Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 03
Practice problems: Part I

Good morning everyone. So, today we are going to discuss Lecture 3 in this course of renewable energy engineering solar wind and biomass energy system. So, Lecture 3 is about practicing problems, and whatever you learnt in Lecture 1 and Lecture 2 mainly these 9 radiation parameter values, we are going to calculate in this particular lecture. The first one is angle of incidence.

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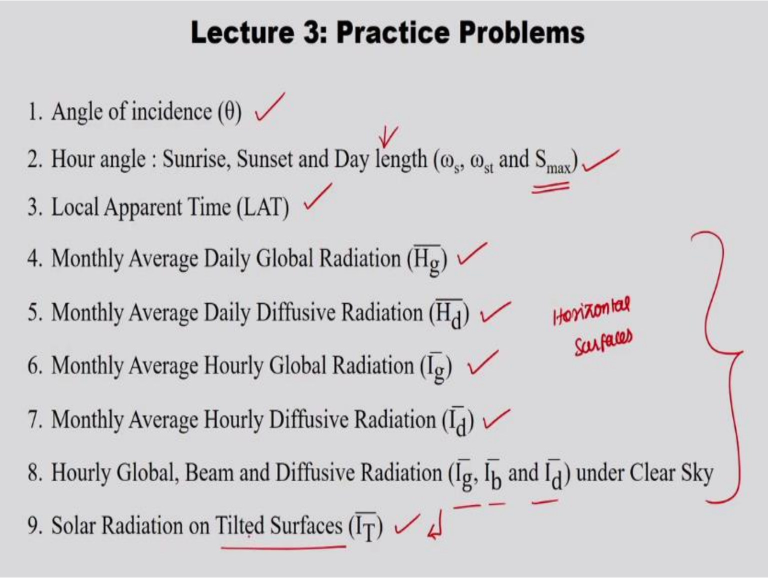

The second one is hour angle sunrise, sunset and also we will calculate day length, which is nothing but, S max maximum possible average sunshine hours. And then we calculate local apparent time and monthly average of daily global, daily diffusive, hourly global, hourly diffusive radiations and hourly global beam and diffusive radiation, I g, I b, I d, under clear sky.

So, remember these all 5 values we would be calculating for horizontal surfaces. So, and then we will see how to convert whatever we have calculated for horizontal surface into tilted surface. So, that is nothing but solar radiation or tilted surfaces.

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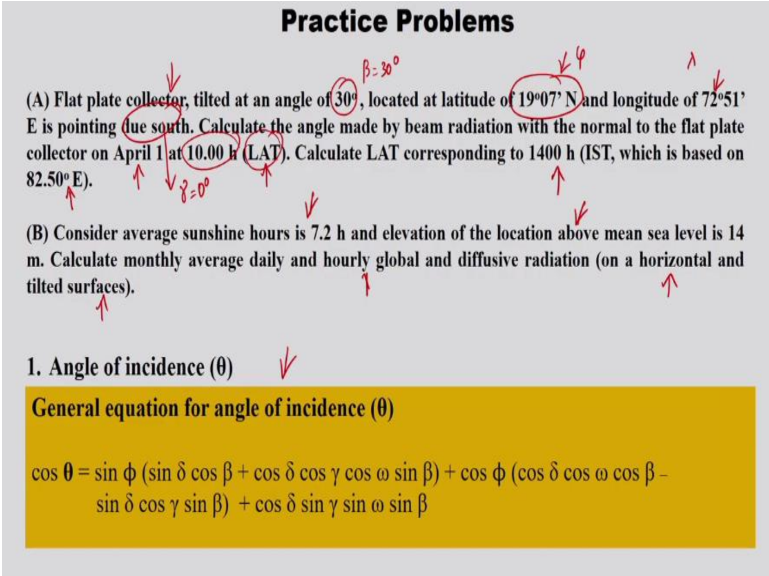

So, the problem what we are going to consider today is the flat plate collector, which is tilted at an angle of 30 degree, which is nothing but beta is 30 degree, which is located at a latitude of 19 degree 7 minutes in the north, which is phi. And then longitude of 72 degree 51 minutes in the east. So, this is nothing but lambda, which is pointing due south where your surface azimuth angle is 0 degree.

So, for this we supposed to calculate the angle made by beam radiation with the normal to the flat plate collector April 1st at 10 hours of local apparent time. And after calculating this angle of incidence we also learn how to calculate this local apparent time for the given Indian Standard Time. So, this Indian Standard Time is measured based on the longitude 82.50 degree east.

After getting to know how to calculate local apparent time, and then angle of incidence, we will do another separate problem using the same location of latitude 19 degree 7 minutes north by considering average sunshine hours of 7.2 hours, and the elevation of the location above the mean sea level is 14 meter. For this particular data, we will calculate the monthly average of daily and hourly, global and diffusive radiation on a horizontal plane as well as for tilted surfaces.

So, as we have seen in the Lecture 2, the angle of incidence, the general equation is given here. So, the first parameter we suppose to calculate is angle of incidence. So, why we need this particular angle of incidence is to convert the value of the beam flux coming from the direction of the sun to an equivalent value corresponding to the normal direction to the surface.

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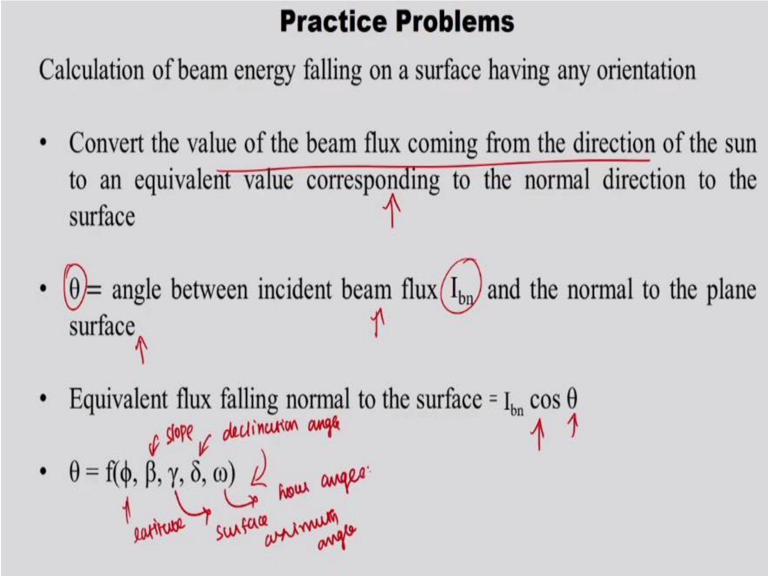

So, in that way this angle theta is nothing but the angle between incident beam flux I bn and, and the normal to the plane surface. And the equivalent flux falling normal to the surface is given as I bn into cos theta, so this is the theta, which is nothing but angle of incidence. So, that is the function of phi, which is nothing but latitude. And then beta is slope, gamma is surface azimuth angle, declination angle and this is hour angle.

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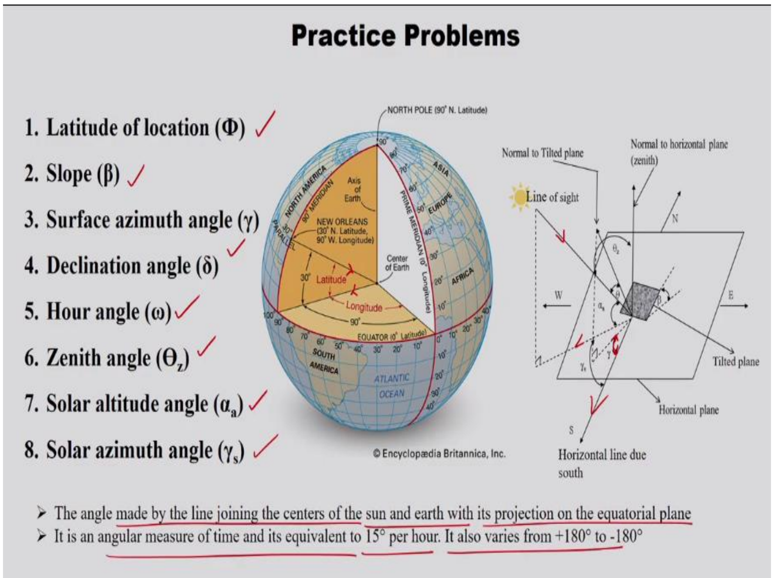

So, the first one is latitude of the location. So, as we have seen in the Lecture 2 itself, that is the angle made between the line joining position to the center of earth and its projection on the equatorial plane. Slope b is the angle between horizontal plane and the tilted plane.

Surface azimuth angle is angle made by the projection of the normal to the tilted plane on horizontal plane to the horizontal line due south.

So, that is this particular angle, and then declination angle, which is the angle made by line joining the centers of the sun and earth with its projection to the equatorial plane. Hour angle, which is the angular measure of time and it is equivalent to 15 degree per hour. It also varies from plus 180 to minus 180. Zenith angle is nothing but angle made between the line of sight or sun's rays to the normal to the horizontal plane which is nothing but zenith.

Solar altitude angle is complementary angle of zenith angle. Solar azimuth angle is nothing but the projection of line of sight on the horizontal plane. So, that particular line, and then the horizontal line due south. So, the angle made between them is called solar azimuth angle. And then, first thing what we supposed to do is.

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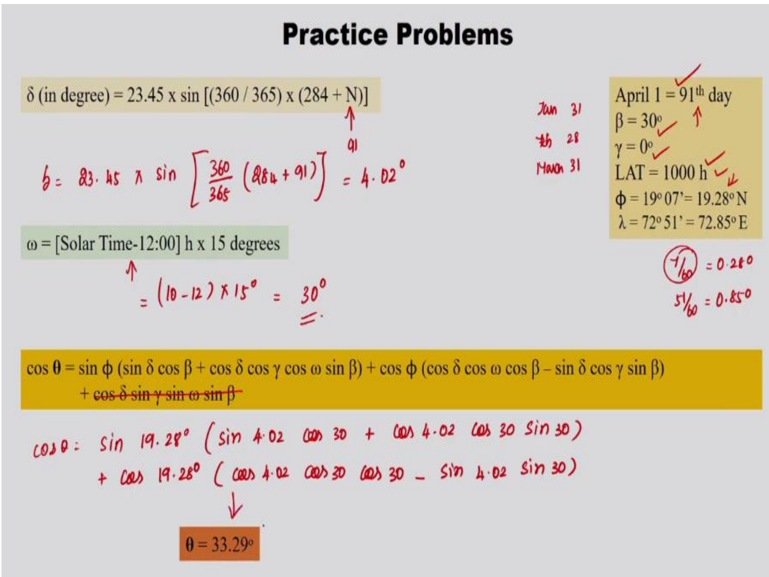

On April 1st which is nothing but 91st day of the year. So, Jan 31st, Feb 28, and then March **(()) (06:29)** 31st, so 91st day of the year and beta is given as 30 degree, and the collectors facing due south, gamma is 0 degree, and the local apparent time is given which is 10 hours. So, phi which is nothing but latitude 19 degree 7 minutes if we convert into totally into degree.

So, 7 minutes upon 60. 60 minutes is 1 degree. So, this becomes 0.28 degree. And then 51 minutes 51 upon 60, which becomes 0.85 degree. So, this is 19.28 degree and this is 72.85 degree in the east. So, this is longitude and here it is latitude. So, to calculate delta, we probably require only N that is 91st day. So, if we calculate delta is 23.45 degree into sin of 360 upon 365 into 284 plus 91, so which becomes 4.02 degree.

So, hour angle is nothing but solar time minus 12 hour into 15 degree. So, solar time is, here it is given as 10 hours, so 10 minus 12 into 15 degree. So, this is given as 10 hours so in the morning. So, we supposed to calculate it as a positive. So, 30 degree and then from that we can calculate the cos theta, which is nothing but, sin of 19.28 degree into sin of declination angle 4.02 cos 30 plus cos 4.02 cos gamma cos of 0, that is 1.

So, we do not need to take into account, cos 30, omega is 30, and then sin 30 beta is 30. So, this term is over. Plus cos phi 19.28 degree and cos of declination angle 4.02 and cos of 30 omega and cos of 30 again beta is also 30, sin of 4.02, and cos gamma cos 0 is 1 anyway. And then sin 30. So, if you see here, sin gamma so that becomes 0 so this term we not **(()) (09:12). So,** if you substitute what you would get is theta is 33.29 degree.

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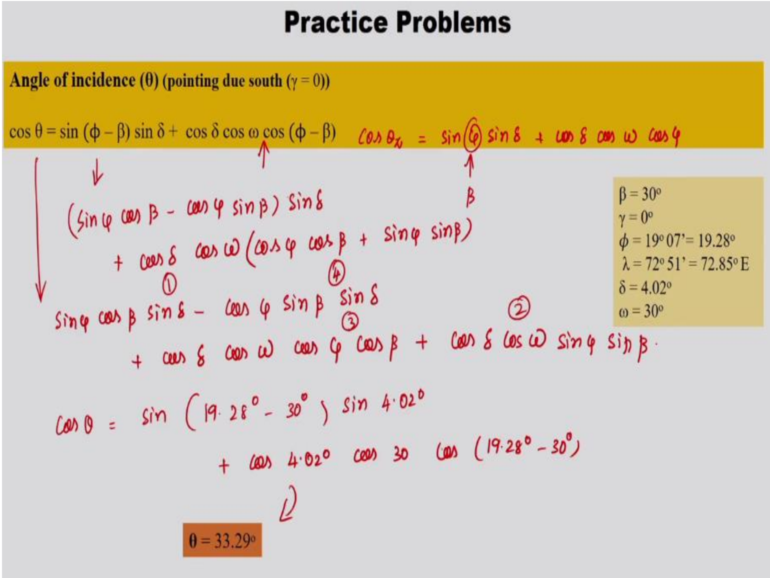

In the same angle of incidence can be calculated using this particular formula as well. So, here if you see this formula is taken from zenith angle which is nothing but cos theta z is sin phi sin delta plus cos delta cos omega and cos phi. So, here in this phi is subtracted with beta. So, that is the formula or if you can substitute the formula sin A cos B minus cos A sin B into sin delta plus cos delta cos omega, and then cos A minus B.

So, we can do it cos A cos B plus sin A sin B. If you expand it, sin phi cos beta sin delta. That is one term. And then, cos phi sin beta sin delta, that is second term. Cos delta cos omega, cos phi, cos beta plus cos delta, cos omega sin phi sin beta. So, this if you see in the angle of incidence, this is the first term, sin phi sin delta cos beta, that is the first term, and cos phi sin beta sin delta, that is fourth term probably.

Fourth term is this term, cos phi cos gamma is anyway due south. So, that is one. So, cos phi sin delta sin beta. So, that is fourth term. So, this is the third term. Third term is here, cos phi cos delta cos omega cos beta. So, this is third term, and then this is second term. So, this ultimately given to **(()) (11:46)** general equation only for the surface pointing due south. But here, you can do it with only phi and beta and delta and omega.

Here, again, if you substitute in this formula cos theta, which is equivalent to sin of 19.28 degree minus 30 degree into declination angle we calculated as 4.02 degree plus cos of 4.02 degree cos of 30 cos of 19.28 degree minus 30 degree. So, this becomes theta as 33.29 degree. And then the same angle of incidence can be calculated using zenith angle, as well as solar azimuth angle.

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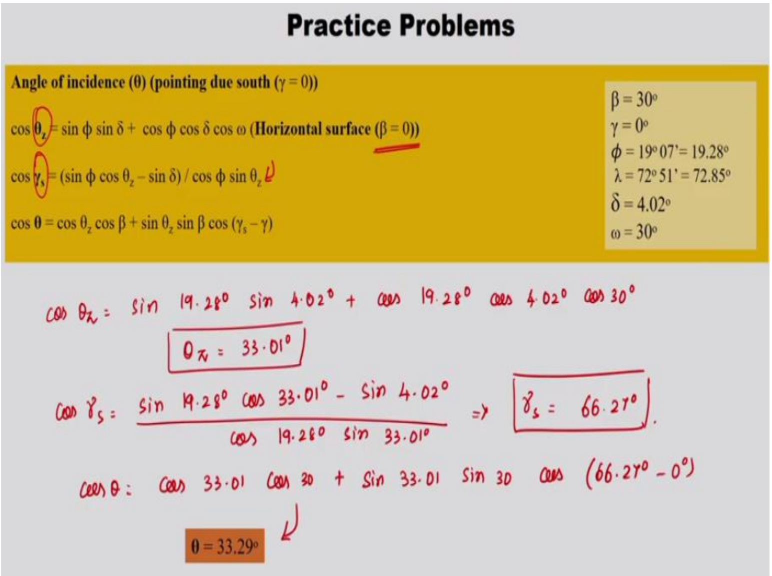

For zenith angle, we have already known, the beta equal to 0 that is on horizontal surface. The theta z is sin phi sin delta plus cos phi cos delta cos omega. For gamma s, which is nothing but solar azimuth angle, this is the formula. So, by calculating these two, then we can substitute in theta formula, and then calculate. So, cos is theta z, if you substitute, it is sin of 19.28 degree sin of 4.02 degree plus cos of 19.28 degree cos of 4.02 degree and cos of 30.

So, if you substitute so what you get is theta z as 33.01 degree. Then, the second formula is cos gamma s which is nothing but, sin phi sin 19.28 degree, and then cos theta z cos of 33.01 degree minus sin of declination angle 4.02 degree divided by cos of 19.28, and sin of 33.01 degree. So, if you substitute and calculate gamma s which is just turned out to be 66.27 degree.

Then we will substitute in cos theta formula, cos of 33.01, cos of 30, plus sin of 33.01 sin of 30 and cos of 66.27 minus 0, the gamma is 0. So, if you substitute, then also you will get theta as 33.29 degree. The next one is the hour angle during sunrise, sunset, and day length, which is nothing but maximum possible sunshine hours. So, here, we already know how to complete the theta z.

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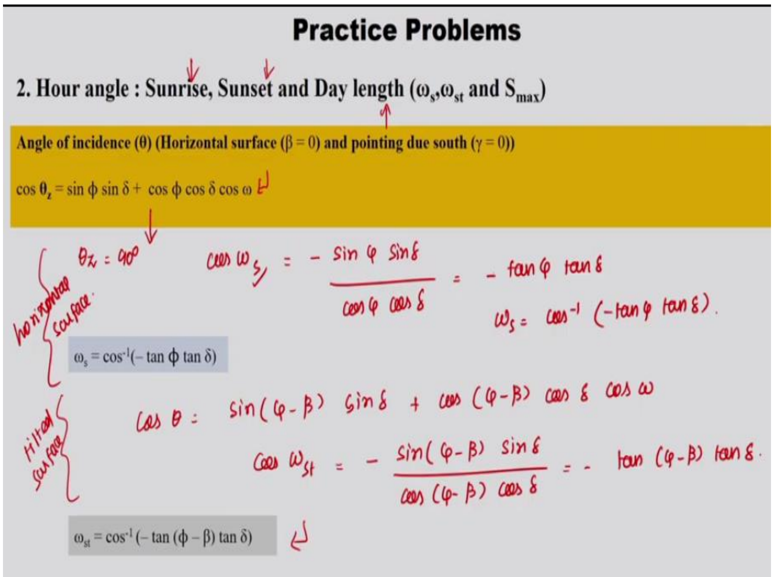

So, we have seen in the lectures for sunrise or sunset that theta z would be 90 degree so cos 90 is 0, so in that way, cos omega during sunrise or sunset that is the subscript s, which is equivalent to minus of sin phi sign delta upon cos phi cos delta, so which is nothing but, minus tan phi and tan delta. So, what you would get is cos inverse of minus tan phi tan delta. And then, as we said earlier so this theta z for tilted surface so this is for horizontal surface.

So, if we want to calculate tilted surface so we know how to calculate theta, which is nothing but, sin of phi minus beta sin theta plus cos phi minus beta cos delta and then, cos omega. So, as we said earlier, if you want to calculate, omega st, that is tilted surface. So, this becomes minus of sin phi minus beta sin delta upon cos phi minus beta into cos delta. So, that becomes minus of tan of phi minus beta into tan delta.

So, that is omega st is nothing but, cos inverse of minus tan phi minus beta tan delta. So, here normally, this particular formula derived for horizontal surface can also be used to calculate the hour angle of sunrise and sunset in a tilted surface as well. But we need to be a little bit careful in doing so.

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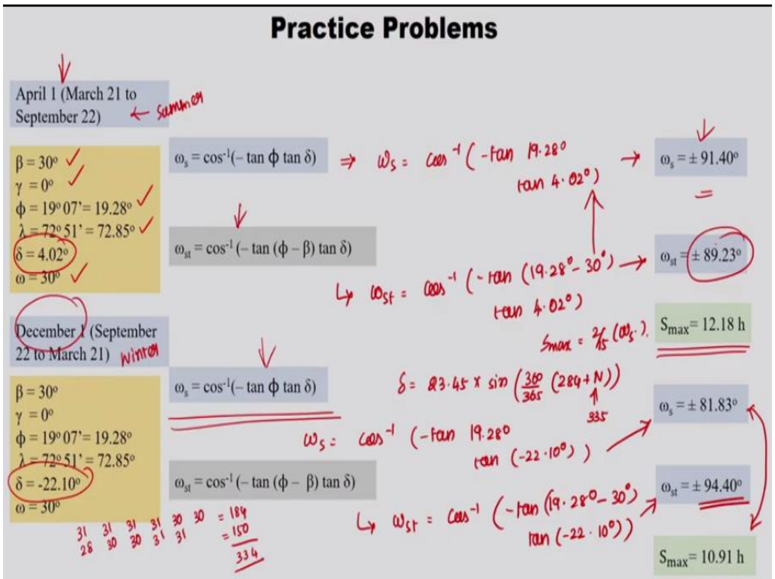

So, that we will see through this example, for example, if I am taking a day of April 1st which is between March 21st to September 22nd, that period it comes. So, this is nothing but during summer, so wherever declination angle is positive. So, for this particular problem, beta is 30, gamma is 0 degree and phi is 19.28 degree and lambda is 72.85 degree, and omega is 30 degree.

So, for this if we calculate the on horizontal surface what we said here is, we can still use this formula to calculate tilted surface. So, here if you substitute omega s is cos inverse of minus tan 19.28 degree tan 4.02 degree. So, if we calculate, we would be getting omega s as plus or minus 91.40 degree. This is for sunset as well as sunrise. So, if we calculate through this particular formula, which is given exclusively for tilted surface.

It is nothing but 19.28 degree minus 30 degree into tan of 4.02 degree. So, if we calculate omega st would be coming around plus or minus 89.23 degree. So, for tilted surface, if we use this formula given for horizontal, it is over predicting. So, this same formula of horizontal surface can be used when the day of the calculation is in between September 22 to March 21st that is supposed to be winter period. So, there your declination angle is minus.

But, if you use it for this particular period of March 21st to September 22 it over predicts the value. So, anyway, the S max should be calculated for the value of this particular omega, which is nothing but 91.40 degree. So, S max is nothing but 2 upon 15 into omega s. So, and then for December 1st, the declination angle we supposed to first to calculate, so 23.45 into sin of 360 upon 365 into 284 plus N. So, N of the year is December 1st.

So, December 1st is nothing but January 31st, February 28, and then March 31st, April 30th, May 31st, June is 30, July is 31st, August is 31st, then, September, October, November. So, here 184, so here 150, so 4, 3, 334, and 335th, so N is 335. So, if we calculate what you would get is declination angle of minus 22.10 degree. So, if you substitute omega s here, so cos inverse of minus tan 19.28 degree into tan of minus 22.10 degree.

So, if you substitute, then what you would get is 81.83 plus or minus. So, if you substitute in this formula for tilted surface cos inverse is minus tan of 19.28 degree and tan of minus 20 2 8 degree minus 30, and tan of minus 22.10 degree. So, if you calculate omega st is coming around 94.40 degree. So, this S max is calculated for this lower value of omega s which is nothing but plus or minus 81.83.

So, here, the horizontal surface formula would be working fine, but when you are calculating for during summer’s days. Then we supposed to calculate it for tilted surface exactly. The next one is the local apparent time, so, which is given by this particular equation that is standard time plus or minus 4 into standard time longitude, and then longitude of the location, plus equation of time correction.

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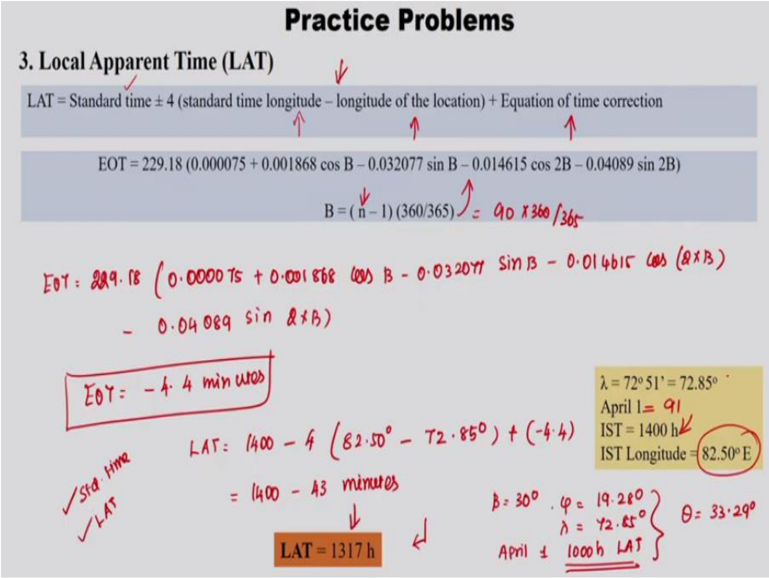

So, equation of time correction is given by this particular formula, where n is nth day of the year, April 1st. April 1st is 91st day. So, if we substitute, we would get here, the B value. Then after substituting here, then EOT is 229.18 and 0.00075 plus 0.001868 cos of B minus 0.032077 sin of B minus 0.014615 cos 2 into B minus 0.04089 sin 2 into B value. So, B value is nothing but 90 into 360 upon 365.

So, if you calculate. So, what you get is EOT is minus 4.4 minutes. And the second correction is plus or minus. We have already told. So, if your calculation is based on eastern hemisphere, then we supposed to use negative symbol. So, the standard time here given is IST of 14 hours.

So, LAT is nothing but 14 hours minus 4 into standard time longitude that is 82.50 minus longitude of the location which is nothing but 72.85 degree plus minus 4.4 minutes of EOT correction. So, if you calculate. So, what you would get is 14 hours minus 43 minutes. **(()) (24:36)** your local apparent time is 13 hours 17 minutes or 1317 hour. So, this is the way we can calculate local apparent time.

So, here we finished the first problem. So, in the first problem, we were given flat plate collector of **(()) (24:54)** of beta 30 degree with the phi is given is 19.28 degree and lambda is given as 72.85 degree. So, with this location for beta of 30 degree on April 1st at 10 hours of local apparent time, we have calculated what is angle of incidence. So, that value is 33.29 degree.

And then we learned how to calculate this local apparent time for the standard time given. As we discussed in our Lecture 2, the solar time can be of two types one is the standard time what we normally use, and then local apparent time. So, this for the given standard time how to calculate local apparent time we have seen in this. So, the next is we would be seeing the hourly, daily global and then diffusive radiation.

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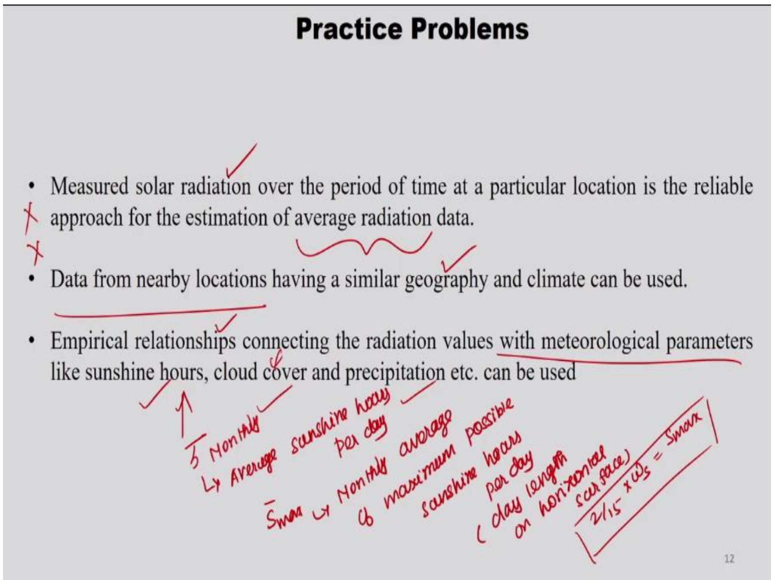

So, as I mentioned earlier, we are supposed to calculate the average radiation data. So, the best thing is measured solar radiation over a period of time at a particular location, or if the data from nearby locations are available so having similar geography or climatic conditions that also can be used. If both are not possible, so we use empirical relationships, connecting the radiation values with the metrological parameters like sunshine hours, cloud cover and precipitation, etc.

But the more reliable one is nothing but sunshine hours so we have now learned two things one is so S bar. So, this is nothing but, monthly average sunshine hours. The second one is S bar max, so, which is nothing but monthly average of maximum possible sunshine hours per day. So, this also average sunshine hours per day. So, this also can be called us day length calculated for day length on a horizontal surface.

So, we have already seen, horizontal surface. So, that is why we told as 2 upon 15 into omega s which is nothing but S max. So, among these metrological parameter sunshine hours seems to be predicting the radiation values more accurately compared to other meteorological parameters. But here, one more thing to tell is the cloud cover. We cannot define a clear day by any parameter.

So, there is a discrepancy or confusion over how to define that particular day. So, because of that reason, mostly or most empirical correlations are given based on sunshine hours. So, the first we what we are going to calculate is monthly average of daily global radiation which is nothing but H g bar is as I said earlier, monthly average. So, the correlation given here is H g upon H naught over bar is there, so that is monthly average, a plus b S bar upon S bar max.

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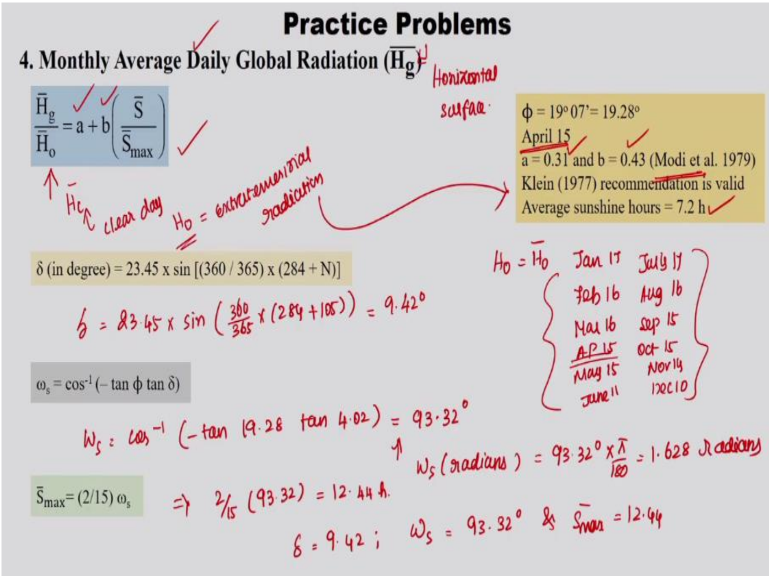

So, this a, b are fitting constants. So, that is given 0.31 and 0.43. This is defined by Modi et al. 1979, so this reference is given this particular lecture. So, when he has proposed to these constants. So, this formula is actually made for H c. So, the H c here is nothing but the monthly average daily global radiation on a clear day. So, as I said earlier, the clear day, so there is a confusion in defining so how to define a clear day.

So, then after that it was replaced by H naught because the H c bar seems to be equivalent to the extraterrestrial, terrestrial radiation. And then, by using H naught what we will be able to do because what we require is monthly average value of that. So, for that this particular researcher Klein, so, he recommended that if you are considering particular day in a year. So, where you are H naught is equivalent to H naught bar, which is nothing but monthly average value.

So, on that particular day, if you calculate H naught, so that would be equivalent to H naught bar. So, that is why, instead of April 1, so here we have taken April 15. So, this particular day seems to be like around now, for example, Jan 17th, Feb 16, March also 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14, and December 10th, so all these days the H naught is equivalent to H naught bar.

So, if we calculate H naught on those days, so that will be equivalent to H naught bar. So, here also it is taken as April 15th to calculate H naught. So, the first thing what we supposed to do is delta, so because delta would change here, so what we have taken is April 15 so which is nothing but 105th day of the year through 360 upon 365 into 284 plus 105, so which is turned out to be 19.42 degree. So, the second one is omega s.

So, remember, this is calculated on a horizontal surface. So, omega s is cos inverse minus tan 19.28 tan 4.02. So, if we calculate, so, omega s is coming as 93.32 degree. And somewhere in the formula of H naught, we supposed to use omega s in radians as well, so radians. So, for that, this 93.32 degree is converted into radian, so which is coming around 2 8 radians 1.628 radians.

So, and then S max bar, so, which is nothing but 2 upon 15 and 93.32, so which is coming around 12.44 hours. So, we have now delta, which is 9.42. We have omega s which is 93.32 degree. And we also have S max bar which is 12.44 hours. So, using this we will go on calculating H naught. Otherwise, we are given a and b values. And we were also given average sunshine hours for this particular location which is 7.2 hours.

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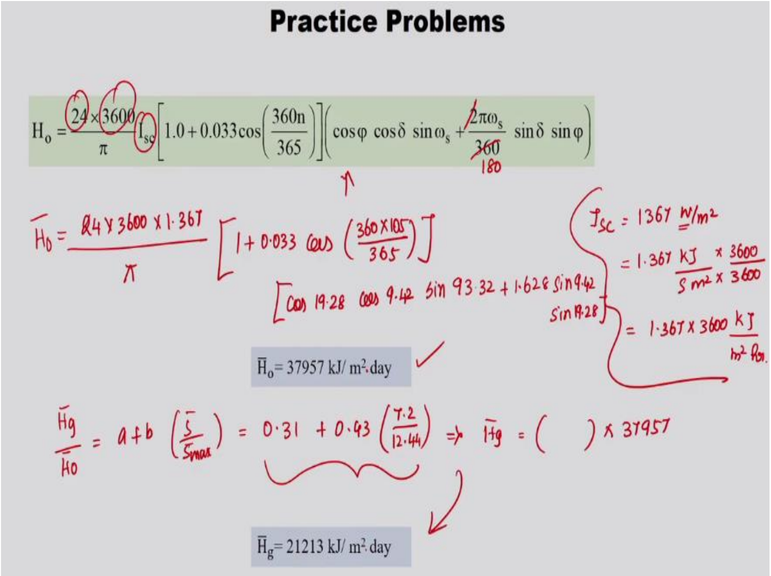

So, here is your formula for H naught. Remember here, this I sc in lectures, you might have seen I sc is nothing but 1367 watt per meter square. So, this value is in watt per meter square. But what we are calculating is in terms of kilojoules per day, because, here if you see it is a daily radiation. So, because of that reason, we supposed to convert this, so 1.367. So, then I will put kilo what is joules per second meter square.

So, if we multiply and divide by 3600, so that is what 367 into 3600. So, this becomes kilojoules meter square, 3600 second is hour. So, and then 24 and 3600 is to take care of that solar constants. So, then what it would be 24 into 3600 into 1.367 upon pi, so this is 1 plus 0.033 cos 360. So, remember what we are calculating is 105, or 105th day of the year upon 365 and then cos 19.28 cos 9.42, that is what your delta.

And then, sin omega s, omega s is 93.32. And here if you see 2 upon 360 that is 180, pi by 180 into omega s that value we already have, so which is nothing but 1.628 radians 6 2 8 sin 9.42 sin 19.28. So, if you calculate. So, this is H naught. Since we are calculating on April 15th, so then that is also equivalent to H naught bar, 37957 kilojoules meter square day. So, then we have a formula, so which is nothing but H g upon H naught bar a plus b S bar S max bar.

So, this a, b, we have already 0.31 and 0.43 0.43 7.2 upon 12.44. So, what we supposed to do is supposed to calculate this value and to find out H g. So, whatever is our calculated value into 37957. So, it turned out to be 21213 kilojoules per meter square day. So, now, we have calculated the monthly average of daily global radiation using correlation so the major assumption, given by Klein 1977, and fitting constants we have taken from Modi et al. a = 0.31 and b = 0.43.

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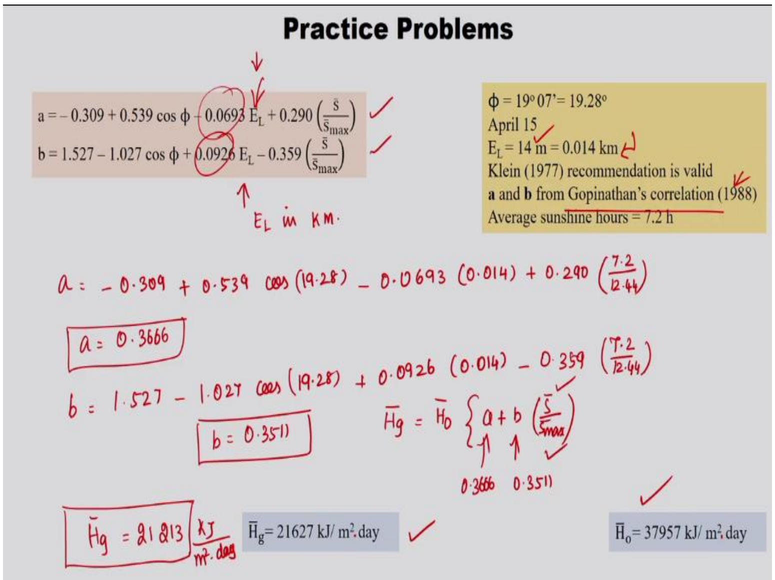

And instead of using that a and b as a fitting constant and this particular researcher, Gopinathan, so, he had come up with this two correlations in 1988, so that correlation if you use, then you would require one more extra data, which was nothing but elevation, height of that location above the sea level. So, that is given as 14 meter. And remember, in that formula E L is given in kilometer.

That is why we have used 0.014 kilometer. So, remember when you use such kind of correlation so make sure that the parameters for example here phi in degree and E L is in kilometer and S max in hours. So, you should be careful about the units what we are substituting otherwise, because these constants fitting constants are derived for that particular unit of the parameter, so that we need to be bit careful about.

So, here if you substitute a equal to minus 0.309 plus 0.539 cos 19.28 minus 0.0693 E L is 0.014 plus 0.290 S bar is 7.2 S bar max is 12.44. So, a is coming around 0.3666. So, earlier researcher proposed it as a 0.31. And then the second is b 1.527 minus 1.027 cos 19.28 plus 0.0926 0.014 minus 0.359, again, 7.2 upon 12.44. So, this b is coming around 0.3511. So, a, b we calculated.

The same way, H g bar, is nothing but H naught bar into a plus b S bar upon S bar max. So, all the values are there, this is 7.2, this is 12.44, a is here 0.3666, b is here 0.3511. So, if you substitute, so what you would get is H g as 21627 kilojoules per meter square day, so H naught is same 37957 kilojoules per meter square day. But here also we got one more H g using a, b proposed by Modi et al.

So, this H g is nothing but 21213 kilojoules per meter square day. So, not much difference is there. So, both can be used based on the situation. So, if you know these two parameters, extra we required right latitude of the location you would know. And you should know as well as the elevation of that location above the sea level. If these two parameters are known, then you can find out a, b, and then from S bar and S max bar, you can directly find out, H g.

So, among these two values we are going to choose this particular value for our further calculation. Because, H naught is only one that is 35957. So, the next one is supposed to be **(()) (42:17)** out us monthly average daily diffusive radiation which is nothing but H g bar, so here, there are three correlations available to calculate H d bar which is nothing but monthly average daily diffusive radiation.

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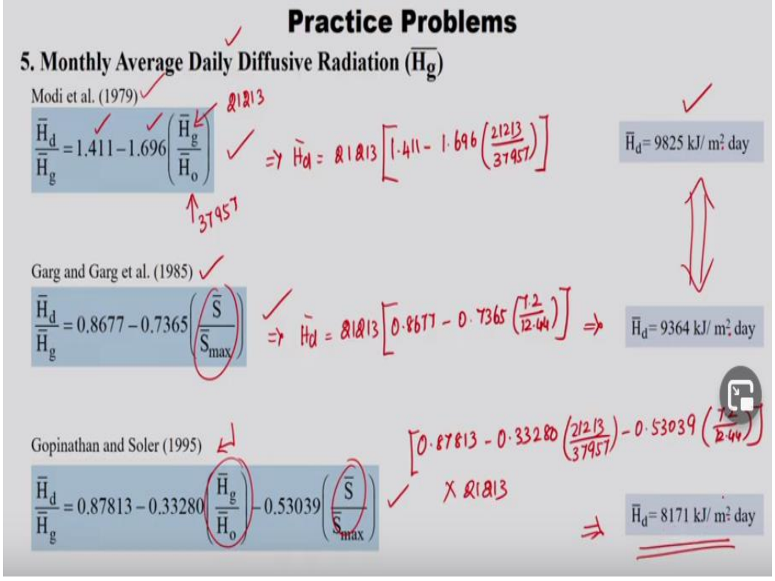

So, the first one is Modi et al. where we have seen that a and b value proposed. So, that H g value only we are going to use here to calculate further because this H g, you are going to use is 21213. So, this H naught is nothing but 37957 and from that a, b, whatever Modi et al. proposed. So, from that a, b we got H g as 21213 kilojoules meter square day. So, these two values we will use here. Then, remaining two things are the constants.

So, from here if you calculate H d is nothing but H g, H g is again 21213 into 1.411 minus 1.696 H g is 21213 upon 37957. So, the value turned out to be 9825 kilojoules meter square day. **(()) (43:44)** another correlation proposed by Garg and Garg et al., so that is based on S bar, S bar max. So, here again, we are using same H g, so to predict H d, 21213 into 0.8677 minus 0.7365 7.2 upon 12.44.

So, this turned out to be, H d is 9364 kilojoules meter square day. And the third correlation is proposed by Gopinathan and Soler in 1995. So, it uses both the things, H g bar upon H naught bar, as well as S bar upon S max bar. So, here, if you substitute 87813 minus 0.33280 H g is 21213 37957 minus 0.53039 S bar is 7.2 12.44. So, this should be multiplied with H g which is nothing but 21213. So, the value is 8171 kilojoules meter square day.

So, it seems that Modi et al. and Garg and Garg et al., so these values are matching with each other. One is 9825, and another is 9364. So, either one of the value, we will use it as H d for further calculation. So, this seems to be the correlation proposed by Gopinathan and Soler seems to be under predicting so it is coming around 8171 kilojoules meter square day.

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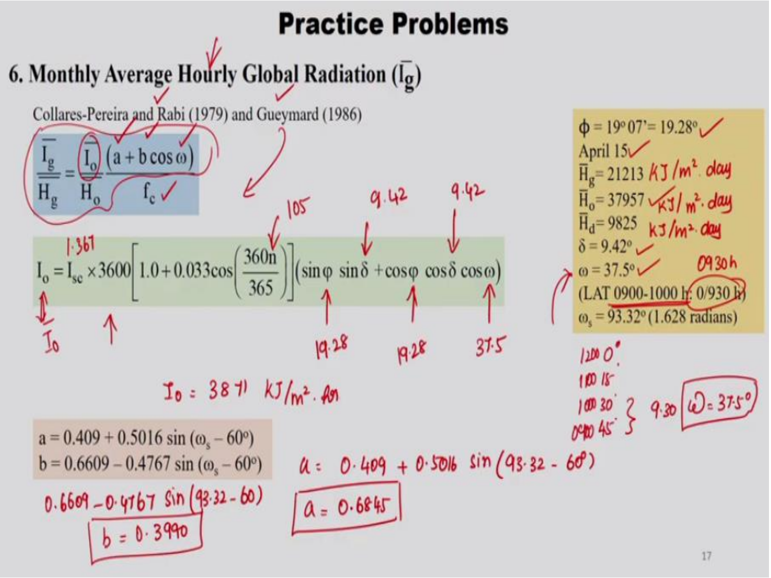

So, the next one to be calculated is monthly average hourly global radiation which is nothing but I g bar. So, here, we use same data. The phi is 19.28, April 15th, because here also we are using I naught. So, remember, this is hourly radiation. So, daily radiation is capital H, hourly radiation is I, otherwise the symbols like global is g and naught is extraterrestrial. Here also we use this April 15, for which I naught is nothing but I naught bar and H naught is already there, 37957, so all are kilojoules meter square day.

So, this is also kilojoules meter square day. So, here also we supposed to follow the convention, and then delta 9.42 for the same day. So, omega, omega here, remember, before that we did not have this problem it is a daily radiation, daily global radiation, daily diffusive radiation, but here it is said that hourly global radiation.

So, right now, for the previous problem that solar flat plate collector problem we have taken LAT as 10 hours, so that is the first part of the problem. So, here we are going to calculate hourly radiation. So, here we are taking 9 to 10 hours, whatever the values we calculate that is solar time of 9 to 10 hours in the morning. But to calculate the delta which is nothing but declination angle we need one particular value.

So, for that, it is not 0 upon, it is 09 30 hour. So, we take this middle value, 9 to 10 hours we take as 9 30 hours. So, for which for that particular LAT we will calculate the hour angle. So, as we said 12 is 0, 11 is 15, 10 is 30, 9 is 9 hours is 45, 10 is 30, 11 is 15, 12 is 0. So, what we are taking is 9.30. So, that is omega is 37.5 hour angle. And we have taken April 15 to calculate delta which is nothing but 9.42 degree.

So, all the datas are given we supposed to substitute here, we calculate the I naught so I sc as I said, 367, 1.367, and 3600. So, here, n is 105th day, already we have seen for April 15th, and then phi is 9.28, delta is 9.42, and phi is again 9.28, delta is 9.42 omega is new omega 37.5. If we substitute, so, what we would get as I naught is 3871. So, it should be kilojoules per meter square hour, because we are calculating hourly radiation.

And then, because it requires a, b and omega, omega already there and f c, there is an another constant. So, a is here given us 0.409 plus 0.5016 sin omega s, omega s, we have already calculated us 93.32. So, this is, remember, omega s is for horizontal surface. So, 93.32 minus 60. So, this is coming around 0.6845, so a is 0.6845, so if we calculate b in the same way 0.6609 minus 0.4767 sin omega s is 93.32 minus 60.

So, your b is coming around 0.3990. So, we got a, b and we supposed to calculate one more correction factor f c. So, remember, so this two researchers one is Collares Pereira and Rabi. So, they said that I g upon H g which is equivalent to I naught upon H naught into a plus b cos omega. That is enough, so they proposed this particular correlation. So, always remember whenever I spell it I g H g I naught H naught that is, bar is also there, that is monthly average.

So, they proposed this correlation, and that Gueymard 1986, he added this correction factor, f c, so that to get I g value, competent enough with the experimental or actual solar radiation value. So, here, f c is given. So, a, b, we have already calculated, which is nothing but 0.6845 plus b we have already calculated 0.3990 into 0.5. So, here, we need to be careful that omega s, the omega s is in radians.

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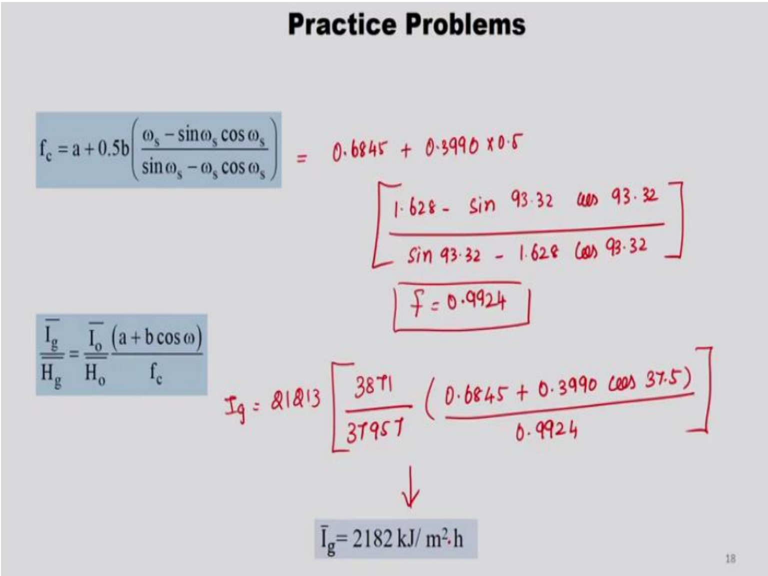

So, here we have given that value 1.628. 1.628 minus sin omega s is 93.32 cos omega s 93.32 upon sin 93.32 minus 1.628 in radians, omega s in radians, cos 93.32. So, this is your f c. So, f c value turned out to be 0.9924. So, this particular location of Mumbai city, because your latitude and longitude is given for Indian city Mumbai. So, for this particular location, f c is around 1.99, it is around 1.

So, whatever the correlation proposed by Collares and Pereira and Rabi that can be used to calculate the hourly global radiation. So, now we have calculated a, b, f c. So, we have already I naught, we have H naught and H g, we supposed to substitute and find out I g. So, I g is nothing but H g. H g value is given here, 21213 into I naught we just calculated, 3871. So, H naught, we already have, 37957 37957 into a is 0.6845 plus b is 0.3990 cos omega is 37.5 upon f c is 0.9924.

So, if you calculate your I g is coming around 2182 kilojoules per meter square hour. So, because what we are calculating here is monthly average hourly global radiation. So, here I will stop for today’s lecture. So, the next values we will calculate in our next lecture. So, here if you see the reference. So, this is the basic formula is the angle of incidence, LAT, all those formulas formulae were taken in from Sukhatme and Nayak.

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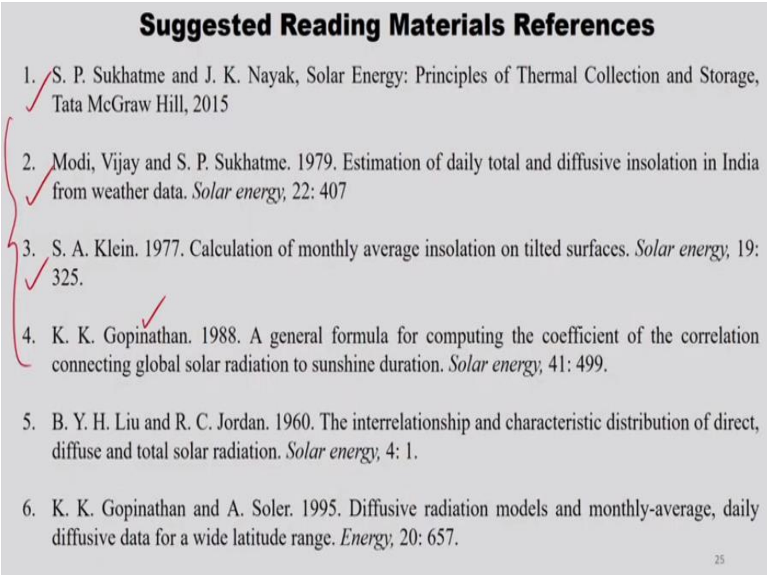

And this is the Modi et al. that particular correlation is taken from this particular research article. And Klein 1997 that recommendation of H naught bar is equal to H naught that is taken from this research article. And we have used Gopinathan relations as well. So, these three references we might have used today. And this also the Collares and Pereira, and Garg and Garg we used, Gueymard we used.

So, the rest of the references we would be using for further calculations that I will let you know, in next lecture. Thank you.