# EN671: Solar Energy Conversion Technology

## Lecture 7: Solar Radiation Estimation

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- Need of correlation
- Classification of weather
- Calculation of monthly average of daily extra-terrestrial radiation
- Different correlations for estimation of monthly average of daily global radiation

Estimation of

(a) Monthly average of daily diffuse radiation
(b) Monthly average of hourly global radiation
(c) Monthly average of hourly diffuse radiation

Cloudy Skies

(d) Hourly global, beam and diffuse radiation under cloudless skies

(e) Radiation on tilted surface

# Relationships for Cloudy skies

- **Monthly average daily diffuse radiation**

Liu and Jordan

$$\frac{\bar{H}_d}{\bar{H}_g} = 1.390 - 4.027\left[\frac{\bar{H}_g}{\bar{H}_o}\right] + 5.531\left[\frac{\bar{H}_g}{\bar{H}_o}\right]^2 - 3.108\left[\frac{\bar{H}_g}{\bar{H}_o}\right]^3$$

Modi and Sukhatme

$$\frac{\bar{H}_d}{\bar{H}_g} = 1.411 - 1.696\left[\frac{\bar{H}_g}{\bar{H}_o}\right]$$

Gard and Garg

$$\frac{\bar{H}_d}{\bar{H}_g} = 0.8677 - 0.7365\left[\frac{\bar{S}}{\bar{S}_{\max}}\right]$$

$\bar{K}_T = \frac{\bar{H}_g}{\bar{H}_o}$ Monthly average clearness index

# Relationships for Cloudy skies

- **Monthly average hourly global radiation**

$$\frac{\bar{I}_g}{\bar{\bar{H}}_g} = \frac{\bar{I}_o}{\bar{\bar{H}}_o}(a + b\cos\omega)$$

Collares-Pereira and Rabl

$$a = 0.409 + 0.5016\sin\left(\varpi_s - 60^o\right)$$

$$b = 0.6609 - 0.4767\sin\left(\varpi_s - 60^o\right)$$

- **Monthly average hourly diffuse radiation**

$$\frac{\bar{I}_d}{\bar{\bar{H}}_d} = \frac{\bar{I}_o}{\bar{\bar{H}}_o}$$

Liu and Jordan

# Terrestrial region

- Clearness index parameters
  - Hourly clearness index ($k_T = \frac{I}{I_o}$): ratio of hourly data of solar radiation in the terrestrial region to hourly data of solar radiation in the extra terrestrial region ***I(t).***
  - Daily clearness index ($K_T = \frac{H}{H_o}$): ratio of daily solar radiation in the terrestrial region to the daily solar radiation in the extra terrestrial region for that day***.***
  - Monthly clearness index ($\overline{K_T} = \frac{\overline{H}}{\overline{H_o}}$): ratio of monthly average solar radiation on a horizontal surface in the terrestrial region to the monthly average extra terrestrial solar radiation***.***

# Relationships for Cloudless skies

- Hourly global, beam and diffuse radiation

$$I_g = I_b + I_d$$

$$I_b = I_{bn} \cos\theta_z$$

$$I_g = I_{bn} \cos\theta_z + I_d$$

In the ASHRAE Model, it is postulated that,

$$I_{bn} = A \exp\left[-B/\cos\theta_z\right]$$

$$I_d = C I_{bn}$$

A, B and C are constants whose values have been determined on month wise basis

# Values of the constants A, B, and C used for predicting hourly solar radiation on clear days

| | A ($W/m^2$) | B | C |
|---|---|---|---|
| **January 21** | 1202 | 0.141 | 0.103 |
| **February 21** | 1187 | 0.142 | 0.104 |
| **March 21** | 1164 | 0.149 | 0.109 |
| **April 21** | 1130 | 0.164 | 0.120 |
| **May 21** | 1106 | 0.177 | 0.130 |
| **June 21** | 1092 | 0.185 | 0.137 |
| **July 21** | 1093 | 0.186 | 0.138 |
| **August 21** | 1107 | 0.182 | 0.134 |
| **September 21** | 1136 | 0.165 | 0.121 |
| **October 21** | 1136 | 0.152 | 0.111 |
| **November 21** | 1190 | 0.144 | 0.106 |
| **December 21** | 1204 | 0.141 | 0.103 |

Ex.M2_L2 Estimate the hourly global, beam and diffused radiations at Guwahati $\left(26^{o}9^{'}N, 91^{o}44^{'}E\right)$ between 1000 to 1400 hours (LAT) on May 15, 2019 and compare these data with measured values given in the following table.

| Sl. No. | LAT | Global radiation ($kJ/m^2$-h) | Diffuse radiation ($kJ/m^2$-h) |
|---|---|---|---|
| 1 | 1000 – 1100 | 3224 | 636 |
| 2 | 1100 – 1200 | 3320 | 737 |
| 3 | 1200 – 1300 | 3538 | 779 |
| 4 | 1300 – 1400 | 3329 | 708 |

| | | | kJ/m$^2$-hr | | kJ/m$^2$-hr | | kJ/m$^2$-hr | |
|---|---|---|---|---|---|---|---|---|
| **Sl. No.** | **LAT** | $\omega$ **Deg** | **M Global** | **P Global** | **M Beam** | **P Beam** | **M Diffuse** | **P Diffuse** |
| 1 | 1000 – 1100 | 22.5 | 3020 | 970.1/ 3492 | 2550 | 850.7/ 3062 | 470 | 119.3/ 429.5 |
| 2 | 1100 – 1200 | 7.5 | 3150 | 1034.2/ 3723 | 2600 | 913.5 3289 | 550 | 120.6 434.2 |
| 3 | 1200 – 1300 | -7.5 | 3318 | 970.1/ 3723 | 2748 | 913.5/ 3289 | 570 | 120.6 / 434.2 |
| 4 | 1300 – 1400 | -22.5 | 3163 | 1034.2/ 3492 | 2678 | 850.7/ 3062 | 485 | 119.3 / 429.2 |

# Solar Radiation on tilted surface

- Beam Radiation
- Diffuse radiation
- Reflected radiation
- Flux on tilted Surface

# Solar radiation on tilted surfaces

- Beam radiation (ratio of beam radiation flux falling on a tilted surface to that falling on a horizontal surface is called the tilt factor for the beam radiation)- facing south

$$r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta\sin(\phi-\beta)+\cos\delta\cos\varpi\cos(\phi-\beta)}{\sin\phi\sin\delta+\cos\phi\cos\delta\cos\varpi}$$

- Diffuse radiation (ratio of diffuse radiation flux falling on a tilted surface to that falling on a horizontal surface is called the tilt factor for the diffuse radiation)

$$r_d = \frac{1+\cos\beta}{2}$$

*(Radiation shape factor for a tilted surface with respect to the sky)*

- Reflected radiation

$$r_r = \frac{\rho(1-\cos\beta)}{2}$$

- Flux on tilted surface

Liu and Jordan

$$I_T = I_b \times r_b + I_d \times r_d + (I_b + I_d) \times r_r$$

**Ex.M3_L3** Calculate the monthly average hourly radiation falling on a flat plate collector facing south $(\gamma = 0^o)$ with a slop of 26°, given the following data

- Location : New Delhi $(28^o 23' N, 77^o 12' E)$
- Month: October
- Time: 1100 -1200 h (LAT)
- Assume ground reflectivity to be 0.2
- $\overline{I}_g = 2350 \text{ kJ/m}^2\text{-h}; \ \overline{I}_d = 986 \text{ kJ/m}^2\text{-h}$

# Summary

- Correlations for estimation of monthly average of daily diffuse radiation, monthly average of hourly global and diffuse radiation on horizontal surface and cloudy skies
- Estimation of hourly global, beam and diffuse on horizontal surface and clear skies
- Total radiation estimation of an inclined surface (Instantaneous, hourly, monthly average of hourly, daily and monthly average of daily)
- Solved numerical problems