RENEWABLE ENERGY SOURCES

MODULE - 01

1. Causes of Energy Scarcity.

At present the whole world is in the grip of energy scarcity, Several countries, including India also, are facing various associated difficulties for its techno-socio-economic development because of energy shortages & Many more things. However, they have been further complicated by the energy dependance on the other countries.

Energy use scenario indicate that how equality (social & economical), can be achieved, 30% population is utilizing 70% of energy & 70% population is forced to live with the 30% of the remaining energy.

Following points may be considered as the principal causes of energy scarcity.

(i) Increasing population:-

Worldwide population is increasing at an alarming rate, these populations are unevenly distributed worldwide. Africa shares the Largest population growth rate, followed by South Asia. & then by europe.

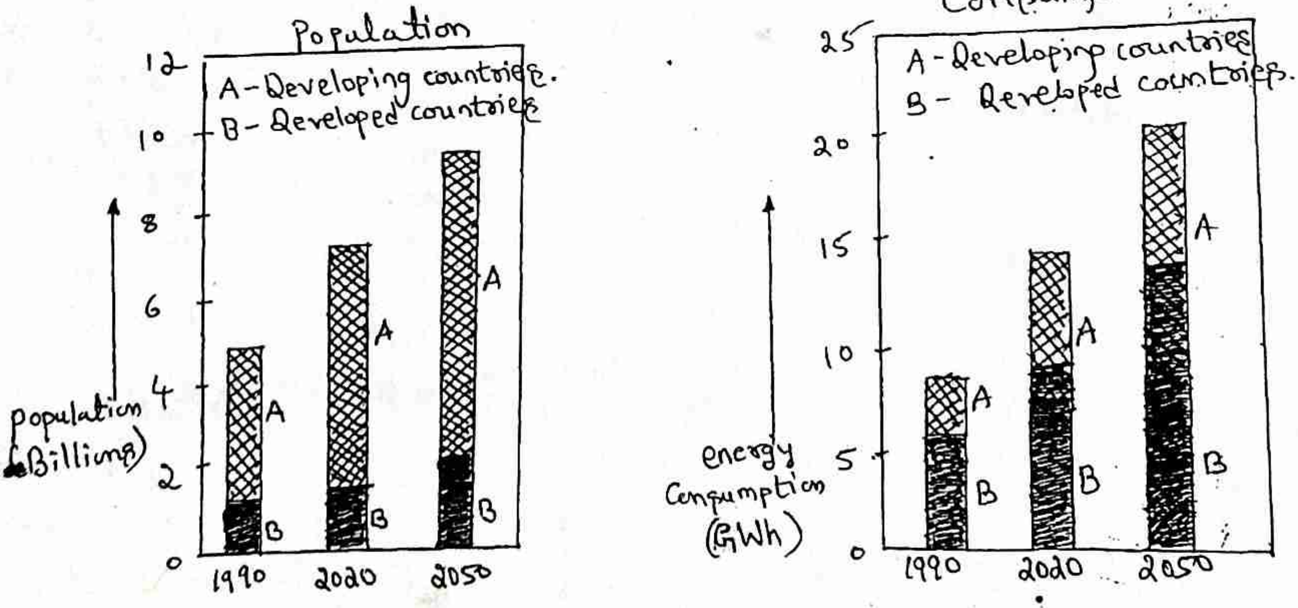


Figure1: Population & energy consumption (energy council).

(ii) Increasing energy usage or consumption:-

An increase in the world population and consequent increase in energy consumption increases energy demands mainfolds. There is a strain on fossil fuels such as oil, gas and coal due to over consumption - which then in turn can put a strain on our water & oxygen resources by causing pollution.

example;. Lighting & cooking, domestic appliances, televisions, computers etc are increasing in modern way of life.

(iii) Uneven Distribution of energy resources:-

Geographical distribution is the main consideration for an unevenly distribution of fossil fuels (coal, oil, gas & nuclear). Renewable energy flows are also spread out unevenly. Cloudiness in equatorial regions reduces solar radiation. Insufficient wind. There are very few sites with the best potential for geothermal, tides or ocean thermal. In fact, a few densely populated region or area have no significant locally available energy sources at all.

(iv) Lack of Technical Knowhow:-

Despite the fact that several countries or regions are having energy in abundance, they are not able to fully utilize them due to the lack of knowledge of conversion, transmission, distribution & utilization.

Because of the lack of technical knowledge, resources are mined & processed in resource enriched countries & then refined & used in developed countries.

(v) Poor Infrastructure
(vi) Unexplored renewable energy options
(vii) Delay in commissioning of power plants
(viii) Wastage of energy.
(ix) Poor Distribution system.
(x) Major Accidents & Natural calamities
(xi) Miscellaneous factors like severe hot summers or cold winter.

energy scarcity or energy crisis.

2. Solution to Energy Scarcity or Energy resources.

Following directions should be systemically diverted to tackle the gignatic energy crunch problems, The solutions are,

(i) Minimizing population growth exploitation & harnessing the Large utilization of known & unknown energy reservoirs.

(ii) Move towards Renewable resources.

(iii) Development of energy conversion techniques to convert basic energy available from energy reservoirs to usable form of energy - such that it is easy to generate, control, transport & utilize.

(iv) Keep the new energy system pollution free as far as possible, thereby environmentally acceptable to human beings.

(v) perform energy audit and Energy management

(vi) Development of cheap & reliable energy storage systems, that should be independent of foreign impact.

(vii) Buy energy efficient products

(viii) Lighting controls, Easier Grid access & Energy simulation.

3. Factors Affecting Energy Resource Development.

The following five factors that make energy resource development more difficult than normally realized.

(i) Energy or Fuel substitution or scale of shift

Today, there is no readily available energy resources that is Large enough to substitute for fossil fuels at requisite scale.

(ii) Energy Density: The amount of energy contained in a unit of material object/energy resource is termed as energy density. for example, the energy density of good quality coal is twice as high (i.e., 25-30 MJ/kg) as that of crude oil (i.e., 42-45 MJ/kg). In order to obtain an equivalent output, replacement of a unit of fossil fuel with approximately 2 kg of phytomass will be needed to substitute solid biofuel. These realities would be reflected in the reserve capacity, cost & operation of the required infrastructure.

(iii) Power Density: Power density refers to the rate of energy production per unit of earth's area and usually expressed in watts per square meters (W/m^2). Owing to lengthy period of formation (from biomass to coal & then from coal to hydrocarbons), fossil fuel deposits are an extraordinarily concentrated source of high quality energy. They are commonly produced with power densities of 10^2 or 10^3 W/m^2 of coal or hydrocarbon field & hence only small land areas are required to supply enormous energy flows. Biomass energy production has densities below $1 W/m^2$, while density of electricity produced by water & wind is below $10 W/m^2$. Only photovoltaic electricity generation can deliver Larger than $20 W/m^2$ although the cost & performance are the constraints of mass utilization.

(iv) Intermittency: Growing demand for fuels, energy, & electricity fluctuates daily & seasonally in modern civilization. Further, the base load, which is defined as the minimum energy required meeting the demand of the day, has been increasing.

On the other hand, wind & direct solar radiation are intermittent & far from practicable. They can never deliver high load factors. Photovoltaic electric generation is still so negligible to offer any meaningfull averages. The annual load factors of wind generation in countries with relatively Large capacities are 20-25%. Unfortunately, we still lack the means for storing wind or solar-generated electricity on a large scale.

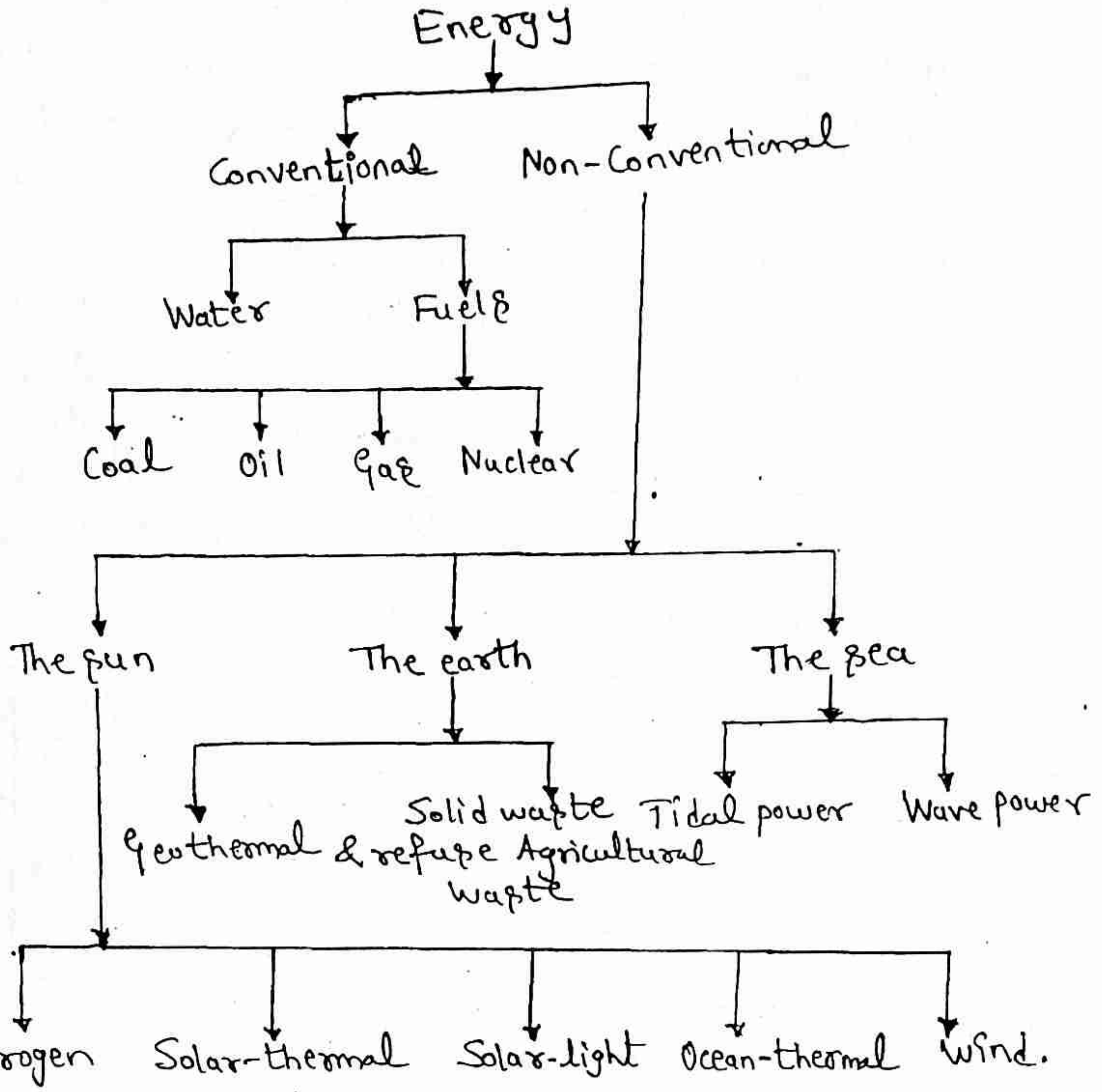
(V) Geographical energy Distribution:-

We know, there are uneven distributions of fossil fuels and non fossil fuels (Solar, wind etc.,). Cloudiness in the equatorial zone reduces direct solar radiation whole stretches of continent has insufficient wind. There are very few sites with the best potential for geothermal, tidal or ocean energy conversions. Based on the abovementioned five basic considerations, energy sources can be considered possible, probable & practicable as given Table 1.

Table 1. Energy options.

Sources	Possible	Probable	Practicable
Solar light	✓	✓	✓
Solar heat	✓	✓	✓
Wind	✓	✓	✓
Water power	✓	✓	✓
Fusion	✓	✓	✓
Fission	✓	✓	✗
MHD	✓	✓	✗
Geothermal	✓	✓	✓
Biomass	✓	✓	✓
Sea Waves	✓	✓	✓
Sea tides	✓	✓	✓
OTEC	✓	✓	✗
Thermionic	✓	✓	✗
Thermoelectric	✓	✓	✓
Super Conducting Gen and Transformer	✓	✓	✗

4. ENERGY RESOURCES AND CLASSIFICATION.



The following are the classification of promising energy resources of immediate interests.

(1) <u>Primary and Secondary energy resources</u>.

* primary energy resources are derived directly from natural reserve.
ex: , chemical fuels, solar, wind, geothermal, nuclear hydropower etc., They are used either in basic raw energy form or by converting them to usable form (secondary energy)

* Secondary energy resources are usable forms of energy generated by means of suitable plants to convert the primary energy.
ex: Steam power, hot water power, electrical energy, hydrogen energy etc.,

primary energy resources further sub-classified as follows
(a) Conventional & Non Conventional energy resources
(b) Renewable & Non-renewable energy resources.

* Conventional energy resources and their technical knowledge are known to mankind to a great extent. They are the energy stored within the earth & the sea. ex: fossil fuels & nuclear energy. These sources have formed over hundreds of millions of years ago and when they are used, there will be no more for future generation.
* Non-Conventional energy resources are also known as infinite energy resources.
* Renewable energy resources are continuously restored by nature.
* Non-Renewable energy resources are the reserve that is once accumulated in nature has practically ceased to form under new geological conditions.

(ii) Oil:- oil companies estimate that the world's proven oil reserves are about 1050 thousand million barrels. This is equivalent to about 6.4X1021 J or 6400 exajoules. Estimates of reserves are always subject to uncertainty and change. There is a very uneven distribution of oil reserves across the world, with some 71% of proven oil reserve being in the middle east. The ultimately recoverable & unconventional reserves are very much more difficult to specify, However, there is general agreement that crude oil is a finite resource that will run short & may sometime become very expensive in the first half of this century.

(iii) Natural Gas:- The proven reserves of natural gas are presently some 152 trillion cubic meters (5900 exajoules), However because gas is more difficult to transport and trade.

There are some prospective regions of the world that have not been fully explored. Technologies for extracting gas constantly improve, thus making it difficult to estimate the sizes of the gas fields.

(iv) Coal:- The world's consumption of coal is still rising (at less than 1% a year), but most industrial countries over recent decades have decreased their dependence on coal. The use of coal is limited more by environmental considerations than by the size of resource. Modern techniques for burning coal using liquefaction & gasification processes can greatly reduce some of the pollutants from coal. However, coal always produces a great deal of carbon dioxide (greenhouse gas). There had been no cost-effecitive way developed for capturing & sequestering this carbon dioxide, but extensive research programs are underway.

(v) Uranium:- The economically accessible reserves of natural uranium were estimated by the World energy council in 1999 at three million tonnes, but due to the slower grown than the expected growth in the nuclear industry & increased availability of uranium & the decommissioning of nuclear weapons, this time frame has been extended. There are public reservations about the cost & the safety of nuclear power plants, but they produce almost no CO_2 & the technology in nature.

(vi) Hydroelectric power:- At present, hydroelectricity provides the second biggest renewable energy contribution to world energy supply, with an annual output of 2600 TWh. Hydropower is dependent on rainfall & climate change could affect this potential. There is also considerable opposition to the building of large dams for social & environmental reasons.

5. Renewable Energy

Renewable energy is the energy that comes from natural resources such as sunlight, wind rain tides & geothermal heat, which are naturally replenished.

(i) Worldwide Renewable Energy Availability

About 16% global final energy consumption comes from renewable as shown in figure 2.

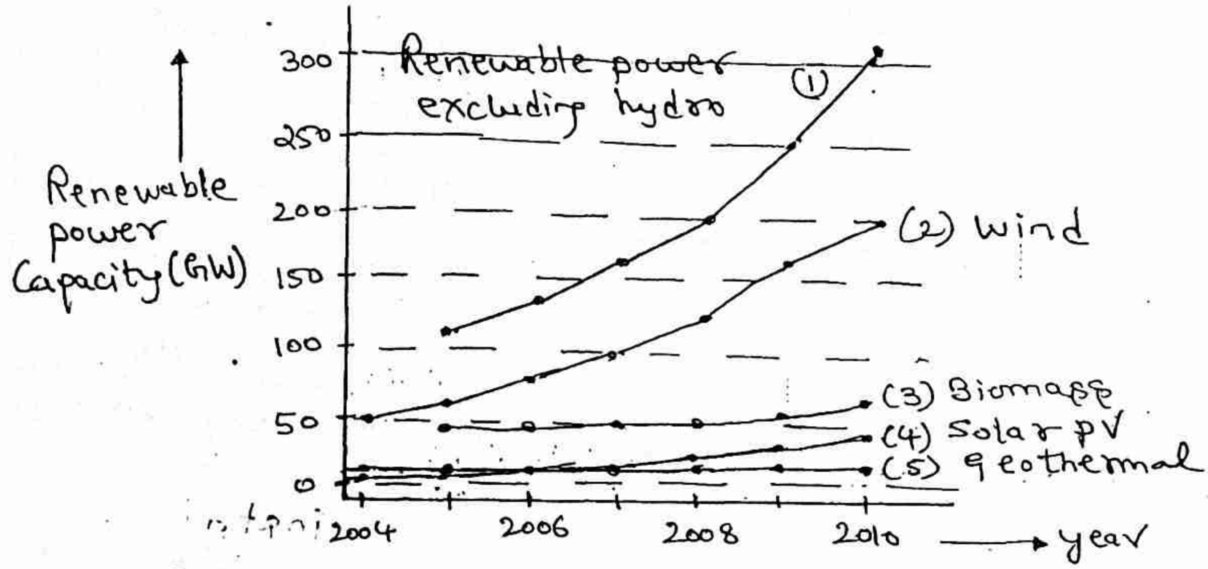


Figure 2: worldwide renewable power capacity excluding hydro.

With 10% coming from traditional biomass, which is mainly used for heating and 3.4% from hydroelectricity.

New renewable energy (small hydro, modern biomass, wind, solar, geothermal and biofuel) accounted for another 3% and were growing very rapidly. The share of renewable energy in electricity generation is around 19%, with 16% of global electricity coming from hydroelectricity and 3% from new renewable energy.

More than half of the energy has been consumed in the last two decades since the industrial revolution, despite advances in efficiency and sustainability. According to IEA world statistics in four years (2004-2008), the world population increased 5% annual CO_2 emissions increased 10% & gross energy production increased 10%.

Potential for worldwide renewable energy is given in table 2.

Energy resource	Energy amount
Solar energy	1600 EJ/440,000 TWh.
Wind power	600 EJ/167,000 TWh.
Geothermal	500 EJ/139000 TWh.
Biomass	250 EJ/70000 TWh
Mini-hydropower	50 EJ/14000 TWh
Ocean Energy	1 EJ/280 TWh.

Table 2: Worldwide Renewable energy potential.

(ii) Renewable Energy in INDIA:-

→ As of December 2011, India had an installed capacity of about 22.4 GW of renewable technology-based electricity, about 12% of its total.

→ As of August 2011, India had deployed renewable energy to provide electricity in 8846 remote villages, installed 4.4 million family biogas plants.

→ Installed 1800 micro-hydel units & 4.7 million square meters of solar water heating capacity.

→ India anticipates adding another 3.6 GW of renewable energy installed capacity by December 2012.

→ India plans to add about 30 GW of installed electricity generation capacity by 2017 based on renewable energy program conducted by the central government's Ministry of New and Renewable energy.

→ Table 3 shows the capacity breakdown by various technologies.

Type	Technology	Installed Capacity (MW)
Grid connected power system	Wind	14989
	Small hydro	3154
	Biomass	1084
	Bagasse Cogeneration	1799
	Waste to energy	74
	Solar	46
Off-grid Captive power	Biomass	141
	Biomass non-Bagasse Cogeneration	328
	Waste to energy	76
	Solar	73
	Hybrid / Aerogen	01

Table:3 India Installed capacity of Renewable energy Till august 2011.

6. SUN-EARTH Geometric Relationship.

→ The earth rotation refers to the spinning of the earth on its axis, one rotation takes exactly 24h and is called a mean solar day.

→ The orbit of the earth around the sun is called earth revolution, to complete one cycle, celestial motion takes 365.25 days.

→ The earth's orbit around the sun is not circular, but elliptical, An elliptical orbit causes the earth's distance from the sun to vary annually.

→ This annual variation in the distance from the sun does influence the amount of solar radiation intercepted by the earth by approximately 8%.

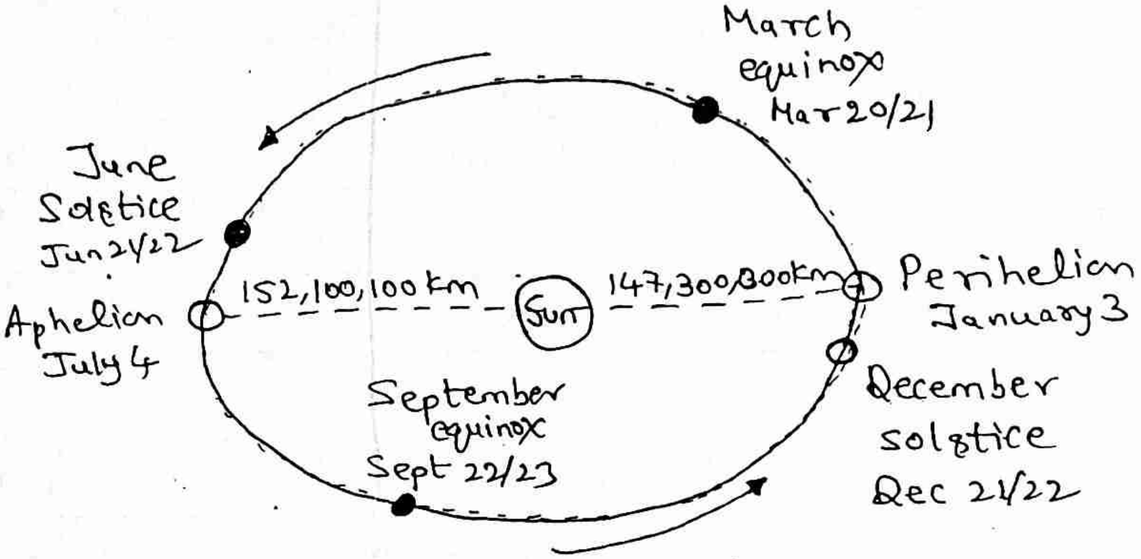


Fig 3. Sun- earth geometry.

→ On January 3rd, the earth comes closest to the sun (147.5 million kilometers) called perihelion.

→ The earth is farthest from the sun on July 4th called Aphelion.

From figure. 3 the following conclusions are derived.

(i) The earth orbit around the sun is elliptical with a mean centre to centre distance from the sun is approximately 9.3×10^6 miles (1.5×10^8 km).

(ii) While the earth makes its daily rotation & yearly revolution, the sun also rotates on its axis approximately once every month.

(iii) The earth's axis of rotation is always inclined at an angle of 23.5° from the ecliptic axis.

(iv) The sun is 109 times Larger in diameter than the earth.

(v) Distance from the sun to the earth varies ±1.7% over the average distance, this causes the solar energy reaching the earth to vary ±3% during a year. The energy is received at its peak on 1st January & the lowest on 1st July.

(vi) The sun appears to move across the sky in an arc from east to west, owing to the rotation of the earth around its north-south axis.

(vii) Viewing the sun from the average miles, it subtends an arc of 0.53° (32 min).

7. Layers of the Sun:-

The sun can be divided into following six layers

1. core
2. Radiative zone
3. convection zone
4. Photosphere
5. Chromosphere
6. Corona.

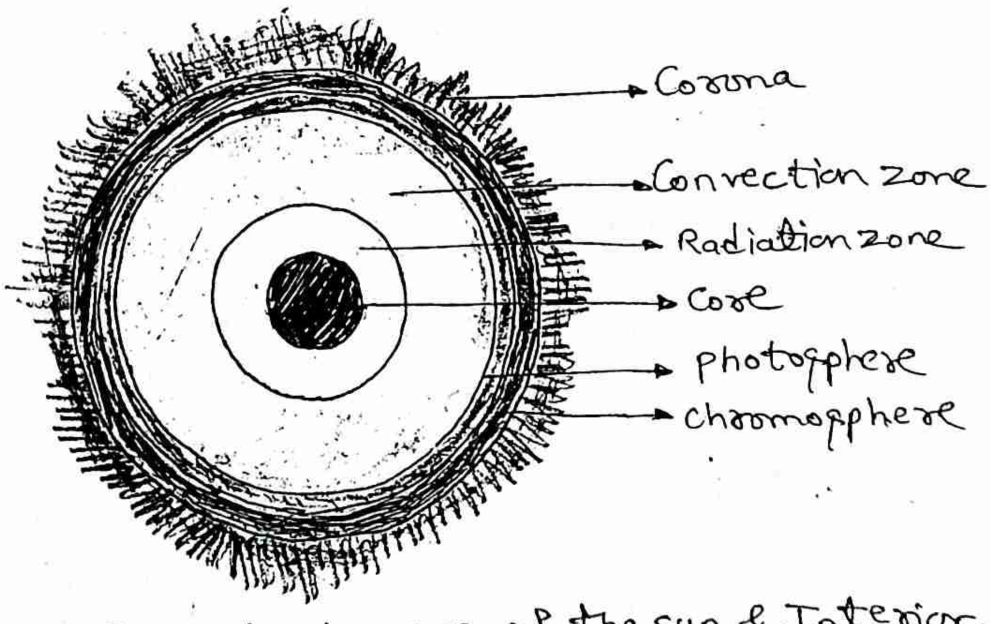


Figure 4. Layers of the sun & Interior.

Core:- The innermost Layer of the sun is called the core. With a density of 160 g/cm^3, which is 10 times that of lead, the core might be expected to be solid.

However, the core's temperature of 1,50,00,000°C keeps it in a gaseous state
In the core, fusion reactions produce energy in the form of gamma rays & neutrinos. Gamma rays are photons with high energy & high frequency.
The neutrinos are extremely non reactive.

Solar envelope:- It consists radiative envelope & convection envelope. Outside of the core is the radiative envelope, which is surrounded by a convection envelope. The temperature is 4 million kelvin. The core contain 40% of the sun's mass in 10% of the volume, whereas solar envelope has 60% of the mass in 90% of the volume. The solar envelope puts pressure on the core & maintains the core's temperature.

Photosphere:- The photo sphere is the zone from which the sunlight is both seen & emitted. The photosphere is a comparatively thin Layer of low-pressure gasses surrounding the envelope. It is only a few hundred kilometers thick with a temperature of 6000°C.

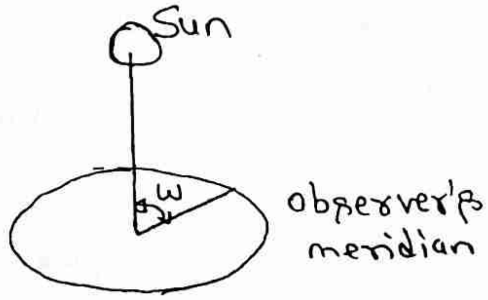
Chromosphere:- During an eclipse, a red circle can sometimes be seen outside the sun, this circle is called the chromosphere. Its red colouring is caused by the abundance of hydrogen. The chromosphere's temperature however, is 7000k, which is hotter than that of the photosphere.

Corona:- The outermost layer of the sun is called the corona. The corona is very thin & faint, therefore very difficult to observe from the earth. Typically we can observe the corona during a total solar eclipse or by using a coronagraph telescope. 10^6 K is corona temperature. The high temperature of the corona can force ions to move as fast as a million kilometers per hour.

8. Earth-Sun Angles and their relationships

In order to understand how to collect energy from the sun, one must first be able to predict the location of the sun relative to the collection device.

(i) **Hour Angle (ω)**:- The hour angle is the angular distance between the meridian of the observer and the meridian whose plane contains the sun.



fig(i) Hour angle(ω).

Hour angle is zero at solar noon (12:00).

Hour angle increases by 15° every hour.

An expression to calculate the hour angle from solar time is,

$$\boxed{\omega = 15 \times (t_s - 12)} \text{; in degrees}$$

where t_s = Solar time in hours

Since earth makes one revolution on its axis in 24h, then 15 minutes will be equal to $\frac{15}{60} = \frac{1}{4}$ min.

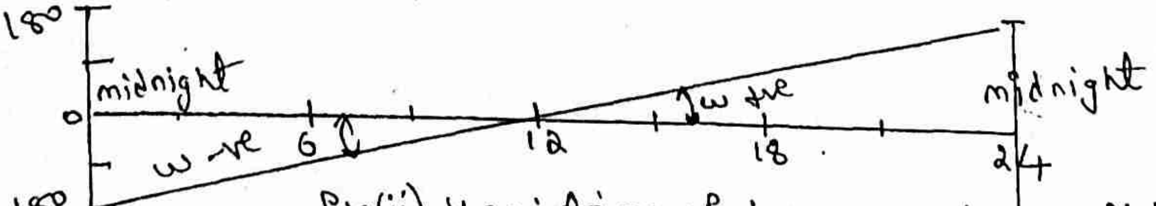
∴ Hour angle (ω) can be calculated simply as follows

$$\boxed{\omega = \frac{1}{4} \times t_m} \text{; in degrees}$$

where t_m = time in minutes after local solar noon,

ω = +ve if solar time is after solar noon.

ω = -ve if solar time is before solar noon. Fig(ii)



fig(ii) Variation of hour angle (ω) 24h.

Example 1

Calculate hour angle when it is 3 h after solar noon

Sol; Solar time $= 12 + 3 = 15:00$

$\therefore \omega = 15 \times (t_s - 12) = 15 \times (15 - 12) = 45°$

Example 2.

Calculate hour angle when it is 2h 20 min before solar noon.

Sol; Solar time $= 12 - [2\text{h } 20\text{min}] = 9:40 = 9$ hour 40 minutes

$9:40 = 9.6667$ hours.

1 hour = 60 min so 40 min = 0.6667 h

$\omega = 15 \times (t_s - 12)$

$= 15 \times (9.6667 - 12)$

$\omega \simeq -35°$

or $\omega = -\frac{1}{4} \times t_m$

$= -\frac{1}{4} \times 140 = -35°$

(ii) Equation of Time (EOT):-

EOT is the difference between the local apparent solar time and the local mean solar time. The actual EOT, which is mathematically defined as apparent solar time minus mean solar time, varies slightly from year to year due to variations in the earth's eccentricity & obliquity and in the time of the solstices and equinoxes. However, for a century, either side of the year 2000, it may be approximated by the formula.

$$EOT = 9.87 \sin(2B) - 7.67 \sin(B + 78.7°) \text{ in minutes} \quad (1)$$

further simplified as

$$EOT = 9.87 \sin(2B) - 7.53 \cos B - 1.5 \sin B \quad (2)$$

where $B = \frac{360(n - 81)}{365}$; in degree $\quad (3)$

Another formula for EOT approximated as.

$$\boxed{EOT = 9.8 \sin(2A) + 7.6 \sin(A - 0.2)} \quad (4)$$

where $A = k \times (n + 10) + 0.033 \sin[k(n - 2)]$, $k = \frac{2\pi}{365}$

n is the total number of days of the year
ex, n=1 on Jan 1 & n=33 for Feb 2.
Note:- During leap year February month will have 29 days.
An approximation for calculating the EOT in minutes is given by Woolf (1968) & is accurate to within about 30s during daylight hours.

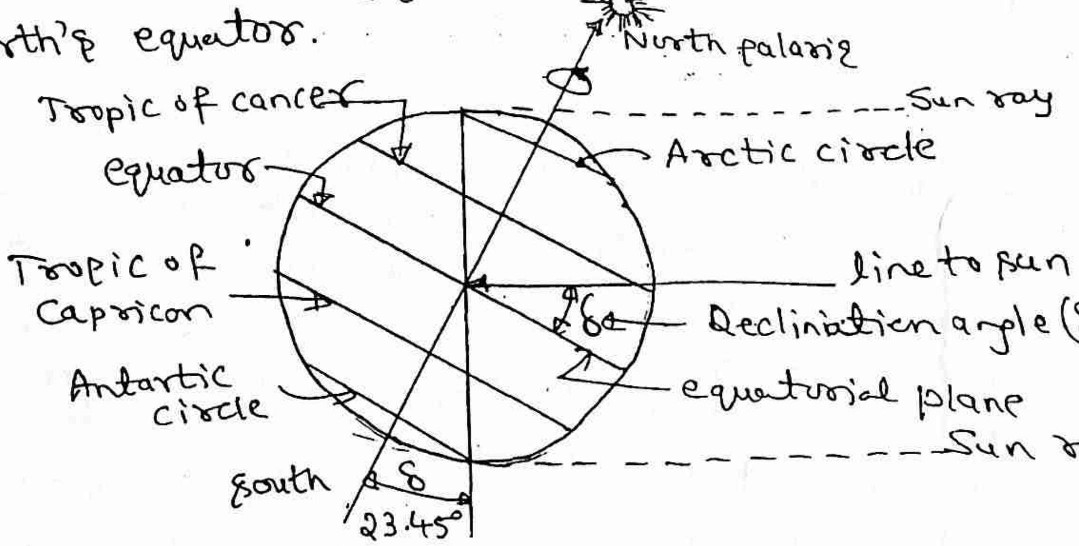
$$\boxed{\begin{aligned} EOT &= 0.258 \times \cos(\alpha_d) - 7.416 \times \sin(\alpha_d) - 3.648 \cos(2\alpha_d) \\ &\quad - 9.228 \times \sin(2\alpha_d); \quad \text{(in minutes)} \end{aligned}} \quad (5)$$

where the angle (α_d) is defined as a function of n.

$$\alpha_d = \frac{360 \times (n-1)}{365.242} \text{ (in degrees)}$$

n = number of days counted from January 1.

(iii) <u>Declination angle (δ):-</u>
The declination angle (δ) of the sun is the angle between the rays of the sun and the plane of the earth's equator.



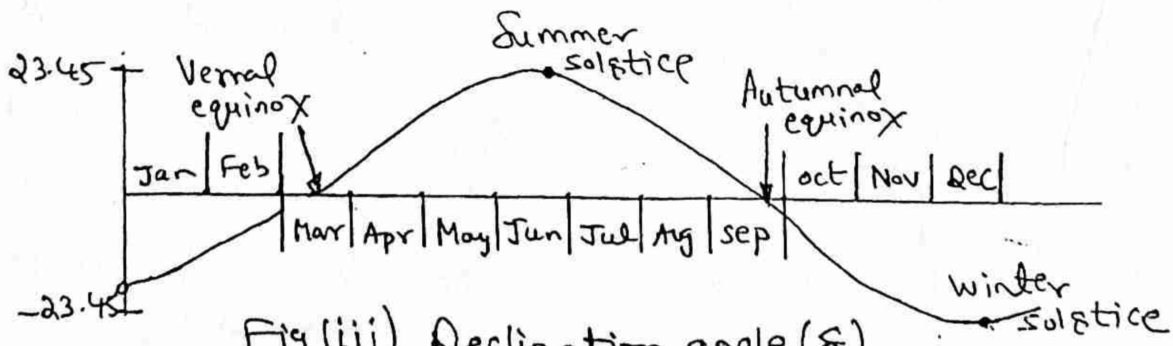


Fig (iii) Declination angle (δ).

At solstices, the angle between the rays of the sun and the plane of the earth's equator reaches its maximum value of $23°26'$.

$\therefore \delta = +23°26'$ at the northern summer solstice.

$\delta = -23°26'$ at the southern summer solstice.

$\delta = 0°$ at equinox

If a line is drawn between the centre of the earth and the sun, then the angle between this line & the earth's equatorial plane is called the declination angle (δ).

The declination angle (δ) can be approximately obtained as

$$\sin(\delta) \approx 0.39795 \cos[0.98563 \times (n-173)]$$

or

$$\boxed{\delta = 23.45 \sin\left[\frac{360 \times (284+n)}{365}\right]}$$

n = total number of days.

(iv) Latitude angle (ϕ).

ie "The Latitute angle(ϕ) is the angle between a line drawn from a point on the earth's surface to the centre of the earth & the earth's equatorial plane."

The intersection of the equatorial plane with the surface of the earth forms the equator & is designated as 0° latitude.

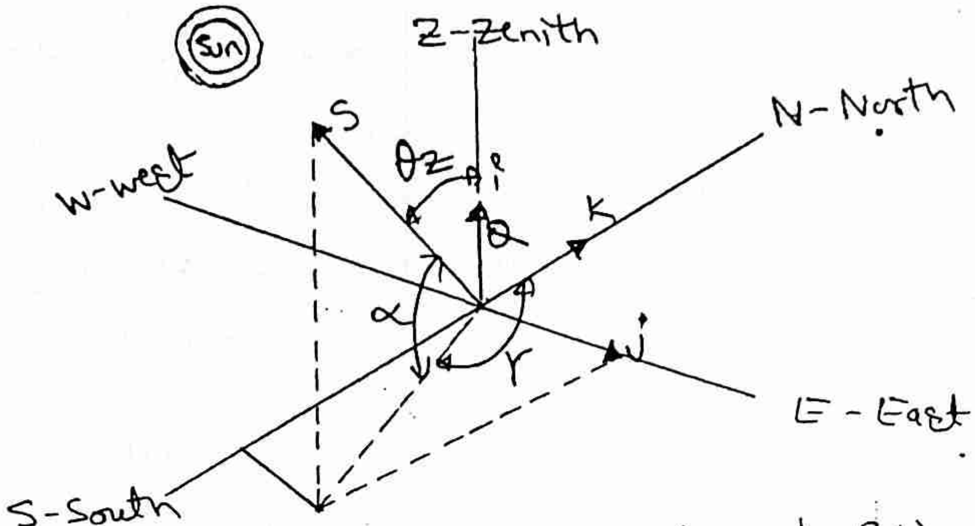
The earth's axis of rotation intersects the earth's surface at +90° latitude [North pole] and -90° latitude [South pole].

Latitude angles of intersect at tropic of cancer are [+23.45° latitude] & Tropic of Capricorn (-23.45° Latitude].

Latitude angles of intersect at Arctic cicle (66.55° latitude) & Antarctic circle [-66.55° latitude].

(V) Solar Altitude angle (α):-

It is defined as the angle between the central ray from the sun & a horizontal plane containing the observer.



fig(iv) Solar altitude angle (α).

The earth's surface coordinates system for the observer at showing the surface Azimuth angle (γ). Solar altitude angle (α) & the solar zenith angle (θ_z) for a central sun ray along direction vector S.

$\therefore \theta_z = 90 - \alpha$ [degree] → compliment of altitude angle (α).

(Vi) Solar elevation angle (α).

The angle between the direction of the geometric centre of the sun's apparent disk & the horizon.

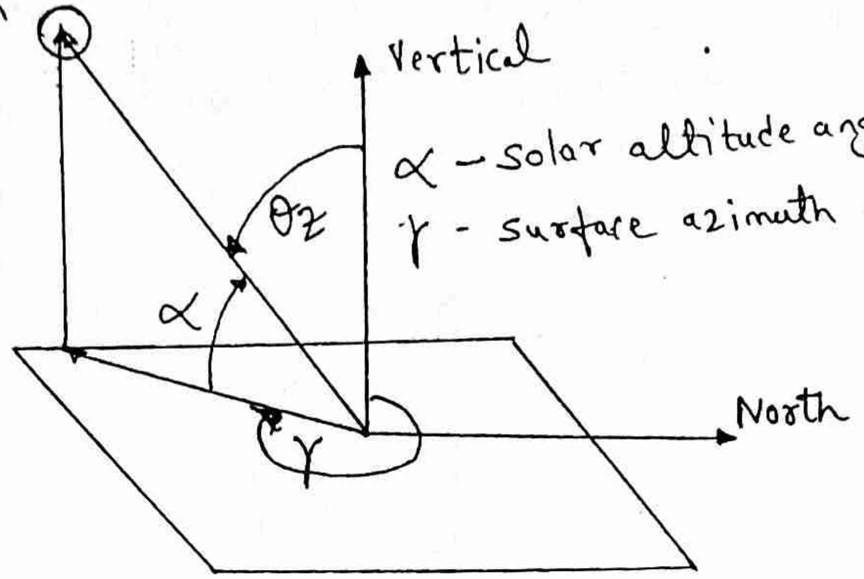
can be calculated by approximate formula.

$$\boxed{\sin\alpha = \cos\phi \cos\delta \cos\omega + \sin\phi \sin\delta}$$

α = solar elevation angle
ϕ = Local latitude
δ = declination angle
ω = hour angle in the Local solar time.

(Vii) Surface Azimuth angle (γ):-

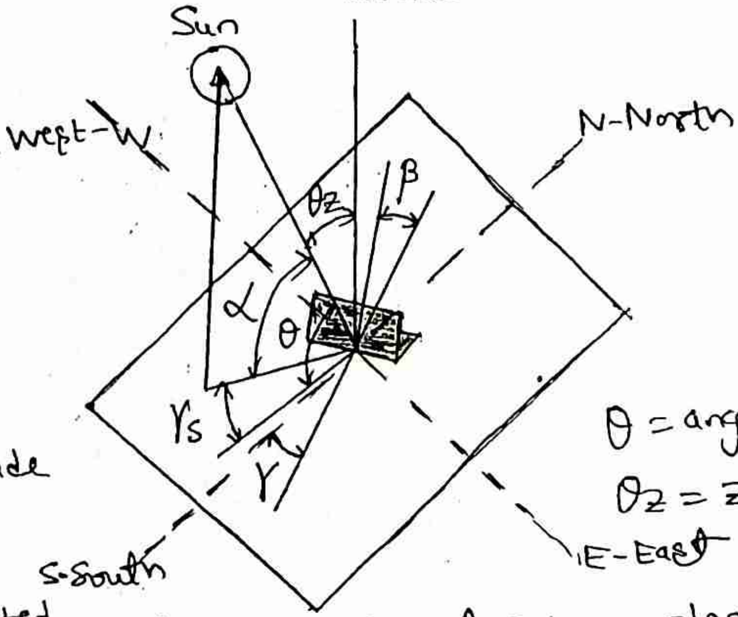
It is the angle measured clockwise on the horizontal plane from the north-pointing coordinate axis to the projection of the sun's central ray.



fig(v) : Surface azimuth angle.

$$\boxed{\sin\gamma = \left[\frac{-\sin(\omega) \times \cos(\delta)}{\cos(\alpha)} \right]}$$

9. Relationship Between Different Sun-Earth angles.



θ = angle of incidence

θ_z = zenith angle

α = solar altitude angle

β = slope angle between the tilted & horizontal surface

fig 5: Different Solar angles.

ϕ = latitute angle

ω = hour angle.

γ = surface azimuth angle

γ_s = solar azimuth angle

δ = declination angle

1. α = Solar altitude angle : It is defined as the angle between the central ray from the sun and a horizontal plane containing the observer.

2. β = Slope angle : It is defined as the angle between tilted & horizontal surfaces

3. γ = surface azimuth angle : It is the angle made in the horizontal plane between the line due south & the projection & of the normal to the surface on the horizontal plane.

4. γ_s = solar azimuth angle : It is the angle made in horizontal plane between the line due south & the projection of line of site of the sun on the horizontal plane.

5. δ = Declination angle : It is the angle made by the line joining the centre of the sun & earth with its projection on the equatorial plane.

6. θ = Angle of Incidence : The angle of incidence of a ray to a surface is measured as the difference in angle between the ray & the normal vector of the surface at the point of intersection.

7. θ_z = Zenith angle : It is simply the complement of the solar altitude angle (α).

8. ϕ = Latitude angle : The latitude angle (ϕ) is the angle between a line drawn from a point on the earth's surface to a centre of the earth & the earth's equitorial plane

9. ω = Hour angle : The hour angle is the angular distance between the meridian of the observer & the meridian whose plane contain the sun.

Local

It has been established that,

$$\cos\theta = \sin\phi \times (\sin\delta\cos\beta + \cos\delta\cos\gamma\cdot\cos\omega\cdot\sin\beta)$$
$$+ \cos\phi(\cos\delta\cos\omega\cdot\cos\beta - \sin\delta\cdot\cos\gamma\sin\beta)$$
$$+ \cos\delta\sin\gamma\sin\omega\sin\beta$$

The expression for incidence angle (θ) can be further simplified as given below.

for horizontal surface, slope $\beta = 0°$ & angle of incidence θ becomes zenith angle θ_z of the sun,

$$\therefore \cos\theta_z = \cos\phi\cdot\cos\delta\cos\omega + \sin\phi\cdot\sin\delta$$

for vertical surface $\beta = 90°$ & then

$$\cos\theta = \sin\phi\cdot\cos\delta\cdot\cos\gamma\cdot\cos\omega - \cos\phi\sin\delta\cos\gamma + \cos\delta\cdot\sin\gamma\cdot\sin\omega$$

10. Sunrise, Sunset, Day length equations & solar time.

The sunrise equation can be used to derive the time of sunrise & sunset for any solar declination & latitude in terms of local solar time (LST) when sunrise & sunset actually occur.

$$\cos\omega_{ss} = -\tan\phi \times \tan\delta$$

where

ω_{ss} = hour angle at either sunrise (when -ve value is taken) or sunset (when +ve value is taken).

ϕ = Latitude of the observer on the earth.

δ = sun declination angle.

with each 15° of longitude equivalent to 1h, the sunrise & sunset from local solar noon is derived as

$$T_H = \frac{1}{15}\omega_{ss} = \frac{1}{15}\cos^{-1}(-\tan\phi \times \tan\delta)$$

$\therefore$ day light hour $= 2T_H$ (day length equation).

Local Solar time; It is the time based on the angular motion of the sun across the sky.

∴ Local solar time, $LST = \text{Standard time} \pm \frac{T_c}{60}$

where T_c = Time correction factor in minutes.

$$\therefore \boxed{LST = \text{standard time} \pm 4 \times [L_{STM} - \text{longitude of location } L_{LOL}] + EOT}$$

In India, Standard time 82.5°E, Twelve noon LST is defined as when the sun in the highest in sky.

L_{STM} = Local standard meridian time zone = 82.5°E (In INDIA)

L_{LOL} = Longitude of location in degree.

EOT = EOT in minutes [equation of time].

11. Problems ※ vv Important

Q1) calculate zenith angle of the sun at Lucknow (26.750 N) at 9:30 am on February 16, 2012

Sol; Count total number of days from Jan 1 2012 till February 16 2012,

Jan - 31 days + Feb 16 days

∴ n = 47 days.

$\phi = 26.75$ N

∴ put $\beta = 0°$ to find θ_z

To find declination angle

$$\delta = 23.45 \times \sin\left[360 \times \frac{(284+n)}{365}\right]$$

$$\delta = 23.45 \times \sin\left[360 \times \frac{(284+47)}{365}\right]$$ Keep calc in degree mode

∴ $\delta = -12.95° \simeq -13°$ (approximately).

hour angle, $\omega = 15 \times [t_s - 12]$

$t_s = 9{:}30\,am = 9.5$ hours

$\omega = 15 \times [9.5 - 12]$

$\boxed{\omega = -37.5^\circ}$ [-ve because given time is before solar noon]

or

$\omega = -\frac{1}{4} \times t_m$ | $t_m = 12{:}00 - 9{:}30 = 150$ minutes

$\omega = \frac{1}{4} \times 150 = -37.5^\circ$

To find zenith angle.

$$\boxed{\begin{aligned}\cos\theta &= \sin\phi \times (\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) \\ &+ \cos\phi(\cos\delta\cdot\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) \\ &+ \cos\delta\cdot\sin\gamma\cdot\sin\omega\cdot\sin\beta.\end{aligned}}$$

put $\beta = 0^\circ$ then θ becomes θ_z called zenith angle
only for north.

$\therefore \cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$

$= \cos(26.75)\cos(-13)\cos(-37.5) + \sin(26.75) \times \sin(-13^\circ)$

$\cos\theta_z = 0.589$

$\therefore \theta_z = \cos^{-1}(0.589)$

$\boxed{\theta_z = 53.914}$ //.

Q2) Find the solar altitude angle at 2h after local solar noon on 1 June 2012 for a city, which is Located at 26.75°N latitude. Find sunrise & sunset hours & the day length.

Soln; No. of days = Jan 31 + Feb(29) + Mar(31) + Apr(30) + May(31) + June(1)

$n = 31+29+31+30+31+1 = 153$ days.

Feb - 29 days, because 2012 is leap year.

The declination angle on June 1.

$$\delta = 23.45 \sin\left[360 \times \frac{284+153}{365}\right]$$

n

$$\boxed{\delta = 22.174^\circ}$$

hour angle at 2h (120 minutes) after local solar noon

$$\omega = \frac{1}{4} \times t_m = \frac{1}{4} \times 120 = 30^\circ$$

$$\boxed{\omega = 30^\circ}$$

$\theta_z = 90^\circ - \alpha$ = Zenith angle.

$$\cos\theta_z = \cos(90^\circ - \alpha) = \sin\alpha$$

$$\therefore \cos\theta_z = \sin\alpha.$$

$$\cos\theta_z = \cos\phi \cdot \cos\delta \cos\omega + \sin\phi \sin\delta$$

$$\sin\alpha = \cos\phi \cdot \cos\delta \cos\omega + \sin\phi \sin\delta$$

$$\sin\alpha = \cos(26.75) \cdot \cos(22.714) \cdot \cos(30^\circ) + \sin(26.75) \cdot \sin(22.174^\circ)$$

$$\sin\alpha = 0.8845$$

$$\therefore \alpha = \sin^{-1}(0.8845) = 62.196^\circ$$

$$\boxed{\text{Solar altitude angle } \alpha = 62.196^\circ}$$

Daylight / Day length $= 2 \times T_H$

$$= 2 \times \frac{1}{15} \cos^{-1}(-\tan\phi \times \tan\delta)$$

$$= \frac{2}{15} \cos^{-1}\left[-\tan(26.75) \times \tan(22.174)\right]$$

$$\boxed{\text{Day length} = 13.58 \text{ hours.}}$$

Enter 5.21 in calci & press [°' ''] this button then we get

$$\therefore \text{Sun rise} = 12:00 - \frac{13.58}{2} = 5.21\text{h}$$

$$= 5:12.36 \text{ am}$$

$$\text{Sun set} = 12:00 + \frac{13.58}{2} = 18.79 \text{ hour}$$

$$= 18:47.24 \text{ PM}$$

Q3) For a city located at 80.50 longitude, calculate the solar time on March 15, 2011 at 10:30am Indian Standard time.

Sol; The number of days on March 15 counted from January 1, 2011

$$n = 31 + 28 + 15 = \underline{\underline{74}} \text{ days}$$

$$EOT = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B$$

$$B = \frac{360(n-81)}{365} = -6.9 \text{ (in degrees)}$$

$$EOT = 9.87 \sin(2\times -6.9) - 7.53 \cos(-6.9) - 1.5 \sin(-6.9)$$

$$\boxed{EOT = -9.65 \text{ minutes}}$$

Local Solar time LST = Indian standard time + T_c

T_c = correction factor. in minutes

$$T_c = \pm 4 \times [L_{STM} - \text{longitude of location } L_{LOL}] + EOT$$

take − sign.

$L_{STM} = 82.5$

$L_{LOL} = 80.50$

$$= -4 \times [82.50^\circ - 80.50] + (-9.65)$$

$$\boxed{T_c = -17.65 \text{ minutes}}$$

$$LST = \text{Indian standard time} + T_c$$

$$= 10:30 - 17.65 \text{ minutes}$$

$$\boxed{LST = 10:12.35 \text{ am}}$$

If EOT is −ve value take. − in T_c equation

If EOT is +ve value take + in T_c equation.

12. Solar Energy Reaching the Earth's Surface.

* Solar radiation is electromagnetic radiation emitted by the sun. The solar radiation that reaches on different Locations of earth depends on several factors such as geographic location, time, season, Local Landscape, Local weather etc.,
* When sunlight passes through the atmosphere, it is subjected to absorption, scattering and reflection by air molecules, water vapour, clouds, dust, pollutants forest fires etc.,
* The radiation intensity on the surface of the sun is approximately $6.33 \times 10^7 \ W/m^2$.
* The solar energy reaching the periphery of the earth's atmosphere is considered to be constant for all practical purposes & is known as the solar constant.
* energy stored on the earth each year by the radiation of hot solar rays at the average rate of $1.35 \ kW/m^2$.
* Solar energy reaching earth surface with variations of solar irradiance through wavelength is called solar radiation spectrum. The spectrum striking on earth surface divided into 5 regions. In increasing order of wavelength [wavelength span 0.1μm to 3μm].

1. Ultraviolet range C: It spans a range of 0.1μm to 0.28μm
2. Ultraviolet range B: It spans 0.28μm to 0.315μm. It is greatly absorbed by the atmosphere, it is responsible for the photochemical reaction leading to the production of the ozone Layers
3. Ultraviolet range A: It spans 0.315μm to 0.4μm.
4. Visible range or light: It spans 0.38μm to 0.78μm, is visible to the human eye.
5. Infrared range: It spans 0.7μm to 1000μm. It is responsible for an important part of the electromagnetic radiation that reaches the earth.

It is also divided into three types on the basis of wavelength.

(a) Infrared - A : 0.7 μm to 1.4 μm

(b) Infrared - B : 1.4 μm to 3.0 μm

(c) Infrared - C : 3.0 μm to 100 μm.

* The standard value for solar constant is take as 1353 to 1367 W/m². Because the earth's orbit is slightly elliptical, the intensity of solar radiation received outside the earth's atmosphere varies as the square of the earth-sun distance. The solar irradiance varies ± 3.4% with the maximum irradiance occuring at the perihelion. given by

$$I_0 = I_{sc}\left[1 + 0.034 \times \cos\left(\frac{360 \times n}{365.25}\right)\right] W/m^2.$$

I_0 = extraterrestial solar irradiance outside atmosphere.

The cosine effect relates to the concept of extraterrestial horizontal irradiance, falling on a surface parallel to the ground is

$$\boxed{I_{OH} = I_0 \times \cos\theta_z}$$

θ_z = solar zenith angle

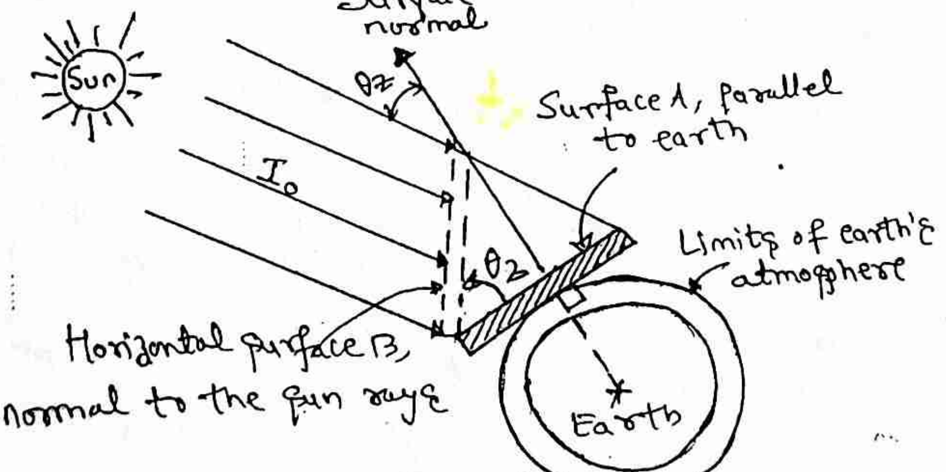
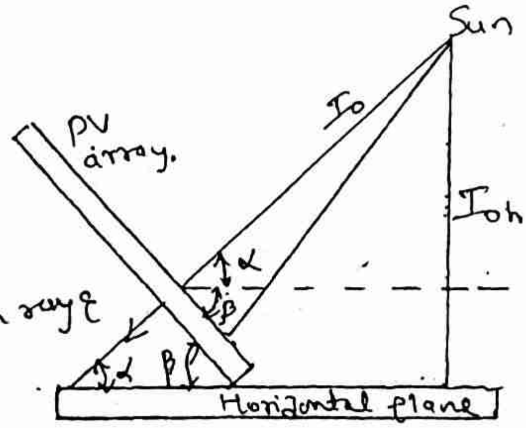


Fig: cosine effect

Cosine effect: Reduction of radiation by the cosine of the angle between the solar radiation & a surface normal is called the cosine effect.

* The rate at which solar energy reaches a unit area at the earth is called the solar irradiance / insolation.
* In view of the absorption & scattering, solar radiation reaching the earth's surface is defined by:
  (i) Beam radiation [direct solar radiation]
  (ii) Diffuse radiation: when solar radiation is subjected to attenuation & reaches the earth's surface from all parts of the sky hemisphere.
  (iii) Global radiation: The sum of beam radiation & diffuse radiation is called Global radiation.

Figure shows how to calculate the solar radiation incident on a tilted surface (I_{TS}) reaching to earth surface.



I_o = Solar radiation measured ⊥lar to sun

I_{oh} = Solar radiation measured on horizontal surface.

figure; Tilted surface.

$$I_{oh} = I_o \sin\alpha$$

$$I_{TS} = I_o \sin(\alpha+\beta)$$

elevation angle $\alpha = 90 - \phi + \delta$

$$\delta = 23.45 \times \sin\left\{\frac{360}{365} \times (284+n)\right\}$$

$$\boxed{I_{TS} = I_{oh} \times \frac{\sin(\alpha+\beta)}{\sin\alpha}}$$

13. Solar Thermal Energy Applications:-

Energy from the sun can be converted into usable form of energy for multi-purpose utilization for the applications based on the controlled technology. These technologies include passive & active systems.

Passive System:- A passive solar system relies on natural sources to transfer heated water for domestic use, which is more prevalent in warmer climates with minor chance of freezing periods

Active system:- Active system use pumps to circulate water or heat absorbing fluid through solar collectors.

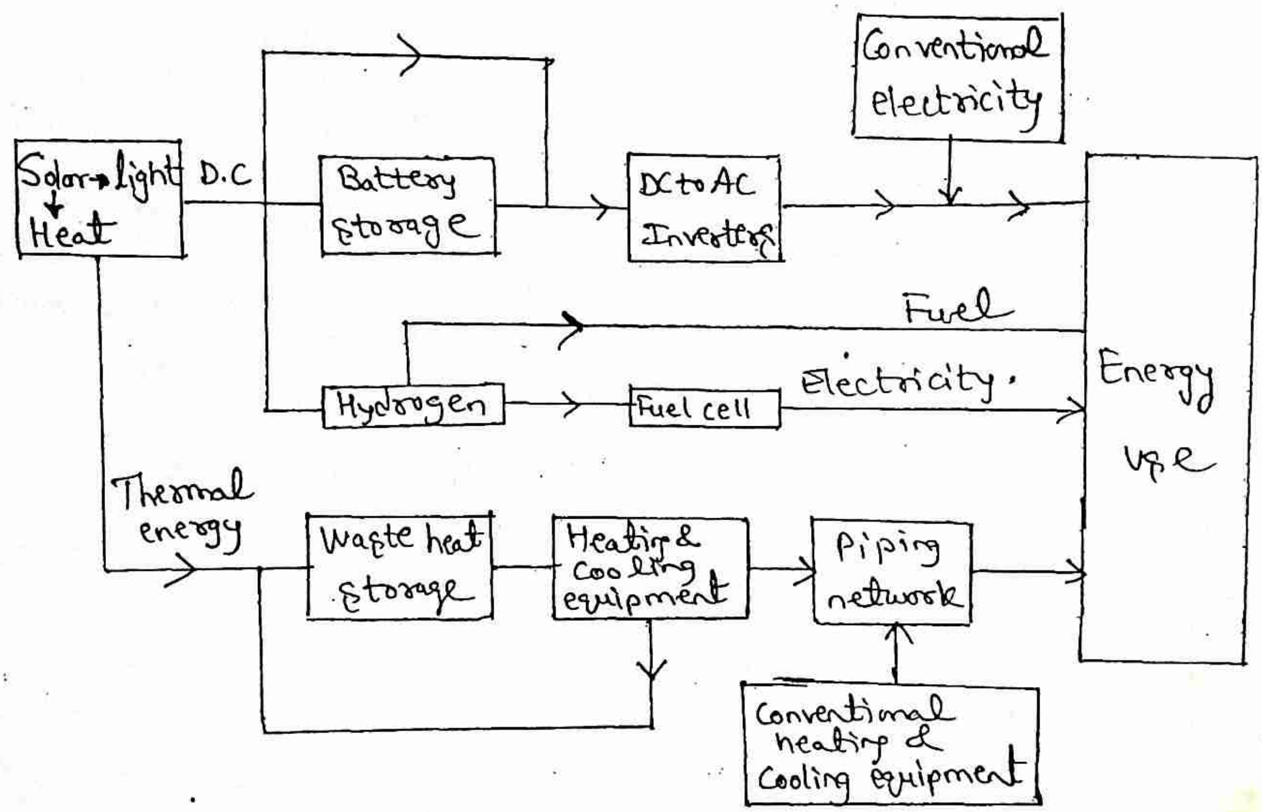


Figure: Multi-purpose utilization of solar energy.

(i) Direct Thermal applications

(a) Low-temperature collectors are flat collectors used to heat swimming pools

(b) Medium-temperature collectors are also usually flat plates but are used for heating water or Air for residential & commercial use.

(c) High-Temperature collectors concentrate sunlight using mirrors or lenses & are generally used for electric power production.

(ii) Low-Temperature solar Thermal systems.

It collects solar radiation to heat air & water for industrial applications including;

(a) Space heating for homes, officies & greenhouses
(b) Domestic & industrial hot water
(c) Pool heating
(d) Desalination
(e) Solar cooking
(f) Crop drying.

(iii) Day lighting

(iv) Solar electric conversion - Application

(a) Solar. Thermo-electro-mechanical conversion (Heat to power).

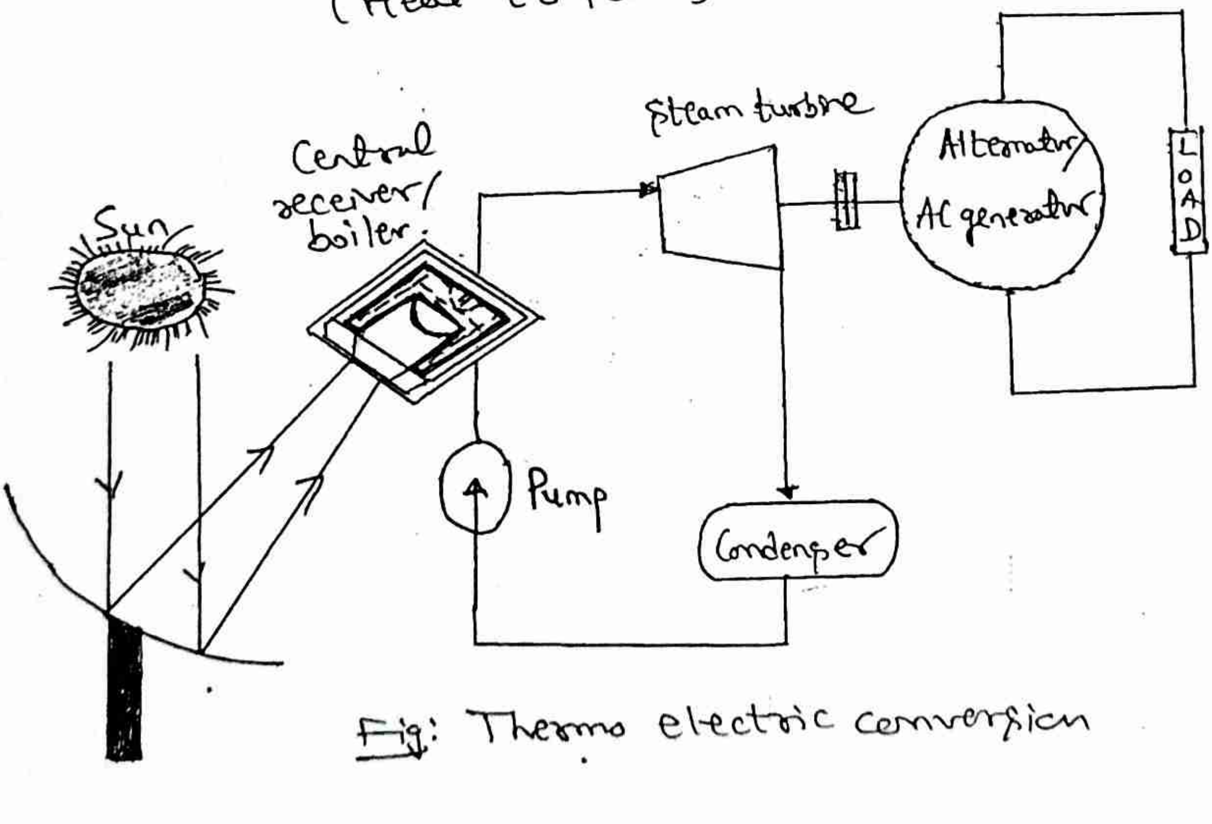


Fig: Thermo electric conversion

(b) Photovoltaic Conversion (light to power)

* Domestic lighting
* Street lighting
* Village electrification
* Water pumping
* Desalination of salty water
* Railway signals
* Powering of remote telecommunication repeater stations
* To meet electricity requirement.