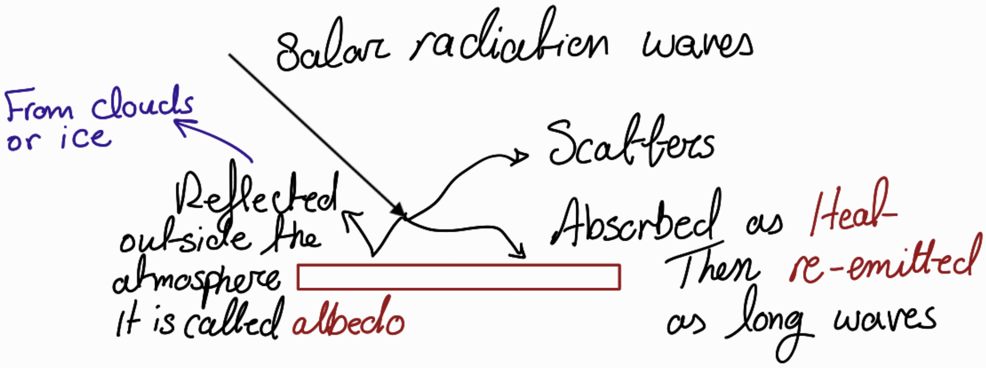
Solar Energy

- There are continuous nuclear fusion between hydrogen atoms
- Solar radiation is reduced due to the earth's atmosphere. The amount of radiation reaching the ground depends on:
  1. Air mass
  2. Angle
  3. Clouds
  4. Haze

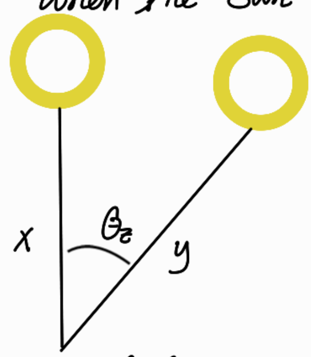


Air mass factor (m): path length of radiation through the atmosphere

$m = 1$ For the vertical path at sea level when the sun is at zenith → overhead

$m = \sec \theta_z = \frac{Y}{X}$

θ_z → zenith angle



Sun Radiation for normal surface

For a normal surface

$E_n = E_o \tau^m$

τ → Transmission coefficient: = 0.1 Overcast day; = 0.8 Clear day

E_o → Solar constant

For an inclined surface

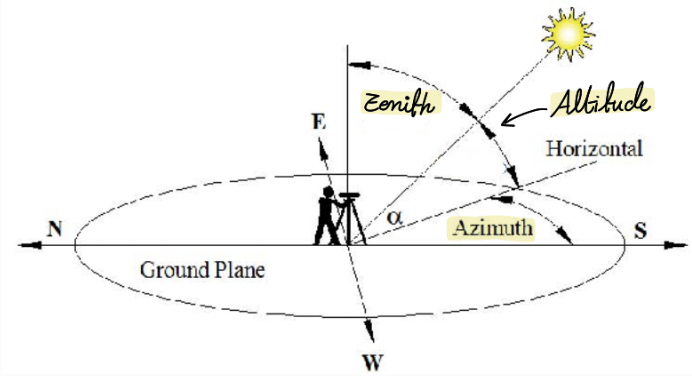
$E_i = E_n \cos \theta_i$

θ_i → Incident angle between sun direction and the normal to surface

$\theta_i = \theta_z$ for horizontal surfaces

Elevation angle α

- It is the angular height of the sun in the sky measured from the horizontal



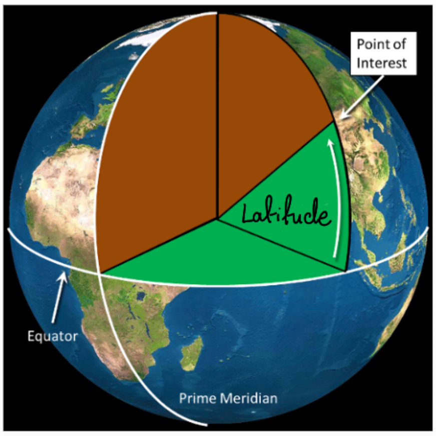
$$\theta_z = 90 - \alpha$$

Latitude angle ϕ

The angle between equator and center of earth lines

$-90^\circ < \phi \leq 90^\circ$

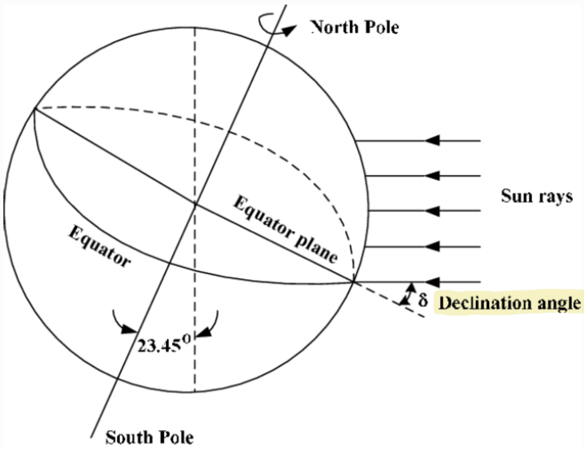
North latitude is positive



Solar declination δ

- Angle between sun's projection on earth's surface and equator
- Changes seasonally due to:

1. Tilt of earth on its axis of rotation
2. Rotation of earth around the sun



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

n → Day of year: Jan 1 → $n=1$

Hour Angle of the Sun

- Angular displacement of the sun east or west of the local meridian due to earth's rotation around its axis 15° per hour

ω:
- $= 0$ at noon
- > 0 after noon
- < 0 before noon
- Add or substract 15° for each hour $= 15 \times$ # of hours from noon

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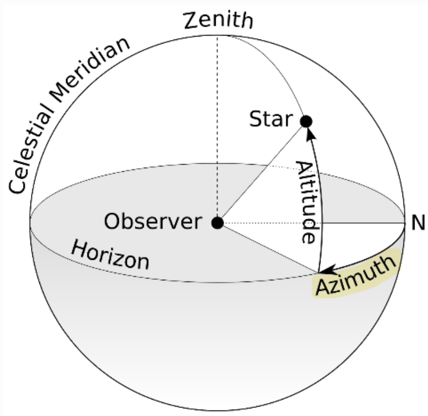
Calculating zenith angle

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

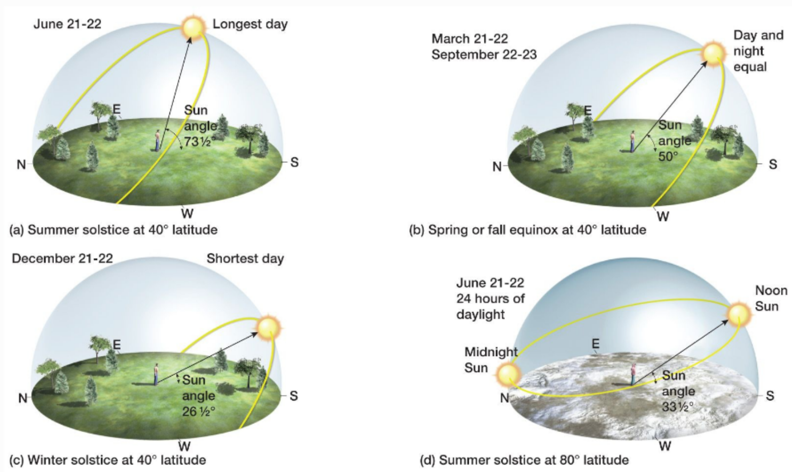
Azimuth angle α_s

- The angle between sun's direction and the north/south meridian on the horizontal plane



Sun path diagram

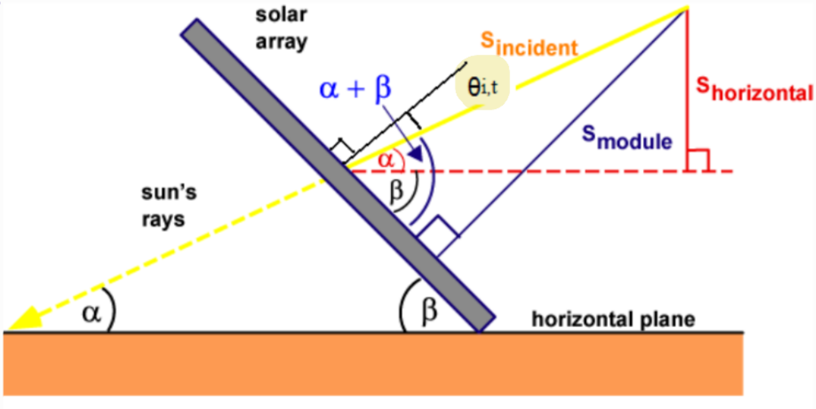
It is a diagram that shows the Sun path at various days of the year from sun rise to sun set at a certain latitude



South facing tilted surface

$$\cos\theta_{i,t} = \sin(\phi-\beta)\sin\delta + \cos(\phi-\beta)\cos\delta\cos\omega$$

Incident angle on the tilted surface



- At noon, when the sun is normal to the tilted surface
  $\theta_{i,t}=0,\ \omega=0$
  $\beta = \beta_n = \phi - \delta$

- Fixed surface tilt
  Solar collectors are installed in a fixed position at β_n

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Non - South facing tilted surface

$$\cos\theta_i = \sin\theta_z \sin\beta \cos(\alpha_s - \gamma) + \cos\theta_z \cos\beta$$

γ → Angle between south meridian and normal surface as measured on horizontal plane

$$\alpha_s = \sin^{-1}\left(\frac{\cos\delta\sin\omega}{\sin\theta_z}\right)$$

Solar tracking

- To track the sun, collector surface should be normal to sun's direction
  $\theta_i = 0 \longrightarrow \cos\theta_i = 1$
- The surface is rotated such that $\alpha_s = \gamma$ (fixed) and tilt angle β is adjusted to maintain $\beta = \theta_z$

Diffuse radiation (D.R)

- Sun rays scattered due to clouds & atm. gases
- For a sunny day: D.R = 10% of total radiation

  For a partly cloudy day: D.R = 50% of total radiation

  For an overcast day: D.R = 100% of total radiation
- Total Radiation = Direct radiation + diffuse solar radiation + reflected radiation (from ground)

$$E_t = E_n \cos\theta_i + F_1 E_d + F_2 \rho (E_n \cos\theta_z + E_d)$$

ρ ← Ground reflectivity of radiation

$$F_1 = \frac{1+\cos\beta}{2}, \quad F_2 = \frac{1-\cos\beta}{2}$$

• For Horizontal surface
$\beta = 0$, $F_1 = 1$, $F_2 = 0$
So $E_t = E_n \cos\theta_i + F_1 E_d$

Solar radiation measurement

Instruments:

1. pyranometer: has a hemispherical view of surroundings and used to measure total, direct and diffuse solar radiation on a surface (solar meter)

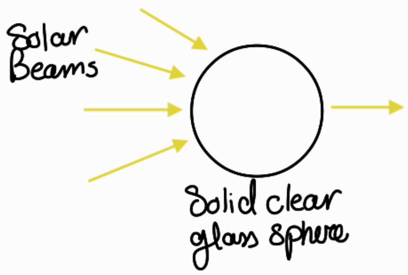
   shadow band to Block Direct sun

2. pyrheliometer: has a restricted view, used to measure direct beam solar radiation. It follows the sun with 2 axis tracking

Sunshine duration

Campbell-Stokes sunshine recorder: used to measure sunshine duration

On the opposite side, there is a strip of heated paper marked with time graduations, the beam burns the paper, the length of burned part of strip gives duration of bright sunshine



Solar collectors ← Electromagnetic waves

- Converts solar radiation into thermal energy

When the solar radiation strikes a surface, part of it is absorbed which would increase temperature of the surfac, a fluid is heated (Thermal energy) to the intake application

Solar Collectors
→ Flat plate collectors
→ Evacuated tube collector
→ Concentrating collectors

Flat plate collectors ← makes use of all sun radiation (Direct, Diffuse & ground reflection)

→ Liquid based collectors
→ Air based collectors

- Equilibrium (Stagnation) temperature: Maximum Collection temperature is the maximum collection temperature

- <u>The liquid based collector construction</u>

  Consists of:
- Glazing: 1, 2 or 3 covers of transparent material like glass.
- Absorber: Absorbs max amount of solar irradiance / conducts heat to working fluid / lose a min heat to surroundings
  * Painted black / electro plated
- Insulation: Minimizes heat losses
- Container

Fluid channels
- Absorbing Plate
- Made of: Metal, Plastic and rubber
- Consist of a flat sheet of metal with tubes

- <u>The Air based collector construction</u>
- For agriculture drying and space heating
- Larger surface area and flow rates needed → Low heat capacity and heat transfer coefficient of air

System can operate with or without a fan ← Enhance heat Transfer

Consists of:
- Glazing
- Absorber plate
- Insulation
- Casing

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Useful heat $(\alpha \tau) A G$

(η_o → $\alpha\tau$; Area m^2 → A; Solar Irradiance W/m^2 → G)

q_u = Solar gain − heat losses

heat losses $= \frac{T_p - T_a}{R_{Th}}$

(T_p: Plate Temp; T_a: Ambient air Temp; R_{Th}: Thermal Resistant from plate to air)

Collector efficiency

$$\eta = \frac{q_u}{\text{Solar Radiation}}$$

AG → Solar Radiation

$$= F_R \left[\alpha\tau - U \frac{(T_i - T_a)}{G} \right]$$

T_i → Inlet fluid Temp

F_R → correction factor (when T_i instead of T_p)

U → over all heat transfer coefficient $= \frac{1}{R_{th} A}$

Solar fraction of heat load

$$= \frac{q_u}{\text{heat loss}}$$

Concentrating collectors

- Achieved by reflecting the incident flux on an aperture area A_a into a smaller recieve or absorber area A_r
- Optical concentrating ratio CR_o

$$CR_o = \frac{I_r}{I_a}$$

I_r ← Solar flux on the reciever

I_a ← Solar flux on the aperture

- Geometric concentration

$$CR = \frac{A_a}{A_r}$$

CR=1 For Flat plate

CR>1 For Concentrating

Useful heat

$$q_u = \eta_o I_c A_a - U(T_c - T_a) A_r$$

η_o → $\alpha\tau$; I_c → radiation; T_a → Ambiant temperature; T_c → Collector temperature

Efficiency

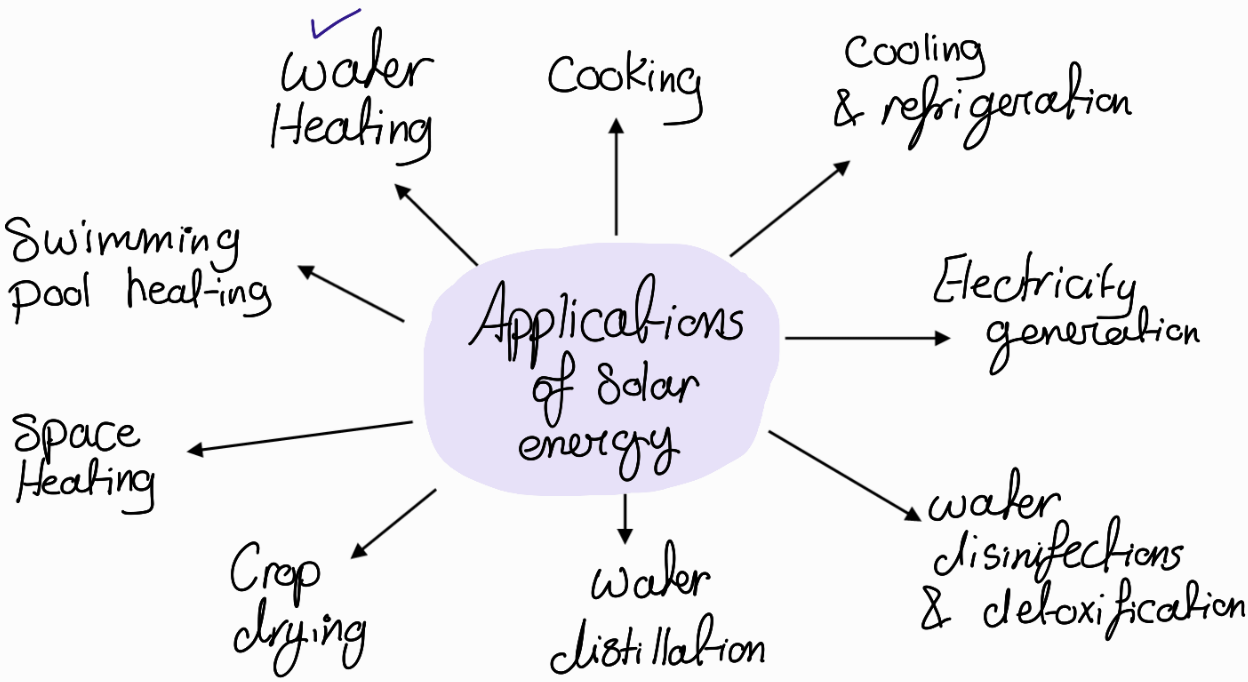
$$\eta = \eta_o - \frac{U_c(T_c - T_a)}{I_c\,(CR)}$$

Types of concentrating collectors

- Parabolic trough : Focuses sun at 30 to 60 times / Consists of a receiver pipe (with oil inside) located along the focal line of the trough Check 122,121
- Parabolic/Spherical dish Check 123
- Power tower check 124
- Stationary check 125

Evacuated tube collectors

Check 126



Solar water heating system

- Consists of : Flat plat collector + Storage tank + connecting pipes and valves
- Water circulation can be: natural or by forced circulation by a pump
- Water heating systems :
  1. Direct : Drawn water is the circulating water
  2. InDirect : Heat exchanger between drawn water and working fluid
  3. Thermosyphon System:
     - Principle of heat-rising
     - Open loop System for nonfreezing climates
     - Closed loop System colder climates

Swimming pool heating

- Consists of: Solar collectors, filter, pump and conventional pool heat
- Plastic collectors only for summer

Solar drying

- Used for crop's drying
- It reduces the moisture in food or increase sugar concentration

Space heating

- Passive or active

Passive: windows, walls and building elements + Use of black walls + Building orientation (Trombe wall)

Active: Solar energy collectors (water or air) + Storage of thermal energy + Distribution system + auxiliary heaters + fans / pumps + dampers

Solar thermal cooling

- Absorption refrigeration cycles, desiccant cycles and solar mechanical processes
- Absorption cycle: works like a refrigerator, uses hot water to compress a gas that expands and absorbs energy which cools the air
- Main problem: the absorber machine works with liquid at 90°C

Solar desalination

- Distills water
- Types : cone shaped , boxlike and pit

Cone Shaped: Impure water is inserted onto the container → evaporated by Sun → water vapor condenses on top and drips down to the side → collected and removed

Solar thermal electricity

- Plants consist of two parts: one that collects solar energy and converts it to heat / Another converts heat to electricity

Solar water disinfection

- Disinfecting water using PET bottles and sunlight

Solar cookers

- Box cooker
- Consists of an insulated container with a transperent lid

Formula Sheet

Air mass factor

$m = \sec \theta_z$

Sun Radiation for normal surface

For a normal surface

$E_n = E_0 \tau^m$ → τ: Transmission coefficient: = 0.1 Overcast day; = 0.8 Clear day

E_0 → Solar constant = 1376

For an inclined surface

$E_i = E_n \cos \theta_i$ → θ_i: Incident angle between sun direction and the normal to surface

Declination Angle δ

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

n → Day of the year

Jan 1 → $n=1$

Hour Angle

ω:
- $= 0$ at noon
- > 0 after noon
- < 0 before noon
- Add or substract 15° for each hour
  $= \pm 15 \times$ # of hours from noon

$\omega = 3 \times -15 = -45$ | $\omega = -30$ | $\omega = -15$ | $\omega = 0$ | $\omega = 15$ | $\omega = 30$ | $\omega = 3 \times 15 = 45$

9 A.m | 10 A.m | 11 A.m | At noon 12 p.m | 1 p.m | 2 p.m | 3 p.m

Note : For minutes $\omega = \omega_{Hours} + \omega_{minutes}$

$= \pm 15 \times Hours + \pm \frac{1}{4} \times$ Number of minutes

Zenith Angle

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

ϕ → latitude (usually Given)

δ → Declination angle

ω → Hour Angle

$\theta_z = 90 - \alpha$ → α: Altitude angle

Incident Angle $\theta_{i,t}$ → Tilted surface at β

South facing Surfaces

$$\cos\theta_{i,t} = \sin(\phi - \beta)\sin\delta + \cos(\phi - \beta)\cos\delta\cos\omega$$

- At Solar noon ($\omega = 0$), when the sun is normal to the tilted surface ($\theta_{i,t} = 0$)

$\beta = \beta_n$ → constant

$$\boxed{\beta_n = \phi - \delta}$$

→ Changes

Non-South facing Surfaces

$$\cos\theta_i = \sin\theta_z \sin\beta \cos(\alpha_s - \gamma) + \cos\theta_z \cos\beta$$

(β → Tilting angle; θ_z → Zenith angle)

$$\alpha_s = \sin^{-1}\left(\frac{\cos\delta \sin\omega}{\sin\theta_z}\right)$$

γ → Angle between south meridian and normal surface as measured on horizontal plane (Usually Given)

- Solar tracking
- To track the sun, collector surface should be normal to sun's direction
  $\theta_i = 0 \longrightarrow \cos\theta_i = 1$
- The surface is rotated such that $\alpha_s = \gamma$ (fixed) and tilt angle β is adjusted to maintain $\beta = \theta_z$

Total radiation

$$E_t = E_n \cos\theta_i + F_1 E_d + F_2 \rho (E_n \cos\theta_z + E_d)$$

(θ_i → Incident Angle; E_n → Normal beam radiation; E_d → Diffuse Radiation; ρ → Ground reflectivity of radiation)

$$F_1 = \frac{1+\cos\beta}{2}, \quad F_2 = \frac{1-\cos\beta}{2}$$

(β → Tilting Angle)

$\eta = 0.6 - 8\left(\frac{60-20}{500}\right)$

$\eta = \eta_0 - U_c\left(\frac{T_c - T_a}{I_c}\right)$

$0.2 = \eta_0 - U\left(\frac{40-20}{400}\right)$

400 W^2/m

$T_a = 20$

$\eta = 0.4$ at $T_p = 30$

$\eta = 0.2$ at $T_p = 40$

$c_p = 4.18$

$\rho = 1000$

$0.2 = x - y\frac{1}{20}$

$-0.2 = \frac{-y}{20} + \frac{y}{40}$

$0.4 = x - y\frac{1}{10}$

$-0.2 = y\left(\frac{2 \times 1}{2 \times 20} + \frac{1}{40}\right)$

$U = 8$

$\eta_0 = 0.6$

$\eta = \frac{q_u}{A G_T}$ ← 2 × 1000, ← 500, A → ?

1000 L

$q_u = Q = m C_p \Delta T$

$= (1000 \times 10^{-3} m^3 \times \frac{1000 \, kg}{m^3}) \times 4.18 \times (60-2$

$= 167200 \, KJ/day$

$= \frac{167200 \, KJ}{} \div \frac{3600 \, s}{hr}$

$= 46.4 \, \frac{KJ}{s} . hr$

$= 46.4 \, kWh$

$= 46.4 \, kWh \div \frac{24 \, h}{day}$

$= \frac{46.4}{24} \frac{kW}{day} . day$

$= 2 \, kW$

a) $\eta = 0.6 - 8\frac{(T_c - T_a)}{I}$

b) 157200 $\frac{KJ}{Day}$

2 kw

c) ?

d) ?