**Solar Energy Technology**
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**Lecture - 23**
**Exercise - I**

We reach some sort of half wave point, we considered the solar radiation processing, and the optical efficiency for the flat plate collectors. And then we considered in detail the theory of flat plate collectors, and various configuration, and then the principle of concentration including the double a compound parabolic collector. Now, the next important thing should be, not just to collector performance, but the system performance. As I was mentioning the bringing of this lectures, that though collector is the heart of the system. But the overall performance will depend upon every component, in the solar energy system, like for example, what is the size of our solar tank for storage, and what is the efficiency of the heat exchangers, pipes, pumping, what is the bandwidth of the controls etcetera, etcetera, etcetera.

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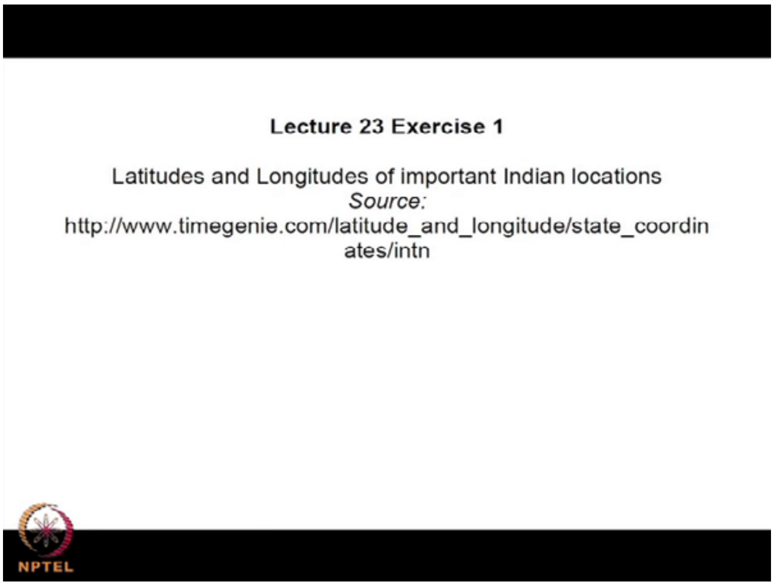


Before, we embark under system concepts, and the prediction not just for a day or a now or, but for a long period of time, like one year, one year is chosen, because the metrological cycle, repeats itself in one year, and the that will bean involved concepts. So, we will have a little break here, and go though some exercise.

So, that you will have a field for numbers, and the choice of the problems and the location mention or not mentioned is actually based upon today home appoint, if the latitude changes, what changes, if the slop changes what changes, if the season is different, what will be the differences etcetera, etcetera, etcetera. So, this lecture shall be devoted to exercise 1, we shall try to do as solve rather as when we numerical problems as possible, in this 56 lecture, and then go on with the topics subsequently.

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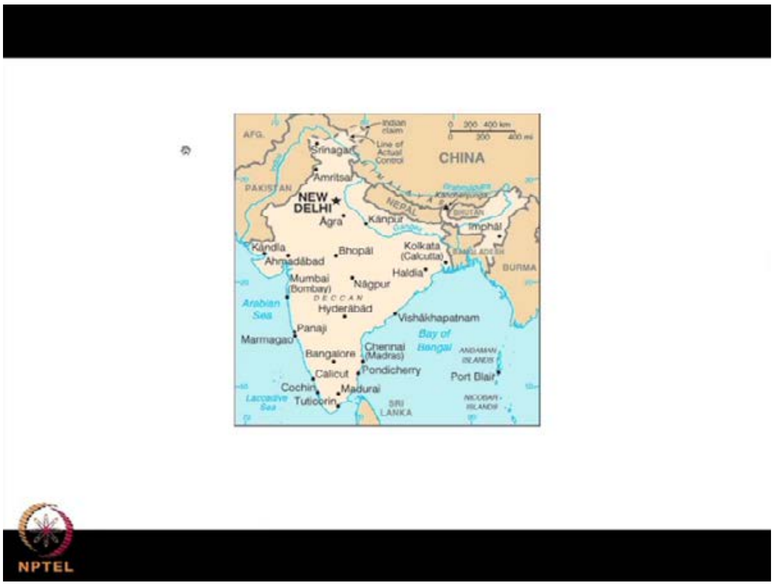


So, this is the exercise 1 and first I should acknowledge the source of time genie, which give a compilation of latitudes, and longitudes of important Indian locations, if you go though the map or I myself was surprised, you have an extensive list of latitudes and longitudes, or like for example, if you consider in state like Andra Pradesh starting with A you have Ancapari, Akabram, etcetera, etcetera, etcetera. So, when I am I am giving these names because I belong to that state I am more familiar, and you have 100, under a 100 under B C D like that. So, but what I am showing here is only a partial list form the time genie; this is the Indian map, which shows the important location including Andaman Nicobar islands.

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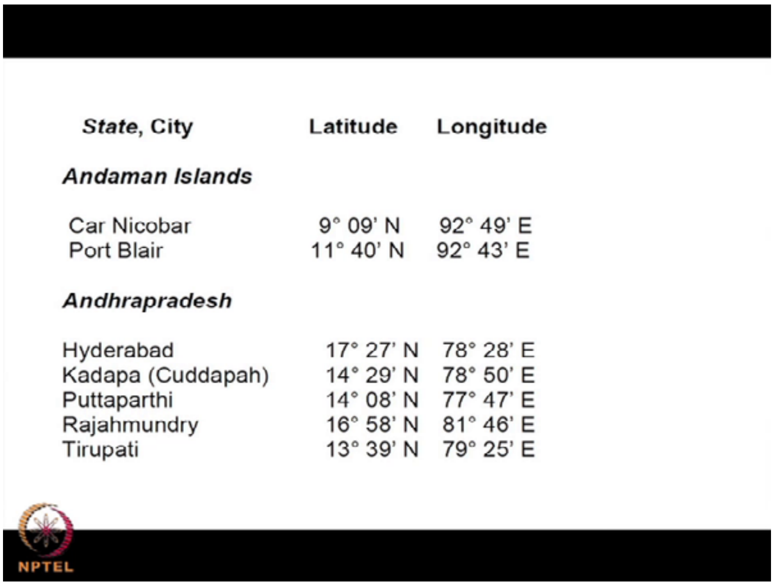


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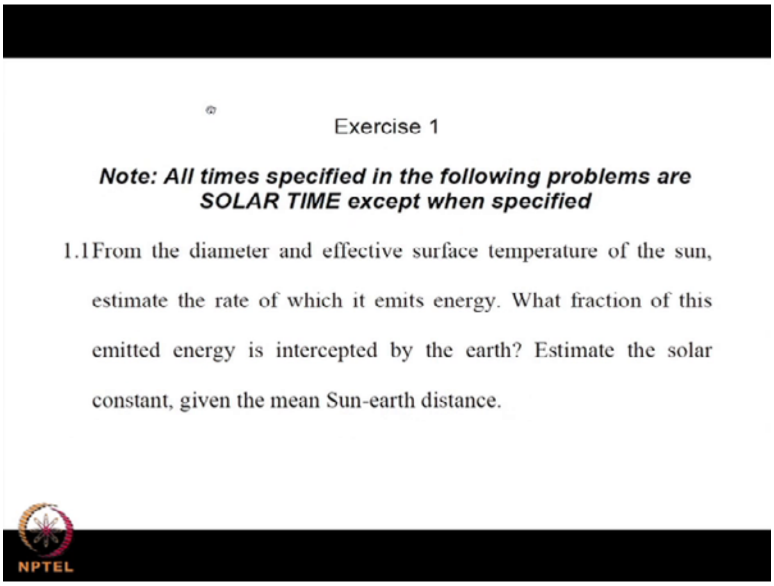


And then you have got, I have a put it into a form of a state, and city, and the state is in the italics and Andaman Island, Andhra Pradesh so on and so forth, latitude and longitudes given in degrees and the minutes. So I might have made a little mistake, here and there that 9 degrees 09 minutes for Car Nicobar, might has been treated as 9 O9 degrees right. Still, it is a small error does not matter, but nevertheless you should understand, it is in degrees and minutes, and 60 minutes is 1 degree.

So, you have got all those states in the alphabetical order, about 110 location longitudes and latitudes, are given you can go to the original web source, and then have a larger numbers of location, including this in a file, and in case there are any mistakes, you can corrects, because it is a taken and then reformatted in that process that might be few mistakes. So, the first question, the data etceteras I shall in the next class, will tell you, where you can look for, and again they are available at website. The first problem deals with from the diameter, and the effect two surface temperature of the sun, estimate the rate at which it had emits energy, and what fraction of the this emitted energy is intercepted by the earth, and estimate the solar constant, given the mean sun, earth distance. This we have briefly discussed in the theory, but I should go though the calculation procedure in detail.

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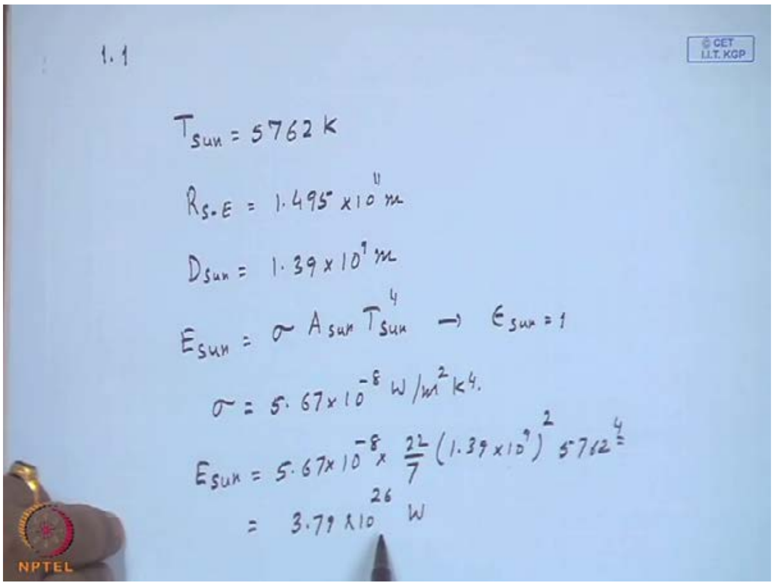


So, this is exercise number 1.1, T sun effect you is 5762 Kelvin. Sun to earth distance is 1.495 times 10 to the power 11 meters, though we have gone through all this things in the lectures and probably, these numbers also given, but I felt a reiteration, would be helpful for you to have a idea of the order of magnitude inward. And diameter of the sun is 1.39 times 10 to the power 9 meters. So, energy emitted by this sun E sun, will be sigma times area of this sun surface area, times T sun to the power 4 4, and you are assuming in this process, epsilon sun equal to 1, and this Stiffen Boltzmann constant sigma equal to 5.67 into 10 to the power minus 8, watts per meters square kilo Newton to the power 4, you can check this numbers, but I believe my answers are correct even these numbers are little wrong, I do not think they are wrong, but nevertheless give pinch of salt.

So, E sun is 5.67 times 10 to the power minus 9 into 22 by 7, that is pi times 1.39 into 10 to the power 9 to square pi d square into 5762 to the power 4 sigma area of the sun into t of the sun to the power 4 which shall be equal to three point seven nine into ten to the power 26 watts. So, this has got watts per meters square degree Kelvin to the power 4 degree Kelvin to the power 4 gets cancels with this meters square gets cancel with this, so I have got 3.79 multiplied by ten to the power 26 watts.

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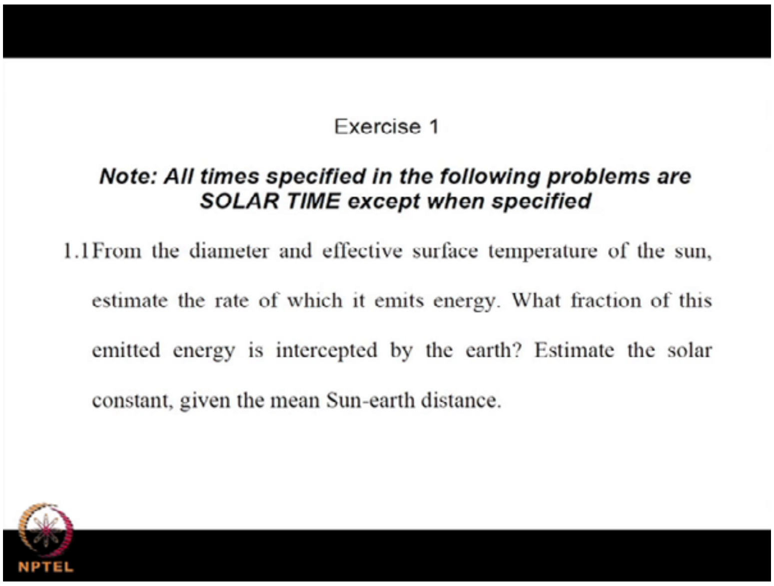

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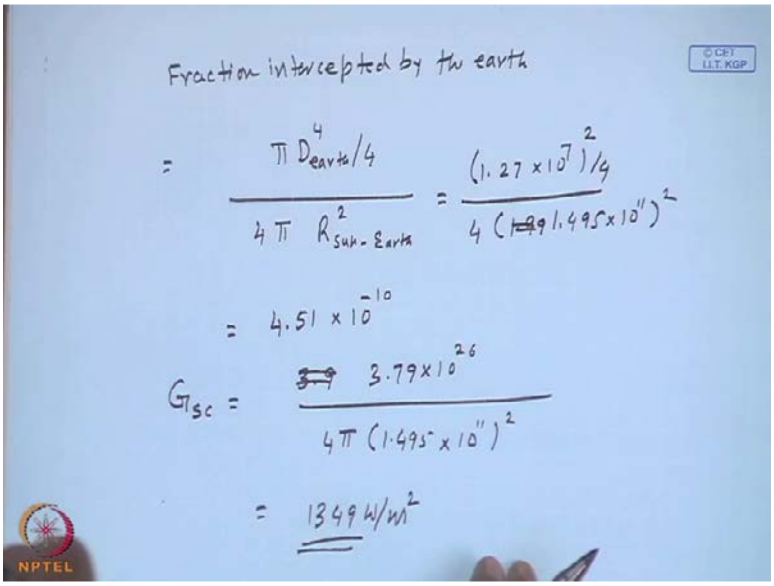


Fraction intercepted by the earth, should be equal to pi D earth to the power 4 by 4 by 4 pi R sun earth square, please note pi D to the power 4 tap by 4 is nothing but the cross section area or the projected area of the earth whereas of course, this is the spherical area of a or earth or sun to earth radius. So, you have got 4 pi R square, instead of pi D to the power 4, as we have written in the case of sun because, it is in terms of diameter.

So, this should be equal to 1.27 into ten to the power 7 square by 4, so pi an pi get cancel upon 4 times 1.49, sorry 1.495 10 to the power 11, whole square that should be equal to 4 .51 times 10 to the power minus 10. So, it is a small fraction of the energy emitted by the sun, that the earth captures, now if I want the solar constant G s c, which should be the solar radiation received by surface normal to sun rays at one sun to earth mean distance. So, the total amount of energy emitted is 3.79 times 10 to the power 26.

Which we have calculated, upon the corresponding area 4 pi 1.495 times 10 to the power 11 square, which comes to 1349 watts per meter square, if you recall G s c is about 1357 to 1367, the estimates are changing, but we got the pretty close number and this close number has something to do with t sun, 5700 and 62 is assumed, would to be suns temperature or you might call it is a bad calculation of the effect to sun, because we are assuming extra decimal derivation of about 13150 watts per meters square ok.

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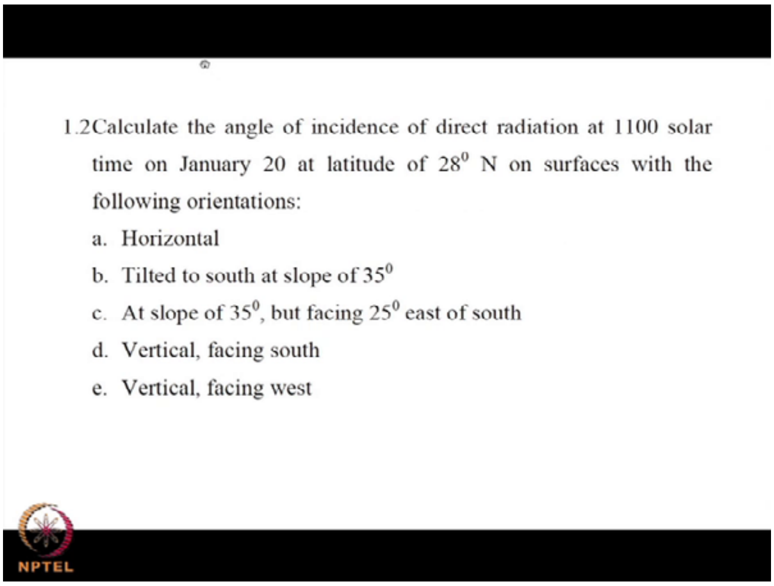


So, we should go to the next problem, these problems are picked up with a particular idea to drive home the point, which were trying to make though the lectures, the first one is nothing, but a little bit of free transfer. So, that you know the radiation emitted by the sun, though any spherical surface at a particular distance with a total amount of measure is those are intensity changes; that is what we are trying to do, what we that we did and what we receive on earth at a certain distance is inversely proportional to the square of the radius, or the distance from the sun, and that is what we got.

So, the second problem deals with calculate the angel of incidence of direct radiation at eleven o clock, so that time on January 28 at a latitude. So, 28 degrees north on surfaces with the following orientation, though out this exercise, we mean only the solar time except, when we state otherwise. So, the first one is a horizontal surface, then tilted to south at a slope of 37 degrees, at a azimuthally angle of 25 degrees east of south, then vertical facing south, and vertical facing west.

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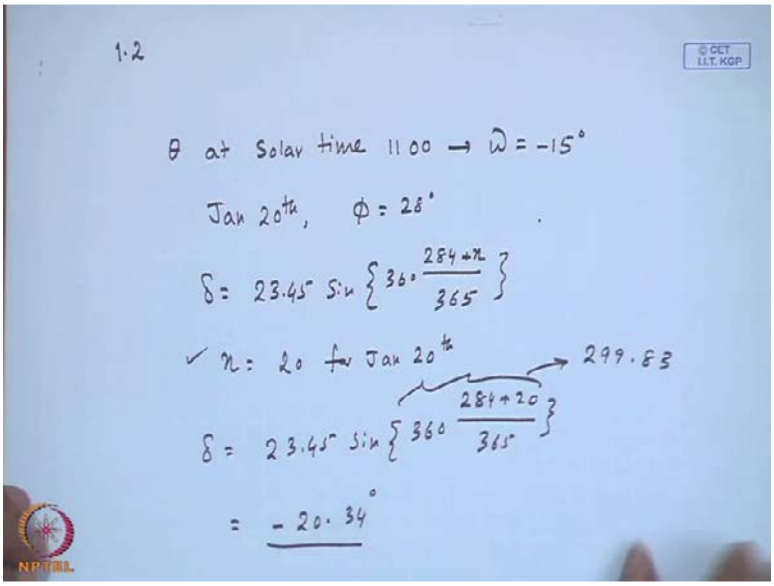


So, these are the examples. So, theta at solar time eleven o clock, lets write, which corresponds to omega equal to minus 15 degrees. Then you have got January 28, as the date given and the latitude is 28 degrees, which is a high latitude, within the Indian geography and the declination, will be 23.45 sin 36 times 284 plus upon 365, and n will be 20 for January 20 th, because n is the Julian day counting one as January 1st. So, on and, so 4th consequently January 20 will have n equal to 20. So, delta will be 23.45 sin 360 times to 284 plus 20 upon 365, this is equal to minus 20.34 degrees right. And, if you calculate this sign of this number will be 299.83, this will be 299.83, you can check up, and the answer tends out to be minus 20 degrees 34 20.34 degrees.

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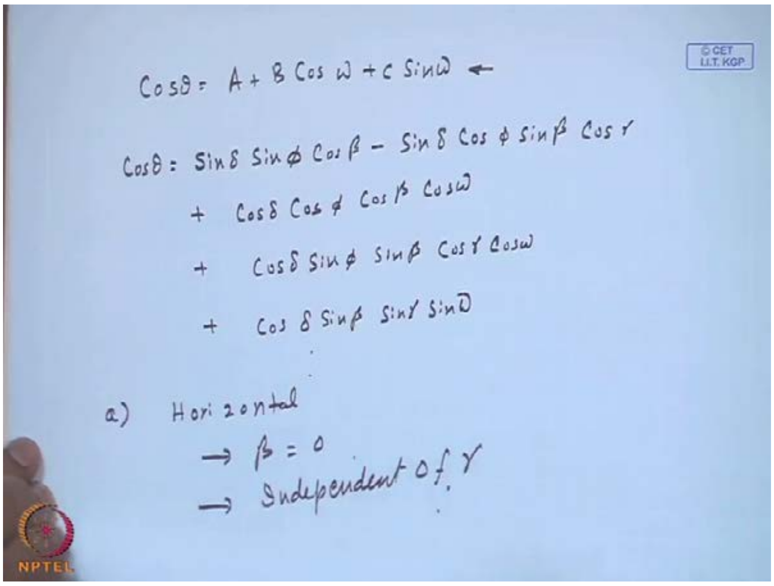


So, you can institute correct, because it is January and is equal to 20, it is sort of winter and declination should be negative and I got the negative answer, this minus 20.34 degrees, you may recall or general equation of cos theta, equal to A plus B cos omega plus C sin omega, or I have deliberately chosen in the initial exercise, I am giving again the equation in detail. So, that you would recall, remember, whatever and at a later date I mean, when we solve some of the problem the detail should be skipped. And I may just said that calculate the angle of from the cos theta over expression, but this is the way that we are expressing cos theta, which expanded once again, it is a reiteration, sin delta sin phi cos beta minus, sin delta cos phi sin beta cos gamma plus, cos delta cos phi cos beta cos omega plus, cos delta sin phi sin beta cos gamma cos omega plus, fifth term cos delta sin beta sin gamma sin omega.

Now, you know of course, what are A, B and C I am not going to spend a lot of time again writing, what is A, what is B and what is c. So, we will just write, this is the law this the equation, which we will take care of whether, it should facing vertical or horizontalor, any gamma beta delta, that you can give delta which we have already calculated, as minus 20.34 further January 28.

So, a horizontal surface right, so what we can have is beta is 0; this also becomes automatically independent of gamma, if you have a horizontal surface, the outer normal will be the zenith, the projection of that on a horizontal plain would be a point consequently, it should not depend upon the azimuthally angle, there is no way to define the azimuthally angle, and very rightly, the cosine theta, expression reduces to be independent of the azimuthally angle, when once you put beta equal to 0.

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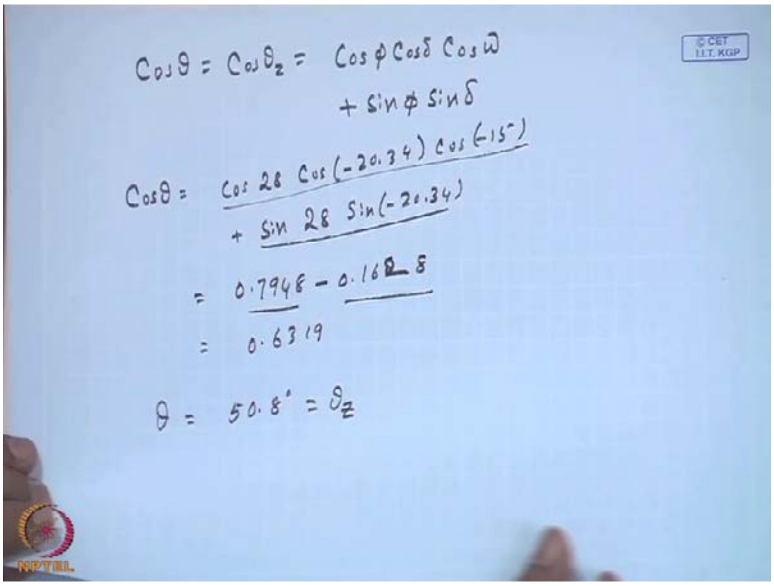


So, you have got cos theta, for a horizontal surface also equal the zenith angle. So, call cos theta z, which is cos phi cos delta cos omega plus sin phi sin delta. So, this should help you to sort of even remember, these equations like I do and you heave, I shall give you little intermediate steps, so cos 28, cos minus 20.34, cos minus 15, plus sin 28 times, sin mimes 20.34 is equal to 0.794 minus point 0.1628 equal to 0.6319. So, that your theta is equal to 50.8 degrees. So, you can check up, whether this quantity is equal to this or not, and this is this or not, but the procedure is basically, you calculate the cosine theta, with a appropriate expression for cos theta from the general expression, in this case beta is 0. And I have got a cos phi cos delta cos omega plus sin phi sin delta as the cosine angle of incidence for the horizontal surface and theta equal to of course, I can by notation say theta z also 50.8 degrees.

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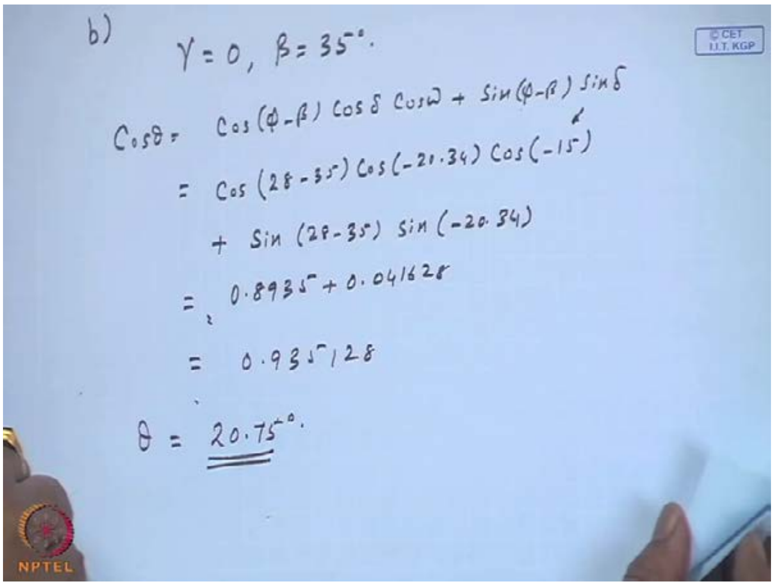


Then b is your, tilted to south a slop of 37 degrees. So, gamma equal to 0, beta equal to 37 degree, so my cos theta will be cos phi minus beta, cos delta cos omega, plus sin phi minus beta, sin delta, right. So, you can equal to cos, once again I am going in detail in future, we should not go go, so detail, this is for you to be more and more familiar, with the equation, and be couscous, whether it is plus minus etceteras, also I can finish my writing. So, cos phi minus beta cos, delta cos omega, plus sin phi, minus beta sin delta will be cos latitude 28 degrees slope 37 degrees time the declination minus 20.34, cosine of and then the cos omega is minus 15, plus sin phi, minus beta and then sin delta.

So, this is equal to 0.8935, plus 0.041628. So, you check up these number because, I have given only the two terms over, here this is equal to 0.935128. So, that cosine number theta will come to 20.75 degrees.

Now, let us have a simple field whether it is good enough estimate or not. So, it is south facing and the time is eleven o clock; that is minus 15 degrees omega, and phi is 28 and beta is larger, beta is equal to 37. So, in winter in general, where the declination is negative a higher, beta is favorable a higher, beta favorable means theta would be lower, and which we have got a reasonably low theta 20.75 degrees, right. So, you have got a gamma equal to 0 south facing radial and the time eleven o clock almost near the solar noon, and then we have chosen phi minus beta to be about minus 7 degrees, and that is a sort of a good orientation that one can have for your negative declination.

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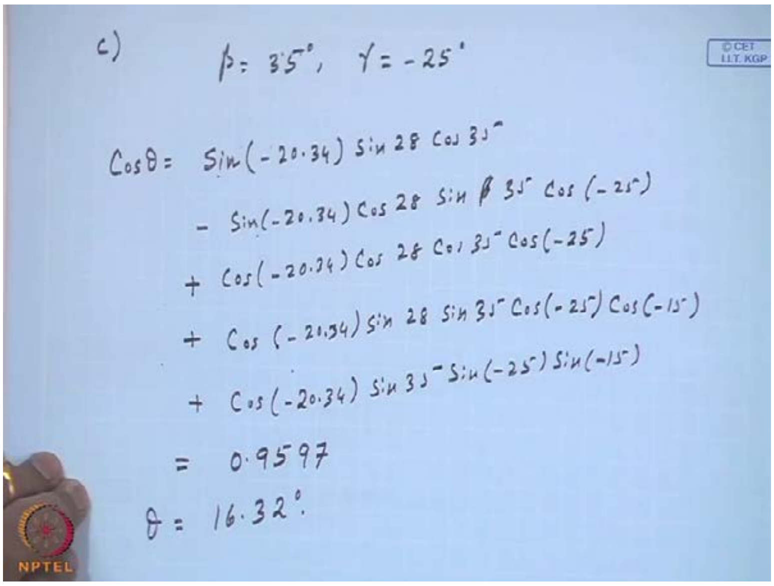


And then c we have a slope of 37 degrees beta 37 degrees, but facing 25 degrees east of south, so gamma will be equal to minus 25 degrees, right. So, that is what you have got and, now you have two though the full equation for cosine theta, which for this example, I would write in completely you, can check up, whether they are sine delta. So, sine phi is and cos beta, minus sin delta, cos latitude phi, sin beta which is 35 times, cos minus 25 gamma, and plus cos minus 20.34 cos phi cos beta and cos gamma again plus cos minus 20.34 sin latitude sin slope cos gamma cos omega plus cos again delta sine of slope sin of azimuthally angle sin of omega. So, I shall not rewrite each term, but the final equal to 0.9597 and theta equal to 60.32, so let us compare what we had earlier this is 60.32.

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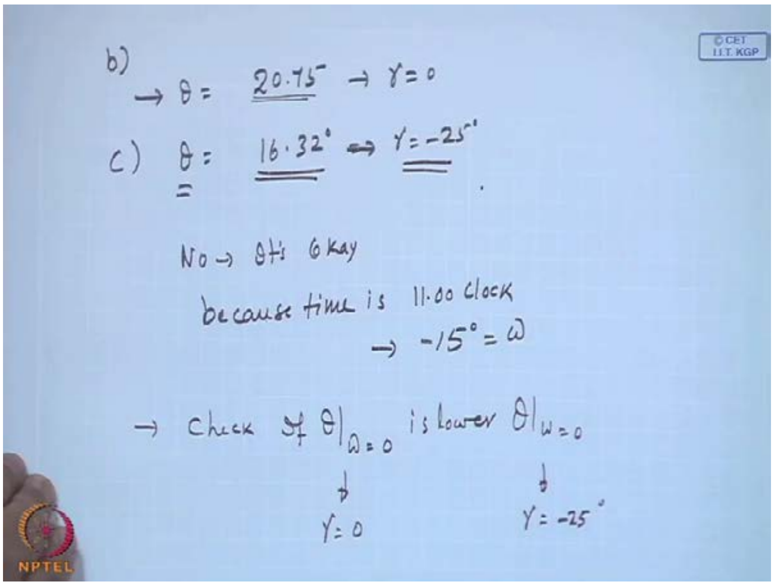


We earlier had a for b theta is equal to 20.75, for c theta is equal to 16.32, this is gamma equal to 0, and this is gamma equal to minus 25, now it is generally believe that a south western surface is optimum for solar collectors, now I have find that the angle of incidence when it is not, but somewhat towards east, seems to be better compare to gamma equal to 0, the south face surface or is it referring No, No its because time is eleven o clock, minus 15 degree is omega.

So, hour towards east and you; however, enter beta fairly well consequently you have a better angle of incidence, compare it to even south facing surface because its time is gamma is equal to 0, omega is equal to minus 15 degrees, if you do the same calculation at omega is equal to 0, the south facing surface will have a better angle of incidence, than the one with gamma equal to minus 25 right, brighter angle means theta is lower.

So, I can leave with check if theta equal to 0 is lower theta, omega is equal to 0; this is for gamma equal to 0, this is for gamma equal to minus 25. So, if you have a east turn toward the east with a 25 degree angle, and facing south with gamma equal to 0 degrees you can check, whether the angle of incidence further south facing surface is lower or not at the noon time.

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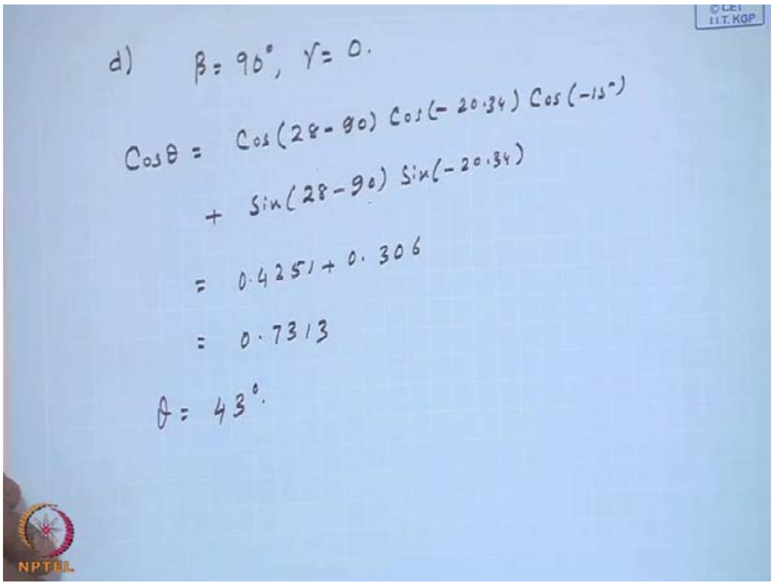


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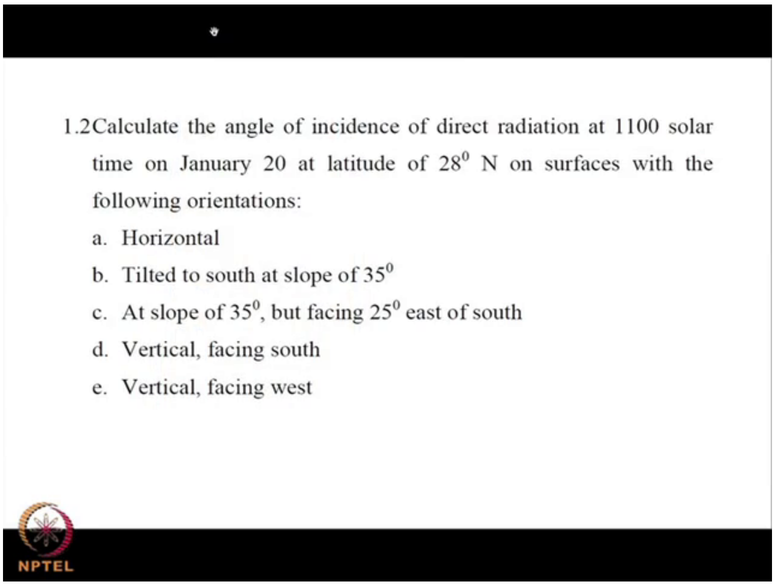


Then, we have d, that is a vertical facing south beta is 90 degrees, gamma is equal to 0, and I have written, cos theta equal to because gamma is equal to 0, I have a simpler expression cos phi minus beta cos delta times cos omega plus sin phi minus beta times sin delta that is all; so you have got, this equal to 0.4251 plus 0.036.

So, whatever is the number you can obtained, here this is 28 minus 90, that will be overall this is no consequences, this is no consequence because cos minus is cos plus also and, this is minus cos theta is minus minus theta, consequently this entire thing will be positive and this is negative, this is negative along with this with becomes overall positive equal to 0.7313 leading to theta equal to 43 degrees. So, please remember particular in your exams, when the angle of incidence is asked not just stop it calculating cosine theta, you have to find out theta also.

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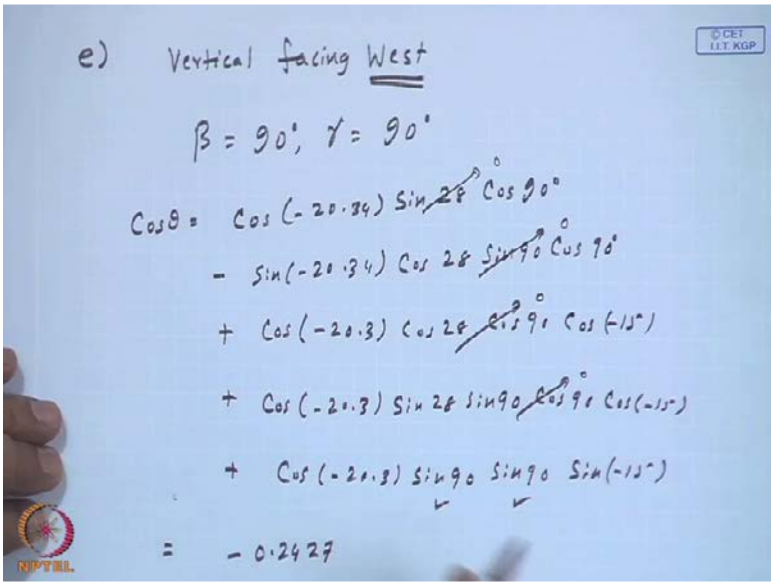


Now, we will go to e that is vertical facing west, that is beta 90, gamma is plus 90. So, you have to involve the fully equation, and there are two illustrate, the point once again I have written the fully equation, which I shall also write the full equation, in terms of cos theta equal to cos delta sin phi times cos, whatever beta or gamma cos 90 degrees minus sin 3 4 cos 28, sin ninety cos 90, you check up with your original equation minus cos probably this is plus I think you can check it up cos minus 20.3, cos 28 cos 90 cos minus 15 plus cos minus 20.3, sin 28 sin 90, cos ninety cos minus 15, seems I have written two times one, two, three, five, does not matter you can just check up, does not matter cos minus 20.3 sin ninety again sin ninety times sin omega. So, in this this is 0, because of cos 90, again 0, because of cos 90, this is also a 0, because of cos 9123, and the also is 0 and this is non 0. So, you have ultimately minus 0.2427, that is only this particular; this is one this is one, and sin minus 15 of course, this is positive, so its becomes negative.

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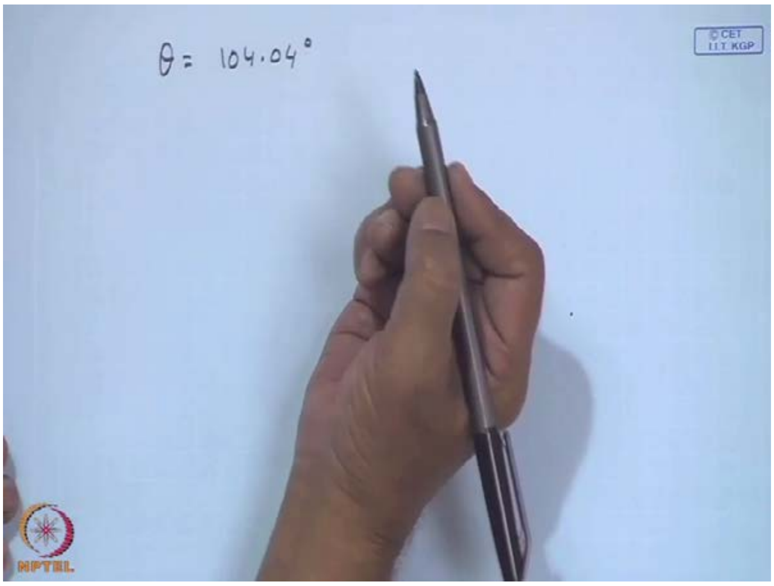


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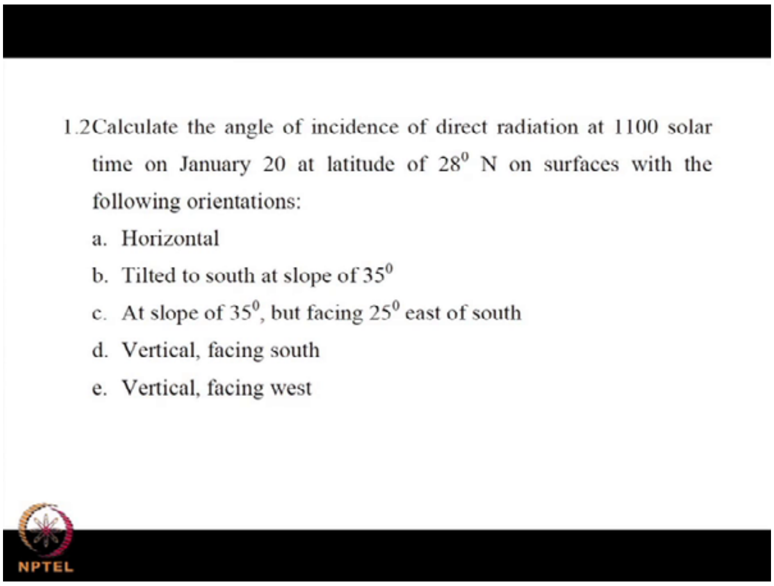


So, theta time should be 104.04 degrees. What is this mean, it is more than 90. So, at eleven o clock, it should not be surprising, if you are surface is oriented towards, the west, I will no receive any sun, so theta will be more than 90 degrees, in this could be it turn to be 104.04 degrees, it does not matter the fact is its more than 90, and also physically you can realized, that the surface oriented toward the west shall not receive any radiation at a time before so other known.

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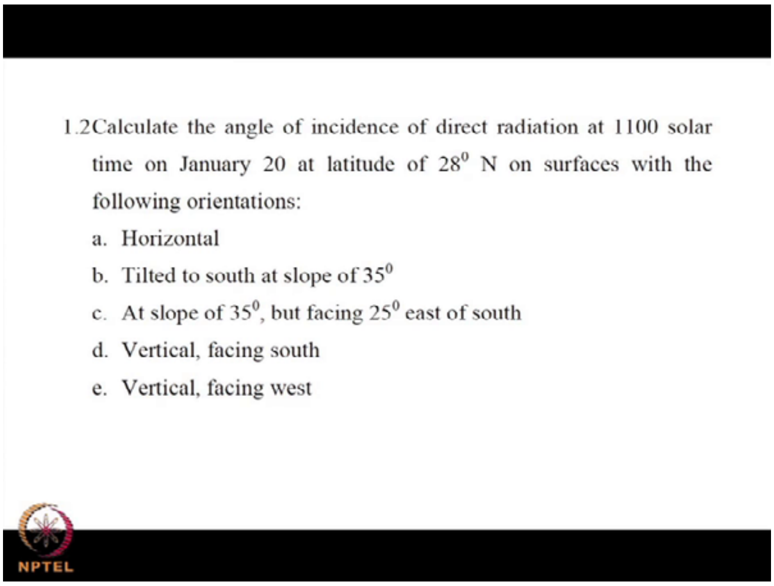


So we should go to problem 1.3, the previous exercise is basically to tell you the difference between a horizontal surface tilted toward south and the effect of time, and whether it is of south facing like azimuthally angle being west, or whatever right. So, naturally you can relate that the angle of incident, should be most favorable at an own solar noon, if it to works out and not. So, favorable I mean larger, if it off south depending upon the time, if it is toward the east eleven o clock will be better, and if it is toward space may be two o clock 2 p m may be better, right.

So, this should not come as a surprise, but nevertheless this is an exercise to learn the orders of magnitudes as well as, what one can expect for little truly from a south western surface, horizontal surface, tilted at particular angle more than the latitude or less than the latitude, which will come a little later.

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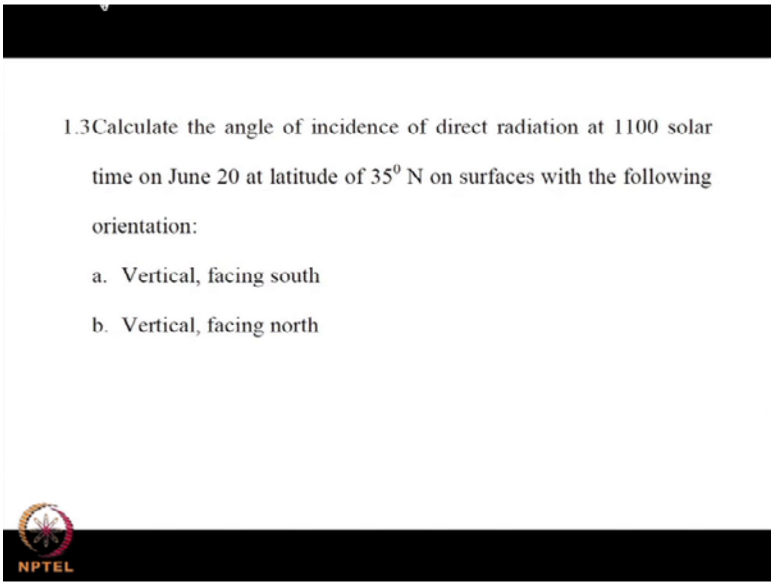


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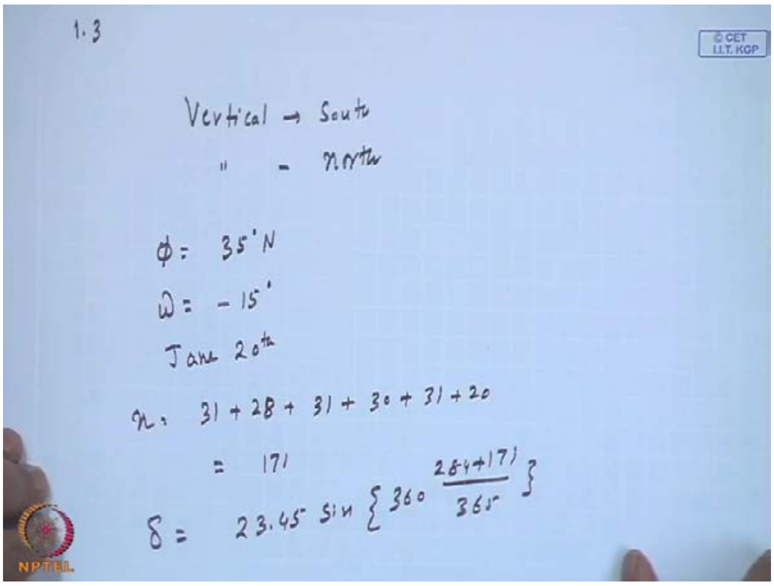


So, this 1.3 deals, with the calculate the angle of incidence of direct radiation, at 11 solar time on June 28, at a latitude of 37 degrees north on surfaces, with the following orientation. So, we just have two things, which I want to demonstrate for some purpose, vertical south, same thing vertical and north, so and latitude is 37 degrees.

So, phi is 37 degrees N, which means within northern hemisphere time is eleven o clock, which imply implies omega is minus 15 degrees, and the day is June 28, consequently n will be 31 of January 28 for February 31, for March 30 for April 31, for may plus 20, which shall be 171. So, that my declination, delta is given be 23.45 sin 360 284 plus 171 upon 365 ok.

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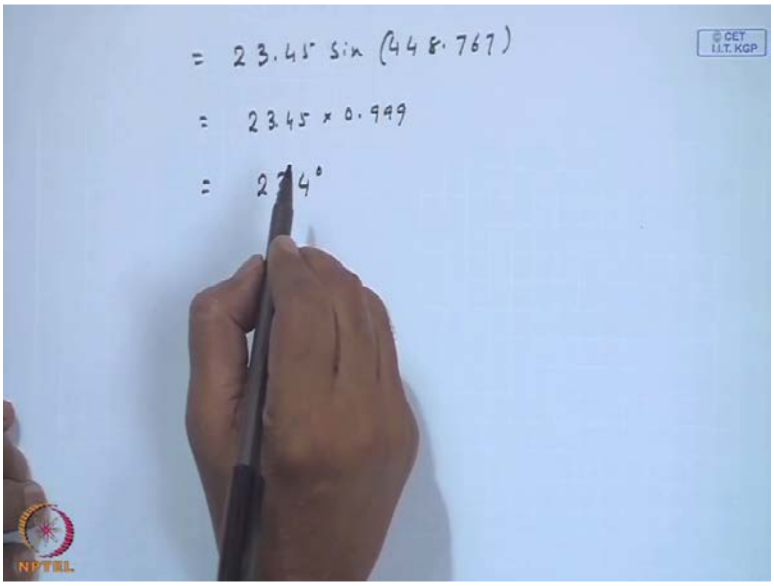


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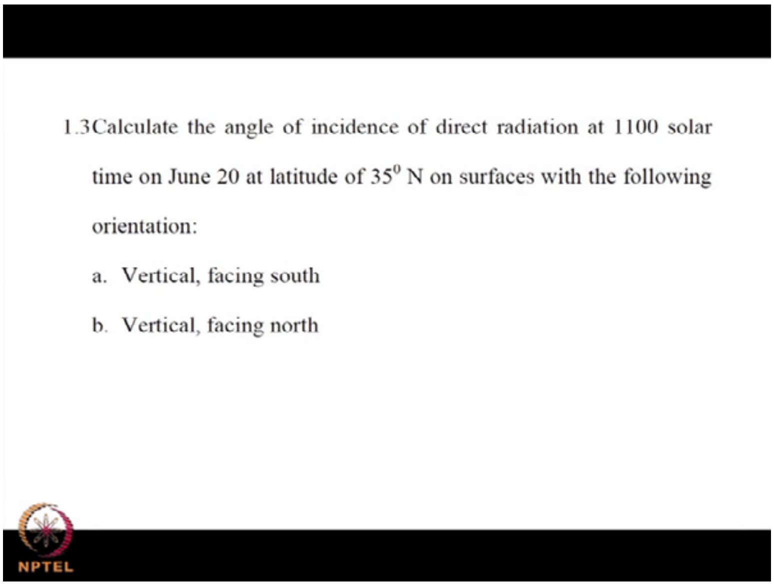

So, this tends out to be 23.45 sin 448.767 equals to, so large number you can calculated 23.45 into 0.999, equal to 20.4 degrees, I am happy because we know in June the maximum declination will be around June 23, which is equal to 23.45 degrees, and around June 28, without all this calculation including sign of 448.767, I got the answer 23 .4 degrees.

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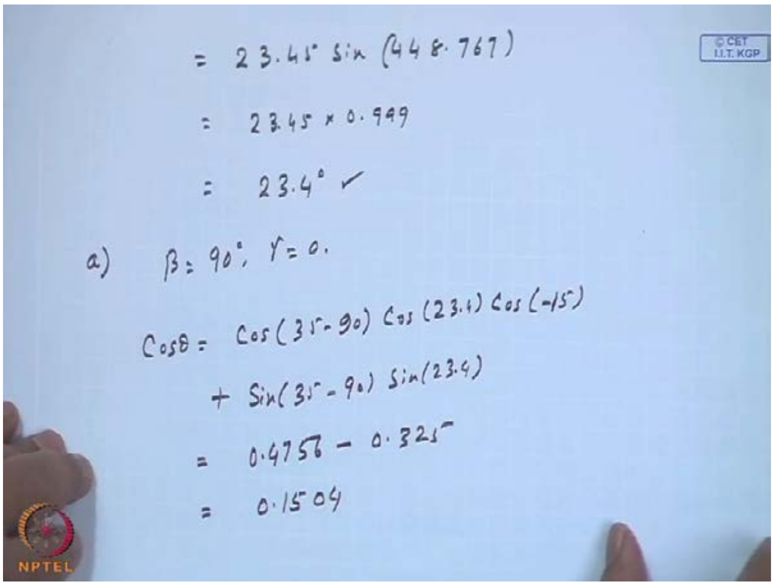


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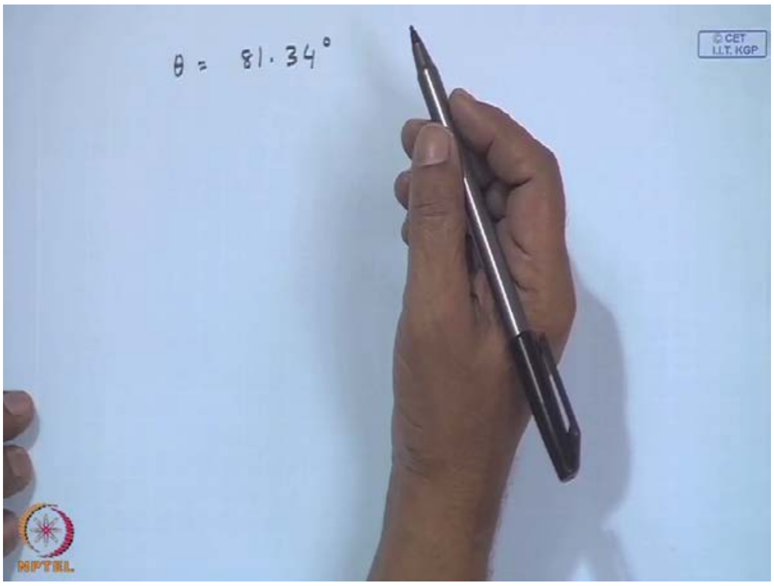

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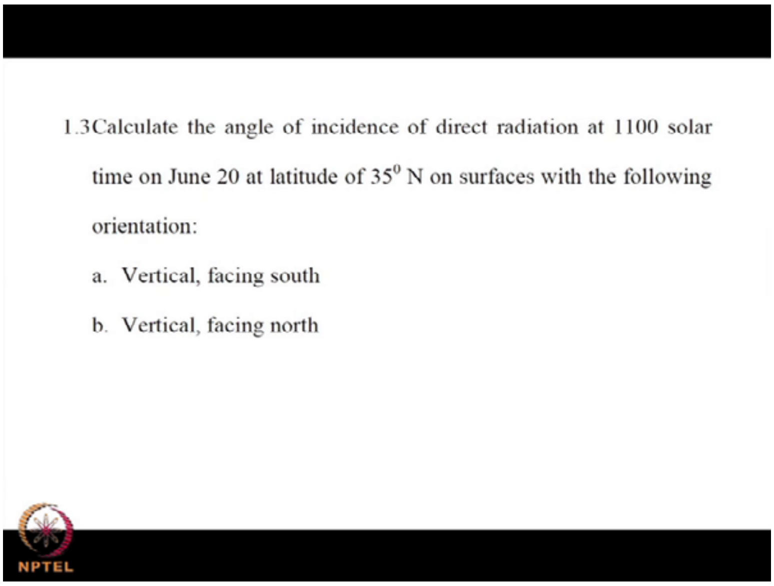


So, it should be now a beta ninety degrees gamma zero. So, cos theta will be cos phi minus beta cos delta cos omega plus sin phi minus beta sin delta, so which is equal to 0.4756 minus 0.35, which is equal to 0.1504, from which we can calculate theta 81.34 degrees. So, you will realize, the latitude is reasonably high 37 degrees it is June. So, the sun will be pretty much high up and almost, the solar noon because its 11 of clock. So, you have a pretty high angle of incidence, some sort of unfavorable angle of incidence right 81.34, where the maximum possible is only 90.

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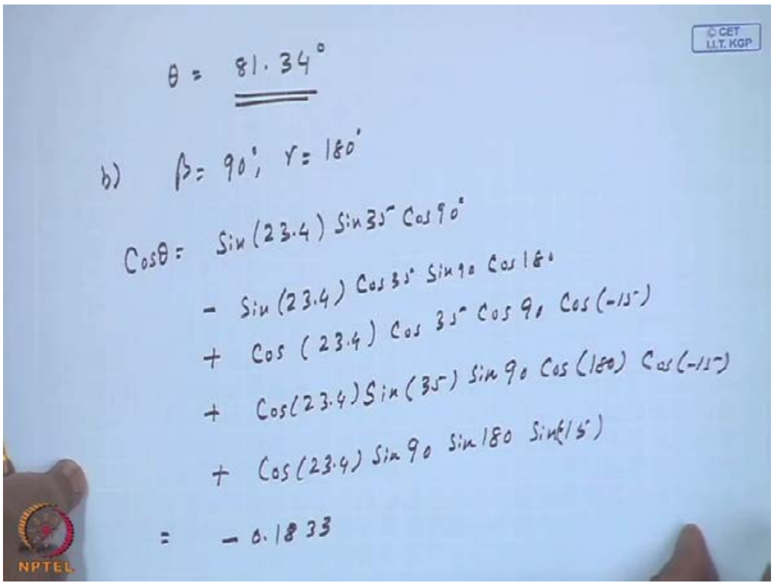

B vertical facing north, so beta is equal to 90 degrees, gamma is equal to 180 degrees, right. cos theta sin 23.4 sin 37 cos ninety minus sin 23.4, you can check with your full equation, whether I am writing phi beta deltas correctly or not because at time I might have got the correct, answer because whether I write cos 90, because beta is 90 or sin some zeros, because something else is 0, I am getaway with that equation, but never the less you please check up cos 90 cos omega plus cos delta sin phi sin 90 cos gamma cos omega plus cos delta sin 90 sin gamma sin minus 15, which is omega.

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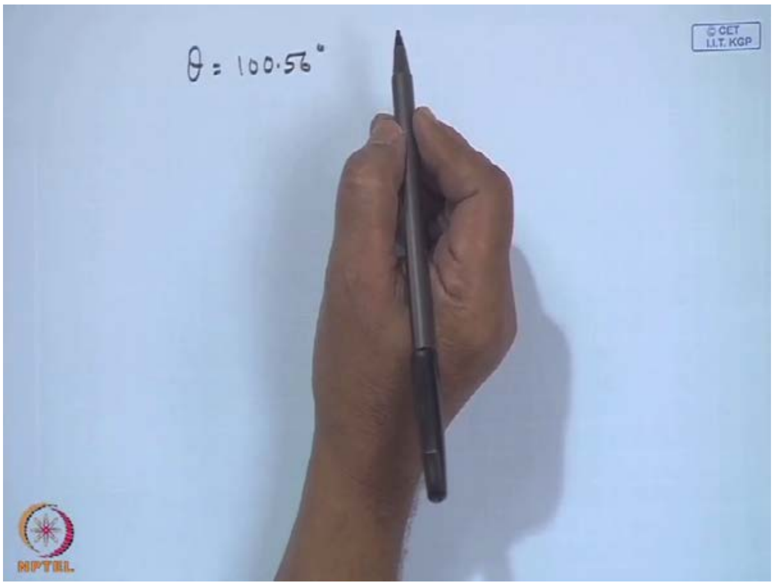


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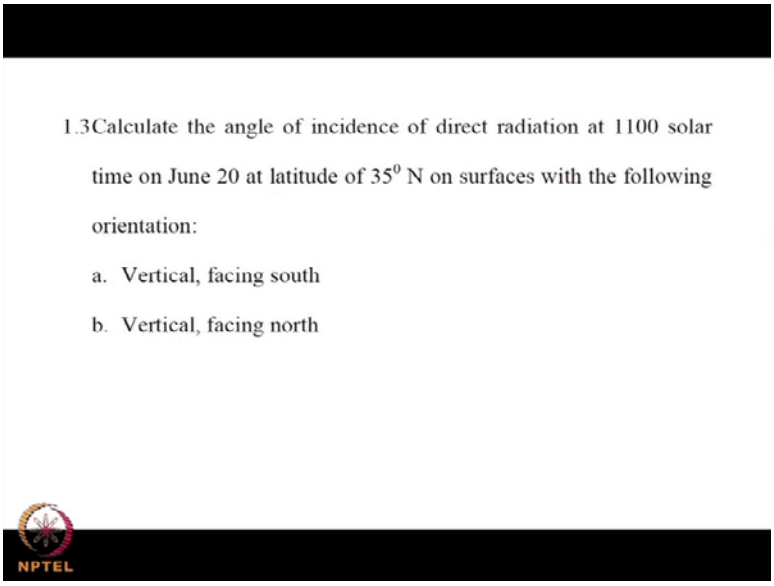

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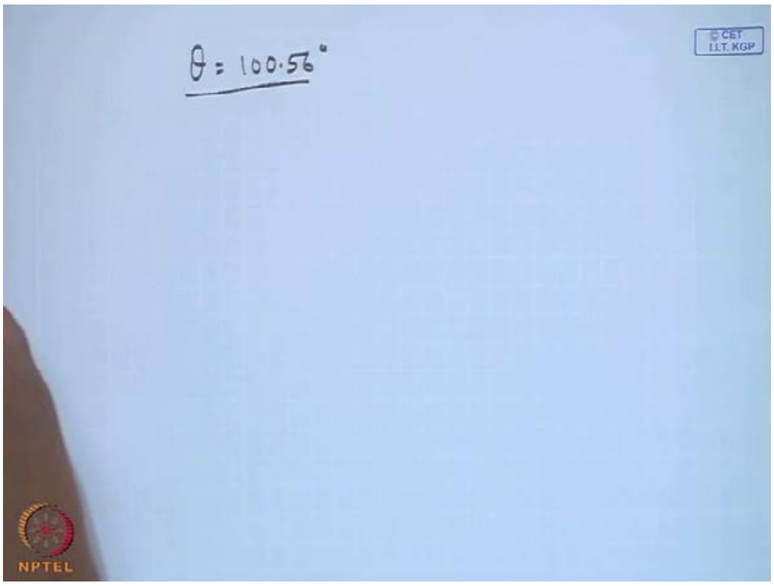


So, that overall, turns out to be minus 0.1833. So, theta yeah, which actually means if you have got a vertical surface, of facing north at eleven o clock; obviously, it will not receive any sun shine, which is indicated by theta being more than 90.

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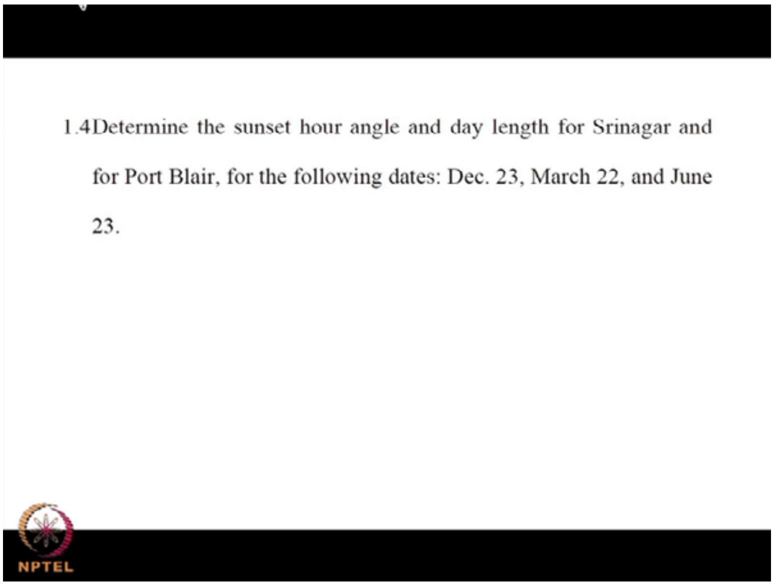

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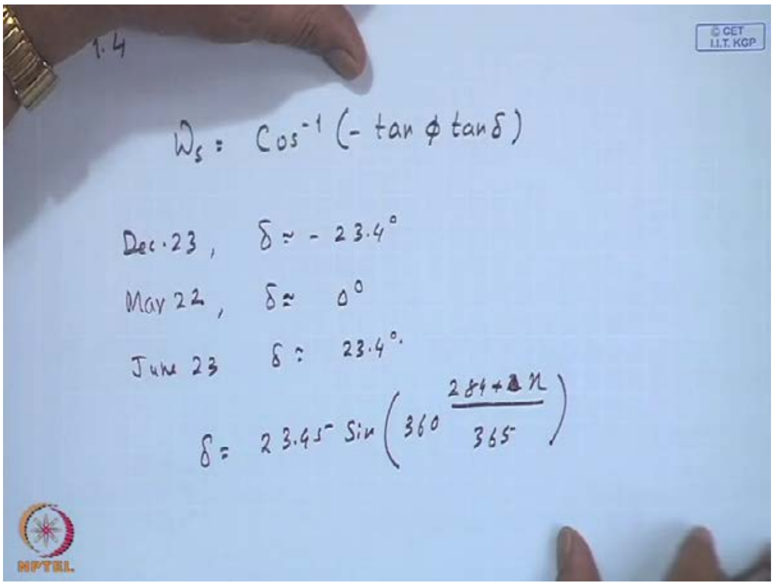


So, let us go to the next example that is 1.4, yes. So, determine the sunset hour angle and day length for Srinagar and for port Blair for the following dates, December 23, march. 20 second and June 23, this problem has been chosen among the data we have got Srinagar, has reasonably if not the highest high latitude, within India and port Blair, if not the lowest, but the low latitude and December march and June, they represent the maximum negative, and maximum positive, declinations along with march being a zero declination.

So, it should be able to make as understand, the variation the day length and or the sun set over angle, depending upon the latitude the season. So, sunset over angle is, nothing but cosine inverse minus tan phi tan delta, and for December, do not worry about 21 or 23 or 22, so I will take it as delta minus 23.4 degrees and March 22 into 0 degrees, you can say approximately and June 23, the issue is it is 0 near, these are 23.4, 20.4 maximum negative and positive values or you can calculate, if you want to be for sake 23.45 sin 360 284 plus 2 or rather sorry N upon 365. And as we have taken the data from the time genie, and you can see in the first few pages of the exercise is chapter this chapter.

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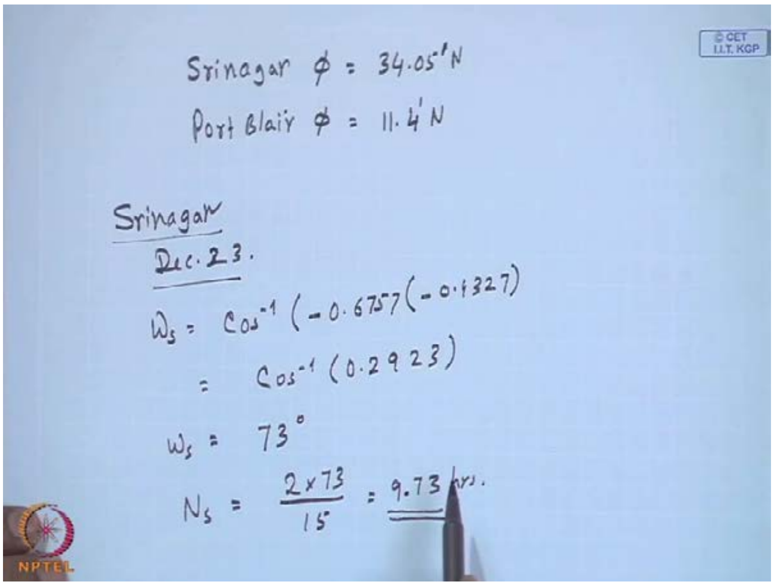


And Srinagar has a latitude of 34.05 degrees, sorry in this should be 18 minutes, it though it does not make much difference Port Blair; you can check up, whether it is 34 degrees or 05 minutes or 34.05 degrees, there will be a slight difference do not worry about it, I might have calculated, as the calculator did.

So both or north latitudes, so we will first consider Srinagar December 23, so omega s will be cosine inverse minus 0.6757; that is cos phi times minus 0.4327 cos delta cos inverse of tan phi tan delta tan delta is negative. So, delta is negative tan delta is negative, and this minus is not at formula, and this is tan phi. So, this is equal to cos inverse 0.2923, which is 73 degrees, this is omega s, N s the number of sunshine hours will be twice 73 by 15, which will be 9.73 hours.

So, as far as this lecture is concern, we shall stop over here, but the important point is Srinagar, December. Winter at a reasonably high latitude you have got the number of sunshine hours 9.73, this is a 0.73, because I calculated and I know for true it not 73 minutes, but 0.73 hours which will be 0.73 into 60 minutes; it is considerably lower than taller which we normally think data I wills taller and night is taller.

But if you go to your high latitude and winter you have considerably less number of sunshine hours, we shall continue with these problems and discussion in the next class, which will gives us some more field, for the numbers, and how the climate, and the latitudes are rather climate in the sun session time, or the year and the latitudes with the orientation, will relate themselves.

Thank you.