Solar Energy Technology
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Lecture - 9
Solar Colector Basics

In this lecture, I will I shall introduce the Basics of Solar Colectors. So, far we have been dealing with radiation processing, with the idea of calculating solar radiation received by surface of different orientation. The applicability is general we may be able to calculate solar radiation received by a wall of a building or a roof of a building or a cold storage or any surface of general orientation. With reference to colectors not only we need to estimate this, there will be what is called a transmittance absorptance product, processed in a similar manner that we have done for the solar radiation. In order that you appreciate that, you need to know some basic configuration for the solar colectors.

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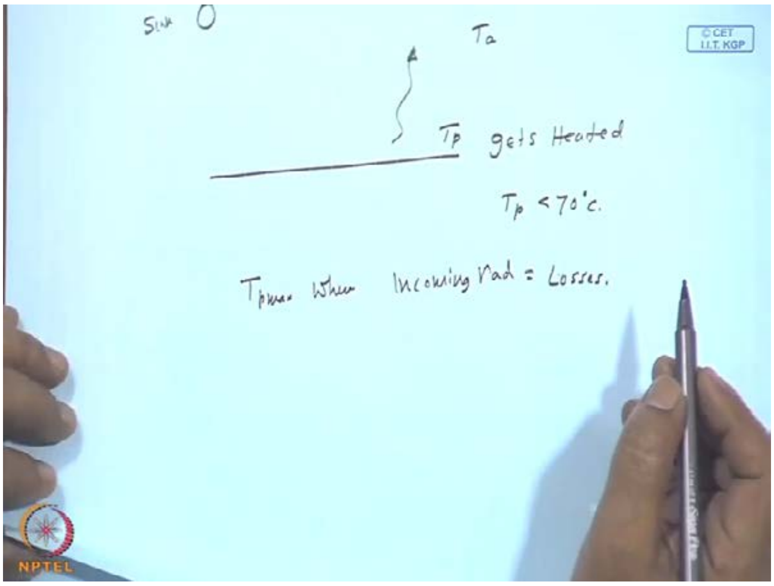

Now, suppose you keep a plate outside in the sun, it gets heated and starts losing heat, and this may be some T plate, and losing heat to the ambient at T a. You will find numerator how long you keep like this, even if you assume that sun is continuously shining, a T p may be less than 70 degrees centigrade. So, it will reach this T p max, when your incoming radiation is equal to the losses, when this happens at a particular T p, there will be no more increasing the temperature.

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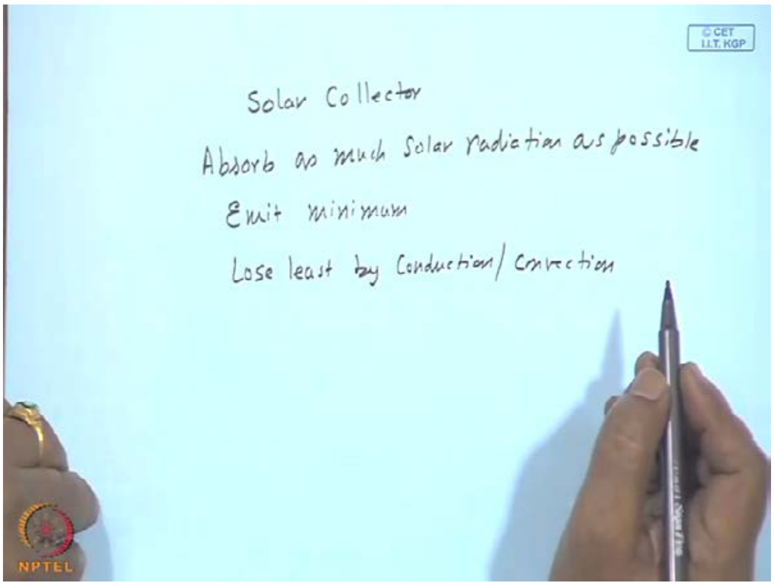

So, the philosophy of the solar colector in general should be thermal colector, absorb as much solar radiation as possible. But then an absorbing surface shall emit also but emit minimum possible and lose least by conduction or convection process.

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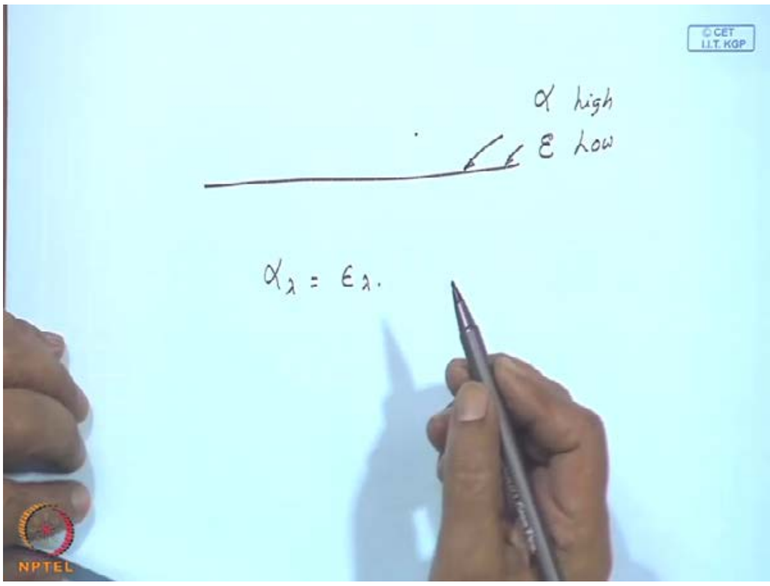

Now, if we try to characterize the surface now, if you know basics of radiation in general, it should have a alpha high and emissivity epsilon low, can we have this, Kirchhoff law says, alpha lambda is equal to epsilon lambda. So, if the surface is having a high absorptivity at a given wavelength, it will also have a high emissivity at the same wavelength.

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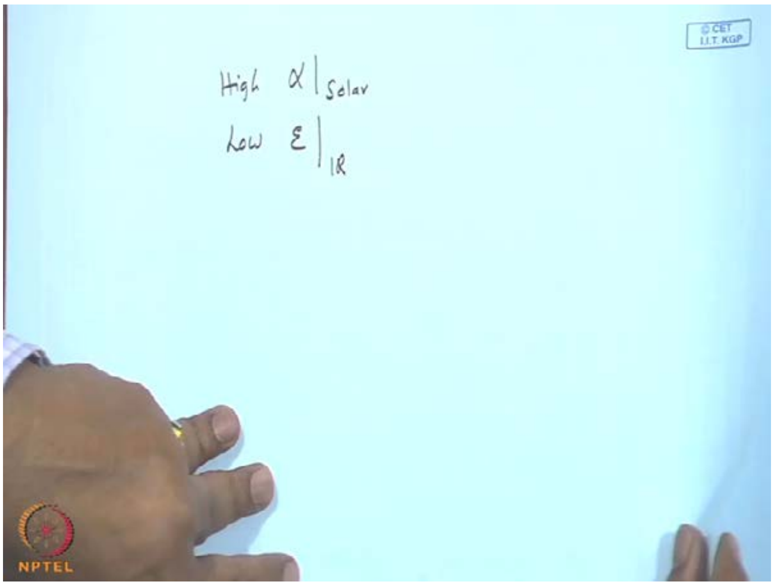

However, we can make use of high alpha in the solar range and low epsilon in the infrared range because the absorption takes place in the wavelength range of 0 to 4 microns. And the emission takes place at considerably higher wavelength, as determined by the waves displacement law, lambda max t is a constant. However, we will not go into the detail right now, how to increase alpha and how to decrease epsilon, but in principle we need to have a high absorptive surface, then reduce the e transfer losses due to conduction and radiation.

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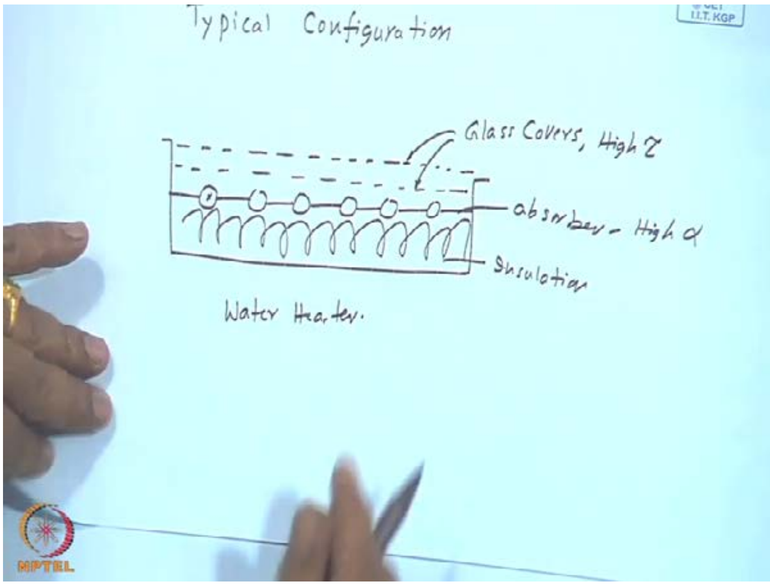

So, one configuration typical actual show for a water heater, which is a most popular (()) tube type of absorber, that is kept in a box and the box is insulated. So that, conduction from the bottom is reduced and there will be 1 or 2 glass covers so this is the absorber, this is insulation and these two are glass covers. My properties are they should have a high transmittance tau, they should have a high alpha, we will not at the moment worry about a high alpha and a low epsilon. But let say, it has got a high absorptivity and fluid flows perpendicular to the plane of the board through this tubes, this is a typical water heater.

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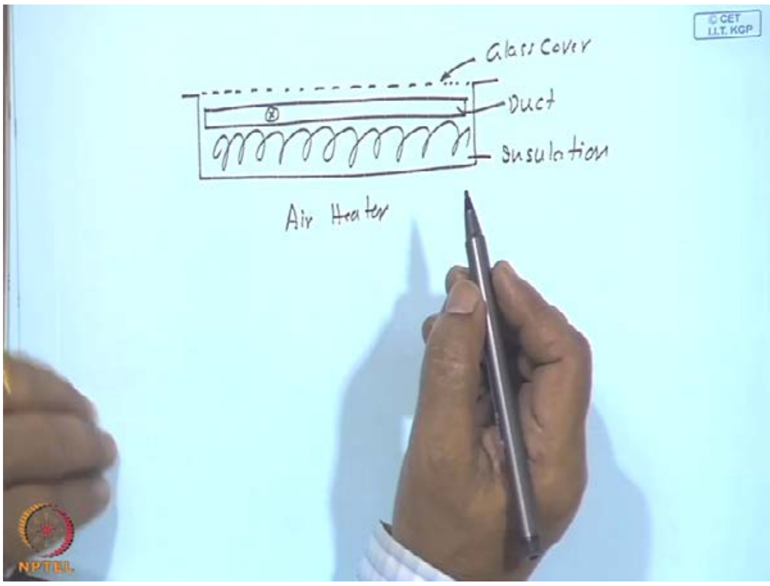

If a similar thing is drawn for a air heater, one may have different compositions configurations but I am just trying to show only one of the most commonly used, I should use another paper. This is again the insulation, this is a duct in place of the tube and fin, and this is the glass cover, it maybe one or two. This is a air flows perpendicular to the plane of the board, you will notice here that, we used a duct, which basically provides a very large flow area compared to tubes in the case of the water heater. This takes into account the fact that, air has a much lower density consequently, it has to handle much larger volumes for a given increase in the energy due to absorption, or by conductive retransfer of whatever solar radiation is, collected by the absorbing surface.

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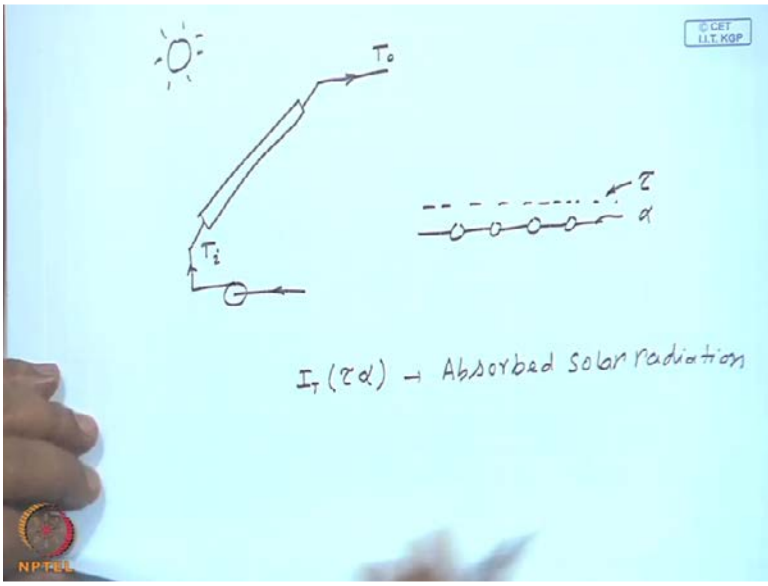

So, having given this now, this may be tilted at certain angle now, there will be a pump or a blower and this is how, enters at T i and exits at T o. We are at the moment, not consent with the rest of the system, and this is the suns ray with certain angle of incidence now, we know how to calculate I T, that is the solar radiation falling on the surface.

So, now, again if we look at this part of the fin and tube configuration with a glass cover, in a simple fashion, if this has got a transmittance tau and this has got a absorptivity alpha. And incoming radiation is I T, that is transmitted a fraction of tau and then absorbed another fraction alpha, this is the absorbed solar radiation.

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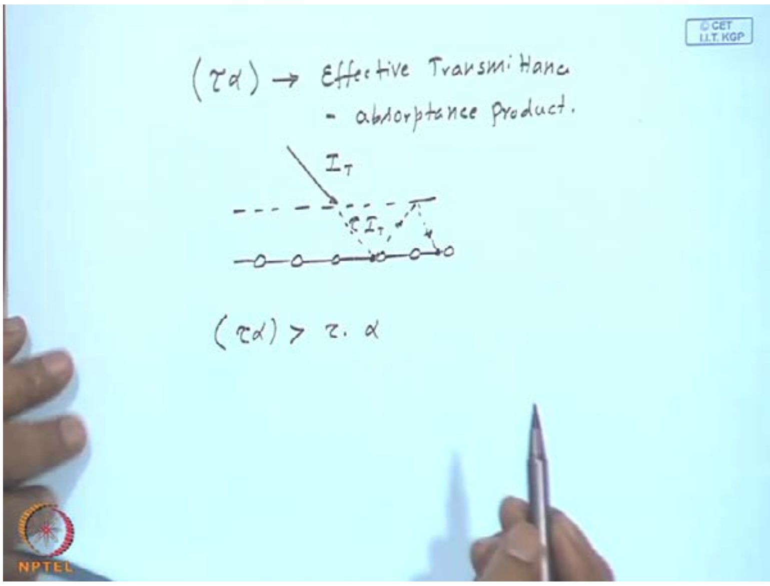

Now, you will notice that I have put tau alpha, which I will call it effective transmittance absorptance product, why effective, if you have a glass cover and then an absorbing surface and incoming radiation of I T, tau into I T reaches this surface. Part of it is absorbed, part of it is reflected, again a part of it is re reflected so a part of it again absorbed. So, there will be multiple absorption and reflection process there by, making instead of, tau into alpha, an effective tau alpha into I T is the absorb radiation by the surface, which will be slightly more than this effect to tau alpha, is more than a tau into alpha. Sufficient to know at this stage this much, though we shall later on we see how to calculate this.

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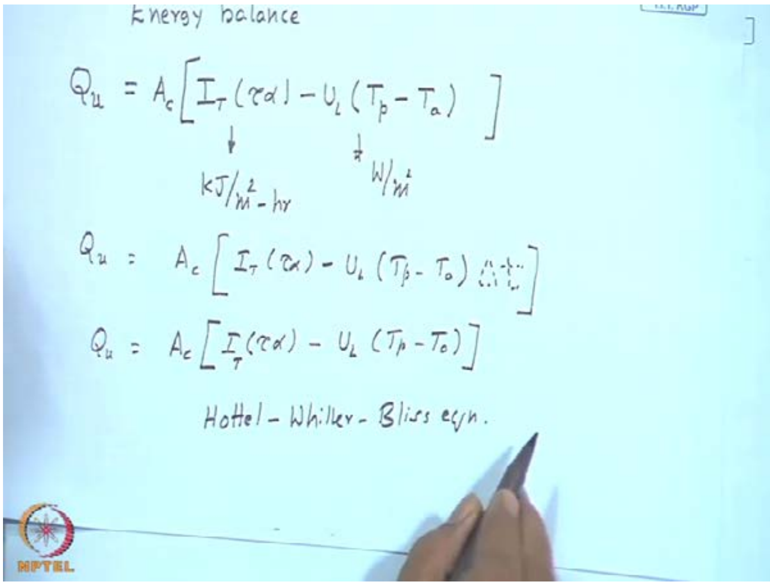

Given this, before you come to energy balance, back installation is provided to reduce the conduction losses and the top glass cover reduces the radiation loss, plus the convection loss due to the wind, that flows over the collector. If you have the absorbed energy is I T, tends to alpha and if I represent all the losses by a overall loss coefficient of U L. And if the colector plate is represented by a single temperature T p and the ambient temperature is T a, this is the loss and I shall deliberately give a little larger area, multiplied by the area of the exposed surface, should be equal to your useful energy gain from the colector right. Whatever is absorbed minus whatever is losses now, if you look at it, this is our let us say, kilo joules per meter square hour and this will be of course, watts per meter square.

So, if I am using a hourly time interval, strictly speaking my Q u should be A c times I T tau alpha minus U L to T p minus T a, into some sort of a hidden time factor. If this is a period of one hour, this delta t is 3600 and this is in watts then I will get a joules, I can make it to kilo joules. But quite often, in solar energy literature that, delta t is not written with the understanding, that one chooses the time factor, depending upon the time factor, that is used in expression the solar radiation. So, this is my colector energy balance more or less proposed long time back by Hottel wheeler and bliss equation.

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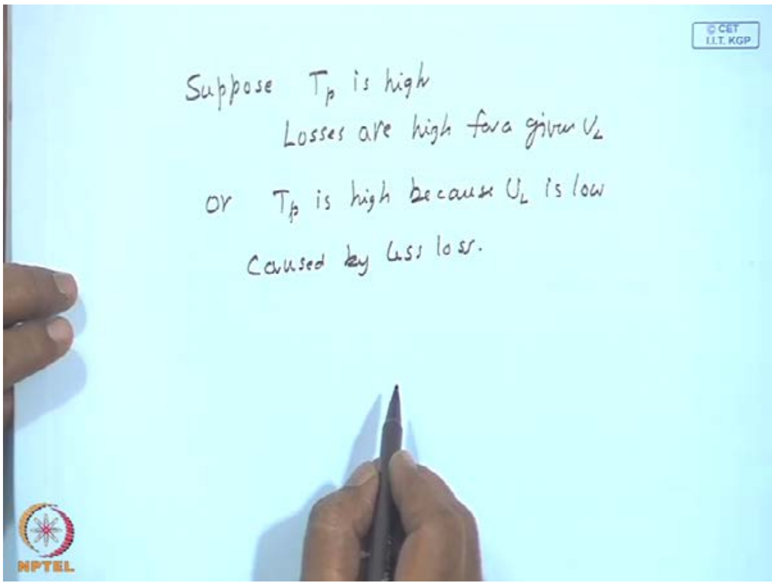

Now, there is a problem with this equation suppose, T p is high so losses are high, for a given U L or T p is high because U L is low caused less loss. That means, higher T p followed because it lost less so there is a possibility of misunderstanding, if the colector plate temperature is 120. It may be an excellent efficient collector, transferring energy to the fluid at high level temperature, or it may be a poor collector since, it is not able to transfer the energy to the fluid, it is at a high temperature. So, to avoid this feature, even if we agree to the simplification that, T p is a nodal value representing entire absorber, as a single value. This has uncertainty, it will not directly reveal, whether it is because of a very efficient colector transferring energy is at a high temperature, or it reach the high temperature since, it was not able to transfer the energy.

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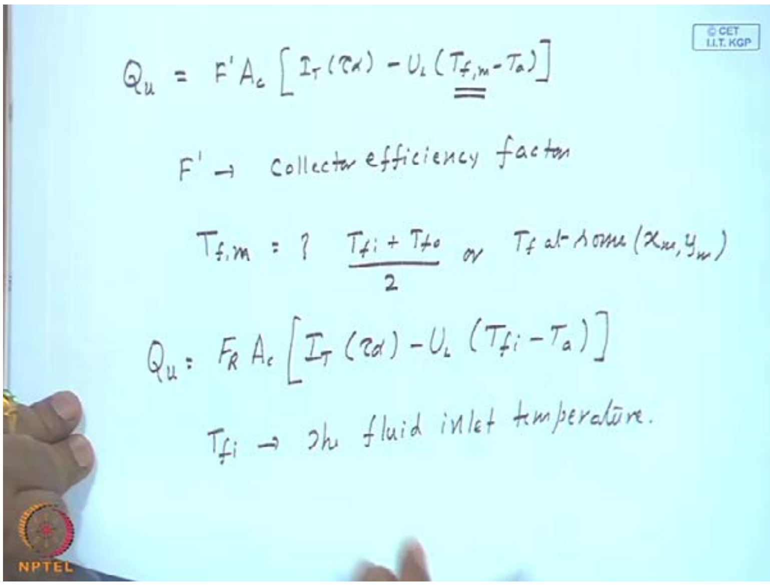

So, the subsequent improvement over that will be A c so they said that, efficiency or inefficiency of the transfer of energy to the fluid, can be taken care by fluid temperature instead of, the plate temperature. That means, the losses are being calculated at the fluid mean temperature, rather than at T p mean. So, this is an under estimate so to compensate that, one has put a factor F dash, which is called the colector efficiency factor.

Then the question rose, what is the mean fluid temperature and one definition could be inlet temperature plus outlet temperatures by 2 or T f at some mean coordinate x m and y m. With these things, again there is uncertainty in the estimation of Q u so this also they thought it is not a very satisfactory answer and further it is refined as Q u A c. So, there is no uncertainty, if you express in terms of the T f I, the fluid inlet temperature and this is again a underestimate compared to T f m. Because, this is the lowest temperature in the system so to compensate that instead of F dash, we will put a factor F R.

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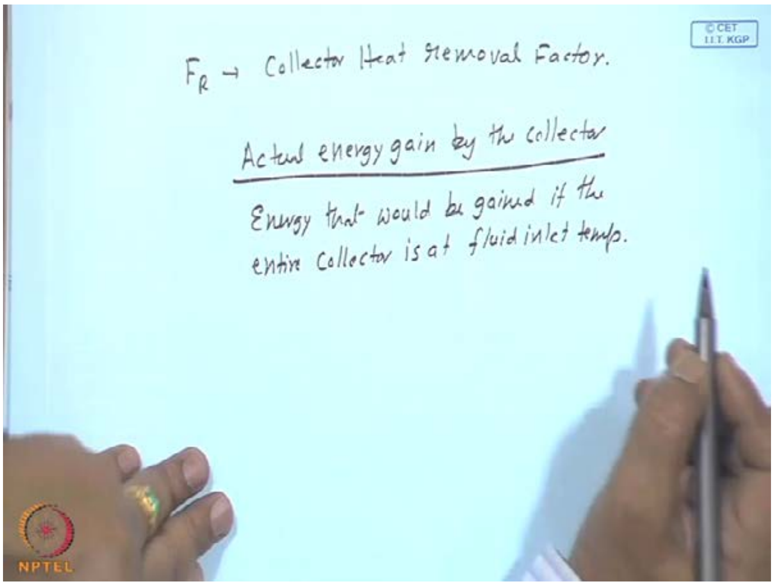

And F R is called the colector heat removal factor so what does it represent, in a way it is the actual energy gain by the colector to the energy that, would be gained, if the entire colector is at fluid inlet temperature. That means, this is a minimum loss that to take place consequently, it will give me the maximum amount of energy gain so that comparatively the actual energy gain is the ratio of F R. Now, with all this developments, one can think of making it a more and more efficient having high alpha, low epsilon, highly transparent tau close to 1 as much as, close to 1 as possible and then better insulation.

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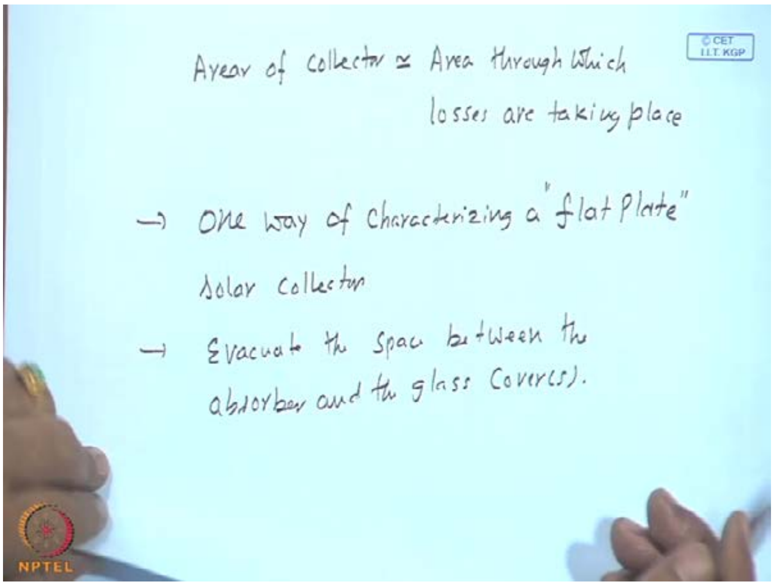

And in spite of that, the area of collection is approximately equal to, if not identically equal to, area through which losses are taking place. This is one way of characterizing a flat plate colector, further improvement can be evacuate the space between the absorber and the glass cover. This can also be done, however, if you have a square meter or a one and half square meters of colector area, a maintaining the vacuum is not easy. And then there may be a breakage and loss of vacuum, which will lead to a detoriation in the performance.

And generally, flat plate colectors are not utilize, I mean do not employee evacuated colectors, though it is quite common in other type of colectors, which we shall come just in a while. So, this is the limit, one can have the efficiency or alternately the temperature, at which the energy delivery can be expected from flat plate colectors in order to, improve that people have proposed.

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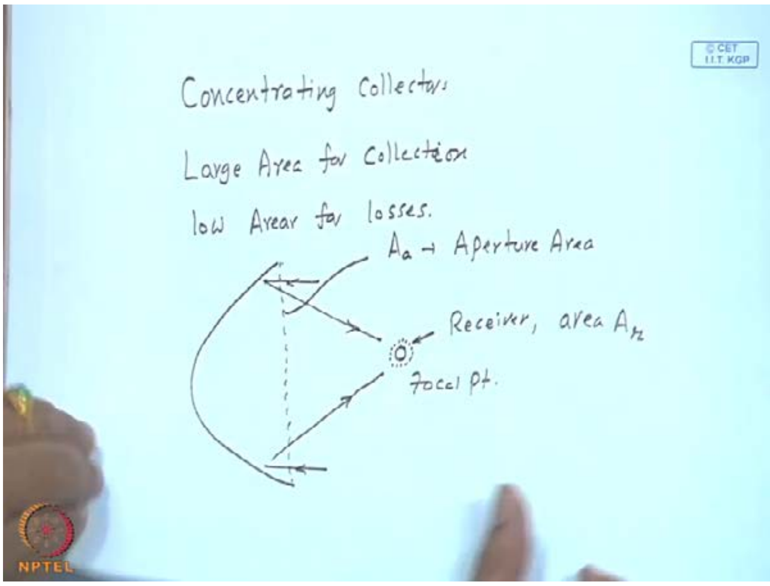

What we call concentrating colectors, principle is large area for collection and low for losses, one such configuration could be, let us have a parabolic dish like this and a receiver over here, at the focal point. We may have a glass cover surrounding it and even evacuate it, and any ray that falls on this, will be reflected on to the focal point. So, this is my actual area of collection, which is called the A a, the aperture area and this is receiver of area A r.

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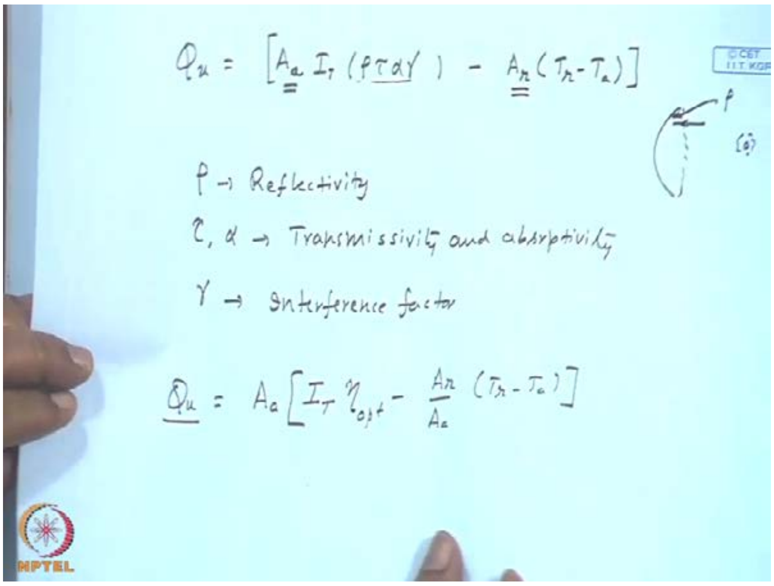

If I try to write down the energy balance of this, Q u should be A c sorry A a into I T something minus a receiver into, T receiver minus T a. Again we have got that hidden time factor, depending upon what is a time scale I choose for I T here, you have got a reflectivity of the aperture receiver area that is what, that is got the rho. And here is tau alpha for the receiver and then another gamma rho is the reflectivity tau and alpha transmissivity and absorptivity.

And gamma is a interference factor, this comes in because all the solar radiation reflected from the reflector may not be reaching the receiver, either due to approximate or inaccurate tracking, or inaccurate optics. Consequently, there will be a factor, gamma interference factor, it is sufficient at this test to know, that all the radiation is passing through the aperture area, going on to the reflector will be reflected. But may not be intercepted by the receiver going to n number of users.

So, we have a factor like this and this is my total energy balance now, the losses are taking place from A r whereas the collection takes place from A a. So, if you write Q u equal to A a, which is analogous to our A c in the case of, flat plate colectors. This multiplied by I T, I will call it overall a eta optics minus A r by A a, into T r minus T a. So, this is written like this, except this eta optical is something and I T, I need to evaluate on a different basis, depending upon how this concentrating colector is tract with respect to the suns position.

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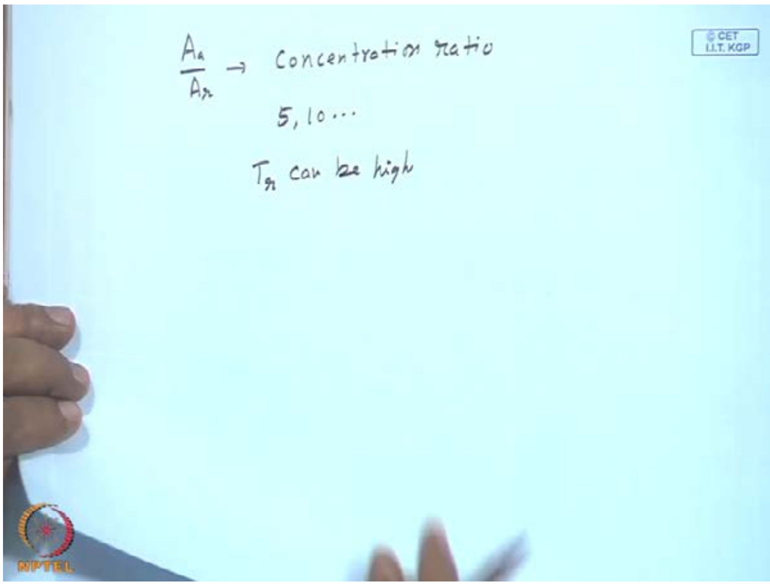

Now, this A a by A r is called the concentration ratio, which may be 5 10 so and so on, higher the concentration ratio, the lesser is the area from which relatively, the losses are takes place. And hence T r can be high so you have a solar collection device, which will give you a receiver temperature far higher than the plate temperature, that you have in the case of, flat plate colectors. Thereby, I may be able to used for power generation or something so these are the two principles of flat plate colector where, the area of collection is the same as almost the area of losses, which we called the flat plate collector. And the other one is the collection area is a much larger than the receiver area there by, the losses being less compared to the incoming radiation and hence, enabling the receiver to reach a higher temperature.

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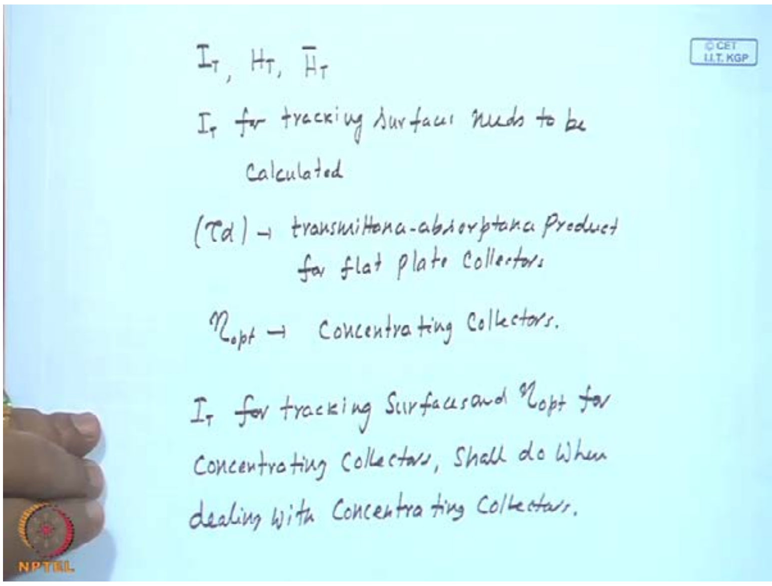

This is to let you know, that we had calculated I T per an hour or H T per a day or H T bar for the month, applicable for fixed surfaces that means, beta is fixed, gamma is fixed right. But these are tracking that is one thing, I T for tracking surfaces needs to be calculated and what is tau alpha, transmittance absorptance product. For flat plate colectors, this has to be estimated similarly, eta optical for concentrating colectors.

So, this I T for tracking surfaces and eta opt for concentrating colectors shall do, when dealing with concentrating colectors. So, for flat plate colectors in order that, though we do not yet know how to design, we know that tau alpha should be high. And we know the method to estimate I T in detail, whatever may be the time scale and estimation of the overall loss coefficient U L, it depends upon the knowledge of heat transfer, which you should be having by know fare amount of it, little bit of radiation, convection losses will be coming into the picture.

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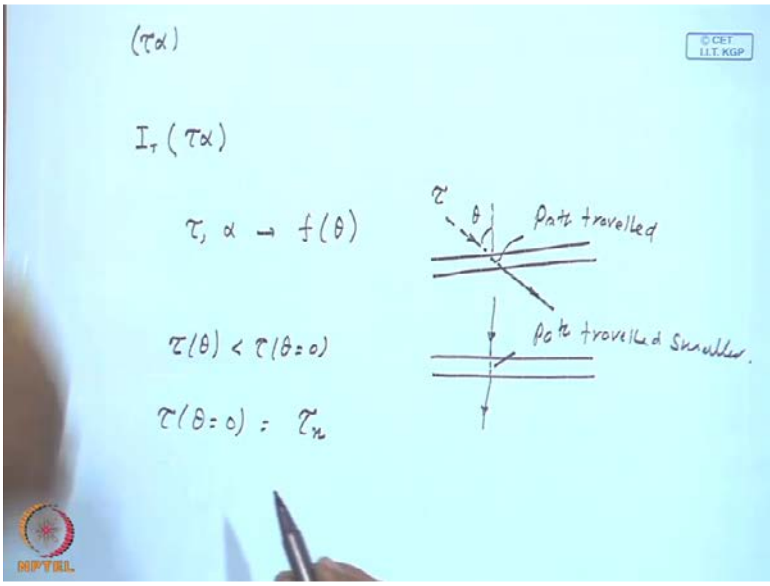

Now, this tau alpha we shall estimate so if I T is incoming radiation, I T times tau alpha will be the absorbed radiation. Now, this tau and alpha will be functions of angle of incidence theta, this you can easily understand. If I have a slab, glass slab of certain thickness, if this is the solar radiation, this is the path travelled at this particular incidence angle. And if you have almost normal radiation, path is smaller so this it is this is tau, theta should be less than tau, theta is equal to 0, this tau at theta is equal to 0 is called the normal incidence value, tau at normal incidence.

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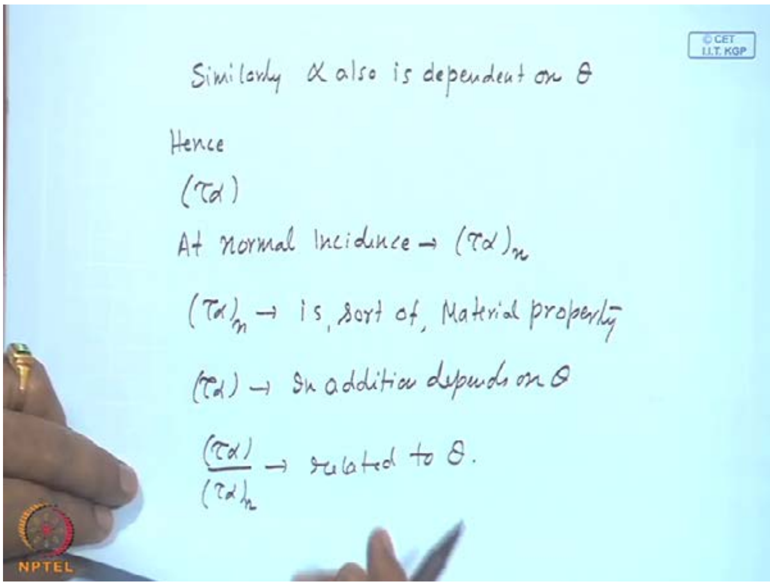

Similarly, alpha also is dependent on theta hence, tau alpha so and at normal incidence we designate by tau alpha n. So, tau alpha n is sort of material property and tau alpha in addition, depends on theta. So, if we want to have a description at different angles of incidence, we need to know by so this we will come to it little later.

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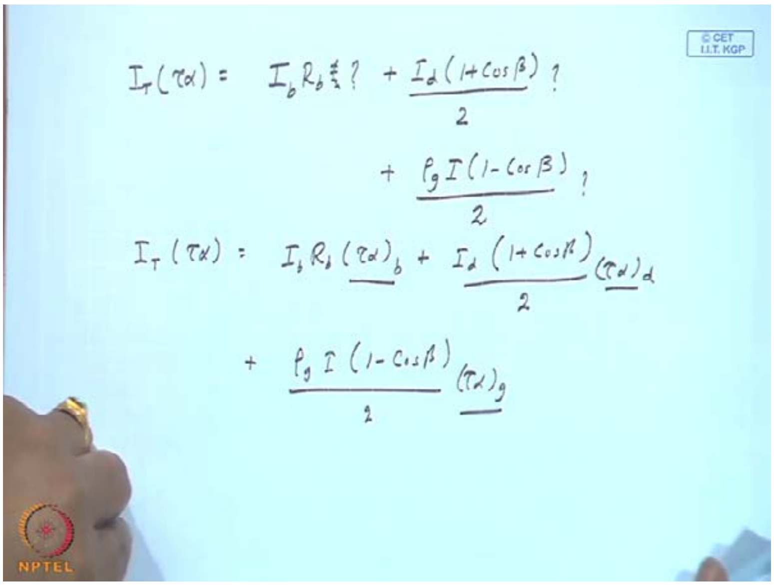

Before that, how do we define, we know that the radiation incoming is I T total multiplied by tau alpha, which is absorbed solar radiation. It will be comprising of the direct radiation I b R b, plus the sky diffuse radiation I d times 1 plus cos beta by 2, plus the ground reflected radiation. Now, these terms are to be associated with the corresponding transmittance absorptance products since, tau alpha by tau alpha ratio, is a function of theta or tau alpha is function of theta.

And this direct radiation will be occurring at a particular angle of incidence, the diffuse radiation is a isotropic and appears in all possible directions. And the ground reflected radiation also as a diffused component, which will be appearing in many orientations. However, even if we assume it by isotropic, the effect of the effective angles, at which the sky diffuse and the ground reflected radiation fall, is a priory not known, though the direct radiation will be occurring at our theta, the angle of incidence.

So, I shall associate each term with the corresponding transmittance absorptance products, we give the symbols tau alpha b for the direct radiation, tau alpha d for the sky diffuse radiation and tau alpha g for the ground reflected radiation.

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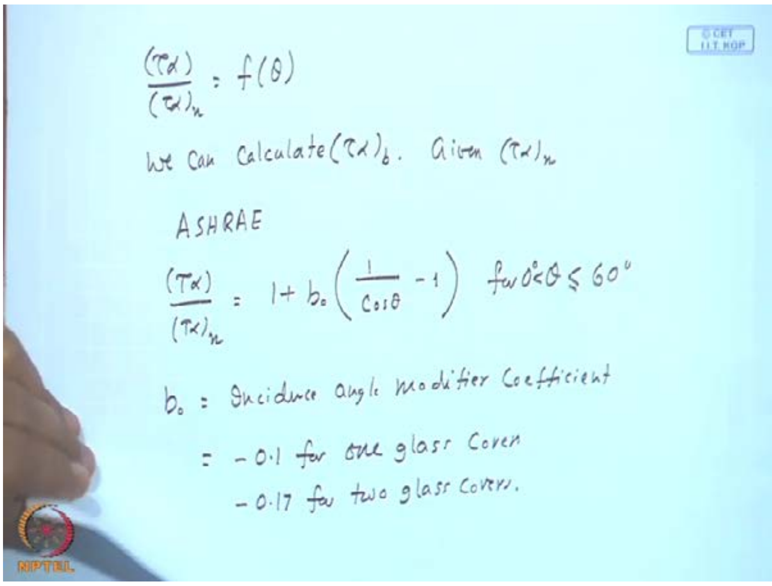

So, when once we know as a function of theta, we can calculate tau alpha b given, tau alpha n. So, fortunately, ASHRAE has given the functional dependence of transmittance absorptance product at any angle, incidence angle theta to its normal value. So, this is recommended that, this be used between 0 to 60 degrees of angle of incidence, and not beyond. And this b 0 is called the incidence angle modifier coefficient, which is about minus 0.1 for 1 glass cover and about minus 0.17 for 2 glass covers.

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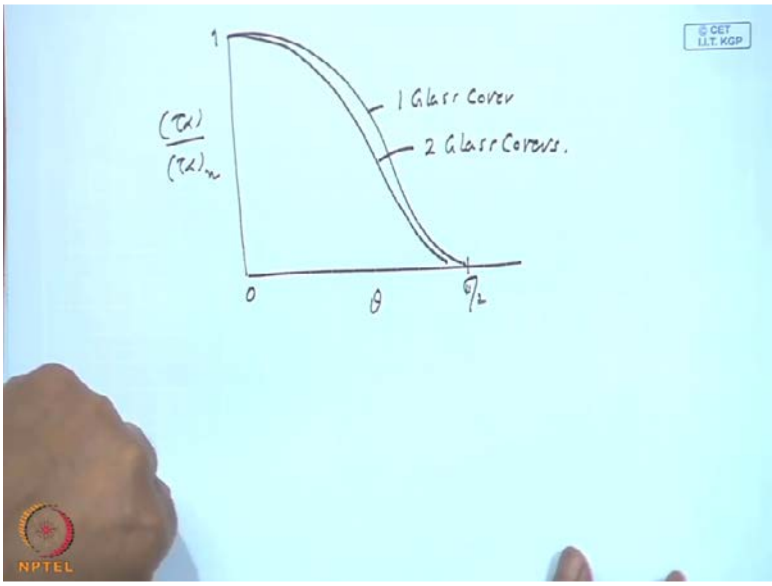

So, if we plot this, it will be something like this, this will be 1 at theta is equal to 0 and it goes to 0 at pi by 2. And then this is 1 glass cover and this is 2 glass covers, you can expect that, tau alpha by tau alpha normal, will be little less for 2 glass cover system, than it is for 1 glass cover.

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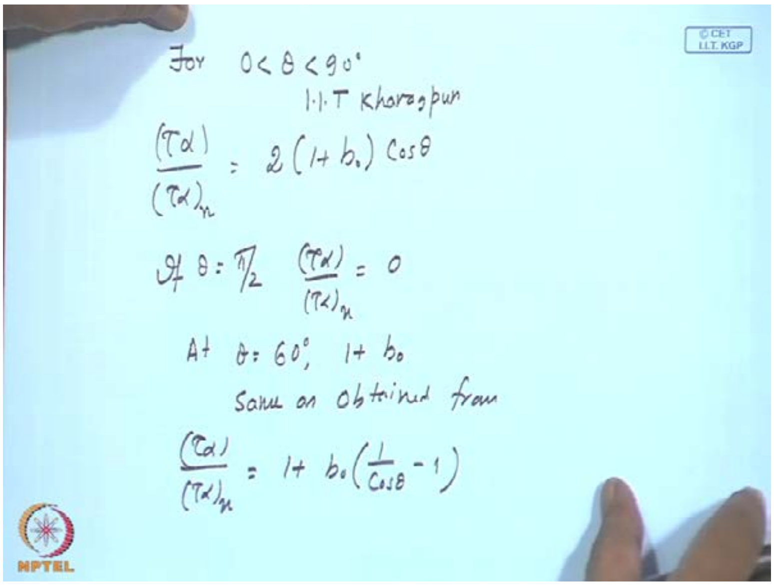

Now, it is proposed at IIT Kharagpur that for, sorry you can see this, if theta is equal to tau alpha by tau alpha normal, has can be expected is 0. And at theta is equal to 60 degrees, this will be 1 plus b 0, same as obtained from, so you if we put theta is equal to 60 to be 2 minus 1, 1 it is 1 plus b 0, this also gives 1 plus b 0.

So, it is continuous, at the point theta is equal to 60 and satisfies at pi by 2, this relation is mainly proposed not so much, to get a value of a tau alpha by tau alpha normal. Because, if you are operating a flat plate colector and the angle of incidence is more than 60 degrees, chances are the radiation received will be less. So, that may not be within the operating range nevertheless, if you want to calculate the average (( )) of certain product or the total absorbed energy, you may require this law.

And it does not harm, it follows the data or whatever are the standard curves pretty closely, and the form of 2 into 1 plus b 0 into cosine theta, fix in with the analytical requirements to make some calculations. And also it satisfies the conditions, that theta is pi by 2, that should be 0 and it should match with the ASHRAE recommended or relation. So, you now know a empirical description for the variation of transmittance of certain products with the angle of incidence.

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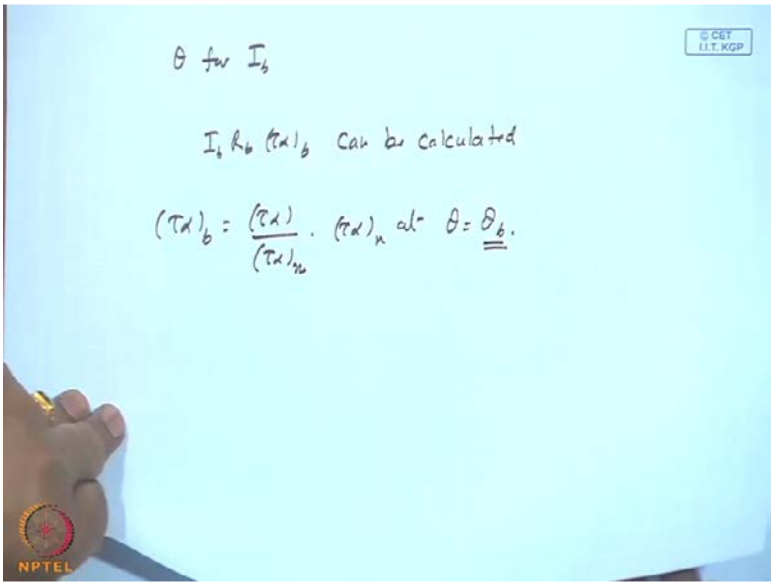

So, having given that and we know at theta for I b, at what angle the tilted radiation occurs also we know so consequently, the first term I b R b tau alpha b can be calculated. And tau alpha b is tau alpha by tau alpha n, into tau alpha n at theta equal to theta b, that is the angle of incidence at with the direct radiation is occurring, which is theta b. At that value, you calculate tau alpha by tau alpha n, multiplied by the material property tau alpha normal, which is known for the colector cover system.

Now, we do not known however, the angles of incidence for the ground reflected and sky diffuse radiation, that we should consider next time. And then find out how to calculate the absorbed energy with the transmittance of certain product, at this stage I should also try to point out, how do you go about for a day.

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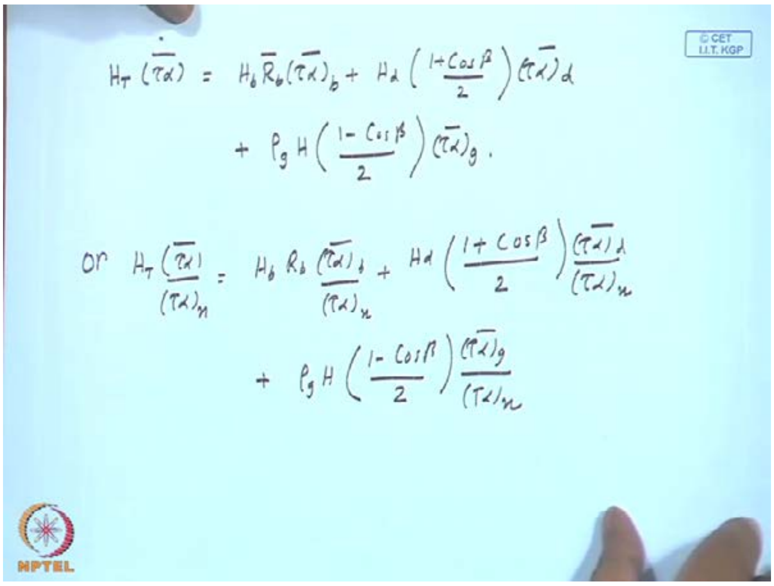

For example, H T into tau alpha bar, like we have done for H T is equal to I b R b summation, this should be equal to H b R b bar tau alpha bar b, plus H d into 1 plus cos beta by 2, plus rho g H into 1 minus cos beta by 2. This should be with tau alpha diffuse, this should be with tau alpha ground or H T tau alpha bar, there should be bars here. Tau alpha n, this is only to write in terms of, what is known to us, namely tau alpha by tau alpha n.

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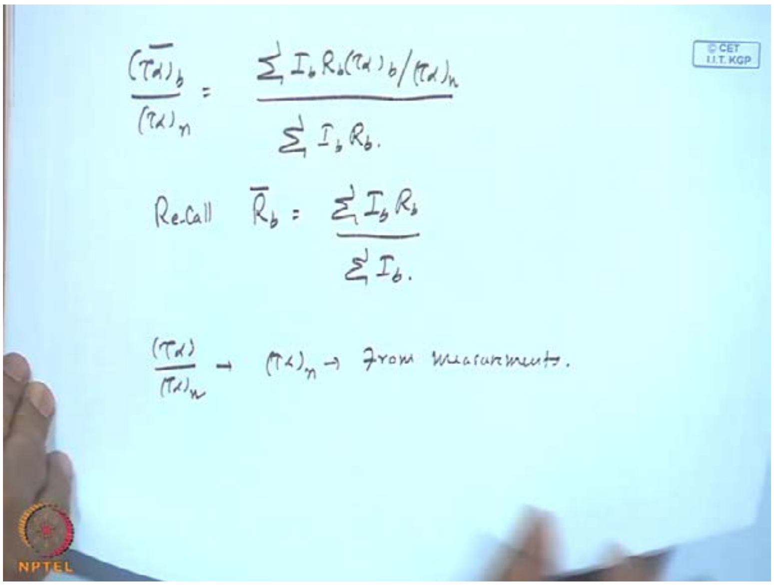

Like we have defined, should be equal to I b R b tau alpha b by sigma I b R b, recall R b bar, so similar to that the transmittance absorptance product also has been calculated as a weighted average. Now, as far as, the sky diffuse and ground reflected radiation are concerned, we should need the angle, we should know whether that angle changes with the time of the day or not.

Depending on that, we have to define the weighted averages so this is the situation in evaluating, first of all tau alpha by tau alpha known, normal. And tau alpha normal from measurements and tau alpha at the corresponding angle of incidence.

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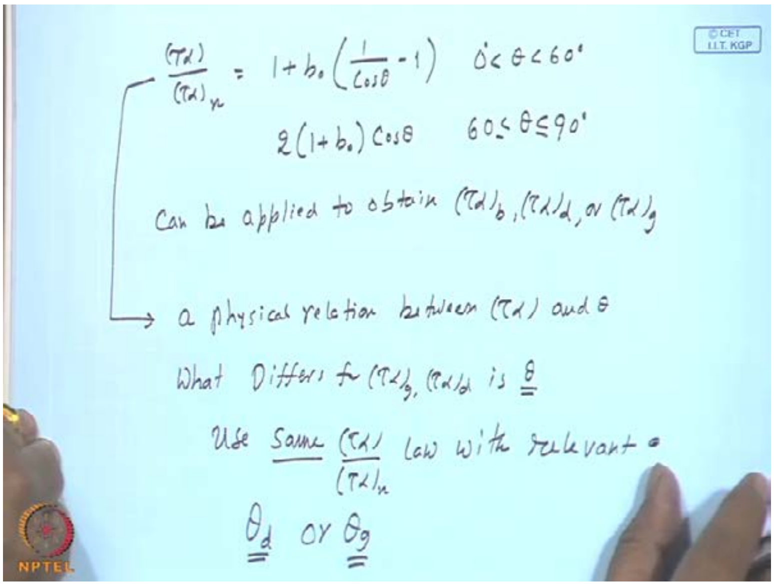

And we should remember one thing, this relation can be applied to obtain tau alpha associated with the direct radiation or tau alpha associated with the sky diffuse radiation or tau alpha associated with the ground reflected radiation. Why I am saying this is, particularly, this is a physical relation between transmittance absorptance product and theta.

What differs for tau alpha g or tau alpha d, is theta so you use the same law but use theta d. If the effective angles of incidence for the sky diffuse radiation is theta d and the effective angle of incidence for the ground reflected radiation is theta g then you will have same law being applied, using theta is equal to theta g or theta d. For the direct radiation, we shall use theta b, as I already being stated so next time we shall find out, how to, what are the values for the theta g and theta d. And then the how to define the weighted average or how to calculate tau alpha bar, applicable for a day or a monthly average day.

Thank you.