RENEWABLE ENERGY SOURCES

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UNIT–I: Fundamentals of Energy Systems and Solar energy Energy conservation principle – Energy scenario (world and India) – various forms of renewable energy - Solar radiation**:** Outside earth's atmosphere – Earth surface – Analysis of solar radiation data – Geometry – Radiation on tilted surfaces – Numerical problems.

Conservation of energy:

In physics and chemistry, the law of conservation of energy states that the total energy of an isolated system remains constant; it is said to be conserved over time. This law means that energy can neither be created nor destroyed; rather, it can only be transformed or transferred from one form to another. For instance, chemical energy is converted to kinetic energy when a stick of dynamite explodes. If one adds up all the forms of energy that were released in the explosion, such as the kinetic energy and potential energy of the pieces, as well as heat and sound, one will get the exact decrease of chemical energy in the combustion of the dynamite. Classically, conservation of energy was distinct from conservation of mass; however, special relativity showed that mass is related to energy and vice versa by $E = mc^2$, and science now takes the view that mass–energy is conserved.

ENERGY SCENARIO INTRODUCTION

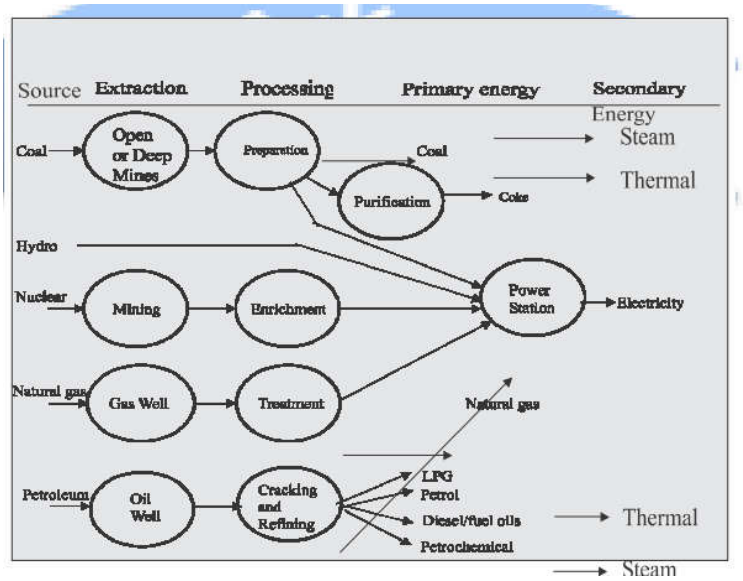
Any physical activity in this world, whether carried out by human beings or by nature, is cause due to flow of energy in one form or the other. The word 'energy' itself is derived from the Greek word 'en-ergon', which means 'in-work' or 'work content'. The work output depends on the energy input.

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever- increasing energy needs requiring huge investments to meet them.

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy
- Conventional and Non-conventional energy
- **Primary and Secondary energy**

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources are shown in Figure Primary energy sources are costly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.



Commercial Energy and Non Commercial Energy

Commercial Energy The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.

Examples: Electricity, lignite, coal, oil, natural gas etc.

Non-Commercial Energy The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

Renewable and Non-Renewable Energy

1. Renewable energy: 'Energy obtained from natural and persistent flows of energy occurring in the immediate environment'. An obvious example is solar (sunshine) energy, where 'repetitive' refers to the 24-hour major period. Note that the energy is already passing through the environment as a current or flow , irrespective of there

being a device to intercept and harness this power. Such energy may also be called Green Energy or Sustainable Energy.

2 Non-renewable energy: 'Energy obtained from static stores of energy that remain underground unless released by human interaction'. Examples are nuclear fuels and fossil fuels of coal, oil and natural gas. Note that the energy is initially an isolated energy potential, and external action is required to initiate the supply of energy for practical purposes. To avoid using the ungainly word 'non-renewable', such energy supplies are called finite supplies or Brown Energy.

Conventional and Non-conventional energy resources:

Conventional Energy: Conventional energy resources which are being traditionall**y** used for many decades and were in common use around oil crisis of 1973 are called conventional energy resources, e.g., fossil fuel, nuclear and hydro resources.

Non-conventional energy: Non-conventional energy resources which are considered for large – scale use after oil crisis of 1973, are called non-conventional energy sources, e.g., solar, wind, biomass, etc.

Advantages & disadvantages of Nonconventional/renewable energy sources:

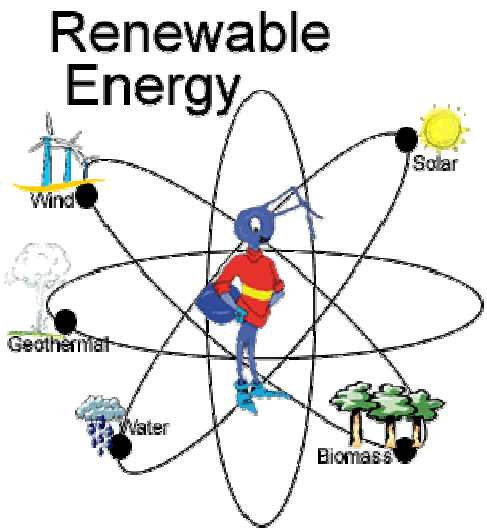
Advantages:

1.Available free of cost
2. Cause no or very little pollution
3. Environment-friendly
4. Inexhaustible
5.Have low gestation period
6. Do not deplete natural resources
7. Can sustain energy supply for many generations.

Disadvantages:

1. available in dilute form in nature
2. Cost of harnessing energy is very high
3. Availability is uncertain
4. Difficulty in transporting such resources

1.



Types of Non conventional Energy Sources:

¬ Solar Energy (energy from sun)
¬ Wind energy
¬ Energy from Bio Mass
¬ Geothermal Energy
¬ Energy from Oceans
  ♣ OTEC
  ♣ Tidal Energy, wave Energy
  ♣ Small Scale Hydro electric (Mini & Micro)
¬ Chemical energy sources
¬ Hydrogen energy
¬ Magneto hydro dynamics

Potential of NCES:

¬ The non-conventional sources of energy in the country are available in abundance and their potential is need to be utilized particularly in a country like India where the basic economy of the majority of the people about 73 percent is based on

agriculture and the demand of energy of rural population is less as compared to urban settlements. In a scenario of increasing urbanization and increasing demands on commercial energy there is an urgent need to utilize the non-conventional source of energy which has a large potential in the country.

¬ Our coastal areas have a large potential of wind energy while the potential of solar energy in the country is of 20 MW / Km2. "Bio-gas" is another source of energy which also has a big potential as we have a bulk of live stock. Majority of our rural population still depends upon the locally available non-conventional sources of energy based on animal dung, crop waste and full wood etc.

¬ In order to ensure the efficient use of conventional energy in an environment friendly manner, it is important to promote the programmers for use of nonconventional energy sources. So far, our national effort in development and application of renewable energy has not yielded it any result of significance.

Table 1.1 Comparison of renewable and conventional energy systems

	Renewable energy supplies (green)	*Conventional energy supplies (brown)*
Examples	Wind, solar, biomass, tidal	Coal, oil, gas, radioactive ore
Source	Natural local environment	Concentrated stock
Normal state	A current or flow of energy. An income	Static store of energy. Capital
Initial average intensity	Low intensity, dispersed: $\leq 300\,W\,m^{-2}$	Released at $\geq 100\,kW\,m^{-2}$
Lifetime of supply	Infinite	Finite
Cost at source	Free	Increasingly expensive.
Equipment capital cost per kW capacity	Expensive, commonly $\approx$US\$1000 kW^{-1}	Moderate, perhaps \$500 kW^{-1} without emissions control; yet expensive >US\$1000 kW^{-1} with emissions reduction
Variation and control	Fluctuating; best controlled by change of load using positive feedforward control	Steady, best controlled by adjusting source with negative feedback control
Location for use	Site- and society-specific	General and invariant use
Scale	Small and moderate scale often economic, large scale may present difficulties	Increased scale often improves supply costs, large scale frequently favoured
Skills	Interdisciplinary and varied. Wide range of skills. Importance of bioscience and agriculture	Strong links with electrical and mechanical engineering. Narrow range of personal skills
Context	Bias to rural, decentralised industry	Bias to urban, centralised industry
Dependence	Self-sufficient and "islanded" systems supported	Systems dependent on outside inputs
Safety	Local hazards possible in operation: usually safe when out of action	May be shielded and enclosed to lessen great potential dangers; most dangerous when faulty
Pollution and environmental damage	Usually little environmental harm, especially at moderate scale Hazards from excess biomass burning Soil erosion from excessive biofuel use Large hydro reservoirs disruptive Compatible with natural ecology	Environmental pollution intrinsic and common, especially of air and water Permanent damage common from mining and radioactive elements entering water table. Deforestation and ecological sterilisation from excessive air pollution Climate change emissions
Aesthetics, visual impact	Local perturbations may be unpopular, but usually acceptable if local need perceived	Usually utilitarian, with centralisation and economy of large scale

Energy Scenario in INDIA:

India is one of the countries with the largest production of energy from renewable sources. In the electricity sector, renewable energy account for 34.6% of the total installed power capacity. Large hydro installed capacity was 45.399 GW as of 31 March 2019, contributing to 13% of the total power capacity. The remaining renewable energy sources accounted for 22% of the total installed power capacity (77.641 GW) as of 31 March 2019.

Wind power capacity was 36,625 MW as of 31 March 2019, making India the fourth-largest wind power producer in the world. The country has a strong manufacturing base in wind power with 20 manufactures of 53 different wind turbine models of international quality up

to 3 MW in size with exports to Europe, the United States and other countries.Wind or Solar PV paired with four-hour battery storage systems is already cost competitive, without subsidy, as a source of dispatchable generation compared with new coal and new gas plants in India.

The government target of installing 20 GW of solar power by 2022 was achieved four years ahead of schedule in January 2018, through both solar parks as well as roof-top solar panels. India has set a new target of achieving 100 GW of solar power by 2022. Four of the top seven largest solar parks worldwide are in India including the second largest solar park in the world at Kurnool, Andhra Pradesh, with a capacity of 1000 MW. The world's largest solar power plant, Bhadla Solar Park is being constructed in Rajasthan with a capacity of 2255 MW and is expected to be completed by the end of 2018. Biomass power from biomass combustion, biomass gasification and bagasse cogeneration reached 9.1 GW installed capacity as of 31 March 2019. Family type biogas plants reached 3.98 million.

Renewable energy in India comes under the purview of the Ministry of New and Renewable Energy (MNRE). India was the first country in the world to set up a ministry of non-conventional energy resources, in the early 1980s. Solar Energy Corporation of India is responsible for the development of solar energy industry in India. Hydroelectricity is administered separately by the Ministry of Power and not included in MNRE targets.

India is running one of the largest and most ambitious renewable capacity expansion programs in the world. Newer renewable electricity sources are projected to grow massively by nearer term 2022 targets, including a more than doubling of India's large wind power capacity and an almost 15 fold increase in solar power from April 2016 levels. These targets would place India among the world leaders in renewable energy use and place India at the centre of its "Sunshine Countries" International Solar Alliance project promoting the growth and development of solar power internationally to over 120 countries. India set a target of achieving 40% of its total electricity generation from non-fossil fuel sources by 2030, as stated in its Intended Nationally Determined Contributions statement in the Paris Agreement. A blueprint draft published by Central Electricity Authority projects that 57% of the total electricity capacity will be from renewable sources by 2027.[7] In the 2027 forecasts, India aims to have a renewable energy installed capacity of 275 GW, in addition to 72 GW of hydro-energy, 15 GW of nuclear energy and nearly 100 GW from “other zero emission” sources.

Global Primary Energy Reserves*

Coal: The proven global coal reserve was estimated to be 9,84,453 million tonnes by end of 2003. The USA had the largest share of the global reserve (25.4%) followed by Russia (15.9%), China (11.6%). India was 4th in the list with 8.6%. **Oil:** The global proven oil reserve was estimated to be 1147 billion barrels by the end of 2003. Saudi Arabia had the largest share of the reserve with almost 23%. (One barrel of oil is approximately 160 litres) Gas The global proven gas reserve was estimated to be 176 trillion cubic metres by the end of 2003. The Russian Federation had the largest share of the reserve with almost 27%. (*Source: BP Statistical Review of World Energy, June 2004) World oil and gas reserves are estimated at just 45 years and 65 years respectively. Coal is likely to last a little over 200 years Global Primary Energy Consumption The global primary energy consumption at the end of 2003 was equivalent to 9741 million tonnes of oil equivalent (Mtoe).

Energy Distribution Between Developed and Developing Countries

Although 80 percent of the world's population lies in the developing countries (a fourfold population increase in the past 25 years), their energy consumption amounts to only 40 percent of the world total energy consumption. The high standards of living in the developed countries are attributable to high energy consumption levels. Also, the rapid population growth in the developing countries has kept the per capita energy consumption low compared with that of highly industrialized developed countries. The world average energy consumption per person is equivalent to 2.2 tonnes of coal. In industrialized countries, people use four to five times more than the world average, and nine times more than the average for the developing countries. An American uses 32 times more commercial energy than an Indian.

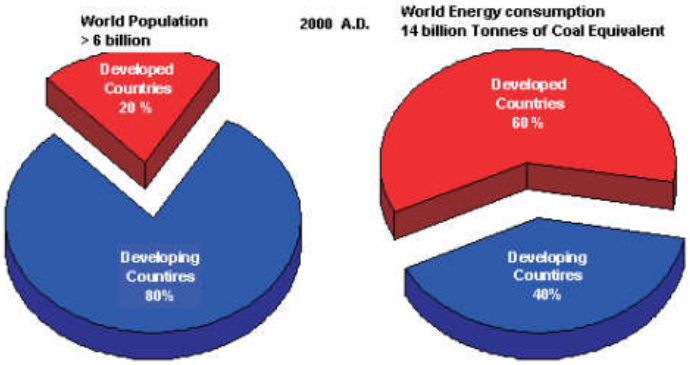


Figure 1.4: Energy Distribution Between D eveloped and Developing Countries

Non conventional energy sources:

The conventional energy sources discussed above are exhaustible and in some cases, installation of plants to get energy is highly expensive. In order to meet the energy demand of increased population, the scientists developed alternate nonconventional natural Resources sources of energy which should be renewable and provide a pollution free environment.

Some nonconventional, renewable and inexpensive energy sources are described below:

1. Solar energy:

Solar energy, a primary energy source, is non-polluting and inexhaustible.

There are three methods to harness solar energy:

(i) Converting solar energy directly into electrical energy in solar power stations using photo cells or photovoltaic cells or silicon solar cell.

(ii) Using photosynthetic and biological process for energy trapping. In the process of photosynthesis, green plants absorb solar energy and convert it into chemical energy, stored in the form of carbohydrate.

(iii) Converting solar energy in to thermal energy by suitable devices which may be subsequently converted into mechanical, chemical or electrical energy.

Since solar energy is non-ending and its conversion to some other energy form is nonpolluting, attention should be paid for the maximum utilization of solar energy.

2. Wind energy: Wind is air in motion. The movement of air takes place due to the convection current set out in the atmosphere which is again due to heating of earth's surface by solar radiation, rotation of earth etc. The movement of air occurs both horizontally and vertically.

The average annual wind density is 3 kW/m^2/day along costal lines of Gujarat, western ghat central parts of India which may show a seasonal variation (i.e., in winter it may go up to 10kW/m^2/day).]

Since wind has a tremendous amount of energy, its energy can be converted into mechanical or electrical energy using suitable devices, now days, wind energy s converted in to electrical energy which is subsequently used for pumping water, grinding of corns etc. As per available data dearly 20,000 mW of electricity can be generated from wind. In Puri, wind farms are set up which can generate 550 kW of electricity.

3. Tidal energy:

The energy associated with the tides of the Ocean can be converted in to electrical energy. France constructed the first tidal power plant in 1966. India could take up Ocean thermal energy conversion (OTEC) and by the process it will be capable of generating 50,000 mW of electricity, to meet the power requirements of remote oceanic islands and coastal towns. The Netherlands is famous for windmills. In India, Gujarat and Tamil nadu have windmills. The largest wind farm has been set at Kanyakumari which generates 380 mW of electricity.

4. Geothermal energy:

The geothermal energy may be defined as the heat energy obtainable from hot rocks present inside the earth crust. At the deeper region of earth crust, the solid rock gets melted in to magma, due to very high temperature. The magma layer is pushed up due to some geological changes and get concentrated below the earth crust. The places of hot magma concentration at fairly less depth are known as hot spots.

These hot spots are known as sources of geothermal energy. Now a days, efforts are being made to use this energy for generating power and creating refrigeration etc. There are a quite few number of methods of harnessing geothermal energy. Different sites of geothermal energy generation are Puga (Ladakh), Tattapani (Suraguja, M.P.), Cambay Basin (Alkananda Valley, Uttaranchal).

5. Bio-mass based energy:

The organic matters originated from living organisms (plants and animals) like wood, cattle dung, sewage, agricultural wastes etc. are called as biomass. These substances can be burnt to produce heat energy which can be used in the generation of electricity. Thus, the energy produced from the biomass is known as biomass energy.

There are three forms of biomass:

(i) Biomass in traditional form:

Energy is released by direct burning of biomass (e.g. wood, agricultural residue etc.)

(ii) Biomass in nontraditional form:

The biomass may be converted in to some other form of fuel which can release energy. For example carbohydrate can be converted into methanol or ethanol which may be used as a liquid fuel.

(iii) Biomass for domestic use:

When organic matters like cow dung, agricultural wastes, human excreta etc. subjected to bacterial decomposition in presence of water in absence of air, a mixture of CH_4, $C0_2$, H_2, H_2S etc. is produced. These gases together is known as biogas. The residue left after the removal of biogas is a good source of manure and biogas is used as a good source of non-polluting fuel.

6. Biogas:

Biogas is an important source of energy to meet energy, requirements of rural area. As per given data, around 22,420-million m^3 of gas can be produced from the large amount of cow dungs obtained in rural areas in a year. The gas is generated by the action of bacteria on cow dung in absence of air (oxygen). There are two types of biogas plants namely. Fixed done type and floating gas holder type (Fig.4.3 & 4.4).

These plants are commonly known as Gobar gas plants because the usual raw material is cow dung (Gobar). The methodology involves in the process is to prepare a slurry of cow dung with water. Sometimes form waters can also be added to the slurry.

The slurry is subjected to bacterial decomposition at 35 .C. There are about 330, 00 biogas plants in India. All India dung production is about 11.30 kg per cattle and 11.60 kg per buffalo with about 67.10 m^3 of gas per ton of wet dung.

7. Petro plants:

In order to release the pressure on mineral oils (a nonrenewable resource), the scientists have discovered some potential plant species from which liquid hydrocarbons can be extracted. The liquid hydrocarbons present in such plants can be converted in to petroleum. Such plants are known as petro plants which belong to families Apocynaceae, Ascalepiadaceae, Euphrobiaceae; Convolvulaceae and Spontaceae. Still research is on to increase the biomass of the petro plants and effective method of converting their hydrocarbons in petroleum.

8. Dendrothermal energy (Energy plantation):

Due to rapid deforestation and overgrazing, a number of denuded wastelands are formed. On these wastelands, fast growing trees and shrubs may be planted which will provide fuel wood, charcoal, fodder, etc. Through gasification, these plants can produce a lot of energy-

9. Baggasse-based plants:

Bagggasse is generated as a waste product in sugar mills. This can be utilised to produce electrical energy. As per available data, the sugar mills in India can generate about 2000 mW surplus electricity during crushing season.

10. Energy from urban waste:

Sewage and solid municipal wastes can also generate energy on their suitable treatments.

What is solar Energy: so·lar en·er·gy (Noun) :Radiant energy Emitted by the sun Solar power is energy from the sun. "Solar" is the Latin word for "sun" and it's a powerful source of energy. Without it, there will be no life. Solar energy is considered as a serious source of energy for many years because of the vast amounts of energy that is made freely available, if harnessed by modern technology.

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaic‟s, solar thermal electricity, solar architecture and artificial photosynthesis, which can make considerable contributions to solving some of the most urgent energy problems the world now faces.[1][2] Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longerterm benefits. It will increase countries‟ energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared

Environmental Impact of solar power

Solar energy has the potential to dramatically change the way the world gets its power. Enough solar energy falls on a 100-square-mile area of the southwestern United States to power the entire nation. While solar is among the world's cleanest forms of energy, plans to develop utility scale solar farms have raised concerns about potential environmental impacts.

Climate Change

The burning of fossil fuels for energy remains the world's No. 1 source of carbon dioxide emissions. Solar power is sometimes described as a zero emissions or emissions-free form of energy, and it is true that greenhouse gas emissions from solar are negligible . However, the construction of new utility scale solar energy projects is bound to result in some greenhouse gas emissions. This fact is acknowledged in the Final Environmental Impact Statement for one proposed solar farm in California.

Water

Creating energy is a water intensive process. In the U.S., electricity production accounts for more than 40 percent of all daily freshwater withdrawals. Solar photovoltaic systems do not require any water to generate electricity. Some solar thermal systems use water, but this water can be reused. Utility scale parabolic and central tower solar energy systems use steam plants to produce power, often relying on water for cooling . There is some concern that these types of systems, when located in arid environments, could put a strain on local water resources.

Land

When placed on existing structured, such as the rooftop of a home or office building, solar energy systems require negligible amount of land space. Utility scale solar farms, on the other hand, do require large amounts of land to produce electricity on a commercial scale. This fact raises concerns about the potential impact of such

projects on natural habitats, concerns the EPA is working to address by citing renewable energy projects on contaminated lands and mine sites.

Hazardous Waste

Solar photovoltaic panels may contain hazardous materials that could be released when a panel is damaged or disposed of improperly . Concentrating solar energy systems may also use potentially hazardous materials like oils and molten salts, creating the potential for spills.

Visual

One person's beauty is another person's eyesore. For some, solar panels evoke positive feelings, even when set in a natural landscape. For others, the sight of a solar panel invading a pristine desert environment is gut wrenching. It's largely a matter of opinion.

Solar Radiation on Earth's Surface:

Solar irradiance (SI) is the power per unit area (watt per square metre, W/m^2), received from the Sun in the form of electromagnetic radiation as reported in the wavelength range of the measuring instrument. Solar irradiance is often integrated over a given time period in order to report the radiant energy emitted into the surrounding environment (joule per square metre, J/m^2), during that time period. This integrated solar irradiance is called **solar irradiation**, **solar exposure**, **solar insolation**, or **insolation**.

Irradiance may be measured in space or at the Earth's surface after atmospheric absorption and scattering. Irradiance in space is a function of distance from the Sun, the solar cycle, and cross-cycle changes. Irradiance on the Earth's surface additionally depends on the tilt of the measuring surface, the height of the sun above the horizon, and atmospheric conditions. Solar irradiance affects plant metabolism and animal behaviour.

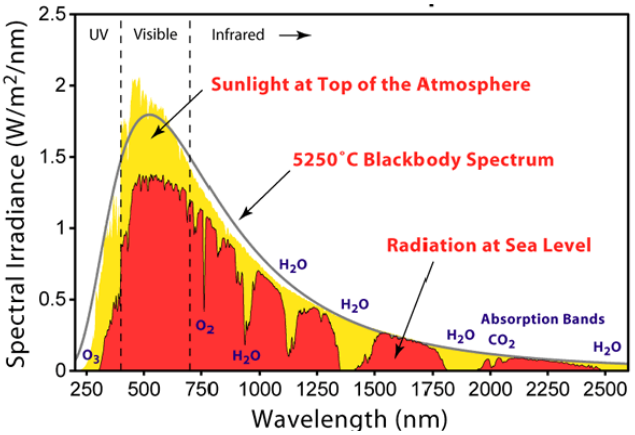
The study and measurement of solar irradiance have several important applications, including the prediction of energy generation from solar power plants, the heating and cooling loads of buildings, and in climate modeling and weather forecasting.

Solar Radiation Spectrum

The concept of solar energy can be abstract. We might know that it is electromagnetic radiation from the Sun, but "WHERE on the electromagnetic spectrum is it?... and "HOW MUCH is there?"

Knowing where and how much gives a person the power of their solar energy inheritance.

Solar Energy is what we've always known as **light**and **heat**.



It's composition is: **6 – 7% ultraviolet light; around 42% visible light and 51% near infra-red**. **99.9%** of the sun's output of energy occurs between 250 and 2500 nanometers. We receive solar energy at an intensity of **1 kilowatt per square meter** at sea level for many hours of the day.

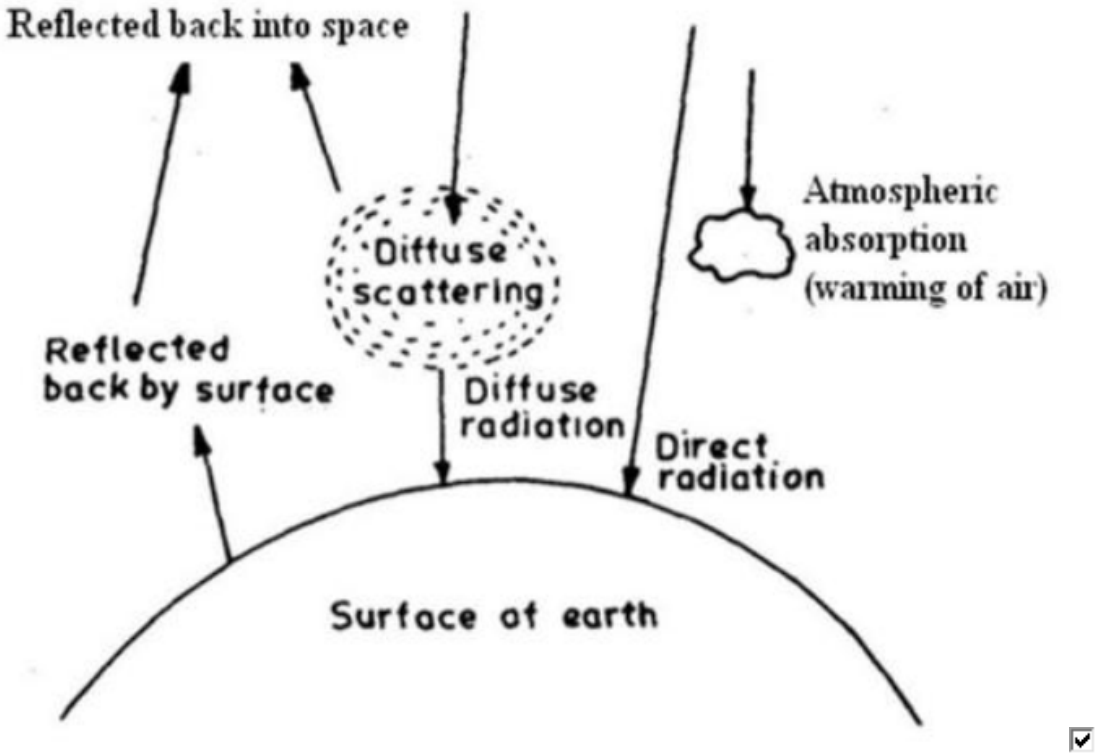
Direct & Diffuse Radiation:

The total or global solar radiation striking a collector has two components, direct beam radiation and diffuse radiation. Additionally, radiation reflected by the surface in front of a collector contributes to the solar radiation received. But unless the collector is tilted at a steep angle from the horizontal and the ground is highly reflective (e.g., snow), this contribution is small.

As the name implies, direct beam radiation comes in a direct line from the sun. For sunny days with clear skies, most of the solar radiation is direct beam radiation. On overcast days, the sun is obscured by the clouds and the direct beam radiation is zero.

Diffuse radiation is scattered out of the direct beam by molecules, aerosols, and clouds. Because it comes from all regions of the sky, it is also referred to as sky radiation. The portion of total solar radiation that is diffuse is about 10% to 20% for clear skies and up to 100% for cloudy skies.

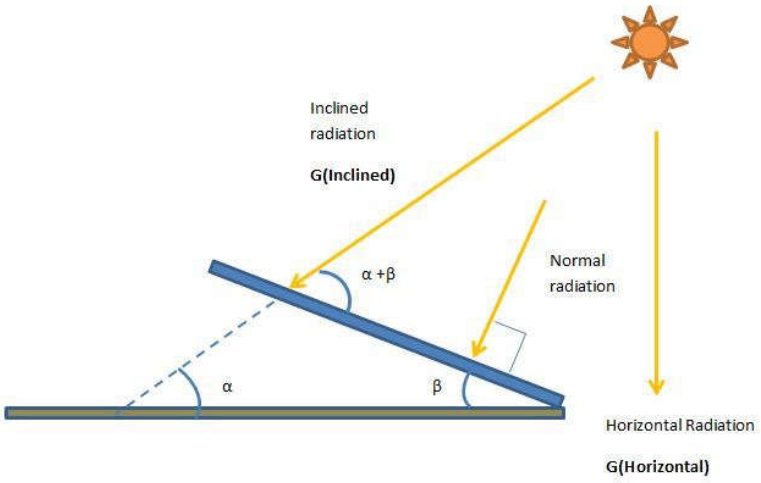
The solar radiation that penetrates the earth"s atmosphere and reaches the surface differs in both amount and character from radiation at the top of the atmosphere. The radiation entering the atmosphere is partly absorbed by molecules, and a part of the radiation is reflected back into the space by clouds. Part of the solar radiation is scattered by droplets in clouds by atmospheric molecules and dust particles. Oxygen and ozone absorb nearly all the ultraviolet radiation where as CO2 and H2O vapor absorbs some energy from infrared range.
1. Part of the radiation is reflected back into the space, especially by clouds.
2. Oxygen and ozone absorbs nearly all the ultraviolet radiation and water vapour and CO2 absorb some of the energy in the infrared range.
3. Some part of the solar energy radiation is scatted by droplets in the clouds by atmospheric molecules, and by dust particles.



Calculating Incident Solar Radiation on Inclined Surface

For every PV installer, hobbyist and Solar Energy consultant, calculating incident Solar radiation on inclined surface can be extremely beneficial for two reasons:

1. Feasibility study can be carried out for a PV panel or a solar water heater installation
2. Optimal tilt angle that maximizes that radiation received can be found for a given location (by reversing the calculation)



Finding solar radiation falling over a slope surface accurately requires complex calculations. It depends upon the time of the day, day of the year, position on earth and also orientation of the receiver.

Most irradiation is received when the receiver is perpendicular to the sun. By employing a tracking system the receiver can be constantly orientated to be perpendicular to sun rays. In many cases the employment of a tracking system is not practical, such as for roof installations. In such cases the receiver has a fixed orientation. The calculation mentioned herein can accept any orientation for the receivers but it has to be a constant value.

In this article, equations of medium complexity are explored.These calculations do not take into account the effect of cloud cover. The use of Microsoft Excel (or any other spread sheet) is most helpful.

Ignoring the cloud cover and other atmospheric effects, the insolation is mainly dependent on two main factors:a) Position of the sun

a) Position of the Sun

The position of the sun is changing constantly in the sky and with that the amount of insolation on the receiver also changes. The position of the sun in the sky is described by the azimuth angle and the elevation angle. The elevation of the sun or how high it is in the sky is dependent upon the latitude as well as declination of the sun. The declination changes from day to day. The elevation angle can be given as: $\alpha=90-\Phi+\delta$ The latitude Φ captures the position on the earth. The declination δ captures time of the year.

For this mid-level calculation, the time of the day which is represented by the hour angle ω is not taken into account.

b) Orientation of the Receiver

The orientation of the receiver has two main features:

- What direction it is facing? (North, South, South East etc.) What is the tilt angle of the receiver?

The direction of the receiver is also sometimes referred to as aspect of the receiver. As mentioned earlier, for simplicity, the orientation of the receiver is considered fixed. To maximize the solar insolation the receiver should be kept facing due south in Northern Hemisphere and vice-versa in Southern Hemisphere.

The energy received on the inclined surface G(inclined) is given as:

G (inclined) = G(horizontal) * Sin (α+β) / Sinα

The latitude **Φ** that is required for the calculation of the elevation angle **α** can be found out for any location.
The declination can be calculated for a location using the following formula:

δ= 23.45° * Sin[360/365 (284+d)]

Where d is the day of the year. d = 1 for 1st January, d = 365 for 31st December.

2.3.2. Solar Insolation

The term *solar insolation* (*incident solar radiation*) is defined as the solar radiation received on a flat horizontal surface on earth at a particular instant of time. It depends on the following parameters.

1. Daily variation (Hour angle).
2. Seasonal variation and geographic location of the particular surface.
3. Atmospheric clarity.
4. Shadows of trees, tall structures, adjacent solar panels, etc.
5. Degree of latitude of the location.
6. Area of exposed surface, m^2
7. Angle of tilt of solar panel.

2.3.4. Sum at Zenith and Air Mass (*m*)

Sum at zenith is defined as the position of the sun directly overhead.

Air mass is the path length of radiation through the atmosphere considering the vertical path at sea level as unity. The air mass *m* is the ratio of the path of the sun rays through the atmosphere to the length of path when the sun is at the zenith.

$m =$ 1, when the sun is at Zenith, *i.e.*, directly overhead.

$m =$ 2, when Zenith angle is 60°.

$m =$ sec θ_z when $m > 3$

$m = 0$ just above the earth's atmosphere.

The *transmission coefficient* or *transmittance* of the atmosphere for direct solar radiation under clear sky condition at sea level is defined as the ratio between the intensity of solar radiation received on the earth's surface and the intensity of extraterrestrial radiation.

2.3.7. Solar Radiation Geometry

In the solar radiation analysis, the following angles are useful.

(i) Latitude of location (ϕ_l):

The latitude of a place is the angle subtended by the radial line joining the place to the centre of the earth with the projection of the line on the equatorial plane. The latitude is taken as *positive* for any location towards the northern hemisphere and *negative* towards the southern hemisphere. For example, the latitude at equator is 0° while at north and south poles are +90° and –90° respectively.

(ii) Declination (δ):

The declination (δ) is the angular distance of the sun rays north (or south) of the equator. It is the angle made by the line joining the centres of the sun and the earth with its projection on the equatorial plane. The value of this angle varies from a maximum of +23.5° on June 21 to minimum of –23.5° on December 21.

The declination for any day can be calculated from Cooper equation given by

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right] \text{ degrees} \quad \ldots. \quad (2.1)$$

where, n = day of the year

(iii) Hour angle (ω):

It is the angle through which the earth must turn to bring the meridian of the plane directly in line with the sun rays. The hour angle (ω) is equivalent to 15° per hour. This angle can also be defined as the

angular displacement of the sun, east or west of the local meridian due to rotation of the earth on its axis at an angle of 15° per hour.

The latitude, hour angle and sun's declination angle are shown in Figure 2.2.

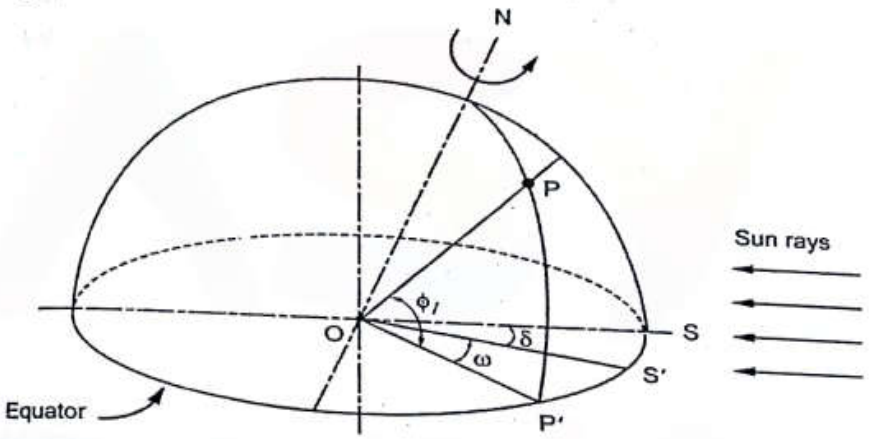


Figure 2.2 Latitude ϕ_l, hour angle ω, and sun's declination δ

(iv) Solar Azimuth angle (γ_S):

It is the solar angle in degrees along the horizon east or west of north. In other words, it is a horizontal angle measured from north to the horizontal projection of the sun rays. This angle is positive when measured from west.

(v) Surface Azimuth angle (γ):

It is the angle of deviation of the normal to the surface from the local meridian, the zero point being south, east positive and west negative.

(vi) Slope or Tilt angle (β):

It is the angle made by the plane surface with the horizontal. It taken to be positive for surfaces sloping towards the south a negative for surface sloping towards the north.

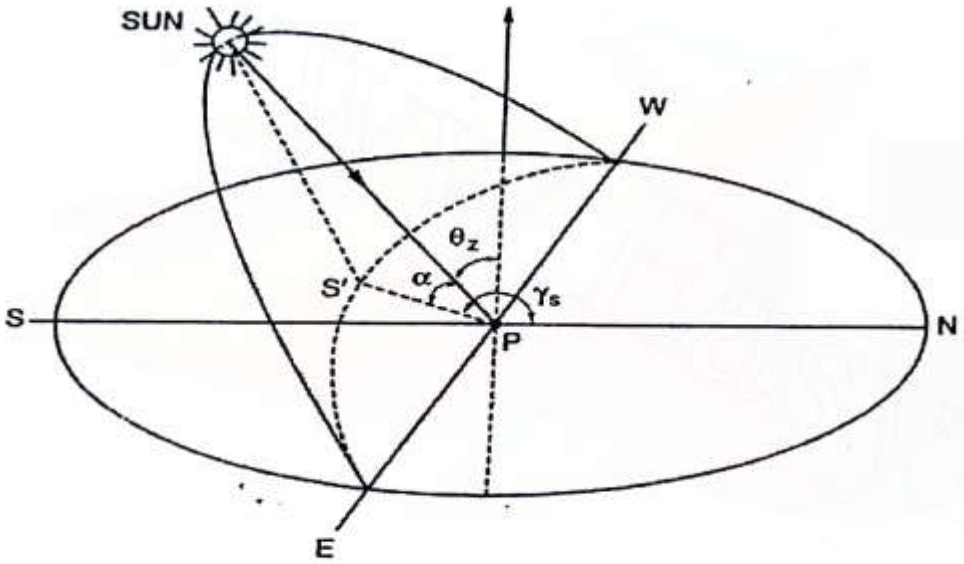


Figure 2.3 Sun's zenith, altitude and azimuth angles

(vii) Altitude angle (α):

It is a vertical angle between the projection of sun rays on the horizontal plane and the direction of sun rays passing through the point.

(viii) Zenith Angle (θ_Z):

It is complimentary angle of sun's altitude angle. It is a vertical angle between the sun rays and a line perpendicular to the horizontal plane through the point.

$$\theta_z = \frac{\pi}{2} - \alpha$$

(ix) Incident angle (θ):

It is the angle being measured between beam rays and normal to the plane. If θ is the angle between an incident beam radiation I and the normal to the plane surface, then the equivalent flux or radiation intensity falling normal to the surface is given by I cos θ. Here, θ is known as *incident angle*.

For the spherical geometry, the relation between θ and other angles is given by

$$\begin{aligned}\cos\theta = {} & \sin\phi_l\,(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) \\ & + \cos\phi_l\,(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) \\ & + \cos\delta\sin\gamma\sin\omega\sin\beta\end{aligned}$$

where
ϕ_l = latitude
δ = declination angle
β = slope or tilt angle
ω = hour angle
γ = surface azimuth angle

2.3.8. Day Length, Sunrise and Sunset

It is evident from our day-to-day life that during summer, sun rises early and sets later and during winter, the sun rises late and sets early. Therefore, the day is longer during summer and shorter during winter. It is due to the fact that the angle of latitude (from equator to north pole) increases during summer and decreases during winter. Hence, the sunrise hour, sunset hour and day-length depends upon the latitude of location and season and day in the year.

Let us consider, the hour angle for sunset and sunrise is ω_s, the horizontal surface equation (2.3) given above may be rewritten by considering the sun light is exactly parallel to the ground surface and hence substituting $\theta = 90°$.

$$\omega_s = \cos^{-1}(-\tan\phi_l \tan\delta) \quad \ldots. (2.6)$$

Total day-length $= \omega_s + \omega_s = 2\omega_s$

$$= 2\cos^{-1}(-\tan\phi_l \tan\delta)$$

Since $15°$ of the hour angle is equivalent to 1 hour, $2\cos^{-1}(-\tan\phi_l \tan\delta)°$ corresponds to $\left[\frac{2\cos^{-1}(-\tan\phi_l \tan\delta)}{15}\right]$ hours.

$$\therefore \quad t_d = \frac{2\omega_s}{15} = \frac{2}{15}[\cos^{-1}(-\tan\phi_l \tan\delta)] \text{ hours} \quad \ldots. (2.7)$$

Thus, the length of the day (t_d) is a function of latitude (ϕ_l) and solar declination (δ).

2.3.9. Local Solar Time or Local Apparent Time

The time used for calculating the hour angle is the local solar time (or) local apparent time. The solar time can be obtained from the standard time observed on a clock by applying two corrections. The first correction has a magnitude of 4 minutes for every degree difference in longitude. The second correction called *equation of time correction*. It is due to the fact that the earth's orbit and rate of rotation are subject to small perturbations. This correction is based on experimental observations. Figure 2.4 shows the equation of time correction for different month in a year.

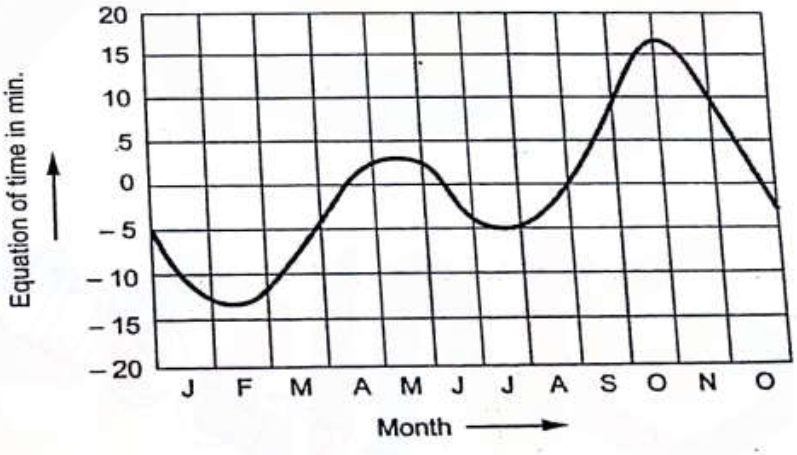


Figure 2.4 Graph of equation of time (E) correction

Local Solar Time (LST)

$$= \text{Standard Time} \pm 4\left[\left\{\begin{matrix}\text{Standard}\\ \text{time}\\ \text{longitude}\end{matrix}\right\} - \left\{\begin{matrix}\text{Longitude}\\ \text{of}\\ \text{location}\end{matrix}\right\}\right] + \left\{\begin{matrix}\text{Equation}\\ \text{of time}\\ \text{correction}\end{matrix}\right\}$$

2.3.10. Apparent Motion of Sun

The rotation of the earth about its axis causes the apparent motion of sun. It changes the angle at which the direct component of light strikes the earth. The sun appears to move throughout the sky from a fixed location of the earth surface. The position of the sun depends on the location of a point on earth, the time of day and the time of a year. Hence, the apparent motion of sun has a major impact on the amount of power received by a solar collector. The power density of the solar collector surface is equal to the inside power density when the sun rays are perpendicular to the collector surface. Intensity of solar radiation on the surface is reduced as the angle between the sun and collector surface changes.

The angle between the fixed location on earth and the sun depends on the particular location i.e. the longitude of the location, the time of year and the time of day. Also, it is the time at which the sun rises and the sun sets which depends on the latitude of the location. Hence, the complete analysis of the sun's angle to a fixed position on earth requires the latitude, longitude, day of the year and time of day.

2.3. MEASUREMENT OF SOLAR RADIATION

It is important to measure solar radiation, owing to the increasing number of solar heating and cooling applications, and the necessity for *accurate solar radiation data to predict performance.*

The following *three* devices are used for measuring the solar radiations.

1. Pyranometer;
2. Pyrheliometers;
3. Sunshine recorders.

2.3.1. Pyranometer

A **pyranometer** is *a device used to measure the "total hemispherical solar radiation"*. The total solar radiation arriving at the outer edge of the atmosphere is called the *'solar constant'*.

The *working principle* of this instrument is that sensitive surface is exposed to total (beam, diffuse and reflected from the earth and surrounding) radiations.

The description of a pyranometer is given below:

Refer to Fig. 2.9.

Construction. It consists of a "black surface" which receives the beam as well diffuse radiations which rises heat. A "*glass dome*" prevents the loss of radiation received by the black surface. A "*thermopile*" is a temperature sensor, and consists of a number of thermo-couples connected in series to increase the sensitivity. The "*supporting stand*" keeps the black surface in a proper position.

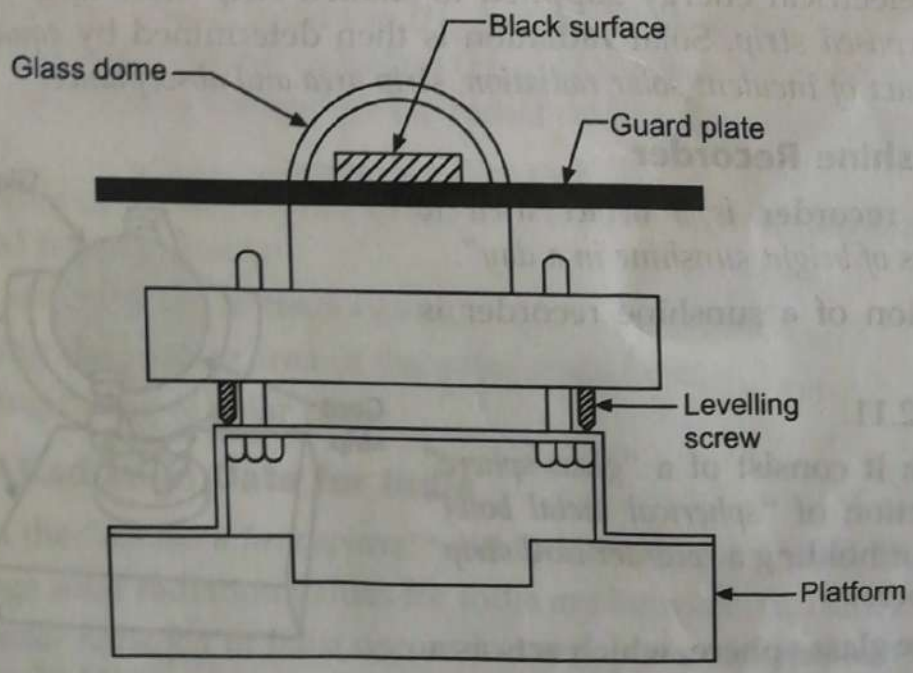


Fig. 2.9. Pyranometer.

Working: When the pyranometer is exposed to sun, it starts receiving the radiation As a result, the surface temperature starts rising due to absorption of the radiation. Th increase in the temperature of the absorbing surface is detected by the *thermopile*. Th thermopile generates a *thermo emf* which is *proportional to the radiations absorbed*; thi thermo emf is *calibrated in terms of the received radiations*. This will measure the globa solar radiations.

2.3.2. Pyrheliometer

A **pyrheliometer** *is a device used to measure "beam or direct radiations"*. It collimates th radiation to determine the beam intensity as a function of incident angle.

This instrument uses a collimated detector for measuring solar radiation from th sun and from a small portion of the sky around the sun at normal incidence.

The description of a thermoelectric type pyrheliometer is given below:

Refer to Fig. 2.10.

Construction: In this instrument, two identical blackened manganin strips A and B are arranged in such a way that either can be exposed to radiation at the base of *collimating tubes* by moving a *reversible shutter*.

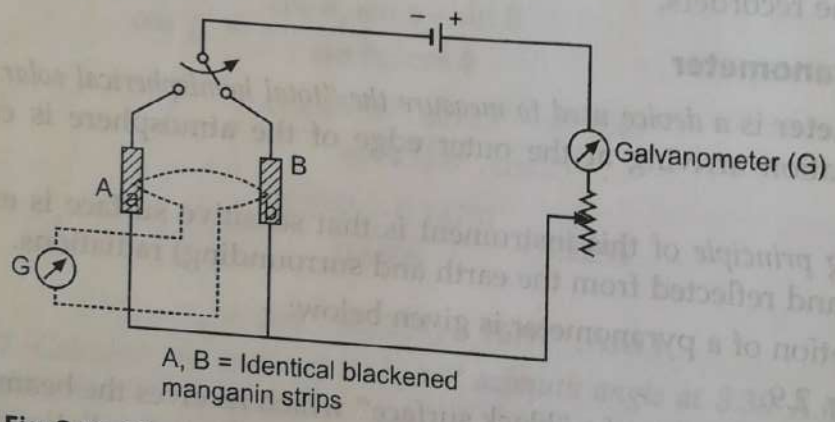


Fig. 2.10. Circuit diagram for the thermoelectric type pyrheliometer.

Working: One strip is placed in radiation and a current is passed through the *shaded strip* to heat it to the same temperature as the *exposed strip*. When there is *no difference in temperature*, the electrical energy supplied to shaded strip *must equal the solar radiation absorbed by the exposed strip*. Solar radiation is then determined by *equating the electrical energy to the product of incident solar radiation, strip area and absorptance*.

2.3.3. Sunshine Recorder

A **sunshine recorder** *is a device used to measure the "hours of bright sunshine in a day"*.

The description of a sunshine recorder is given below:

Refer to Fig. 2.11.

Construction: It consist of a *"glass-sphere"* installed in a section of *"spherical metal bowl"* having grooves for holding a *recorder card strip"* and the glass sphere.

Working. The glass-sphere, which acts as a convex lens, focusses the sun's rays/beams to

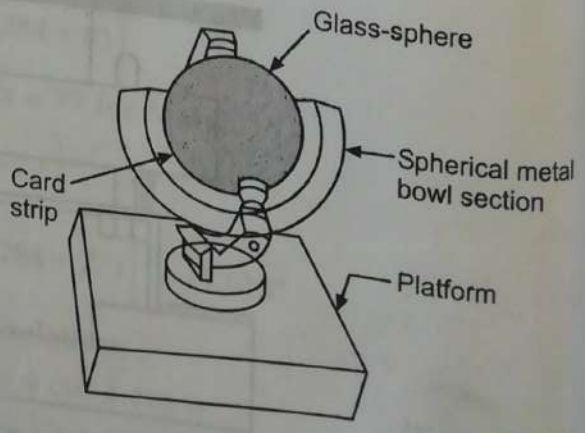


Fig. 2.11. Sunshine recorder.

a point on the card strip held in a groove in the spherical bowl mounted concentrically with the sphere.

Whenever there is a *bright sunshine, the image formed is intense enough to burn a spot on the card strip*. Through the day, the sun moves across the sky, the image moves along the strip. Thus a burnt space whose *length is proportional to the duration of sunshine* is obtained on the strip.

2.4. SOLAR RADIATION DATA

2.4.1. General Aspects

Solar radiation data should include the following informations:

(*i*) Whether they are *instantaneous* measurements or values *integrated* over some period of time (usually hour or days,) (*ii*) The *time* or *time period* of the measurements; (*iii*) Whether the measurements are of *beam, diffuse* or *total radiation* and the *instrument used*; (*iv*) The receiving surface *orientation* (usually horizontal, it may be inclined at a fixed slope or normal); (*v*) If averaged, the *period* over which they are averaged.

An instrument called **Solarimeter** is used to measure most of the data on solar radiation received on the surface of the earth. It gives *readings for instantaneous measurements at rate throughout the day for total radiation on a horizontal surface*. Integrating the plot of rate of energy received per unit area per unit time over a whole day gives the "*langleys*" of radiation received on a horizontal surface (the unit 'langley' has been adopted in honour of Samuel Langley who made the first measurement of the spectral distribution of the sun; 1 *langley* = 1 cal/cm^2).

- When data are *not* available, '**Maps**' can be used as a source of average radiation. **Charts** are also available for *clear day horizontal radiation for any period for any latitude*. **Tables** are also available for *hours of sunshine for various locations*.
- The solar radiation data is collected for various locations in the world on the basis of:

1. Solar power calculations with reference to the movement of the sun, latitude of the location etc.
2. Hourly measurements of solar radiation at the location and calculation of:
   (*i*) "*Daily average*" global radiation (H_{dg}) at the location for the month ($kJ/m^2.day$); (*ii*) "*Monthly average*" global radiation (H_{mg}) at the location for various months ($kJ/m^2.month$); (*iii*) "*Yearly average*" global radiation (H_{yg}) at the location for a few years ($kJ/m^2.year$).

The data in terms of kJ/m^2. day or kWh/m^2. day for various days/months/an year can be readily used for calculating:

(*i*) Available solar energy at the location;
(*ii*) Determining the surface area of the solar collectors;
(*iii*) Determining rating of solar plant.

2.4.2. Solar Radiation Data for India

- India is in the "*northern hemisphere*" within latitudes of 7° and 37.5° N.
- The average solar radiation values for India are between 12.5 and 22.7 $MJ/m.^2$ day.
- The *peak solar radiation in India* occurs in some parts of Rajasthan and Gujrat and is equal to 25 MJ/m^2.
- The solar radiation *reduces to about 60 percent* during monsoon months.

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