.

•A wind tower works well for individual units not for multi-storeyed apartments.

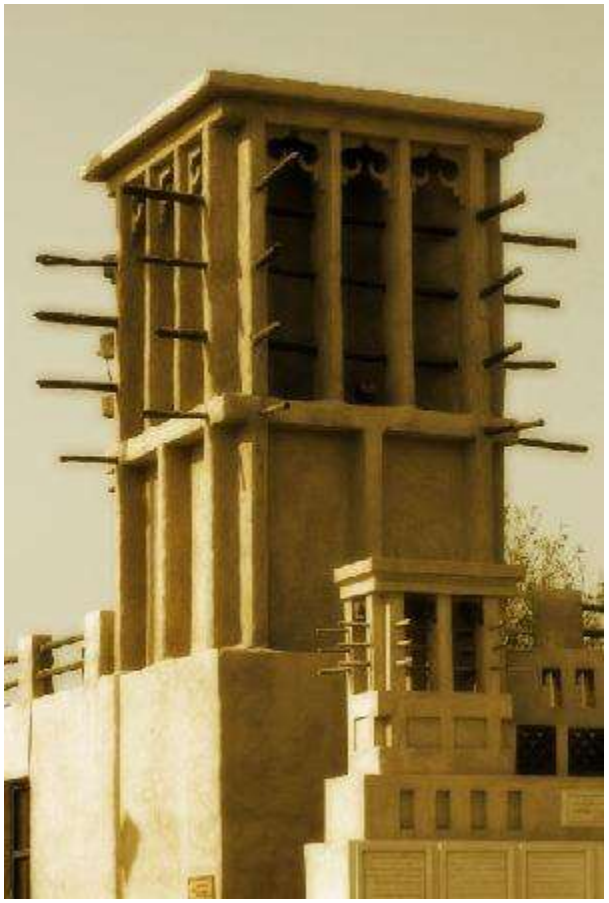
•In dense urban areas, the wind tower has to be long enough to be able to catch enough air.

• Also protection from driving rain is difficult.



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

Building-integrated chimney in **Sudha and Atam Kumar's residence** in New Delhi from effective ventillation especially during humid season.

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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.

•Its physical principle lies in the fact that the heat of air is used to evaporate water, thus cooling the air, which in turn cools the living space in the building.

•To enhance the process of evaporation, fountains were used which mixed the moisture to the air and increased the humidity.

•At times, *salsabil*was used to maintain the water pressure to force the water to come out of the fountain head.

•Evaporative cooling lowers indoor air temperature by evaporating water.

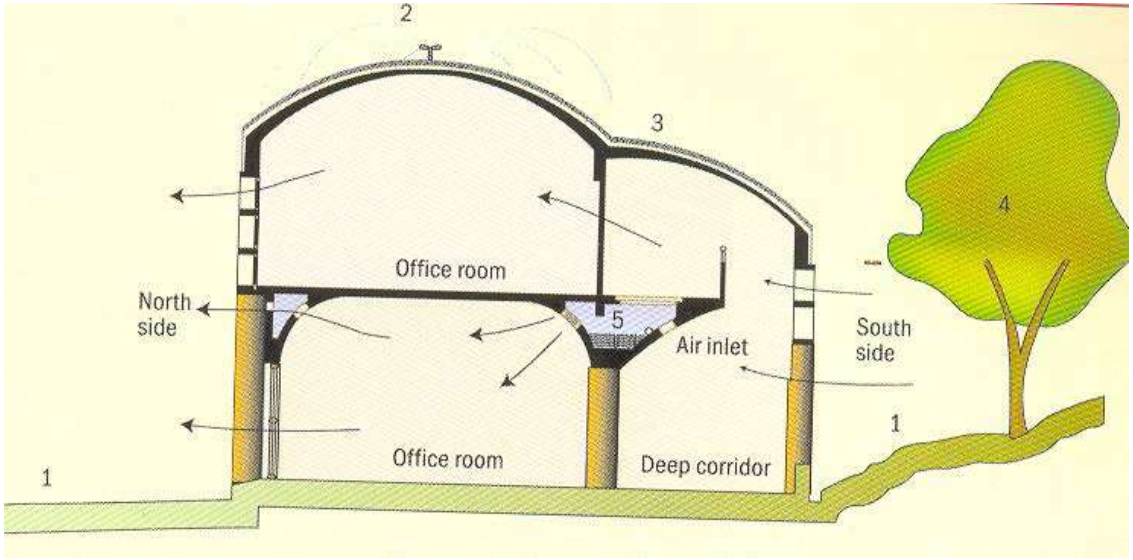
•In evaporative cooling, the sensible heat of air is used to evaporate water, thereby cooling the air, which, in turn, cools the living space of the building.

Methods of evaporative cooling include:

- *Roof pond systems*
- *Water spraying*

Evaporative Cooling

1. **Ground cover**
2. **Water sprinkler**
3. **Insulated roof**
4. **Shading trees**
5. **Water trough**



a typical section showing passive solar features of WALMI building, Bhopal

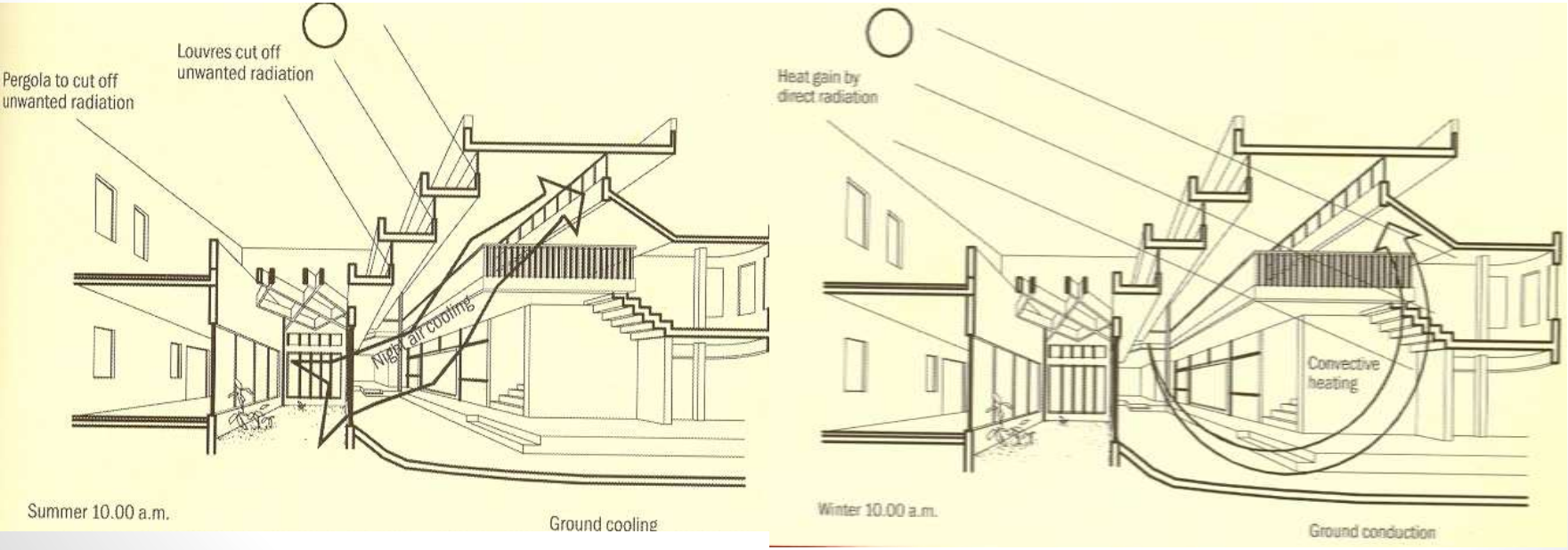
Courtyard Effect

- Due to incident solar radiation in a courtyard, the air gets warmer and rises.

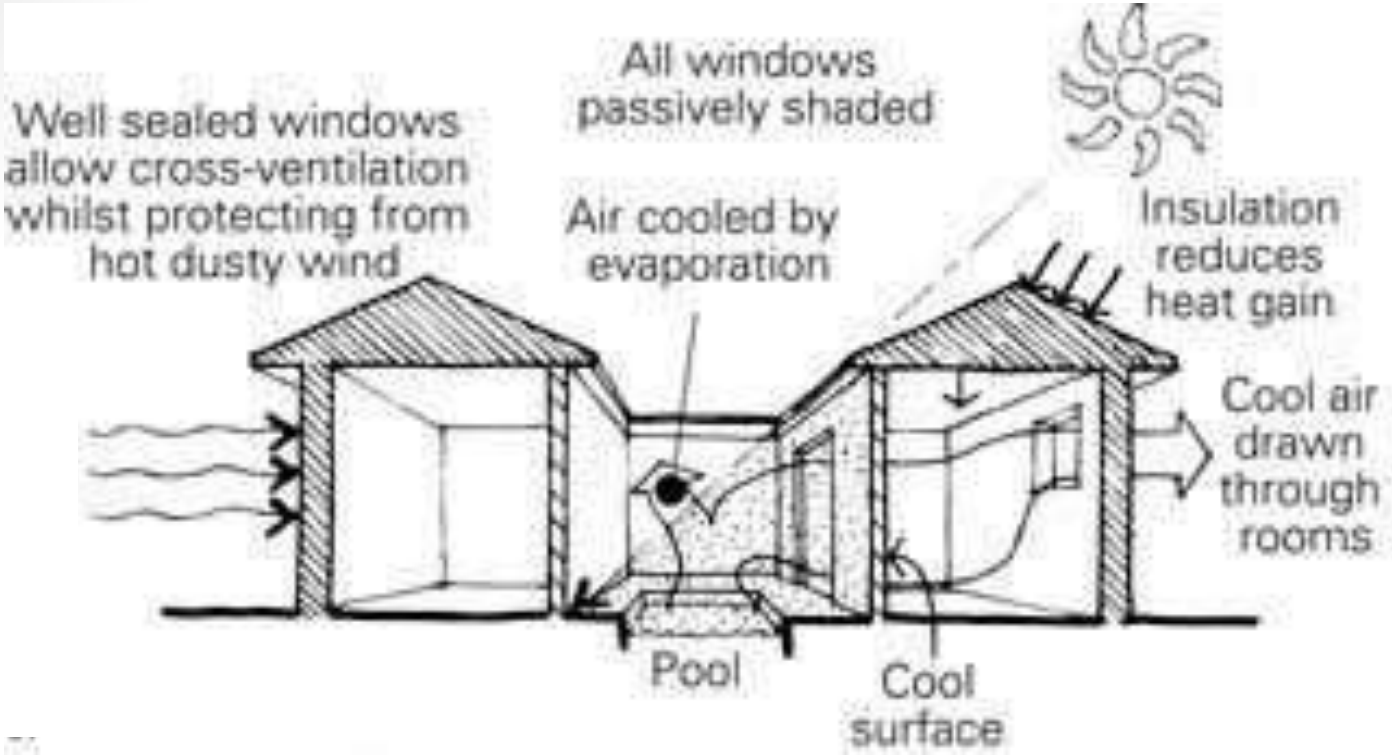
- Cool air from the ground level flows through the louvered openings of rooms surrounding a courtyard, thus producing air flow.

- At night, the warm roof surfaces get cooled by convection and radiation.

- If this heat exchange reduces roof surface temperature to wet bulb temperature of air, condensation of atmospheric moisture occurs on the roof and the gain due to condensation limits further cooling.



Courtyard as a moderator of internal climate



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

• However, care should be taken that the courtyard does not receive intense solar radiation, which would lead to conduction and radiation heat gains into the building.

Courtyard with vegetation and water body enhances humidity.

Courtyard provide shade.

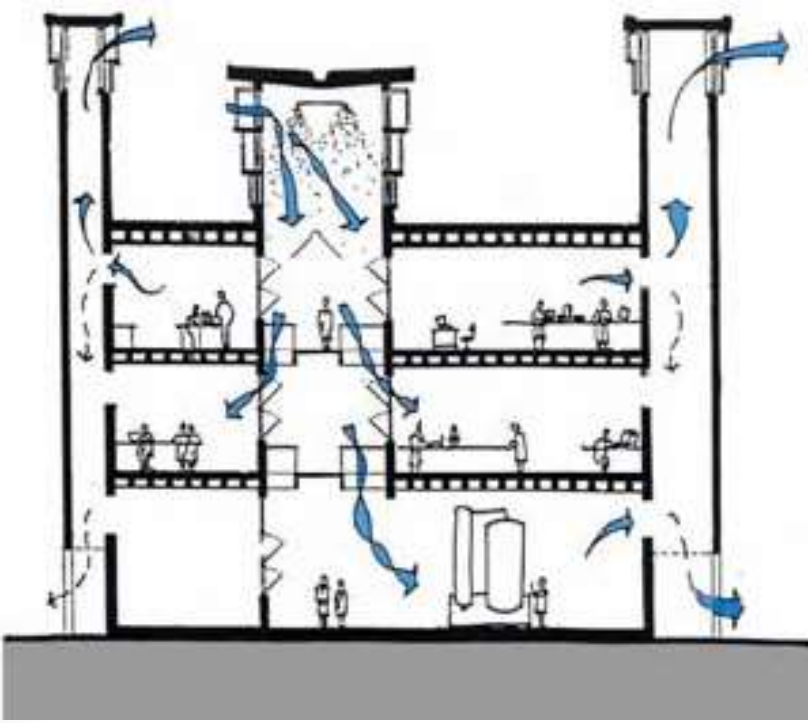
Universal Business School, Karjat, Mumbai

LONG SECTION

The Courtyard House,
Beawar, Rajasthan

SHORT SECTION

Landscaped courtyard



Passive Down Draught Cooling

•Passive downdraft evaporative cooling systems consist of a downdraft tower with wetted cellulose pads at the top of the tower.

•Water is distributed on the top of the pads, collected at the bottom into a sump and re-circulated by a pump.

•These towers are often described as reverse chimneys.

•While the column of warm air rises in a chimney, in this case the column of cool air falls.

•The air flow rate depends on the efficiency of the evaporative cooling device, tower height and cross section, as well as the resistance to air flow in the cooling device, tower and structure (if any) into which it discharges.

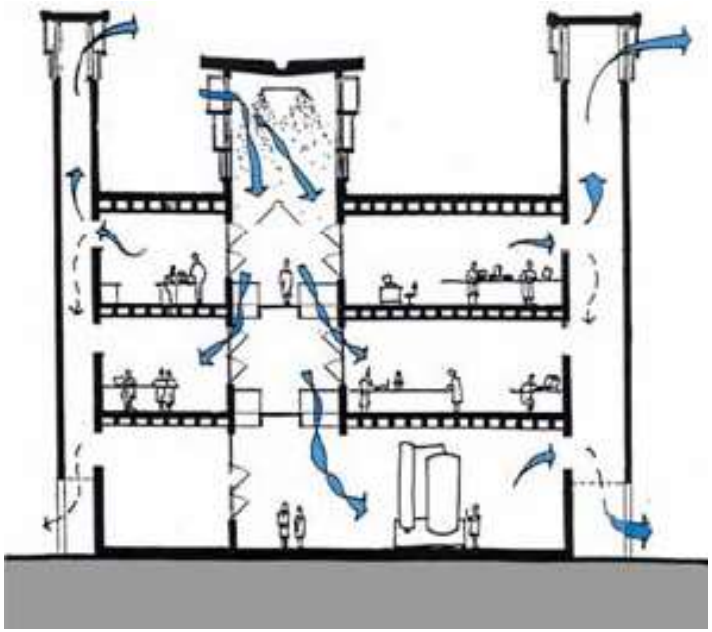
Passive Down Draught Cooling

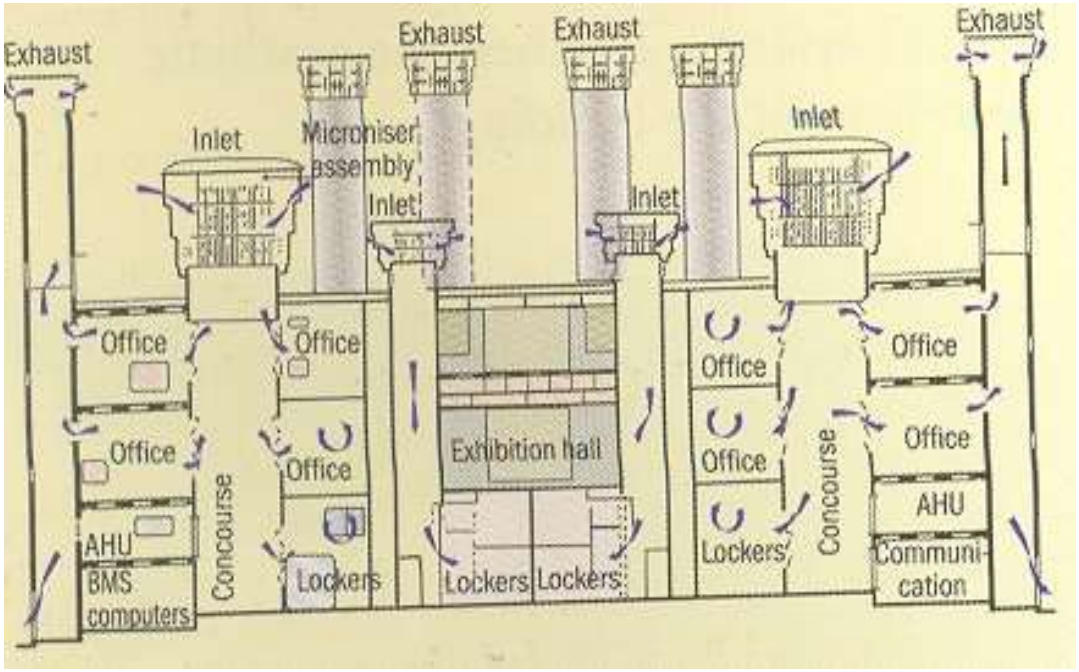
•Evaporative cooling has been used for many centuries in parts of the middle east, notably Iran and turkey.

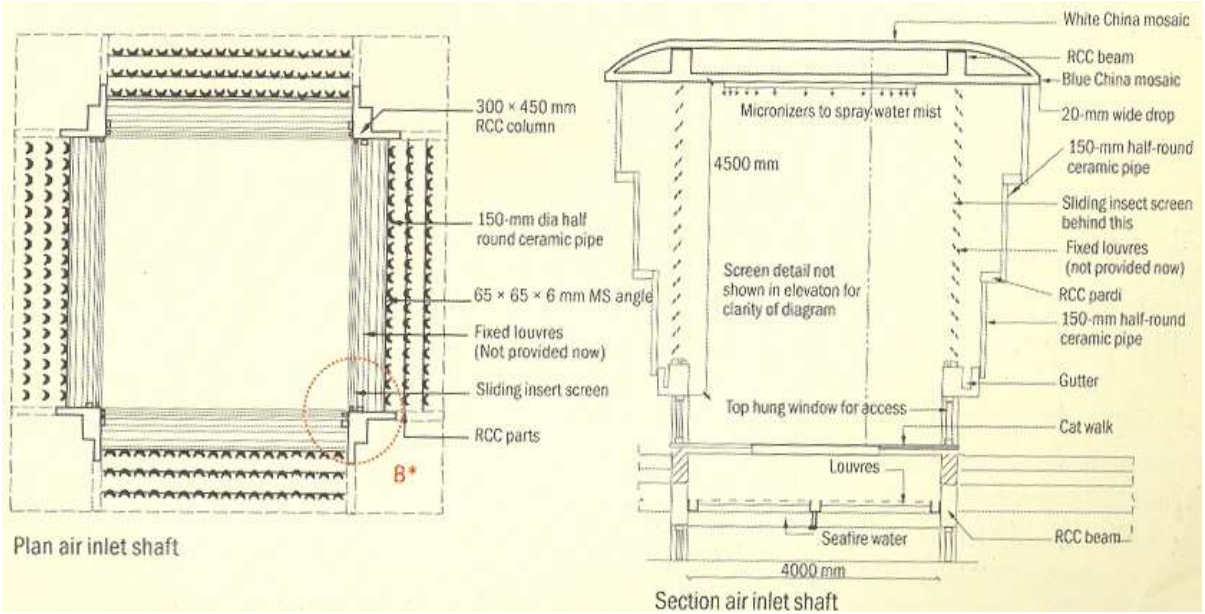
•In this system, wind catchers guide outside air over water-filled pots, inducing evaporation and causing a significant drop in temperature before the air enters the interior.

•Such wind catchers become primary elements of the architectural form also.

•Passive downdraught evaporative cooling is particularly effective in hot and dry climates. It has been used to effectively cool the **Torrent Research Centre** in **Ahmedabad**.







DETAILS OF THE PASSIVE DOWN DRAUGHT COOLING INLETS

Lattice Screen (Jaali)

Jaali ensures privacy and provide diffuse light and view.

Jaali work featured in ITM business school, Gwalior

S C Techno School, Bangalore

- It controls the airflow and lower down the temperature of internal spaces on the other.
- When there is sunshine outside in the day, the internal spaces are not clearly visible from outside.
- however, the diffused light is spread throughout the interiors.
- To get a clear outside view, a cutout is provided at eye level for the viewer sitting on the floor.
- *Jaali* in Mughal buildings mostly have a low sill or sometimes without sill so that the air could move near the floor.

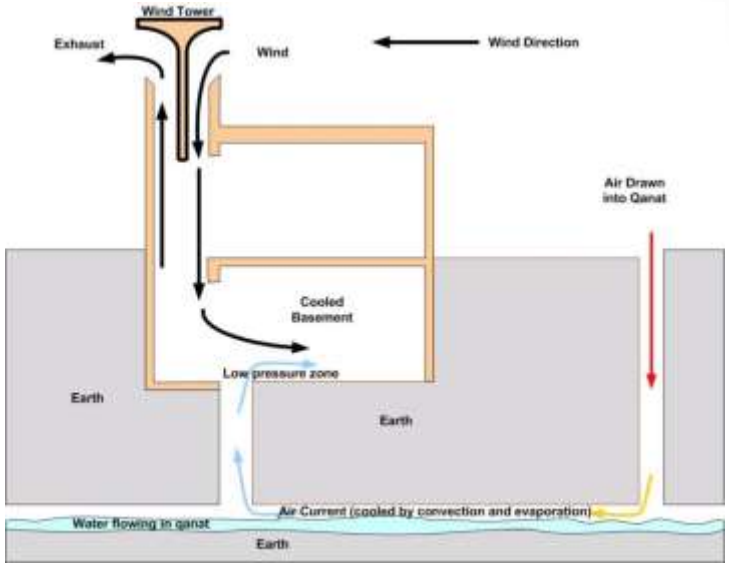
Earth Air Tunnels

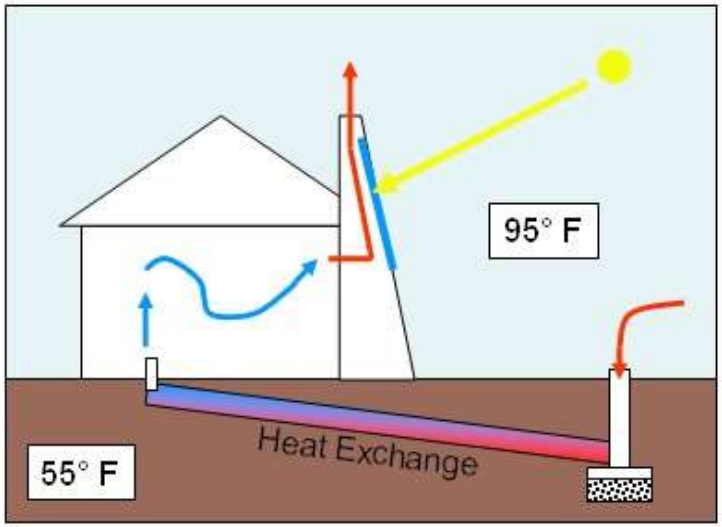
•Daily and annual temperature fluctuations decrease with the increase in depth below the ground surface.

•At a depth of about 4 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to the annual average temperature of the place.

•A tunnel in the form of a pipe or otherwise embedded at a depth of about 4 m below the ground will acquire the same temperature as the surrounding earth at its surface.

•Therefore, the ambient air ventilated through this tunnel will get cooled in summer and warmed in winter and this air can be used for cooling in summer and heating in winter.





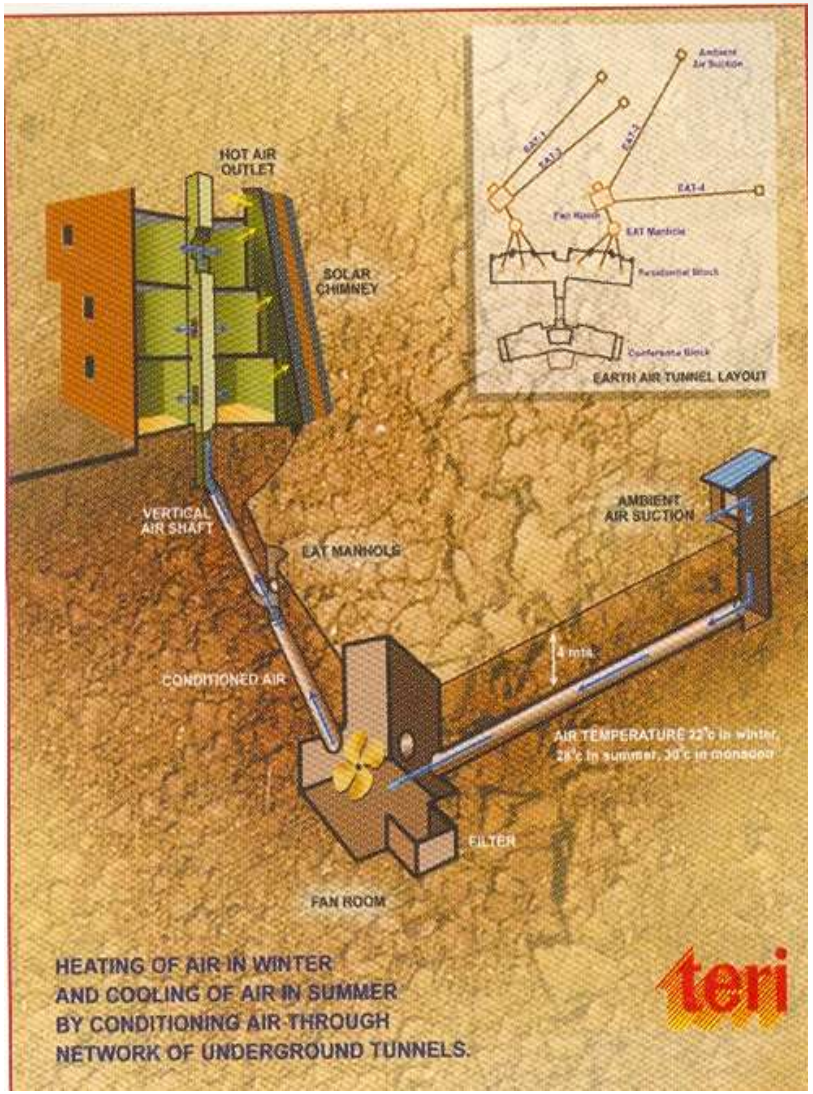
•This technique has been used in the composite climate of **Gurgaon** in **RETREAT building**.

•The living quarters (the south block of RETREAT) are maintained at comfortable temperatures (approx. 20-30 degree Celsius) round the year by the earth air tunnel system, supplemented, whenever required, with a system of absorption chillers powered by liquefied natural gas during monsoons and with an air washer during dry summer.

•However, the cooler air underground needs to be circulated in the living space. Each room in the south block has a 'solar chimney; warm air rises and escapes through the chimney, which creates an air current for the cooler air from the underground tunnels to replace the warm air.

•Two blowers installed in the tunnels speed up the process.

•The same mechanism supplies warm air from the tunnel during winter.



PASSIVE SPACE CONDITIONING
USING EARTH AIR TUNNEL SYSTEM

Advantage of Passive Solar Design

- Eliminate heating and cooling costs
- Reduce greenhouse gas emissions
- Clean process
- Eco-friendly
- Cost
- Attractive living environment
- Low maintenance
- Unwavering comfort

Disadvantage of Passive Solar Design:-

- Great deal of work for the engineers to arrange this system.
- All systems are not same.
- Careful construction required
- Improperly designed not work well
- Sunshine not available all day
- Extra heat and the higher temperatures
- Thermal wall loses heat back to the out-of-doors through the glass

THANK YOU…