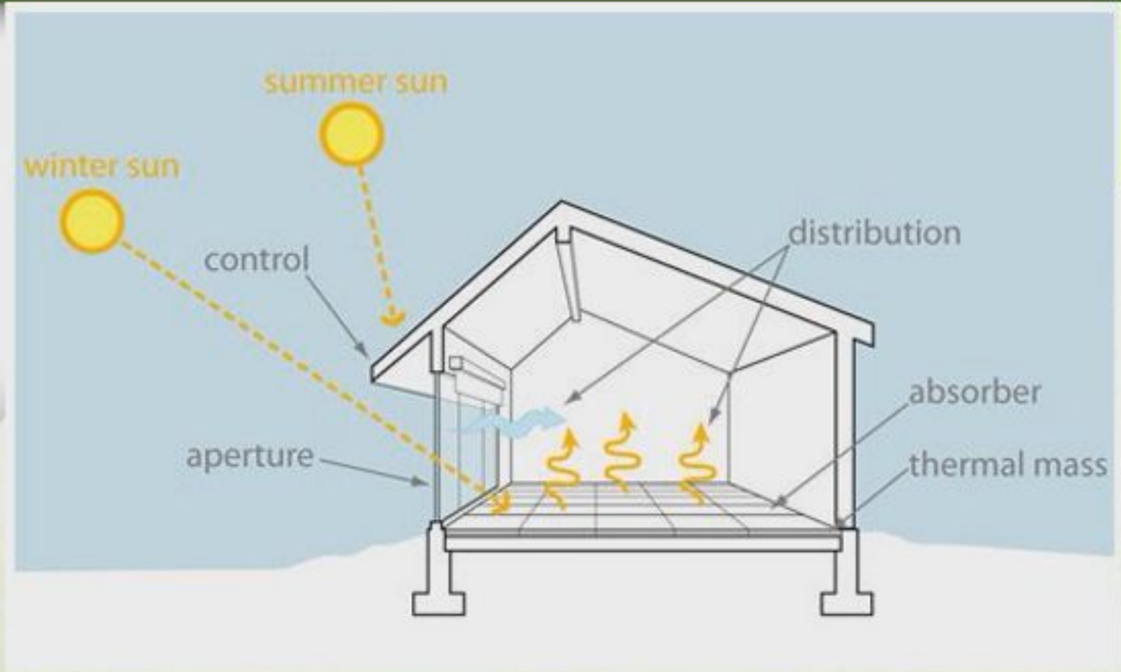
18MEO103T – Energy systems for Buildings

Unit – II Passive solar heating & Cooling

Differentiating Passive vs. Active Design

Passive design results when a building is created and simply works "on its own".



Active design uses equipment to modify the state of the building, create energy and comfort; ie. Fans, pumps, etc.

Passive Solar Heating system

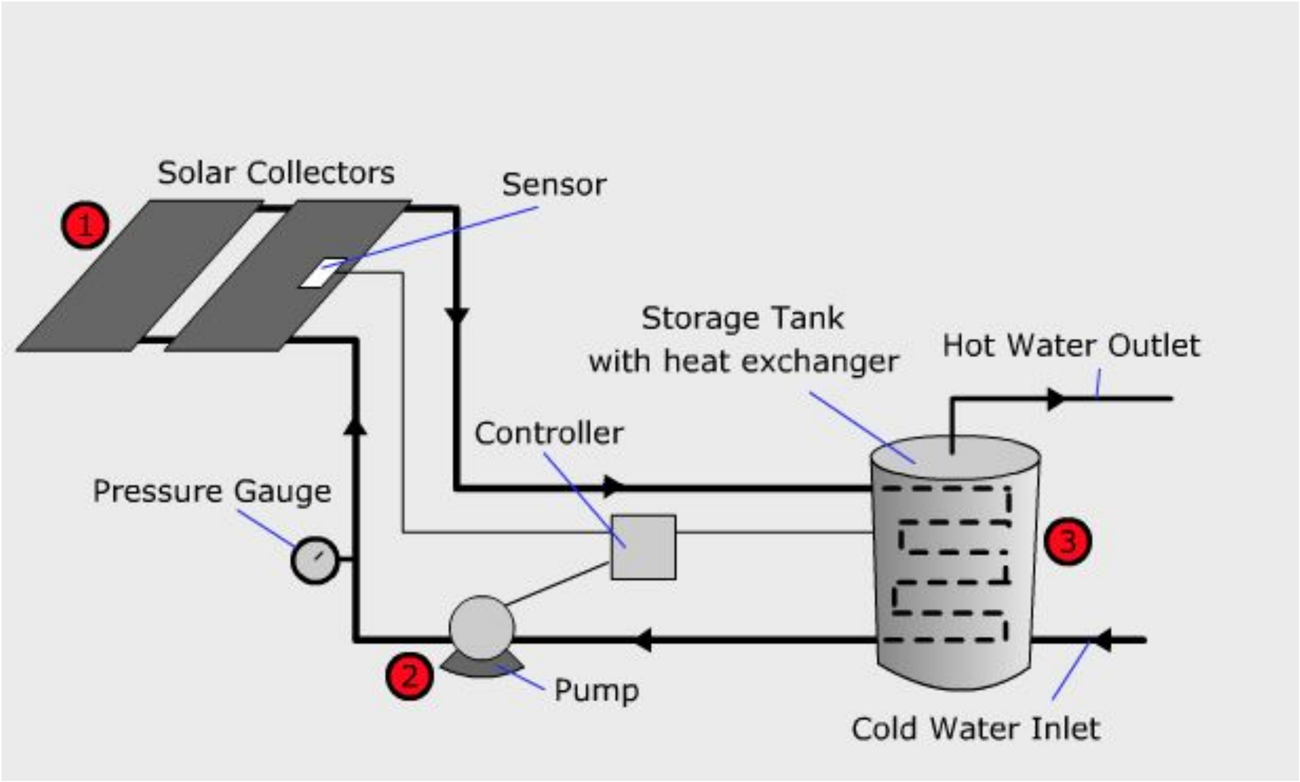
- Passive systems do not use mechanical devices such as fans, blowers, or pumps to distribute solar heat from a collector. Instead, they take advantage of natural heat flow to distribute temperature. An example of a passive system for space heating is a sunspace or solar greenhouse.
- Passive systems also make use of materials with large heat capacities (stone, water, or concrete) to store and deliver heat.

Advantages

- Passive solar design is highly energy efficient, reducing a building's energy demands for lighting, winter heating, and summer cooling.
- Energy from the sun is free. Strictly passive designs capture it without additional investments in mechanical and electrical "active solar" devices such as pumps, fans, and electrical controls.
- The passive solar design also reduces greenhouse gases that contribute to global warming because it relies on solar energy, a renewable, nonpolluting resource.

Active Heating

- Active solar space heating uses mechanical equipment like fans, pumps, blowers, and ducts to collect, store, and distribute heat throughout the air/space inside our homes.
- These active solar systems can be either liquid-based or air-based. The liquid-based systems use large water tanks to store and distribute the heat.



Types of Active Solar Energy

Active Solar Space Heating

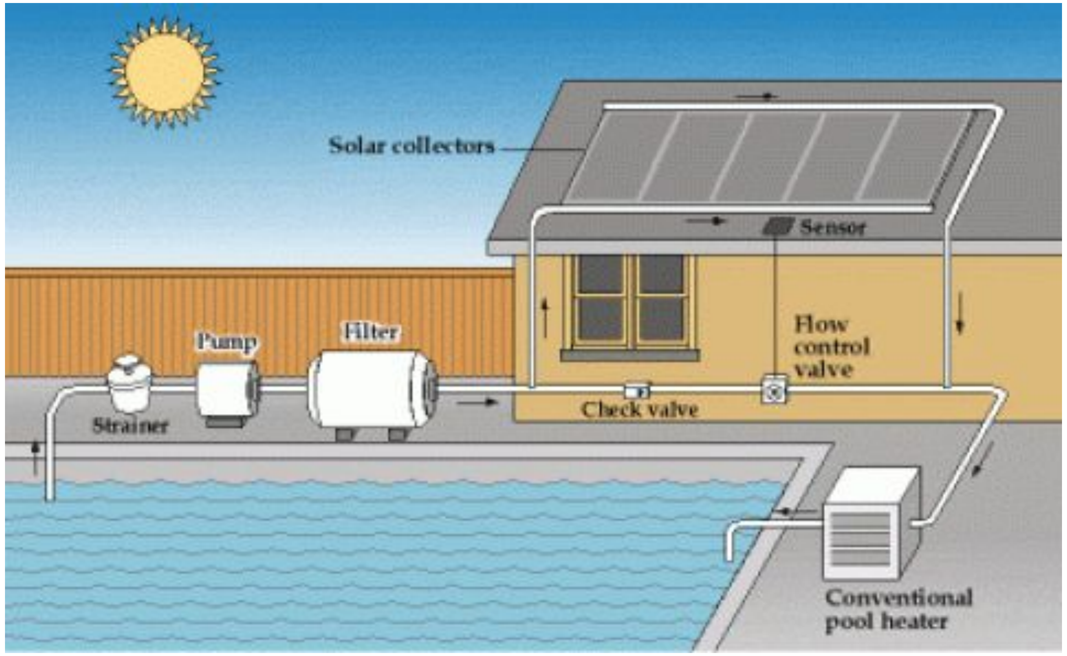
- Active solar space heating uses mechanical equipment like fans, pumps, blowers, and ducts to collect, store, and distribute heat throughout the air/space inside our homes.

Active Solar Water Heating

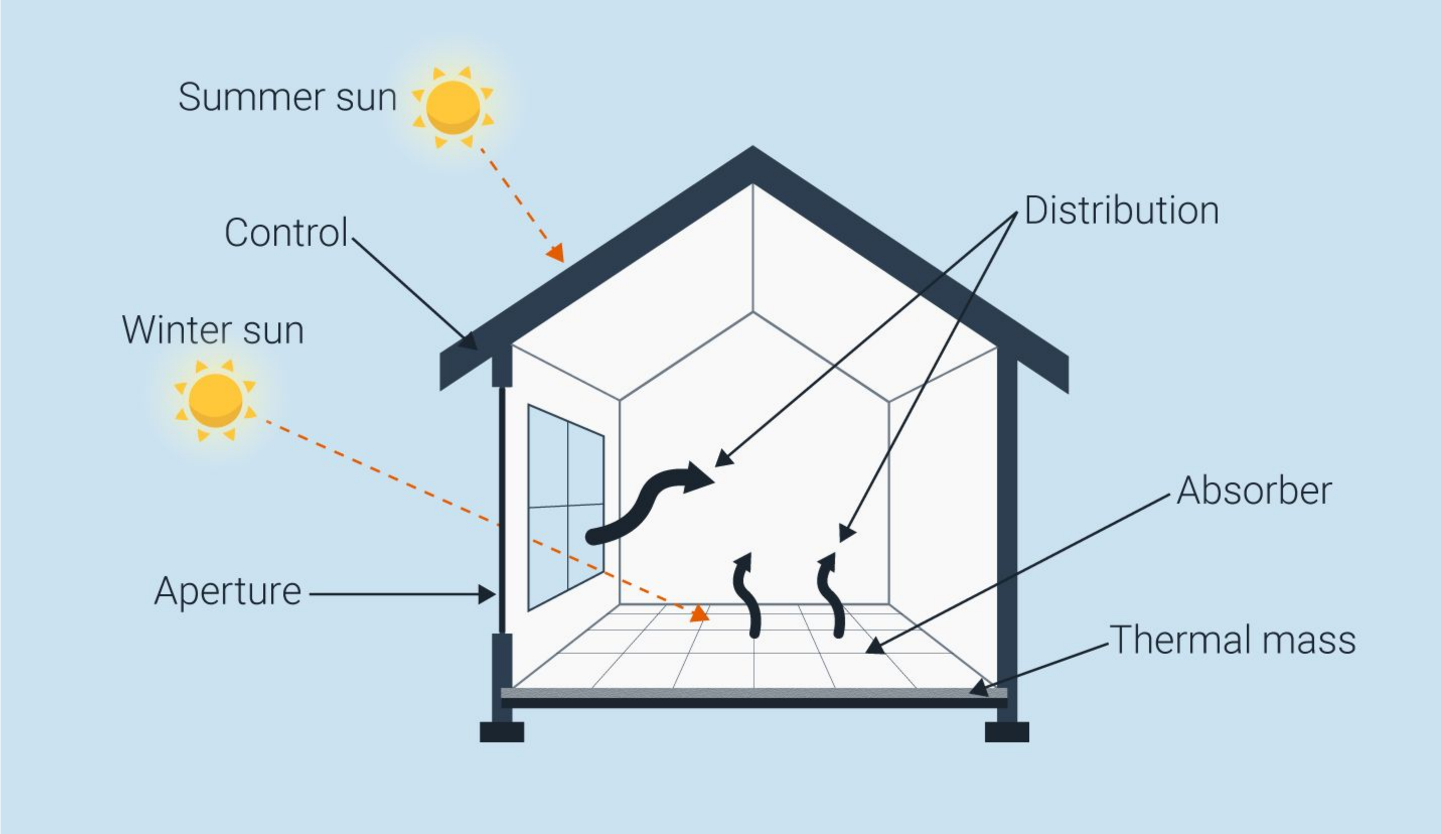
- Active solar water heating systems are used to heat the water in homes. It uses pumps to circulate the water or heat-transfer fluid through the system.

Active Solar Pool Heating

In the active solar pool heating, the water from the pool is passed through solar collectors and once it is heated it is piped back into the pool area. This eliminates the need for storage tanks.



Five key elements of solar passive design



There are five important components or mechanisms of a passive solar heating system: apertures, absorbers, thermal mass, distribution, and control.

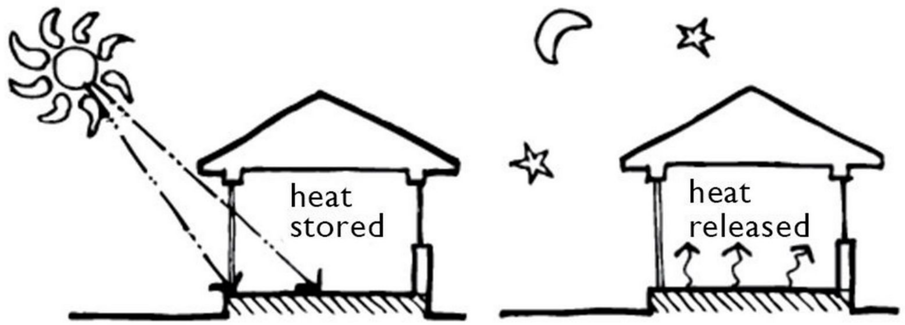
- Passive solar **aperture** (admitting sunlight/solar energy)
- Passive solar energy **control** (seasonal needs)
- Passive solar heat/energy **distribution** through the building
- Passive solar **absorber** to surface absorption of energy for later release
- Passive solar **thermal mass** providing heat storage

Absorbers

Absorbers are hard surfaces that are directly in the path of the sun, designed to capture (not reflect) solar energy in the form of heat.

Thermal mass

Thermal mass is the ability of a material to absorb and store heat energy. Thermal mass is often made of materials like brick, stone, and tile, but can also be water, stored inside an absorber like a dark-colored tank.



Distribution

Distribution of solar heat happens in three primary ways, sometimes aided by fans and blowers:

- ***Conduction*** happens when heat is transferred between two objects in direct contacts, like your bare feet on a hot floor
- ***Convection*** happens when heat is transferred via air or water. Warm air will naturally flow to cooler areas; this is why your food is more thoroughly cooked in a convection oven than in a standard microwave
- ***Radiation*** occurs when you feel the heat from sources around you, like your skin on a hot day

Control

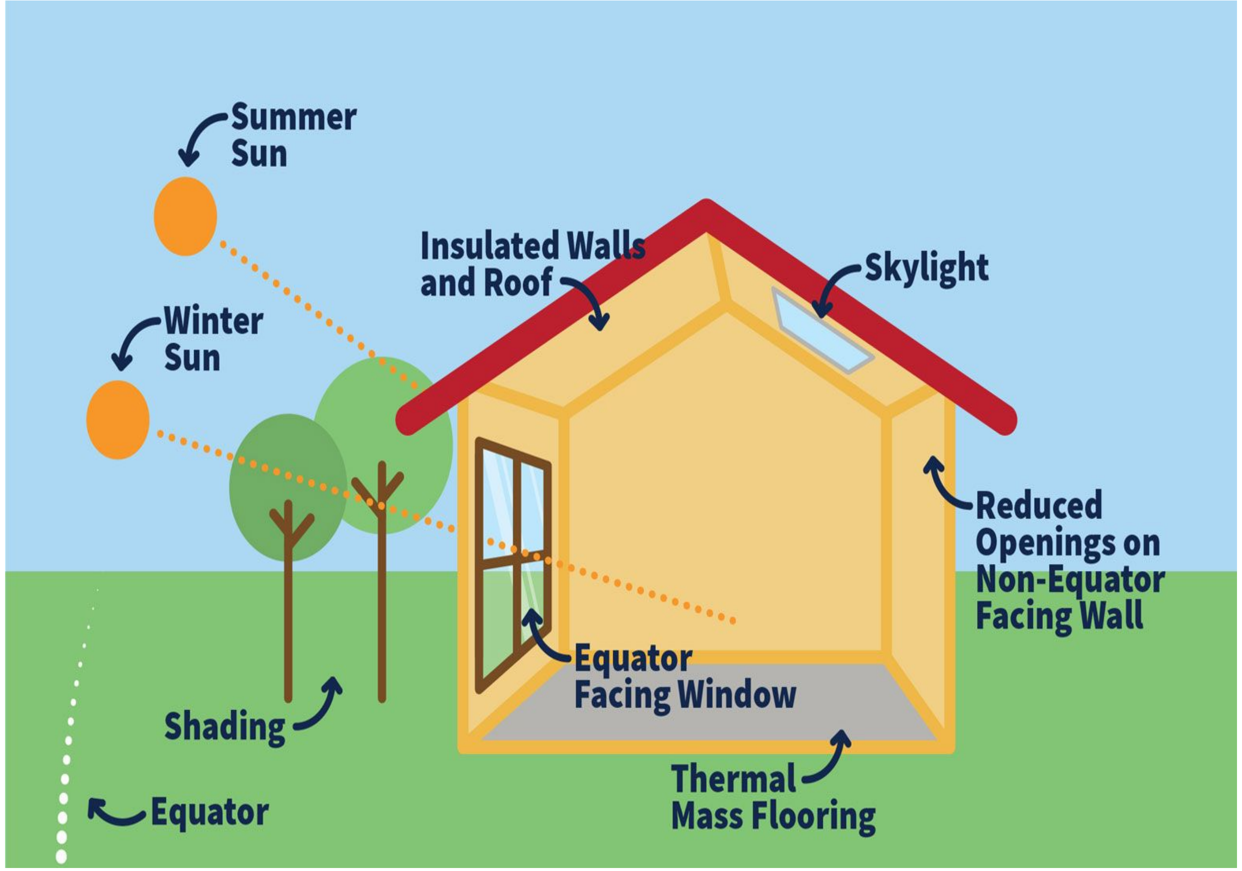
Control mechanisms like sunshades, roof overhangs, and blinds provide custom control over the amount of heat entering your home, while insulation and ventilation methods provide control over heat loss.

Apertures

Apertures are essentially windows or open spaces that have complete, or close to complete, access to the sun, and are ideally south-facing.

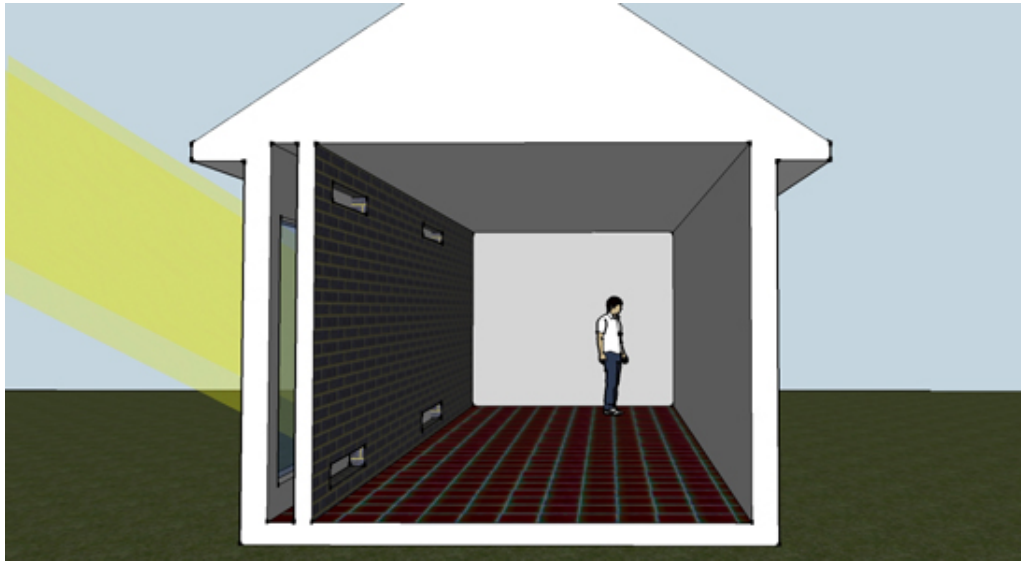
Passive systems can be categorized into three types:

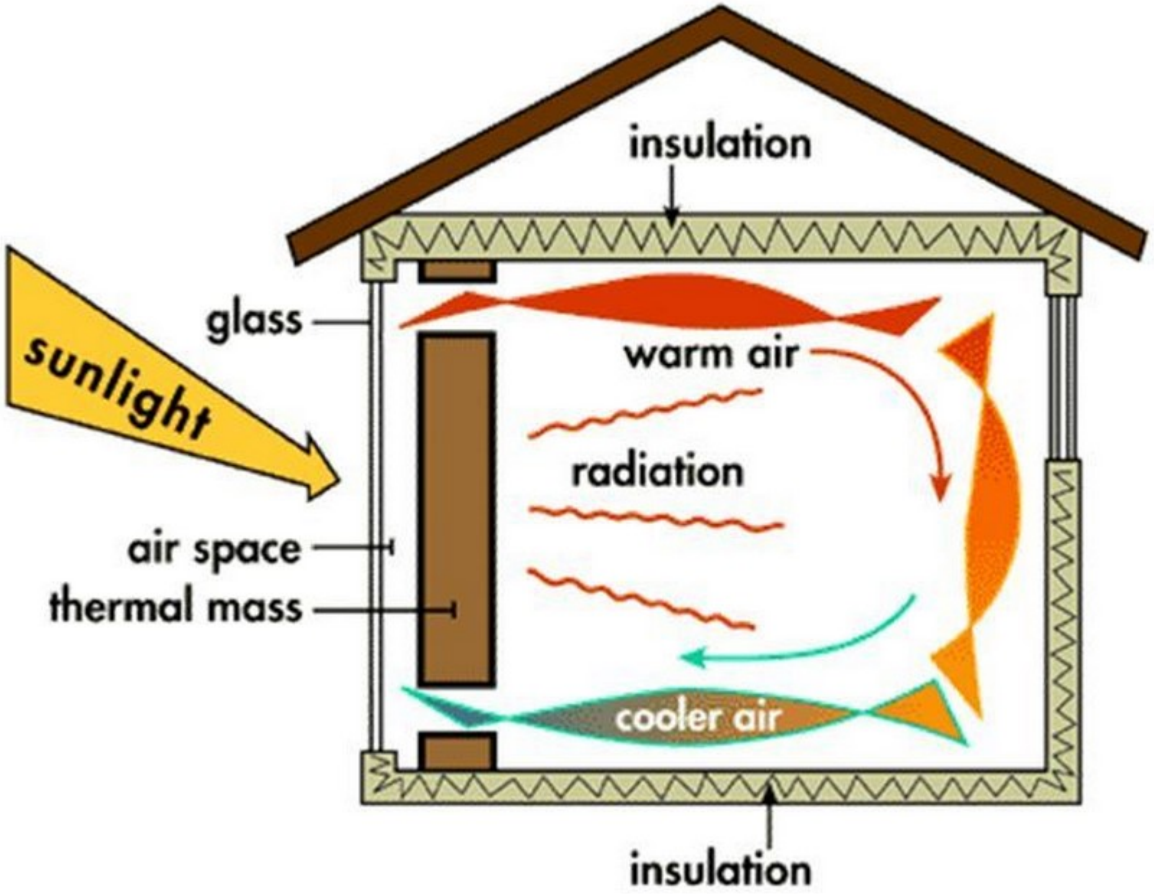
- **Direct Gain** - Allows the solar energy to come in through the south-facing window glasses. Wall apertures allow sunlight to directly enter the building and heat the interior living space.
- The glazing should be well insulated to prevent the leakage of heat into the exterior. It is also essential to prevent brightness and too much heat during summer.

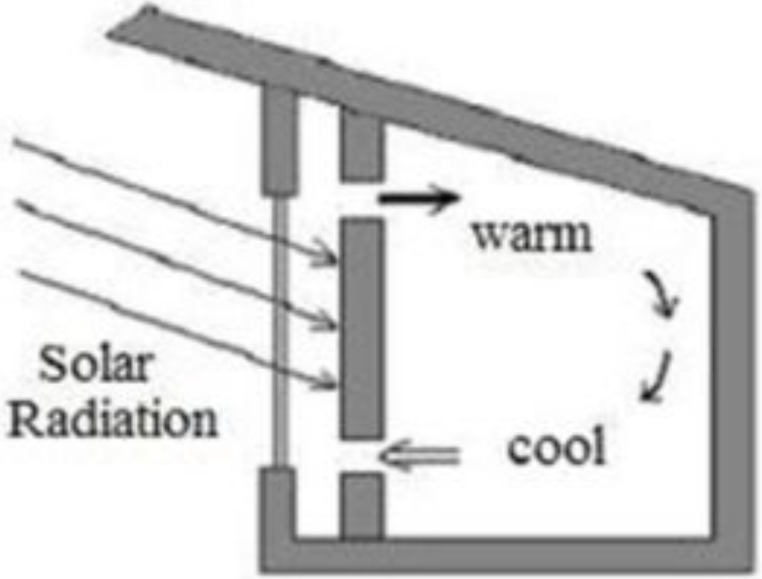


•**Indirect Gain** - Allows the solar radiation to heat a wall and then the energy is slowly delivered into the interior of the house. Openings in the wall (called a Trombe Wall), as shown in the figure below, promote convective currents:

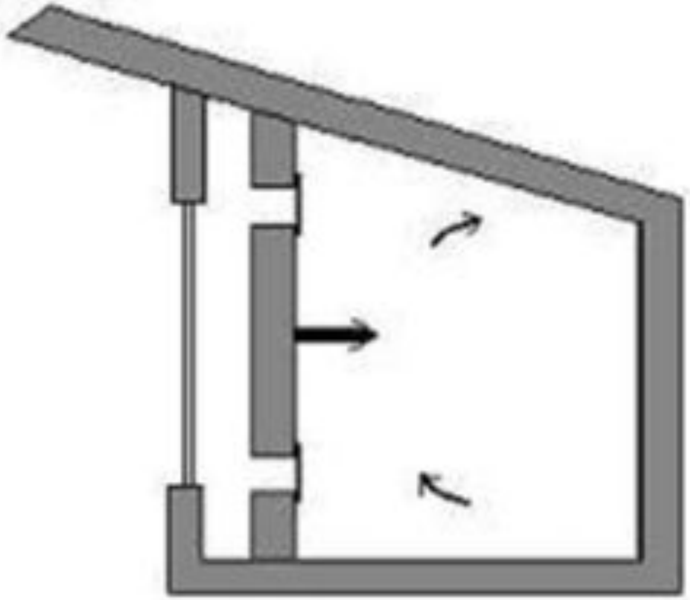
- Cold room air enters the space between the glass panel and the wall through the bottom opening.
- As this cold air gets heated, it rises to the top and comes in through the top opening.







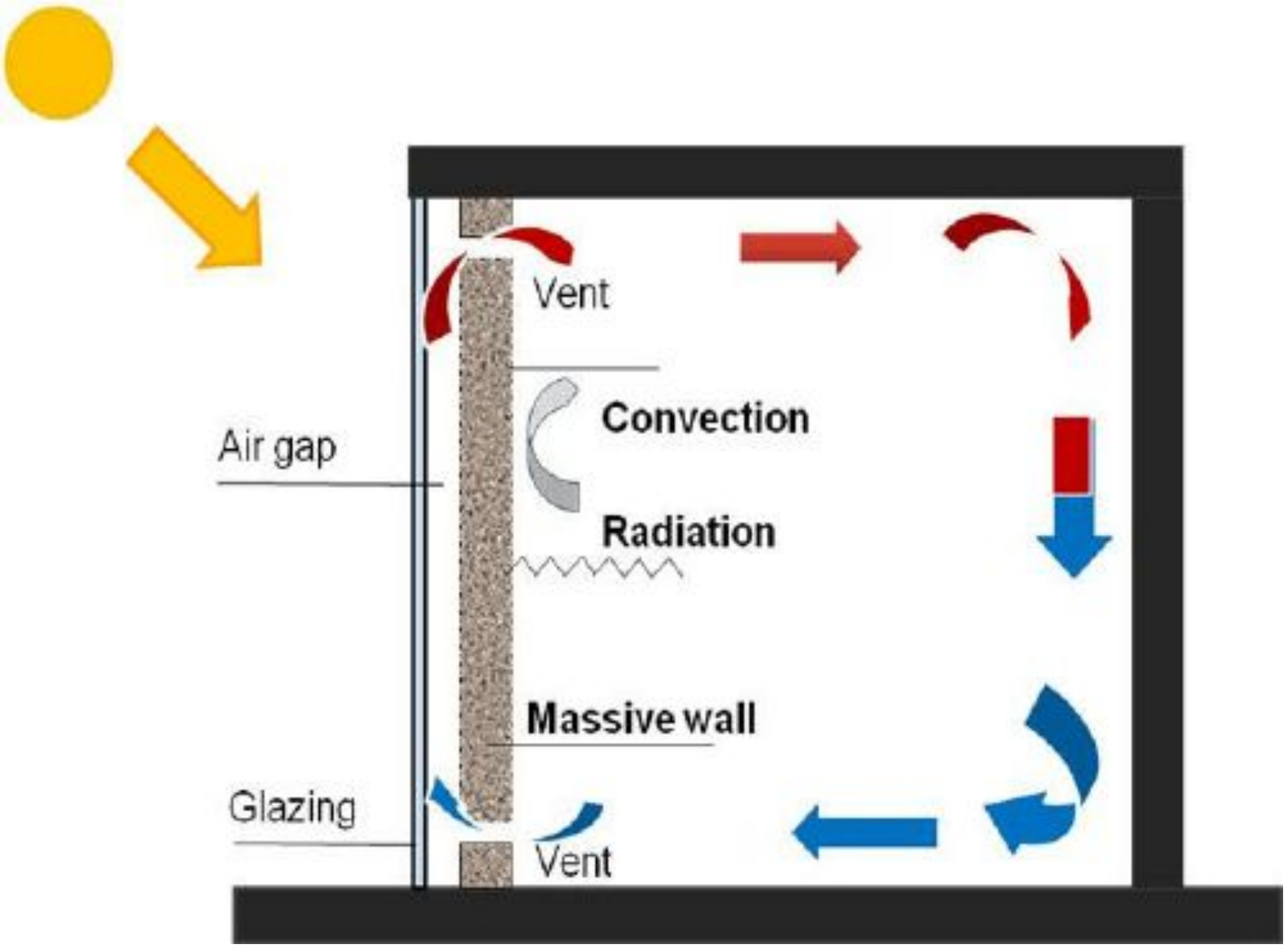
Daytime - vents are open, wall stores heat & heats room



Night time - vents are closed wall heats room

Trombe wall

The thermal storage wall system absorbs and stores heat during the daytime. Excess heat is transferred by air between wall and glass through the thermosiphon principle (the device uses these forces to create a cyclic fluid flow from areas of high heat to low heat) into the living space. During the night, vents of the Trombe wall are closed, then heat energy is circulated into the interior space.



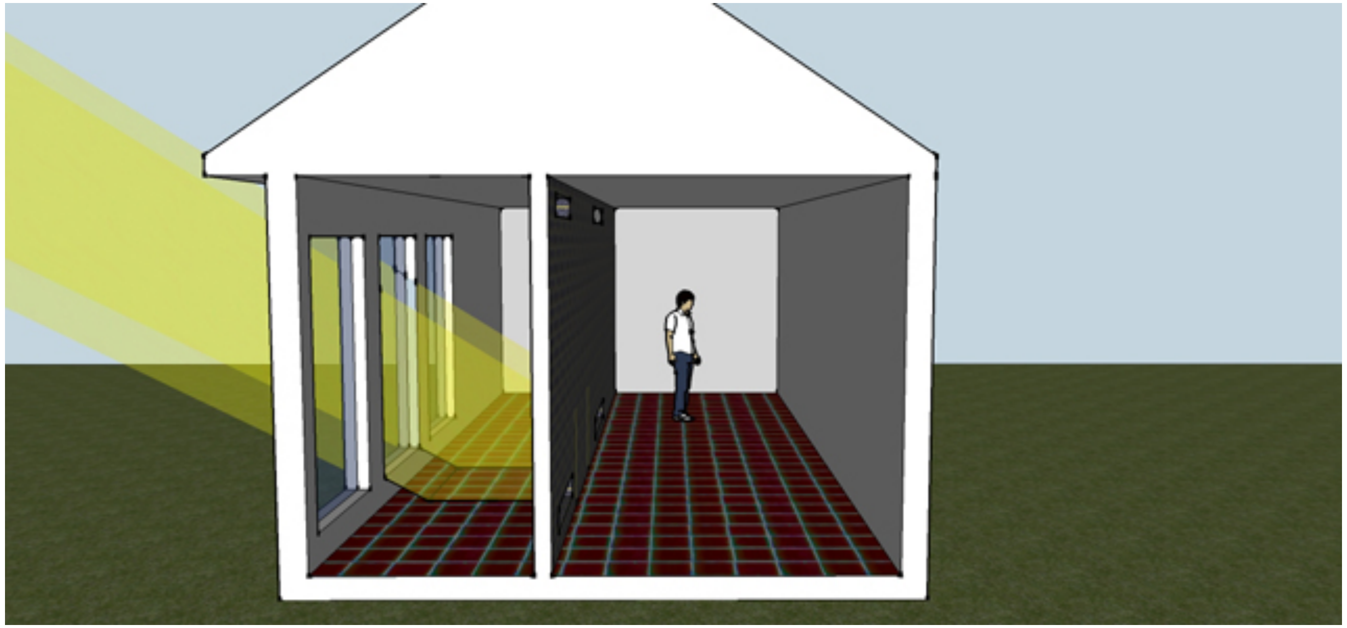
Material thickness (mm)	Time lag (ho
Double brick (220)	6.2
Concrete (250)	6.9
Autoclaved aerated concrete (200)	7.0
Mud brick/adobe (250)	9.2
Rammed earth (250)	10.3
Compressed earth blocks (250)	10.5
Sandy loam (1000)	30 days

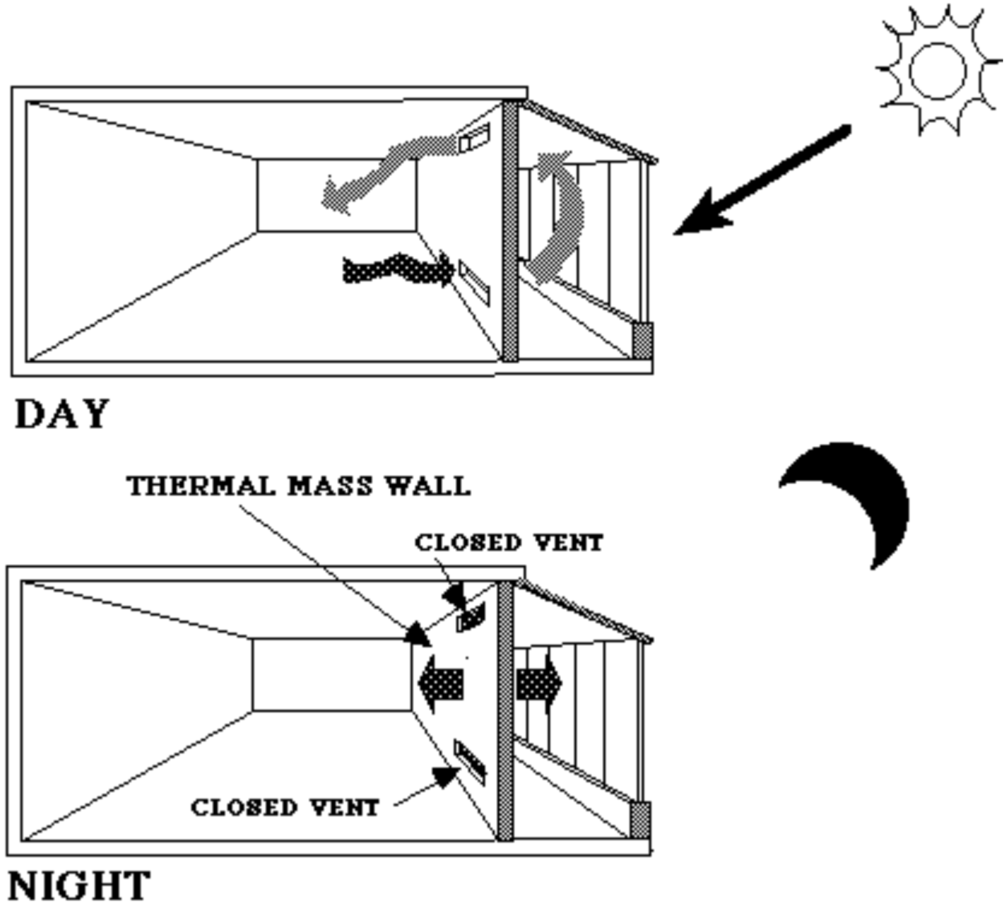
Material	Thermal mass (volumetric heat capacity, KJ/m³.k)
Water	4186
Concrete	2060
Sandstone	1800
Compressed earth blocks	1740
Rammed earth	1673
Fibre cement sheet (compressed)	1530
Brick	1360
Earth wall (adobe)	1300
Autoclaved aerated concrete	550

Influencing factors

- High density
- Good thermal conductivity
- Appropriate thermal lag
- Low reflectivity
- High volumetric heat capacity (VHC)

Isolated Gain - The distribution of heat to the house can be accomplished through vents, windows, or doors from the sunspace to the adjacent home interior. Most homes with isolated gain separate the sunspace from the home with doors and windows, so the home doesn't overheat during the summer months. Fans and operable windows can assist in cooling the sunspace when it is overheating.





What is passive cooling?

Passive cooling is where the building design and materials are used to control the temperature in hot weather.

Cooling buildings is about:

- Reducing heat gain (for example, by installing insulation and shading windows, walls, and roofs)
- Increasing heat loss and access to cooling sources

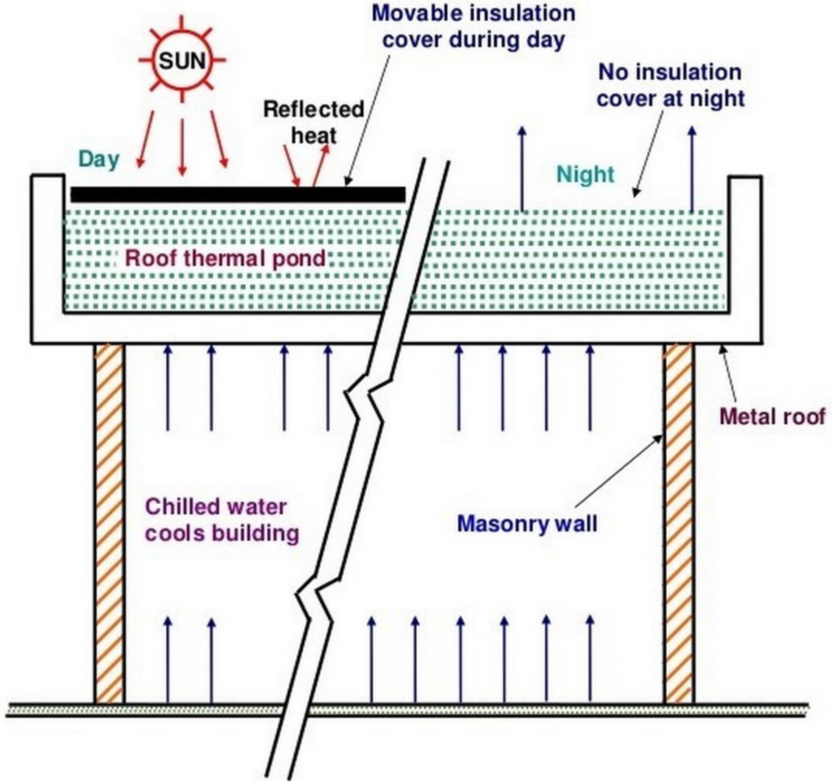
Cooling people is about:

- Psychological comfort (psychological factors that affect our perception of comfort, for example, levels of adaptation and air movement, radiation, and conduction).

Roof ponds

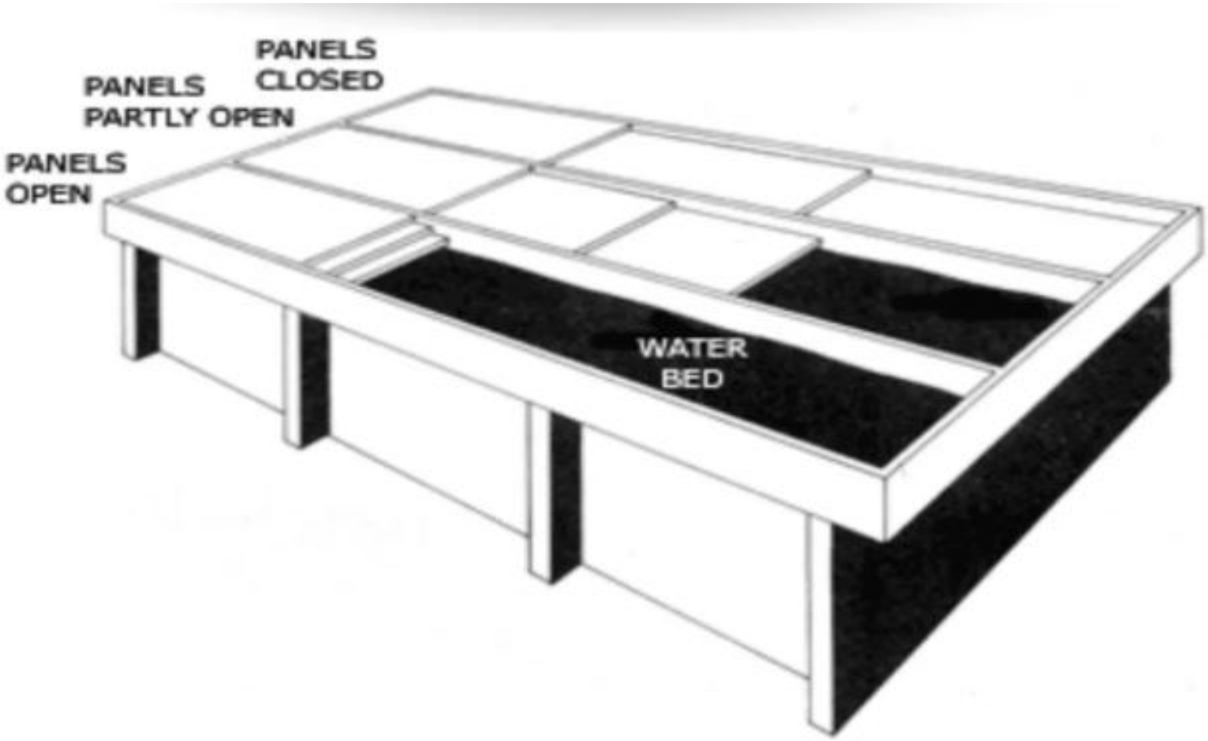
Roof ponds are similar to thermal walls. The roof pond is covered with a movable insulated reflective surface, which during the day bounces off the sun's rays and maintains a cool temperature inside the house as the pond is filled with cold water. At night, the pond is left uncovered and is naturally cooled.

During the nighttime, the movable insulation is removed, and the water disperses heat outside the living room.

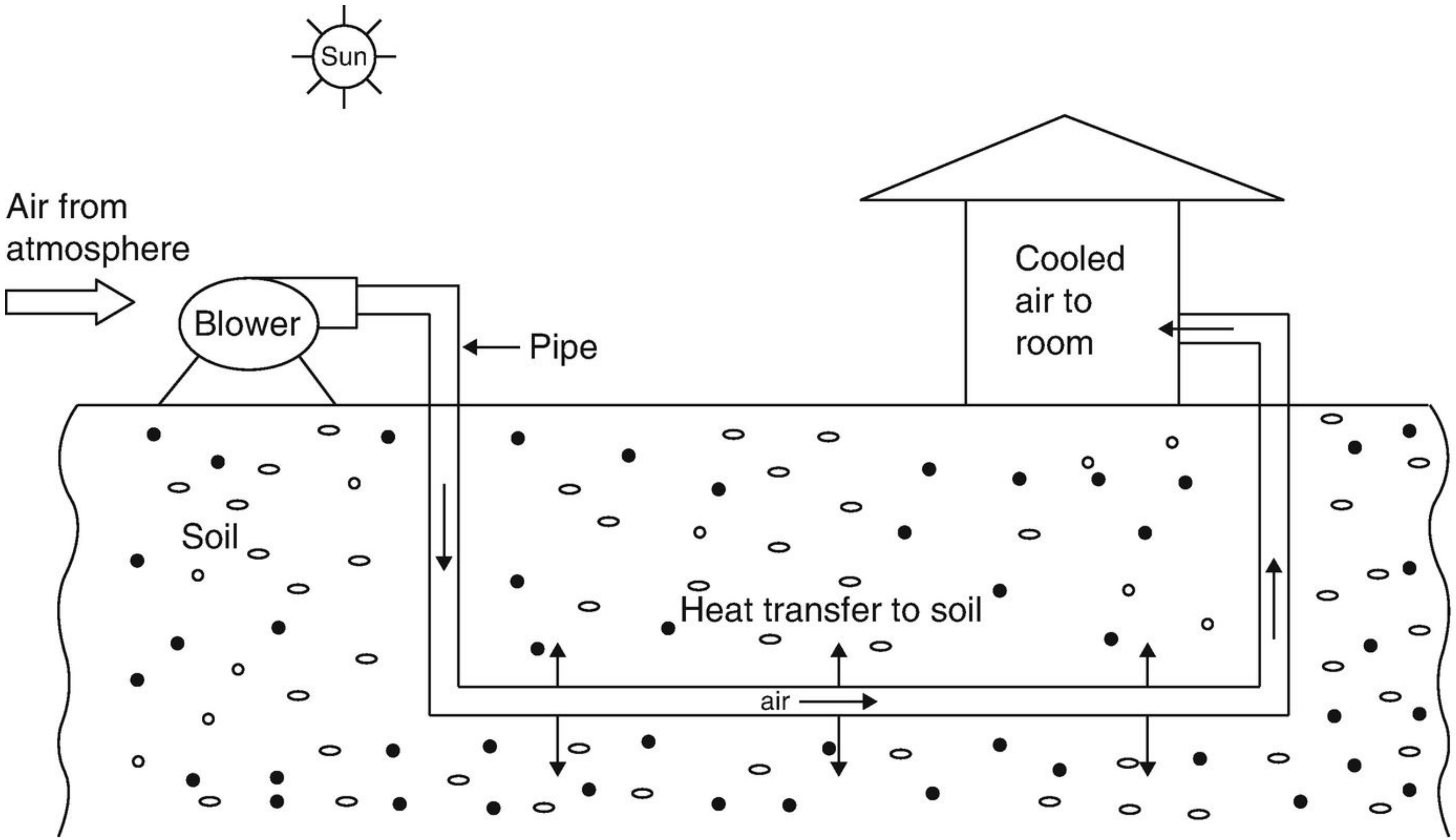


Water Wall

The water wall consists of transparent containers filled with water. During the day, the water absorbs and stores the sun’s heat and disperses it into living space at night.

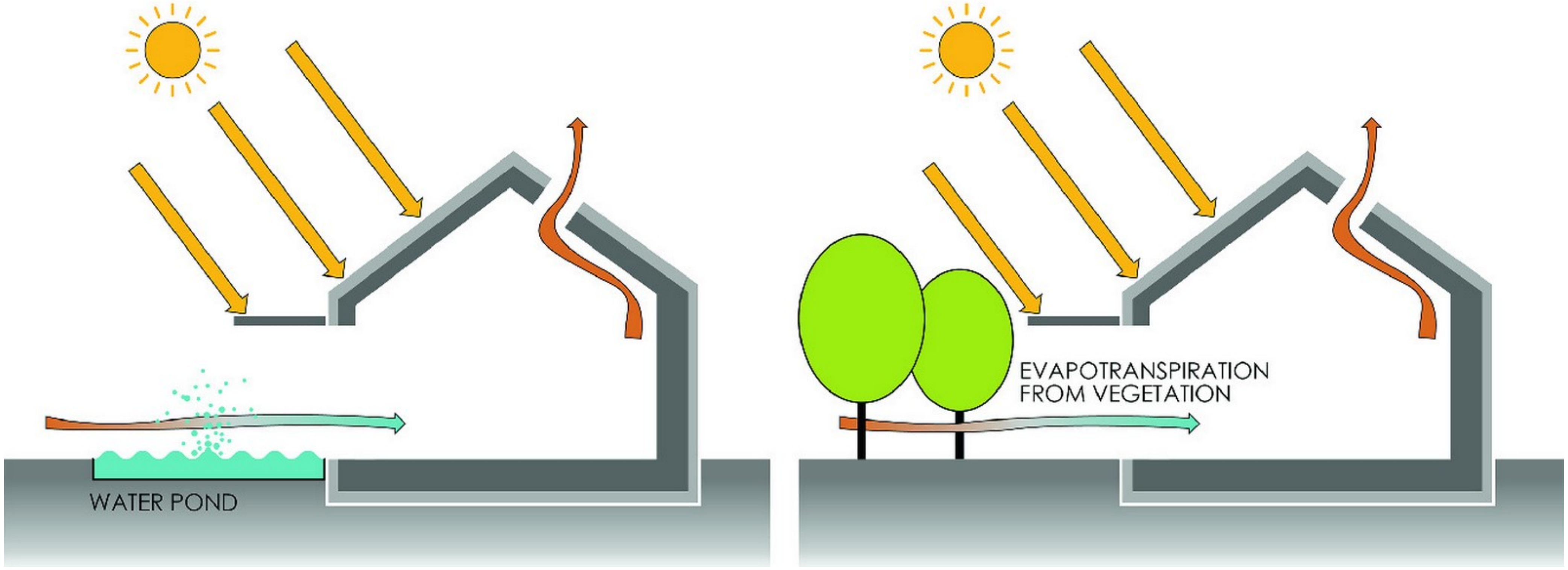


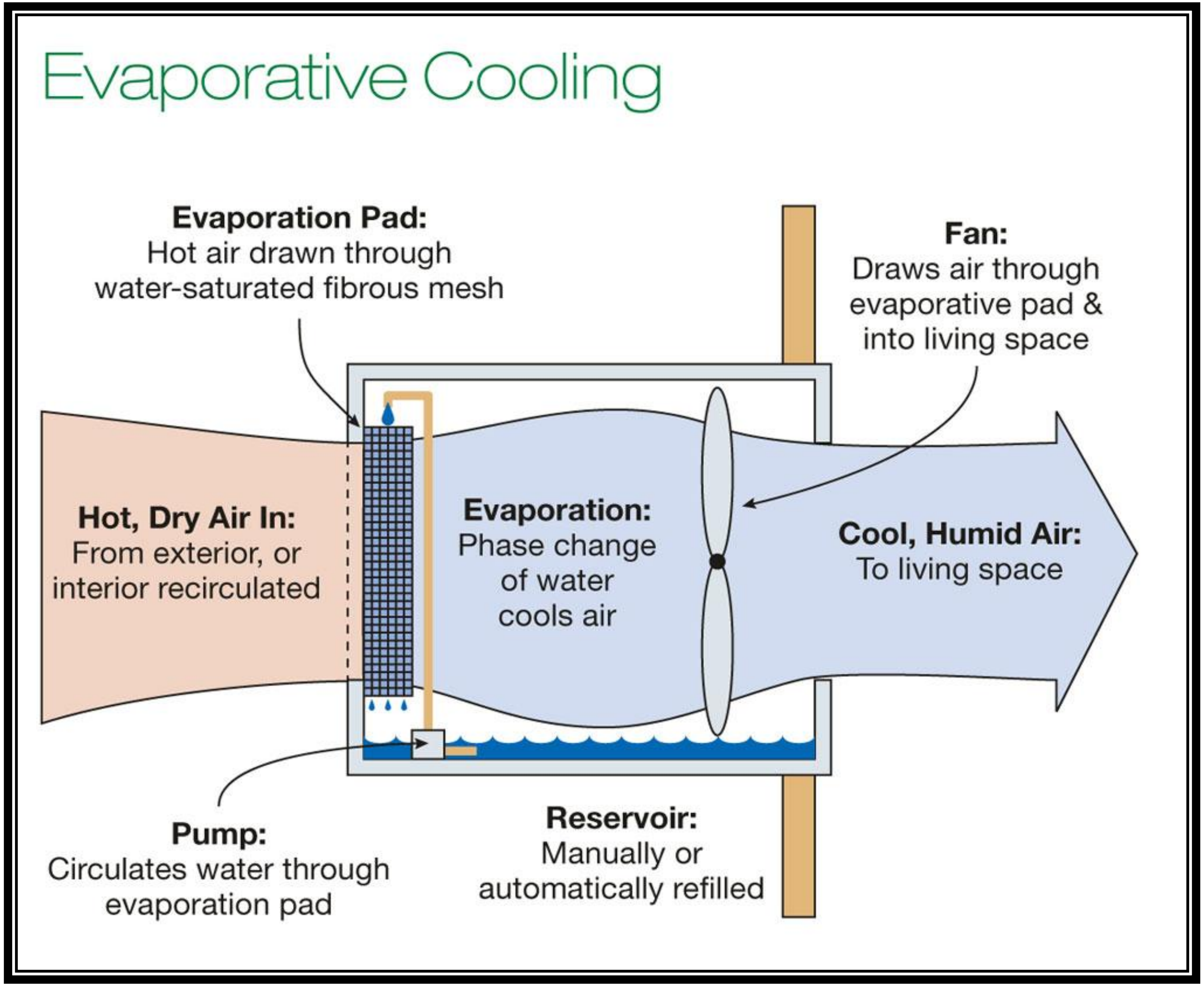
- An earth-coupling or ground-coupled heat exchanger is an underground heat exchanger that can capture heat from and/or dissipate heat to the ground. They use the Earth's near-constant subterranean temperature to warm or cool air or other fluids for residential, agricultural, or industrial uses.
- The temperature of the ambient air fluctuates throughout the year but the temperature of the ground at a certain depth remains constant throughout the year all around the globe.

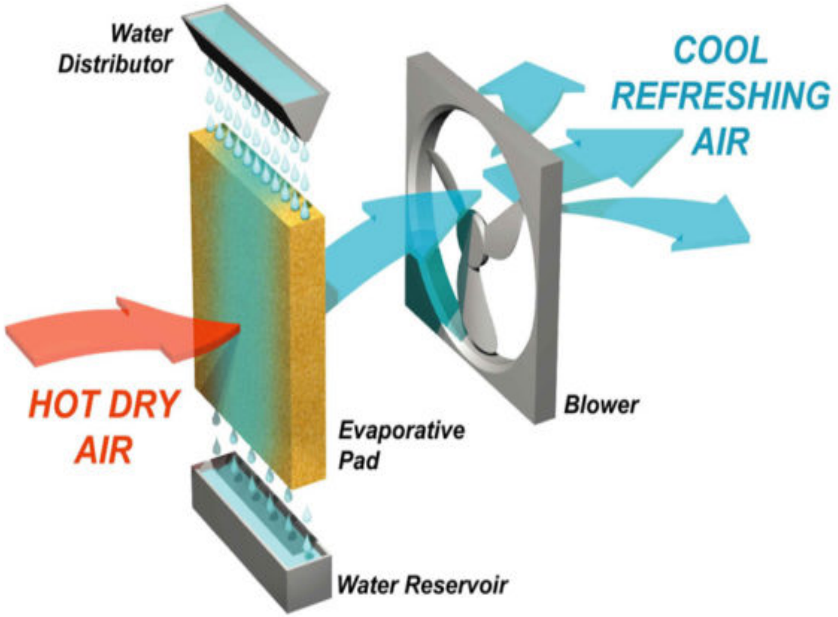


Evaporative cooling

This method of cooling is adopted in places where the air is very dry and hot. Here the major problem is dryness, and so to increase the relative humidity level, water ponds are placed. The space around a pond is cooled by the removal of latent heat by the evaporating molecules, thus creating a comfortable space.




Evaporative Cooling
Evaporation Pad:
Hot air drawn through
water-saturated fibrous mesh
Fan:
Draws air through
evaporative pad &
into living space
Hot, Dry Air In:
From exterior, or
interior recirculated
Evaporation:
Phase change
of water
cools air
Cool, Humid Air:
To living space
Pump:
Circulates water through
evaporation pad
Reservoir:
Manually or
automatically refilled


Water
Distributor
COOL
REFRESHING
AIR
HOT DRY
AIR
Evaporative
Pad
Blower
Water Reservoir

COMPARISION

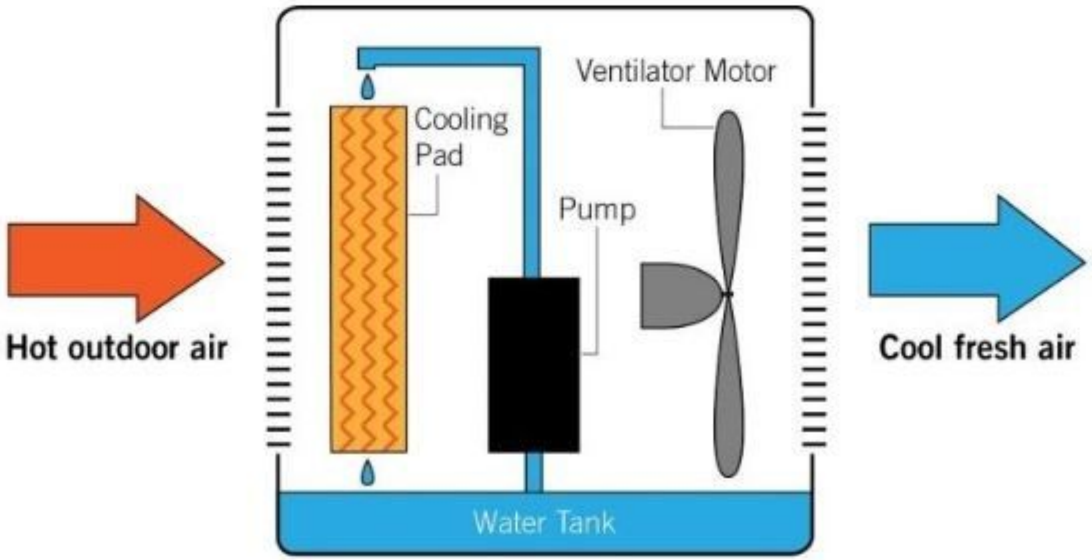
EVAPORATIVE AIR COOLING	AIR CONDITIONING
Introduce 100% fresh air.	Re-circulate the same stale air.
Windows and doors can be left open.	Windows and doors must be shut.
Keeps the air moist, good for allergic and asthmatic conditions.	Reduces the moisture, which can be troublesome for asthma and allergy sufferers.
100% fresh air eliminates many causes of Sick Building Syndrome.	Re-circulated air may contain germs and can result in sick Building Syndrome.
Increased cooling capacity as outside temperature rises.	Reduced efficiency and capacity as outside temperature rises.
80% less running cost than Air conditioning.	Higher running costs.
Is healthier for the environment – No Harmful emissions & No synthetic refrigerants.	Synthetic refrigerants

Advantages of evaporative cooling over modern air conditioning:

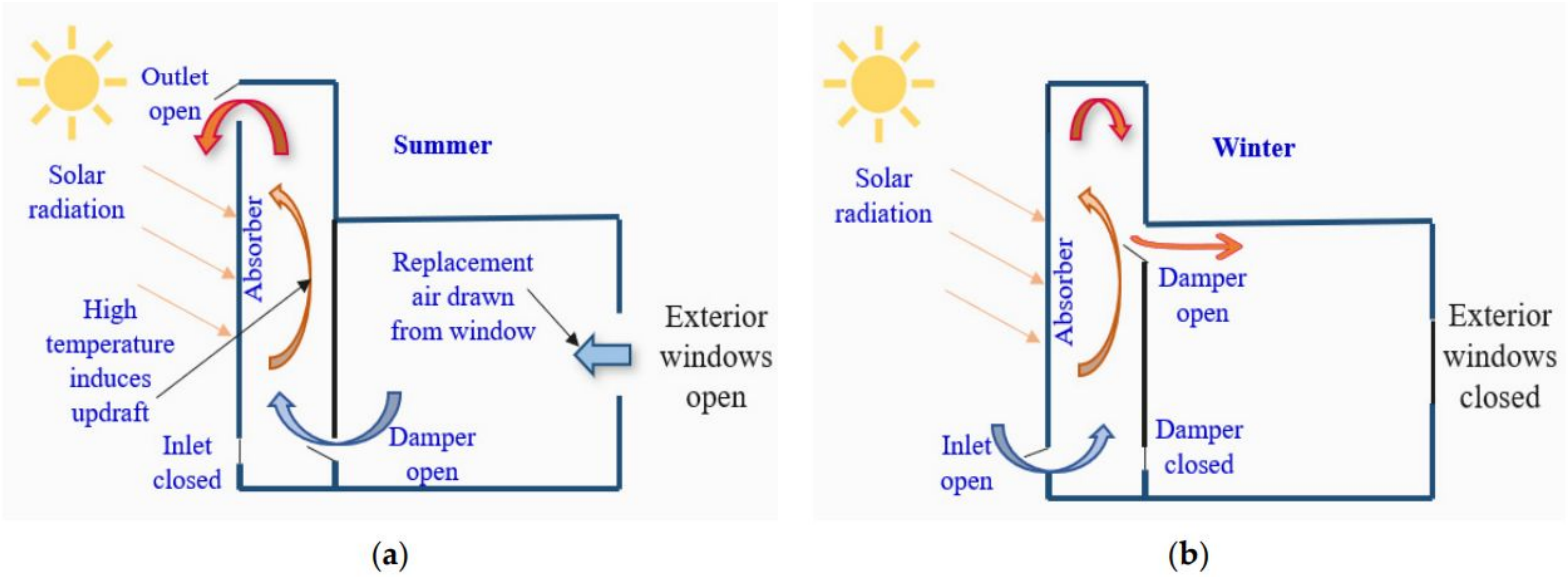
- Lower equipment and installation costs
- Lower operating and power costs (energy savings can be as high as 75 percent)
- Ease of fabrication and installation
- Lower maintenance costs
- Ensures very good ventilation due to the large air flow rates involved
- Very environment-friendly as no harmful chemicals are used

Disadvantages of evaporative cooling over modern air conditioning:

- Not applicable when the low humidity level in a conditioned space is required
- Exact control of temperature and humidity in conditioned space is not possible
- May lead to health problems due to micro-organisms

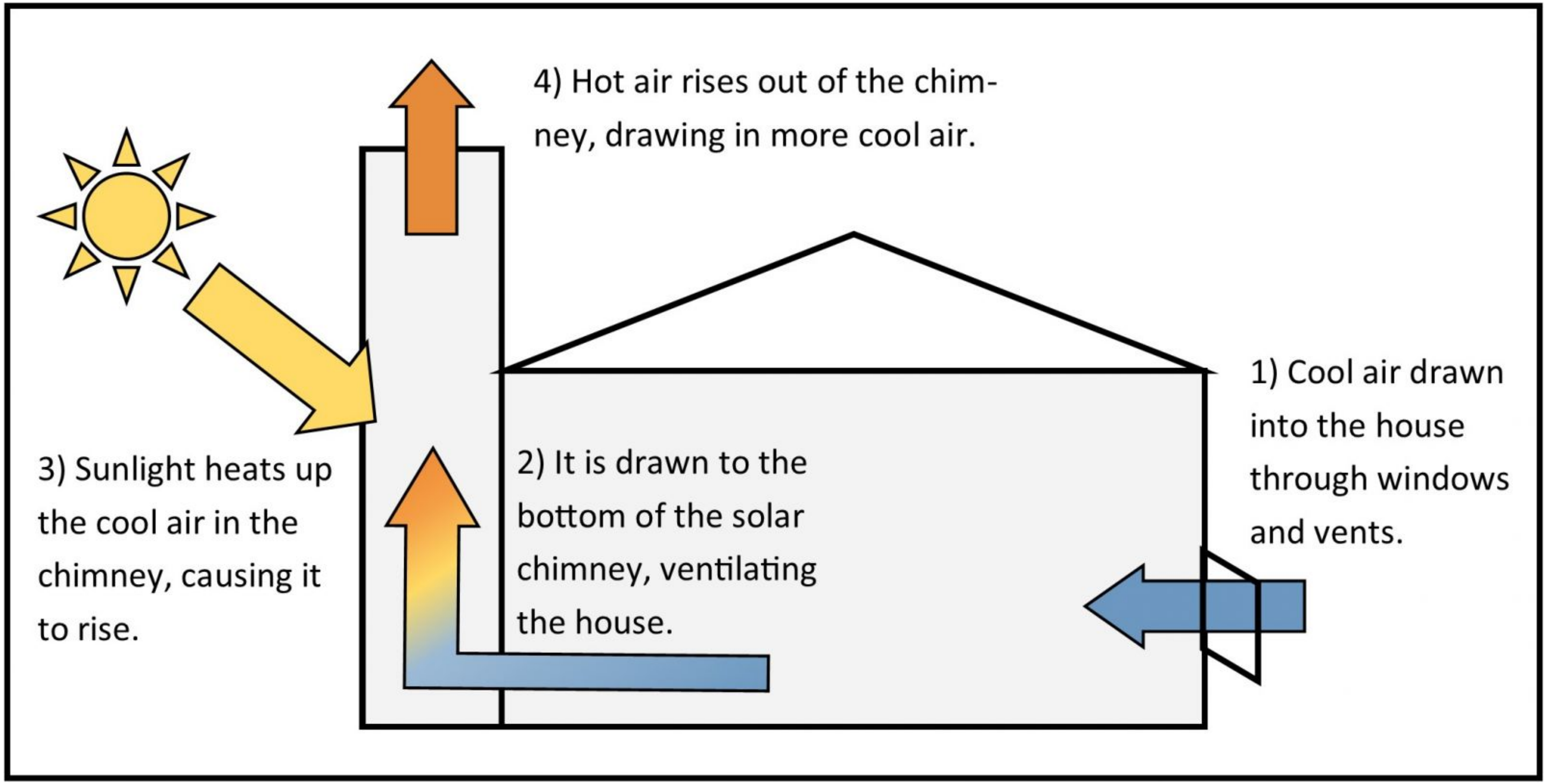


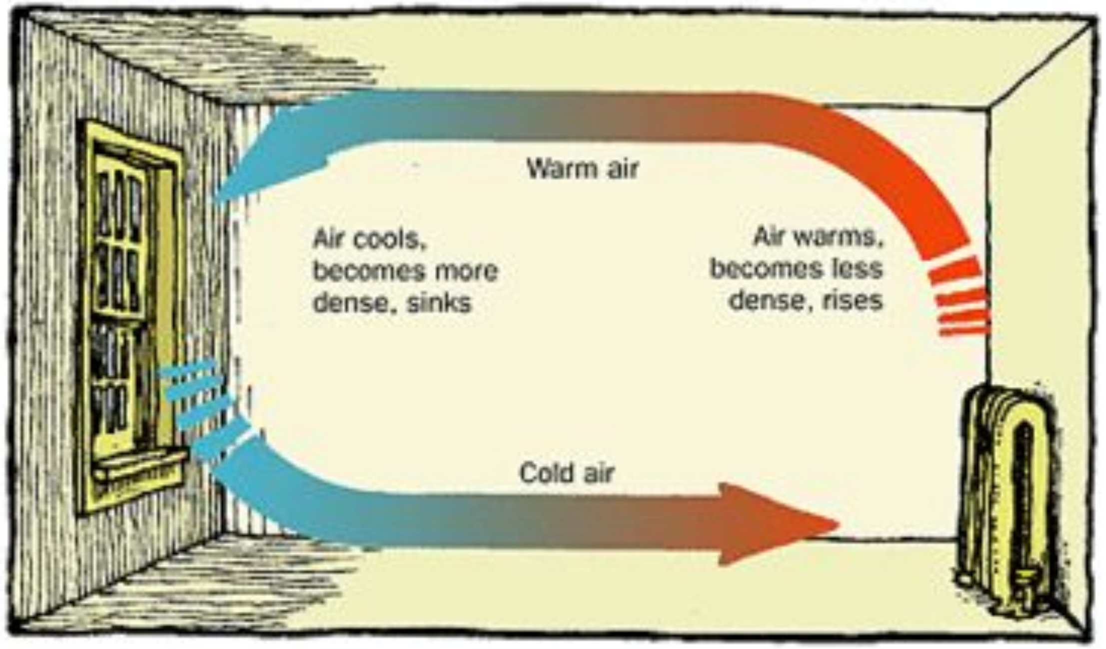
- A **solar chimney** is a renewable energy system used to enhance the natural ventilation in a building based on solar and wind energy.
- When solar radiation hits the side of the chimney, the air inside the chimney gets heated. If the top exterior vents of the chimney remain closed, the heated air moves back into the living space.
- This provides a type of convective air heating. As the air gets cooled in the room, the lighter air tends to move up towards the solar chimney, heating it again. This cycle is repeated, and the process of heating continues.

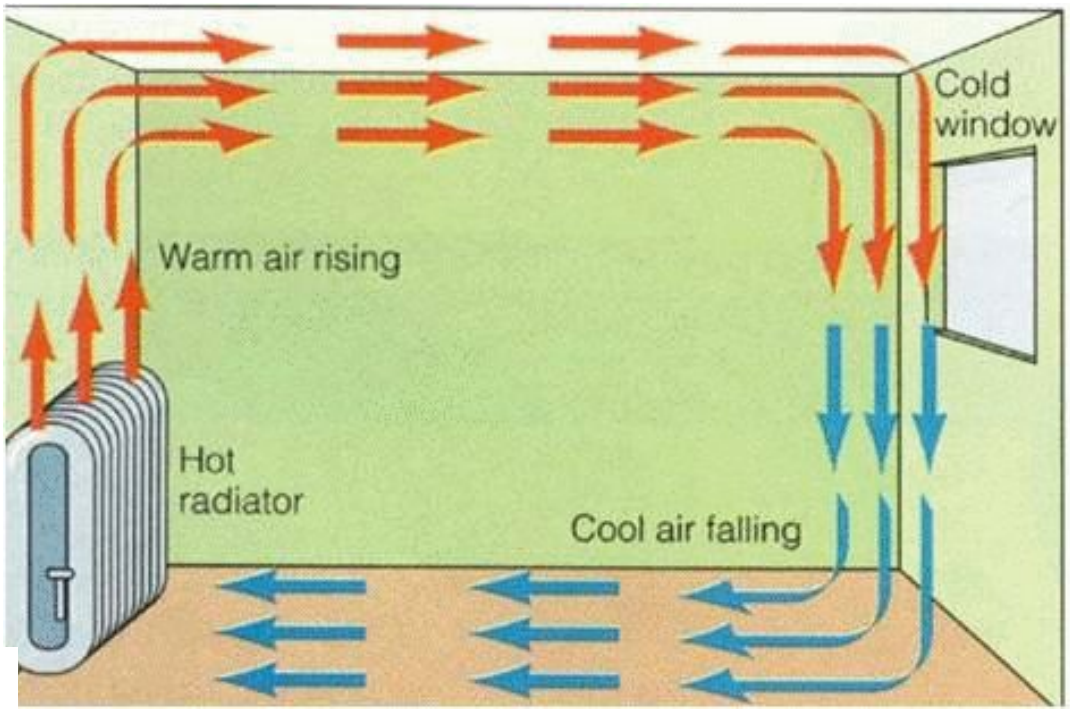


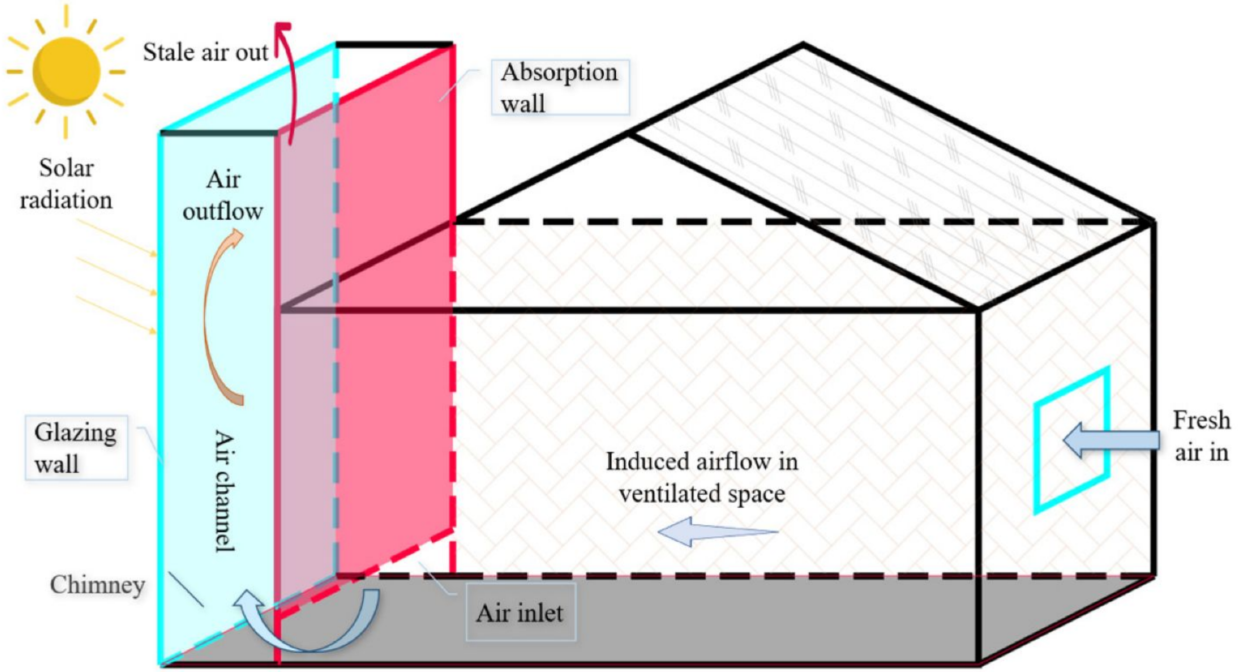
Schematic of solar chimney under heating and cooling modes: (**a**) cooling mode of a solar chimney; (**b**) heating mode of a solar chimney.

Solar Chimney

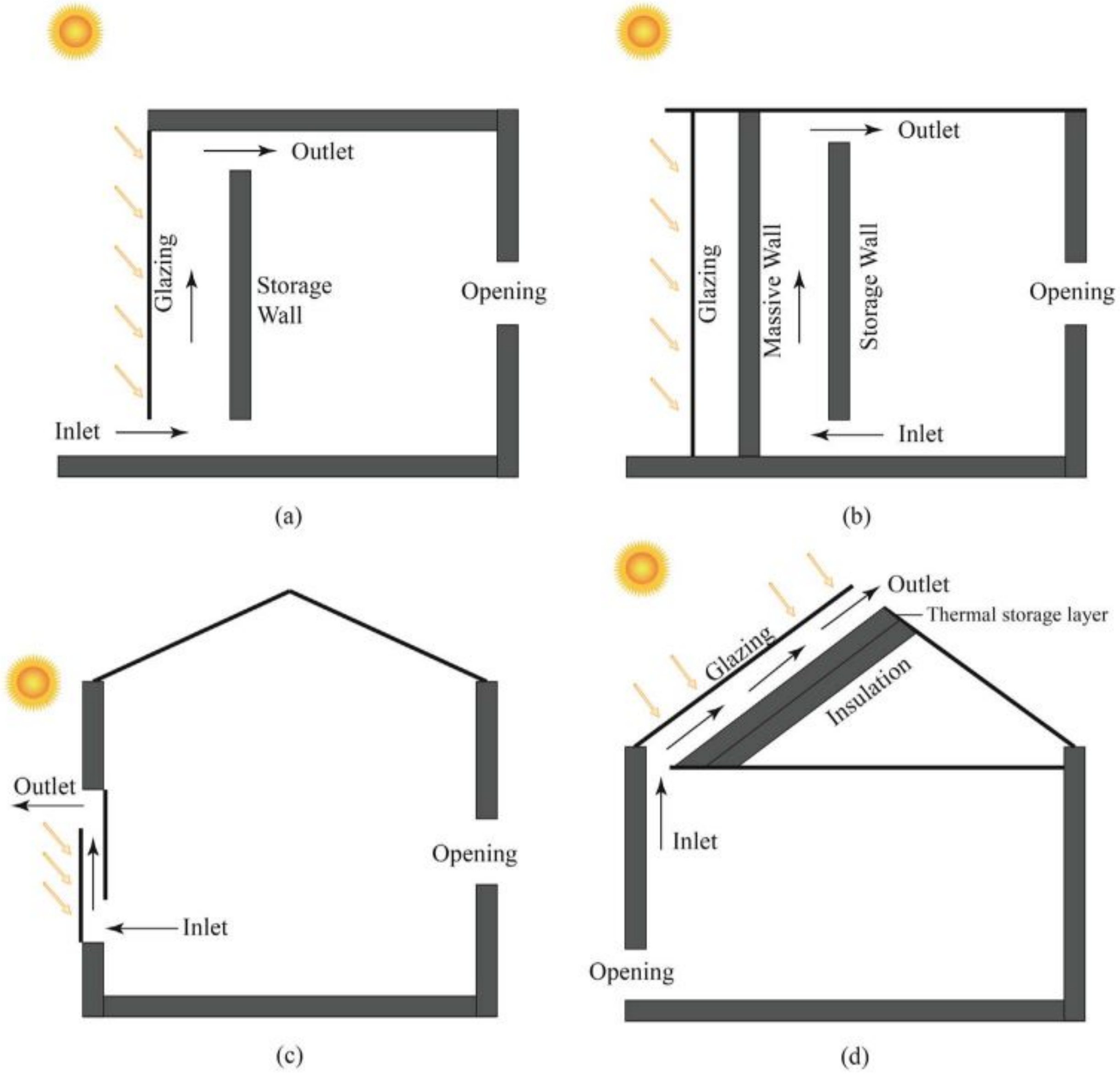


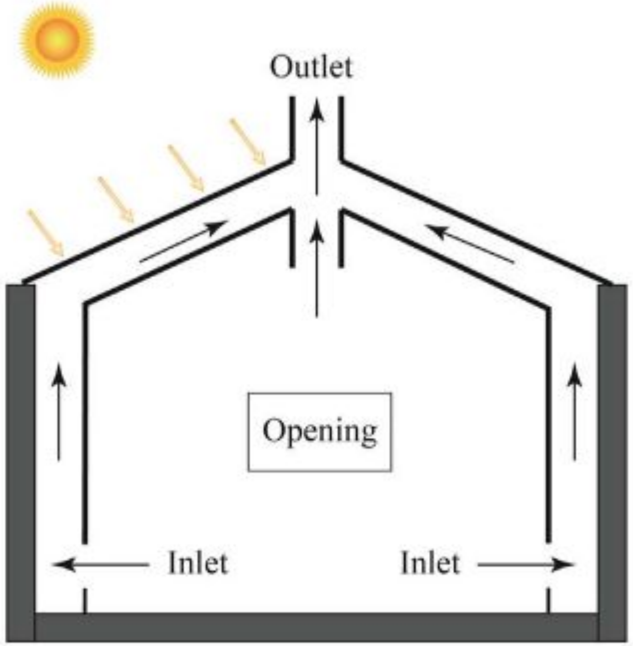


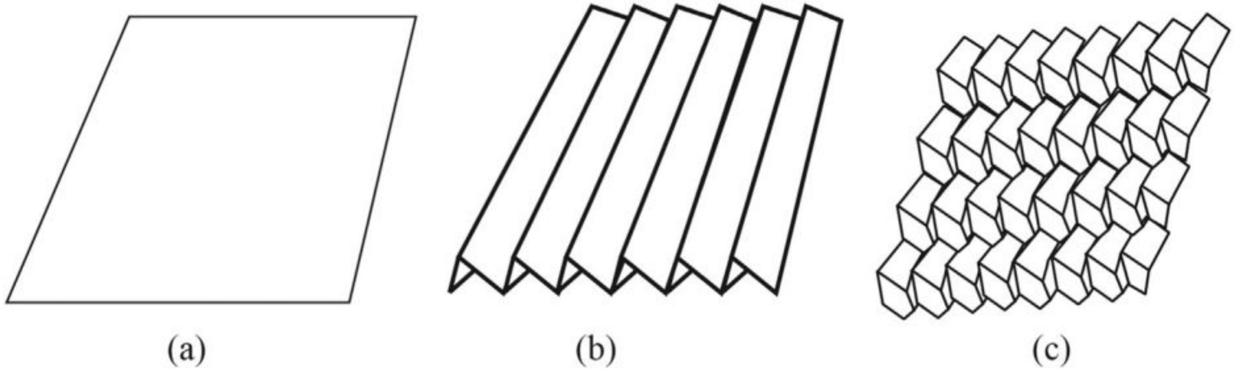




Convective air loops







Three types of solar absorber plates were used for roof solar chimney: (a) flat; (b) V-grooved; and (c) chevron pattern.

Thermal Insulation

Thermal insulation in an air conditioning system is primarily used to reduce heat gain or heat loss from the piping.

Insulation Characteristics

- Low thermal conductivity.
- Reasonable strength
- Non-flammable.
- Resistance to Fouling such as one that is based on ASTM G21 standard.
- Corrosion resistance.

Pipe insulation materials can be manufactured from rubber, wool, glass fibers or cork. The polyurethane or P.U. is a synthetic material that is commonly used these days due to its low thermal conductivity and other good properties.

Thermal insulations

Why Insulation?

Buildings without insulation and air-tight envelope can result in major energy wastage.

Benefits of Insulation

- 5-8% energy savings with a payback of 1-2 years
- Provides thermal as well as acoustical insulation
- Resistant to moisture
- Resistant to air infiltration

Applications of Insulation materials

- Exterior walls
- Interior walls
- Over the deck (roof)

Autoclaved Aerated Concrete Blocks

Autoclaved Aerated Concrete (AAC) blocks are produced using materials including silica sand, lime, cement, gypsum, water, fly-ash and aluminum powder. The special combination of these substances yields a material with excellent construction properties such as thermal insulation, structural strength, density and fire resistance.

ASHRAE* Building Envelope Requirements

Opaque Elements (Insulation)	Non Residential		Residential	
	Assembly Maximum (W/m^2K)	Insulation Minimum R value (m^2K/W)	Assembly Maximum (W/m^2K)	Insulation Minimum R value (m^2K/W)
Roofs, entirely above deck	U-0.360	R-2.6 ci[#]	U-0.360	R-2.6 ci
Roofs, entirely under deck	U-0.720	R-5.2 ci	U-0.720	R-5.2 ci
Walls, above grade	U-3.293	-	U-0.857[a]	R-1.6 ci[a]

*ASHRAE - American Society of Heating, Refrigerating and Air-Conditioing Engineers
[#]ci - continuous insulation

Typical thermal properties of insulation materials:

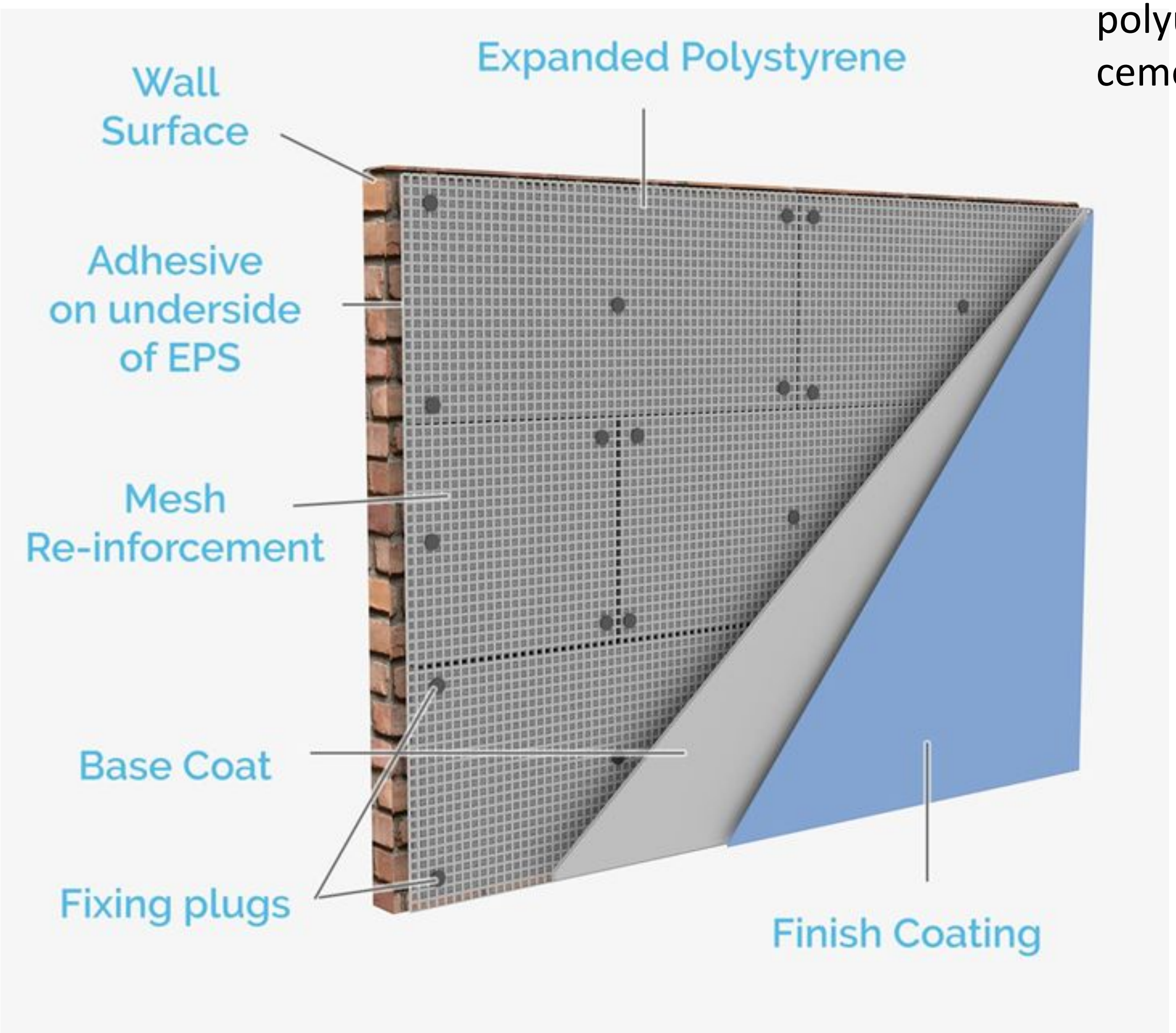
The typical U values of walls & roof materials are given below:

Material	U-value (W/m^2K)	Thickness (mm)
RCC Walls	1.95	225
AAC Blocks	0.67	230
Concrete Roof	2.5 – 3.0	150

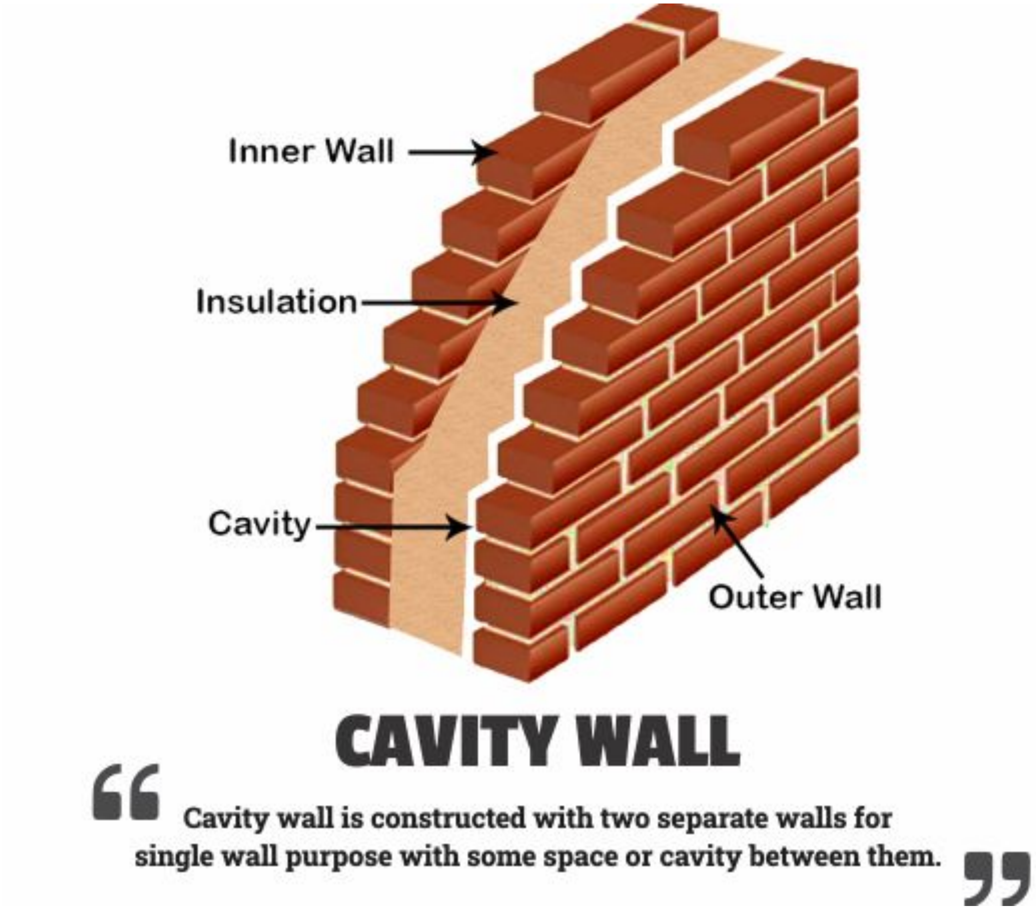
The U-values of common insulation materials are given below:

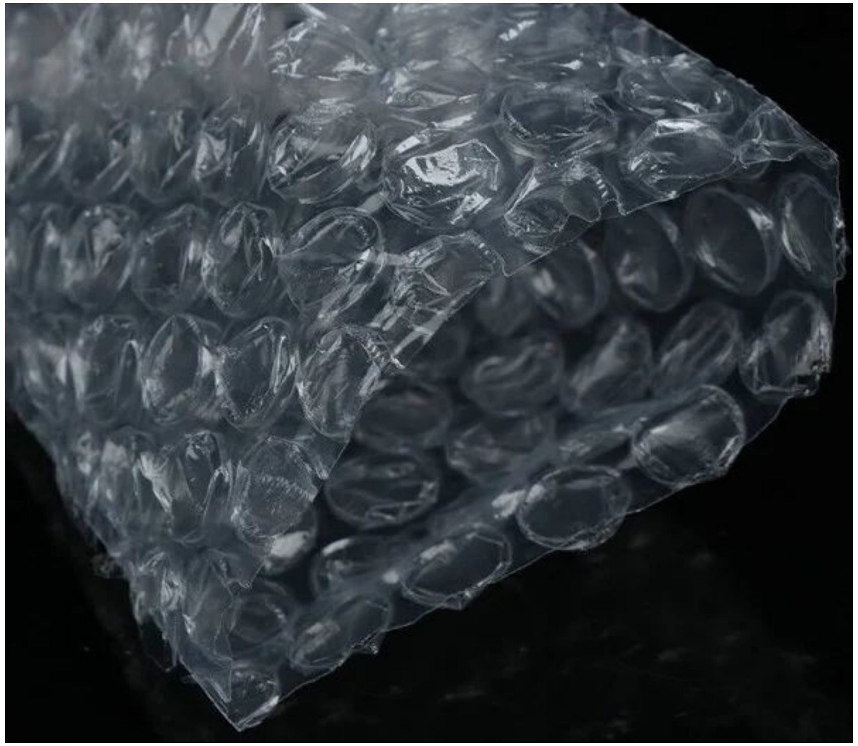
Material	U-value (W/m^2K)	Thickness (mm)
Extruded Polystyrene (XPS)	0.028	60
Glass Wool stuffing	0.25	150
Expanded Polystyrene (EPS)	0.30	100
Air (Still)	0.20	30

Wall Insulation



An external wall insulation system (or EWIS) is a thermally insulated, protective, enhancing exterior cladding procedure involving the use of expanded polystyrene, mineral wool, polyurethane foam, or phenolic foam, topped off with a reinforced cement-based, mineral, or synthetic finish and plaster





The Air cavity wall is **composed of two building materials walls separated by an air space**. The outer wall is made of brick and faces the outside of the building structure. The inner wall may be constructed of masonry units such as concrete blocks, structural clay, brick, or reinforced concrete.

Roof insulation method to prevent heat penetration from the outside environment to the inside of the building. The method provides temperature stability and prevents unwanted noise penetration. The importance of thermal insulation has increased recently mainly due to changing insulation standards worldwide, which put higher demands on the thermal resistance of building structures to reduce energy loss for heating or cooling.

Types of roof insulation materials

Advantages.

- It provides high thermal performance. Gives good mechanical strength
- It is resistant to solar radiation. Act as a barrier for air, wind, and moisture
- Prevent vapor transmission by applying exterior and interior insulation
- Lessens your carbon footprint

Requirements for Ventilation

- Heat removal: The human body has a thermal efficiency of up to 20%, the remaining energy is sent to the atmosphere
- Supply of oxygen and removal of carbon dioxide
- Removal of body heat dissipated by the occupants
- Removal of moisture dissipated by the occupants
- To provide sufficient air movement and air distribution in occupied space
- To maintain the purity of air by removing odor and dust.

TYPES OF VENTILATION SYSTEMS

1. NATURAL

a) Wind driven ventilation
b) Pressure driven flows
c) Stack vent / Stack effect

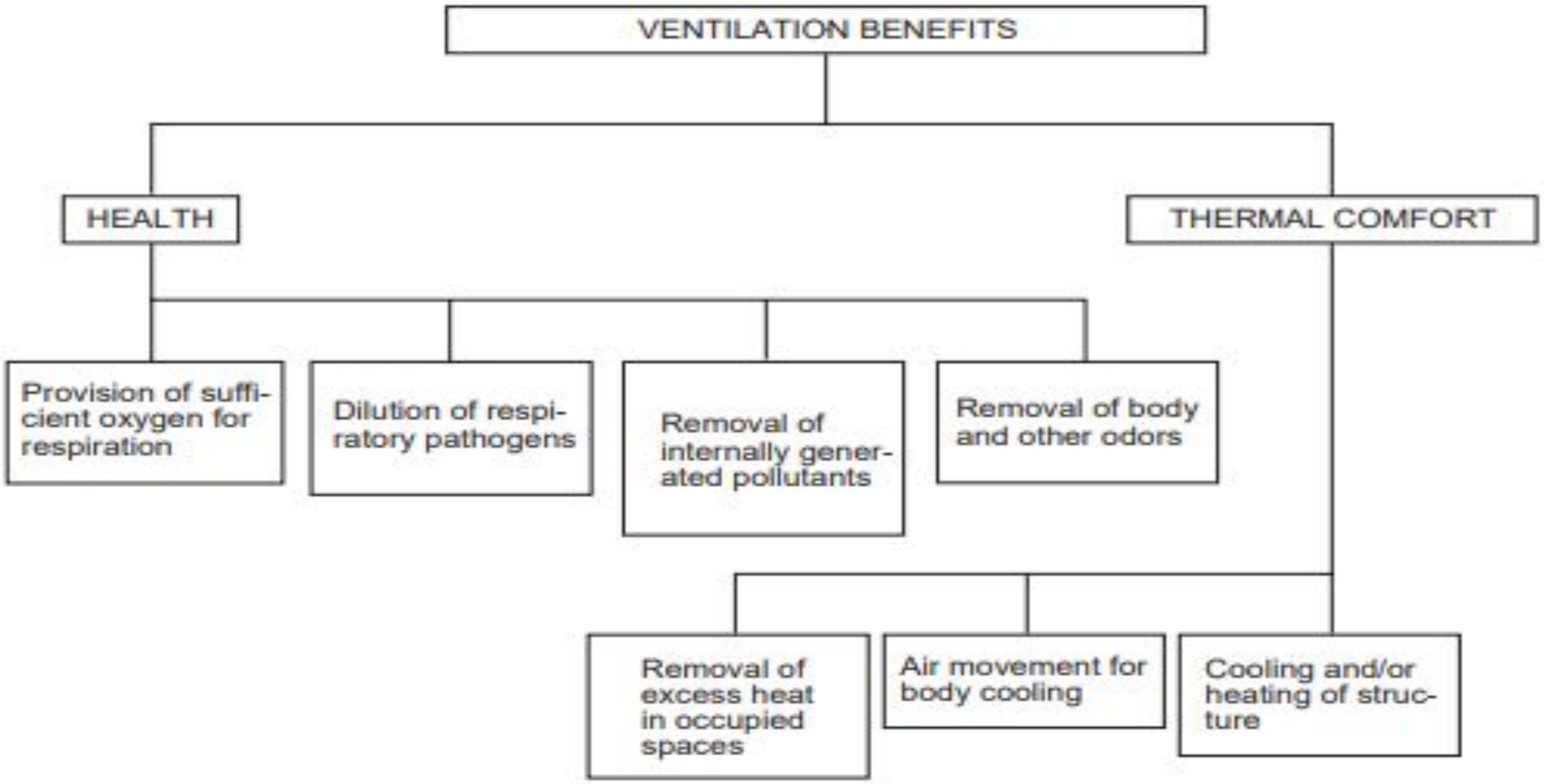
2. MECHANICAL

a) Natural inflow & outflow
b) Natural inflow & mechanical outflow
c) Mechanical inflow & natural outflow
d) Mechanical inflow & outflow

Advantage of Natural Ventilation

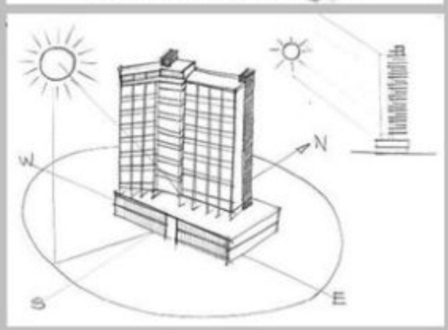
1. Does not require any mechanical appliances.
2. No operational cost.
3. No maintenance cost for the appliances/ equipment.
4. Silent processes.
5. Combination of ventilation and lighting which is additional benefit

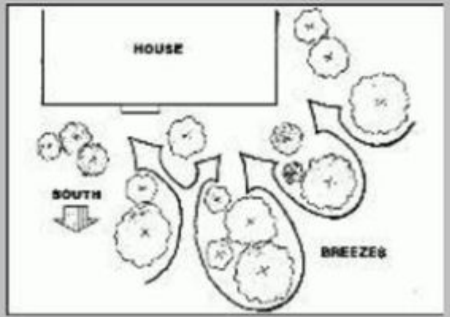
Benefits of ventilation



Natural ventilation depends on 6 factors:

1. Building orientation and shape
   – opening and air movement.
2. External elements
   – house surrounding/tree.
3. Cross ventilation
   – allow the air movement from one opening one opening…window, wall….
4. Opening location
5. Opening size
   – high and width of window, double door…
6. Opening control
   – types of opening : sliding/ram window
   - full / half opening…



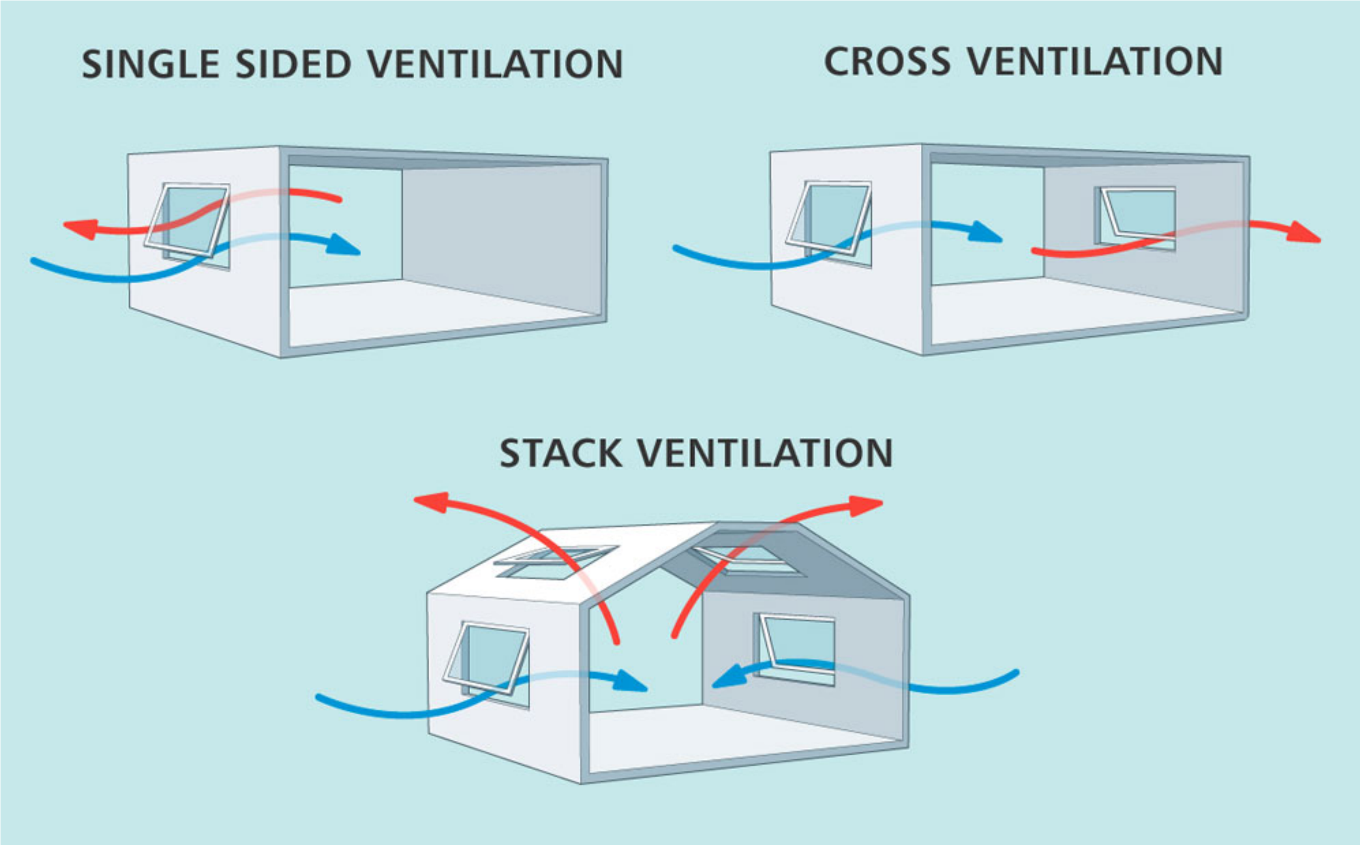


Natural ventilation is a method of supplying fresh air to a building or room by means of passive forces, typically by wind speed or differences in pressure internally and externally.

Natural ventilation relies on natural forces: wind from the surrounding environment as well as buoyancy forces that develop due to temperature gradients within the building.

The following points should be considered while providing natural ventilation in a room:

- Doors and windows should be so located that they provide maximum in-flow air.
- The height of the room should be sufficient to allow air movement.
- Inlet openings should not be obstructed.

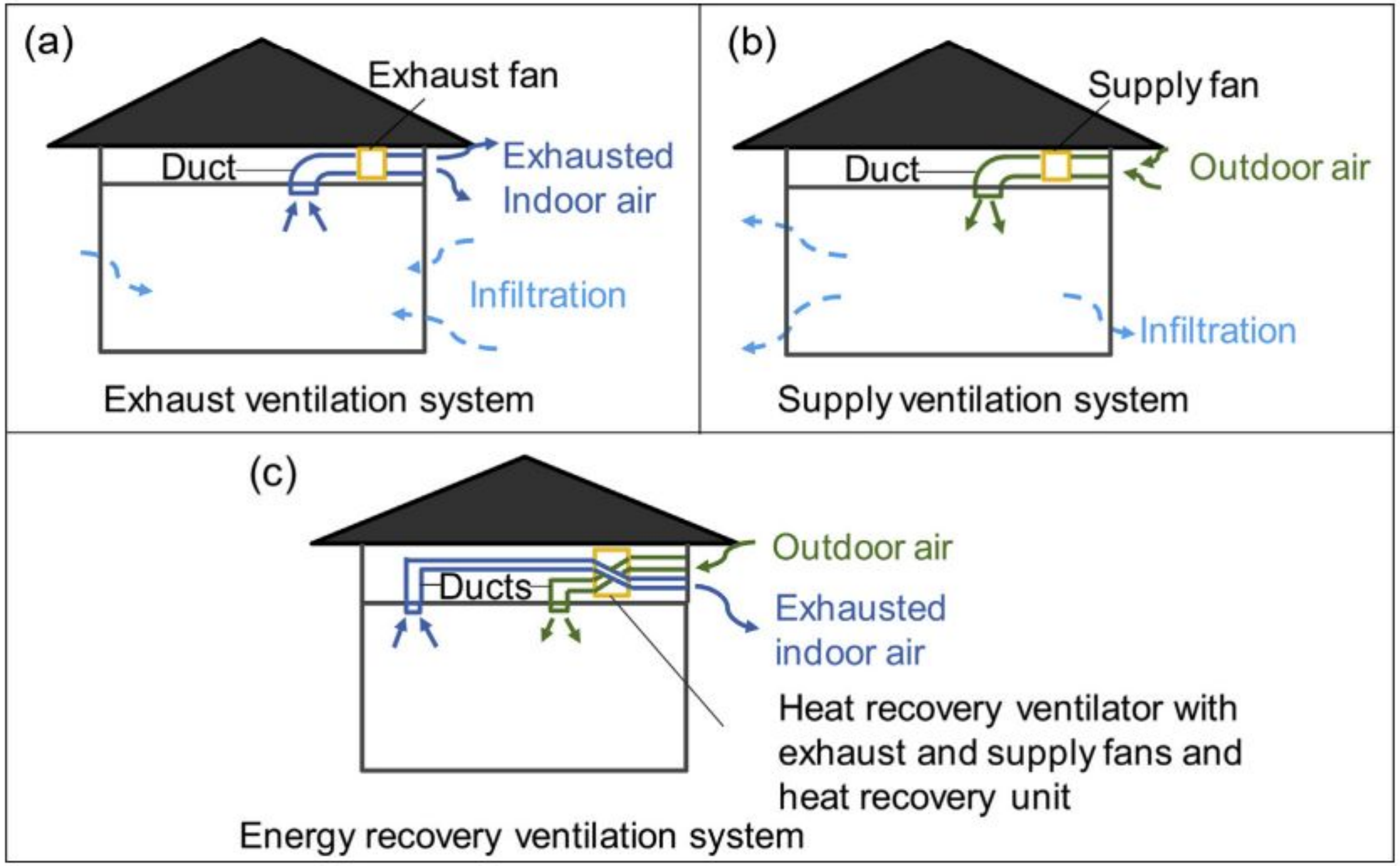


Single-side ventilation involves having openings only on one external wall and generally towards the wind direction. Air exchange happens through wind turbulence.

Cross ventilation, openings are located such that the ones at the receptive end allow maximum inflow of fresh air, and the outlet openings are placed such that the air gets circulated in the space efficiently and is pushed out with the inflow of fresh air.

Stack ventilation is based on the fact that cooler air is light in weight and hot and stale air is heavier. Receptive openings are given on the lower sides in the wind-ward directions and for an outlet, openings are given on the upper side.

Mechanical Ventilation/Artificial Ventilation:



Schematics of (a) supply ventilation system, (b) exhaust ventilation system, and (c) energy recovery ventilation system.

Exit by Exhaust Fan:

- In this method, the hot air of a room is thrown outside the room with the help of an exhaust fan, and the fresh air enters through the doors and windows.
- The exhaust fan should be set near the ceiling.

ii. Entrance by Exhaust Fan:

- In this method, a fan is set on the outer wall of the room. It pushes fresh air into the room and throws out the used hot air of the room through ventilators.
- These fans should be installed on the doors or windows at a height more than the head of a person.

An energy recovery ventilator (ERV) is a type of mechanical equipment that features a heat exchanger combined with a ventilation system for providing controlled ventilation into a building. This type of equipment was introduced as ‘air-to-air’ heat exchangers in the colder regions of the U.S., Canada, Europe, and Scandinavia. In these areas, tightly built modern houses were developing problems with indoor air quality and excessive humidity during the winter.

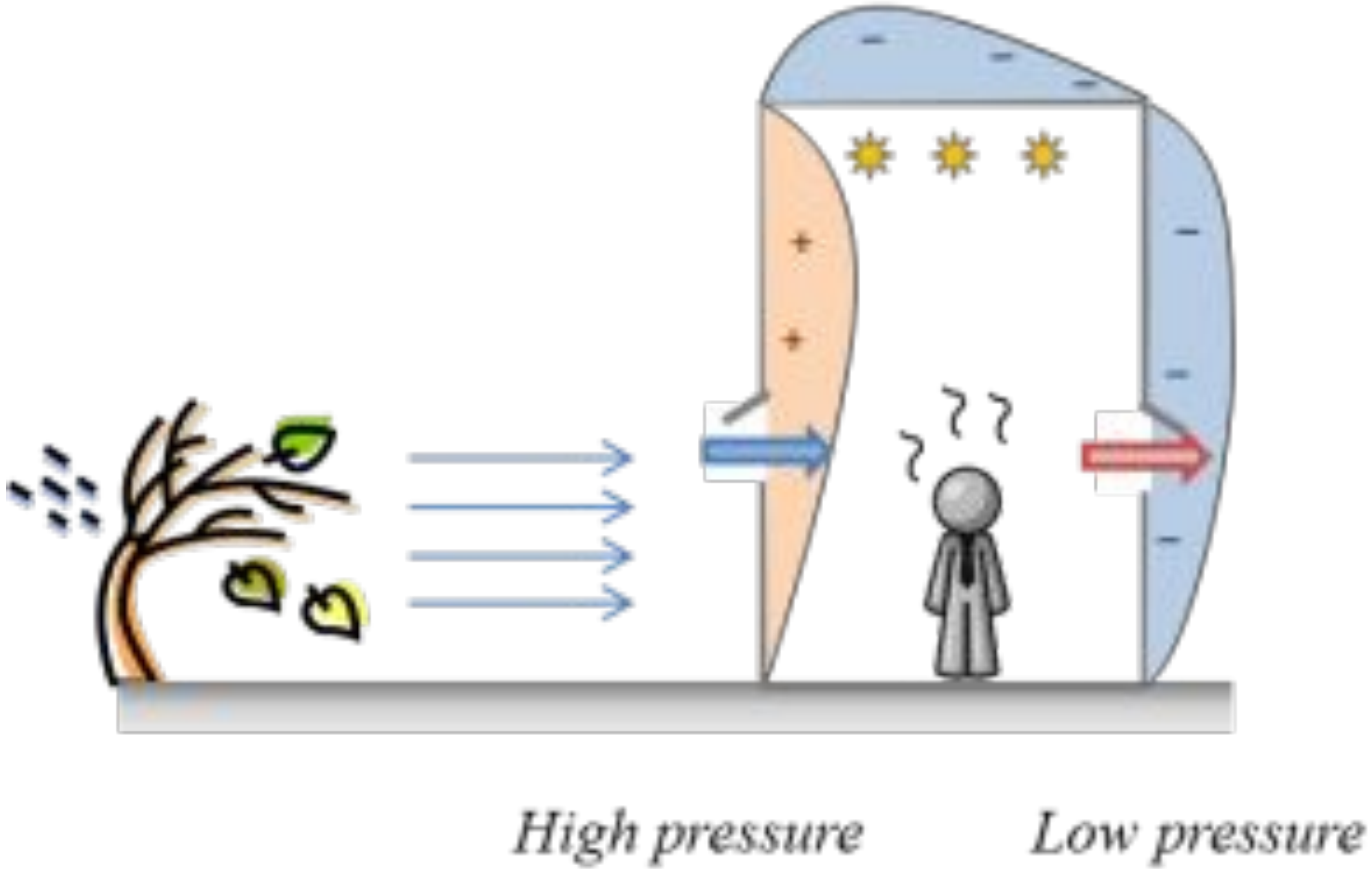
Requirements of ventilations

- Oxygen supply: human body converts chemical energy into mechanical energy and dissipates carbon dioxide.
- Each person requires 0.65 m^3 of oxygen per hour under normal condition and produces 0.2 m^3 of carbon dioxide.

CO_2 consumption is index of oxygen consumption.

- 2 % of CO_2 = difficult to breathe
- 6 % of CO_2 = extreme discomfort
- 10 % of CO_2 = unconsciousness

Ventilation



Stack ventilation in buildings

- Stack ventilation is an alternative design strategy that works based on the buoyancy of warm air to rise and exit through the openings located at ceiling height. Cooler outside area replaces the rising warm air through carefully designed inlets placed near the floor.