Solar Energy Technology
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Lecture - 24
Exercise – I (Contd.)

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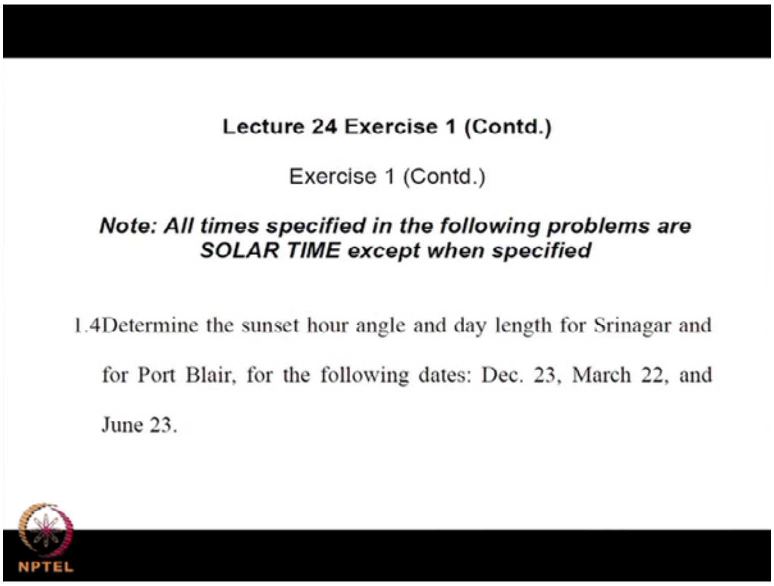

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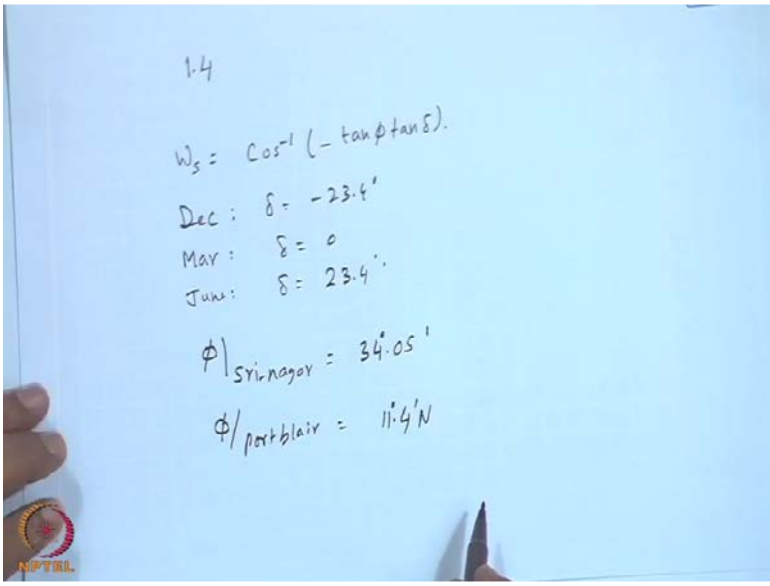

So, last time, we were solving some problems, which involve or the angle mainly as seen by the surface. And then we were half way to point problem 1.4, which deals with determine the sun set over angle and day length for Srinagar and Port Blair for the following dates: December 23, March 22, and June 23. These dates were deliberately chosen December and June, they have the maximum magnitude declination, negative in December and positive in June, whereas March 22 will be equinoctial day does not matter where it is 21 or 22. So, we will feel that declination to be 0.

So, the first thing we calculated was the sun set over angle which is given by cosine inverse minus tan phi tan delta. So, I will specify December delta as minus 23.4 degrees and March as equinoctial day 0 and June delta plus 23.4 degrees. So, we can latitude of Srinagar is 34.05, and then Port Blair. So, degrees and the minutes does not make much difference, whether you use it as a point or minuses converted to degrees.

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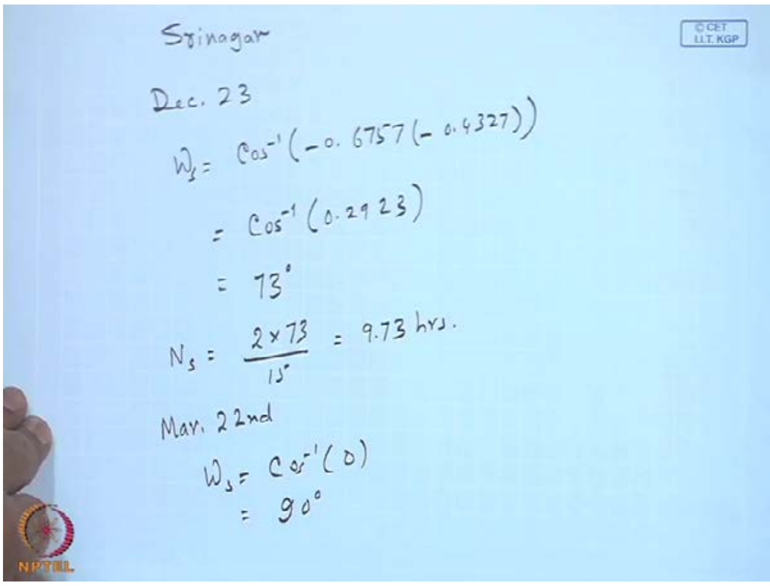

So, for Srinagar, first we shall do the calculation December 23, omega s is cos inverse tan phi which is 6757 and tan delta negative 0.4327, and this is cos inverse 0.2923, which is 73 degrees. So, your sun set over angle is less than pi by two as can be expected in a winter month and number of sun shine hours N s be twice of omega s by 15 degrees which will be 9.73 hours, March 22 and since delta is 0 omega s is cos inverse of 0 should be equal to 90 degrees.

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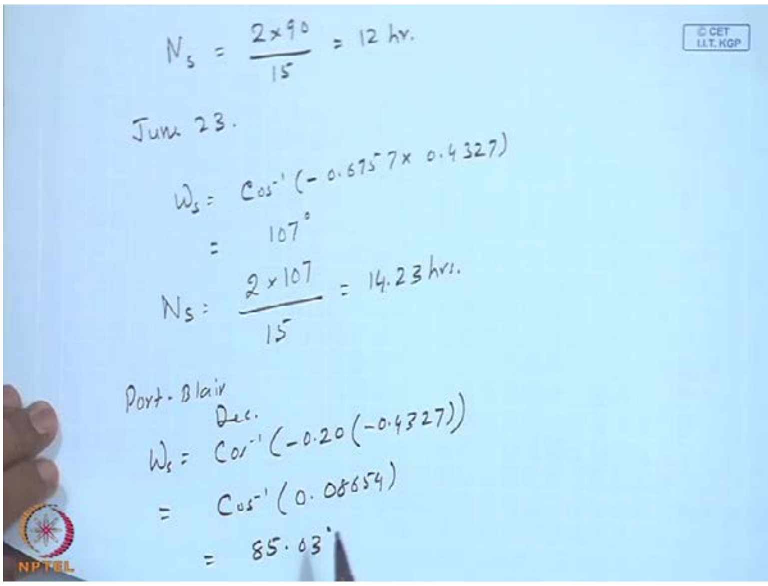

And the number of sun shine hours N s will be 2 times 90 by 15, should be equal to 12 hours, you have any equal day and night on the equinoctial day, then you go for June 23, you have to the sun set over angle is cosine inverse same minus 0.6757 times 0.4327, declination is positive. So, the consequently delta has been negative, this will be equal to 107 degrees. So, number of sun shine hour will be twice 107 by 15 degrees per hour which will be 14.23 hours, you will notice that the previous number of hours which we got as 9.73 hours in December and this has 14.23 in June, the summation would be 24 hours. So, for equal magnitude declination a given location will have 90 plus, some degrees has a sun set over angle or 90 minus the same number of degrees for the winter or the corresponding negative or positive declination.

So, will go to Port Blair, the whole idea is to show, the effect of the days which I have chosen the extreme of the March December and June and then on the latitude of the Srinagar has the more or less the highest, higher latitude in India compare to the Port Blair which has got the latitude of only, what is the latitude, I think, I must have given previously and omega s or you can see form the table that we have provided earlier, we will go for December omega s cos inverse minus 0.20, whatever is that tan latitude minus 0.4327, because it is December, you have a negative declination, this will be cosine inverse 0.08654 which is 85.43 degrees.

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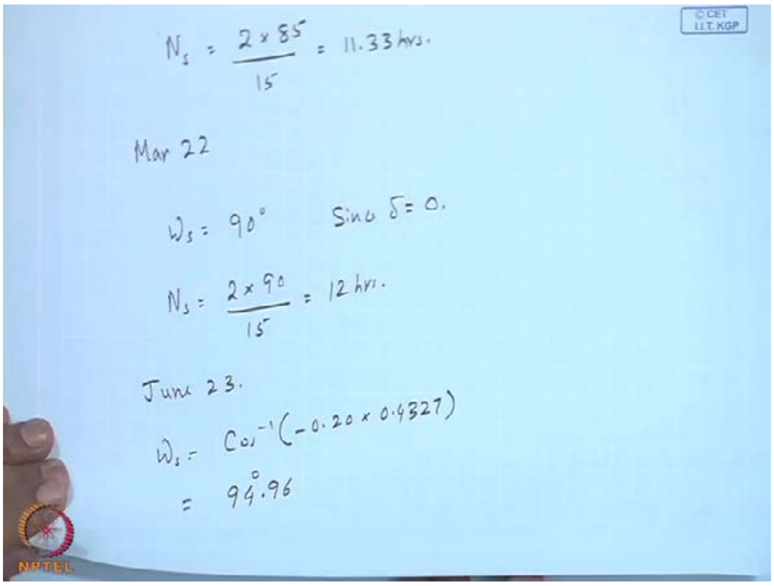

And the number of sun shine hour N s will be 2 into 85 by 15, which should be 11.33 hours, you would find that this is pretty close to 12 hours and they compare to what we had for Srinagar, this is considerably higher and if you go for March 22 omega s will be simple 90 degrees, since delta is equal to 0 and N s will be 2 into 90 by 15 should be 12 hours. So, our equinoctial days, wherever you are you have a equal day and equal night equal to 12 hour, and June 23 so omega s will be cos inverse of tan latitude of whatever times tan delta positive, now that should be equal to 94.96 degrees, so you will find this is about 4.96 degrees higher and the previous one is 4.96 degrees lower than 90.

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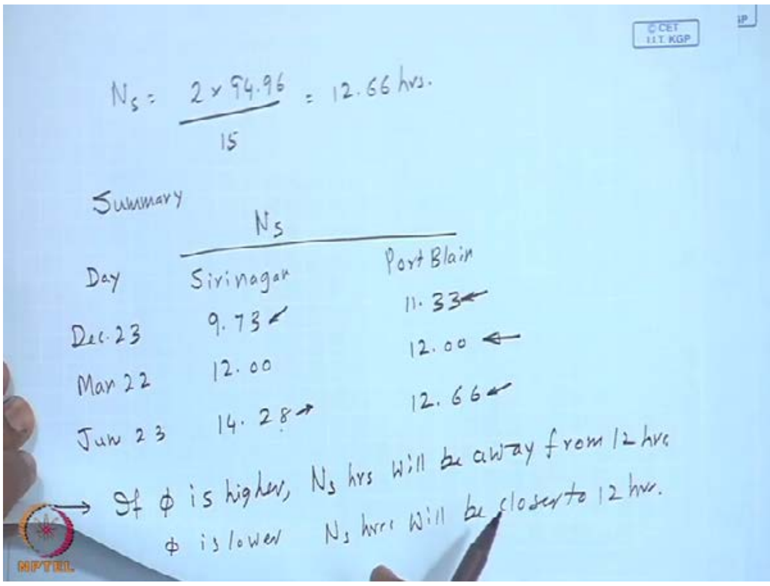

So, you have N s, the number of sun shine hours equal to twice 94.96 upon 15, which shall be 12.66 hours, once again this sum for the December and June will be 24 hours. So, this will be that much in excess of 12 hours and December, it will be the same amount more or less, I mean the corresponding declination less than the 12 hours mark. So, if I make a summary, so that we can draw some conclusion, day I will set up myself a table and I am giving the number of sunshine hours for Srinagar and Port Blair.

So, this is December 23, 9.73, 11.33, March 12 hours 12 hours, and June 14.28 and 12.66. So, the following observation can be made, if the latitude phi is higher. So, number of sunshine hours will be away from 12 hours. So, this is when I say, it is away, it can be high, it can below, so for example, December it is lower and for June it is higher right, and if consequently if phi is lower, N s hours will be closer to 12 hours, whatever may be the season and that is evidence by 11.33, 12.66 that they differ only by 33 minutes and the 66 or in the summer and in the winter where as you can see it is 9.73 hours and 14.28 hours and of course, if the declination is 0 then there is no difference or the effect of latitude is not felt and you have equal day and equal night on equinoctial day whatever will be location.

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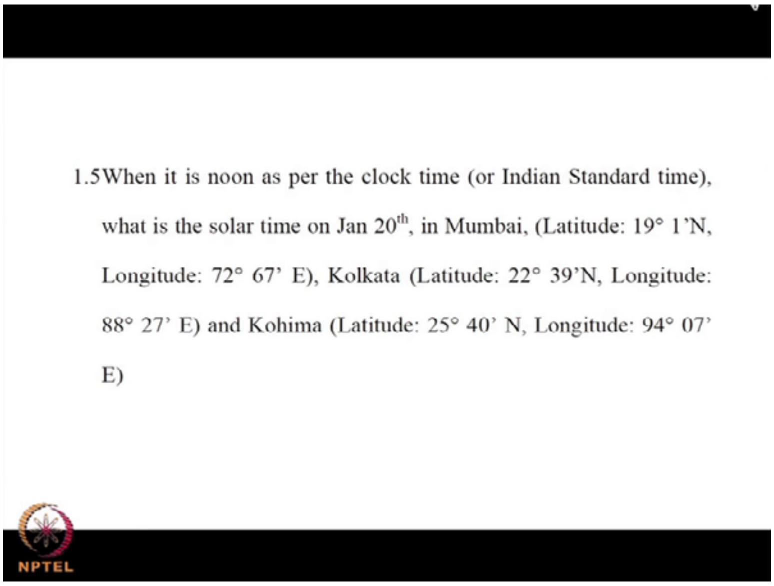

So, we should go the next problem 1.5, when it is noon as per the clock time or the Indian standard time, what is the solar time on January 20 th in Mumbai or has certain latitude and longitude in Kolkata and Kohima. So, these locations once again I pick it up, so that one has the west most more or less in India and the other one the easternmost longitude in India. So that, that will give the time difference compare it to the standard time and the time so called solar time.

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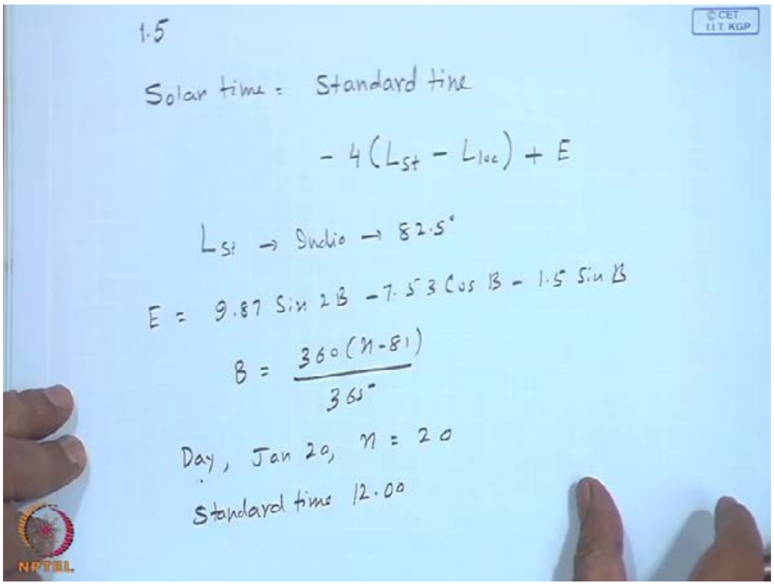

So we know that, solar time is the standard time that is the time that we will see in the clock based on the longitude and which hour our Indian standard time is based minus 4 times longitude of the standard time minus L location. So, this minus sign is for the east longitudes plus a correction; so called equation of time, for L s t India is 82.5 degrees that is about 5 and half hours of ahead of the Greenwich mean time, and the equation of time E is 9.87 sin 2 B minus 7.53 cos B minus 1.5 sin B, you please check the earlier equation that we have written I am deliberately repeating. So, that at least one will be correct, B will be 360 time n minus 81 upon 365, where n is the day of the Juliann date. So, we are having day as January 20, so n is equal to 20, and the we are given that standard time as12 0 0, it can be anything, the correction will be remain the same.

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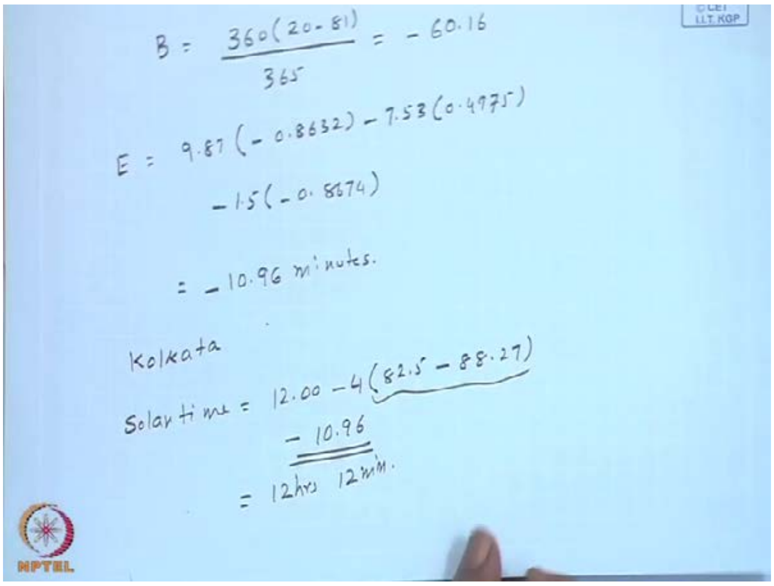

So, first we should calculate B should be equal to 360 times 20 minus 81 by 365 right, n is 20 and that 81 is 81, this shall be equal to minus 60.16. So, E is 9.87, that is the constant, minus 0.8632 minus 7.53 times 0.4975, those are the cosine angles of B and sine angel of 2 B 1.5 minus 0.8674, which is 10.96 minutes, because the equation of time is given in minutes. So, correction is in minutes, which is sorry, minus 10.96 minutes. Now we will go to Kolkata and solar time is 12 point o o minus 4 times 82.5, this standard longitude minus the longitude of Kolkata 88.27 minus the equation of time which is minus number 10.96 and this comes to 12 hours 12 minutes. So, Kolkata time is ahead of the standard time which can be expected, because it is eastern time but, you should also note that the equation of time E is not an significant member, depending upon sign if you look at that that will go plus positive, it may eight or oppose the correction due to the longitude, otherwise if this has been plus or you will 0, you would have a higher time ahead of the standard time for Kolkata in the month of January.

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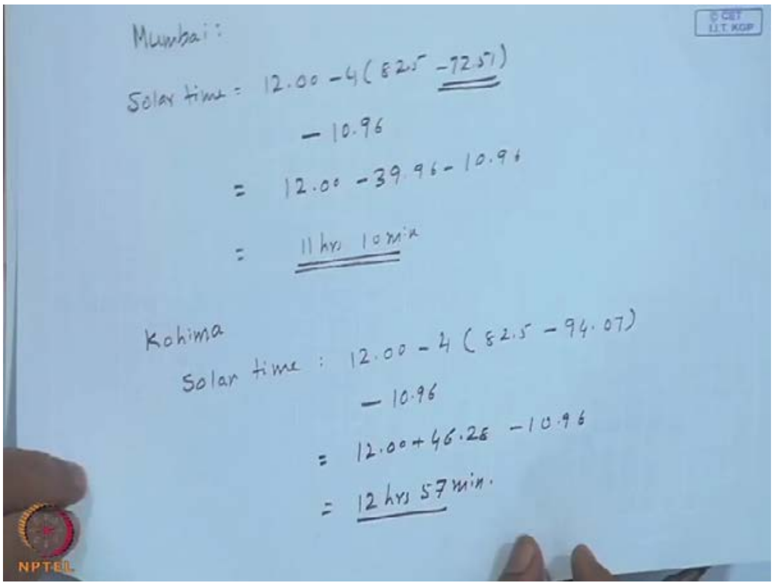

So, we go to Mumbai, so solar time at 12'o clock, clock time will be minus 4 82.5 minus 72.51, please note that the longitude of Mumbai is less than the longitude of the standard time, this passes though Allahabad, and this is to the west consequently to be lower than 82.5 minus of course, the equation of time is independent of the latitude or longitude given by 10.96, which will become 12 o o minus 39.96 minus 10.96, which will come to 11 hours 10 minutes, so you will find that there is a 50 minutes difference between the standard time and the solar time in Mumbai on January, Kohima which is a eastern extreme sort of solar time will be 12 o o minus 4 times 82.5 minus 94.07, the longitude is 94.07 e and east this is 10.96 the equation of time which you have calculated remains the same, that should be equal to 12 o o plus 46.28 minus 10.96 that is something like, 12 hours 57 minutes. So, the solar time is much ahead of the clock time in Kohima which is the longitude much more to the east of the longitude on which our Indian time is based.

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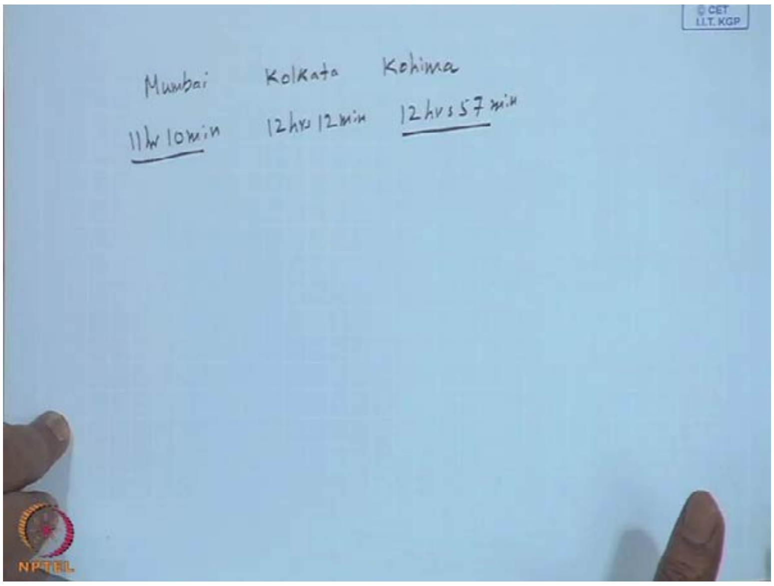

So, once again as the contrast you can see Mumbai, now I have put it in the increasing order of the longitude Kolkata and then Kohima, 11 hours 10 minutes, 12 hours 12 minutes and 12 hours 57 minutes, so for a given clock time of 12’o clock, if you look at the solar time in Kohima and Mumbai, there is a considerable difference almost equal to 2 hours. So, this illustrates the point that the solar time can be different why different or up to an hour or a hour and a half and the depending upon the season of course, because the correction E depends upon the day and of course, the longitude difference that is either it is a plus or a minus depending upon, whether you are to the east or to the west of standard longitude on which the time of that location is based.

So, India has one time zone only, and whereas US has got of course, US across from the east coast to west coast is much longer or much more further than what we have from let say Kohima to Mumbai and the a consequently they divided into 4 time zone. So, in India, I do not know, there are more sometime back to have 2 time zones but, never the less the difference appears to be significant.

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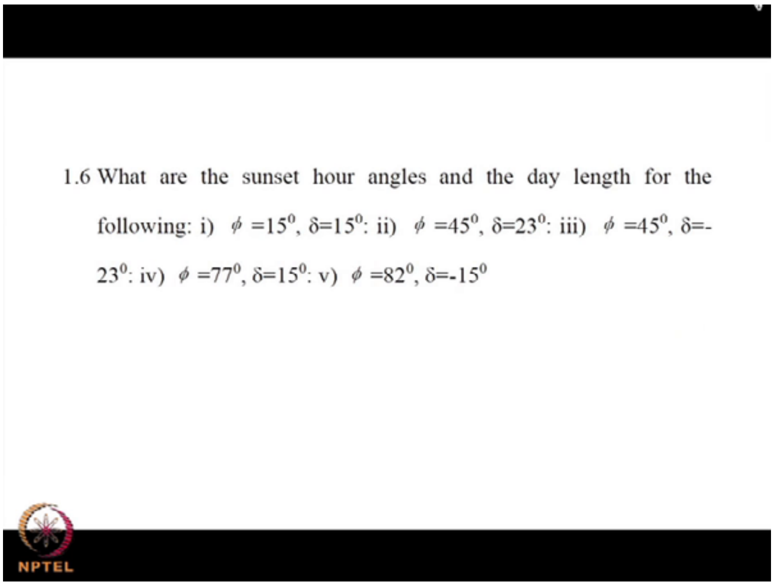

So, we will go to the next problem 1.6, what are the sunset over angles and the day length for the following.

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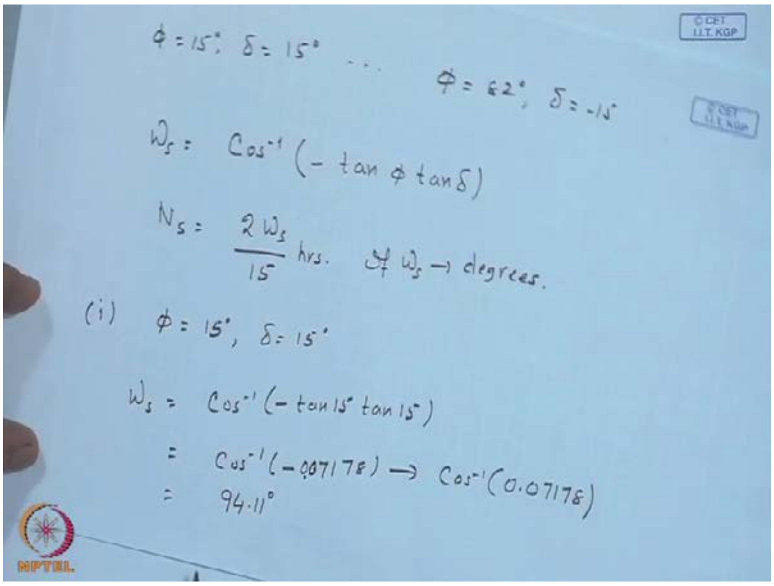

So, here I did not specify the name or the location but, just these examples phi for example, 15 degrees and declination 15 degrees so and so forth, up to latitude of 82 degrees, and declination of minus 50. So, five examples were given, we would like to draw, some conclusion out of competition that we will do for the sunset over angle and the day length for the following combination of latitudes and the declination.

So, first the formulae omega is this given by cosine inverse minus tan phi tan delta, and the number of sunshine hours is twice omega s by 15 hours, if omega s is in degrees. So, we will go one by one, first combination is latitude 15 degrees and the declination 15 degrees not that phi is equal to delta, I just wanted to pick up a sort of average positive declination, which will be 0 to 23, 15 is a good number, omega s is cosine inverse minus tan phi which is 15 and tan delta which is also 15. So, this will be equal to cosine inverse minus 0.7178, which will be 94.11, this a large, this is 0 point, this is let me rewrite cosine inverse 0.07178, I was just wondering, because why this is, so close to 90, if it is 0.71, so 94.11 on degrees. So, this is sun set over angle.

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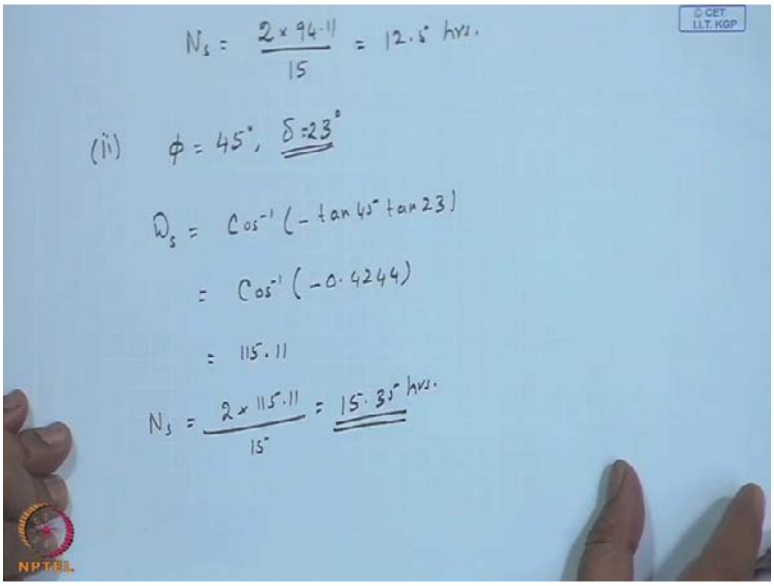

So, you develop a field for the since, you know the functional dependence upon of cosine or sine whatever, and one should be able to have a check, whether the number that you get is okay, is constant with the number that you have over here. So, sunshine hours will be N s twice 94.11 by 15, that is equal to 12.5 hours, So here, I mean a decimal is smaller 12.5 hours means 12 hours 30 minutes, and second case is a higher latitude of 45 degrees and declination also high, which is more or less corresponds to June, omega s will be cosine inverse of minus tan 45 tan 23 equal to cosine inverse minus 0.4244, which is 115.11, that is much more than that 90 degrees, so called average day. So, the number of sun shine hours N s will be twice 115.11 upon 15 should be 15.35 hours. So, compare to the common usual perception that the average is sunshine is about 12 hours, if you have a high latitude and high declination, you have as much as 15 hours plus something day time.

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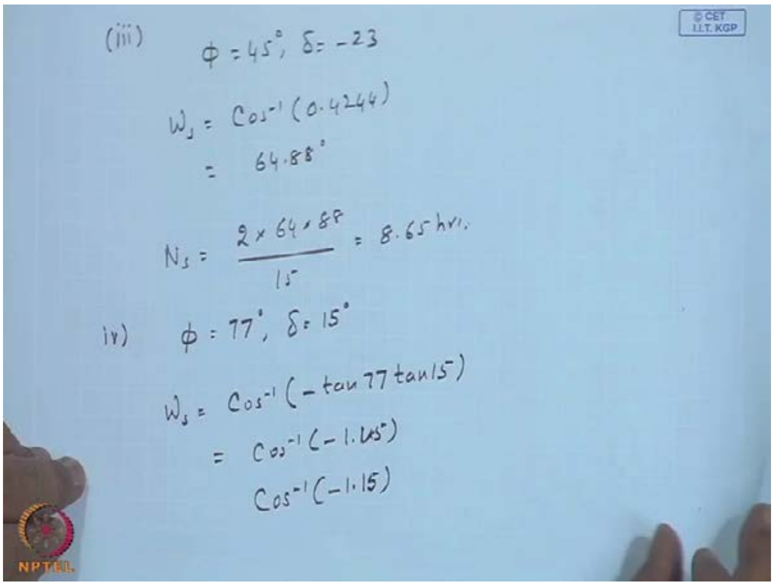

And the third you have got phi equal to 45, delta is minus 23. So, we will take correspondingly negative declination which will correspond to June someday. Sorry, December someday and omega s will be number will remain in same except it will be positive 0.4244, which is 64.88 degrees only. So, this N s or the number of sunshine hours will be 2 into 64.88 by 15 which shall be 8.65 hours, again you will see that previous summation of number of all angles of 15.35 and 8.65, this will make a 24 hours right, because declination are equal but, opposite in sign at the same location.

So, case four deals with an extreme latitude of phi 77 degrees and declination 50, I was cautioning, whether I have discussed in detail or the cases where the latitude is more than 66.55 degrees, depending upon the declination, you will have a little problem with a trigonometric relation of omega s is cos inverse minus tan phi tan delta. Let us see what the problem is omega s is cos inverse minus tan 77 tan 15, which is cos inverse minus 1.15, sorry, 1.5 is not there, let me rewrite cos inverse minus 1.15, you know that cos inverse is not define but, the modulus of the number is more than 1.

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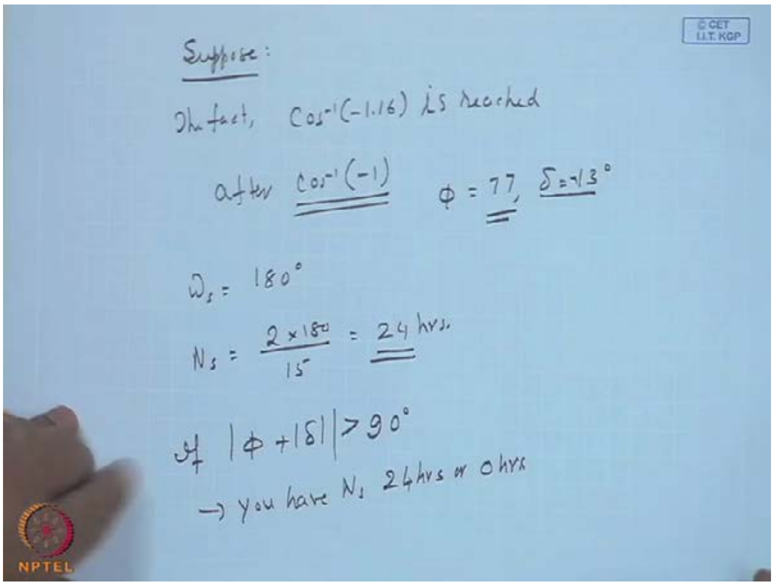

So, this cannot be evaluated, but suppose this is an important statement or argument and rather not a supposition the fact, this cosine inverse minus 1.16 is reached after cosine inverse minus 1. So, what I shall do is I will take it as a limiting case and set omega s equal to 180 degrees, because minus 0.1 for certain declination for example, if you take let us say phi 77 and declination 13 degrees, you can trigonometrically, also prove it if this summation is equal to 90 degrees that tan phi tan delta the product will be just equal to 1, and the sign is according to declination being positive or negative.

So, omega s is 180 then my N s would be twice 180 by 15 which is 24 hours; that means, if you have a latitude of 77 degrees and the declination of minus 13 or less mathematically or magnitude wise minus 13, minus 14, minus 15, they are smaller numerically but, we consider them to be a higher magnitude. So then I will be having a cosine inverse of a number of magnitude greater than 1. So, when declination is equal to minus 13, you have reached this 24 hours data and beyond which it remains 24 hours but, it cannot be since it cannot be more than 24 hours.

So, this is one thing then, where is the is this wrong cosine inverse of minus sine phi tan delta no, because we have put innocently theta is equal to pi by 2 and to find out my sun set over angle or the sun rise over angle, what we subconsciously thought was? This sunrise and sunset is within 24 hours which does not happen, if the latitude plus the magnitude of the declination is more than 90 degrees, 90 degrees or more than if phi plus mod delta is greater than 90 degrees, you have N s 24 hours or 0 hours. So, without solving, we have just look at that phi plus delta magnitude of delta, whether it is more than 90 or less than 90.

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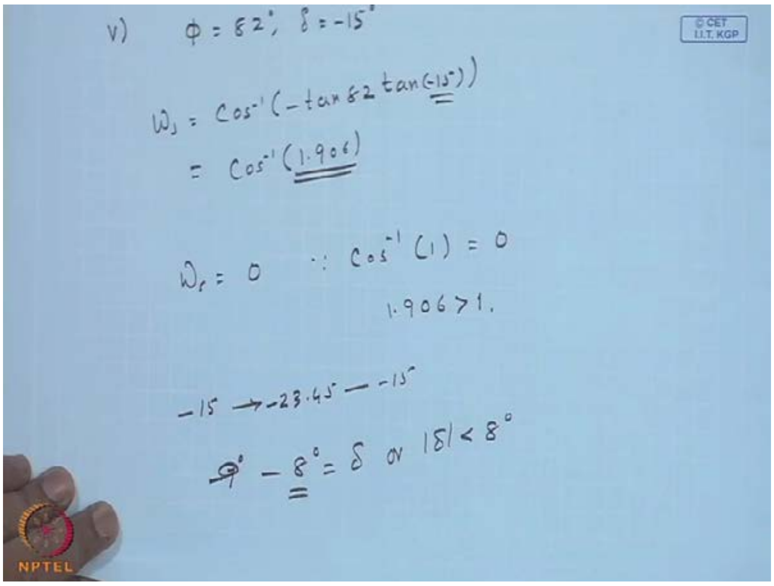

So, though illustrate the point, the last one is phi 82 degrees, I might sure that this definitely a large number and minus 15 degrees, omega s will be cosine inverse minus tan 82 and tan minus 15, which will be cosine inverse 1.906, again I have same problem if the even though it is positive greater than 1, cosine inverse is not defined. So, I will presume that it has reached 1 and then gone to become 1.906 in the negative declination. So, you will have omega s 0 since cos inverse 1 equal to 0 and 1.906 is greater than 1, what physically it means is? The sun set does not occur just within 24 hours but, it goes to minus 15 to minus 23.45, then back to minus 15 and in this case, since I have a latitude of 82 degrees only when it is minus 7 degrees, sorry, minus 8 delta or mode delta less than 8 degrees, we have a omega s right or else if all values of declination greater than magnitude delta 8 degrees or minus 8 minus 9 minus 23 back to minus 8, it will have 0 sun shine hours.

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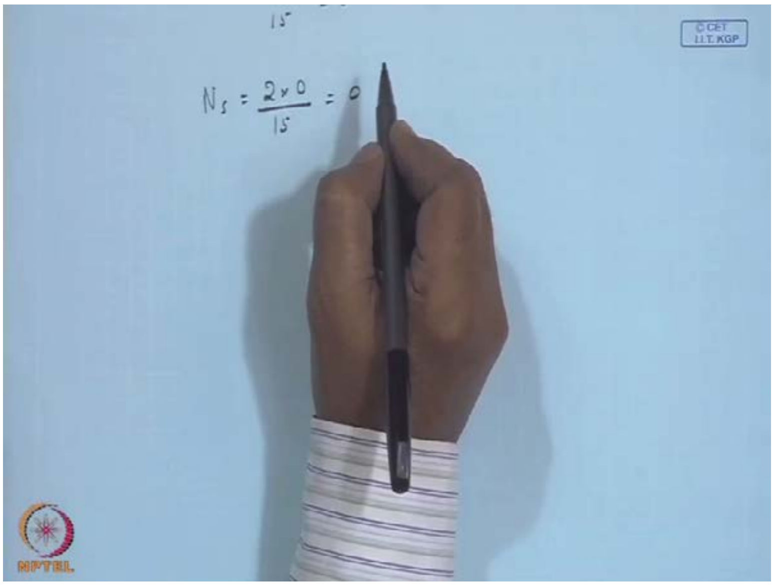

So, N s is twice or 0 by 15 also is 0.

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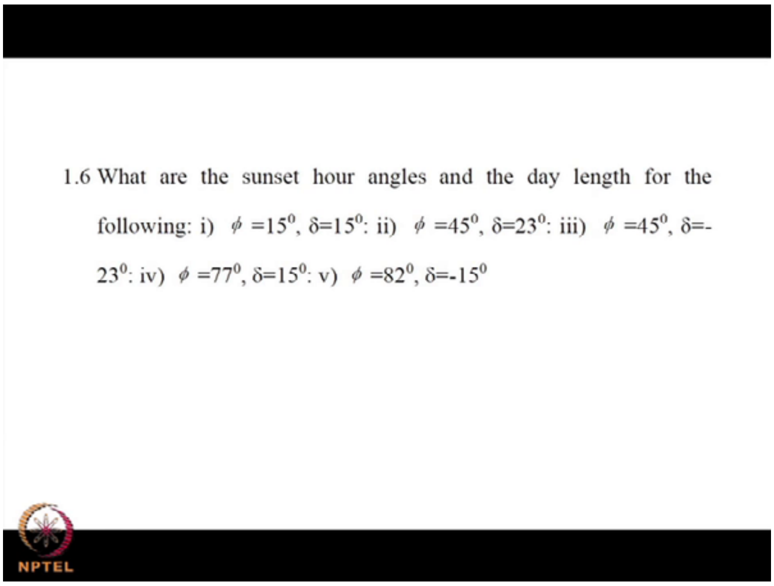

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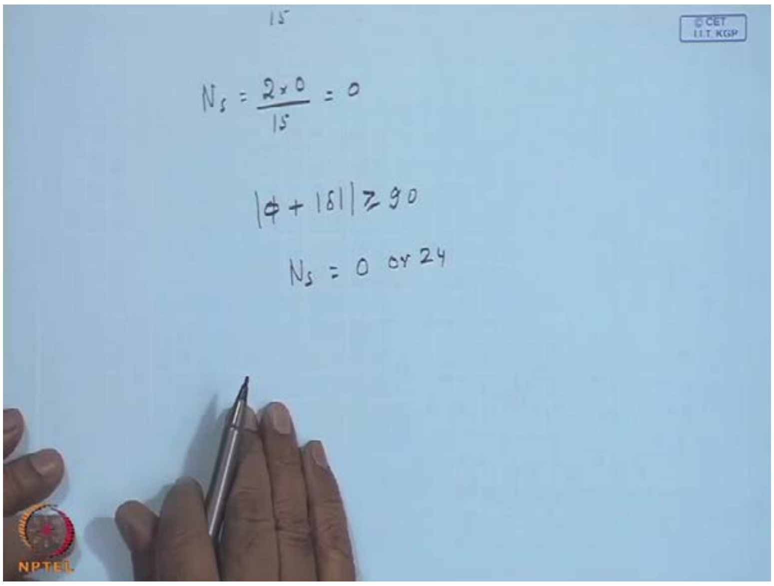

Let me rewrite N s. So, what we found is as the latitude increase in the positive declination, you have higher sunshine hours and low when the declination is negative and the difference between the negative and positive declination will decrease, if the latitude is lower in case. In fact, if the latitude is phi 0 on the equator, there will be no difference in the sun day time and the night time whatever will be the declination or the month and beyond if phi plus mod delta is greater than or equal to 90. Then you have got N s 0 or 24, so you have all the time that is exactly, if you go to the north pole for example, you have all the 6 months, when the declination is positive, you have sun above the horizon and all the days when the declination is negative, sun will not raise it is bellow the horizon.

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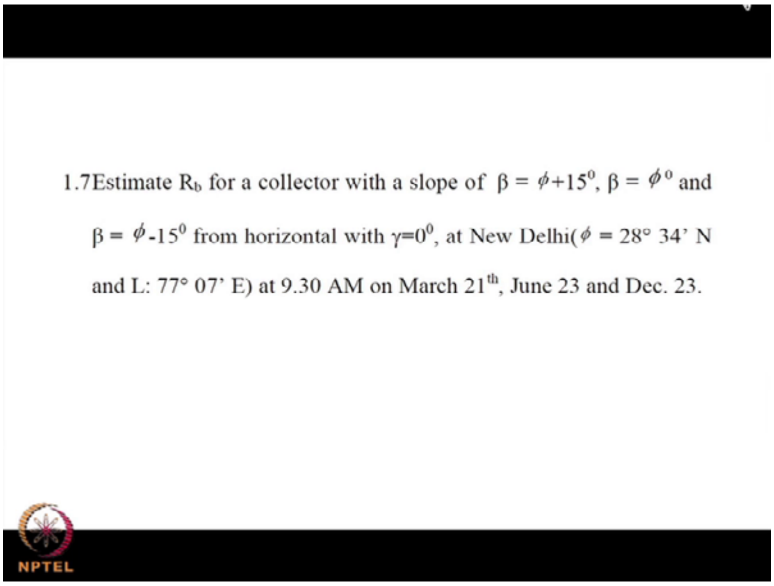

So, this is. So, much about the angles of incidence and the time correction and the number of sunshine hours then, we go to find problem 1.7.

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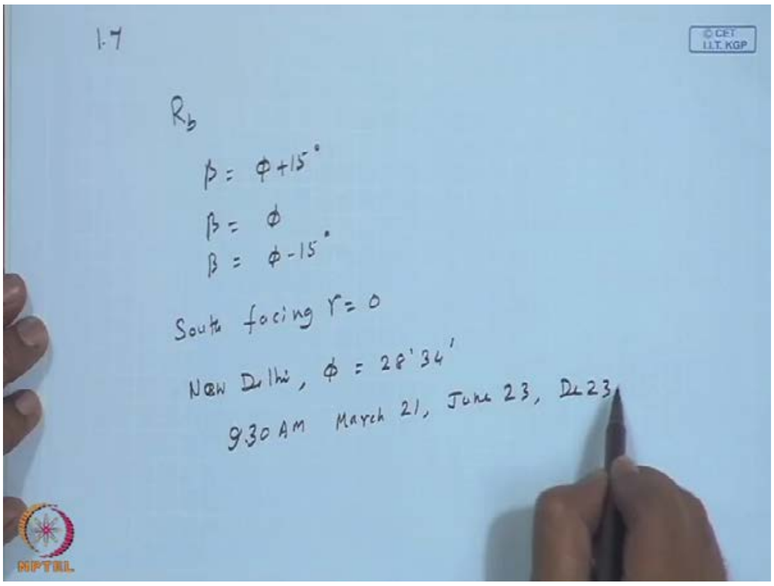

Estimate R b 1.7, that is the tilt factor for the direct radiation for the collector with three slopes phi plus 15 and beta equal to phi and then beta is equal to phi minus 15 degrees from the horizontal, and the south facing that is gamma 0 for locations New Delhi latitude is 28 degrees 34 minutes or at 9.30 AM March 21, again I thought, I will pick up these days to demonstrate the effect of extreme negative declination and extreme positive declination and 0 declination.

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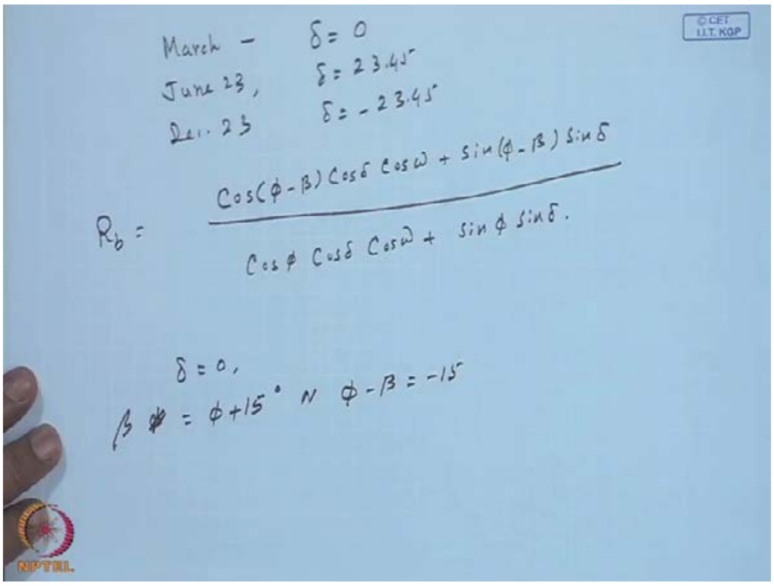

So, this is south facing I will write down the declination first, it is 0 June maximum positive 23.45 December is a negative extreme, my r b for a south facing surface is a simple formula I can remember. So, you should be able to remember, cos phi minus beta cos delta cos omega plus sin phi minus beta sin delta over cos phi cos delta cos omega plus sin phi sin delta, so for declination equal to 0 and the phi equal to phi plus 15, sorry, beta equal to or phi minus beta equal to minus 15. So, you will find out that the slope is higher than the latitude.

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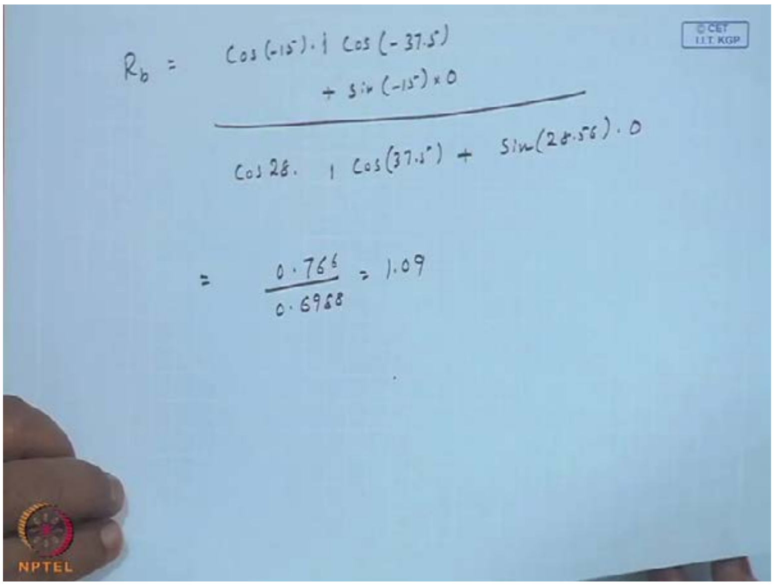

So, r b you can put down cos minus 15 times 1, because this cos delta equal to cos 0 times cosine nine thirty will corresponds to minus 37.5 time plus sin phi minus beta into sin delta which is 0 upon, you rewrite cos 28 that is cos phi cos delta is 1 and you have got cos omega plus sin phi minus beta sin phi, sorry, 25.56, and sin delta which is 0 this will come to 0.766 by 0.6988 into 1.09. So, the r b fact is pretty close it unity in other words it is not much of optimization you have chosen the beta to be higher than the latitude, and on the equinoctial dates it is not really an optimum, which will lead to a r b factor only slightly more than 1.

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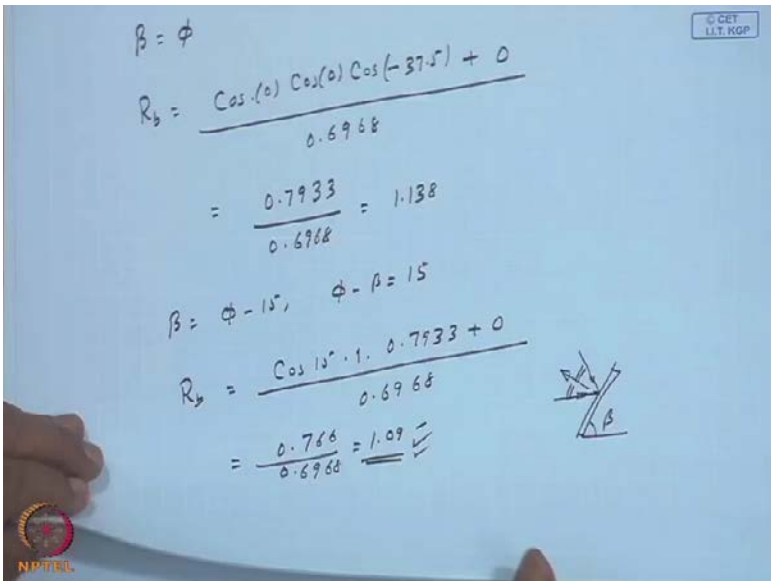

You choose beta is equal to phi. So, we have first finishing for delta 0 and this is second case then r b will be cos phi minus beta, which is 0 cos delta which is 0 times cos minus 37.5 that is cos omega plus of course, this second term vanishes which will be 0 by the same quantity 6968, this is you can calculate 7.7933 by 0.6968, which is 1.138, now this is considerably more, if you look at that way then 1.09, which we have got for phi minus beta is equal to minus 15. So, because declination is 0, this satisfy phi minus is equal to delta because, phi is equal to beta which was one of the optimum orientation which we had considered in connection on with considering collector, then you have got third case, beta is equal to phi minus 15 or phi minus beta is equal to plus 15. So, again delta is 0.

So, r b you can write down cos phi minus beta cos delta is 1 into cos omega is0.7933 plus this will be 0, because of sine delta upon 0.6968, this is nothing but, the cosine of the zenith angle, theta z which will not differ by given time, this will be 0.766 by 0.6968 equal to 1.09, this does slightly better right, because even though it is equinoctial day phi minus beta is positive and beta is less than the latitude and you have a higher factor but, at the same time it is also the same thing that we found for phi minus beta equal to minus 15 in the first instance, because on the equinoctial day if you have a surface like this depending upon your beta and this is the outer normal to the surface either you have angle of incidence like this or a ray coming like this but, this two angle should be the same it will be an a conical surface around the outer normal to the surface. So, you have exactly the same value as you have got for phi minus beta plus 15 and phi minus beta minus 15 for delta equal to 0.

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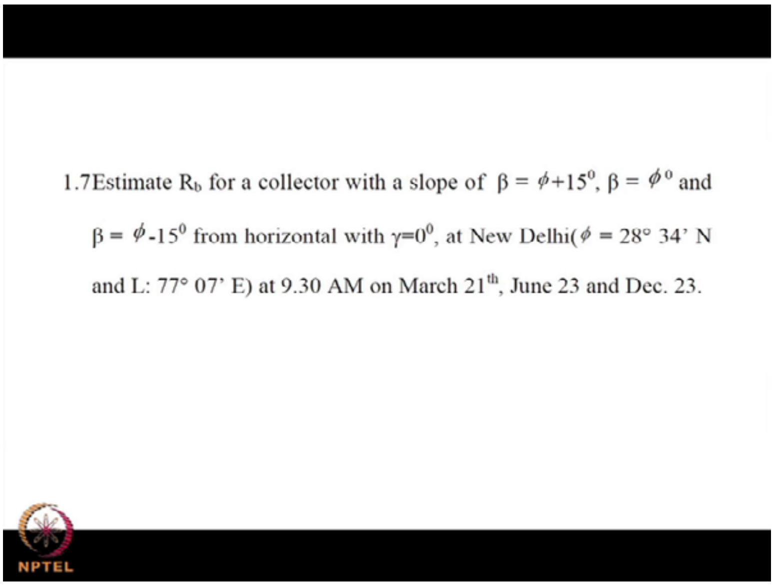

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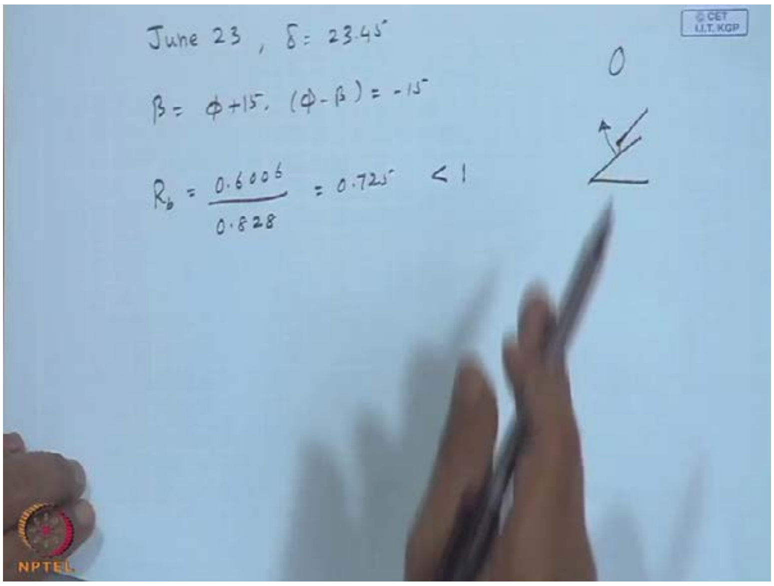

Now, we will go to June and delta 23.45. So, first case is beta is phi plus 15 or phi minus beta equal to minus 15 and you can calculate your R b with all the numbers it will turn out to be 0.6006 upon 0.828, which is 0.725. Now you will find that this is even less than unity; that means, the direct radiation is not really augmented by this orientation in June. In June, the sun is pretty much high up something like this, this is your slope and you have chosen beta to be higher than the latitude. So, it will be very nearly away from the normal incidence something like this, leading to a low R b factor of less than 1, So horizontal surface would be better than or this type of fair on orientation.

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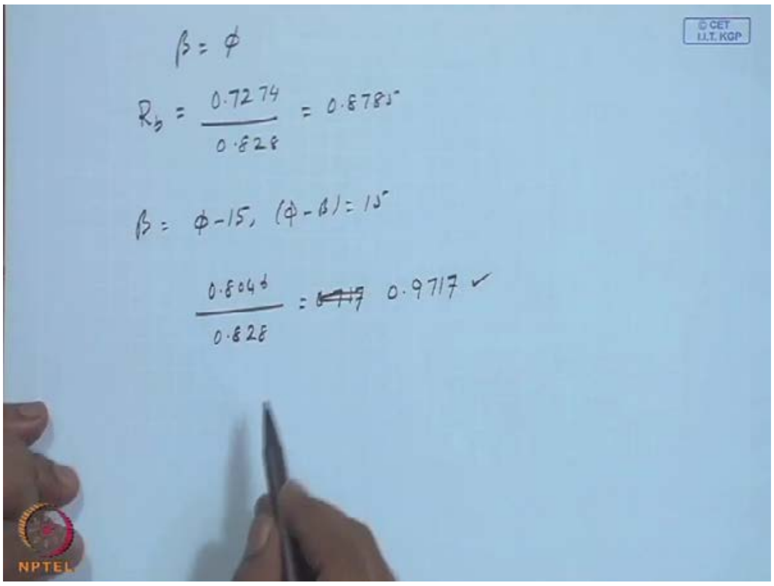

So, if you choose beta is equal to phi, your R b will be 0.7274 by 0.828 equal to 0.8785, which is of course, higher than the previous value but, still less than that, and the last is beta is phi minus 15 or phi minus beta equal to 15, and you have got a delta positive right which we have done it June 23. So, you will for this condition you will have 0.8046 by 0.828 equal to 0.9717, so this will be sorry, 0.9717. So, you are still in the positive declination June and you have chosen a beta higher than phi right and consequent lower than phi. So, that should be little favorable consequently you have a value higher than the previous rotations, and we go to December 3rd.

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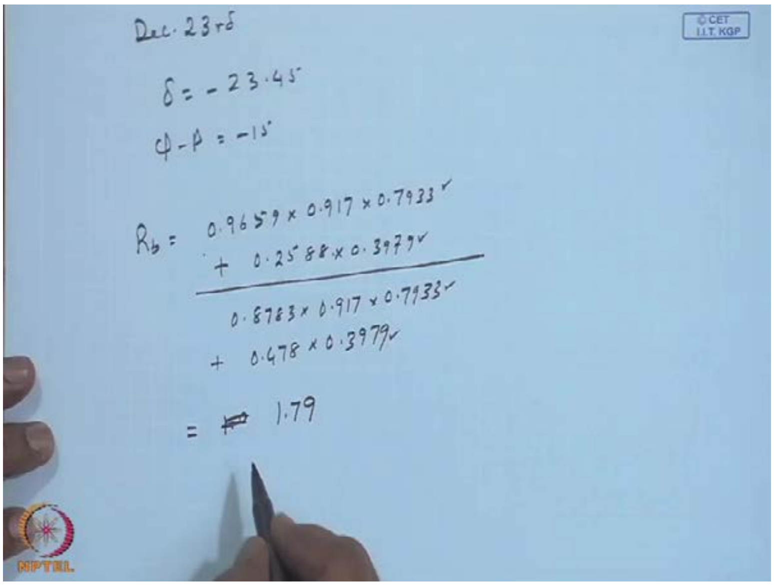

Sorry, December 23rd, declination is minus 23.45 and with 5 minus beta equal to minus 15, so R b will be cos phi minus beta which is 0.9659 times 0.917 cos delta cos omega that remains the same nine thirty plus sin phi minus beta 0.2588 into sin delta 0.3979, please note that cos phi minus beta is negative. So, is sin delta consequently this remains plus upon I would to rewrite the whole thing, cos phi times cos delta cos omega plus sin phi into sin delta 3979 as a check this is the same as this, this is the same as this, of course, I could have counted this takes both the places. This will turn out to be 1.79, pretty high values compare to less than 1 and 1.49 values.

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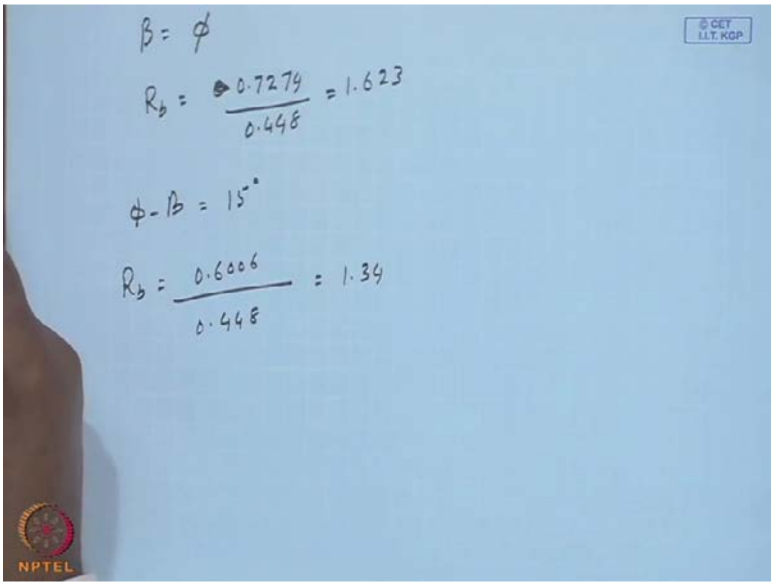

The next case will be, beta is equal to phi and you will have your R b please put down phi minus beta 0 over giving you cos minus beta 1 and sin phi minus beta 0. So, that this is simple way to calculate, 0.7274 by 0.448 equal to 1.623, which is comparable to the previous one though not higher, then you have got phi minus beta is equal to 15 and you have R b as again 0.6006 upon 0.448 equal to 0.134. So, this is illustrates, when you choose December in general R b factors are larger.

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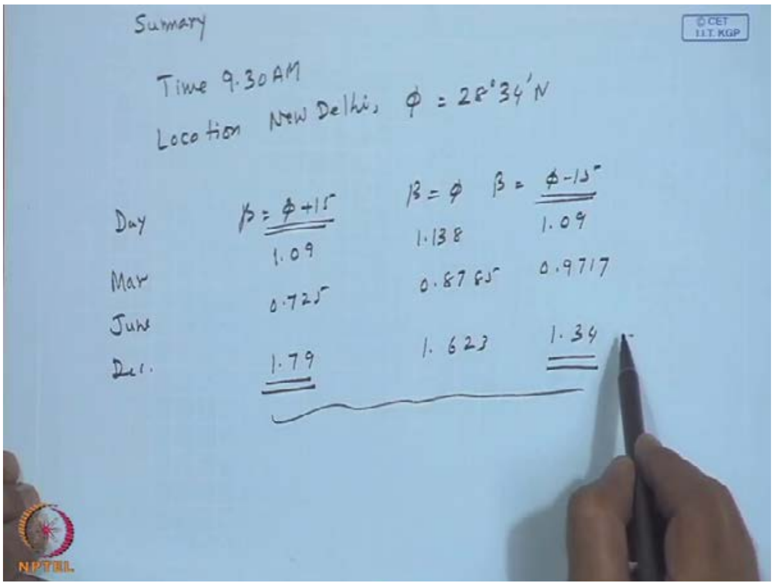

So, will summarize to have a little more or out of this, a time is 9.30 AM and location New Delhi latitude 28 degrees 34 minutes North. So, day and the corresponding to beta is equal to phi plus 15, beta is equal to phi and beta is equal to phi minus 15, March, June December, the corresponding maximum declination or 0 declination, 1.09, 1.138, 1.09, and this is 0.725, 0.8785, 0.9717, 1.79, 1.623 and 1.34. So, this is beta greater than latitude, you have in December the highest, beta lower than the latitude, you have the lowest among these three, the other things the summer will have lower R b factors in general unless you orient your collector very correctly and you have got March non captive almost around 1, because declination is 0, when you change your beta from the latitude value by plus minus 15 degrees that is it we shall continue next time until then bye.