LECTURE NOTES ON

RENEWABLE ENERGY SOURCES

6TH SEMESTER ETC

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CHAPTER – 1

ENERGY SITUATION AND RENEWABLE ENERGY SOURCES

- Energy plays a very important role in our lives, providing comfort, increasing productivity and allowing us to live the way we want to. Since the beginning of mankind, we have made use of wood, water, and fossil fuels as a means of heating and making machines work. Almost for all types of activities, we rely on one or another form of energy.
- Amount of energy used by a society is an indicator of its economic growth and development. Without energy even our body would be unable to perform basic functions like respiratory, circulatory, or digestive functions to name a few. Plants would also be unable to complete the process of converting Carbon dioxide, water and minerals into food without the light from the Sun.
- Almost all the machines used for the production and manufacture of different types of items would be unable to operate without the use of a source of electrical energy.
- Almost everything we see around us, the clothes we wear, the food we eat, the houses we live in, the paper we write on, the vehicles we drive, all need energy to be created or transformed from some natural resource to the final product.
- Nowadays, the electrical energy has become so important that almost in all walks of life electricity is required.
- For example all electrical appliances in our homes and at our workplace require electricity. All the industries and factories run on electricity.

1.1- Renewable and Non-renewable Energy

- In simple terms we can say that anything out of which usable energy can be extracted is a source of energy. There is a variety of sources that provide us energy for different purposes. You must be familiar with coal, petrol, diesel kerosene and natural gas which are called fossil fuel.

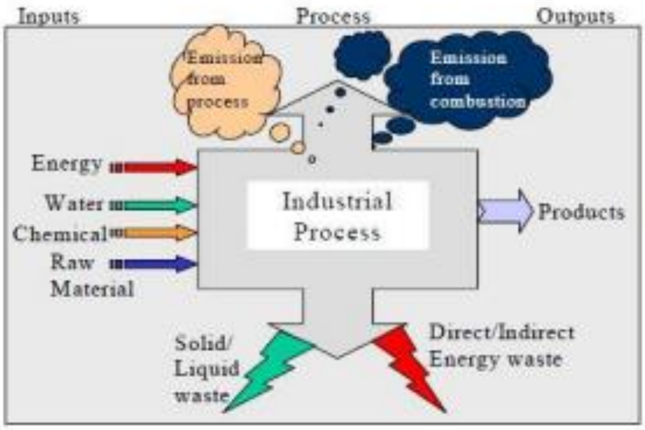
- In general Energy is classified into two categories:

a) Conventional Energy Source (Non-Renewable energy)
b) Non-Conventional Energy Source (Renewable energy)

An energy sources that will run out or will not be replenished for thousands or even millions of years called **conventional energy or non-renewable energy**. Most sources of non-renewable energy are fossil fuels Coal, wood, petroleum product, natural gas etc.

Features of comparision	***Renewable energy supplies***	***Nonrenewable energy supplies***
Examples	Wind, solar, biomass, tidal etc.	Coal, oil, gas etc.
Source	Natural local environment	Concentrated stock
Normal state	A current of energy	Static store of energy
Life time of supply	Infinite	Finite
Cost at source	Free	Increasingly expensive
Location for use	Site and society specific	General and international use
Scale	Small scale, economic, large scale may present difficulties	Increased scale often improves supply costs, large scale frequently favored
Skills	Interdisciplinary and varied wide range of skills	Strong links with electrical and mechanical engineering. Narrow range of skill
Context	Rural, decentralized industry	Urban, centralized industry
Dependence	Self-sufficient system encouraged	Systems dependent on outside inputs
Pollution and environmental damage	Usually little environmental harm, especially at moderate scale. Hazards Wind, solar, biomass, tidal etc. from excessive wood burning, soil erosion from excessive biofuel use, large hydro reservoirs disruptive	Environmental pollution common, and especially of air and water Deforestation and ecological sterilization from excessive air pollution
Safety	Local hazards possible in operation, usually safe when out of action	May be shielded and enclosed to lessen great potential danger

1.2- Energy and Environment



- Non-renewable resources such as coal and petroleum cause more harm to the environment when compared to renewable resources in the form of air and water pollution, the generation of toxic wastes, etc.
- Coal gives out sulfur as emissions that harm the trees. The process of coal mining results in the production of acid mine drainage, whereby heavy metals dissolve and infiltrate into the ground and surface water. The process may entail the displacement of vast quantities of topsoil, ultimately resulting in erosion, habitat degradation, and pollution.
- Oil production and usage result in releasing the poisonous carbon oxides into the air. An oil spill refers to the release of petroleum into a vast water body, resulting in significant economic and ecological issues. The presence of oil on the ocean's surface hinders the penetration of sunlight and decreases the level of dissolved oxygen, thereby endangering various forms of aquatic life. Additionally, crude oil damages the insulating and waterproofing abilities of feathers and fur, which can cause oil-covered marine animals and birds to suffer from hypothermia and perish.
- Even renewable resources are not completely eco-friendly. The generation of energy from the wind, the sun, tides, etc., also creates harmful environmental impacts and affects biodiversity to a significant level.
- The exhausts from natural gas release nitrogen and even methane oxides, which affect people and animals that use water from the affected water bodies. The burning of fossil fuels results in the emission of significant quantities of carbon dioxide, a greenhouse gas, into the atmosphere. These gases have the ability to trap heat in the atmosphere, which ultimately leads to global warming.
- Biomass also results in the generation of harmful gases. Ash created on burning biomass is another unwanted waste that causes disposal issues due to its lead and cadmium content.
- Manufacturing photovoltaic (PV) cells produce toxic chemicals.
- Although hydropower does not cause air or water pollution, it severely impacts the fish population. It causes the relocation of the people and animals living near the dam sites. Moreover, it changes the water temperature.

  Thus, all energy resources have an impact on the environment. There is no such thing as a 'clean' source of energy. The consolation is that renewable resources cause lesser environmental impacts than non-renewable resources of energy. Research is still on for the development of resources that are long-lasting and have minimal environmental impacts.

1.3- Origin of Renewable energy sources

The most popular renewable energy sources currently are:

- Solar energy
- Wind energy

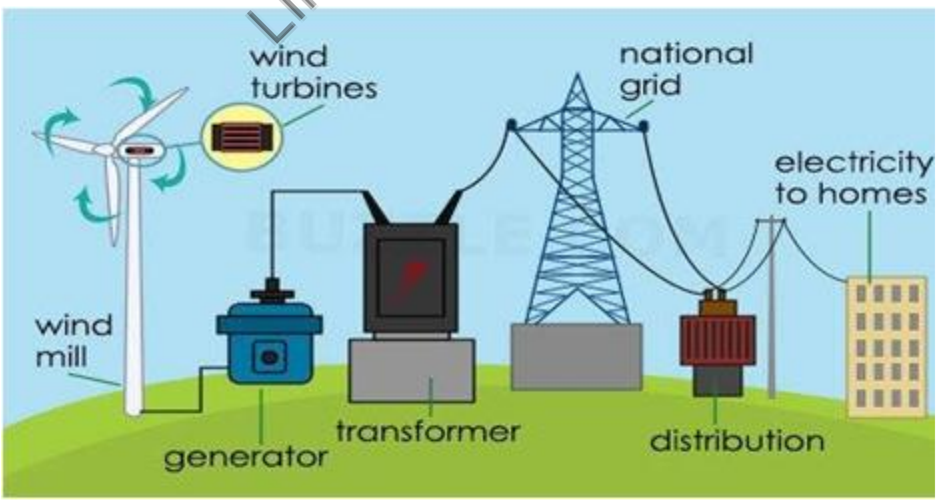
- Hydro energy
- Tidal energy
- Geothermal energy
- Biomass energy

1) Solar Energy:

Sunlight is one of our planet's most abundant and freely available energy resources. The amount of solar energy that reaches the earth's surface in one hour is more than the planet's total energy requirements for a whole year. Although it sounds like a perfect renewable energy source, the amount of solar energy we can use varies according to the time of day and the season of the year as well as geographical location. In the UK, solar energy is an increasingly popular way to supplement your energy usage.

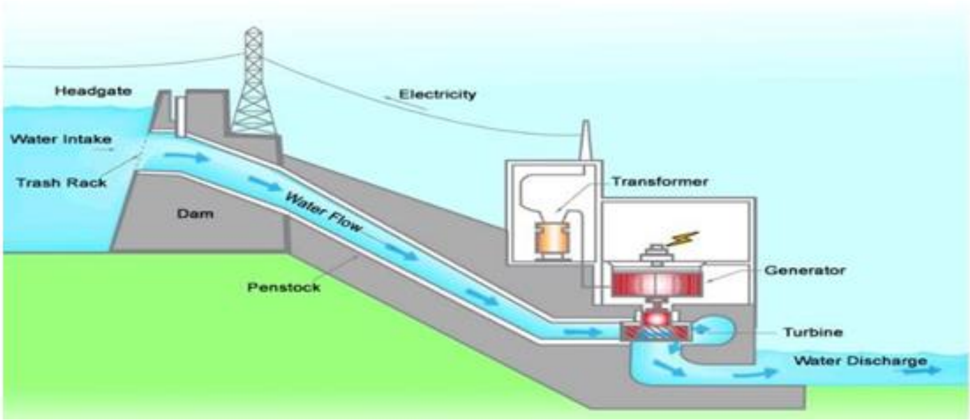
2) Wind Energy:

Wind is a plentiful source of clean energy. Wind farms are an increasingly familiar sight in the UK with wind power making an ever-increasing contribution to the National Grid. To harness electricity from wind energy, turbines are used to drive generators which then feed electricity into the National Grid. Although domestic or off-grid' generation systems are available, not every property is suitable for a domestic wind turbine.



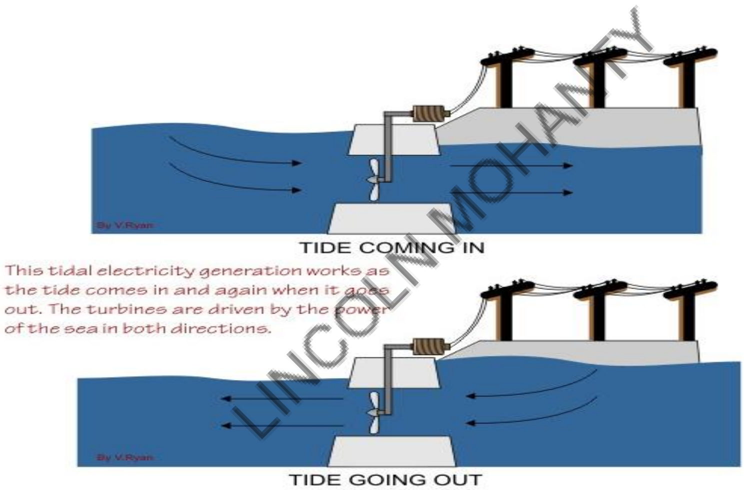
3) Hydro Energy:

As a renewable energy resource, hydro power is one of the most commercially developed. By building a dam or barrier, a large reservoir can be used to create a controlled flow of water that will drive a turbine, generating electricity. This energy source can often be more reliable than solar or wind power (especially if it's tidal rather than river) and also allows electricity to be stored for use when demand reaches a peak. Like wind energy, in certain situations hydro can be more viableas a commercial energy source (dependent on type and compared to other sources of energy) but depending very much on the type of property, it can be used for domestic, ‘off-grid’ generation.



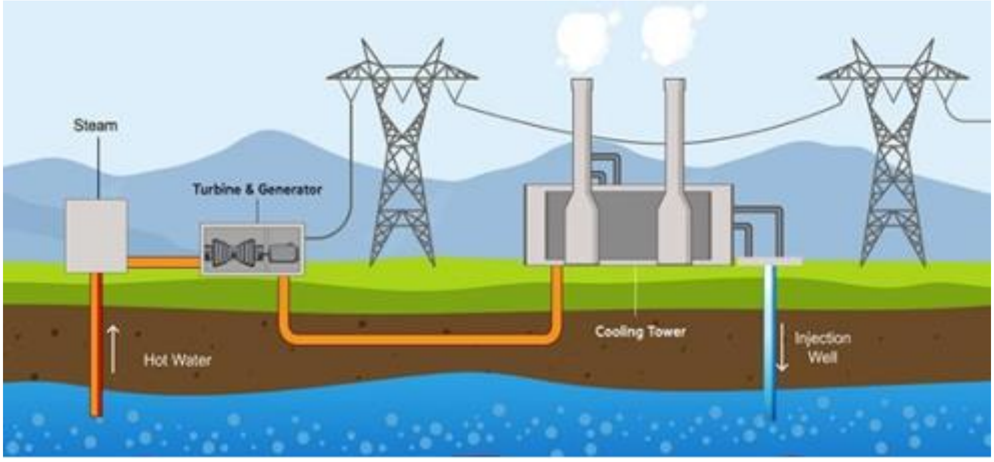
4) Tidal energy:

This is another form of hydro energy that uses twice-daily tidal currents to drive turbine generators. Although tidal flow unlike some other hydro energy sources isn’t constant, it is highly predictable and can therefore compensate for the periods when the tide current is low.



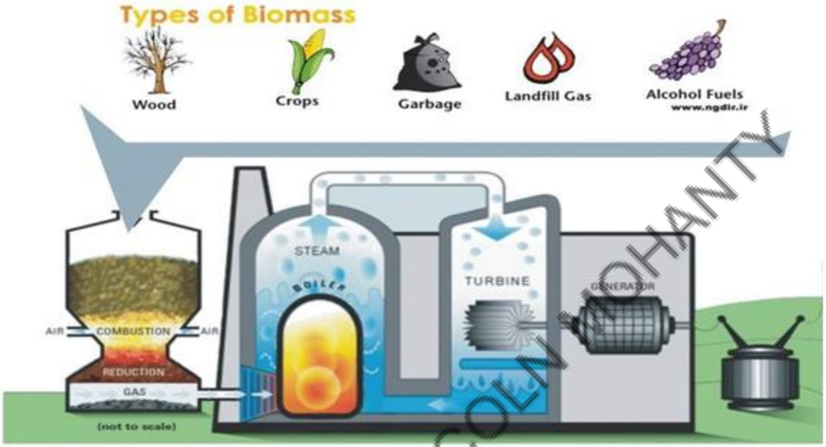
5) Geothermal energy:

By harnessing the natural heat below the earth’s surface, geothermal energy can be used to heat homes directly or to generate electricity. Although it harnesses a power directly below our feet, geothermal energy is of negligible importance in the UK compared to countries such as Iceland, where geothermal heat is much more freely available.



6) Biomass Energy:

This is the conversion of solid fuel made from plant materials into electricity. Although fundamentally, biomass involves burning organic materials to produce electricity, and nowadays this is a much cleaner, more energy-efficient process. By converting agricultural, industrial and domestic waste into solid, liquid and gas fuel, biomass generates power at a much lower economicand environmental cost.



1.4 Potential of Renewable Energy Sources:

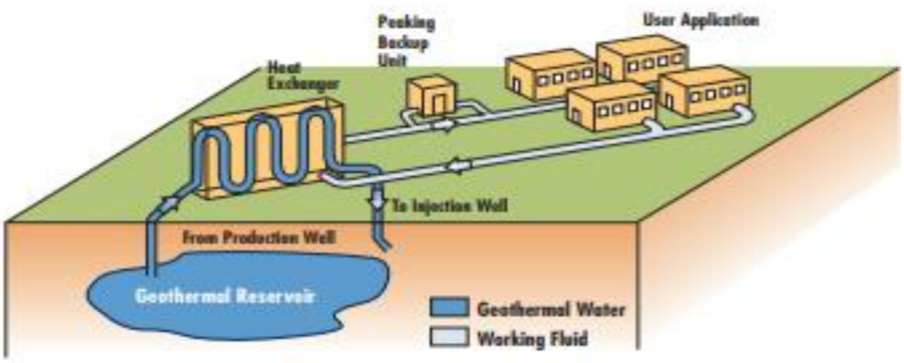
The relevance of the increasing use of renewable energy sources in the transition to a sustainable energy base was recognised in India even in the early 1970s. Since the early 1980s, a significant thrust has been given to the development, trial and induction of a variety of renewable energy technologies for use in different sectors. To begin with, the endeavours were steered and overseen by the Commission for Additional Sources of Energy (CASE) set up in 1981. In 1982, a separate Department of Non-Conventional Energy Sources (DNES) was created in the Ministry of Energy and was entrusted with the charge of promoting nonconventional energy sources. A decade later, this was upgraded and thus MNES (Ministry of Non-Conventional Energy Sources) started funding as a separate Ministry from 1992 to develop all areas of renewable energy. As per its mandate, the MNES has been implementing a broad-based programme covering the whole spectrum of renewable energy technologies. The aim of the programme is to (a) increase me share of renewables in the overall installed capacity power generation (b) meet the energy needs of rural and remote areas for a variety of applications (c) minimize the drudgery and health hazards faced by rural women in following the age-old practice of cooking with fuel-wood collected from long distances and in traditional chulhas which emit a lot of smoke and (d) extract energy from urban and industrial waste besides chemical, ocean and geothermal sources. The underlying idea of the programme is not to substitute but to supplement the conventional energy generation in meeting the basic energy needs of the community at large. Current Status The national programmes in different areas of renewable energy sector have resulted not only in generation of public awareness about the advantages of renewable energy but also in a visible increase in the deployment of renewable energy systems and devices for varied applications. Consequently, the contribution of renewable energy to total installed capacity of power generation has been progressively rising. As on October, 2003, the contribution of renewables has reached 4132 MW, representing about 4% of total grid capacity, as compared to 2414 MW on October 1999. Almost all the areas namely solar, wind, biomass, small hydro and urban as well as industrial waste have contributed to the satisfactory achievement of renewable energy sources in the country. With a wind power capacity of 2000 MW, India now ranks fifth in the world. Small hydropower generation, which is particularly suitable for remote and hilly regions, is being expanded. India is the largest producer of cane sugar and the world's largest bagasse based co-generation programme is being implemented in the sugar mills. There is also considerable scope for extracting energy from urban and industrial wastes. The programmes to meet the rural energy needs are the National Project on Biogas Development (NPBD) and the National Programme on Improved Chulhas (NPIC). The NPBD aims at harnesing the fuel value of the cattle dung, human waste and non-woody organic wastes without losing their manurial value and minimising the drudgery of rural woman in walking long distances to collect fuel wood. The objective of NPIC is to improve efficiency of biomass fuels without indoor air pollution. Rapid urbanisation and industrialization have led to generation of huge quantities of wastes, which are rich sources of energy. Under the National Programme on Energy Recovery from urban, municipal and industrial wastes, promotion and development of projects leased on appropriate conversion technologies such as biomethanation, gasification, palletisation and land fills is being undertaken. This programme aims at harnessing the estimated power generation potential of about 1000 MW from urban and municipal wastes and about 700 MW from industrial wastes. Projects with an aggregate capacity of 26 MWe have been completed.

1.5 Direct-use Technology

Direct use equals smart use. Direct use of geothermal resources is the use of underground hot water to heat buildings, grow plants in greenhouses, dehydrate onions and garlic, heat water for fish farming, pasteurize milk, and for many other applications. Some cities pipe the hot water under roads and sidewalks to melt snow. District heating applications use networks of piped hot water to heat buildings in whole communities.

Direct-use systems are typically composed of three components:

• A production facility – usually a well – to bring the hot water to the surface;
• A mechanical system – piping, heat exchanger, controls – to deliver the heat to the space or process;
• A disposal system – injection well, storage pond, or river – to receive the cooled geothermal fluid.



Graphical representation of a geothermal district-heating system.

CHAPTER – 2

SOLAR RADIATION COLLECTOR:

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies. However, the technical feasibility and economical operation of these technologies at a specific location depends on the available solar resource.

2.1. Solar Radiation Through Atmosphere:

As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by:

- Air molecules
- Water vapor
- Clouds
- Dust
- Pollutants
- Forest fires
- Volcanoes.

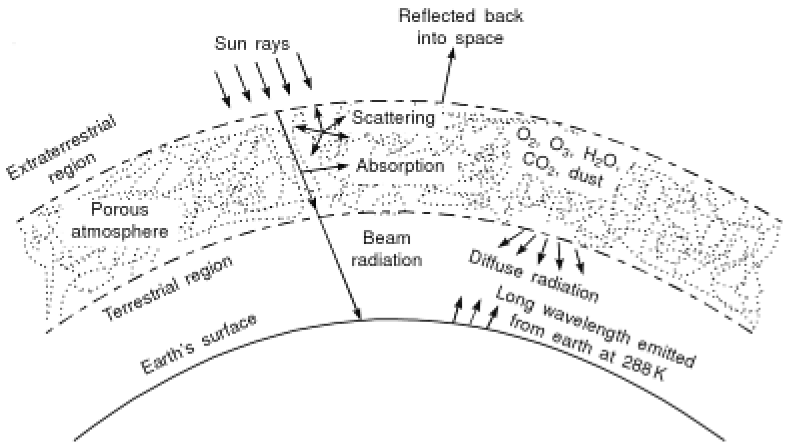
This is called *diffuse solar radiation*. The solar radiation that reaches the Earth's surface without being diffused is called *direct beam solar radiation*. The sum of the diffuse and direct solar radiation is called *global solar radiation*. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

DISTRIBUTION

The solar resource across the United States is ample for photovoltaic (PV) systems because they use both direct and scattered sunlight. Other technologies may be more limited. However, the amount of power generated by any solar technology at a particular site depends on how much of the sun's energy reaches it. Thus, solar technologies function most efficiently in the southwestern United States, which receives the greatest amount of solar energy.

2.2.Terrestrial Solar Radiation

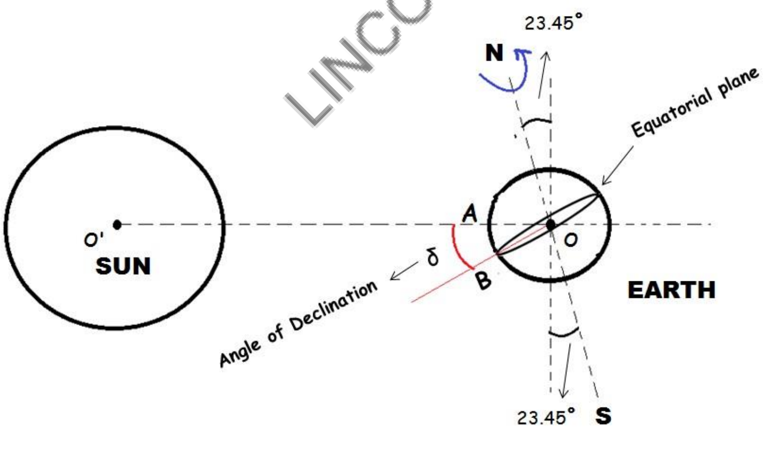
Terrestrial Radiation is the thermal radiation of the earth’s surface. Since the surface of the earth has a comparatively low temperature, it radiates electromagnetic waves with wavelengths of 380 microns, which fall into the infrared portion of the spectrum, which is invisible to the eye. The surface of the earth cools down because of its intrinsic radiation. The flow of intrinsic radiation of the surface of the earth is directed upward and is absorbed almost entirely by the atmosphere, thus heating it. The atmosphere, in turn, sends counter radiation toward the surface of the earth (atmospheric counter-radiation) at approximately the same wavelengths, which partially compensates for the loss of heat by the surface of the earth as a result of its intrinsic radiation. The difference between the radiation of the surface of the earth and the counter-radiation is called the effective radiation. On clear nights the counter-radiation decreases and the effective radiation increases; therefore, the surface of the earth is cooled abruptly and the lower layers of the air are cooled by it. In the process fog or dew may occur, and in the spring and fall, there may be frosts. On cloudy nights, on the other hand, the counter-radiation increases because of the radiation of the clouds, and the effective radiation and cooling of the surface of the earth are reduced. During the day the surface of the earth also receives solar radiation in addition to the counter-radiation. Together they exceed terrestrial radiation for most of the day (during the warm part of the year in moderate latitudes), and the surface of the earth heats up. Terrestrial radiation is one of the most important factors determining the thermal conditions of the surface of the earth and of the atmosphere.



- It is the electromagnetic radiation which originates from earth and its atmosphere.
- Terrestrial Radiation is a longer wavelength which is totally infrared.
- When the terrestrial solar radiation reaches the earth's surface, it is broken into two components i.e., diffuse radiation and beam radiation.
- Beam Radiation is the solar radiation which moves through the atmosphere in a straight line without being scattered, reflected or absorbed by particles in the air.
- Diffuse Radiation is the solar radiation which is being scattered, reflected or absorbed by the particles while passing through the atmosphere but ultimately reaches the earth's surface.

Azimuth angle, Zenith angle, Hour angle, Irradiance, Solar constant:

- **Angle of Declination (δ):** It is the angle between the line extending from the centre ofSUN to the centre of the EARTH and the projection of this line upon equatorial plane.

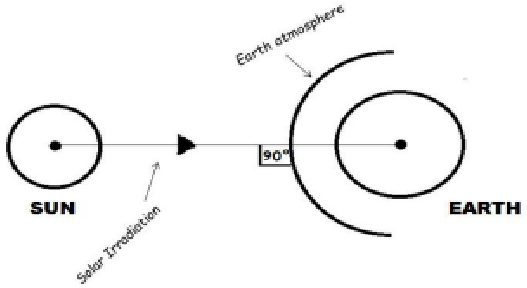


Where OB = Projection of OA line on equatorial plane

$\angle AOB = \delta$

The angle of Declination is given as, $\delta = 23.45^\circ \sin\left[\frac{360^\circ}{365\,days} \times (284 + n)\right]$, where n = no. of Days.

- **Solar Constant** (I_{SC})**:** The rate at which energy received from the SUN on the EARTH atmosphere in perpendicular direction is known as Solar constant.

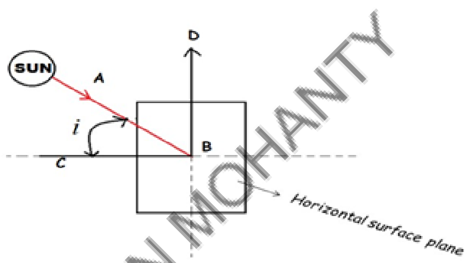


The solar constant (I_{sc}) value varies from **1344 w/m² to 1412 w/m²**. The average value of Solar constant is **1367 w/m²**.

I_{sc}' = Solar constant at a particular day

$$I_{sc}' = I_{sc}\left[1 + \left(0.033 \times \cos\left(\frac{360^{\circ}}{365 days} \times n\right)\right)\right]$$

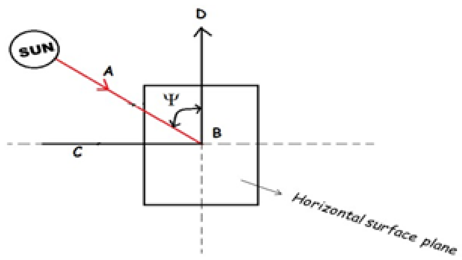
- **Inclination angle** (*i*)**:** The angle between the SUN ray and its projection on the horizontal plane is known as Inclination angle.



Sun ray $\rightarrow AB$

$\angle ABC = i$. It is also called as angle of altitude.

- **Zenith angle (Ψ):** The angle between the SUN ray's and perpendicular to the horizontal plane is known as Zenith angle.

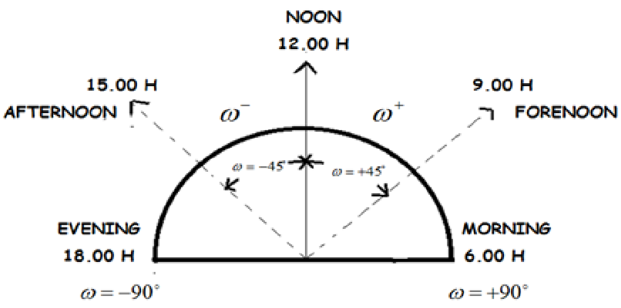


$\angle ABD = \Psi =$ Zenith angle, $i + \Psi = 90^{\circ}$ or, $\Psi = 90^{\circ} - i$

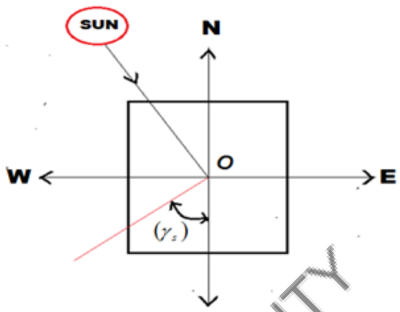
- **Hour angle :** It is the angle through which the earth must be rotated to bring the meridian of a point directly in line with the sunray.

  OR,

  It is the angle representing the position of the SUN w.r.t. clock hour and with reference to SUN's position at 12:00 noon.



- **Solar Azimuth angle** (γ_s) **:** It is the angle on a horizontal plane between the line due south and the projection of the SUN's ray on the horizontal plane.



- **Irradiance:** Irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface. ... In the case of solar irradiance, we usually measure the power per unit area, so irradiance is typically quoted as W/m², that is, Watts per square meter.

2.3 Measurement of Solar Radiation

Scientists measure the amount of sunlight falling on specific locations at different times of the year. They then estimate the amount of sunlight falling on regions at the same latitude with similar climates. Measurements of solar energy are typically expressed as total radiation on a horizontal surface,or as total radiation on a surface tracking the sun.

Radiation data for **solar electric (photovoltaic) systems** are often represented as kilowatt-hours per square meter (kWh/m^2). Direct estimates of solar energy may also be expressed as watts per square meter (W/m^2).

Radiation data for solar **water heating** and **space heating** systems are usually represented in British thermal units per square foot (Btu/ft^2).

2.4 Classification of Solar Radiation Instruments

Solar Collector:

- Solar collectors are used to collect the solar energy and convert this energy into the thermal energy by absorbing them.
- This thermal energy further is used to heating a collector fluid such as water, oil or air.
- Solar collector surface is designed for high absorption and low emission.
- Solar collectors directly collect the radiation heat from the SUN and after collecting the heat it transform that heat to the fluid and after this heat transferred, fluid delivers that heat to thermal storage tank or boiler or heat exchanger etc. for utilising the heat.
- Area of collector to grasp the solar radiation = Area of absorber plate.

Solar collector is classified into two types. Such as:

- Non – concentrating type [Flat plate collectors].

- Concentrating type.

2.5 Flat Plate Collectors (NON – CONCENTRATING TYPE)

- ➢ It is a heat exchanger device which converts the solar energy into heat energy.
  OR
- ➢ It is a device which is used to collect the heat from solar radiation.
- ➢ Its main function is to collect the heat from SUN's radiation.
- ➢ We use this heat energy for domestic and commercial purpose.

- ➢ It is used for below 90°C.
- ➢ It has rectangular shape.
- ➢ It absorbs both direct & diffuse radiation.

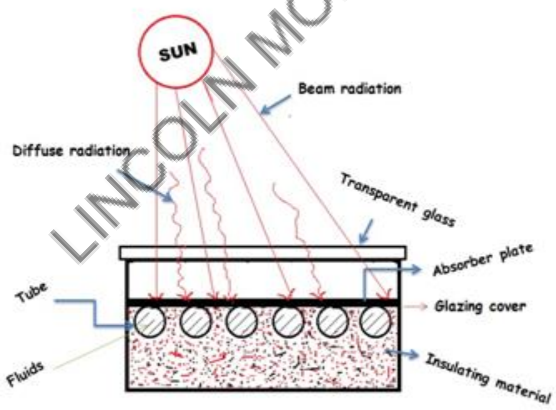
Direct radiation: When radiation of SUN directly reaches to earth surface, it is known as direct radiation.

Diffuse radiation: When radiation of SUN reaches to earth by reflecting from cloud, moisture or any object, it is known as diffuse radiation.

- ➢ Flat plate collector is again classified into two types. Such as,
  1. Liquid heating collector
  2. Air heating collector

1. Liquid heating collector:

Construction:

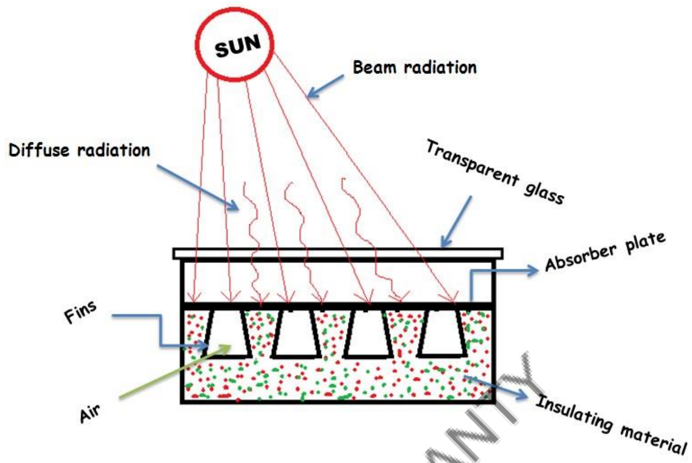


- Outer surface of the collector is made up of transparent glass or plastics dia. of (4 to 5mm). So the dissipation of the heat from the absorber plate is minimum to the environment.
- Absorber plate is made up of copper or aluminium or steel with thickness 2 cm approximately.
- Absorber plate is coated with black colour to absorb maximum radiation heat.
- Absorber plate is used to absorb solar energy and convert it to heat.
- Glazing cover helps to maintain the heat across the absorber plate.
- Tubes are attached to the bottom of the absorber plate and made up of metal or plastics in dia. from 1 to 1.5 cm. approximately through which heat transfer fluid flows.
- Tubes are insulated by the insulating materials of foam, glass wool, rock wool etc, which maintains the heat across the tube. Insulation thickness remains about 5 to 10cm approximately.

Working:

- When the solar radiation (both beam & diffuse) strikes on the absorber plate temperature of the absorber plate increases by absorbing the heat from radiation.
- Since the absorber plate covered by the transparent glass, that's why heat stored in heating chamber and the insulation maintains the heat.
- Since the tube is attached with the absorber plate, so tube will also heat.
- Now the liquid inside the tube get heated. After that hot water is used for domestic purposes.

2. Air heating collector:



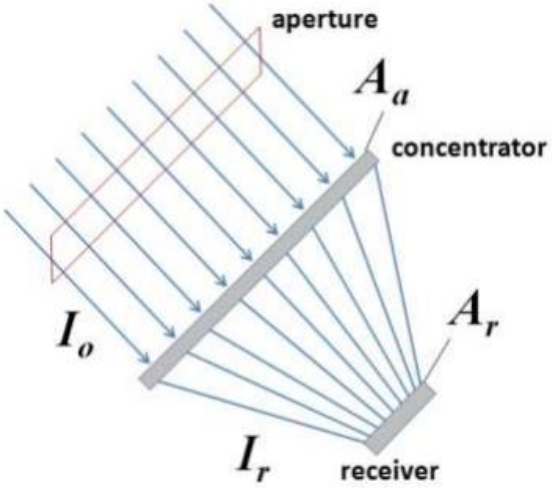
- Almost working & construction is similar to the liquid heating collector.
- Main difference is that, tubes are not attached with absorber plate. Instead fins are attached with absorber plate.
- Fins are used to increase the contact area.
- As an insulation mineral wool is used, this maintains the heat across the fins.
- When radiation strikes on the absorber plate, the heat is absorbed by the plate.
- Since, fins are attached with the absorber plate, so fins are also heated.
- When air flow along fins, air is heated due to high temperature. And we use that hot air for general purpose.

Optical Characteristics

Solar concentrators are classified by their optical characteristics such as the concentration factor, distribution of illumination, efficiency, focal shape, and optical standard.

(1) Concentration Factor:

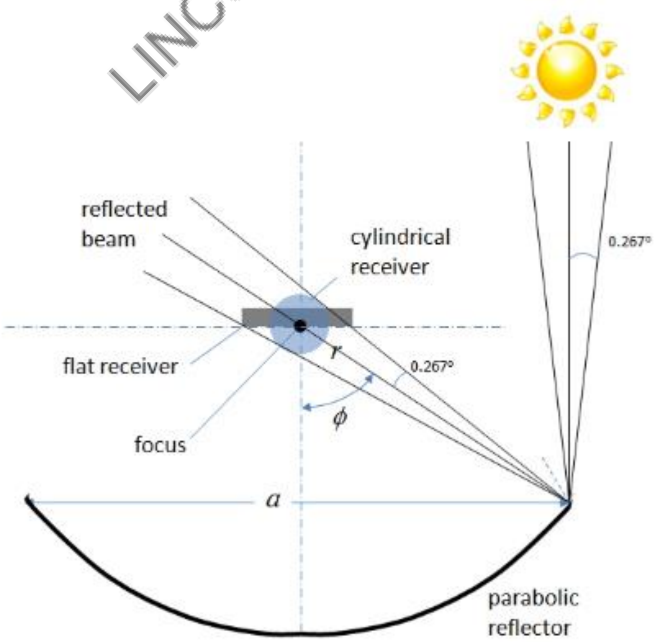
The light concentration process is typically characterized by the concentration ratio (C). By physical meaning, the concentration ratio is the factor by which the incident energy flux (Io) is optically enhanced on the receiving surface (Ir) - see Figure. So, confining the available energy coming through a chosen aperture to a smaller area on the receiver, we should be able to increase the flux.



$$C_{geo} = \frac{\text{area of the aperture}}{\text{area of the receiver}} = \frac{A_a}{A_r}$$

In the above equation, C_{geo} is called the geometric concentration ratio. It is easy to use, as the areas of the devices are known, although it is adequate only when the radiation flux is uniform over the aperture and over the receiver. Also, please note that for some imaging concentrators, the area of the available receiver surface can be different from the area of the image produced by the concentrator on the receiver. So, if the image does not cover the entire surface of the receiver, we need to use the image area to estimate the concentration ratio.

(2) Efficiency: The efficiency is the ratio between the incoming radiant flux (measured in watts) and the outgoing wattage, or the fraction of the incoming energy that the device can deliver as usable output energy (not the same as light or electricity, some of which might not be usable). In the previous example, half the received wattage is re-emitted, implying efficiency of 50%.



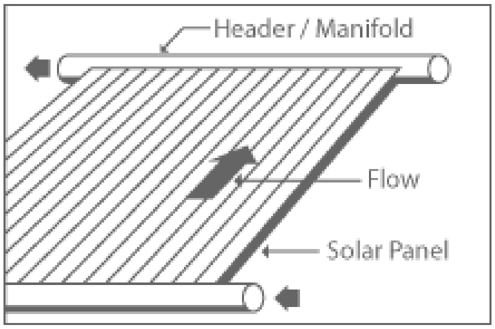
CHAPTER-3:

LOW-TEMPERATURE APPLICATIONS OF SOLAR ENERGY

3.1 Swimming Pool Heating

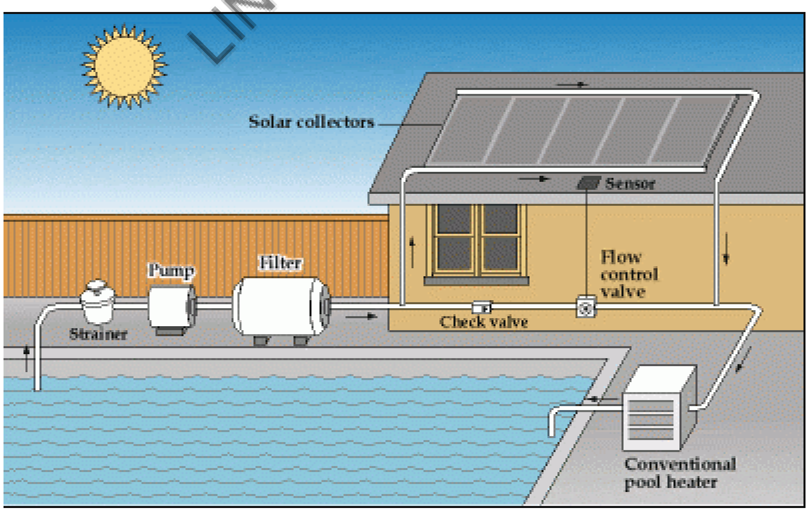
Most solar pool heating systems include the following:

- A solar collector -- the device through which pool water is circulated to be heated by the Sun



- A filter -- removes debris before water is pumped through the collector
- A pump -- circulates water through the filter and collector and back to the pool
- A flow control valve -- automatic or manual device that diverts pool water through the solar collector.

Pool water is pumped through the filter and then through the solar collector(s), where it is heated before it is returned to the pool. In hot climates, the collector(s) can also be used to cool the pool during peak summer months by circulating the water through the collector(s) at night.



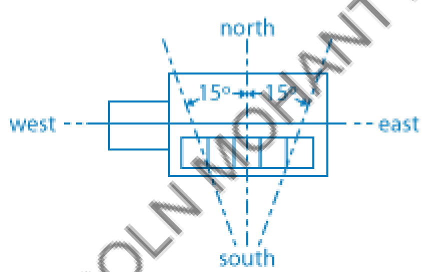
Some systems include sensors and an automatic or manual valve to divert water through the collector(s) when the collector temperature is sufficiently greater than the pool temperature. When the collector temperature is similar to the pool temperature, filtered water simply bypasses the collector(s) and is returned to the pool.

Solar pool collectors are made out of different materials. The type you'll need depends on your climate and how you intend to use the collector. If you'll only be using your pool when temperatures are above freezing, then you'll probably only need an unglazed collector system. Unglazed collectors don't include a glass covering (glazing). They are generally made of heavy-duty rubber or plastic treated with an ultraviolet (UV) light inhibitor to extend the life of the panels. Because of their inexpensive parts and simple design, unglazed collectors are usually less expensive than glazed collectors. These unglazed systems can even work for indoor pools in cold climates if the system is designed to drain back to the pool when not in use. Even if you have to shut the system down during cold weather, unglazed collectors may be more cost effective than installing a more expensive glazed collector system.

Setting a Solar Swimming Pool Heater's Collector

Collectors can be mounted on roofs or anywhere near the swimming pool that provides the proper exposure, orientation, and tilt toward the sun. Both the orientation and tilt of the collector will affect your solar pool heating system's performance. Your contractor should consider them while evaluating your site's solar resource and sizing your system.

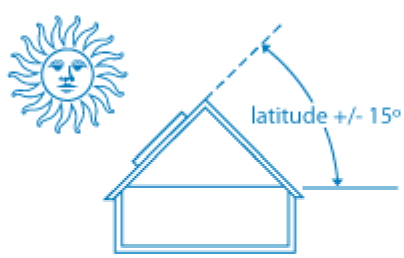
Collector Orientation



Solar collector orientation

Solar pool heater collectors should be oriented geographically to maximize the amount of daily and seasonal solar energy that they receive. In general, the optimum orientation for a solar collector in the northern hemisphere is true south. However, recent studies have shown that, depending on your location and collector tilt, your collector can face up to 45º east or west of true south without significantly decreasing its performance. You'll also want to consider factors such as roof orientation (if you plan to mount the collector on your roof), local landscape features that shade the collector daily or seasonally, and local weather conditions (foggy mornings or cloudy afternoons), as these factors may affect your collector's optimal orientation.

Collector Tilt



Solar collector angle

The angle at which a collector should be tilted varies based on your latitude and the length of your swimming season (summer or year-round). Ideally, collectors for summer-only heating should be tilted at an angle equal to your latitude minus 10º–15º. Collectors for year-round heating should be tilted at an angle equal to your latitude. However, studies have shown that not having a collector tilted at the optimum angle will not significantly reduce system performance. Therefore, you can usually mount collectors flat on your roof, which might not be at the optimum angle but more aesthetically pleasing. You will, however, want to take roof angle into account when sizing your system.

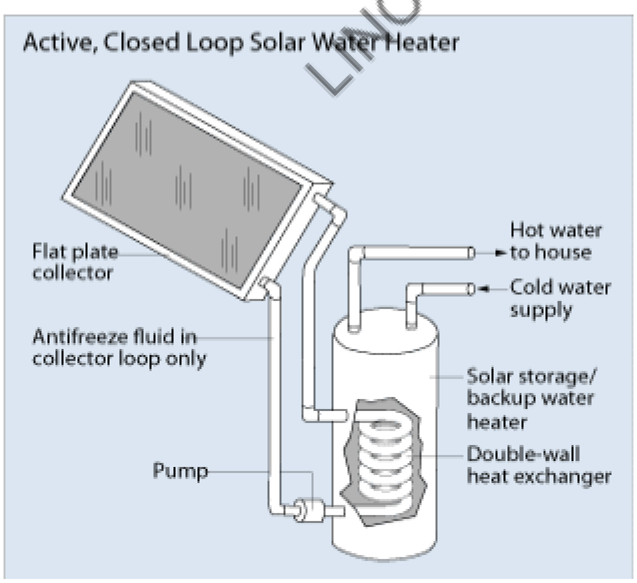
3.2 Solar water Heating Systems

Solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which don't.

Active Solar Water Heating Systems

There are two types of active solar water heating systems:

- Direct circulation systems
  Pumps circulate household water through the collectors and into the home. They work well in climates where it rarely freezes.
- Indirect circulation systems
  Pumps circulate a non-freezing, heat-transfer fluid through the collectors and a heat exchanger. This heats the water that then flows into the home. They are popular in climates prone to freezing temperatures.

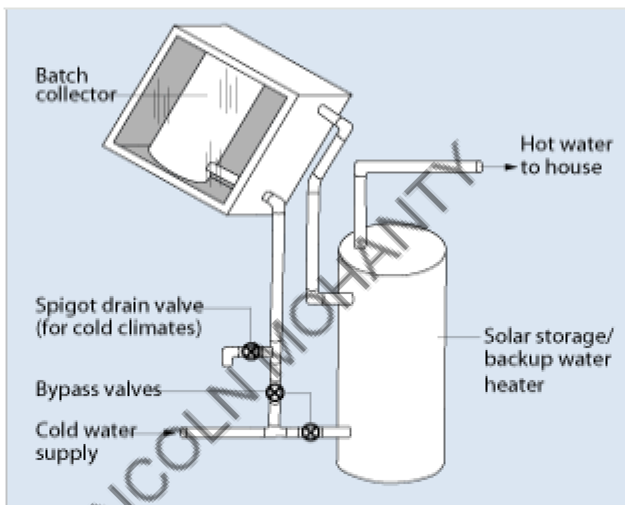


Passive Solar Water Heating Systems

Passive solar water heating systems are typically less expensive than active systems, but they're usually not as efficient. However, passive systems can be more reliable and may last longer. There are two basic types of passive systems:

- **Integral collector-storage passive systems**
  These consist of a storage tank covered with a transparent material to allow the sun to heat the water. Water from the tank then flows into the plumbing system. These work best in areas where temperatures rarely fall below freezing. They also work well in households with significant daytime and evening hot-water needs.

- **Thermosyphon systems**
  Water is heated in a collector on the roof and then flows through the plumbing system when a hot water faucet is opened. The majority of these systems have a 40 gallon capacity.



Storage Tanks and Solar Collectors

Most solar water heaters require a well-insulated storage tank. Solar storage tanks have an additional outlet and inlet connected to and from the collector. In two-tank systems, the solar water heater preheats water before it enters the conventional water heater. In one-tank systems, the back-up heater is combined with the solar storage in one tank.

Three types of solar collectors are used for residential applications:

- **Flat-plate collector**
  Glazed flat-plate collectors are insulated, weatherproofed boxes that contain a dark absorber plate under one or more glass or plastic (polymer) covers. Unglazed flat-plate collectors -- typically used for **solar pool heating** -- have a dark absorber plate, made of metal or polymer, without a cover or enclosure.

- **Integral collector-storage systems**
  Also known as ICS or *batch* systems, they feature one or more black tanks or tubes in an insulated, glazed box. Cold water first passes through the solar collector, which preheats

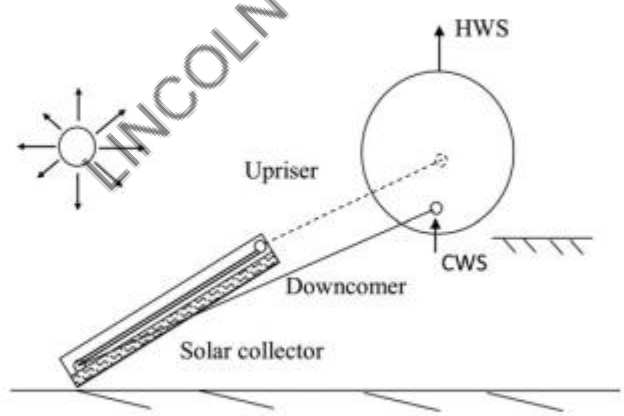
the water. The water then continues on to the conventional backup water heater, providing a reliable source of hot water. They should be installed only in mild-freeze climates because the outdoor pipes could freeze in severe, cold weather.

- **Evacuated-tube solar collectors**
  They feature parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radiative heat loss. These collectors are used more frequently for U.S. commercial applications.

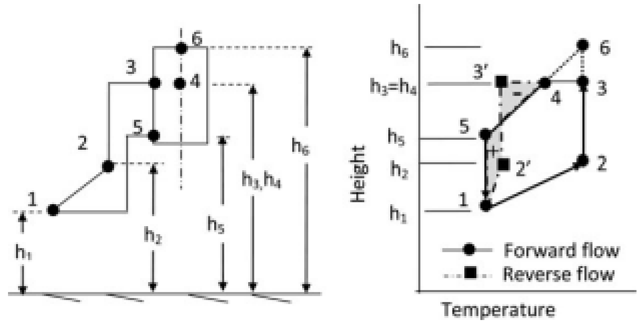
  Solar water heating systems almost always require a backup system for cloudy days and times of increased demand. **Conventional storage water heaters** usually provide backup and may already be part of the solar system package. A backup system may also be part of the solar collector, such as rooftop tanks with thermosyphon systems. Since an integral-collector storage system already stores hot water in addition to collecting solar heat, it may be packaged with a **tankless or demand-type water heater** for backup.

3.5 Natural Convection water Heating Systems

Natural convection in a horizontal water layer differentially heated at the bottom and top boundaries with density inversion in the bulk leads to the formation of an upper stably stratified fluid region, and a lower convectively unstable region from which motion can propagate upwards.



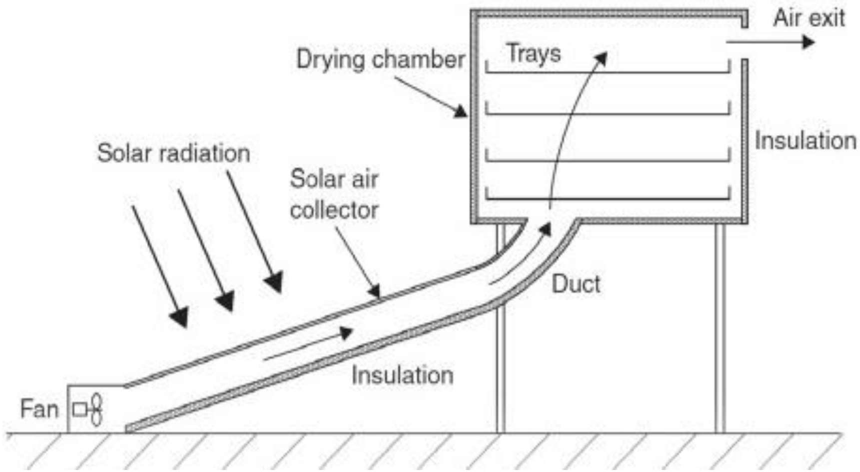
The natural convection solar water heater (SWH) shown in Figure operates on the principle of thermal buoyancy. The solar collector heats up the water in the tubes of the collector plate which rises up the upriser pipe to the storage tank. Denser cold water in the storage tank flows down the downcomer pipe to take its place. This natural convection recirculating flow of water occurs throughout the day as long as heat is absorbed in the collector plate. As a result, hot water collects and is stored in the insulated hot water storage tank during the day. At night, the flow reverses itself and heat is lost from the collector to the night sky



A hypothetical system temperature distribution for the natural convection SWH system is illustrated in above Figure . The relative heights of the collector and storage tank are indicated by h1, h2, h3, h4, h5 and h6. The temperature distribution between the collector inlet (T1) and the collector outlet (T2) is assumed to be linear. Assuming no heat losses in the connecting pipes and as long as the collector is collecting heat during the day, the temperature at the inlet to the tank (T3) will be equal to that at the outlet of the collector (T2). The location of point 4 in the tank (T4) is assumed at the same level as the tank inlet connection from the collector outlet. The temperature of the water in the storage tank at location 4 (T4) is less than the temperature at location 3 because of mixing in the storage tank. The temperature at the top of the tank (T6) is assumed equal to that at T3. In other words, the temperature at the upper portion of the storage tank is assumed uniform. The temperature distribution between point 4 and point 5 (T5) is assumed linear. The temperature distribution for forward flow is indicated by the solid lines shown in Figure 2. The magnitude of forward thermosyphon flow is reflected by the area bounded by 123 451. This means the area is always positive giving rise to forward flow. When solar radiation is absent at night, temperatures T2 and T3will drop to T20 and T30, respectively. These temperatures will be lower than the tank temperature (T4), giving rise to a negative net area bounded by 12’3’451 and hence leading to reverse flow.

3.4 Solar Drying

Solar dryers are used to eliminate the moisture content from crops, vegetables, and fruits. The solar dryer consists of a box made up of easily available and cheap material like cement, galvanized iron, brick, and plywood. The top surface of the dryer is covered by transparent single and double-layered sheets. The inside surface is colored black to absorb the incoming solar radiation. Since the box is insulated, the inside temperature of the box is raised. The air is ventilated through the small holes at the top of the box. As the inside air gets warm, it rises by the natural circulation process and removes the moisture from the fruits, vegetables, and the crops placed in trays inside the box.



Components of a solar dryer

- A solar dryer may be considered as it comprises of three main components — a drying chamber, a solar collector, and some type of airflow system, as illustrated in Figure.
- In the drying chamber, drying takes place, and the material is spread on the chamber to get dehydrated, whereas the solar collector converts the solar radiation spectrum into heat.

A solar dryer may also have the following components or accessories.

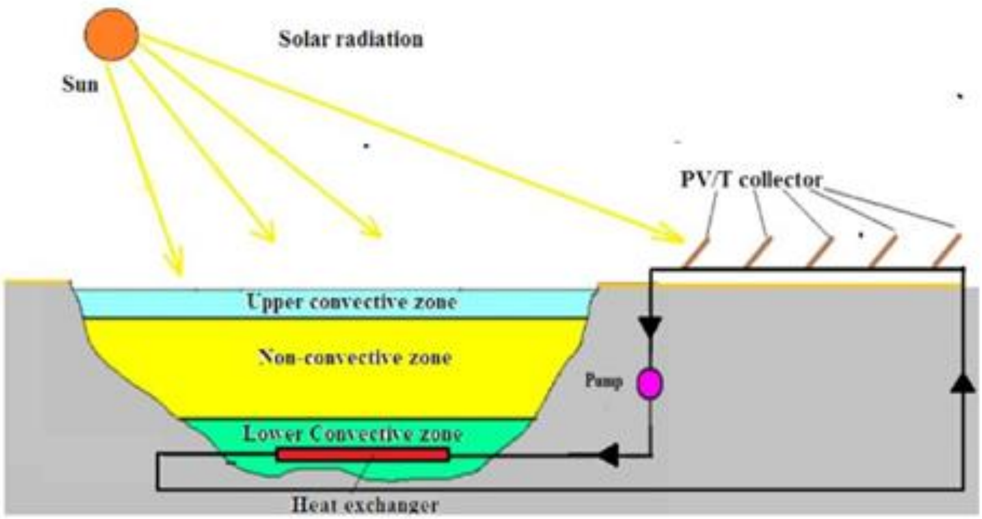
- Equipment of heat transfer for transporting thermal energy to the air or product
- Device for keeping the circulation of drying air
- Thermal energy storage system (non-compulsory)
- An alternative energy source (non-compulsory)
- Measurement and control equipment (non-compulsory)
- Transparent cover, absorber, trays, ducts, pipes, circuits, solar chimney (optional), and other appliances.

3.5 Solar Pond

- One way to tap solar energy is through the use of solar ponds. Solar ponds are large-scale energy collectors with integral heat storage for supplying thermal energy. It can be use for various applications, such as process heating, water desalination, refrigeration, drying and power generation.

- The solar pond works on a very simple principle. It is well-known that water or air is heated they become lighter and rise upward e.g. a hot air balloon. Similarly, in an ordinary pond, the sun's rays heat the water and the heated water from within the pond rises and reaches the top but loses the heat into the atmosphere.

- The net result is that the pond water remains at the atmospheric temperature. The solar pond restricts this tendency by dissolving salt in the bottom layer of the pond making it too heavy to rise.



- A solar pond has three zones. The top zone is the surface zone, or UCZ (Upper Convective Zone), which is at atmospheric temperature and has little salt content.
- The bottom zone is very hot, 70°– 85° C, and is very salty. It is this zone that collects and stores solar energy in the form of heat, and is, therefore, known as the storage zone or LCZ (Lower Convective Zone).
- Separating these two zones is the important gradient zone or NCZ (Non-Convective Zone). Here the salt content increases as depth increases, thereby creating a salinity or density gradient. If we consider a particular layer in this zone, water of that layer cannot rise, as the layer of water above has less salt content and is, therefore, lighter.
- Similarly, the water from this layer cannot fall as the water layer below has a higher salt content and is, therefore, heavier.
- This gradient zone acts as a transparent insulator permitting sunlight to reach the bottom zone but also entrapping it there.
- The trapped (solar) energy is then withdrawn from the pond in the form of hot brine from the storage zone.
- Though solar ponds can be constructed anywhere, it is economical to construct them at places where there is low cost salt and bittern, good supply of sea water or water for filling and flushing, high solar radiation, and availability of land at low cost.
- Coastal areas in Tamil Nadu, Gujarat, Andhra Pradesh, and Orissa are ideally suited for such solar ponds.

CHAPTER-5

SOLAR THERMAL POWER PLANTS

5.1 Introduction

Solar thermal power/electric generation systems collect and concentrate sunlight to produce the high temperature heat needed to generate electricity. All solar thermal power systems have solar energy collectors with two main components: *reflectors* (mirrors) that capture and focus sunlight onto a *receiver*. In most types of systems, a heat-transfer fluid is heated and circulated in the receiver and used to produce steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. Solar thermal power systems have tracking systems that keep sunlight focused onto the receiver throughout the day as the sun changes position in the sky. Solar thermal power plants usually have a large field or array of collectors that supply heat to a turbine and generator.

5.2 Solar Collection System

A solar collector is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use. These collectors are generally mounted on the roof and must be very sturdy as they are exposed to a variety of different weather conditions.

The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time. As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

Types of Solar Collectors

There are many different types of solar collectors, but all of them are constructed with the same basic premise in mind. In general, there is some material that is used to collect and focus energy from the Sun and use it to heat water. The simplest of these devices uses a black material surrounding pipes that water flows through. The black material absorbs the solar radiation very well, and as the material heats up the water it surrounds. This is a very simple design, but collectors can get very complex. Absorber plates can be used if a high temperature increase isn't necessary, but generally devices that use reflective materials to focus sunlight result in a greater temperature increase.

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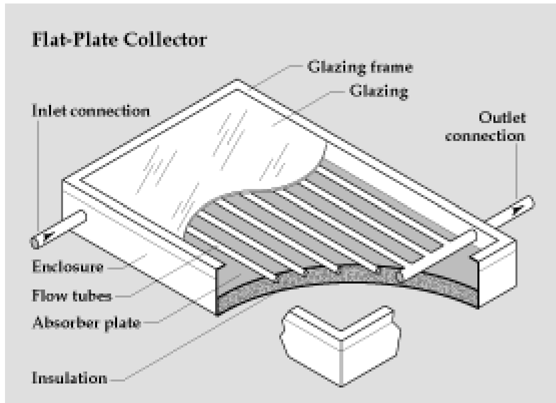
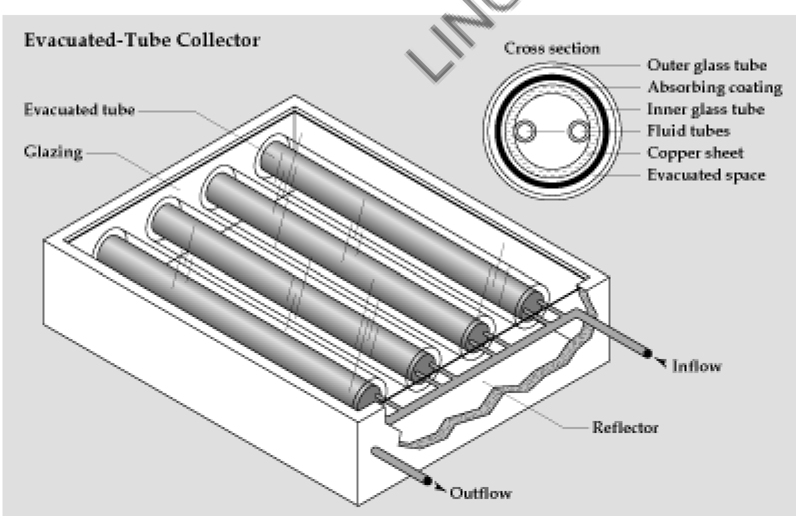
Flat Plate Collectors



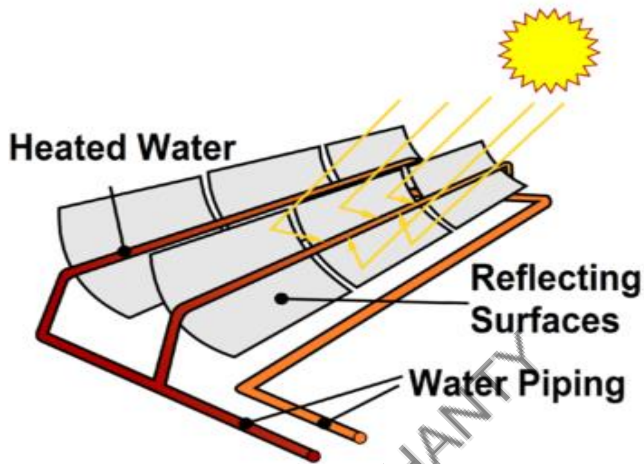
These collectors are simply metal boxes that have some sort of transparent glazing as a cover on top of a dark-coloured absorber plate. The sides and bottom of the collector are usually covered with insulation to minimize heat losses to other parts of the collector. Solar radiation passes through the transparent glazing material and hits the absorber plate. This plate heats up, transferring the heat to either water or air that is held between the glazing and absorber plate. Sometimes these absorber plates are painted with special coatings designed to absorb and retain heat better than traditional black paint. These plates are usually made out of metal that is a good conductor - usually copper or aluminum.

Evacuated Tube Collectors



This type of solar collector uses a series of evacuated tubes to heat water for use. These tubes utilize a vacuum, or evacuated space, to capture the suns energy while minimizing the loss of heat to the surroundings. They have an inner metal tube which acts as the absorber plate, which is connected to a heat pipe to carry the heat collected from the Sun to the water. This heat pipe is essentially a pipe where the fluid contents are under a very particular pressure. At this pressure, the "hot" end of the pipe has boiling liquid in it while the "cold" end has condensing vapour. This allows for thermal energy to move more efficiently from one end of the pipe to the other. Once the heat from the Sun moves from the hot end of the heat pipe to the condensing end, the thermal energy is transported into the water being heated for use.

Line Focus Collectors



These collectors, sometimes known as parabolic troughs, use highly reflective materials to collect and concentrate the heat energy from solar radiation. These collectors are composed of parabolically shaped reflective sections connected into a long trough. A pipe that carries water is placed in the center of this trough so that sunlight collected by the reflective material is focused onto the pipe, heating the contents. These are very high powered collectors and are thus generally used to generate steam for Solar thermal power plants and are not used in residential applications. These troughs can be extremely effective in generating heat from the Sun, particularly those that can pivot, tracking the Sun in the sky to ensure maximum sunlight collection

Point Focus Collectors

These collectors are large parabolic dishes composed of some reflective material that focus the Sun's energy onto a single point. The heat from these collectors is generally used for driving Stirling engines. Although very effective at collecting sunlight, they must actively track the Sun across the sky to be of any value. These dishes can work alone or be combined into an array to gather even more energy from the Sun.

Point focus collectors and similar apparatuses can also be utilized to concentrate solar energy for use with Concentrated photovoltaics. In this case, instead of producing heat, the Sun's energy is converted directly into electricity with high efficiency photovoltaic cells designed specifically to harness concentrated solar energy.

5.3 Thermal Storage for Solar Power Plants

TWO-TANK DIRECT SYSTEM

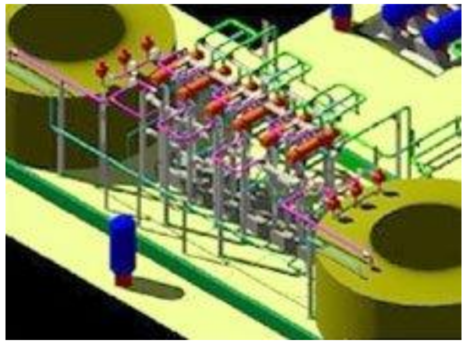
Solar thermal energy in this system is stored in the same fluid used to collect it. The fluid is stored in two tanks—one at high temperature and the other at low temperature. Fluid from the low-temperature tank flows through the solar collector or receiver, where solar energy heats it to a high temperature, and it then flows to the high-temperature tank for storage. Fluid from the high-temperature tank flows through a heat exchanger, where it generates steam for electricity production. The fluid exits the heat exchanger at a low temperature and returns to the low-temperature tank.

Two-tank direct storage was used in early parabolic trough power plants (such as Solar Electric Generating Station I) and at the Solar Two power tower in California. The trough plants used mineral oil as the heat-transfer and storage fluid; Solar Two used molten salt.

TWO-TANK INDIRECT SYSTEM

Two-tank indirect systems function in the same way as two-tank direct systems, except different fluids are used as the heat-transfer and storage fluids. This system is used in plants in which the heat-transfer fluid is too expensive or not suited for use as the storage fluid.

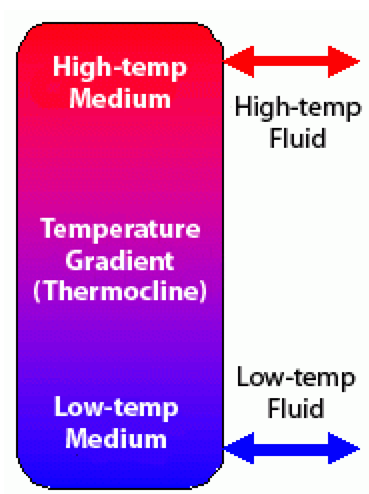
The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid. The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to a high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which adds cost to the system.



This system will be used in many of the parabolic power plants in Spain and has also been proposed for several U.S. parabolic plants. The plants will use organic oil as the heat-transfer fluid and molten salt as the storage fluid.

SINGLE-TANK THERMOCLINE SYSTEM

Single-tank thermocline systems store thermal energy in a solid medium—most commonly, silica sand—located in a single tank. At any time during operation, a portion of the medium is at high temperature, and a portion is at low temperature. The hot- and cold-temperature regions are separated by a temperature gradient or thermocline. High-temperature heat-transfer fluid flows into the top of the thermocline and exits the bottom at low temperature. This process moves the thermocline downward and adds thermal energy to the system for storage. Reversing the flow moves the thermocline upward and removes thermal energy from the system to generate steam and electricity. Buoyancy effects create thermal stratification of the fluid within the tank, which helps to stabilize and maintain the thermocline.



Using a solid storage medium and only needing one tank reduces the cost of this system relative to two-tank systems. This system was demonstrated at the Solar One power tower, where steam was used as the heat-transfer fluid and mineral oil was used as the storage fluid.

5.4 Capacity Factor and Solar Multiple

The effect on the cost of electricity from concentrating solar power (CSP) plants of the solar multiple, the capacity factor and the storage capacity is studied. The interplay among these factors can be used to search for a minimal-cost objective that can serve as a technical criterion to guide in the design of economic incentives for CSP plants. The probability-density function of irradiation is used in conjunction with screening models to evaluate the performance characteristics and costs of concentrating solar power plants.

Capacity: generally refers to the maximum output (generation) of a power plant. Capacity is typically measured in a kilowatt (kW), megawatt (MW), or gigawatt (GW) rating. Rated capacity may also be referred to as “nameplate capacity” or “peak capacity.” This may be further distinguished as the “net capacity” of the plant after plant parasitic loads have been considered, which are subtracted from “gross capacity.”

Capacity from PV systems may be measured by either their AC or DC capacity. PV modules produce direct current (DC) voltage. This DC electricity is converted into alternating current (AC). As a result, PV power plants have both a DC rating (corresponding to the output of the modules) and an AC rating, which is always lower than the DC rating because of losses associated with converting DC to AC. AC rating better corresponds to traditional power plant ratings. CSP plants are rated by their net AC capacity in the same manner as conventional power plants.

Capacity factor is a measure of how much energy is produced by a plant compared with its maximum output. It is measured as a percentage, generally by dividing the total energy produced during some period of time by the amount of energy the plant would have produced if it ran at full output during that time. Capacity value refers to the contribution of a power plant to reliably meet demand.

The **capacity value** (or capacity credit) is measured either in terms of physical capacity (kW, MW, or GW) or the fraction of its nameplate capacity (%). Thus, a plant with a nameplate capacity of 150 MW could have a capacity value of 75 MW or 50%. Solar plants can be designed and operated to increase their capacity value or energy output.

5.5 Energy Conversion

Solar panels are responsible for generating electricity and in most cases they are located on the roof of any building. Hence it is through these solar panels where the real story begins and solar energy gets converted into electricity. These solar panels also known as the modules are usually southern faced for maximum potential and electricity production.

Each of these solar panels is made up of a special layer of silicon cells, a metal frame, a glassed casing which is further surrounded by special film and wiring. For maximum electricity production, the solar panels are arranged together into "arrays". This through these solar cells also known as photovoltaic cells, where the sunlight is absorbed during the daylight hours.

Conversion of absorbed solar energy into electrical energy

- Photovoltaic meaning light and electricity and hence installing these solar cells or photovoltaic cells is the first initial step to convert solar energy.
- Each Solar cell has a thin semiconductor wafer which is made up of two layers of silicon. Now silicon is a naturally occurring chemical element, one of the greatest semiconductors. Silicon semiconductors can act as both conductors as well as insulators.
- One silicon layer is positively charged known as the N-type and the other silicon layer is negatively charged known as the P-type. N-type gives away electrons easily while on the other side P-side semiconductor receives the extra electrons in the electric field. This positive and negative layer hence compliments the formation of an electric field on the solar panel.
- We all know that energy from the sun comes on the earth in the form of little packets called photons When the sunlight strikes these photovoltaic cells already forming an electric field, the photons of sunlight startle the electrons inside these cells activating them to start flowing.
- These loose electrons that start flowing on the electric field further create the electric current.

How electrical energy gets converted for usage

The electrical energy which we get from the solar energy through the photovoltaic cells is normally known as the Direct current (DC) electricity. But this direct current electricity cannot be used to power homes and buildings, therefore to utilize this generated electrical energy, we need to convert it into Alternating current (AC) electricity.

Further to convert Direct current into alternating current special solar inverters need to be installed. In modern solar systems, these investors can be configured as one of the inverters for the entire system, or micro-mini inverters need to be attached behind the panels. The inverter turns DC electricity to 120 volts AC that can be further put into immediate use for the home appliances. The power produced by solar energy initially passes through the electrical panel in your home and then passes out into the electric grid. When in the case your solar plant is generating more electricity than your immediate consumption, your utility meter will turn backward.

Once your DC gets converted to AC, the current then runs through your electrical panel installed in your home and hence supplies power to all the home appliances. The electricity generated in the solar power system is the same power generated through the grid by your electric utility company; therefore no changes in the home are required to get power from solar energy.

CHAPTER-6:

SOLAR PHOTOVOLTAICS

6.1 Band Theory of Solids, Physical Processes in a Solar Cell

Band theory of solids describes the quantum state that an electron takes inside a metal solid. Every molecule comprises various discrete energy levels. The way electrons behave inside a molecule is well explained through band theory. Band Theory was developed from the knowledge gained during the quantum revolution in science. In 1928, Felix Bloch applied quantum theory to solids.

In atoms, electrons are filled in respective energy orbits following Pauli's exclusion principle. Two atomic orbitals combine to form a molecular orbit with two distinct energy levels. In solids, 10^{23} stacked up lines confined in a tiny space would look like a band. Thereby forming an energy continuum called energy bands. Band theory helps to visualise the difference between a conductor, semiconductor, and an insulator by plotting available energies for an electron in a material.

Energy Bands in Solids

In the band theory of solids, there are many energy bands but the following are the three most important energy bands in solids:

- Valence Band
- Conduction Band
- Forbidden Band

Valence band

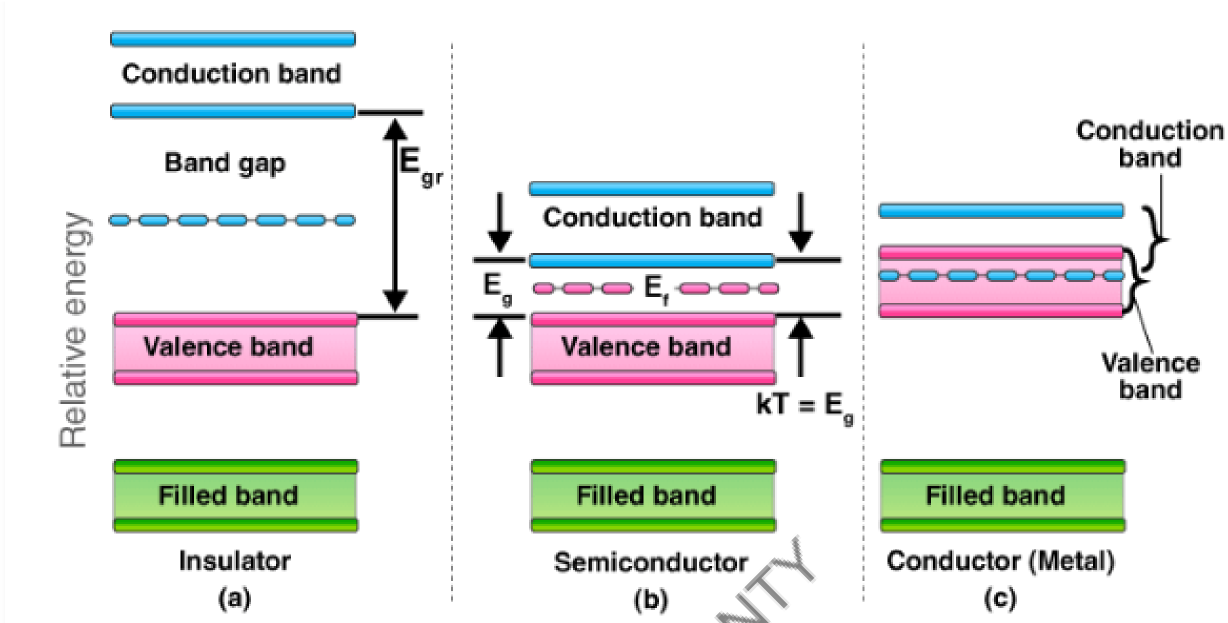
The energy band that consists of valence electrons energy levels, is known as the valence band. The valence band is present below the conduction band and the electrons of this band are loosely bound to the nucleus of the atom.

Conduction band

The energy band that consists of free electrons energy levels, is known as the conduction band. For electrons to be free, external energy must be applied such that the valence electrons get pushed to the conduction band and become free.

Forbidden band

The energy gap between the valence band and the conduction band is known as the forbidden band which is also known as the forbidden gap. The electrical conductivity of a solid is determined by the forbidden gap and also the classification of the materials as conductors, semiconductors, and insulators.



Conductors

Gold, Aluminium, Silver, Copper, all these metals allow an electric current to flow through them.

There is no forbidden gap between the valence band and conduction band which results in the overlapping of both the bands. The number of free electrons available at room temperature is large.

Insulators

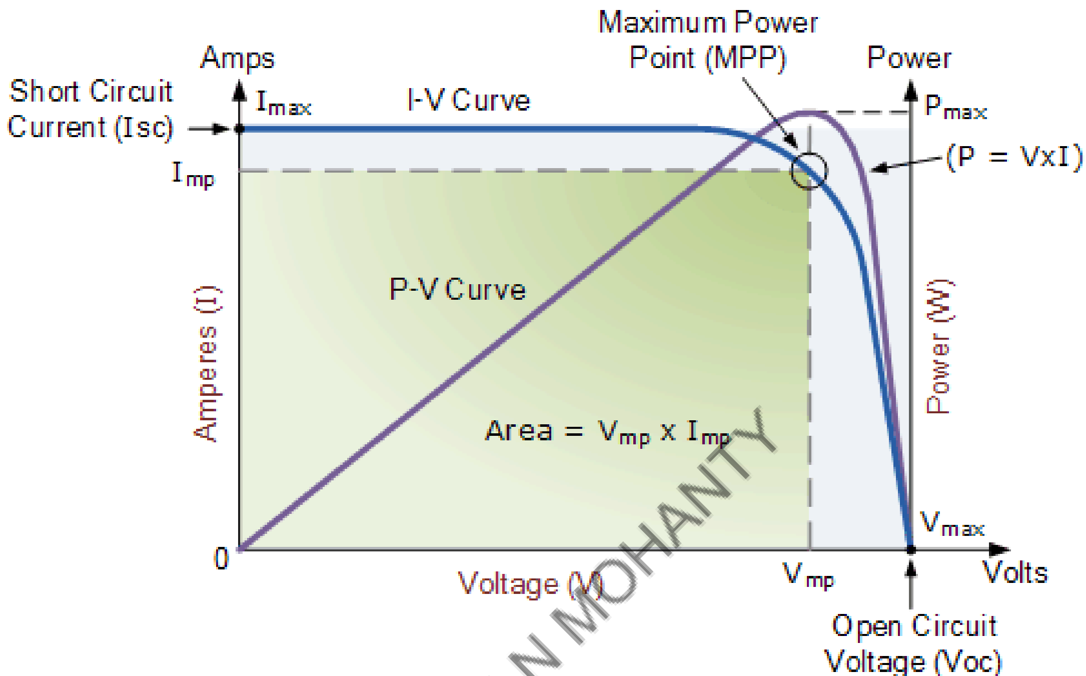
Glass and wood are examples of the insulator. These substances do not allow electricity to pass through them. They have high resistivity and very low conductivity.

The energy gap in the insulator is very high up to 7eV. The material cannot conduct because the movement of the electrons from the valence band to the conduction band is not possible.

Semiconductors

Germanium and Silicon are the most preferable material whose electrical properties lie in between semiconductors and insulators. The energy band diagram of semiconductors is shown where the conduction band is empty and the valence band is completely filled but the forbidden gap between the two bands is very small that is about 1eV. For Germanium, the forbidden gap is 0.72eV and for Silicon, it is 1.1eV. Thus, semiconductor requires small conductivity.

6.2 Solar Cell Characteristics



The above graph shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

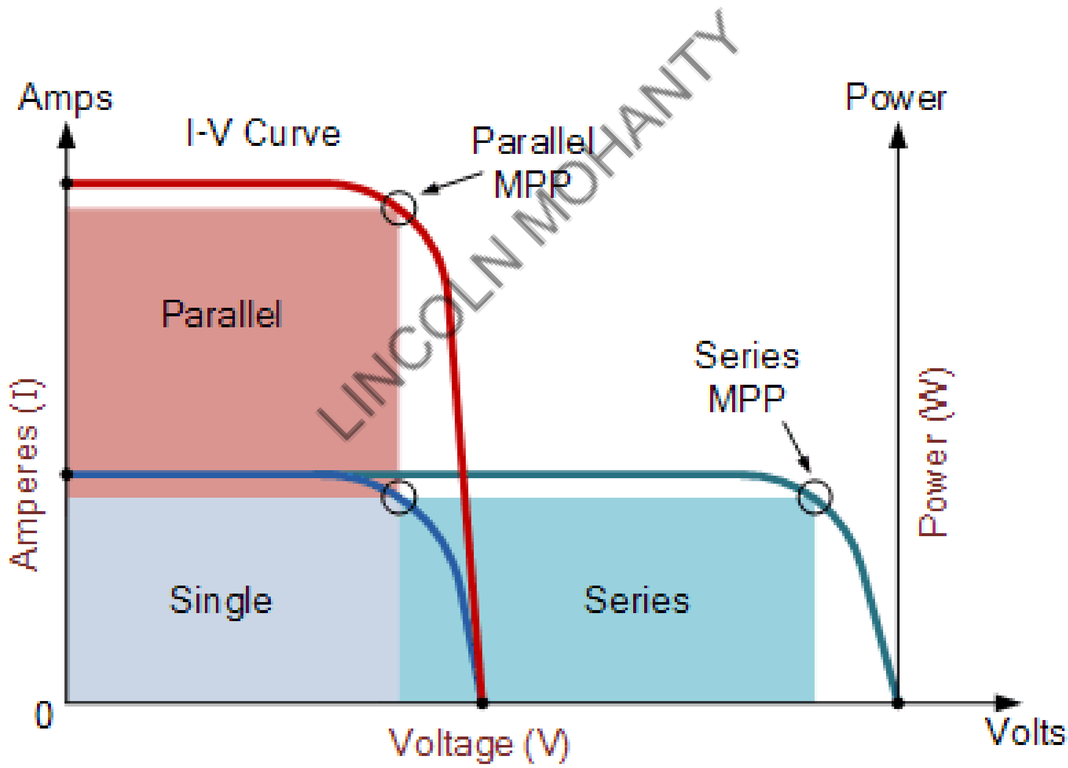
With the solar cell open-circuited, that is not connected to any load, the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells open circuit voltage, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current, or Isc

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the **maximum power point** or **MPP**. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

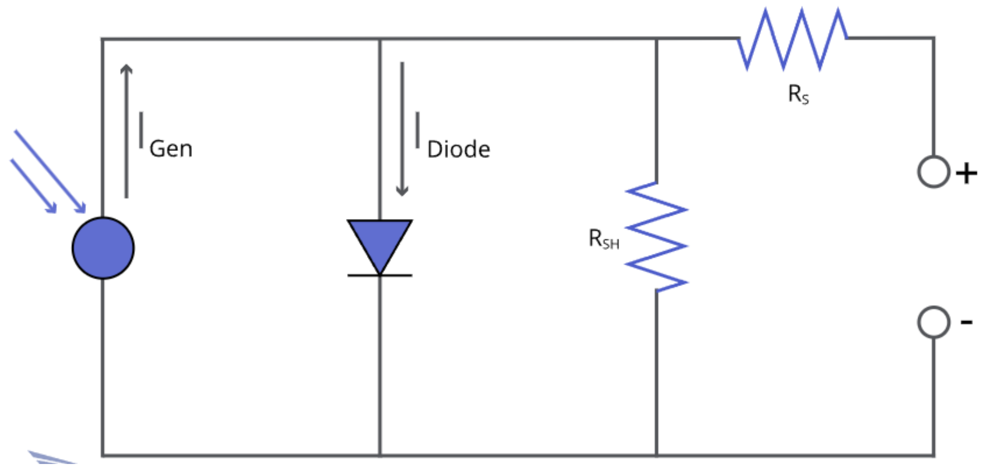
The *maximum power point* (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95)Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

Thus far we have looked at **Solar Cell I-V Characteristic Curve** for a single solar cell or panel. But a photovoltaic array is made up of smaller PV panels interconnected together. Then the I-V curve of a PV array is just a scaled up version of the single solar cell I-V characteristic curve as shown.



6.3 Equivalent Circuit Diagram of Solar Cells

The equivalent circuit of a solar cell consists of an ideal current generator in parallel with a diode in reverse bias, both of which are connected to a load. The generated current is directly proportional to light intensity. This highlights how important it is to accurately replicate the solar spectrum when testing solar cells, and why solar simulators are an indispensable piece of equipment in this context. Although the amount of current produced varies with light intensity, there are other limitations in solar cells which cap their efficiency. These limitations are represented by the other components in the circuit.



Parallel to this ideal current generator is a diode. The power that can be extracted from a device (P) is equal to current (I) times by voltage (V):

If the resistance across the load surpasses that of the diode, the diode will draw current, increasing the potential difference between the terminals, but diminishing the current directed through the load. Alternatively, if the diode's resistance is greater than the load's, electrons easily flow through the load, leading to a higher current. However, the potential difference between the terminals will be relatively low. This illustrates a core constraint with solar cells: optimizing current often means compromising on voltage. There is a sweet spot, the maximum power point, where both voltage and current are optimized, maximizing power output.

Additionally, you can represent device losses using equivalent circuit diagrams. In the above ideal circuit diagram of a solar cell, there are components which represent series resistance and shunt resistance. Shunt resistance accounts for all losses that result in electrons travelling straight between the terminals, such as shorts in the device. It is therefore represented by a resistor running parallel to the ideal current generator and you should aim to increase shunt resistance as much as possible. This means you should do everything you can to ensure your terminals remain separated i.e., no pinholes or defects.

The other component in the diagram represents series resistance, which accounts for all current losses due to poor charge transfer between or within layers of your device. In the equivalent circuit diagram, this is depicted as a resistor in series with the ideal current generator. You should do everything you can to lower series resistance in order to allow seamless electron movement through the device.

6.4 Cell Types - Crystalline Silicon Solar Cell , Solar Cells for Concentrating Photovoltaic Systems , Dye –sensitized Solar Cell (DSC)

Crystalline Silicon Solar Cell:

Crystalline silicon or (c-Si) Is the crystalline forms of silicon, either polycrystalline silicon (poly-Si, consisting of small crystals), or monocrystalline silicon (mono-Si, a continuous crystal). Crystalline silicon is the dominant semiconducting material used in photovoltaic technology for the production of solar cells. These cells are assembled into solar panels as part of a photovoltaic system to generate solar power from sunlight.

In electronics, crystalline silicon is typically the monocrystalline form of silicon, and is used for producing microchips. This silicon contains much lower impurity levels than those required for solar cells. Production of semiconductor grade silicon involves a chemical purification to produce Hyper-pure Polysilicon, followed by a recrystallization process to grow monocrystalline silicon. The cylindrical boules are then cut into wafers for further processing.

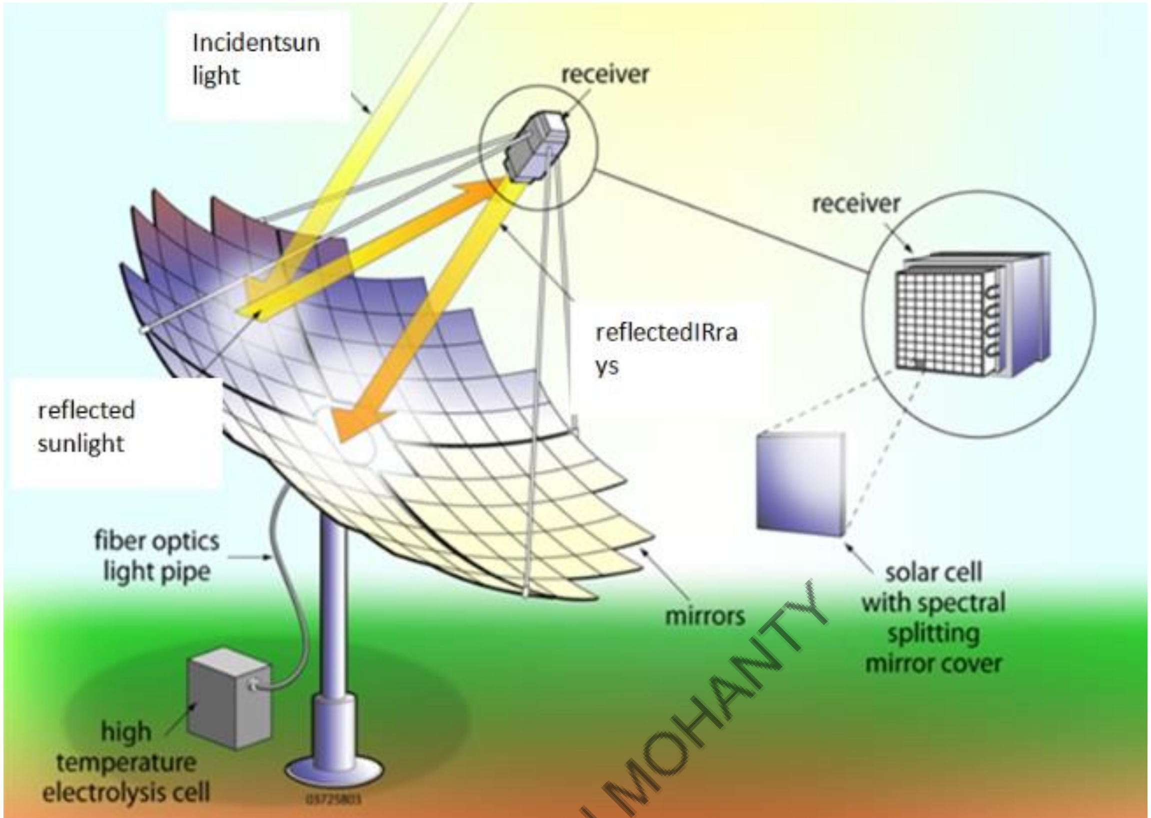
Solar cells made of crystalline silicon are often called conventional, traditional, or first generation solar cells, as they were developed in the 1950s and remained the most common type up to the present time.Because they are produced from 160 to 190 μm thick solar wafers—slices from bulks of solar grade silicon—they are sometimes called wafer-based solar cells.

Solar cells made from c-Si are single-junction cells and are generally more efficient than their rival technologies, which are the second-generation thin-film solar cells, the most important being CdTe, CIGS, and amorphous silicon (a-Si). Amorphous silicon is an allotropic variant of silicon, and amorphous means "without shape" to describe its non-crystalline form.

Solar Cells for Concentrating Photovoltaic Systems

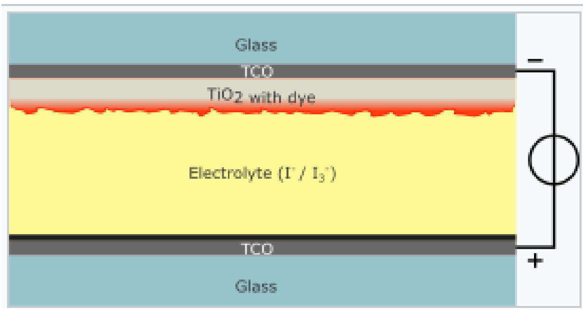
Concentrator photovoltaics (CPV) (also known as concentrating photovoltaics or concentration photovoltaics) is a photovoltaic technology that generates electricity from sunlight. Unlike conventional photovoltaic systems, it uses lenses or curved mirrors to focus sunlight onto small, highly efficient, multi-junction (MJ) solar cells. In addition, CPV systems often use solar trackers and sometimes a cooling system to further increase their efficiency.

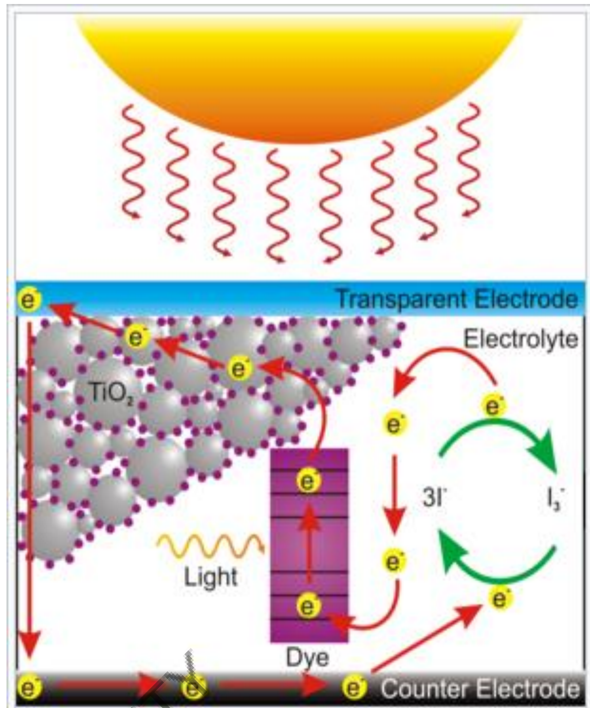
Systems using high-concentration photovoltaics (HCPV) possess the highest efficiency of all existing PV technologies, achieving near 40% for production modules and 30% for systems. They enable a smaller photovoltaic array that has the potential to reduce land use, waste heat and material, and balance of system costs. The rate of annual CPV installations peaked in 2012 and has fallen to near zero since 2018 with the faster price drop in crystalline silicon photovoltaics. In 2016, cumulative CPV installations reached 350 megawatts (MW), less than 0.2% of the global installed capacity of 230,000 MW that year



Dye –sensitized Solar Cell:

A dye-sensitized solar cell (DSC) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photoelectrochemical system.





A modern n-type DSSC, the most common type of DSSC, is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The titanium dioxide is immersed under an electrolyte solution, above which is a platinum-based catalyst.

The working principle for n-type DSSCs can be summarized into a few basic steps. Sunlight passes through the transparent electrode into the dye layer where it can excite electrons that then flow into the conduction band of the n-type semiconductor, typically titanium dioxide. The electrons from titanium dioxide then flow toward the transparent electrode where they are collected for powering a load. After flowing through the external circuit, they are re-introduced into the cell on a metal electrode on the back, also known as the counter electrode, and flow into the electrolyte. The electrolyte then transports the electrons back to the dye molecules and regenerates the oxidized dye.

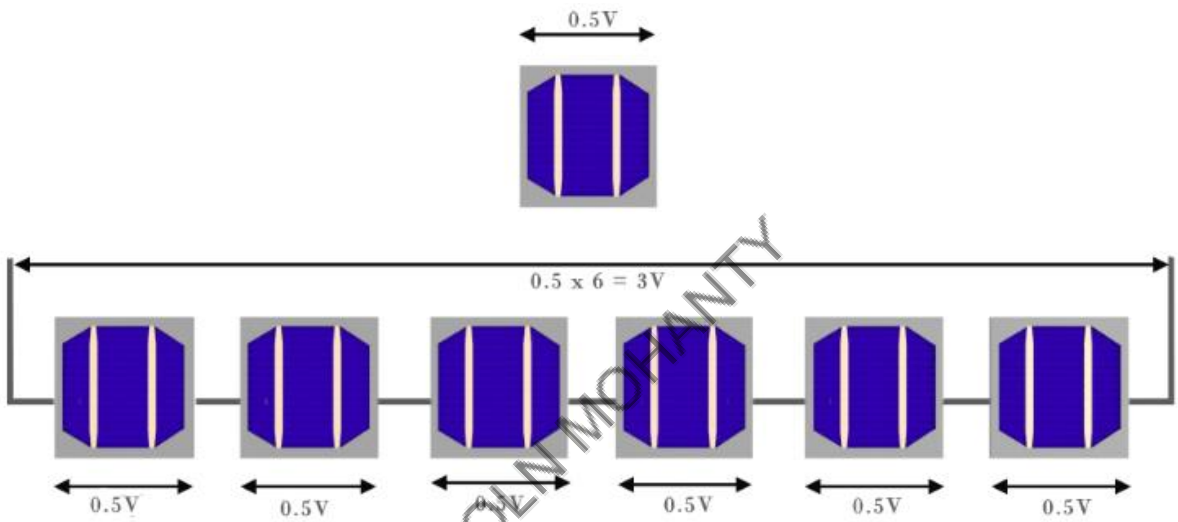
6.5 Solar Module

Also called solar panels, a solar module is a single photovoltaic panel that is an assembly of connected solar cells. The solar cells absorb sunlight as a source of energy to generate electricity. An array of modules are used to supply power to buildings.

A single solar cell cannot provide required useful output. So to increase output power level of a PV system, it is required to connect number of such **PV solar cells**. A solar module is normally series connected sufficient number of solar cells to provide required standard output voltage and power. One solar module can be rated from 3 watts to 300 watts. The solar modules or PV modules are commercially available basic building block of a solar electric power generation

system.
Actually a single solar PV cell generates very tiny amount that is around 0.1 watt to 2 watts. But it is not practical to use such low power unit as building block of a system. So required number of such cells are combined together to form a practical commercially available solar unit which is known as **solar module or PV module**.

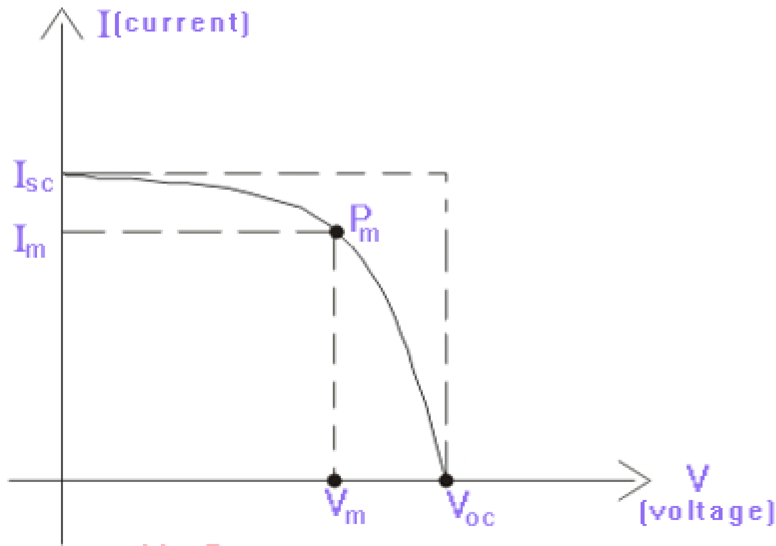
In a solar module the solar cells are connected in same fashion as the battery cell units in a battery bank system. That means positive terminals of one cell connected to negative terminal voltage of solar module is simple sum of the voltage of individual cells connected in series in the module.



Series Connected Solar Module

V-I Characteristic of Solar Module

If we draw a graph by taking X-axis as voltage axis and Y-axis as currents of a solar module, then the graph will represent V-I characteristic of a solar module.



V - I Characteristics

Fill Factor of a Solar Module

Fill factor of a solar module is defined as the ratio of maximum power ($P_m = V_m \times I_m$) to product of open circuit voltage (V_{oc}) and short circuit current (I_{sc}).
Higher the Fill Factor(FF), better is the solar module.

$$\therefore Fill\ Factor\ (FF) = \frac{P_m}{V_{oc} \times I_{sc}}$$

Efficiency of Solar Module

Efficiency of solar module is defined as the ratio of maximum power at standard test condition, to the input power. Input power of a solar module is solar radiation which is considered as 1000 w/m^2. So, actual input power to the cell is 1000A W. Where, A is the exposed area of the solar module.
Therefore, efficiency,

$$N = \frac{P_m}{1000A} \times 100\%$$

6.6 Further System Components -

Solar inverters

A solar inverter or photovoltaic (PV) inverter is a type of power inverter which converts the variable direct current (DC) output of a photovoltaic solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical balance of system (BOS)–component in a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar power inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

Mounting Systems

Photovoltaic mounting systems (also called solar module racking) are used to fix solar panels on surfaces like roofs, building facades, or the ground. These mounting systems generally enable retrofitting of solar panels on roofs or as part of the structure of the building (called BIPV). As the relative costs of solar photovoltaic (PV) modules has dropped, the costs of the racks have become more important and for small PV systems can be the most expensive material cost. This has caused an interest in small users deploying a DIY approach. Due to these trends, there has been an explosion of new racking trends. These include non-optimal orientations and tilt angles, new types of roof-mounts, ground mounts, canopies, building integrated, shading, vertical mounted and fencing systems.

Storage Batteries

There are four types of solar batteries: lead-acid, lithium-ion, nickel cadmium, and flow batteries. The most popular home solar batteries are lithium-ion. Lithium-ion batteries can come as AC or DC coupled. AC-coupled batteries can be connected to existing solar panel systems, while DC-coupled batteries are most suited for being installed at the same time as solar panels.

1.Lead acid batteries: Lead acid batteries are the tried and true technology of the solar battery world.

These deep-cycle batteries have been used to store energy for a long time - since the 1800's, in fact. And they’ve been able to stick around because of their reliability.

There are two main types of lead acid batteries: flooded lead acid batteries and sealed lead acid batteries.

2. **Lithium ion batteries:** Lithium ion batteries are the new kids on the energy storage block.

As the popularity of electric vehicles began to rise, EV manufacturers realized lithium ion’s potential as an energy storage solution. They quickly became one of the most widely used solar battery banks.

3. **Nickel cadmium batteries:** Nickel cadmium (Ni-Cd) batteries aren't as widely used as lead acid or lithium ion batteries.

Ni-Cd batteries first sprung on the scene in the late 1800's, but they got a makeover in the 1980s that greatly increased how much energy they could store. They are a favorite amongst the aircraft industry.

4. **Flow batteries:** Flow batteries are an emerging technology in the energy storage sector.

They contain a water-based electrolyte liquid that flows between two separate chambers, or tanks, within the battery. When charged, chemical reactions occur which allow the energy to be stored and subsequently discharged. These batteries are now beginning to rise in popularity.

Their larger size makes them more expensive than the other battery types. The high price, combined with the large size, makes it hard to adapt them to residential use. However, redflow manufacturers a residential flow battery, which they call ZCell.

CHAPTER-7:

WIND ENERGY

Movement of air is called wind, which is created by (i) uneven heating of earth surface (local wind), (ii) the rotation of earth around its axis (planetary winds).

Local winds: Unequal heating & cooling of ground surfaces & warm bodies in day & night i.e., lake, sea, desert etc.

Planetary wind: Caused by rotation of the earth about its axis & the combined effect of different in temperature at equator & pole region. Warm air moves from tropical region to pole & cold air from pole to tropical region.
Wind energy is a source of renewable power which comes from air current flowing across the earth's surface. Wind turbines harvest this kinetic energy and convert it into usable power which can provide electricity for home, farm, school or business applications on small (residential), medium (community), or large (utility) scales.

Wind energy is one of the fastest growing sources of new electricity generation in the world today. These growth trends can be linked to the multi-dimensional benefits associated with wind energy.

- **Green Power:** The electricity produced from wind power is said to be "clean" because its generation produces no pollution or greenhouse gases. As both health and environmental concerns are on the rise, clean energy sources are a growing demand.
- **Sustainable:** Wind is a renewable energy resource; it is inexhaustible and requires no "fuel" besides the wind that blows across the earth. This infinite energy supply is a security that many users view as a stable investment in our energy economy as well as in our children's' future.
- **Affordable:** Wind power is a cost-competitive source of electricity, largely due to technological advancements, as well as economies of scale as more of these machines are manufactured and put online around the world.
- **Economic Development:** As well as being affordable, wind power is a locally-produced source of electricity that enables communities to keep energy dollars in their economy. Job creation (manufacturing, service, construction, and operation) and tax base increase are other economic development benefits for communities utilizing wind energy.

7.1 Wind Flow and Wind Direction

Thermal wind balance

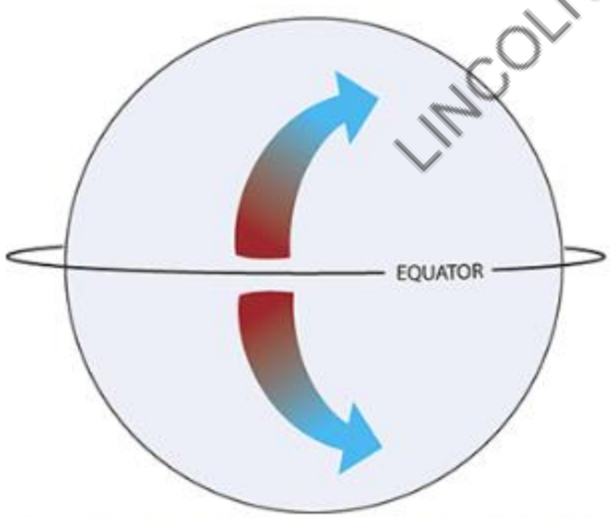
Thermal wind is the first of four main types of atmospheric flow. The most complex type of wind, it drives weather systems across the globe. It’s born from differences in the temperatures between the equator and the poles.

Thermal wind is what is created as those masses flow down this slope, carrying heat away from the equator. Meteorologists refer to this natural movement of solar energy out of the equator as “poleward heat transport.” Without it, most folks living outside the tropics would be buried beneath a sheet of ice. The equator would also be hot as a furnace.

As sun-warmed air rises near the equator and begins to move toward the poles, it also starts to drift eastward. This is due to Earth’s spin. It swirls the air from west to east around the planet.

That poleward-moving air also speeds up — dramatically. This is because Earth is an *oblique* (Oh-BLEEK) spheroid. If you took horizontal slices of the planet, those slices would be widest at the equator and narrowest at the poles. As Earth’s radius “shrinks” as one approaches the poles, the air has to speed up. This is because the air gets funneled into a smaller and smaller path. As it does so, its flow rate increases. (This process is due to what’s known as the *conservation of angular momentum.*) In the Northern Hemisphere, this makes the air flow to the right with increasing speed. This swirling action is known as the Coriolis force.

Earth’s rotation and the change in the planet’s radius mean that moving air will always want to turn a bit to the right in the Northern Hemisphere (and the opposite direction in the Southern Hemisphere). This affects everything. A football tossed from one end of a stadium to another will naturally deflect 1.26 centimeters (a half inch) to the right! It’s also why winds in the upper atmosphere are relatively weak near the equator. Closer to the mid-latitudes, they howl. They’ve curved so much to the right that they often are speeding eastward at an impressive clip.



The Earth’s spin causes air to flow a bit to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

The jet stream

This is how the *jet stream* forms. This current of air snakes around the planet at speeds greater than 322 kilometers (200 miles) per hour. It's found winding its way directly overhead of the strongest temperature contrasts at the surface.

This temperature gradient creates a steep density "hill" in the atmosphere where the air quickly sloshes down. The more rapidly it moves, the more the northern jet stream curves east. It's just like riding a bicycle down a hill: The steeper the slope, the faster you go.

But as the air moves poleward, it never actually gets *to* the poles. Instead, it curves to the right rapidly because of Earth's rotation and that Coriolis force. As a result, the jet stream meanders as it circles the Earth in each hemisphere. In the North, it moves air west to east in a circle around the mid-latitudes (and the opposite in the Southern Hemisphere), changing its path from season to season.

Poleward of the jet stream, the atmosphere is turbulent. Dozens of "eddies" of high and low pressure rotate around the globe, dragging wacky weather with them. On the equator side, the flow is described as "laminar." That means it's relaxed, and not chaotic.

Along this temperature boundary, a fierce atmospheric battleground develops. Colliding air masses of different temperatures spin up cyclones and other severe weather. Indeed, that's why meteorologists refer to the jet stream's position as a "storm track."

The position of the jet stream influences the type of weather a region encounters. Consider the Northern Hemisphere, for instance. From December through February, the sun doesn't reach the North Pole. This allows an extensive dome of super-cold air to bank up nearby. Atmospheric scientists refer to this flowing pool of cold air and low pressure as the *polar vortex.* It swells in size during winter. And when this flow of cold air surges southward, it pushes the jet stream into southern Canada and the northern United States. That can bring seemingly endless snowstorms to the upper Midwest and Northeast during the dead of winter.

Geostrophic winds

In summer, the poles warm. This weakens the temperature gradient between these zones and the equator. The jet stream responds by retreating some 1,600 kilometers (a thousand miles) northward. Now, the weather in the lower 48 U.S. states calms down. Sure, scattered thunderstorms erupt from time to time. But there are no huge storm systems spanning 1,600 kilometers or more to influence day-to-day events. Instead, the weather becomes *geostrophic* (GEE-oh-STRO-fik) — meaning relatively tranquil.

Ordinarily, air would flow from high pressure to low pressure. It would move across a *pressure gradient.* So the driving force would be known as the *pressure gradient force.* But the Coriolis force is still at play. So as parcels of air try to move down the gradient, they're tugged to the right in the Northern Hemisphere (and the opposite direction in the southern one). These two forces cancel out. Like a perfectly-matched game of tug-of-war, the air isn't yanked in either direction. It just meanders slowly around large pressure systems.

As a result, the air ends up circling around high- or low-pressure systems without moving toward or away from them. Closer to the surface, the flow is slightly *ageostrophic* (meaning the winds are no longer in complete balance), due to the effects of friction with things at or near the surface.

Other large-scale wind-balancing effects

Sometimes, however, a low-pressure system spins *so* fast that a *third* force develops. It's the same outward shove you feel on a merry-go-round or a vehicle rounding a corner. This is *centrifugal force.*

Rings of air in constant balance between these two forces spin around a storm's center indefinitely. Their rather constant distance from the center is due to what's known as *cyclostrophic* (Sy-klo-STROW-fik) balance. This represents a harmony — complementary actions — of the pressure-gradient and centrifugal forces.

On rare occasions, the Coriolis, centrifugal and pressure-gradient forces can all counteract one another. This perfect trifecta marks what scientists call *gradient wind balance.* It's not worth a lot of fanfare. It does, however, dictate which way air parcels will move along the outer edges of a cyclone, any spinning column of air.

Clearly, there are a lot of moving parts that control the way the wind blows.

Local winds

The last category of winds are the ones you experience every day. And they're different depending on where you are. Head down to the beach, for instance. On sunny days in the afternoon, air over land warms and rises. Cooler air sitting above the ocean rushes in to coastal regions, filling the void caused by the air rising over land.

This generates a line of puffy little cumulus (KEWM-u-lus) clouds that die out after the sun sets. Along peninsulas like Florida, colliding sea breezes can result in *convergent* winds. These colliding air masses force pockets of moist air high up into the atmosphere, forming thunderstorms. That's why folks in the Southeast always carry umbrellas, even on sunny mornings. The "self-destruct" sunshine routinely generates scattered afternoon boomers.

The same process that sparks these storms reverses overnight. Since the ground cools faster than the water, the direction of the flow of air reverses. Instead of a sea breeze, a "land breeze" develops. Now, storms move out from the land, to the ocean. That's the reason many people along the Gulf Coast can enjoy gorgeous offshore displays of evening lightning.

7.2 Wind Measurements

Wind speed is typically measured using an instrument called an anemometer. Some common methods are :

1. **Cup Anemometer:**
   - This widely used device consists of three or four cups mounted symmetrically around a vertical spindle.
   - The cups are conical or hemispherical in shape.
   - When the wind blows into the cups, it creates a pressure difference inside and outside the cup.
   - This pressure difference, along with the force of the wind, causes the cups to rotate.
   - Electric switches measure the speed of rotation, which is directly proportional to the wind speed.
   - Hot-Wire Anemometer:
   - In this type of anemometer, an electrically heated, thin wire is placed in the wind.
   - The amount of power needed to keep the wire hot is used to calculate the wind speed.
2. **Sonic anemometer:**
   - Where wind measurements are made in extreme weather conditions, such as on the top of mountains, a heated sonic anemometer is used having no moving parts. The instrument measures the speed of acoustic signals transmitted between two transducers located at the end of thin arms. Measurements from two pairs of transducers can be combined to yield an estimate of wind speed and direction.
   - The distortion of the air flow by the structure supporting the transducers is a problem which can be minimized by applying corrections based on calibrations in a wind tunnel.
3. **Measuring gusts and wind intensity:**
   - Because wind is an element that varies rapidly over very short periods of time it is sampled at high frequency (*every 0.25 sec*) to capture the intensity of gusts, or short-lived peaks in speed, which inflict greatest damage in storms. The gust speed and direction are defined by the maximum three second average wind speed occurring in any period.
   - A better measure of the overall wind intensity is defined by the average speed and direction over the ten minute period leading up to the reporting time. Mean wind over other averaging periods may also be calculated. A gale is defined as a surface wind of mean speed of 34-40 knots, averaged over a period of ten minutes. Terms such as 'severe gale', 'storm', etc are also used to describe winds of 41 knots or greater.

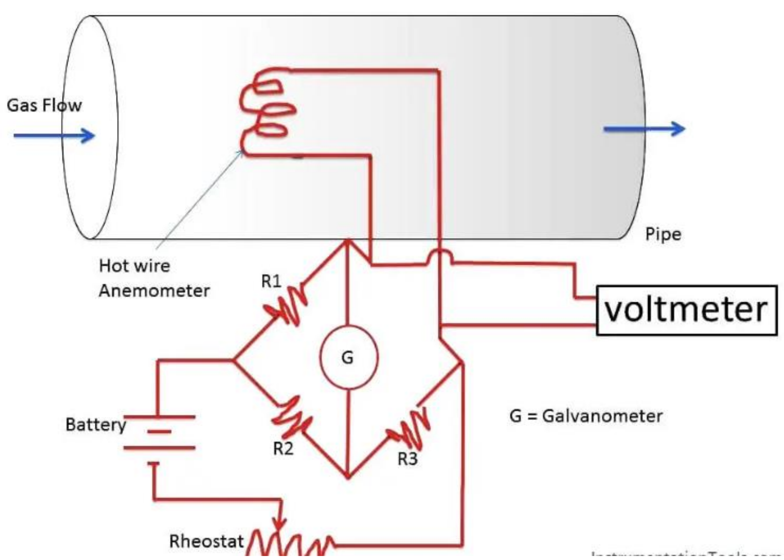
7.3 Measurement of Pressure Head

The pressure on a structure due to wind, which increases with wind velocity approx. in accordance with the formula $p = 0.003\ v^2$, where p is the pressure in pounds per square feet of area affected, and v is the wind velocity in miles per hour.

An anemometer is an instrument that measures wind speed and wind pressure. Anemometers are important tools for meteorologists, who study weather patterns. They are also important to the work of physicists, who study the way air moves.

Air pressure can simply be measured with a barometer by measuring how the level of a liquid changes due to different weather conditions. In order that we don't have columns of liquid many feet tall, it is best to use a column of mercury, a dense liquid. The aneroid barometer measures air pressure without the use of liquid by using a partially evacuated chamber. This bellows-like chamber responds to air pressure so it can be used to measure atmospheric pressure. Air pressure records: 1084 mb in Siberia (1968) 870 mb in a Pacific Typhoon. An Ideal Gas behaves in such a way that the relationship between pressure (P), temperature (T), and volume (V) are well characterized. The equation that relates the three variables, the Ideal Gas Law, is $PV = nRT$ with n being the number of moles of gas, and R being a constant. If we keep the mass of the gas constant, then we can simplify the equation to $(PV)/T = \text{constant}$. That means that: For a constant P, T increases, V increases. For a constant V, T increases, P increases. For a constant T, P increases, V decreases. Since air is a gas, it responds to changes in temperature, elevation, and latitude (owing to a non-spherical Earth). Air pressure decreases naturally as we rise in the atmosphere, or up a mountain, we must make correction to the air pressure owing to elevation above sea level. These corrections are easily made by adding the the air pressure that would be exerted by the air column at that elevation. For example, in the figure below, at sea level no correction is needed. At 1000 m elevation, a correction of 99 mb is required so that the adjusted sea level pressure of station B is 1014 mb. For an elevation of 1800 m, a correction of 180 mb is needed. So, for a temperature of 20°C, the elevation correction is approximately equal to 0.1 x elevation. Note, this correction is good only for approximately 20°C

7.4 Hot wire Anemometer



The bridge arrangement along with the anemometer has been shown in diagram. The anemometer is kept in the flowing gas stream to measure flow rate.

A current is initially passed through the wire.

Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and this tends to change the temperature and hence the resistance of the wire.

The principle in this method is to maintain the temperature and resistance of the sensing wire at a constant level. Therefore, the current through the sensing wire is increased to bring the sensing wire to have its initial resistance and temperature.

The electrical current required in bringing back the resistance and hence the temperature of the wire to its initial condition becomes a measure of flow rate of the gas when calibrated.

7.5 Cup Anemometer (Robinson's Anemometer)

An anemometer is an instrument used to measure the speed of the wind, which is a common weather station instrument, or to calculate any form of current gas. The term is derived from the Greek word anemos meaning wind which was first explained by Leon Battista Alberti who was an Italian artist and an architect in the year 1450. He used a mechanical anemometer which was placed perpendicular to the wind direction such that the wind velocity as indicated by the angle of inclination of the disc.

How To Make An Anemometer

Anemometer can be easily made by assembling a few basic materials. There are various types of anemometer depending on different situations, measurements, and ecosystems. An anemometer also uses Ultrasonic and Laser techniques to get accurate measurements of the wind.

For the science experiment of 5th grade, the anemometer is prepared with disposable cups. It is commonly called as Robinson Anemometer. It uses disposable cups to catch the wind that induces to spin. To calculate the wind speed, one has to measure the number of spins in a given time interval. This will show how fast the wind is moving.

Materials Required

- 5 small paper cups
- Empty plastic bottle
- 3 thin wooden dowels
- Scissors
- Hole punch
- Duct tape
- Stopwatch

Procedure

- Make a hole on the side of four paper cups using the hole punch.
- The last cup will be the center of an anemometer, make 4 holes evenly spaced around the rim of the last cup.
- Slide 2 wooden dowels through the holes in the center cup.
- Now insert the other end of the wooden dowels into the other cups holes and tape them. Make sure that all cups are facing the same direction.
- Use the last wooden dowel and attach it to the bottom of the center cup.
- Put the center wooden dowel into an empty plastic bottle.

Observation

The cup anemometer expressed in this experiment is not capable of displaying the wind speed, but it can give an idea of how fast the wind is blowing. However, you can record the speed of wind using this anemometer only by measuring revolutions per minute. Meanwhile, the higher capacity anemometer that is used in weather forecasting measures the wind speed by kilometer per hour or miles per hour.

You can keep a record of the wind by revolution per minute for a few days and calculate the average wind speed in a week. You can also check the wind speed at different times of the day. Verifying the speed in the morning, afternoon, evening, and at night.

Uses Of Anemometer

Other than measuring the speed of the wind, the anemometer is used for the following purposes:

- To measure the wind pressure.
- To measure the flow of the wind.
- To measure the direction of the wind.
- It is used by the drone users or RC plane users to check the weather conditions before testing their devices.
- Also used by long-range shooters and pilots.
- Used by skydivers to evaluate wind velocity before they leap into the abyss.
- Used in aerodynamics to measure the airspeed.

7.6 Wind Direction Indicators

Wind direction indicators, also known as wind tells, are devices or visual cues used by sailors to determine the direction and strength of the wind while out on the water. They provide valuable information for sail trim, tacking, boat handling, and overall navigation.

Wind direction indicators come in various forms, and their purpose is to show the relative wind direction and sometimes wind speed. Here are some common types of wind direction indicators:

Wind Vane: A wind vane is a physical device that is mounted on top of the mast or another elevated location on the boat. It typically consists of a small arrow or fin that points into the wind. The boat's crew can visually observe the wind vane to determine wind direction by noting the direction in which the vane is pointing. WindTrak is a popular type of wind vane that consists of a lightweight vertical spar or pole with an arrow-shaped indicator at the top. It is designed to pivot freely and align itself with the wind. The WindTrak is mounted on top of the mast, making it easily visible to the crew.

Windsock: A windsock is a fabric tube open at both ends. It is commonly found in marinas, on docks, or onshore near water bodies. The windsock's shape and movement provide an indication of wind direction and sometimes wind speed. Sailors can observe the windsock from a distance to assess the prevailing wind conditions.

Ribbon or Streamers: Sailors sometimes attach lightweight ribbons or streamers to the shrouds, stays, or other parts of the rigging. These fluttering indicators can help provide a visual reference of the wind direction and intensity.

Telltale Streamers: Telltales (such as Davis Instruments' Air-Flow Tels) are small strips of fabric or lightweight material attached to the sails or rigging. They are strategically placed to indicate the airflow over the sail surface. By observing the movement of telltales, sailors can fine-tune their sail trim to optimize performance based on wind direction.

Wind direction indicators are essential tools for sailors as they provide real-time information about the wind, helping them make informed decisions about sail adjustments, boat heading, tacking and overall strategy. By interpreting the information provided by wind direction indicators, sailors can harness the wind effectively and sail their boats more efficiently.