

Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 4
Practice Problems_ Part II

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Lecture 3: Practice Problems

1. Angle of incidence (θ) ✓
2. Hour angle : Sunrise, Sunset and Day length (ω_s, ω_s and S_{max}) ✓
3. Local Apparent Time (LAT) ✓
4. Monthly Average Daily Global Radiation ($\overline{H_g}$) ✓
5. Monthly Average Daily Diffusive Radiation ($\overline{H_d}$) ✓
6. Monthly Average Hourly Global Radiation ($\overline{I_g}$) ✓
7. Monthly Average Hourly Diffusive Radiation ($\overline{I_d}$) ✓
8. Hourly Global, Beam and Diffusive Radiation (I_g, I_b and I_d) under Clear Sky
9. Solar Radiation on Tilted Surfaces ($\overline{I_T}$) ✓

Horizontal Surfaces (written in red next to items 5, 6, and 7)

Good morning everyone. So, in yesterday's lecture, we were to calculate these 9 values angle of incidence; sunrise, sunset hour angle and day length; local apparent time; monthly average of daily and hourly global and diffusive radiation and then hourly global, beam and diffusive radiation under clear sky and solar radiation or tilted surface. So, we could calculate till here. So, monthly average hourly global radiation.

So, remember till now, we have calculated only for horizontal surfaces. As we told you earlier, the best method is to measure the solar radiation values using equipment actual data. If not available, we can use the similarity between 2 locations and try to calculate the solar radiation values for particular places. So, even that is also not possible then we use normally the correlations proposed by various researchers.

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Practice Problems

(A) Flat plate collector, tilted at an angle of 30° , located at latitude of $19^\circ 07' N$ and longitude of $72^\circ 51' E$ is pointing due south. Calculate the angle made by beam radiation with the normal to the flat plate collector on April 1 at 10.00 h (LAT). Calculate LAT corresponding to 1400 h (IST, which is based on $82.50^\circ E$).

(B) Consider average sunshine hours is 7.2 h and elevation of the location above mean sea level is 14 m. Calculate monthly average daily and hourly global and diffusive radiation (on a horizontal and tilted surfaces).

1. Angle of incidence (θ)

General equation for angle of incidence (θ)

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

So, our problem had 2 parts. The first part is we supposed to calculate angle of incidence. So, that we have reviewed. So, why we need the angle of incidence value and then we also learn to calculate local apparent time corresponding to Indian Standard Time. Then the second part of the problem is for the average sunshine hours of 7.2 hour and the elevation of the location about main sea level is 14 meter, we were calculated the monthly average daily and hourly global and diffusive radiation. That was our second part of the problem.

Here we are going to calculate for tilted surfaces as well. So, while discussing the problem, we have also seen some of the concepts behind calculating each radiation values. So, now, we will directly go to what we suppose to calculate and where we stopped yesterday. So, I think we stopped here.

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Practice Problems

6. Monthly Average Hourly Global Radiation (I_g)

Collares-Pereira and Rabl (1979) and Gueymard (1986)

$$\frac{I_g}{H_o} = \frac{I_o}{H_o} (a + b \cos \alpha)$$

$$I_o = I_{sc} \times 3600 \left[1.0 + 0.033 \cos \left(\frac{360n}{365} \right) \right] (\sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega)$$

$I_g = 3871 \text{ kJ/m}^2 \cdot \text{An}$
 $a = 0.409 + 0.5016 \sin(\alpha_s - 60^\circ)$
 $b = 0.6609 - 0.4767 \sin(\alpha_s - 60^\circ)$
 $a = 0.409 + 0.5016 \sin(93.32 - 60^\circ)$
 $a = 0.6845$
 $b = 0.3990$

$\phi = 19^\circ 07' - 19.28^\circ$
 April 15
 $\bar{H}_o = 21213 \text{ kJ/m}^2 \cdot \text{day}$
 $\bar{H}_n = 37957 \text{ kJ/m}^2 \cdot \text{day}$
 $\bar{H}_d = 9825 \text{ kJ/m}^2 \cdot \text{day}$
 $\delta = 9.42^\circ$
 $\omega = 37.5^\circ$ (09:30 h)
 (LAT 0900-1000 h: 0.930 h)
 $\alpha_s = 93.32^\circ$ (1.628 radians)

$\bar{I} = \text{hourly}; \bar{H} = \text{monthly}$
 $\frac{I_g}{I_o} = \frac{H_g}{H_o}$

120°
 100°
 100°
 $09:45$ } $9:30$ $\omega = 37.5^\circ$

So, we calculated monthly average hourly global radiation, so, using the correlation proposed by Collares-Pereira and Rabi and Guevmard. So, here we calculated the constant values a, b and f c using that we could get the relation between this is I, is always hourly. So, H is for daily. So, both if you want to take monthly average that bar comes. So, this is what we have done here.

In this formula, it is nothing but I g bar upon I 0 bar, which is equivalent to H g d bar, H 0 bar; not equivalent to it is proportional. So, that proportionality constant is hour the correction factor whatever we may call it or fitting constant, so, that is nothing but a + b cos omega upon F c. So, the first researcher Collares-Pereira and Rabi, so, they told that we can simply take a + b cos omega that is enough.

Then Guevmard said that there is another correction factor we suppose to include to match it with actual data. So, for that a and b is given here. So, here we use omega s which is for horizontal surface hour angle during sunrise or sunset.

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Practice Problems

$$f_c = a + 0.5b \left(\frac{\omega_s - \sin \omega_s \cos \omega_s}{\sin \omega_s - \omega_s \cos \omega_s} \right) = 0.6845 + 0.3990 \times 0.5$$

$$= \frac{1.628 - \sin 93.32 \cos 93.32}{\sin 93.32 - 1.628 \cos 93.32}$$

$$f_c = 0.9924$$

$$\frac{\bar{I}_g}{\bar{H}_g} = \frac{\bar{I}_0}{\bar{H}_0} \frac{(a + b \cos \omega)}{f_c}$$

$$\bar{I}_g = 2182 \text{ kJ/m}^2\text{h}$$

And I 0, I 0 bar we discussed yesterday and then we calculated f c as well, then from that value we predicted I g bar is nothing but 2182 kilojoules meter square hour.

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Practice Problems

7. Monthly Average Hourly Diffusive Radiation (\bar{I}_d)

Liu and Jordan (1960) and Satyamurty and Lahiri (1992)

April 15th

$\bar{H}_g = 21213 \text{ kJ/m}^2 \cdot \text{day}$

$\bar{H}_0 = 37957 \text{ kJ/m}^2 \cdot \text{day}$

$\bar{H}_d = 9825 \text{ kJ/m}^2 \cdot \text{day}$

$\bar{I}_g = 2182 \text{ kJ/m}^2 \cdot \text{h}$

$\bar{I}_0 = 3871 \text{ kJ/m}^2 \cdot \text{h}$

$\omega_s = 37.5^\circ$

(LAT 0900-1000 h 930 h)

$\omega_s = 93.32^\circ (1.628 \text{ radians})$

$$\frac{\bar{I}_d}{\bar{H}_d} = \frac{\bar{I}_0}{\bar{H}_0} (a + b \cos \omega)$$

$a = 0.4922 + \frac{0.27}{\left(\frac{\bar{H}_d}{\bar{H}_g}\right)}$ for $0.1 \leq \frac{\bar{H}_d}{\bar{H}_g} \leq 0.7$

$a = 0.76 + \frac{0.113}{\left(\frac{\bar{H}_d}{\bar{H}_g}\right)}$ for $0.7 \leq \frac{\bar{H}_d}{\bar{H}_g} \leq 0.9$

$b = 2(1-a) \frac{(\sin \omega_s - \omega_s \cos \omega_s)}{(\omega_s - 0.5 \sin 2\omega_s)}$ $f(\omega_s, \theta_s)$

$\bar{I}_d = 999 \text{ kJ/m}^2 \cdot \text{h}$

Handwritten notes: $\bar{H}_g, \bar{H}_d, \bar{I}_g \& \bar{I}_d$ Horizontal surfaces
 $\frac{\bar{I}_d}{\bar{H}_g} = \frac{9825}{81813} = 0.4631$
 $a = 0.4922 + \frac{0.27}{0.4631} = 1.0751$
 $b = 2(1-1.0751) \left(\frac{\sin 93.32 - 1.628 \cos 93.32}{1.628 - 0.5 \sin(2 \times 93.32)} \right)$
 $b = -0.097$
 $\bar{I}_d = \frac{2871}{3.7957} (1.0751 - 0.097 \cos 315)$

So, today we are going to see how to calculate monthly average hourly diffusive radiation \bar{I}_d bar. So, for that the proposed correlation is \bar{I}_d bar upon \bar{H}_d bar which is equal into \bar{I}_0 bar upon \bar{H}_0 bar into $a + b \cos \omega$. As I said earlier, the Leon and Jordaa said that, so, this is, this itself is enough. So, there will not be any proportionality constant is needed. That means proportionality constant is 1.

But again Satyamurty and Lahiri in 1992, they proposed this particular correlation \bar{I}_d upon \bar{H}_d bar which is equal into \bar{I}_0 bar upon \bar{H}_0 bar into $a + b \cos \omega$. So, for that they said the constant a can be calculated based on the ratio of \bar{H}_d upon \bar{H}_g . So, if this ratio comes out to be between 0.1 to 0.7, we supposed to use this particular formula. If the ratio is between 0.7 to 2.9, we supposed to use this formula for a and b is again function of, b is a function of a ω_s , a and ω_s .

So, ω_s , we already have 93.32 degree which is nothing but 1.628 radians. And for the local apparent time or solar time of 9 to 10 hours, we calculated ω_s 37.5 degree and \bar{I}_0 we just calculated yesterday, \bar{I}_0 is around 3871. So, that value is given here. So, kilojoules per meter square hour. Then \bar{I}_g value, we have calculated 2182 kilojoules per meter square hour.

Then \bar{H}_d value so, yesterday's calculation also we have chosen the \bar{H}_d value calculated from Modi et al. So, that we have given here. So, kilojoules per meter square day, because it is a daily average and \bar{H}_0 , we already calculated 37957 kilojoules meter square day and \bar{H}_g bar

that also we have already calculated kilojoules meter square day. So, we have chosen April 15. Why? Because, we supposed to equate I_0 to I_0 bar. So, all the values are given.

So, we supposed to calculate what is the ratio between H_d bar upon H_g bar. So, H_d is given us 9825 upon H_g , which is nothing but 21213. So; which is turned out to be 0.4631. So, then we supposed to use the first formula, so, a is equal to $4922 + 0.27$ upon 0.4631. So, this is 1.0751. So, remember when you calculate these values, we sometimes take 2 digits; sometimes take 3 digits.

So, in that way, when you calculate, there will be minor difference in this value. So, the way you calculate, for example, somebody calculate this ratio first and then add it. Somebody do it directly. And when you are using this value for further calculations, so, you may use the whole value instead of making it to 2 digits or 3 digits. So, in that way, there would be small variations. For example, if I am getting 999, you may get 1001 as well.

So, please do not worry about that. And then we supposed to calculate b . So, b is nothing but 2 into $1 - 1.0751$ and $\sin \omega_s$ in degree 93.3 to $- 1.628$ which is ω_s and $\cos 93.32$ upon $1.628 - 0.5 \sin^2$ into 93.32 . So, if you calculate, so, your b would turn around $- 0.097$. So, we calculated a ; we calculated b then we go back and substitute in this value.

So, I_d is one we supposed to calculate. So, I_0 that is 3871. H_0 that is 37957 and then a , a is $1.0751 + b - 0.097 \cos \omega_s$ is 37.5. So, if you calculate your I_d is 999 kilojoules per meter square hour. So, we calculated monthly average hourly diffusive radiation, so, all these values. So, what is that H_g , H_d , I_g and I_d so, all are calculated for the horizontal surfaces.

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Practice Problems

8. Hourly Global, Beam and Diffusive Radiation (I_g, I_b and I_d)

$I_g = I_b + I_d$

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

$I_{bn} = A_e \left(\frac{-B}{\cos \theta_z} \right)$

$I_d = C I_{bn}$

δ (in degree) = $23.45 \times \sin [(360 / 365) \times (284 + N)]$

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

$\cos \theta_z = \sin 19.28 \sin 11.57 + \cos 19.28 \cos 11.57 \cos 37.5$

$\cos \theta_z = 0.7998$

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

$I_b = 8650 \text{ kJ/m}^2 \cdot \text{h}$

$I_d = C I_{bn} = 0.120 \times 8650 = 1038 \text{ kJ/m}^2 \cdot \text{h}$

$I_g = 3048 \text{ kJ/m}^2 \cdot \text{h}$

$I_d = 397 \text{ kJ/m}^2 \cdot \text{h}$

$\phi = 19^\circ 07' = 19.28^\circ$

April 2

$A = 1130 \text{ w/m}^2 = 4068 \text{ kJ/m}^2 \cdot \text{h}$

$B = 0.164$

$C = 0.120$

$\beta = 30^\circ$

$\omega = 37.5^\circ$

(LAT 0900-1000 h) 930 h

$\delta = 11.57^\circ$

ASHRAE (1972)

Climatic conditions, water vapour content, sun-earth positions

US data

American Society of Heating Refrigerating and Air-Conditioning Engineers

So, the next one is hourly global beam and diffusive radiation I_g, I_b and I_d . So, this is under clear sky. So, how do we define this clear sky? Because nowadays we have sophisticated instruments to calculate the values exactly, but still these correlations were proposed long back, but here we are making ourself comfortable how to calculate, how to get these data. So, these data to calculate so, what are all the parameters we would be requiring.

If the actual measurement of solar radiation values are not available. So, this particular formula or model is proposed by ASHRAE. So, this is American Society of Heating Refrigerating and Air Conditioning Engineers. And also if we remember the ASHRAE, so, this particular model is proposed based on US data. So, to calculate here if you see we need A, B and C the constants.

So, here we have A, B, C. So, this is proposed for over a year. But it is for the year but each month will have different constants, throughout the year, the constant do not be same. Because we know the climatic conditions and the water vapour content because these constants are used to calculate beam radiation as well as diffusive radiation. So, the water vapour content and the dust in that atmosphere and sun and earth position because that also changes throughout the year.

So, all these 3 constants are function of all these things. So, because of that each month, they proposed different constants and also it is totally based on US data, but still we use this here to learn about how to predict the global radiation using their model. As I said earlier, so, this

is for particular day. They have given in year April 21st these 3 constants are available A, B, C.

And if you see here a constant is nothing but flux watt per meter square. So, this, we supposed to convert into kilojoules meters square hour. So, in that case we suppose to convert. So, what does joule per second meter square so, we supposed to multiply and divide by 3600 to make it to joule meter square and then hour. And we suppose to calculate this as a kilojoules as well.

So, 4068 and we multiply and divide by 1000 as well. Because we supposed to get the values as kilo. So, we have to divide by 1000 as well. So, in that case, you would get 1130 would be converted into 4068 kilojoules meter square hour. So, B, C constants are unit less. So, that we do not bother about that. So, the beta value is not required at all here because we are still calculating for horizontal surface only and omega is 37.5.

So, lat we have taken us 930 hour, so, for that, the delta is 11.57. Why delta we supposed to calculate? So, now, it became April 21st. So, April 21st is nothing but 111th day of the year. So, we supposed to substitute 111 here, so, and then calculate delta. So, that is 11.57. And we would require here $\cos \theta_z$. So, that is we still calculate for the same location. So, $\sin 19.28$ and $\sin \delta$ is $11.57 + \cos 19.28 \cos 11.57$, omega is 37.5.

So, if you calculate, so, your $\cos \theta_z$ is nothing but 0.7998. So, from this we will calculate the hourly beam radiation I_b , which is equivalent to $I_{bn} \cos \theta_z$. So, I_{bn} is nothing but the beam radiation in the direction of sun rays. So, I_{bn} we supposed to calculate again we need I_{bn} for this. So, I_{bn} we are going to calculate using the ASHRAE model. So, $A e^{-B}$ upon $\cos \theta_z$.

So, it is nothing but exponential decay of the beam radiation . So, we have here A is 4068 that is A and then e to the power - B, - 0.164 so, $\cos \theta_z$ is 0.7998. So, if we calculate this is I_{bn} , so, this is becoming 3314 kilojoules per meter square hour. So, if we substitute I_{bn} value here, so, I_b turned out to be 2650 kilojoules per meter square hour. So, I_b we calculated. I_d is nothing but C into I_{bn} .

So, I bn value we already have. C is nothing but 0.120. I bn is nothing but 3314. So, how much I d we get is 397 kilojoules per meter square hour. So, if we add I b and I d then what you get is I g. I g is 3048 kilojoules meter square hour. So, here we used the US data. So, what we can do is we can get the actual data of Indian climate and compare both. How much I b value we get for a particular location and how much I d value we get.

So, there, based on the US data we are getting beam radiation is high and diffusive radiation is as much as low but based on the Indian climate maybe diffusive radiation would be high and beam radiation would be low but they compensate each other and probably we might be getting global radiation is same around. So, that we can always compare and check whether that particular model would be able to calculate this global beam and diffusive radiation under clear sky.

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Practice Problems

9. Solar Radiation on Tilted Surfaces ($\overline{I_T}$)

$$\frac{\overline{I_T}}{\overline{I_g}} = \left(1 - \frac{\overline{I_d}}{\overline{I_g}} \right) \overline{r_b} + \frac{\overline{I_d}}{\overline{I_g}} \overline{r_d} + \overline{r_r}$$

$$\overline{r_b} = \frac{\cos \theta}{\cos \theta_0} = \frac{\sin \delta \sin(\phi - \beta) + \cos \delta \cos \omega \cos(\phi - \beta)}{\sin \delta \sin \phi + \cos \delta \cos \omega \cos \phi}$$

$$\overline{r_d} = \frac{1 + \cos \beta}{2} = \frac{1 + \cos 30}{2} = 0.9580$$

$$\overline{r_r} = \rho \frac{1 - \cos \beta}{2} = 0.2 \left(\frac{1 - \cos 30}{2} \right) = 0.0133$$

$\phi = 19^\circ 07' = 19.28^\circ$
 April 15
 $\overline{I_g} = 2182$ ✓
 $\overline{I_d} = 999$ ✓
 $\delta = 9.42^\circ$
 $\beta = 30^\circ$
 $\omega = 37.5^\circ$
 (LAT 0900-1000 h: 0930 h)
 $\rho = 0.2$

$$\overline{I_T} = \overline{I_b} \overline{r_b} + \overline{I_d} \overline{r_d} + \overline{I_g} \overline{r_r}$$

$$\frac{\overline{I_T}}{\overline{I_g}} = \overline{r_b} \frac{\overline{I_b}}{\overline{I_g}} + \overline{r_d} \frac{\overline{I_d}}{\overline{I_g}} + \overline{r_r}$$

$$= \sin 9.42 \sin(19.28 - 30) + \cos 9.42 \cos 37.5 \cos(19.28 - 30) + 0.9580 + 0.0133$$

$$= \sin 9.42 \sin 19.28 + \cos 9.42 \cos 37.5 \cos 19.28 + 0.9713$$

$$\overline{r_b} = 0.9316$$

Solar radiation on tilted surfaces: So, here the formula is total radiation which is falling on tilted surface which is equivalent to $\overline{I_b} \overline{r_b} + \overline{I_d} \overline{r_d} + \overline{I_g} \overline{r_r}$ which is nothing but $\overline{I_b} \overline{r_b} + \overline{I_d} \overline{r_d} + \overline{I_g} \overline{r_r}$. This, we have seen in the lectures already. So, this is divided by $\overline{I_g}$ throughout because we already have the values of $\overline{I_g}$ as well as $\overline{I_d}$ that is global as well as diffusive radiation. So, we wanted to convert in terms of $\overline{I_d}$ and $\overline{I_g}$.

So, this is $\overline{I_b}$. $\overline{I_b}$ can be written as $\overline{I_g} - \overline{I_d}$ upon $\overline{I_g}$. So, this becomes $1 - \frac{\overline{I_d}}{\overline{I_g}}$. So, $1 - \frac{\overline{I_d}}{\overline{I_g}}$ into $\overline{r_b} + \frac{\overline{I_d}}{\overline{I_g}}$ upon $\overline{I_g}$ into $\overline{r_d}$. So, $\overline{I_b} + \overline{I_d}$ which is nothing but $\overline{I_g}$. So, this becomes $\overline{r_r}$. So, to calculate that we would require that conversion factor alliterated factor so, $\overline{r_b}$, $\overline{r_d}$ and $\overline{r_r}$. So,

r_b is as we discussed in the lecture, it is $\cos \theta_i$ upon $\cos \theta_z$, so i is nothing but angle of incidence. Z is nothing but Zenith angle.

So, we have all the parameters, $\sin \delta$ is $9.42 \sin 19.28 - 30 + \cos 9.42 \cos 37.5 \cos 19.28 - 30$. So, this is $\cos \theta_i$ and $\cos \theta_z$ is nothing but, \sin of $9.42 \sin 19.28 + \cos 9.42 \cos 37.5 \cos 19.28$. So, if you calculate this value, it is coming around 0.9316. So, we have calculated r_b . So, this bar refers to monthly average and r_d and r_r is very straightforward $1 + \cos 30$ upon 2 which is nothing but 0.9330.

And r_r is row which is 0.2 taken for concrete surfaces into $1 - \cos 30$ upon 2 which is 0.0133. So, we have r_d ready, r_r ready, r_b ready.

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Practice Problems

$$\frac{\bar{I}_T}{\bar{I}_g} = \left(1 - \frac{I_d}{I_g}\right) \bar{r}_b + \frac{I_d}{I_g} \bar{r}_d + \bar{r}_r$$

$$= \left(1 - \frac{999}{2182}\right) 0.9316 + \left(\frac{999}{2182}\right) 0.9330 + 0.0133$$

$$\frac{\bar{I}_T}{\bar{I}_g} = 2182 \left[\quad \quad \quad \right]$$

$\bar{I}_T = 2063 \text{ kJ/m}^2 \text{ h}$

So, then we supposed to substitute in the equation \bar{I}_T upon \bar{I}_g is equivalent to $1 - I_d$ upon I_g into $r_b + I_d$ upon I_g into $r_d + r_r$. So, this particular values $1 - I_d$ upon I_g . So, this value is given here. So, I_d is 999; I_g is 2182. r_b , we calculated as 0.9316 plus I_d is 999 upon 2182, r_d , we calculated as $0.9330 + 0.0133$. So, from this we calculate \bar{I}_T as \bar{I}_g . \bar{I}_g is nothing but 2182 into this total value.

So, if you calculate, your \bar{I}_T is coming around 2063 kilojoules per meter square hour. So, these values also calculated as kilojoules per meter square hour. So, this is also kilojoules per meter square hour.

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Practice Problems

Daily Basis

$$\frac{\overline{H_T}}{\overline{H_g}} = \left(1 - \frac{\overline{H_d}}{\overline{H_g}}\right) \overline{R_b} + \frac{\overline{H_d}}{\overline{H_g}} \overline{R_d} + \overline{R_r}$$

$$\overline{R_b} = \frac{\omega_s \sin(\phi - \beta) \sin \delta + \cos \delta \sin \omega_s \cos(\phi - \beta)}{\omega_s \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega_s}$$

$$\overline{R_b} = \frac{1.539 \sin(19.28 - 30) \sin 9.42 + \cos 9.42 \sin 88.20 \cos(19.28 - 30)}{1.628 \sin 19.28 \sin 9.42 + \cos 19.28 \cos 9.42 \cos 37.5 \sin 93.32}$$

$$\overline{R_b} = 1.11$$

$$\overline{R_d} = \frac{1 + \cos \beta}{2} = 0.933$$

$$\overline{R_r} = \rho = 0.0133$$

$\phi = 19^\circ 07' = 19.28^\circ$
 April 15
 $\overline{H_g} = 21213$
 $\overline{H_d} = 9825$
 $\delta = 9.42^\circ$
 $\beta = 30^\circ$
 $\omega = 37.5^\circ$
 (LAT 0900-1000 h: 930 h)
 $\rho = 0.2$
 $\omega_s = 88.20^\circ$ (1.539 radians)
 $\omega_z = 93.32^\circ$ (1.628 radians)

So, the same way, you can also use the correlations to calculate on a day basis which is daily basis as well. So, daily basis also formula is same. H_T upon H_g into $1 - H_d$ upon H_g $r_b + H_d$ upon H_g r_d and r_r . So, but if you see the way we calculate r_b that is tilt factor for a beam radiation that is different for calculating on daily basis. So, here we have that ω_s also in place and ω_z also is in place.

So, that we have already so, for ω_s is 88.20 and ω_z is 93.32. So, we supposed to substitute here. So, r_b is here, ω_s we supposed to substitute in radians. So, $1.539 \sin 19.28 - 30 \sin$. Our delta is (()) (24:24) similar. So, April 15th so, $9.42 + \cos 9.42 \sin \omega_s$ $88.20 \cos 19.28 - \beta$, β is 30 upon ω_z which is 93.32. This is degree but we supposed to substitute in radians $1.628 \sin 19.28 \sin 9.42 + \cos 19.28 \cos 9.42 \cos 37.5 \sin \omega_z$ 93.3.

So, if you calculate, your r_b is coming as 1.11. r_d is same whatever we calculated previously 0.933, r_r is also same which is 0.0133.

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Practice Problems

$$\frac{\bar{H}_T}{\bar{H}_g} = \left(1 - \frac{\bar{H}_d}{\bar{H}_g}\right) \bar{R}_b + \frac{\bar{H}_d}{\bar{H}_g} \bar{R}_d + \bar{R}_r$$

$$= \left(1 - \frac{9825}{21213}\right) 1.11 + \left(\frac{9825}{21213}\right) 0.933 + 0.0133$$

$$\bar{H}_T = \left[\quad \right] 21213$$

$$\bar{H}_T = 22089 \text{ kJ/m}^2 \cdot \text{day}$$

So, then we supposed to calculate \bar{H}_T upon \bar{H}_g bar, which is $1 - \frac{\bar{H}_d}{\bar{H}_g}$ bar into \bar{R}_b bar + $\frac{\bar{H}_d}{\bar{H}_g}$ bar \bar{R}_d bar + \bar{R}_r bar. So, here we have \bar{H}_g and \bar{H}_d in place. So, \bar{H}_d is 9825. \bar{H}_g is 21213 into \bar{R}_b what we calculated is 1.11, \bar{H}_d is 9825 21213 into \bar{R}_d , \bar{R}_d is 0.933 + 0.0133. So, how much \bar{H}_d you would get is, this total into \bar{H}_g . \bar{H}_g is 21213. So, \bar{H}_d what you get is 22089 kilojoules per meter square day.

So, this is total flux falling on daily average basis. So, in this way you would be able to calculate the \bar{H}_d that is total flux falling on a tilted collector which is the total radiation of beam diffusive and reflective radiation. So, that is all. So, we learned in this particular lecture to calculate various solar radiation values using correlations and formula presented in past 2 classes. So, here we have listed out the references.

(Refer Slide Time: 27:36)

Suggested Reading Materials References

1. ✓ S. P. Sukhatme and J. K. Nayak, Solar Energy: Principles of Thermal Collection and Storage, Tata McGraw Hill, 2015
2. ✓ Modi, Vijay and S. P. Sukhatme. 1979. Estimation of daily total and diffusive insolation in India from weather data. *Solar energy*, 22: 407
3. ✓ S. A. Klein. 1977. Calculation of monthly average insolation on tilted surfaces. *Solar energy*, 19: 325.
4. ✓ K. K. Gopinathan. 1988. A general formula for computing the coefficient of the correlation connecting global solar radiation to sunshine duration. *Solar energy*, 41: 499.
5. B. Y. H. Liu and R. C. Jordan. 1960. The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. *Solar energy*, 4: 1.
6. K. K. Gopinathan and A. Soler. 1995. Diffusive radiation models and monthly-average, daily diffusive data for a wide latitude range. *Energy*, 20: 657.

So, these four references were used yesterday. So, today we used Liu and Jordan.

(Refer Slide Time: 27:44)

Suggested Reading Materials References

1. ✓ H. P. Garg and S. N. Garg. 1985. Correlation of monthly-average daily global diffusive and beam radiation with bright sunshine hours. *Energy Conversion and Management*, 25: 409.
2. ✓ M. Collares-Pereira and A. Rabl. 1979. The average distribution of solar radiation correlations between diffuse and hemispherical and between daily and hourly insolation values. *Solar energy*, 22: 155.
3. ✓ C. Gueymard. 1986. Mean daily averages of beam radiation received by tilted surfaces as affected by atmosphere. *Solar energy*, 37: 261.
4. V. V. Satyamurty and P. K. Lahiri. 1992. Estimation of symmetric and asymmetric hourly global and diffusive radiation from daily values. *Solar energy*, 48: 7.
5. ASHRAE. 1972. *Handbook of Fundamentals*. American Society of Heating, Refrigerating and Air-conditioning Engineers, pp. 385-443

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So, another journal paper and Satyamurty and Lahiri we used and ASHRAE which is Handbook of fundamentals, that particular model to calculate the beam global and diffusive radiation under clear sky. So, these are suggested references and all the formula and the correlations, you would get from Sukhatmc and Nayak, solar energy principles of thermal collection and storage. Thank you.