PHYSICS FOR CIVIL ENGINEERING – PH 8201

UNIT – I THERMAL PERFORMANCE BUILDINGS

Thermal performance of buildings is considered as one of the most important criteria to provide comfortable environment for occupants and minimizing the energy demand.

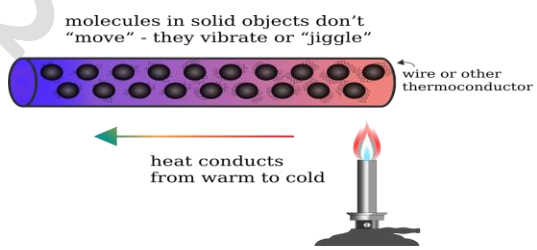
1. Heat Transfer

Heat transfer is the process of transfer of heat from high temperature zone to low temperature zone in three different modes of heat transfer.

- Conduction
- Convection
- Radiation

1.1 Conduction: Transfer of heat without any actual movement of particles. Here, the energy is transferred through adjacent molecules.

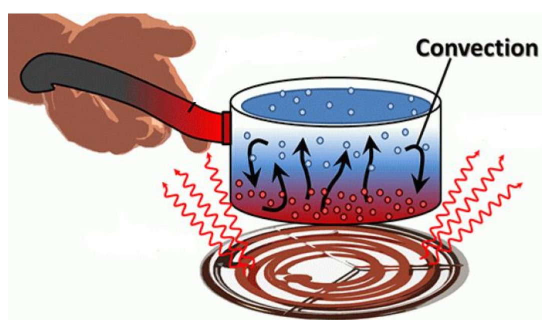
$$Q_{conduction} = \frac{KA(T_h - T_c)}{d}$$



Q – Amount of heat flow (w)
K – Thermal conductivity ($W/M^{-1}K^{-1}$)
A – Area of cross section (m^2)
T_h – Temperature of hot surface (k)
T_c – Temperature of cold surface (k)

1.2 Convection: Heat transfer through actual movement of particles due to the density variation in fluids.

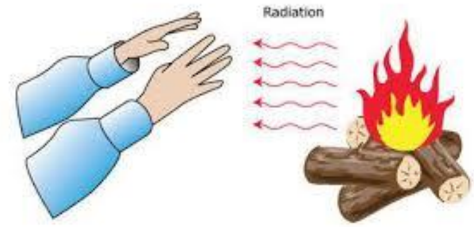
$$Q_{convection} = \left(hA(T_h - T_c)\right)$$



Q – Amount of heat flow (w)
h – Heat transfer Coefficient (W/M^{-2} - K)
A – Area of cross section (m^2)
T_h – Temperature of hot surface (k)
T_c – Temperature of cold surface (k)

1.3 Radiation: Heat transfer without any intervening medium is known as radiation.

$$Q_{Radiation12} = \left(\varepsilon_{eff} A\sigma(T_1^4 - T_2^4)\right)$$



Q_{12} – Amount of heat flow (w)

ε_{eff} – Effective emissivities

$$\varepsilon_{eff12} = \left(\frac{1}{\varepsilon_1} + (\frac{1}{\varepsilon_2} - 1)\right)$$

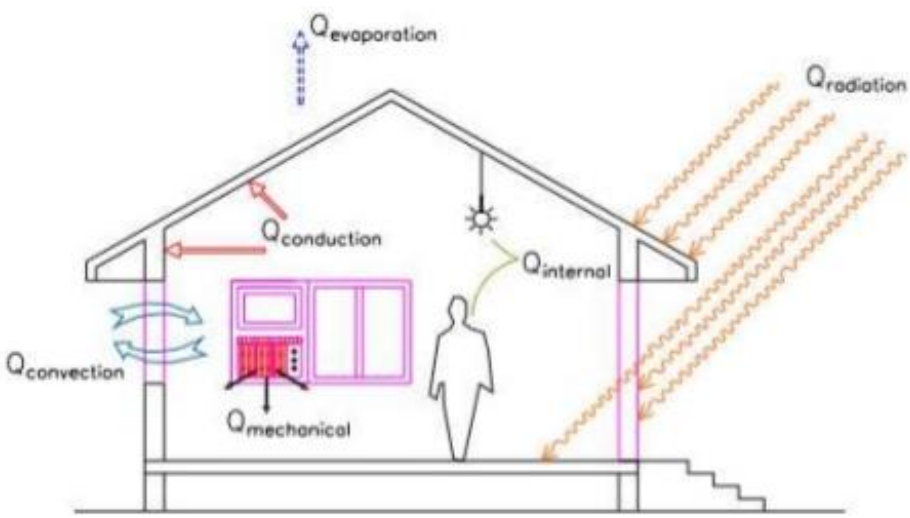
A – Area of cross section (m^2)

σ – Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^2-K^4)

T_1 – Temperature of hot surface (k)

T_2 – Temperature of cold surface (k)

In general heat exchange process between building and outer environment occurs in following ways



2. Heat gain and heat loss estimation

The Heat exchange is determined by the temperature difference between the two zones or areas considered. The greater the temperature difference, the faster the rate of heat flow. The equations and the calculations are valid only when both the out-door and indoor temperature are constant. Such static conditions do not occur in the nature, and hence the assumption of the steady state conditions is a simplification. Calculations based on steady state assumptions are useful to determine the maximum rate of heat loss or gain and also for establishing the cooling or heating load for mechanical installations

The **heat balance equation** is given as; $Qi + Qs +- Qc +- Qv +- Qm -Qe = 0$
(+ is gain. – is loss and +- is gain/loss)

Thermal balance i.e. the existing thermal condition is maintained if the sum of the above equation is zero. If the sum of this equation is less than zero (negative), the building will be cooling and if more than zero, the building temperature will increase

Q_i – Internal heat gain result from the heat output of human bodies, lamps, motors and other appliances
Q_s – Heat gain due to the effect of solar radiation on opaque surfaces.
Q_c – Conduction heat through the walls either inwards or outwards.
Q_v – Heat exchange takes place with the movement of air, i.e. ventilation.
Q_m - The heat flow rate of the mechanical systems subjected to the removal of heat or cooling as per the designer's intention. It can thus be taken as a dependent variable in the equation, i.e. it can be adjusted according to the balance of the other factors.
Q_e - If evaporation takes place on the surface of building (e.g. roof pool) or within the building (human sweat) the vapors are removed, this will produce a cooling effect, the rate of which is denoted as Qe

3. Fenestrations

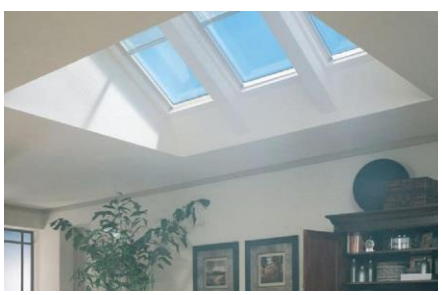
In architecture, any opening in a building's envelope such as windows, doors, curtain walls and skylights which are designed to permit the passage of air, light, vehicles or people are referred as fenestrations.

Fenestration systems

Glazing

Window

Curtain wall



Skylights

Exterior door

<u>**Fenestrations provides**</u>

- Day light, heat and outside air to the building
- Visual communication to the outside world
- Aesthetics to the building
- Escape routes in case of fires in low-rise buildings

Fenestrations affect buildings energy use through following mechanism;

- Thermal Heat Transfer
- Solar Heat gain
- Air leakage
- Day lighting

<u>4. Thermal insulation</u>

The process of reducing the heat transfer between the indoor and outdoor regions to protect the heat loss or entrance within the buildings by conduction, convection or radiation is known as thermal insulation. Thermal insulation can be done in *walls, doors and windows, floors and ceilings*.

Properties of thermal insulating material for buildings;

- Materials should be fire proof
- Should have low thermal conductivity
- Should be a poor absorber of moisture
- Should withstand for any environmental conditions
- Should be low cost
- Should be good looking

4.1 Benefits of thermal insulation

- Buildings that are thermally insulated remain warmer in winter and cooler in summer. Hence, thermally insulated building provides ***great comfort*** both in summer and winter.
- No need of air conditioning, cooler and heater etc. for maintaining the temperature inside the building which ***saves extra energy and cost***.
- Provision of thermal insulation ***prevents the formation of moisture, bacteria***, etc. on the envelope of buildings.
- Thermal insulation ***prevents the roof deck from cracking***
- ***Sound insulation*** is also achieved, while using fibrous insulation material for thermal insulation.
- Thermal insulation materials are ***environmental friendly*** and maintenance is not required

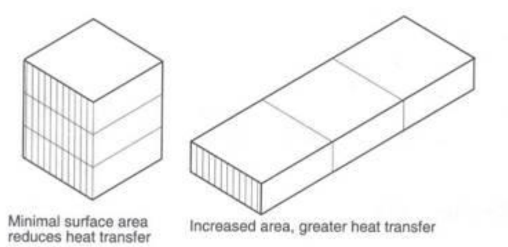
5. Factors affecting thermal performance of buildings

Thermal Performance of building is defined as "the process of modeling the energy transfer between a building and its environment". The factors affecting thermal performance of building are majorly classified as

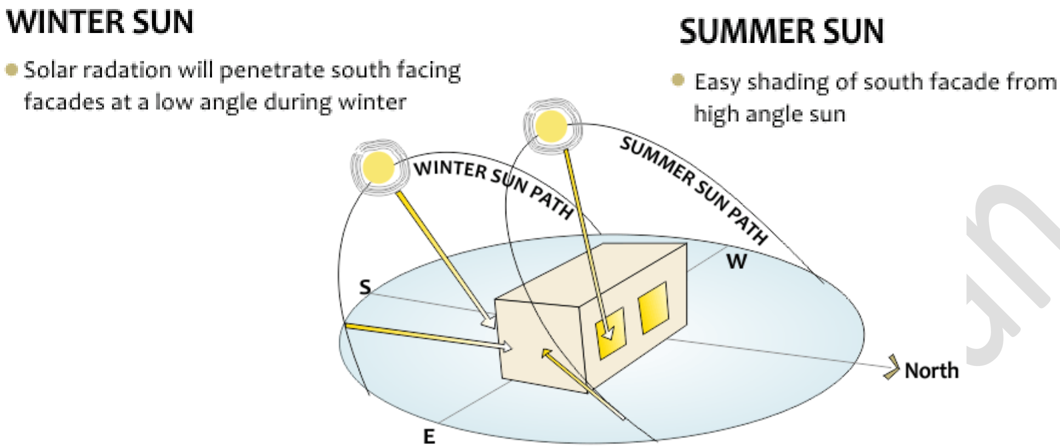
- Building design variables
- Material properties
- Climatic factors
- Building occupancy and operations

5.1 Building Design variables :

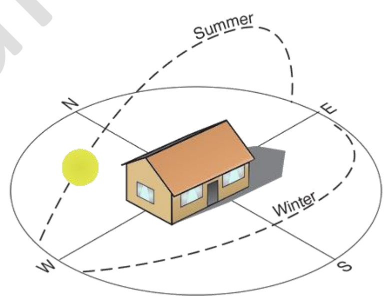
5.1.1 Building's Shape plays a vital role in determining the amount of solar radiation received by the building's surface. For example, small ratio of building ***surface to the volume*** is one of the main characteristic to maintain the thermal balance. Small S/V ratio implies minimum heat gain and heat loss.



5.1.2. Building Orientation is another important factor must be taken into consideration for better thermal performance of building. Orientation is the positioning of a building in relation to seasonal variations in the sun's path as well as prevailing wind patterns. Good orientation can increase the energy efficiency more comfortable to live.



Principles of good orientation



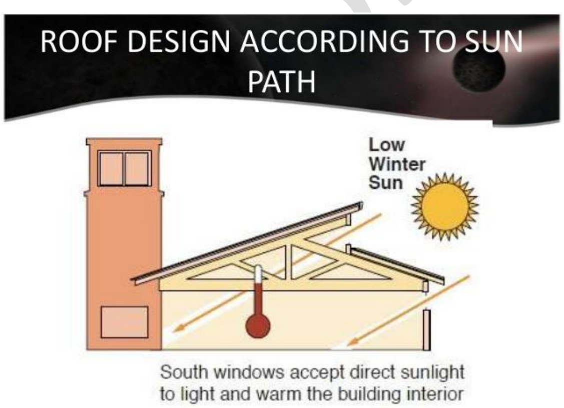
Summer Sun

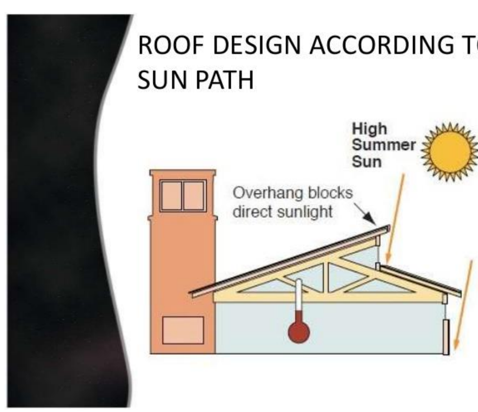
- Sun path is at high angle in north to E-W Axis
- Glare free day light is easily available on north façade as minimum solar radiation will fall at high angle
- Easy shading is possible in south façade due to high angle sun

Winter Sun

- Sun path is at low angle in south to E-W Axis
- Solar radiation will penetrate south facing façade a low angle during winter

East and west façade will receive uniform, strong solar radiation throughout the year





5.2. Material Properties:

Material properties of building components play an important role in controlling heat transfer. The most important thermal properties are;

- Thermal conductivity
- Thermal Resistivity
- Thermal Transmittance

5.2.1Thermal conductivity (K)

"Thermal conductivity is defined as the amount of heat flow in 1 m thick solid per unit time and unit area when the temperature gradient is 1k". If the value of thermal conductivity is less, then the thermal transmission will also be less

Basic equation of thermal conductivity is $$K = \frac{Qd}{(T_2 - T_1)tA}$$

Q – Amount of heat flow, d – Thickness of sample, A – Area of cross section, t – Time

5.2.2 Thermal Resistance (R)

Thermal Resistance of material is the resistance to heat flow between two surfaces at different temperatures.

Basic equation of thermal resistance is $$R = \frac{tA}{Q}$$

A – Area of cross section, Q – Amount of heat flow, t – Time.

5. 2.3 Thermal Transmittance (U)

It is obtained by reciprocating the total thermal resistance of the building component. $$U = \frac{1}{R}$$

5.3 Climatic factors

It is important to understand the general and microclimate of the region to achieve comfort and save energy

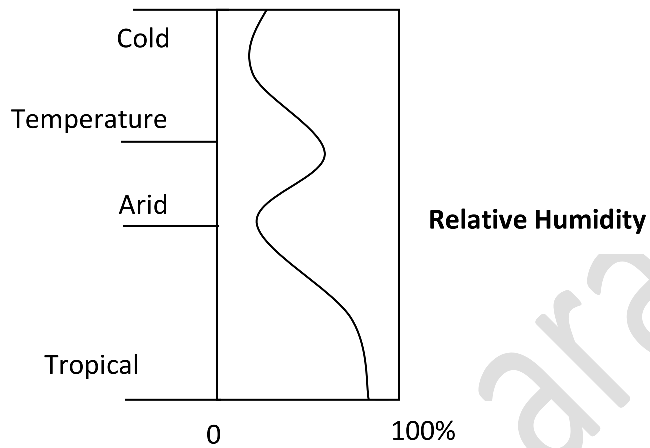
- Solar radiation
- Humidity
- Pressure, Wind etc.,

5.3.1 Solar radiation

It is defined as the ***"intensity of sun rays falling per unit time per unit area usually expressed in Watts per square meter"***. It consists of direct radiations, diffused radiation (through walls and surfaces) and reflected radiations (from ground, vegetations and adjacent buildings)

5.3.2 Humidity

Humidity is defined as the ***"ratio of density of water vapor in air to the standard density of water vapor at same temperature and pressure".*** Humidity differs according the climate conditions as shown below.



There are an inverse relationship between relative humidity and air temperature. It decreases as the air temperature rises. Humidity affects the rate of Respiration, evaporation which affects the ability of the body to dissipate heat at high ambient temperatures.

5.3.3 Pressure, Winds

Wind has a great influence of buildings design and their thermal performance. It affects the convective heat exchanges of a building envelope and the air infiltration. It's necessary to avoid the effect of winter wind which increases the infiltration heat loss and utilizing the summer wind in encouraging ventilation.

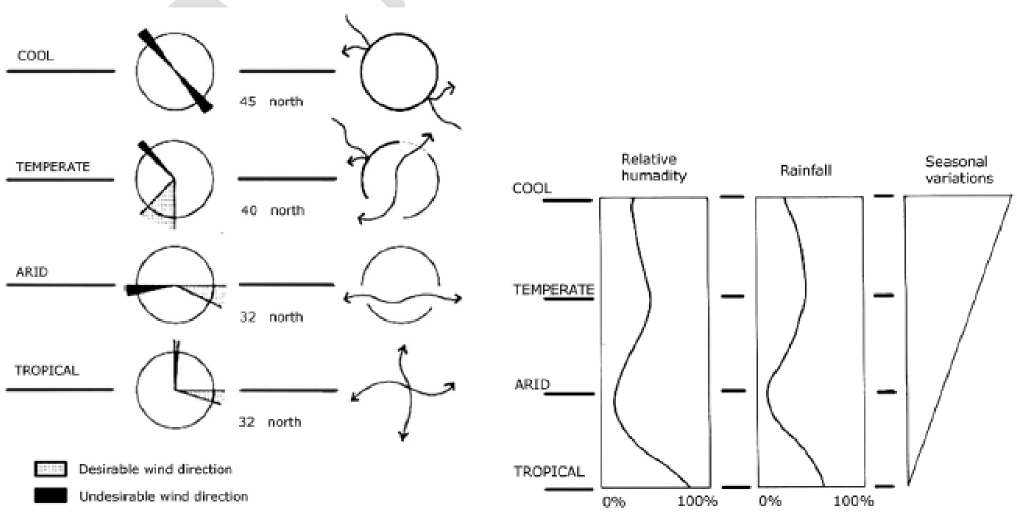
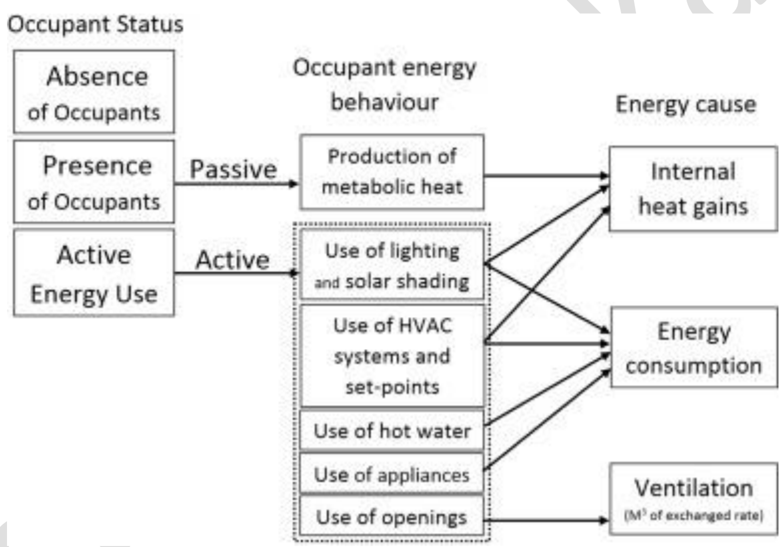


Figure 1. Desirable and Undesirable Wind Directions
Figure 2. Seasonal Variations

Formation of a strong pressure zone is inevitable in the direction of the wind. It is possible to increase or decrease the amount of this pressure by means of corridors created between buildings. While airflow is needed in hot and humid regions, shadowing measures should be taken in hot and dry regions. For this reason, direction of buildings is determined according to the angle of sunrays in some regions while planning is made according to the dominant wind directions in summer in some other regions. Determination of wind requirement differs in each climate region.

5.4 Occupancy and operations

Occupancy in a building and occupant activities (Operations) are the impacting factors for thermal performance of building. Occupancy results in heat gain due to the metabolisms and activities, and is associated with the use of the building systems, equipments and applicances. (e.g., lighthing, fan and motors) as shown below.



6.0 Thermal Comfort, indices and Measurements.

Thermal comfort is a condition of mind that expresses satisfaction with the thermal environment. To maintain the thermal comfort, heat generated must be equal to heat lost inside the building. Any heat gain or loss beyond this generates substantial discomfort. Measurement of thermal comfort levels are complex. Hence there has been several thermal comfort indices are used over years. These indices can be divided into;

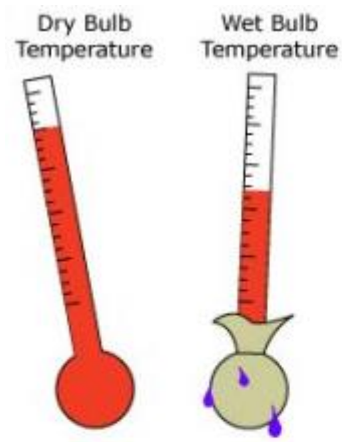
- Direct indices
- Derived Indices

6.1. Direct indices

The direct indices are the **Dry bulb Temperature (DBT)**, **Wet-bulb Temperature (WBT)**, **Humidity ratio (RH)**, **Globe Temperature (T_g),** and the **Mean Radiant Temperature (T_{mrt})**

- ***Dry-bulb temperature (DBT)*** is a measure of air temperature. It is referred as dry bulb temperature because the thermometer bulb is dry and so the temperature recorded does not vary with the moisture content of the air.

- ***Wet-bulb Temperature (WBT)*** is the temperature recorded by a thermometer that has its bulb wrapped in cloth and moistened with distilled water.



- The difference between Dry-bulb Temperature and Wet-bulb Temperature is related to the **Relative Humidity (RH)** of air

- **Globe temperature T_g** is the measure of temperature due to the combined effects of radiation, air temperature and air velocity. It is measured using a globe thermometer, a hollows copper sphere painted matt black to absorb variant heat with a temperature sensor at its centre.

- **Mean Radiant Temperature (T_{MRT})** is a measure of the average temperature of the surfaces that surround a particular point. It can be measured by using the following relation.

$$(T_{MRT})^4 = (Tg)^4 + CV^{\frac{1}{2}}[T_g - T_a]$$

Where,

T_g = Globe temperature, T_a = Ambient Dry Bulb Temperature, K

V = Air velocity in m/s, and C = A constant, 0.247 X 10^9

6.2. Derived indices

The derived indices combine two or more direct indices into a single factor. Important derived indices are the Effective temperature(ET) and Operative temperature(T_{OP}).

Effective temperature (ET):

This factor combines the effects of dry bulb temperature and air humidity into a single factor. It is defined as the temperature of the environment at 50% RH.

Operative temperature (T_{op}):

This factor is a weighted average of air DBT and T_{mrt} into a single factor. It is given by;

$$T_{OP} = \frac{T_{MRT} + T_{DBT}}{2}$$

The operating temperature for winter and summer zones required for thermal comfort are as follows; **In winter zone**

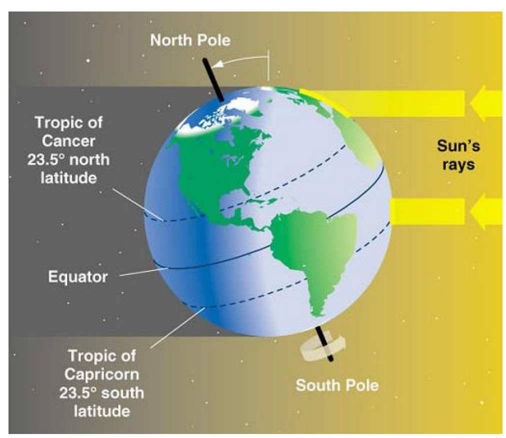
T_{op} between 20.0 to 23.5 °C at RH of 60%

In summer zone

T_{op} between 20.5 to 26.0 °C at RH of 60%

7. Climate and solar deign

Weather is the day-to-day state of the atmosphere, and its short-term variation generally in minutes to weeks. **Climate** is the weather of a place averaged over a period of time, often in 30 years. Climate responsive architecture is highly essential to design comfortable and energy efficient homes. Solar radiation plays a major role for the heat gain in buildings as well as the climatic changes. Due to the tilted position of sun, the area receiving the maximum intensity moves north and south between the tropic of cancer and the tropic Capricorn. This is the main cause of seasonal changes.



According to the thermal performance of buildings the different climate zones are

- Hot and Dry
- Warm and Humid
- Moderate
- Cold and Cloudy
- Cold and Sunny

Hot and dry

Main characteristic

- Low ground water level
- Much cooler at night than during the day

Design

- Longer walls facing north and south so that the building gets minimum solar exposure.

Warm and Humid

Main characteristic

- High humidity with high temperatures
- Vegetations are abundant in these regions

Design

- Employ light weight construction
- Height of the building should not exceed 3- storeys because height buildings receive too much radiation and obstruct wind to neighboring buildings.

Moderate

Main characteristic

- Solar radiation is almost same throughout the year.
- Generally located on hilly or high plateau regions

Design

- Heat lost will be promoted by using ventilation by providing windows, exhausts etc.

Cold and cloudy climate

Main characteristic

- Low precipitation and variation in temperature between day and night

Design

- Windows should be faced south to facilitate direct gain.
- North side of the building should be well insulated

Cold and Sunny climate

Main characteristic

Design

- During building construction, the north side of the building has been designed with solid walls in order to eliminate heat loss, while the south side has been designed to maximize solar penetration.

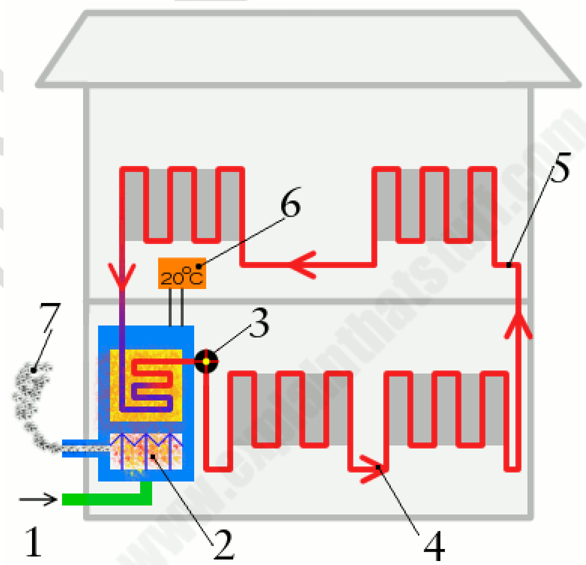
8. Central Heating

Central heating system provides warmth to the various rooms and spaces throughout the building from one point.

Principle

Natural gas is heated through a boiler and the heat is transferred from gas to water and transported to various places of the building. The heat radiated from the tube maintains the room as warm.

Construction



1. Heat inlet
2. Gas chamber
3. Pumping motor
4. Radiator coil
5. Interior radiator coil
6. Temperature measurement
7. Natural gas inlet

Working

- Natural gas enters the pipe is heated inside a boiler. .
- Heat energy from the gas is transferred to the water.
- An electric pump pushes the heated water from the boiler to the radiator coil.
- The water flows around the radiator, entering at one side and leaving at the other side of the building.
- Water acts as a heat-transporting device that picks up heat from the gas in the boiler and drops it off at various places of building through the radiator.
- The pump is powerful enough to push the water upstairs through the radiators.
- Thermostat mounted in room monitors the temperature and switches the boiler off when it's hot enough and switching the boiler back on again when the room gets too cold.
- The water is permanently sealed inside the system (unless it is drained for maintenance)

- Waste gases from the boiler leave through a small smokestack called a flue and dispersed to the air

Advantages

- Electrical energy used for heating can substantially reduced
- Requires less maintenance

Disadvantages

Different methodologies should be adopted for different shapes and size of the buildings