Solar Energy Technology
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Lecture - 5
Estimation of Solar Radiation or Details

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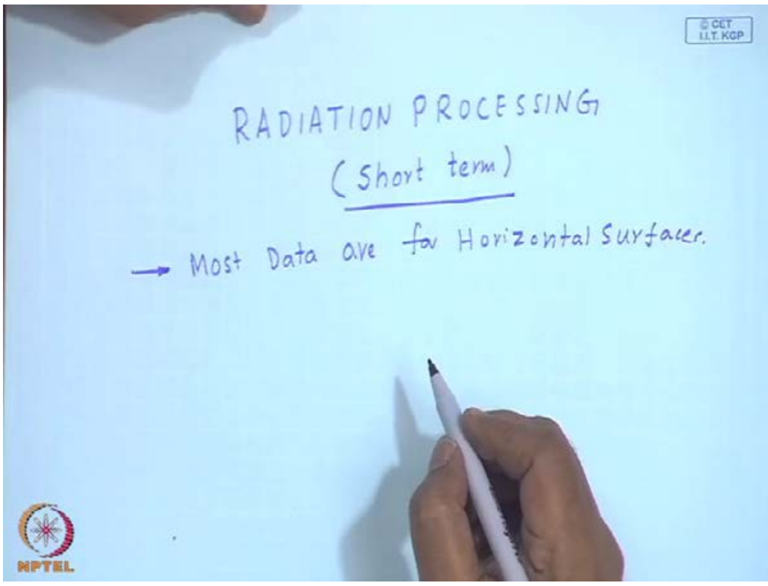

Now, we learnt about Radiation solar radiation measurement. And some useful correlations, which will help us generating the detail of solar radiation given certain broad averages or long time periods, longer time period. Then, what we shall be discussing here is radiation processing. First I will call it short term, later on we shall go to the long term processing. And we know from the data most data are for horizontal surfaces. Now here, in order that you appreciate why we do this radiation processing, very briefly I shall explain about a simple solar collector. So, that you will understand why we do this particular part.

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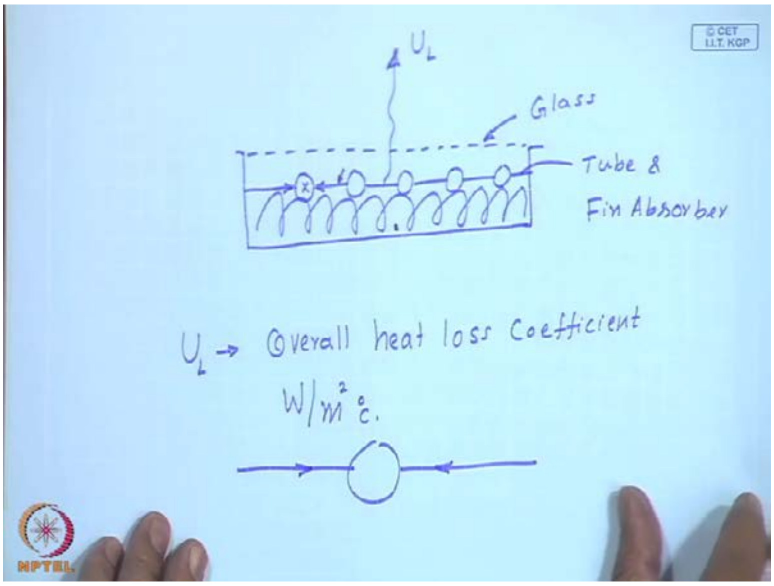

So, you may have a fin a tube a fin another tube another tube like this we set spacing This is kept in a box and the bottom of which is insulated. And there is glass cover this is a typical water heater this is called a tube, and fin absorber. So, overall there will be some loss which I will represent by a loss coefficient Ul. So, those are familiar with heat transfer this is called a overall heat loss coefficient. And which will have the units watts per meter square degree centigrade. And the fluid flows through these tubes The central portion painted black over here. Heat will flow towards the colder fluid side thereby heating the fluid. In other words if, I exaggerate there will be heat flow towards the tube right.

So, this is based upon the fact given per say a black painted surface will absorb solar radiation more than a non-bright non-black painted absorber. And to reduce the losses we have put a insulation at the bottom. And then a glass cover at a top to reduce by radiation, and convection process, still there is a certain loss taking place at the rate of Ul watts per meter square degree centigrade.

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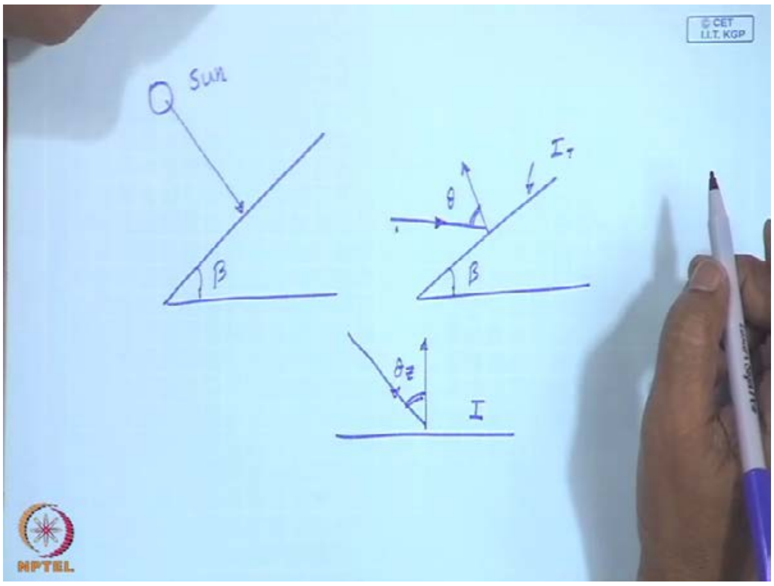

We, also know that a surface having a particular slope beta will receive maximum radiation if the sun's rays or normal to the surface. If you want to keep it you have to keep on tracking it. But, never the less I may choose some sort of a slope beta with may have may or may not be this is the outer normal to the surface sun's ray may be like this. And the angle of incidence be theta. What I have got is a measurement sun a horizontal surface with the sun's rays making an angle theta z. This is my eye this is my eye on the tilted surface.

So, we want to estimate in general on any surface given the value on the horizontal surface this may be on the hourly time scale. So, our objective will be to find out what is a solar radiation received by a surface of given orientation. Known that there is a solar radiation available measured or otherwise on a horizontal surface.

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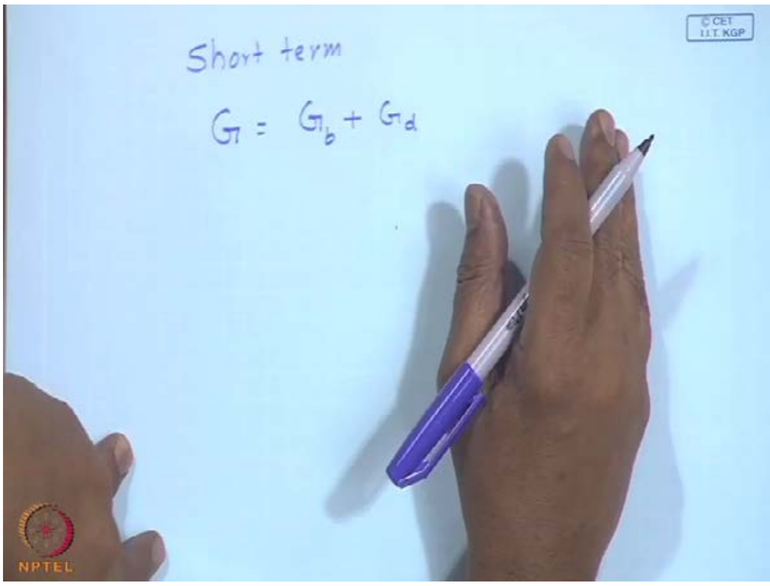

So, first since I called it short term I will talk about, in tensed G. which will consist of Gb direct part plus Gd the diffuse part. Now, these are may be divided by 3600 or the solar radiation for the hourly value or let us assume that we know the intensity.

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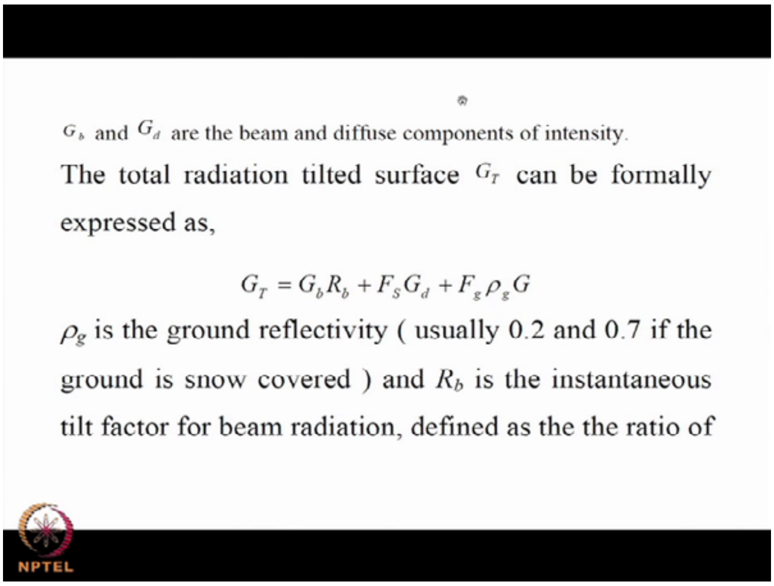

First if I know how to do it for a instant then we will be able to find out for this number of developments by Liu and Jordan. Again, they classified that the radiation received by the tilted surface. Now, what I have got is beta outer normal. And the sun's ray making angle theta compare and this is Gt watts per meter square compared to horizontal surface making an angle theta z where, this is G equal to Gb plus Gd o, we have a tilted surface with a slope beta other descriptions right now are unnecessary which we will come to it later whose outer normal is n cap and the sun's rays will make an angle theta in general.

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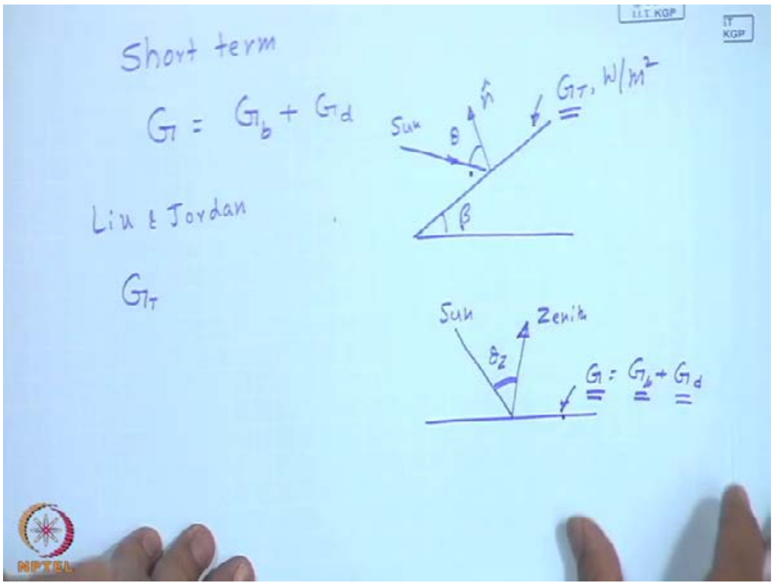

And the radiation falling on that is Gt no matter how to calculate that, what we have is measured information a g intensity on the horizontal plane which is characterized by the zenith, and the sun makes an angle theta z with respect to this we also have the information that G comprises of Gb and Gd.

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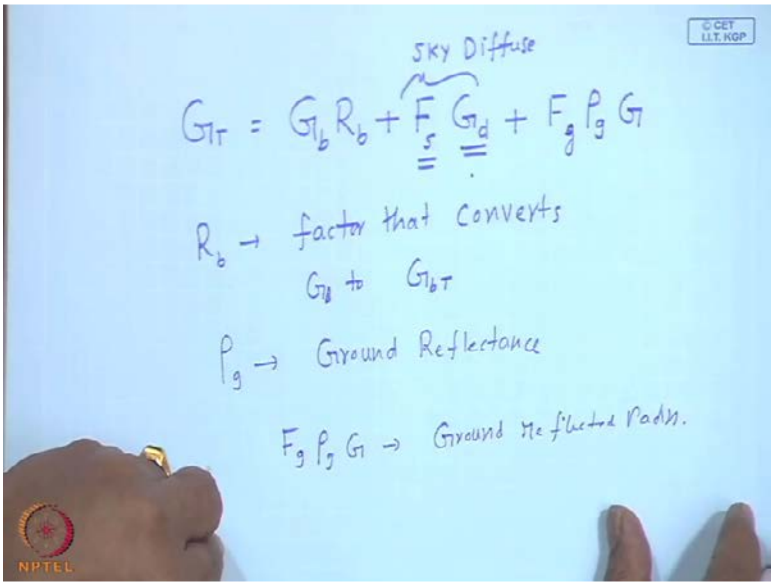

Pupil have expressed this G t comprises of direct radiation part plus a fraction of the diffuse radiation plus another fraction of the ground effected radiation. So, R b is a factor that converts G b to if I may say G b on the tilted plane, this is purely geometric then g d is the diffuse part but, a fraction will be received by that which will be called sky diffuse. And rho G ground reflectance, so, this Fs a, fraction f this should be Fg Fg rho G is the ground reflected radiation.

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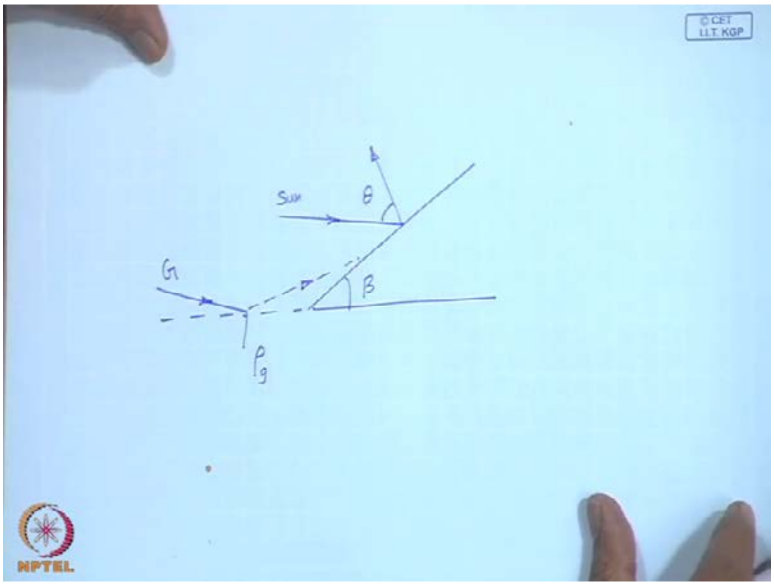

Now, to make you appreciate if there is a collector which set and slope again and then of course, I will keep on showing this, where sun's ray with an angle theta is this is sun. And if this is the ground sun's ray will fall on this, this 2 should be parallel. And which will be reflected this is rho g the ground reflectance makes G reflect back some of it reflect on to the collector surface, which will give you that Fg rho G into G term.

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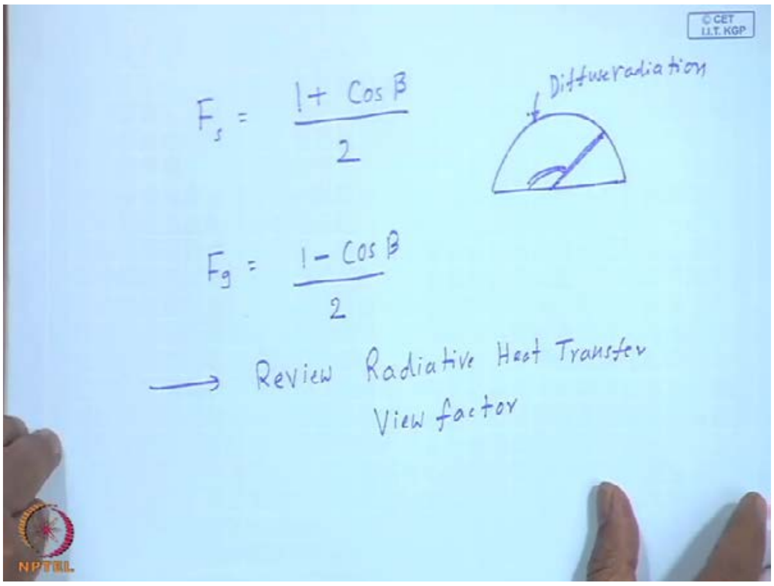

Similarly, this Fs associated with Gd is given by 1 plus cos beta by 2 where beta is a slope. Now, if you imagine a hemisphere it is a collector. All the diffuse radiation over the hemisphere is your Gd. So, this portion will be received by the solar collector. You will have this factor 1 plus cos beta by 2 and if, you make beta equal to 0 this 1 plus 1 by 2 by 2 equal to 1 that means if it is a horizontal surface. It will receive in full the diffuse radiation. And again if you have a vertical surface beta is equal to 90 degrees making this as one and half. So, a quadrant of that will make it receive only one and half so, sufficient to understand this 1 plus cos beta by 2 comes as a factor associated with the diffuse radiation which basically is a sector proportional assuming the diffused radiation to be isotropic.

Then Fg is again 1 minus cos beta by 2 you should review radiative heat transfer where view factors are given. So, you can see if there are 2 surfaces with a angular orientation the ground effected radiation will be 1 minus cos beta by 2 factor. Again if you put beta equal to 0 it will be 0 in other words say horizontal surface will not receive any reflected radiation from ground also be in horizontal.

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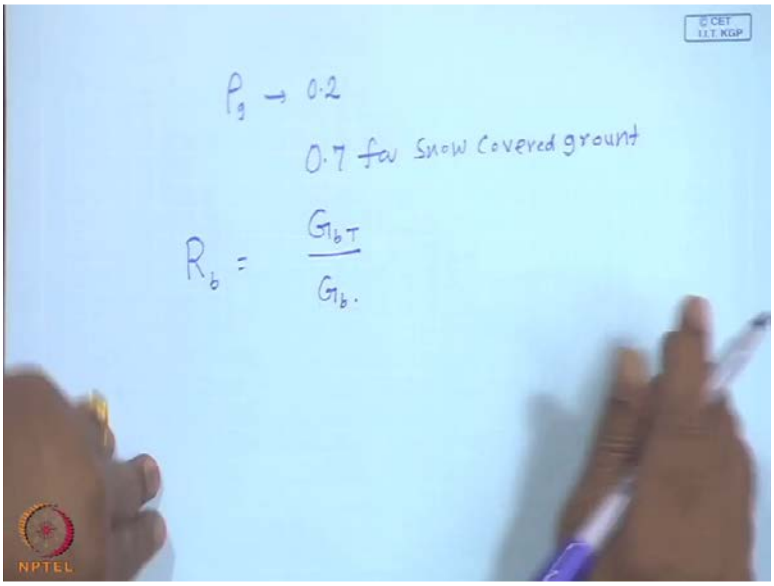

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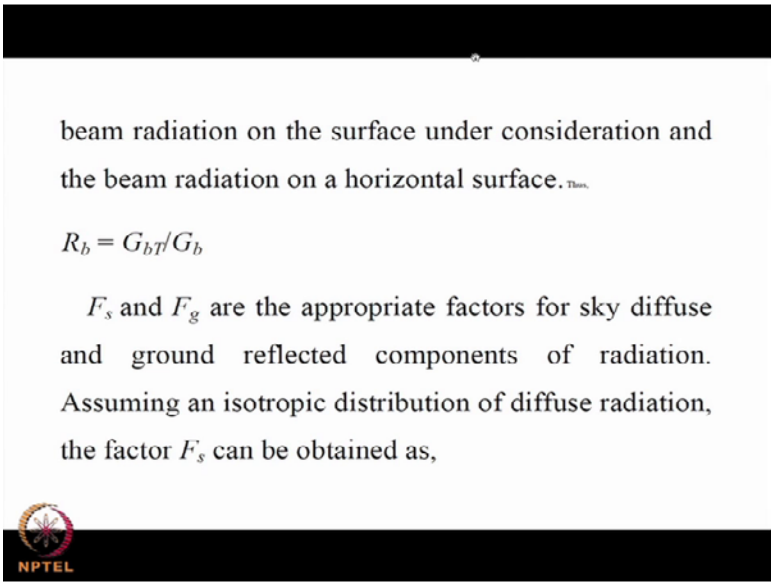

And this rho g where is typically point 2 for a ground and it could be as say as point 7 for snow covered. Of course, you may wonder if snow cover is there the solar radiation will be low whether your solar collector should be operating or not. Now this Rb is the instantaneous tilt factor that is what we try to find out.

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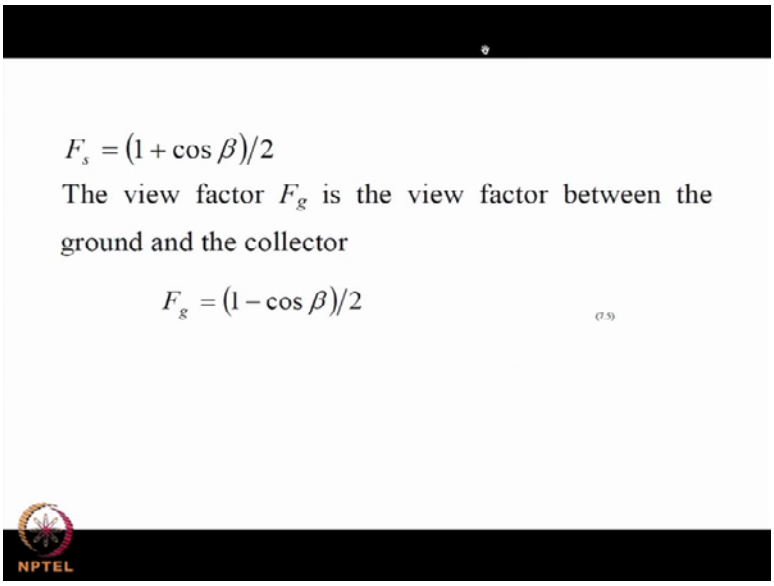

So, I can write r b as g b on the tilted plane by Gb on the horizontal plane and we have already talked about Fs and FG or the factors associated with the sky diffuse and ground reflected factors. Which are given by 1 plus cos beta by 2and 1 minus cos beta by 2.

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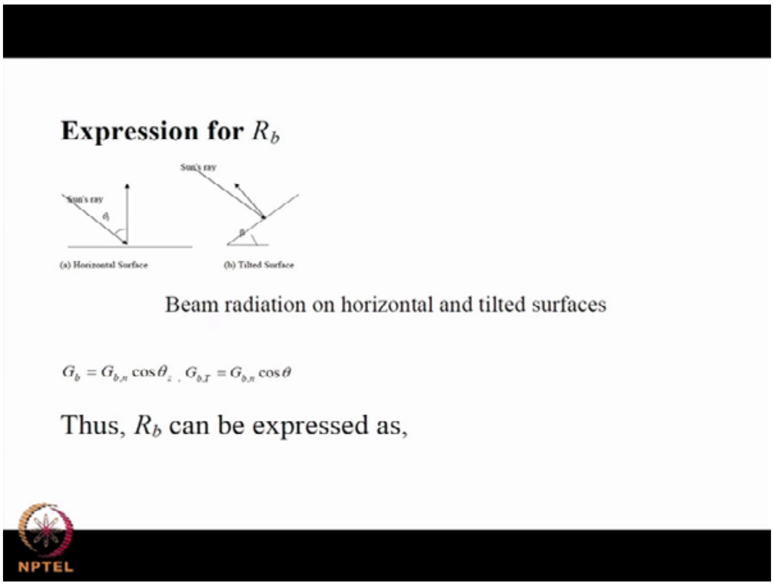

Now, this figure I should make it little bigger, if you have the horizontal surface. And the outer normal, and this is the sun's ray and it has got the angle theta z. And simultaneously we have the tilted surface beta outer normal. And the sun ray, and this makes an angel theta. So, we can say Gb what I shall do is if I draw a plane perpendicular to the sun's ray this is Gg b n according to our relation G o n was a corresponding extraterrestrial value.

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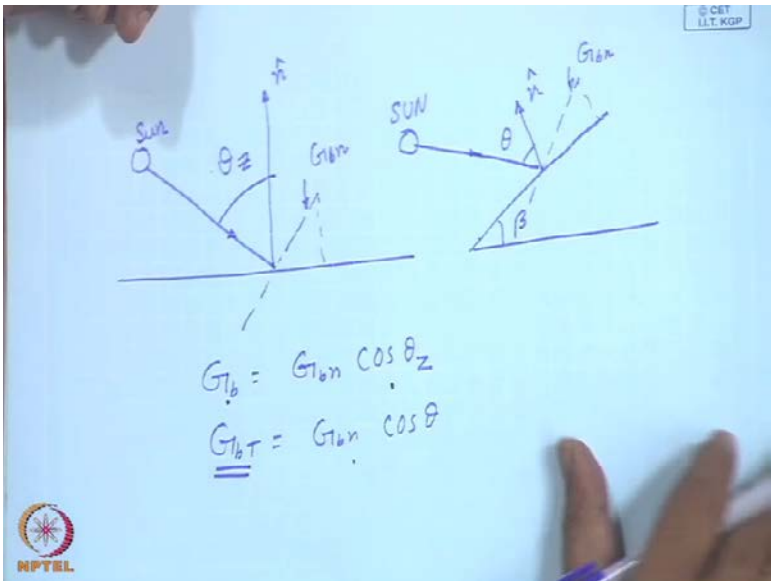

Now, I will call it g b n beta the still value of the direct radiation normal to the sun's ray, that, also will be Gb n the reason being this is the plane normal to the sun's ray. Whether there is a tilted surface or a horizontal surface is no consequence. So, the horizontal radiation Gb will be either Gb normal into cos theta z here projection of this, or Gb normal into cos theta which will be Gb t.

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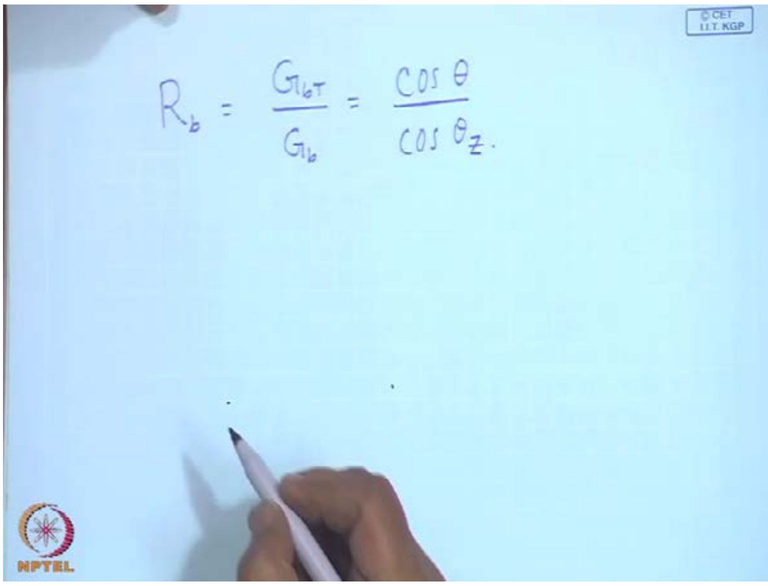

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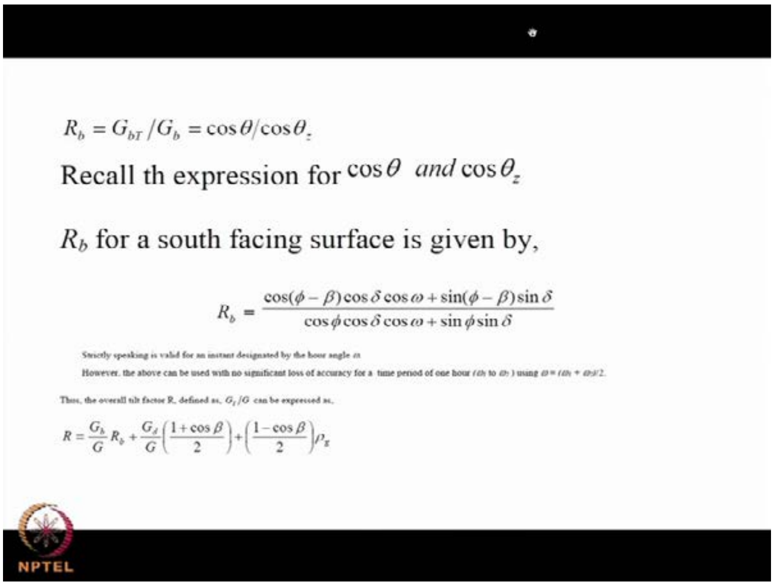

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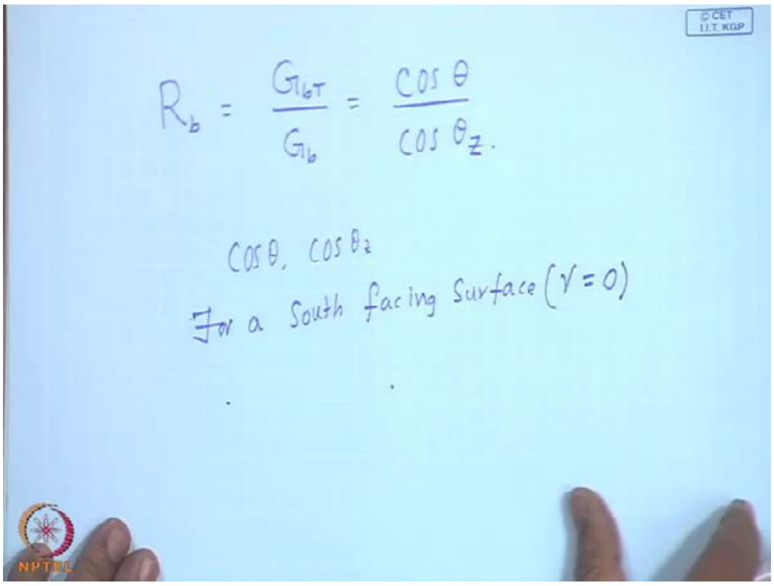

So, now Rb is by definition. Gb t by g b equal to cos theta cos theta z. Now, we have got this expression for Rb. And you can recall your cos theta expressions and cos theta z expressions. And I can remember easily for a south facing surface that is your surface at the metal angle is gamma 0.

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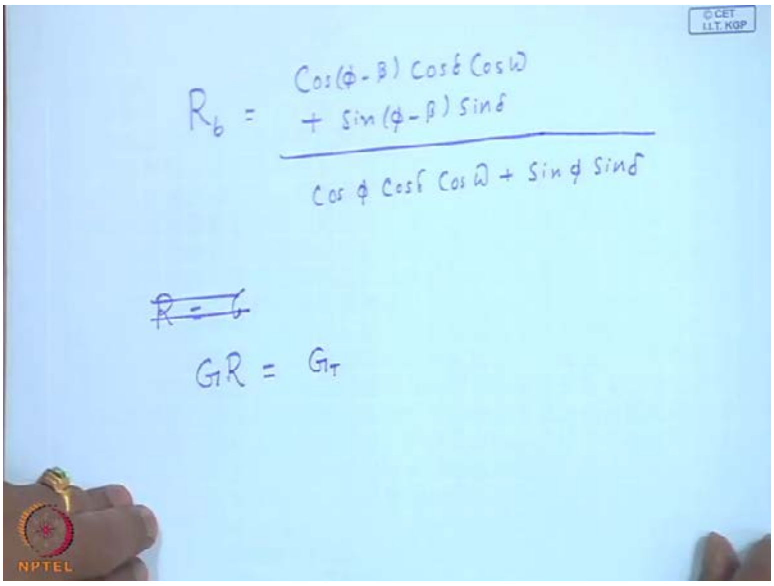

So, now my Rb can be written as easy way of remembering is this is cos theta z which will not depend upon gamma. This is cos theta for gamma equal to 0. So, if you put a beta equal to 0 you will get this result. So, this is Rb for a south facing surface. Now, what I shall do is, if I define a overall R factor. Which is Gb T let me put it this way GT total tilted radiation will be your g into R then that will be equal to GT.

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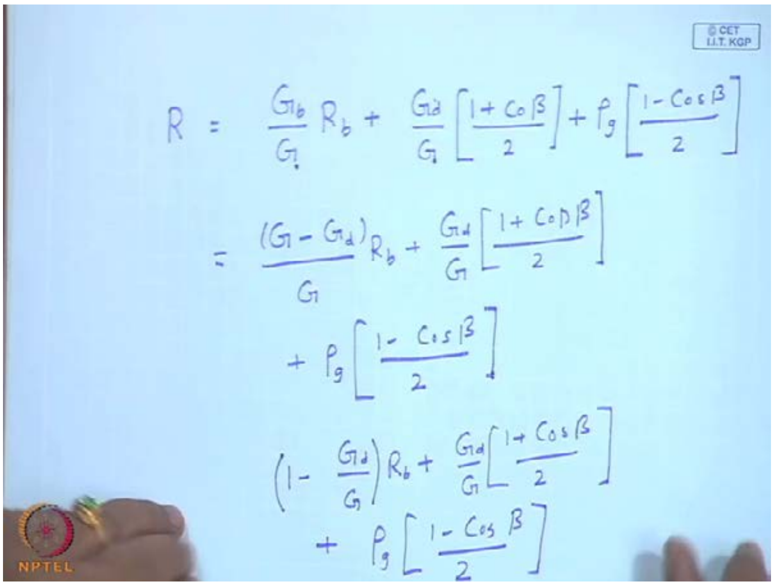

So, now I can define a, overall r factor as the same thing I have written. If we multiply throughout by G into R will be your GT. And hence, this is written in a particular fraction. Now, you will find that everywhere I have got a Gb by G, Gd by G. Of course, this G gets canceled this can be again written as G minus Gd by G times Rb plus Gd by G times 1 plus cos beta by 2 plus rho G1 minus cos beta by 2. This is 1 minus plus rho G.

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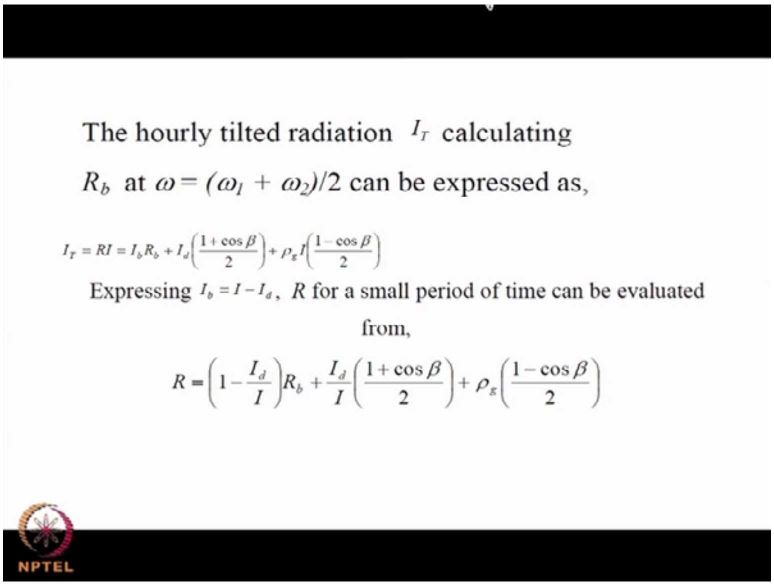

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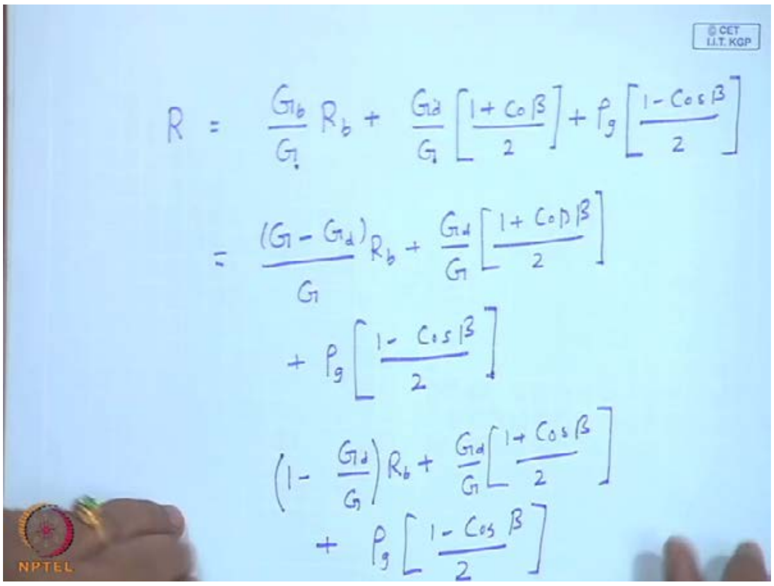

Now, what I am finding out is that this is a ratio of only Gd by g, now you realize why we spend some time in generating the correlations for id by I. Though Id. And I are separately required. But, if given I everything we try to write in terms of a, diffused fraction ratio which we know can be calculated knowing I.

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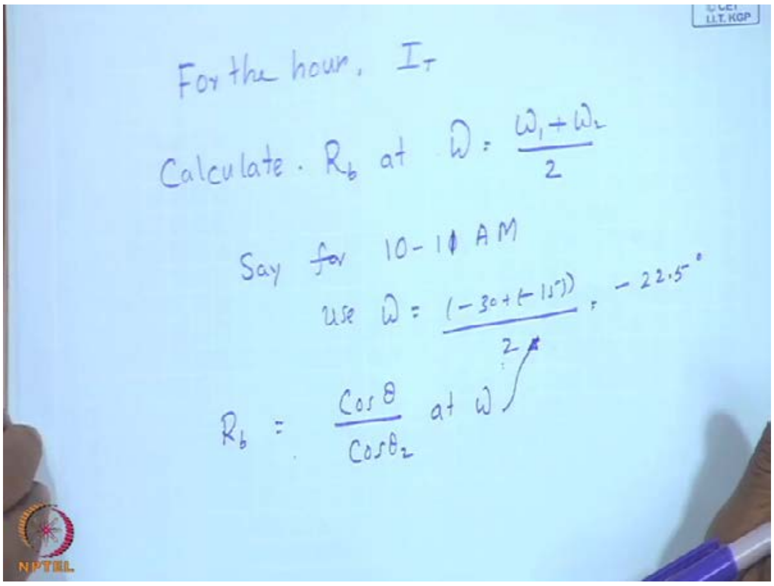

Now, I shall make an approximation for the hour the corresponding value will be It right instead of Gt it will be It calculate Rb at mid 1 midpoint of the hour. That is say for 10 to 11 use omega is equal to, How much it will be this is minus 15 minus 30 correct and calculate your Rb. Which in general simply cos theta by cos theta z at this omega given by omega 1 plus omega 2 by 2..

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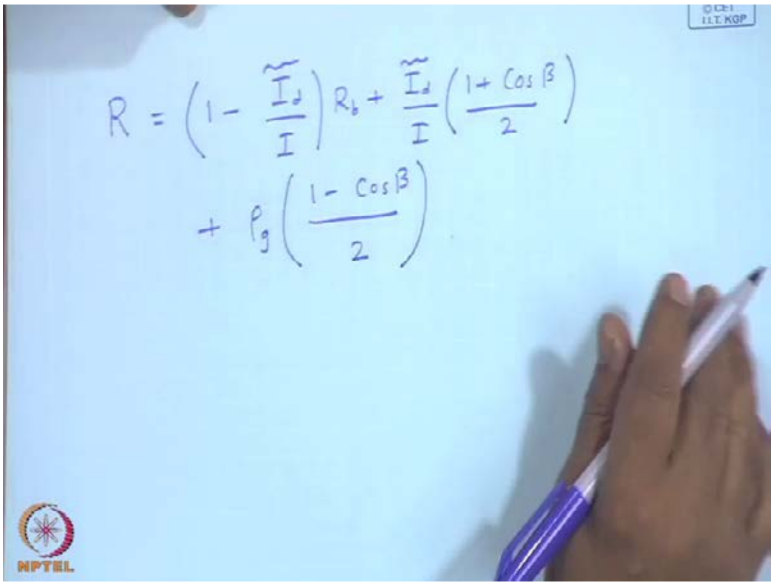

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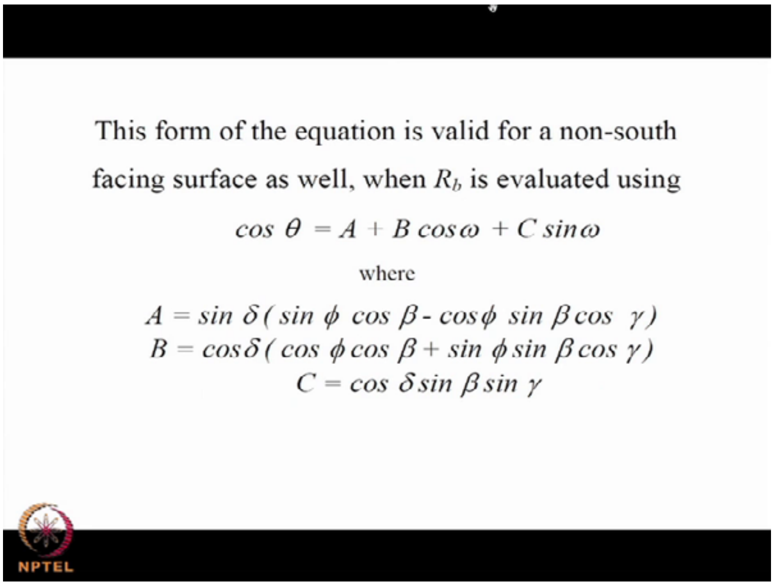

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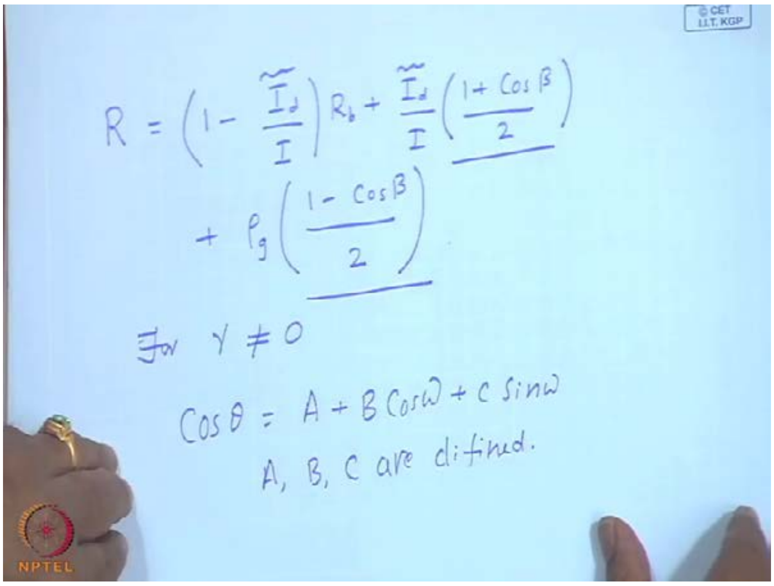

If, I straight away extend the result that we have written for the instantaneous values. my factor R will be 1 minus I d by I, times Rb plus Id by I, 1 plus cos beta by 2 plus rho G1 minus cos beta by 2. Now, we got everything in terms of Id by I. So, you can easily write for we have this we have this general expression. A plus b cos omega plus C sine, omega where A,B,C are defined. So, fortunately these factors.

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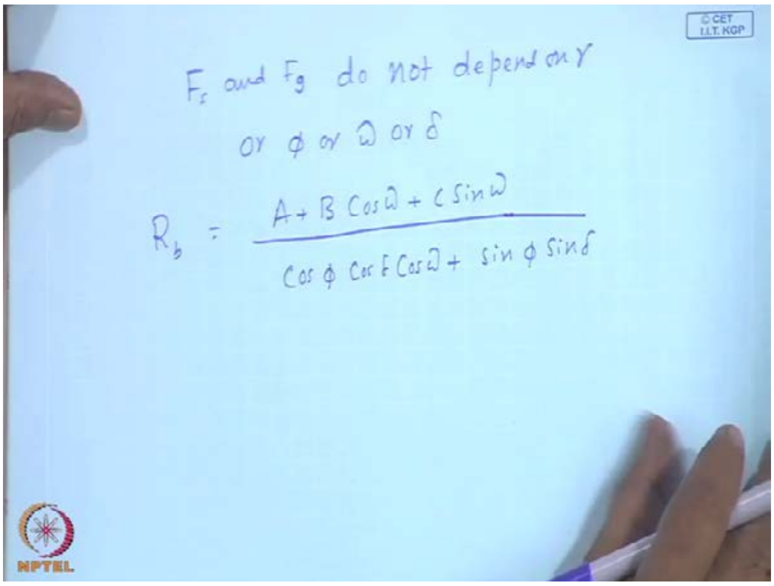

Fs and Fg do not depend on gamma or phi or omega or even delta. So, I can in general have this is the general expression for cos theta. And this expression for cos theta z.

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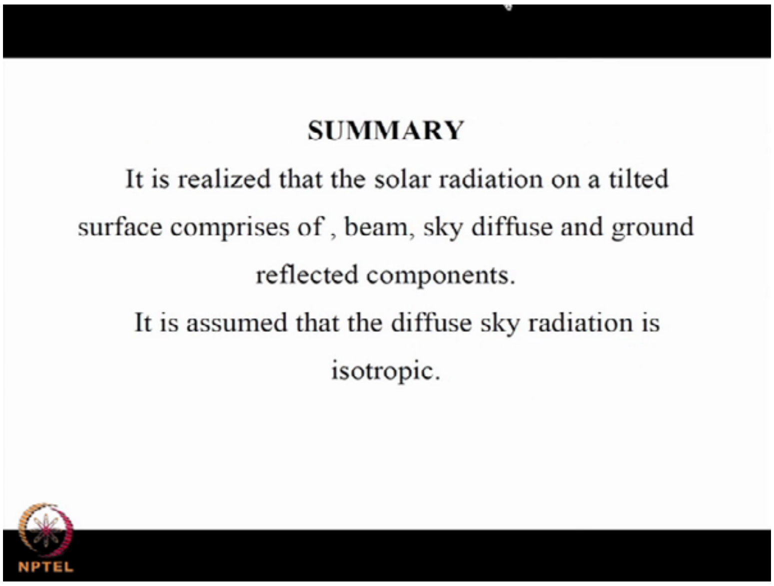

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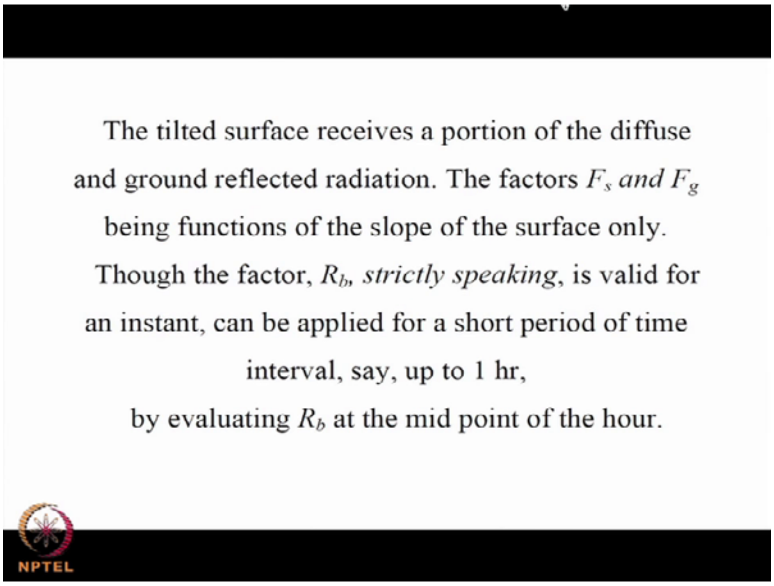

So, now we have a method of calculating r b in general. If we summarize solar radiation on a tilted surface comprised of beam sky diffuse and ground reflected components. And it is assumed that this sky diffuse radiation is isotropic, and the tilted surface this is a portion of the sky diffuse and the ground reflected radiations. And though the Rb factor is strictly to be applicable to be calculate for an instance without significant or almost 0 loss of accuracy. You can calculate at the midpoint of the hour. Now this is short term processing.

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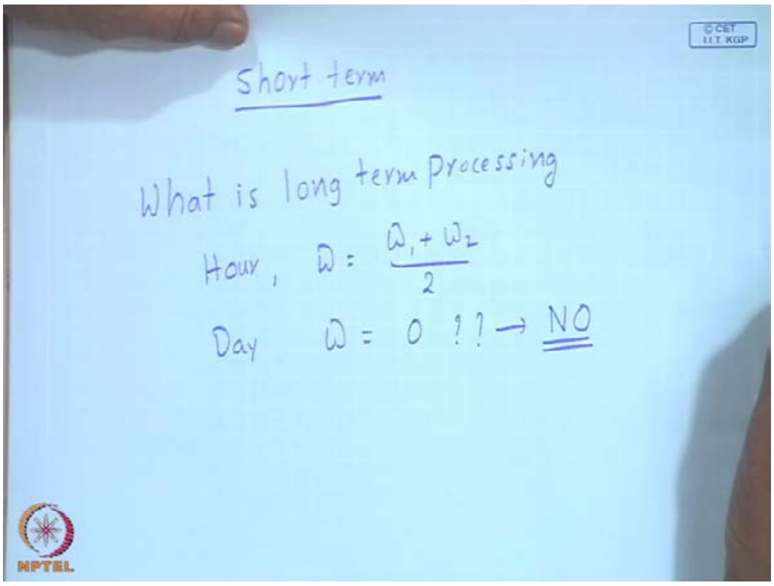

We will have little bit of introduction for what is long term. For an hour we are able to calculate omega 1 plus omega 2 by 2, What about a day can I calculate the midpoint of the day, which is a solar room which is omega is equal to 0? Answer is obviously a big no because, it will have the if it is a south facing surface. You will have the perhaps best orientation at the noon time. And hence, Rb calculated omega is equal to 0 cannot be represented of the entire day.

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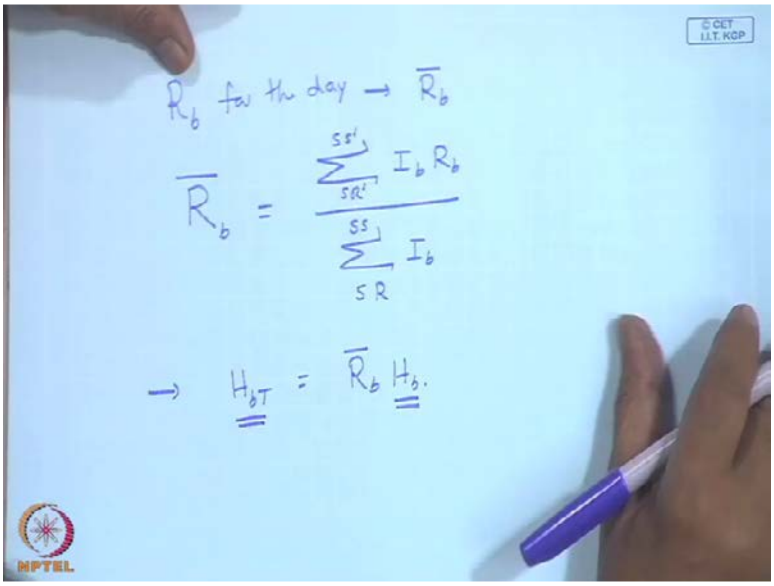

But, how do I define if I want to have a daily Rb for the day, let us call it Rb bar like we have been doing it. So, this Rb bar should be equal to summation of Ib Rb summation of Ib from again categorically from sunrise to sunset sunrise to sunset.

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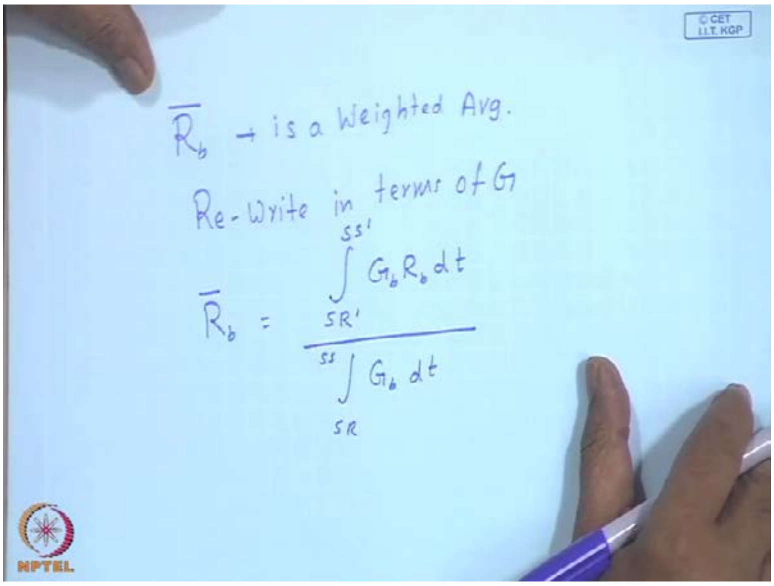

Little later we will find out these are not the physical sunrise and sunset but, this should be sum SR dashed. And SS dashed which apparently the surface sees during the day. But, never the less if we properly calculate it even if I categorically say from sunrise to sunset and ignore a negative Rb etcetera. You will still get a correct value. So, if I am asked to find out Rb bar or in general this leads to h t should be equal to Rb bar hb.

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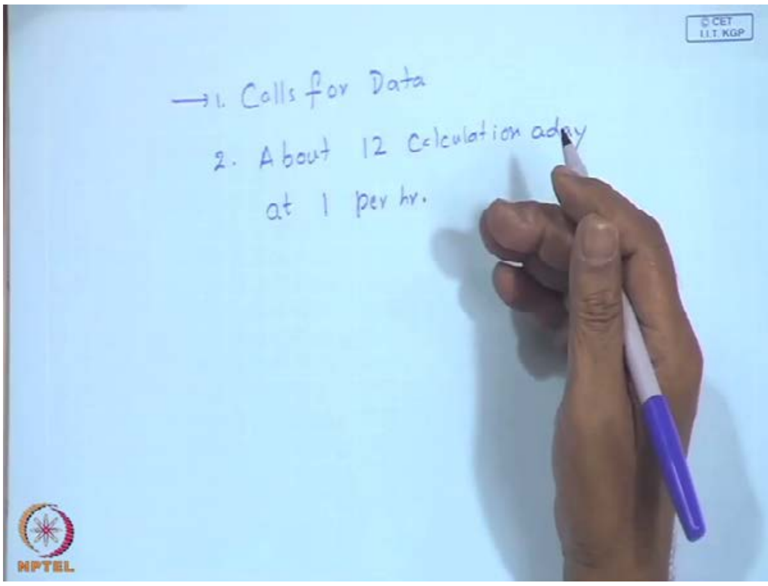

If, I have the daily beam radiation on a horizontal surface, I will be able to calculate the daily direct radiation on the tilted surface. By this factor Rb bar into hb. so, this is Rb bar is a weighted average assuming I can transfer just to be mathematically consistent. Either I sum up or by over Rf calculate for categorical reasons as Gb Rb dt in terms of an integral.

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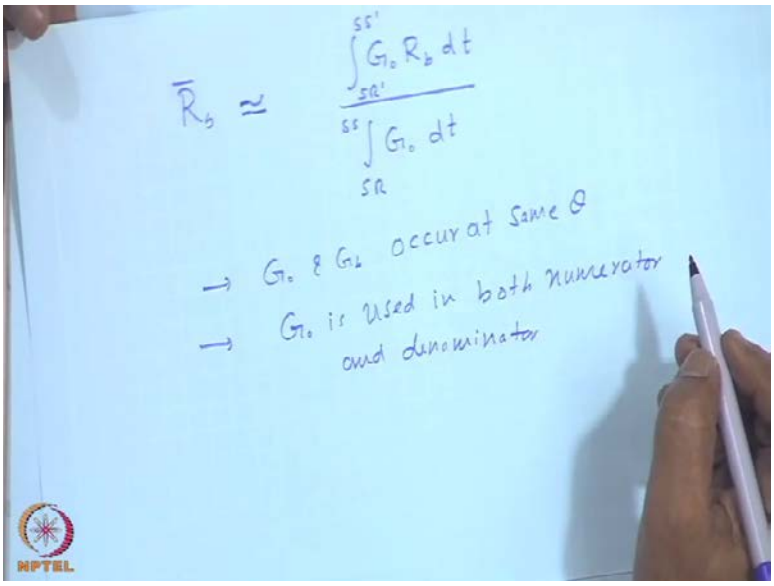

But, this calls for data 1, 2 about 12 calculations a day at 1 per hour. all the days may not exactly have 12 hours. But, about that on an yearly basis this average is. so this is a conversion process. And if you want to calculate for the month you need to calculate for 12 into 30 days for the year it will be even more multiplied by 365. So, how to solve this problem what people have suggested is the data calls for the numbers and a numerical integration. But if you approximately calculate under extraterrestrial conditions, what are my justifications justifications are G0. And Gb occur at same theta, the angle of incidence of the extraterrestrial radiation on a horizontal plane.

And the instantaneous Gb at a instant will have same theta what differs is G0 numerically differs from Gb. So this is an approximate symbol based upon this then second sort of justification is a G0 is used in both numerator and denominator. So, if there is an error in the numerator there is some error in the denominator. Also though not exactly the same consequently some error is likely to get canceled. So, this appears to be a good approximation.

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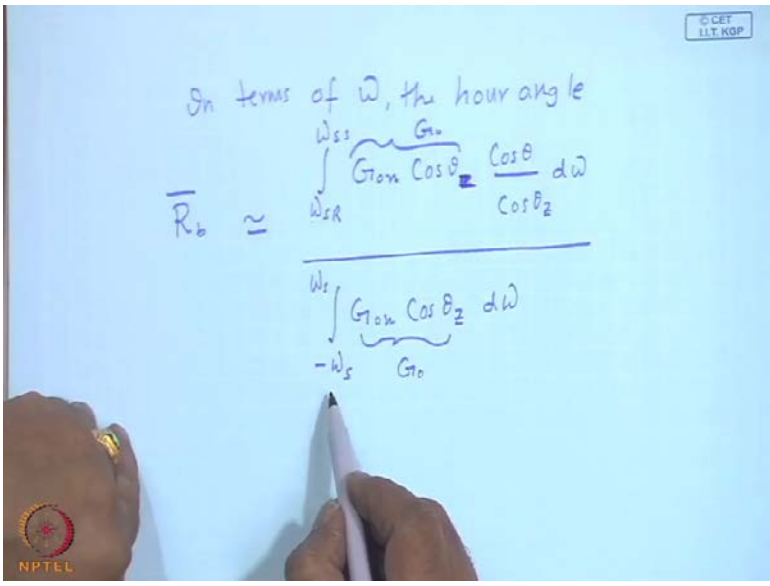

Converting into in terms of omega the hour angle bar approximately, I will now call it omega Sr to omega SS and this G0 will be cos theta times cos theta z. So, this is a normal radiation multiplied by cos theta z which will be the nothing but, G0 which is a same G0 over here. and my Rb is categorically cos theta upon cos theta z. I am now distinguishing the tilted surface may not see the radiation all the time. As the physical sun sees the horizontal surface or above the horizon.

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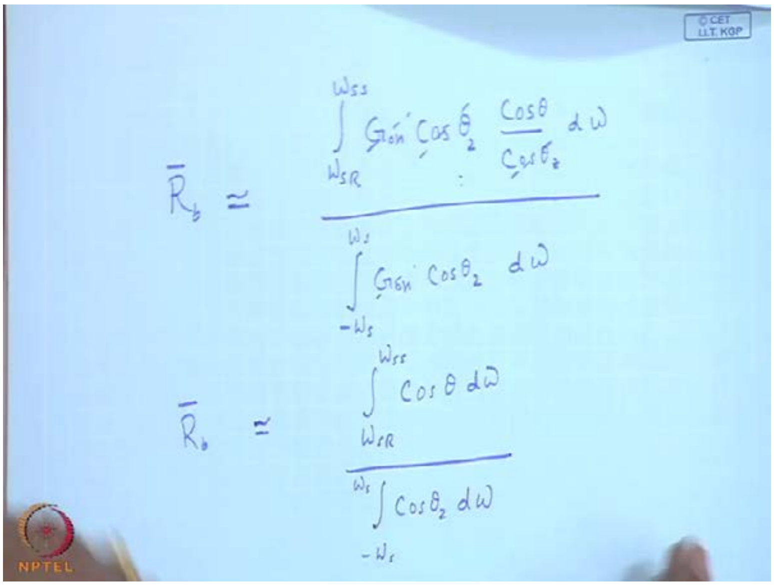

Let me rewrite it at the moment do not bother about this omega s r and omega s s except physically except that any tilted surface are arbitrarily oriented surface. We, shall not see the sun all the time that the sun is above the horizon. So, this simplifies to you can write GSC into 1 plus point 0.033 cos 360 n by 365. And this cos theta z gets cancelled with this cos theta z. And this also cancels with this so, my Rb bar is approximately equal to integral omega SRr to omega SS of cos theta d omega by minus omega S to plus omega S cos theta zd omega.

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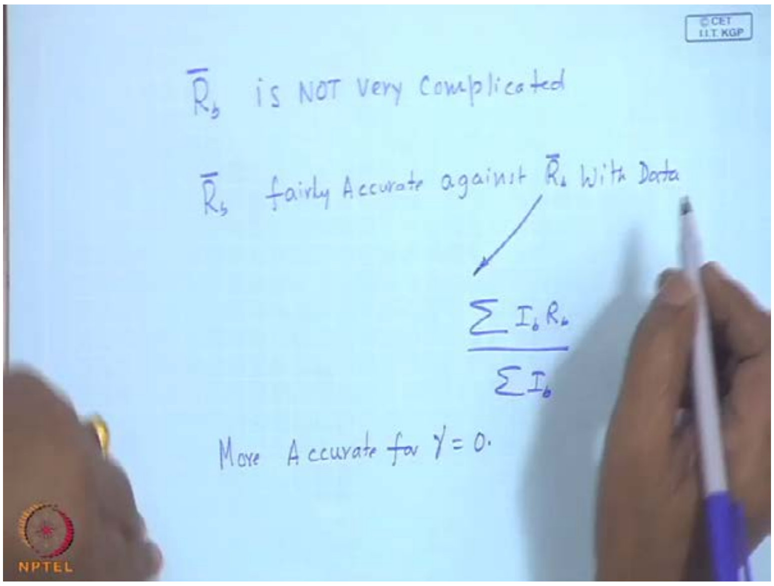

So, Rb bar is not very complicated. So, surprisingly it looks like a that you are integrating a numerator of Rb. And the denominator of Rb separately that is integral cos theta by integral cos theta z, to get Rb bar though that is not a mathematically correct argument. And you it so, turned out that cos theta z term gets canceled. And hence you will have this result. And this Rb bar fairly accurate against Rb bar with data, in other words you compute this with sigma Ib Rb by sigma Ib. This will be within 3 to 5 percent and this is more accurate gamma is equal to 0.

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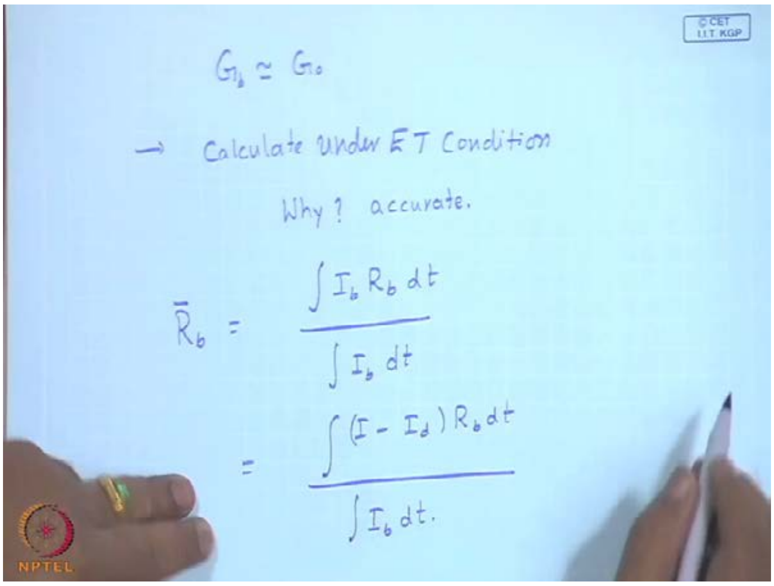

So, can we find any reason why this works well. Now, many people have made calculations we also made calculations, we found this Rb bar obtained. So, called extraterrestrial conditions basically Gb being equated to G0. That means calculate under Et now we shall use this short form for extraterrestrial condition. Now you may think of, Why, we can put forth 1 argument again? If we do not bother to much about the rate. And the intensity or the hourly value, basically it is Ib Rb dt by Ib dt limits are un important for the argument that is going to follow. So, this is I minus Id Rb dt.

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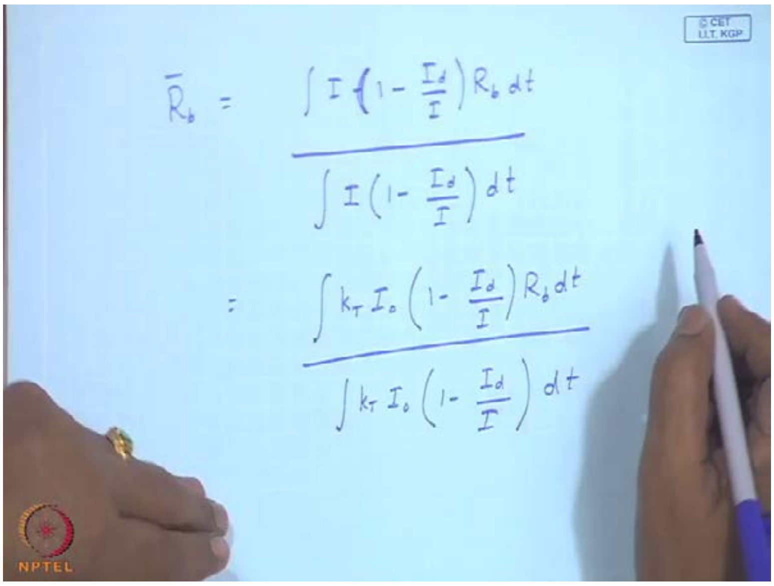

I am trying to assume that I have got analytically representable function, or discredited function or some correlation for I. And I write it in this particular fashion this is exact under terrestrial conditions. Now we this once again so, what all I have done is the terrestrial radiation is nothing. But, clearness index multiplied by the extraterrestrial radiation this everything else is now uniform and we realize a sum function of clearness index.

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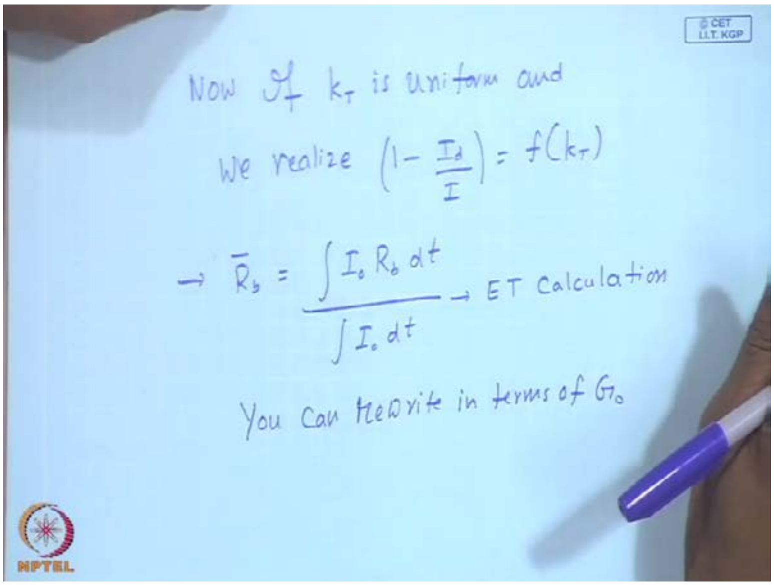

Because, all Id by I correlations and hd by h correlations are just functions of KT mainly. If that is so, my Rb bar will be simply you have I0 Rb dt by I0 dt that means ET calculation. You can again I can make it the intensity and bring back my old theory.

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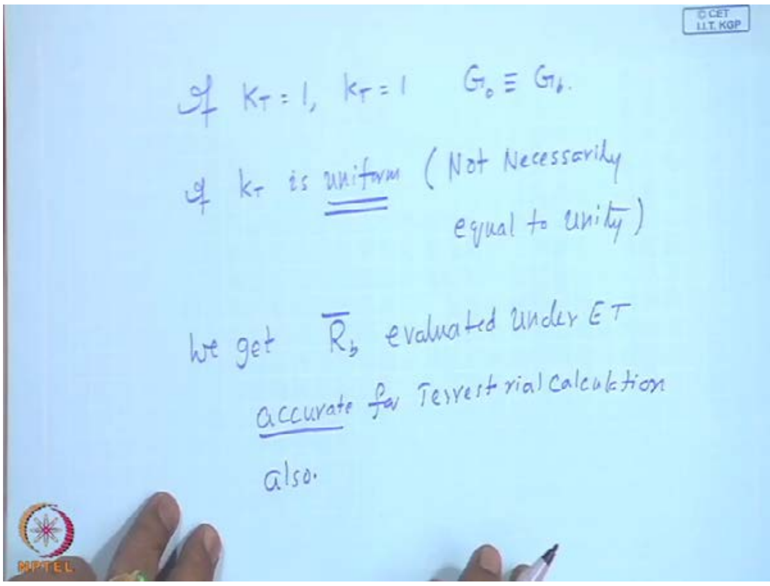

Now, what did we achieve by showing this what we achieved was what we realized is, if the clearness index has been 1. We, know that extraterrestrial and terrestrial radiation would be the same. There will be no diffused radiation by this we proved if KT small KT is uniform. That means not necessarily equal to unity, we get Rb bar evaluated ET accurate enough for terrestrial calculation also. What really in simple English means is you need not have atmosphere transmittance unity. But, you need to have uniform atmosphere transmittance.

That means if you have a uniformly cloudy or uniformly bright day your extraterrestrial calculation will be very close to the terrestrial calculation. And there are little favorable things if you think little more 80 percent of the radiation will be about, 5 to 6 hours mid part of the day 10 to 4. For example, that is when your Rb factors will be high that is also when your clearness index is likely to be more or less uniform. So, the weightage because of non-uniformity occurring at a lower radiation values will be small there. By making Rb bar calculated under extraterrestrial conditions. With a analytical expression will be fairly close to your values that you will have obtained using the data. Of course, there are deviations when the surface is not to south under certain extreme conditions. But, most of the time the extraterrestrial approximate calculation is acceptable.

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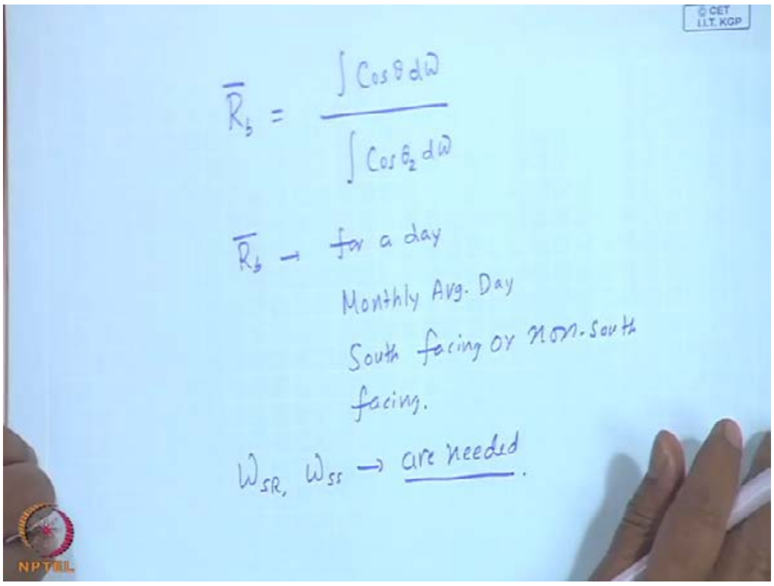

So, Rb bar is simple before we proceed to examine this in fact even Rb bar this can be for a day then a monthly average day. And it could be south facing or non south facing. So, we shall try to evaluate this occurred omega SR and omega SS are needed. So we have a method of calculating the tilted radiation for a hour, we have it for a day which works well. And we will examine how it performs for the monthly average day. And how we estimate this so, called apparent sunrise and sunset hour angles for the tilted surface.