Solar Energy Technology
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Lecture - 41
Summary

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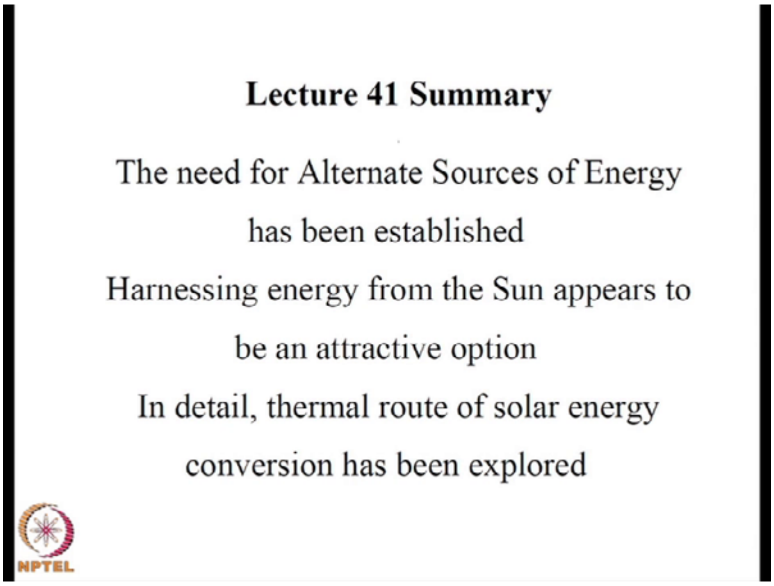

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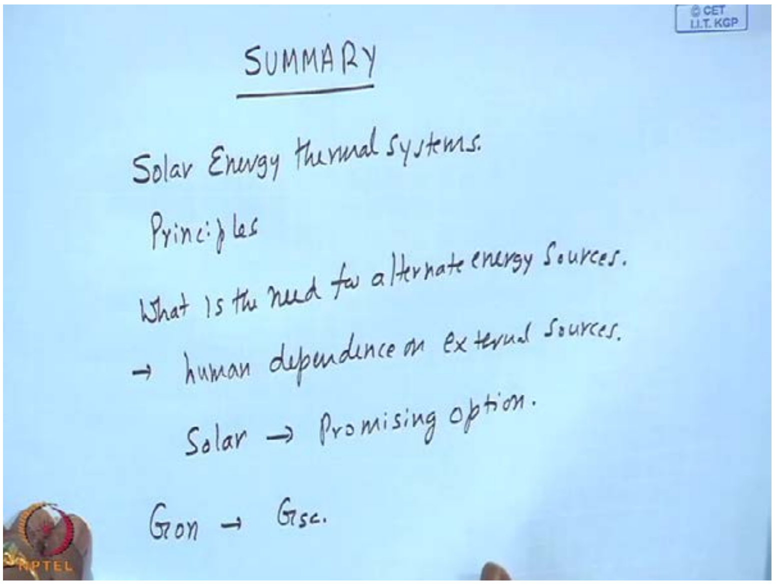

So, we have covered quite number of topics. I thought I shall take this opportunity to view my last or the concluding talk, which will summarize what we have done. In this about 40 lectures Firstly, the limitation is how, we have considered only solar energy, thermal systems, and in that we tried to give emphasis more for the principles rather than a particular system. And the base for that is, we tried to establish, what is the need for in general alternate energy sources? From which we have said that human dependence on external sources. These external sources being limited and being depleted at faster and faster rate of people started having a look at the alternate sources of energy. And out of which solar appears to be a promising option; this is sort of our introduction. So, we have gone through a lot of mathematics and then we defined G o n that is the solar radiation on a surface normal to the sun's rays under extra terrestrial conditions on a given day which is in terms of the solar constant G s e, which is if the surface is normal to the sun's rays under extra terrestrial conditions, at mean sun earth distance.

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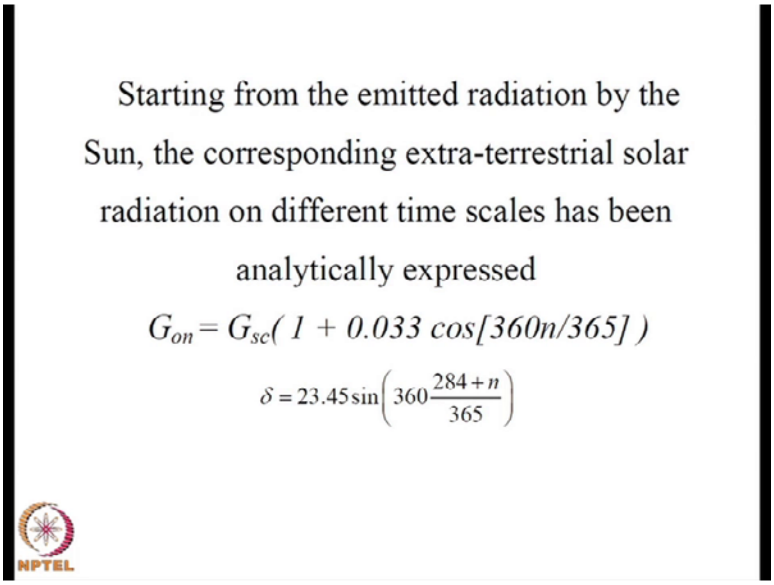

So, that is how the solar constant is defined.

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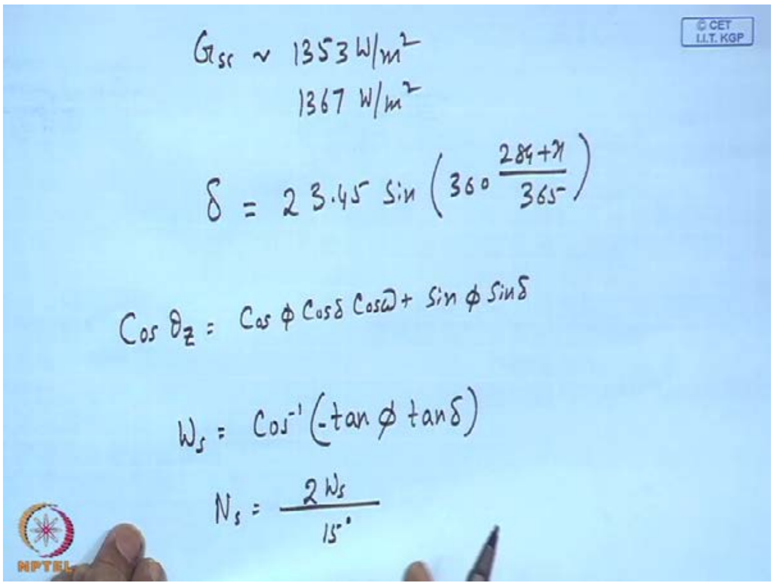

And this is of course, the estimates are varying it could be 1353 watts per meter square even 1367 per meter square. As we are getting more and more rather better or satellite data are this is being revised. And then we said that earths declaration delta is given by n equation 23.45 sin 360 times 284 plus n upon 365 of course, I am not going to rewrite all these equation.

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$$Solar\ time = Standard\ time \pm 4(L_{st} - L_{loc}) + E$$

$$E = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B$$

$$B = \frac{360(n-81)}{364}$$

So, more exposure will be given to each frame then everything is in standard time as far as we are consult and the calculation shall be done in terms of solar time which is given in terms of the standard time plus 4 minutes per degree of the let longitude of the location and the longitude based on which the time of the countries based L s t minus L o c by plus a E E is the equation of the time which is again related to the d of the year by the equations E and B.

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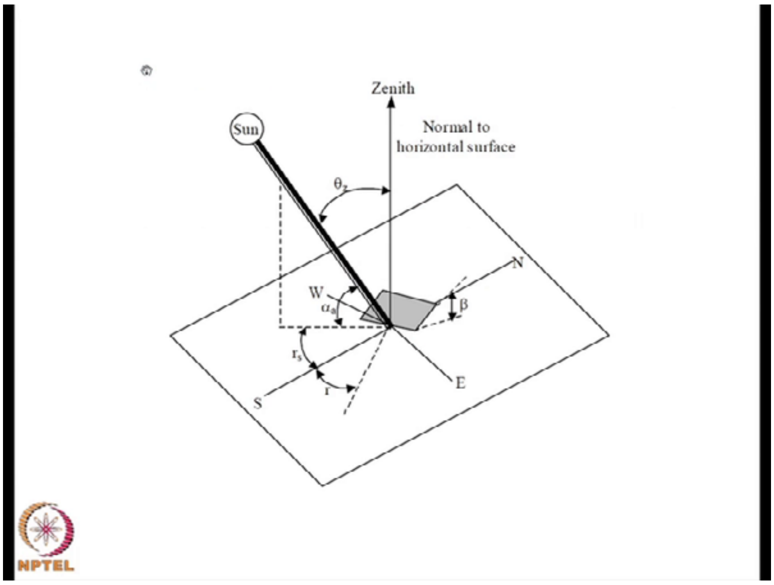

So, the plus will be for the western and minus of the east longitudes general we tried define N numbers of angles where in you have got a surface and it is inclined at an angle of beta then this is north south axis or north south direction and this is the west east and it is not in general in line with north south. So, there may be a azimuthal angle of gamma. Its look like r, but that is gamma is the location or notation we have been using and zenith is nothing, but the vertical to the horizontal which makes an angle theta z with respect to the suns ray and with respect to the outer normal to the surface the suns ray will make an angle of incidents of theta.

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$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma$$
$$+ \cos\delta\cos\phi\cos\beta\cos\omega$$
$$+ \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

$$\cos\theta = A + B\cos\omega + C\sin\omega$$

$$A = \sin\delta(\sin\phi\cos\beta - \cos\phi\sin\beta\cos\gamma)$$
$$B = \cos\delta(\cos\phi\cos\beta + \sin\phi\sin\beta\cos\gamma)$$
$$C = \cos\delta\sin\beta\sin\gamma$$

So, that theta in general a function of the latitude slope and of course, the time omega and the azimuthal angle gamma is a long relation which can be put in a shorter form as cosine theta equal to A plus B cos omega plus C sin omega where A is this expression and B is another expression and C is cos delta sine beta sin gamma.

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$$\cos\theta_z = \cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi$$

$$\omega_s = \cos^{-1}[-\tan\phi\tan\delta]$$

$N_s = 2\omega_s/15$, ω_s, is in degrees

$$G_o = G_{on}\cos\theta_z$$

$$I_o = \int_{t_1}^{t_2} G_o\,dt$$

And if the surface is horizontal the angle of incidences is also called the zenith angle it will be a simple expression which you can obtain were by putting beta equal to 0 as simply cos phi cos delta cos omega plus sin phi sin delta. Now, You will find this cos theta z to be independent of gamma because if you have a horizontal surface the projection of the outer normal will be a point and you cannot define a azimuthal angle and very rightly the equation reduces to be independent of the azimuthal angle then we defined omega s the. So, called. Sunset hour angle which is cosine inverse of minus tan phi tan delta and this is the physical time that sun will be appearing and the number of sun shine hours will be twice omega s by 15 because it takes 24 hours for the earth to rotate. So, 15 degrees per hour. So, twice of omega s by15 will be the number of hours that the sun will be above the horizon.

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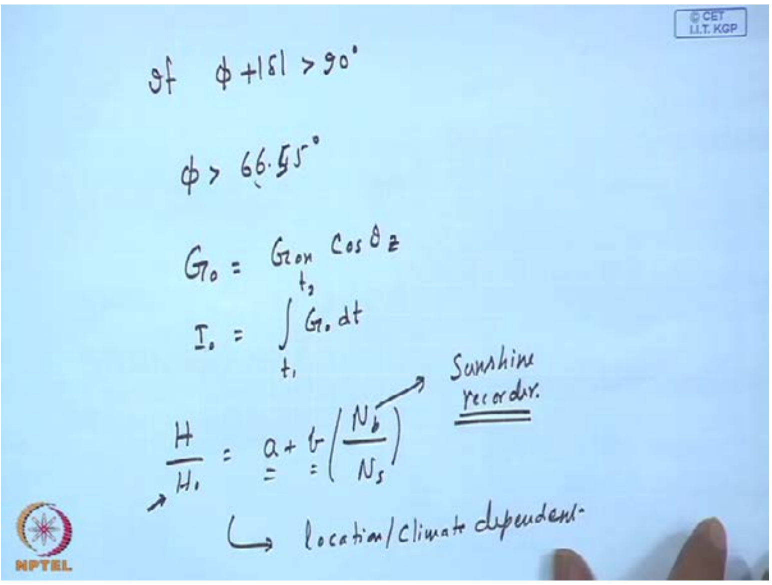

Of course, this gives to some problems if phi plus modules of delta is greater than 0 or it will go to A cos inverse of a negative number smaller then minus 1 or a positive number greater than plus 1 and for which is cosine inverse is not defined this typically happens if phi is greater than 66.45 degrees because maximum of delta is 23.45 it should be 55.So, any where beyond this latitude or you may have a 24 hours no sunshine at all or all the 24 hours sun being above the horizon. So, that is we have dealt in detail how to deal with this sort of a situation and from G o n on the horizontal surface G o n cos theta z and over a period of time like one hour from t 1 to t 2 that we will designated by I 0 which will be G 0 d t which will be G 0 d t.

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$$I_o = \frac{12x3600}{\pi} G_{sc}(1 + 0.033\cos[360n/365])x$$
$$[\cos\phi\cos\delta\sin(\omega_2 - \sin\omega_1) + \sin\phi\sin\delta(\omega_2 - \omega_1)]$$

$$H_o = \frac{24x3600}{\pi} G_{sc}[1 + 0.033\cos(360n/365)])x$$
$$[\cos\phi\cos\delta\sin\omega_s + \sin\phi\sin\delta\ \omega_s]$$

$$H/H_o = a + b\ (N_b/N_s)$$

Orgil and Hollands [7]

And when you are integrate it with G o n is equal G s c in to 1 plus 0.33 cos 360 n by 365 multiplied by this cosine theta z you will have a wrong expression for your I 0 over here and then you can have for the day by integrating it from minus omega s to plus omega s or twice of 0 to omega s. So, it will be the similar expression except these hourly values of omega to omega 1 or replaced with omega s it will be a twice omega s that is why this 12 becomes this particular 24. And of course, the young storm type of relation H upon H 0 is a plus b by number of bright sunshine hours by the possible sunshine hours this a and b are location dependent or location or climate this is measure with a sunshine recorder.

So, you know a strip that gets burnt or N b the bright sunshine hours upon the possible N s sunshine hours for the location for the particular day and you can correlate with the extra terrestrial radiation H 0 which is calculable analytically to the solar radiation on the f surface this could approximate relation, but nevertheless or the sunshine recorder has the ability to record and give you the N b without external power.

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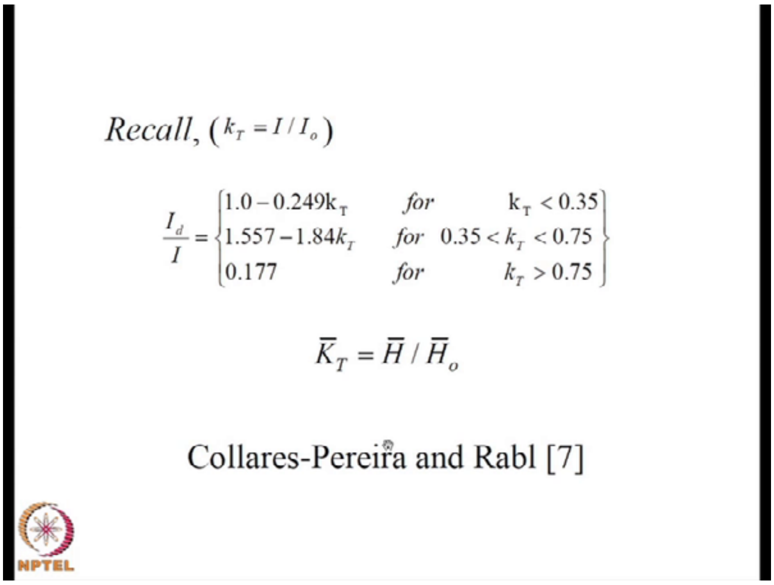

So, then we have gone through a large number of a correlations for that essential.

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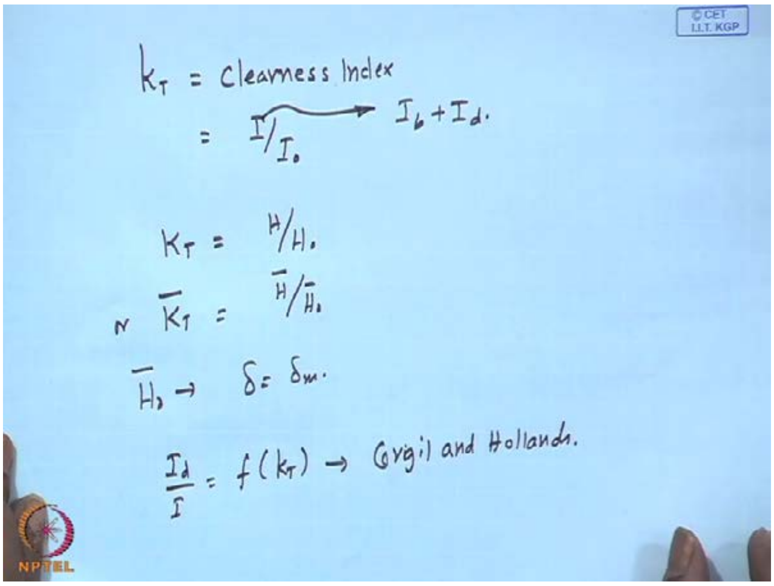

And key in gradient is the cleanness index K T on a hourly times square it is I by I 0 I is the component measured on the terrestrial which will comes to stop the direct radiation plus the defused radiation or you can visit upon the day which upon is H upon H 0 or K T bar the monthly average daily value H bar upon H 0 bar. And this H 0 bar will be calculated with delta equal to delta m where the recommended mean declaration values are given in the books or in case you do not remember or you are supplied you can use the mid day of the month for calculating delta mean. So, you have got first off all a I d by I a functional of clearness index due to Orgil and Hollands, Orgil and Hollands. Now, you might be wondering what is the purpose of these things why? Why should we have this relation when we have I d and I most of the time.

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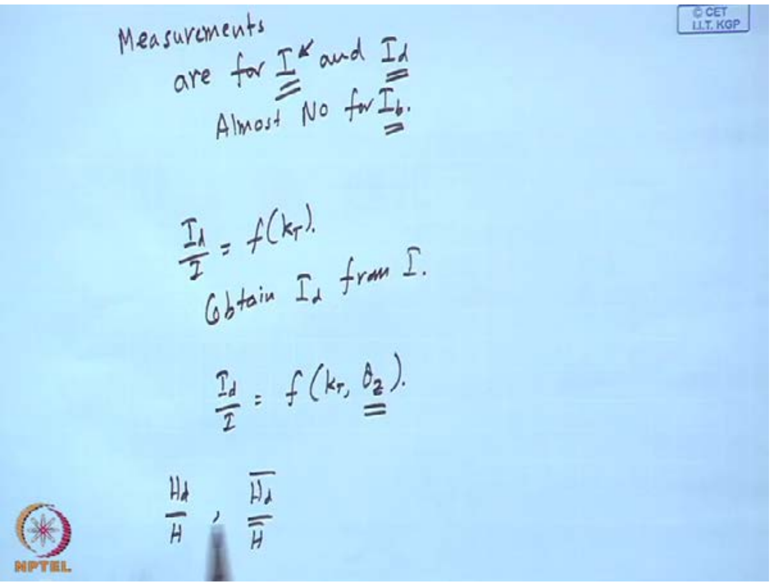

The measurements or and I d almost no for I b the direct radiation if you want to measure you should align it with the direction of the suns ray and have a tracking mechanism and any small error in the tracking is likely to lead to a larger error. So, what is normally done is measure the global or the total radiation and the defuse radiation which can be obtained by shading the direct radiation part of it. And if this is not available only if this is available then my correlation for I d by I as a functional the clearness index K T will help me obtain I d from I. So, you can generate the defuse radiation component from the global radiation if you have a correlation and apparently orgil and hollands correlation in term of the hourly clearness index is reasonably good.

Though there are improvements over this which contained I d by I a function of K T and may be theta z at that particular hour. So, people try to distinguish what is the path that the sun’s rays will travel through this angle of incidence which will depend upon the session and the location.

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Recall, $(K_T = H/H_o)$

$$\frac{H_d}{H}\begin{cases} = 0.99 & for \quad K_T \le 0.17 \\ = 1.188 - 2.272\,K_T + 9.473\,K_T^2 - 21.865\,K_T^3 + 14.648\,K_T^4 & for \quad 0.17 < K_T < 0.75 \\ = -0.54\,K_T + 0.632 & for \quad 0.75 < K_T < 0.80 \\ = 0.2 & for \quad K_T \ge 0.80 \end{cases}$$

Recall, $\overline{K}_T = \overline{H} / \overline{H}_o$

So, collares pereira and rabl they have given the relation for the daily defuse fraction and the monthly average daily defuse fraction H d by H bar and H d bar by H bar . So, these relations I have shown over here H d by H and then the next one.

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$$\frac{\overline{H}_d}{\overline{H}} = 0.775 + 0.00653(\omega_s - 90) - [0.505 + 0.00455(\omega_s - 90)]\cos[115\overline{K}_T - 103]$$

Liu and Jordan [8]

$$r_d = I_d / H_d$$

$$r_d = \frac{I_d}{H_d} = \frac{\pi}{24} \frac{\cos\omega - \cos\omega_s}{\sin\omega_s - (2\pi\omega_s/360)\cos\omega_s}$$

Collares-Pereira and Rabl [7]

$$r_t = I / H$$

Is in term of H d bar by H bar which is the function of clearness index for the month K T bar. And then, The detail of radiation.

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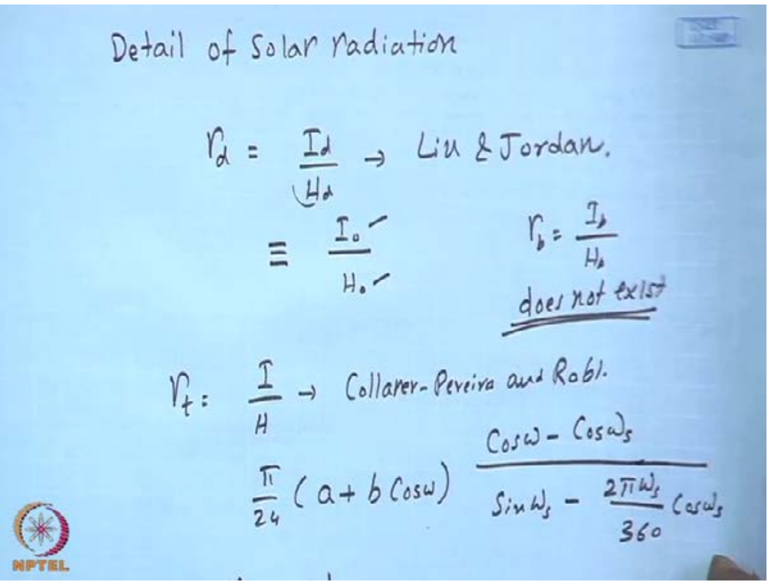

So, these correlations one should understand that they are developed if you do not have the data detailed how to generate some data which will mimic the tries to made make at least in reasonable error limits the actual data or it may be extremely convenient to computer implement. So, your r d first is due to I d by H d liu and jordan. So, it is nothing, but I d by H d given in terms this your relation phi by 24 cos omega minus cos omega s into this much. And by the way this is also identically equal to I 0 by H 0 if you take the extra terrestrial radiation and the corresponding daily extra density radiation that will turn out to be the same relation though it is a surprising thing how the extra terrestrial radiation which is comprises of purely direct radiation is. So, well correlated to the defuse radiation and not to the direct radiation nobody talks about something like r b equal to I b by H b does not exist. May be ,Because the measurements are I b are limited that could be a reason then r t similarly is I by H develop by collares pereira and rabl.

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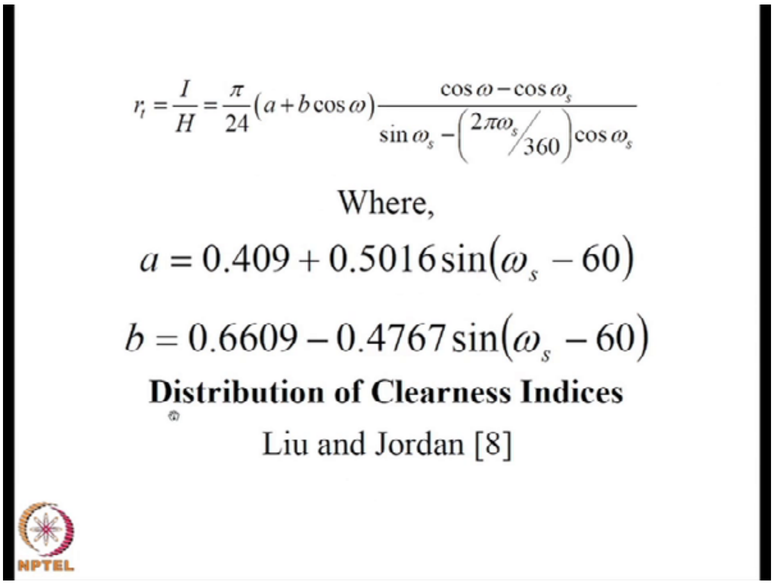

So, this is in addition to the same term of I d by H d you have got in terms of pi by 24 times a plus b cos omega times cos omega minus cos omega s up on sin omega s minus 2 phi omega s by 360 cos omega s. And you should remember omega s is n degrees.

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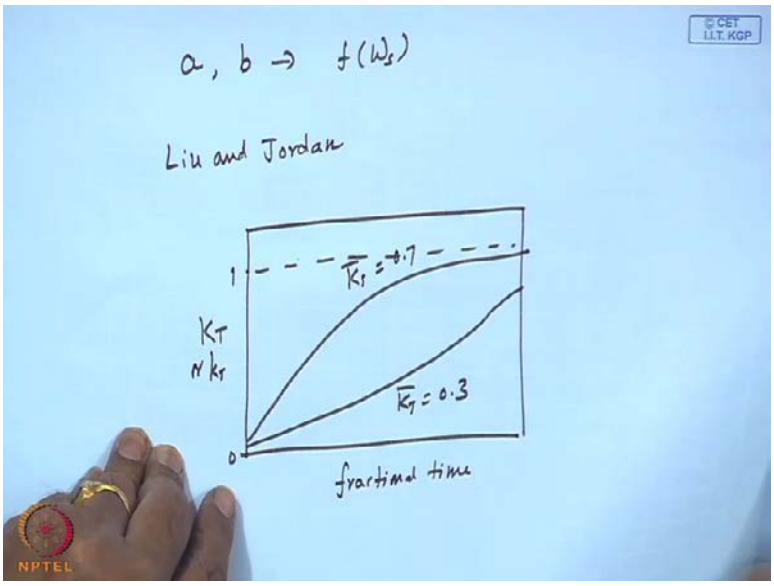

And the constants a and b are in terms of functional of omega s you know the day length a inter influences r t then like any statistical distribution liu and jordan again.

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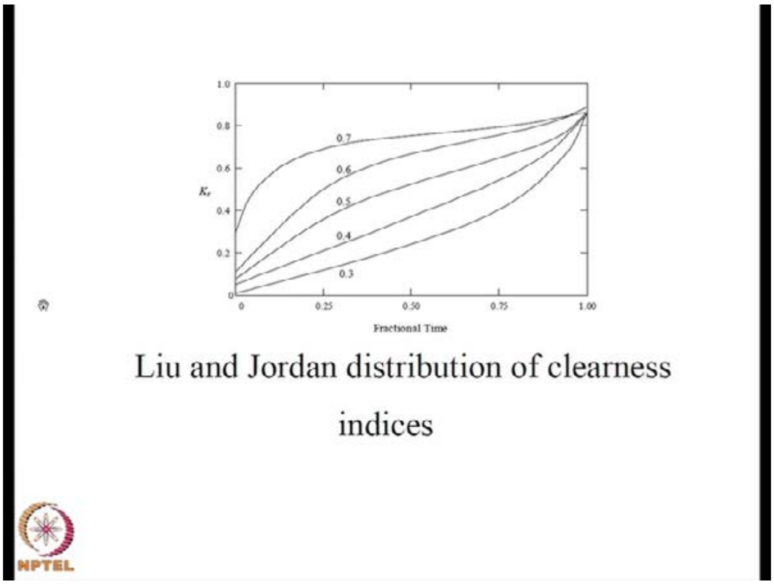

So, they have given cumulative frequency or fractional time verses K T daily or hourly or I will write small K T. This is for K T bar equal to 0.3 this may be for K T bar equal to 0.7 this may be approximately one and this is 0. So, what basically it means is if you take a month for example, there are 31 days or 30 days. So, you have daily clearness indexes.

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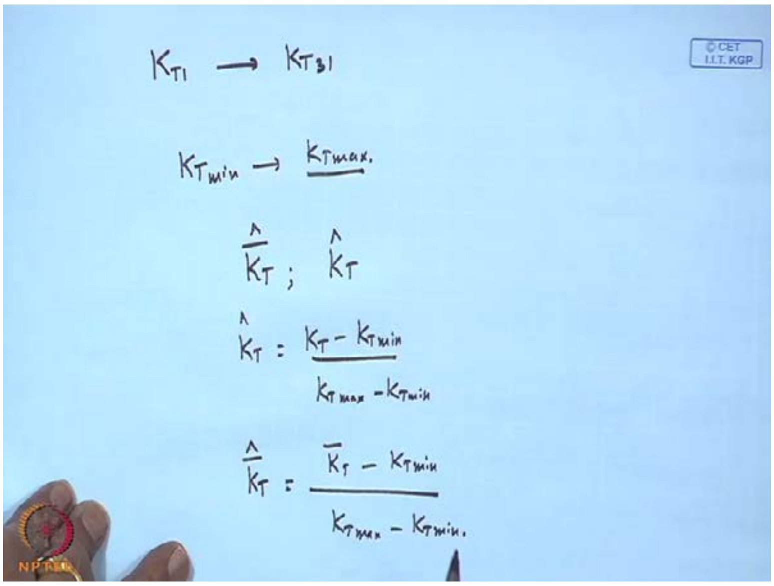

K T 1 to K T 31. So, I can it is not necessary the first of the day of the month is the lowest, but there are 31 values out of which I have got changes from K T minimum to some K T maximum. So, If you the cumulative frequency can be defined as refractional time or the number of days of below which a particular value of clearness index occurs. So, for example, If K T max is there all the days will have clearness index less than K T max. And if K T minimum is there there are no days with K T less than K T minimum that corresponds to that fractional time being 0 and this corresponds to fractional time being one. So, it is something like your marks in the class if there are 100 students or. So, and less than 10 percent there may be 20 fellows and less than 30 percent there be another 10 percent fellows and less then 90 percent everybody may be there.

So, if you plot that that will give you the. So, called occurrence of cumulative frequency or the fractional time or fractional distribution. So, these curves are develop with the north Indian north American locations and they are more or less acceptable for quite a few climates although there have been number of reports which show that they do not work for obstruction climate for such certain climate. So, In fact, our own investigation we used a K T bar cap and a K T cap which will be defined as K T minus K T minimum by K T max minus K T minimum. Similarly K T bar cap will be K T bar minus K T minimum up on K T max minus K T minimum. So, the x axis remains the same

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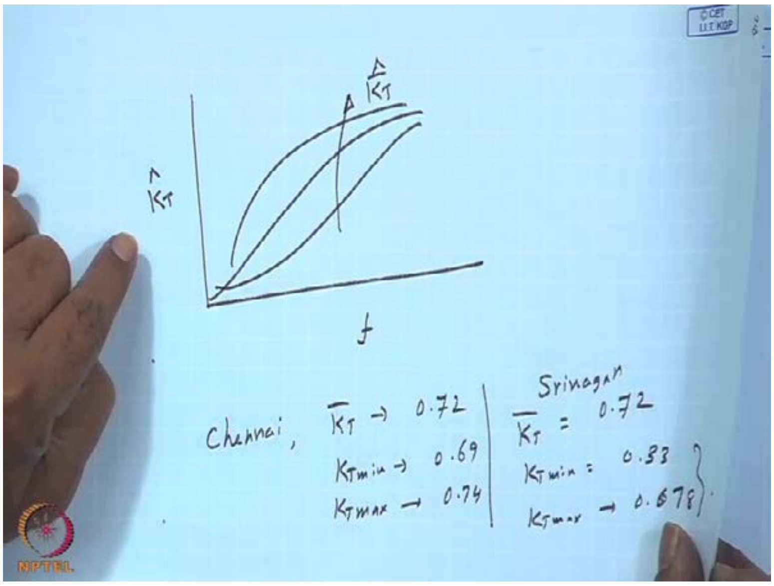

Fractional time f and you have got a K T cap over here and the function they looks similar or this is K T bar cap. So, what we tried to bring in here is by putting that K T minimum and K T maximum in defining this modified variables you are taking that location specific characteristic for example, If you have a Chennai and if you have the average clearness index of let us say 0.72 in summer and K T min may be 0.69 K T max may be just 74 against for example, you have a let us say srinagar assuming K T bar in some month is 0.72 this may have a K T min of 0.33 and K T max of point should be more then that 78 particular day. So, you have got a large swing if the location is different compare to a low latitude location at chennai. So, this will taken care of in this type of plots where as liu and jordans will not in general accommodate the varying low and varying high clearness indexes for a given average.

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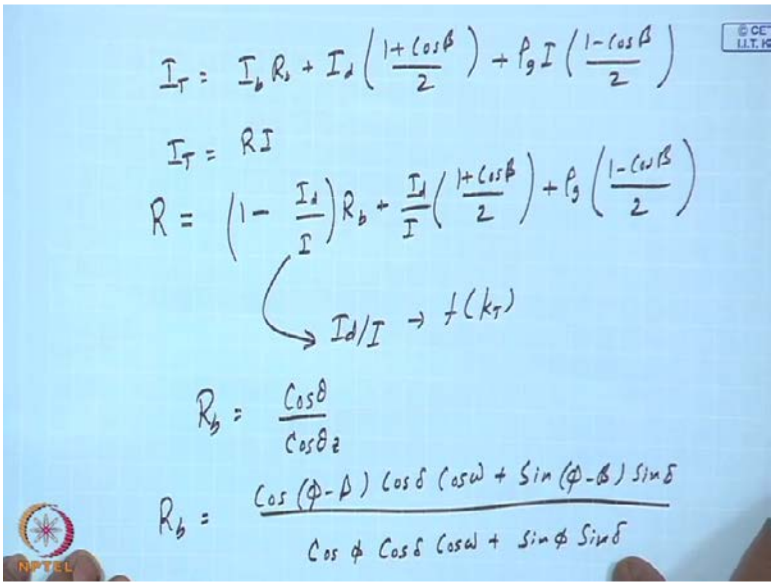

So, we tried to express the solar radiation on a tilted surface as consisting of the direct radiation plus the sky defuse radiation plus the ground refracted radiation and of course, over all factor are if I T is equal R into I can be rewritten as 1 minus I d by I though it is a simple relation I chose to show this and the summary which is specific idea which follows. You should see that everything is written in terms of I d by I which are correlated to clearness index. So, if you have a measurement of only I and then the use of the correlation of I d by I or H d by H is very much understood. Then this R b is cos theta by cos theta z which of course.

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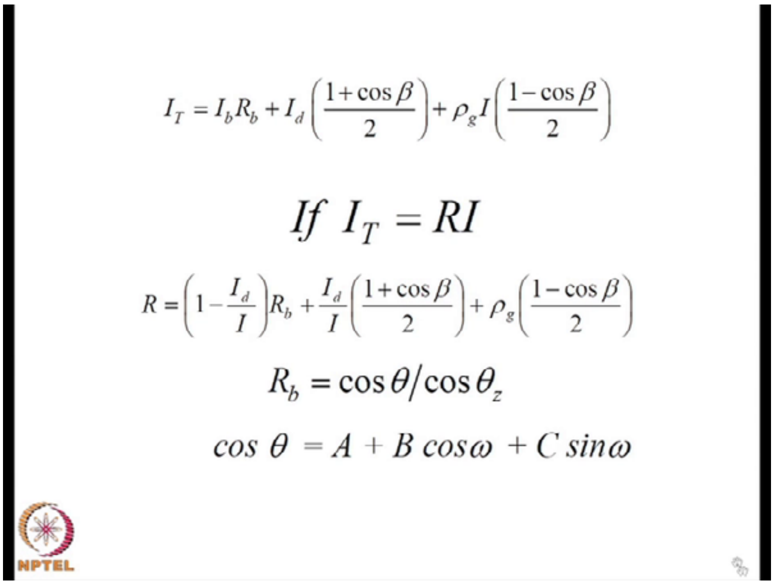

Where you have got your cos theta is A plus B cos omega plus C sin omega as we have already explained.

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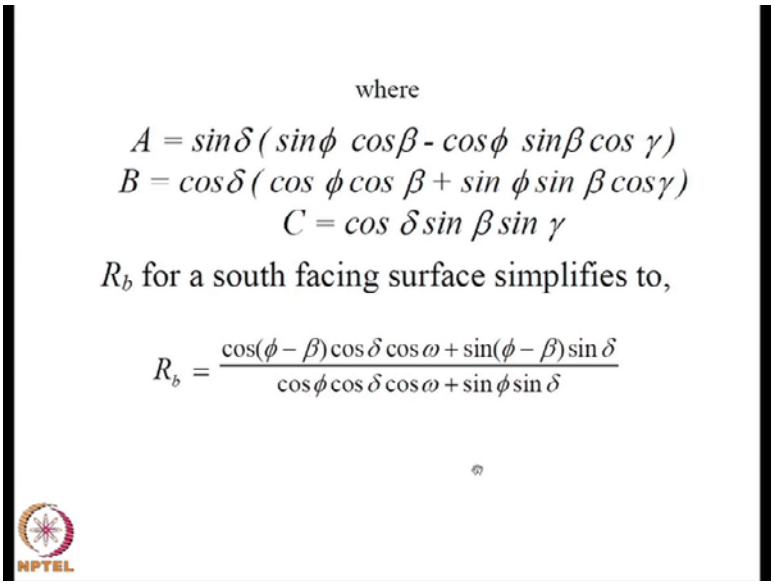

And then where A B C are given and R b for a south facing surface is simple like R b equal to cos phi minus beta cos delta cos omega plus sin phi minus beta sin delta by cos theta z which is cos phi cos delta cos omega plus sin phi sin delta. So, these relations are I am giving it again and again. So, that you should become familiar not be just afraid to look at long expressions there is logic the way we write it the way we develop it and if you pick up that you shall be able to remember also.

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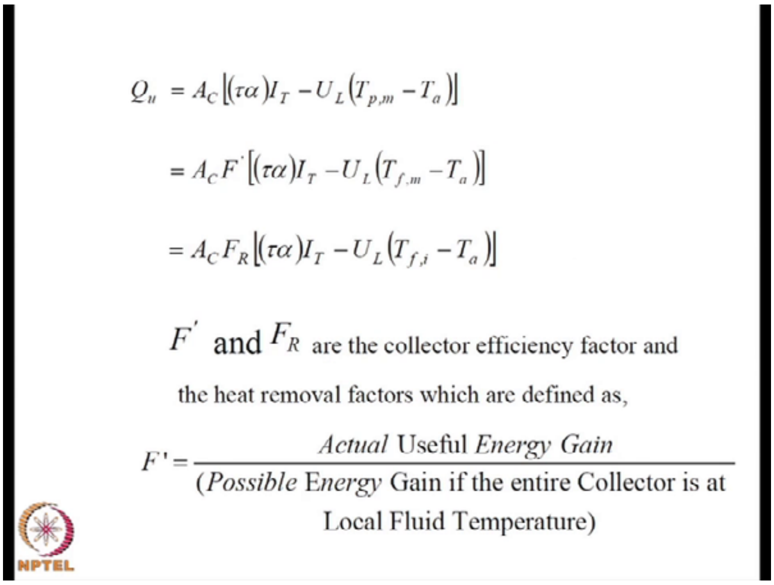

Though it is not necessary you should have them by heart, but you should be able to no the functions of it.

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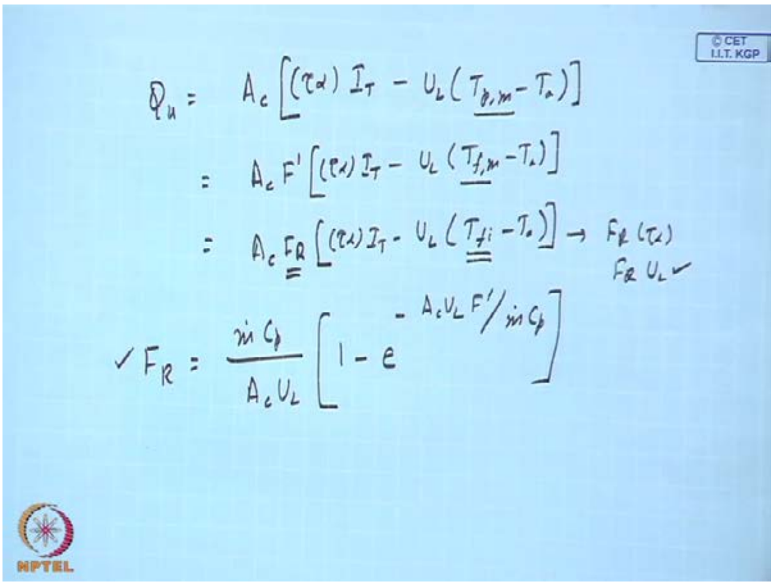

Then from a solar energy collector useful energy gain is a expressed in terms of course, the area the optical efficiency are the transmitters of certain product the radiation falling at the collector minus the losses evaluated between mean tray temperature and the ambient temperature ultimately this has been rewritten in terms of the collector efficiency factor minus the losses evaluated from the mean fluid temperature or in terms of the heat removal factor tau alpha times I T minus U L into T f i minus T a. So, by putting everything in terms of f R I am able to have a single point temperature. So, that there is no possibility of a miss interpretation or miss understanding or miss calculation of T f m or T p m. So, you have got f dash is the collector efficiency factor mind U it is not the collect efficiency and A F R is the heat removal factor.

Which have been defined in terms of the actual useful energy gain to the possible energy gain if the entire collector is at local fluid temperature that is F dash.

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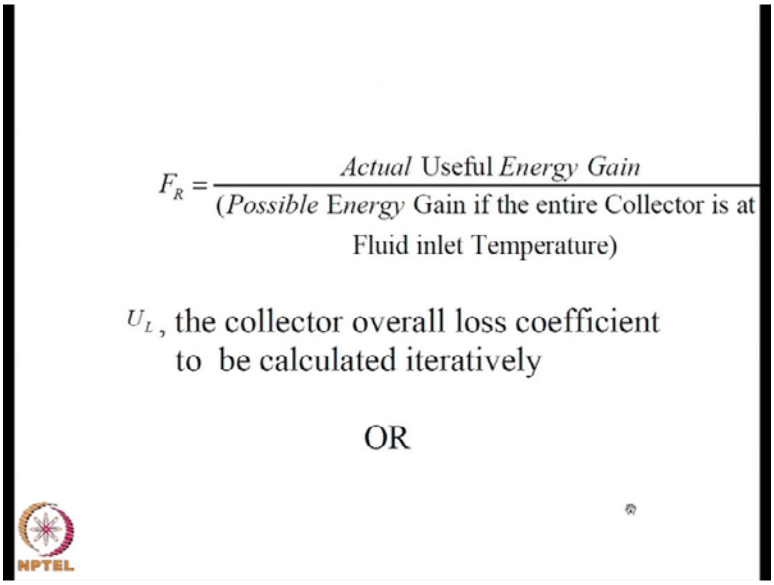

And your heat removal factor F R is the actual useful energy gain by possible energy gain if the entire collector is at the fluid inlet temperature in other words the losses cannot be lower than that corresponding to the inlet temperature and if anybody gives more value than that you can find out that the measurements are not been right and U L is the collector overall loss coefficient which needs to be calculated iteratively you assume a plate temperature T p and then guess a cover temperature or for a given plate temperature guess a cover temperature calculate the losses and those losses should be equal to whatever is the loss from the glass cover also. , you can alternately calculate the overall loss coefficient by first estimating the top loss coefficient duty a long expression.

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$$U_t = \left\{ \frac{N}{\frac{C}{T_{p,m}}\left[\frac{(T_{p,m} - T_a)}{(N+f)}\right]^{e}} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma(T_{p,m} + T_a)(T_{p,m}^2 + T_a^2)}{(\varepsilon_p + 0.00591Nh_w)^{-1} + \frac{2N + f - 1 + 0.133\varepsilon_p}{\varepsilon_g} - N}$$

where

N = Number of glass covers

$$f = (1 + 0.089h_w - 0.1166h_w\varepsilon_p)(1 + 0.07866N)$$

$$C = 520(1 - 0.000051\beta^2) \quad for\ 0^0 < \beta < 70^0.$$

This has been correlated by claim in terms of the number of glass covers the wind heat transform coefficient emissivity of the plan of the plate emissivity of the glass mean plate temperature ambient temperature and of course, Stephen Boltsman’s concept and where this f and c are again in terms of other quantities like beta the slope.

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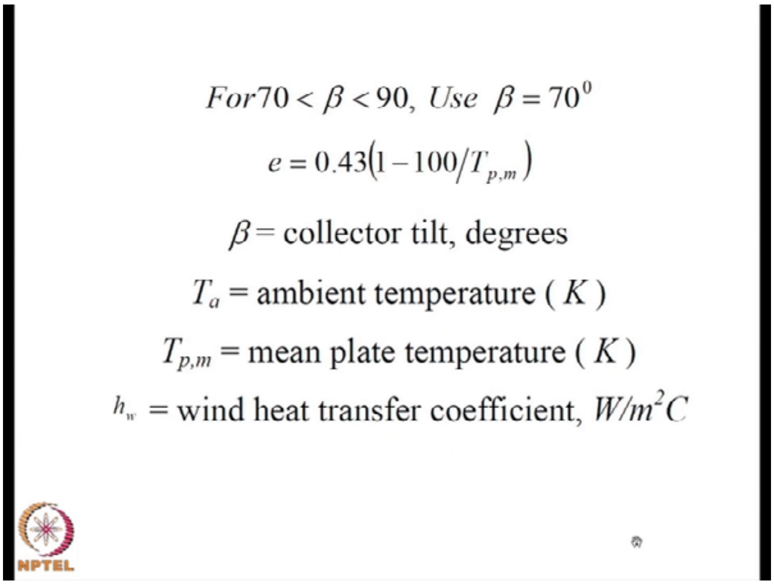

And everything is explained over here. So, this can be readily used and then you can calculate U t U L as U t plus U b the black loss coefficient which is nothing, but the resistance inverse of the conduction or the insulation kept at the bottom of the absorber plate.

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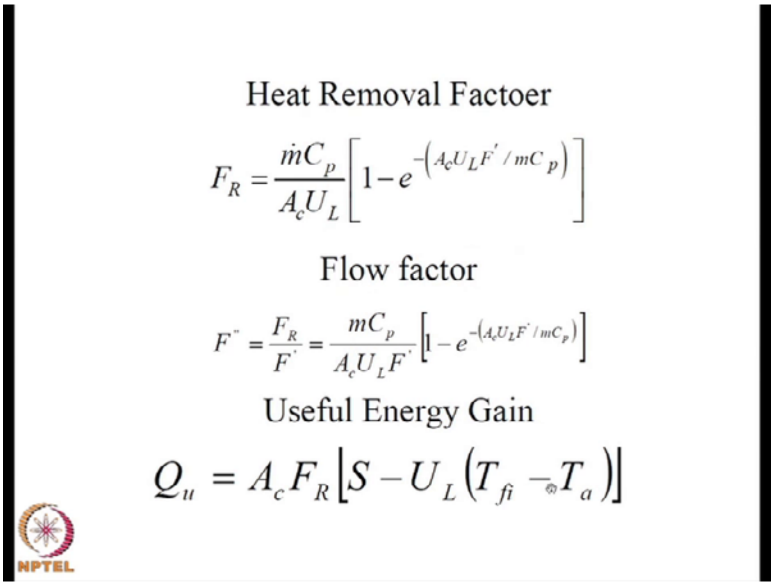

So, if you go through little bit of algebra we got a simple expression for the heat removal factor which I will give you a minute m dot C p A c U L times 1 minus exponential A c U L F dash by m dot C p. So, if you look at this equation my independent parameters are

F R tau alpha and F R U L. So, We know how to calculate U L. We know now how to calculate F R and tau alpha will be calculated later on. So, that your q u the useful energy gain is A c F R times s minus U L into T f i minus T a. So, that tau alpha yes we were talking about it and well it appears here.

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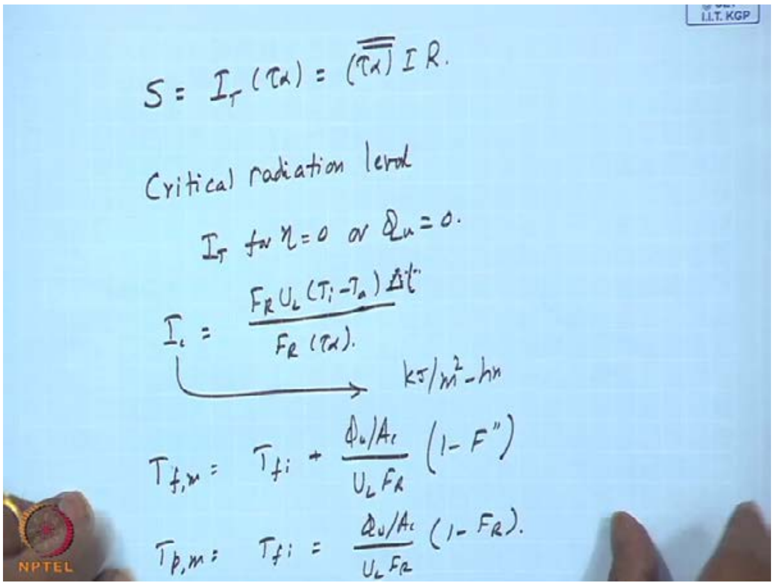

So, if s is the absorbed energy over a period of 1 hour let us say that should be equal to I T into tau alpha which is tau alpha into I into I into r. Now what we find is that this tau alpha comprises of the direct radiation component contributed by the plus the defuse radiation and the ground reflected radiation we will come to it little later and in the same context we define a critical radiation level which you know it has become very essential in calculating the utilizability which is basically you can say that I T for efficiency is equal to 0 or Q is equal to 0 which by equating Q expression you will got F R U L into T I minus T a by F R tau alpha. Once again I should remind you that there should be a hidden time factor delta T e because I do not know this will be watts and I c in general is kilo joules per meter square hour according to our notation. So, F R expression already we have given

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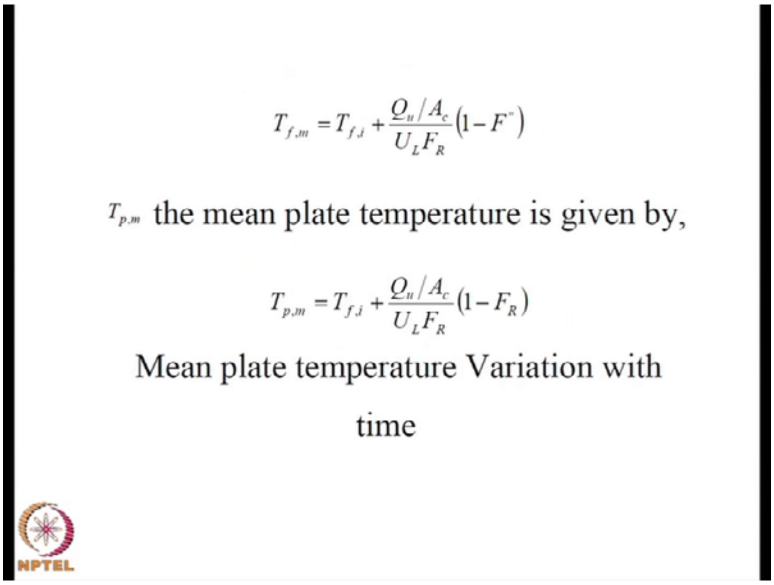

Now you can express fluid mean temperature T f m as T f i plus the Q u by A c it is only a rewriting of it not that you can really calculate by this equation you cannot do that unless you know Q u. and the plate temperature is T f i plus same thing Q u by A c by U L into F R times 1 minus F R .So, subsequently we have analyzed for a number of other configurations not just final tube, but different arrangements for the liquid based as well as the air based collectors.

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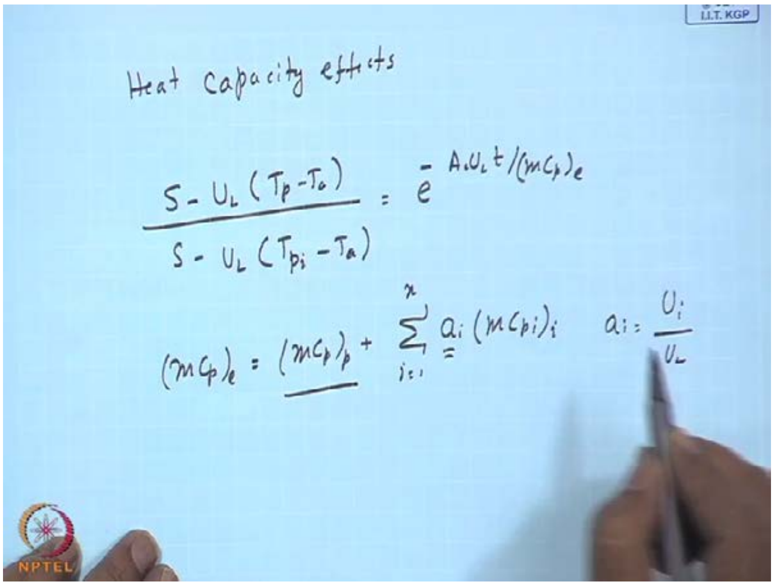

And we tried to take in to the account the heat capacity effect with certain approximations of the temperature of the plate T p varies with time as given by this equation if U L is the overall loss coefficient and T p i is the initial temperature and T a is the ambient temperature is related to e to the power minus A c you l time by m C p effective. And this m C p effective is m C p of the plate plus sigma a i m C p i i. So, I is equal to 1 to n. If there is n number of glass cover we are trying to convert that into an equivalent plate by putting that m C p effective is that of the m C p of the plate plus this is the ratio of the overall loss coefficient from the cover under the consideration to the ambient to the overall loss coefficient. So, a I is you I by U L.

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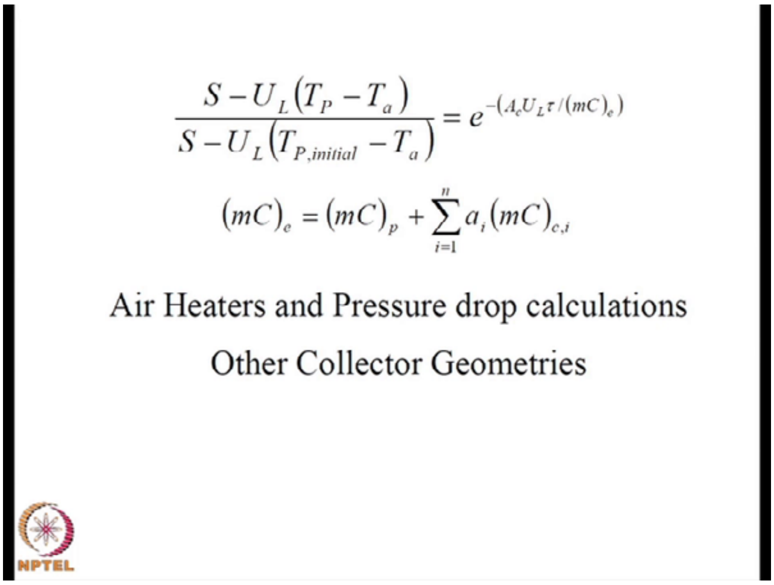

Then, For air heater pressure drop could be issue. So, we tried to give some formulae to calculate the pressure drop as if it is a duct which is quite and then the other geometries that tube can be below the absorber or above the absorber as we are shown over here in a tube arrangement or two that is what I call then. of course, The collector corresponding efficiency factor is given over here there will be slight variation compare to what you have for the first configuration that we have studied let me just seems to be. So, you have got the f dash.

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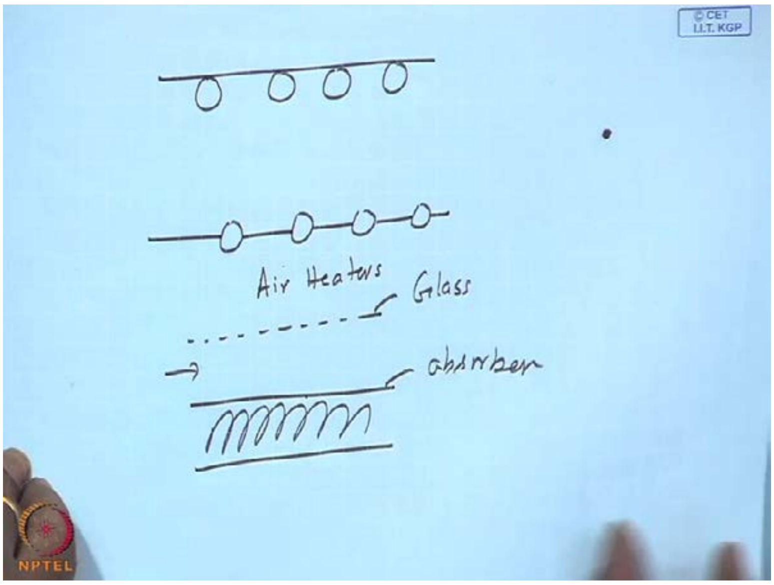

And very first configuration we studied was with the tubes below the absorber. And this one is above the absorber.

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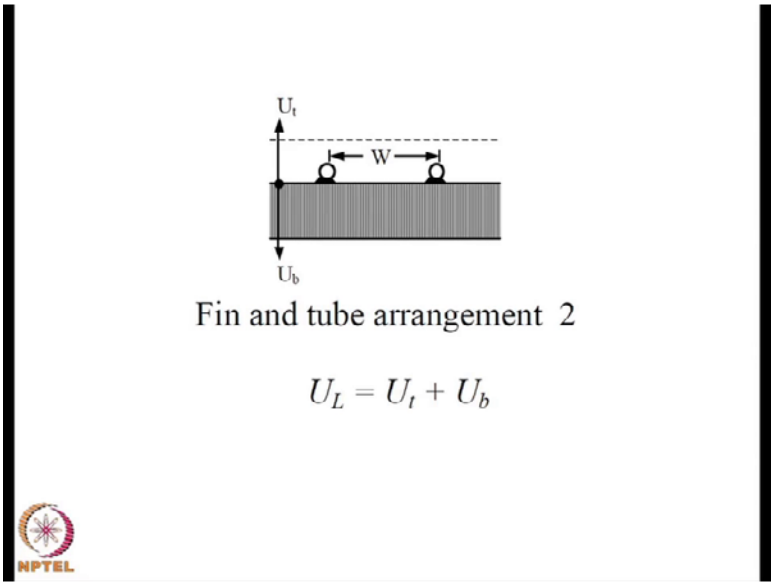

There are plus and minus points because some people argue that this tube will be absorbing directly the solar radiation, but some people also argue that it can directly loose also by emission.

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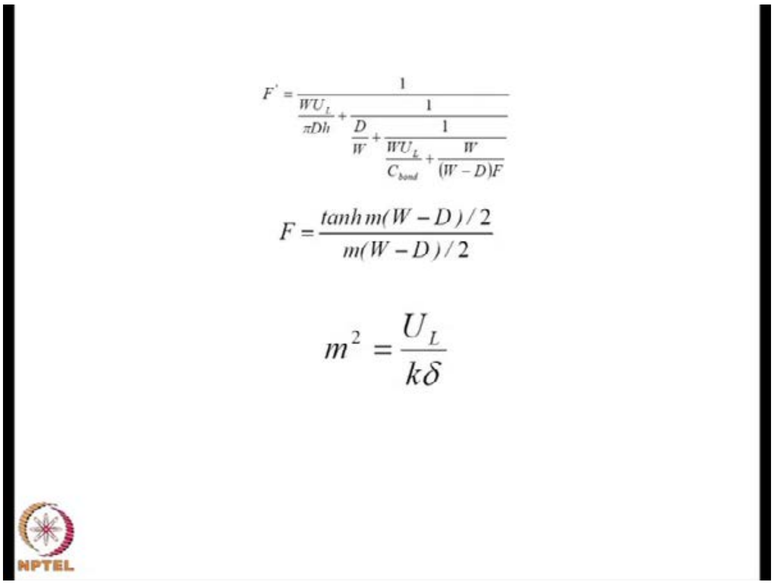

Basically it is a convenience of the manufacturing. And you have got of course, The classical half way. So, given your U L is always equal to the top plus the back loss coefficient in these arrangements.

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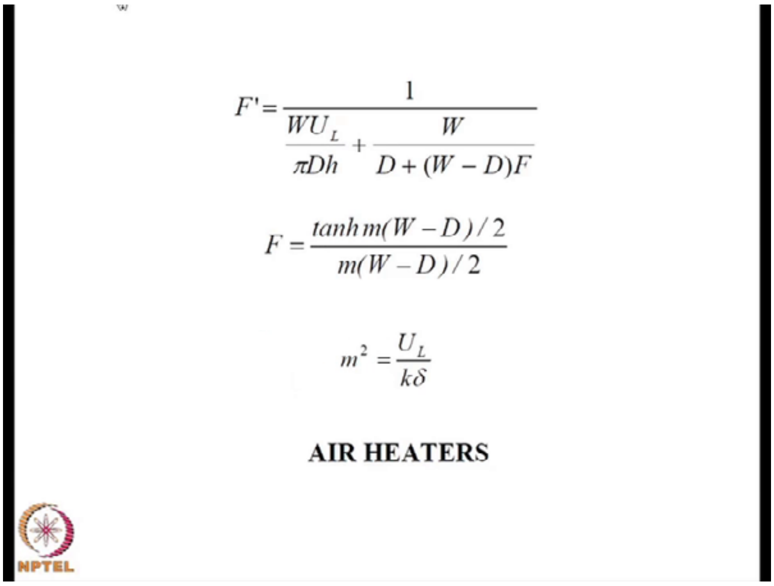

And I have again given there will be slight differences in the expression for F dash because how much of area indirectly this used and it is not and fine efficiency is the similar at an h m l by m l as you know from equation where your l is w minus D by 2. So, then considered the air heaters.

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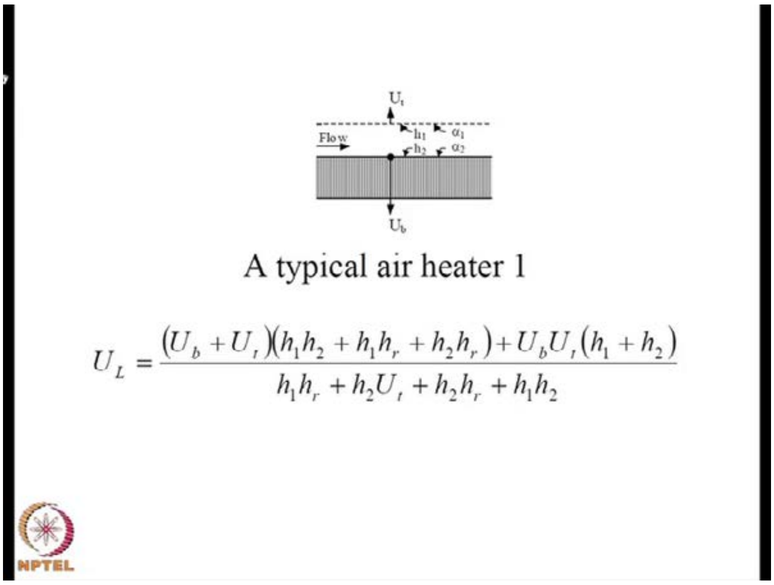

So, you can have a flow. insulated glass cover is the absorber the flow is between the absorber and the top glass cover. So, now, the hot fluid is directly in contact with the glass which loses for energy to the ambient consequently your. So, called over all loss coefficient U L is not a completely loss, but actually it goes the fluid two and you have expressed U L and if you put U b equal to 0 U L will not reduce to U t in this particular instance. And collector efficiency factor then the radioactive heat transfer coefficient the next one is a regular duct.

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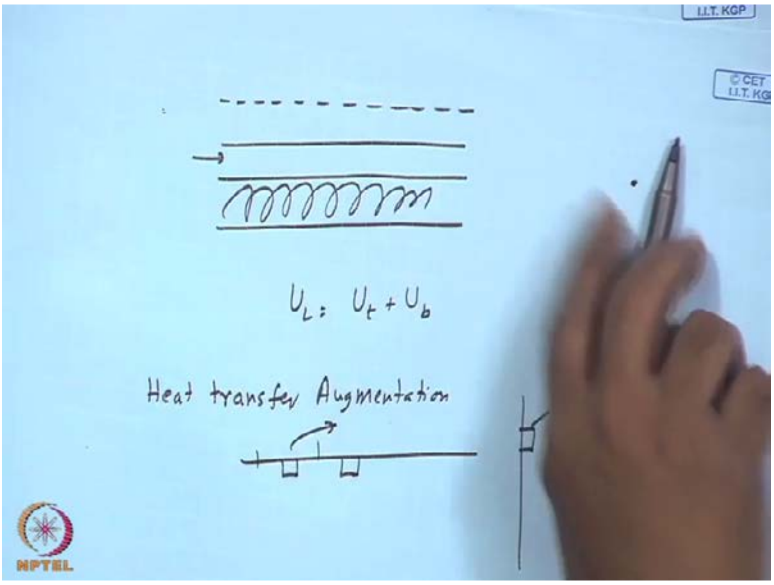

You have the glass cover and the duct through which the flows and of course, you have insulation. So, here is U L equal to U t plus U b. So, there are no issues. So, you have that a F dash efficiency factor and the radioactive heat transfer coefficient. And this is to have a heat transfer augmentation particularly for air collectors people provide sort of.

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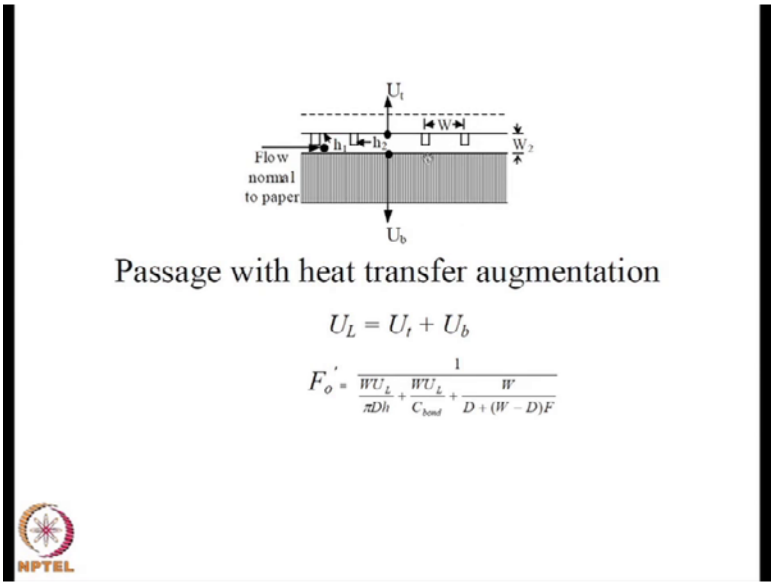

Corrugation or the paths in between. So, this will break the sort of boundary layer or mix the hot and cold fluids from the bottom and the top between the duct thereby improving the heat transfer between the fluid and the absorber plate. So, this is analyzing terms of the spacing h 1 and h 2 are the heat transfer coefficient and the expressions are over here.

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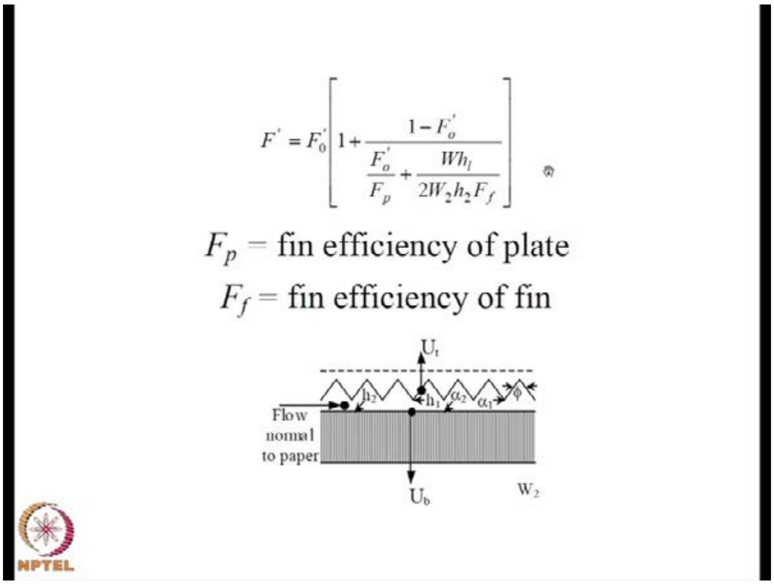

So, now, you can define the fin efficiency of the plate and fin efficiency of the fin because when I talk about these two this the fin efficiency of the plate and if you take this as a fin this is the fin efficiency of the fin. Now, people try to improve the heat transfer characteristics particularly for the air arrangement by having the flow through a corrugated sheet.

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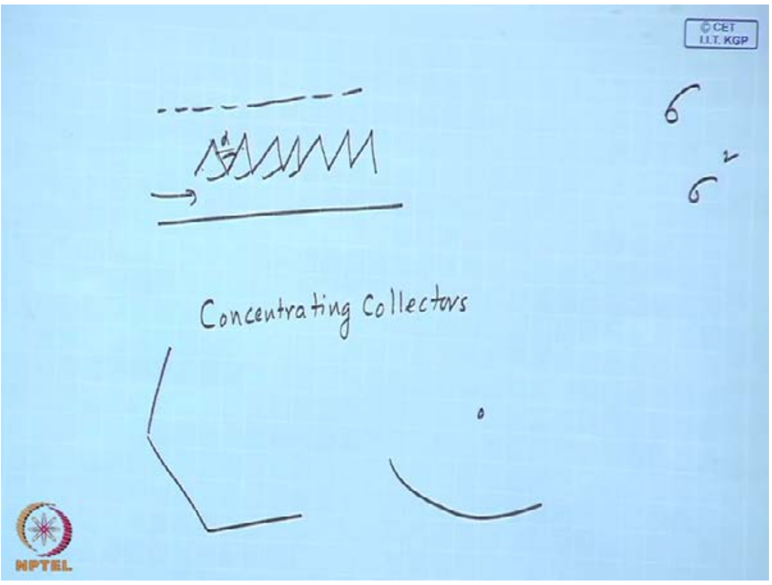

So, if you have a corrugated sheet like this of course, like the configurations we have discussed it can be through this or it can be through the top and there may be a glass cover what this corrugated sheet does is effectively it will have a higher absorptions because there will be re reflection between this two surfaces, but then high absorption also follows by high emissivity though that is at a lower temperature consequently still the gain may be little more than the loss and, But, provides a much larger area for heat transfer and then continues to the boundary layers are broken by this corrugations.

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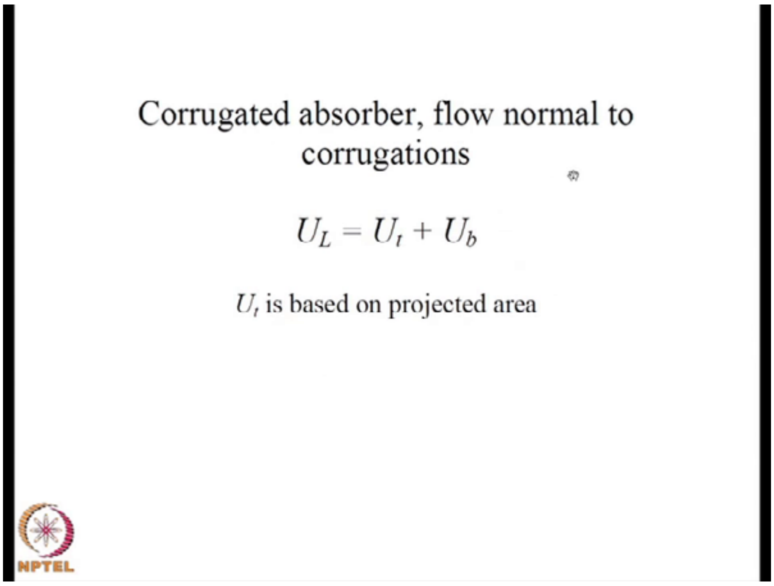

So, here also its not directly coming in contact with a heat losing surface. So, U L equal to U t plus U b. So, this is a insight the tube which we have done then f dash the collector efficiency factor is given on here.

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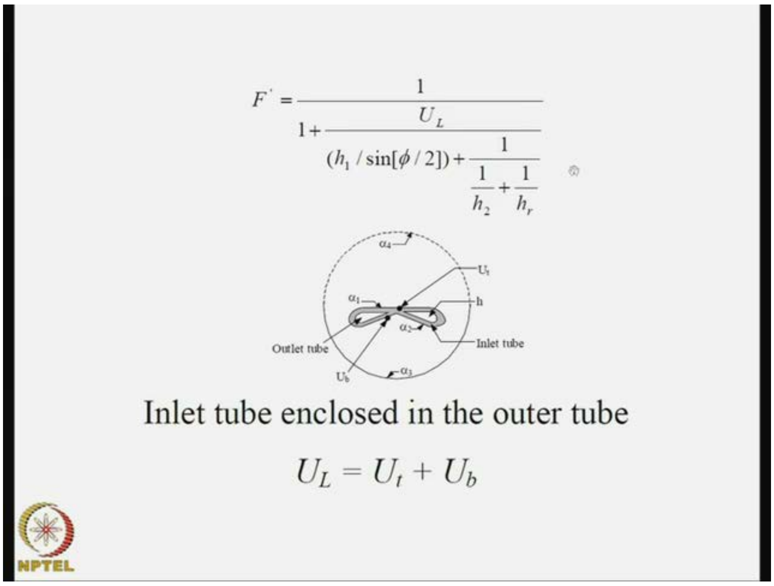

So, this is a insight the tube which we have done then f dash the collector efficiency factor is given on here.

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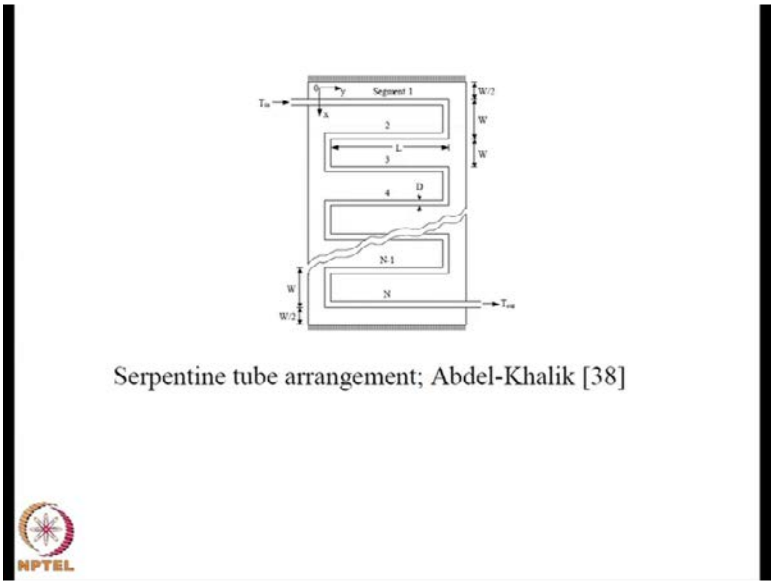

Given over here serpentine tube arrangement the advantages it had got the fin efficiency plus also at the of the pressure drop though the entire fluid will be going through the pipe. There by your heat transfer characteristics may be better though there will be additional a pressure drop also this is done by Abdul Khalik. So, these relations we have given in detail in the class notes on the earlier lectures.

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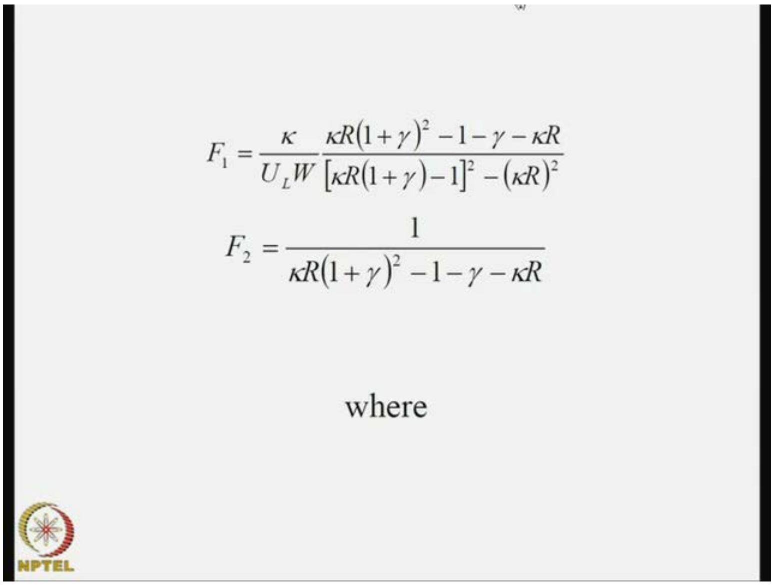

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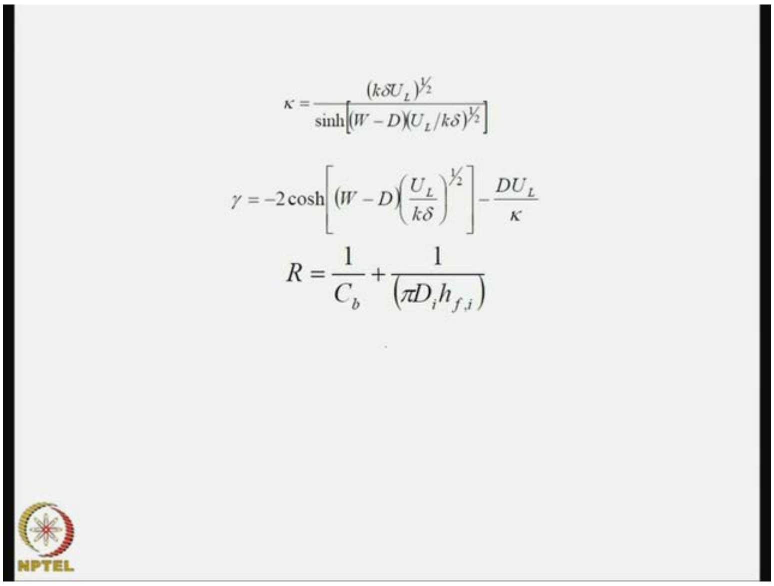

So, these relations we have given in detail in the class notes on the earlier lectures.

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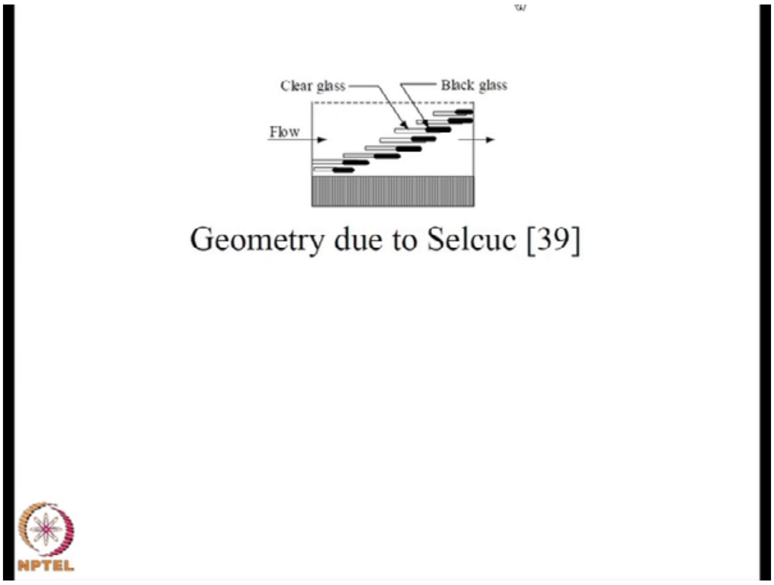

This is once again a large surface area are trying to mix the hot and the cold fluids a geometry due to Selcuc.

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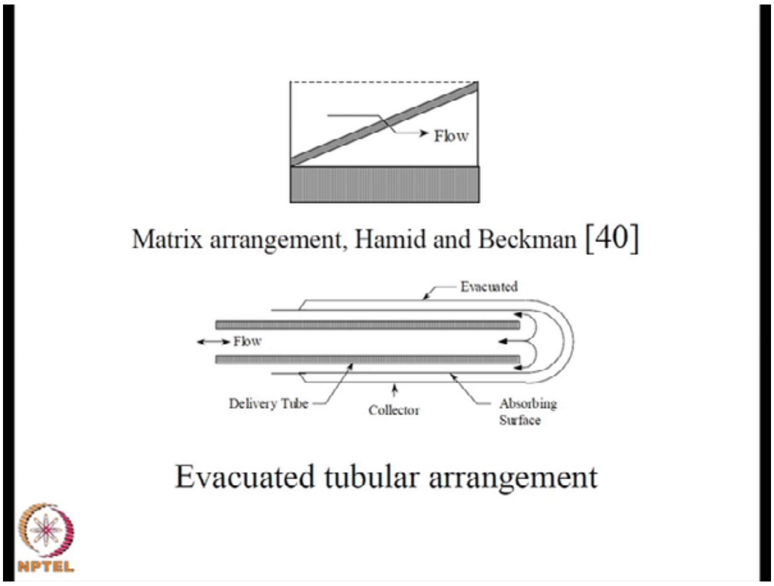

Then a matrix arrangement has been suggested by Hamid and Beckman and of course, the advantage here is the flow goes to this matrix. like some sort of a Porus medium having a large exposed area for heat transfer though the pressure drop would be higher and this is what we are comparing the. So, called evacuated tubular arrangement when we are considering the economics the cost per tube or the evacuated tubular arrangement verses the flat plate collectors. So, then we went through concentrating collectors. So, there are different.

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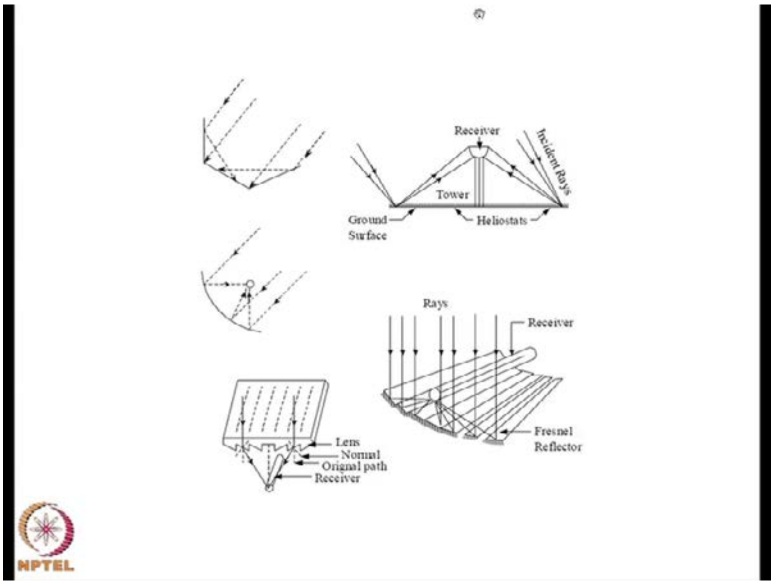

Concentration methods which you may find it here is simple rather they are something like two boosters and then you may have the central receiver concept or a parabola idol dish at the focal point being the receiver and the Fresnel lens or a Fresnel reflector. So, the necessary condition for a concentrating collector is they need to be tracked.

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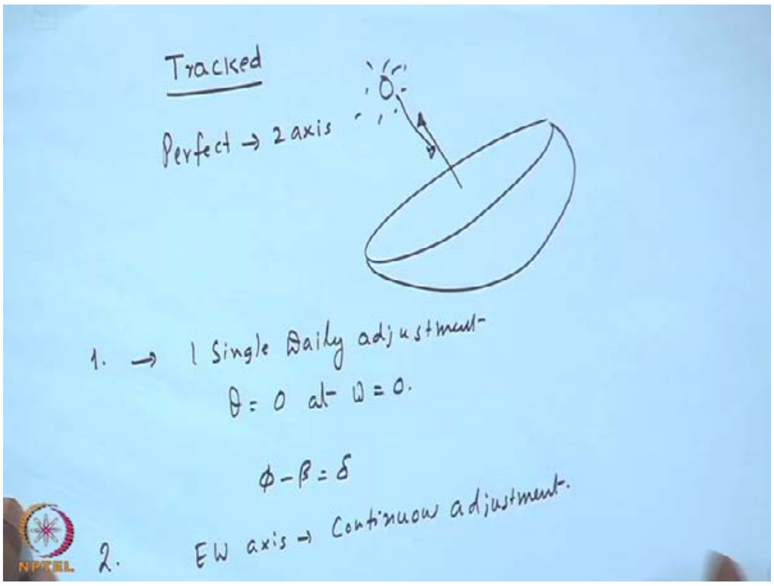

In other words there should be pointing towards the sun prefect is 2 axis So, if you have got a parabolic dish and here is the sun and the outer normal is always in line with the sun's rays. So, that requires moving from east to west as well as swilling around a north south axis other simpler Tracking's could be first mode which is one single daily adjustment. such that theta is equal to 0 at solar noon omega is equal to 0. So, that gives a simpler expression for this gives the condition phi minus beta should be equal to delta.

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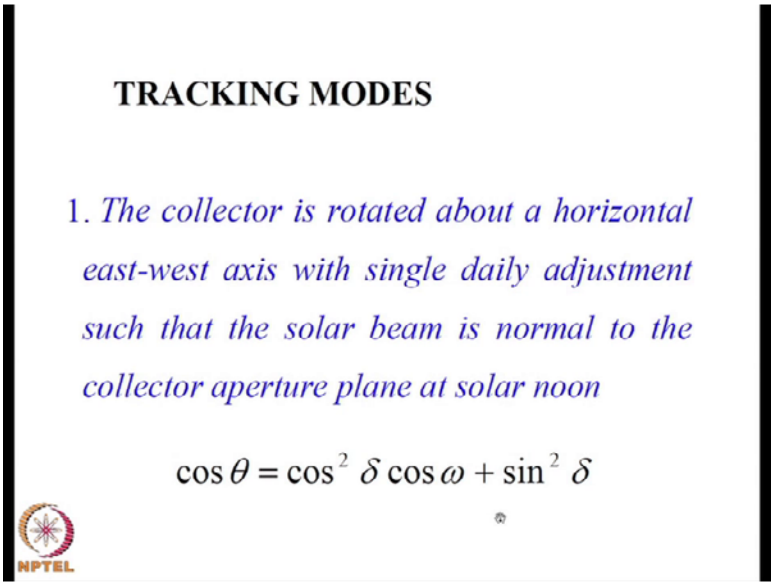

And you have got cosine theta a simpler expression. Then whatever we have for this is essentially it is a flat plate turned towards south with a particular Dec beta changing from day to day depending upon phi minus beta is equal to delta.

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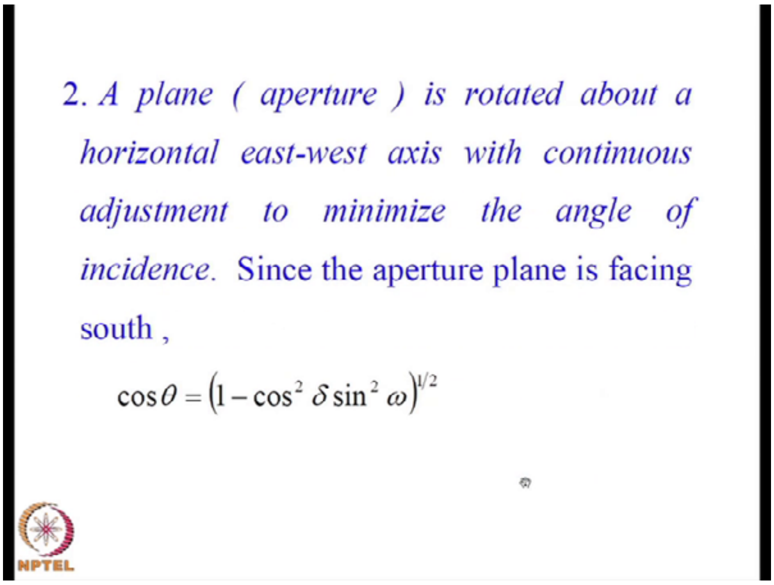

Then this is again same thing, but I want to minimize at every instance. So, that my beta will be changing continuously throughout the day and you have got a cos theta. So, east west access with continuous adjustment. So, this requires a continuous adjustment throughout the day and of course, you can design derive the expression for beta and cosine theta expression is given here for this mode. And then you have got the third mode.

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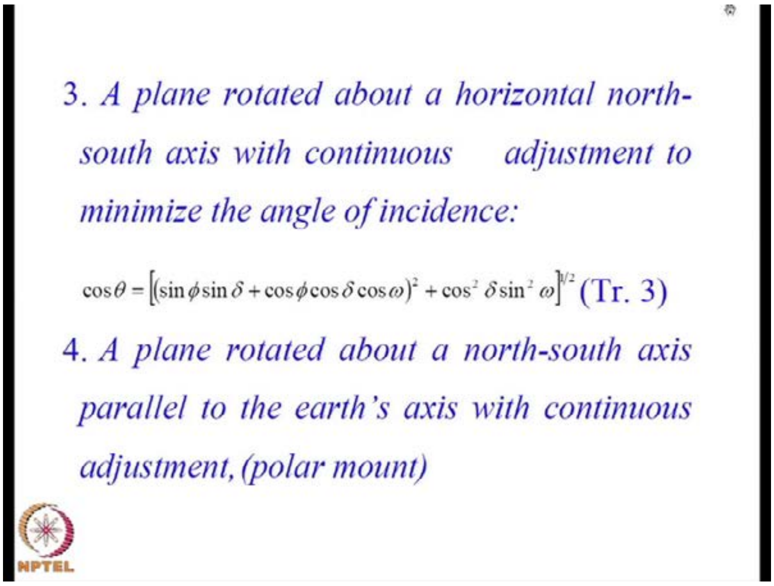

A north south horizontal axis which will have the cosine theta in this particular form this once again you can read as for the third mode.

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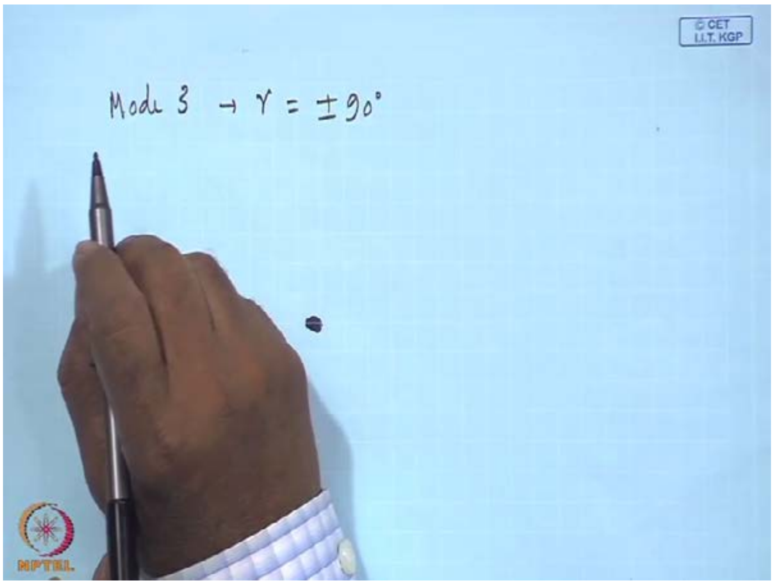

Mode three you choose gamma is equal to plus or minus 90 degrees depending upon the four noon or the afternoon because it is whenever it is facing rotate it from east to west on a north south axis until forenoon or the noon it will be gamma minus nineteen and after noon it will be gamma is equal to plus 90. Then, the polar mount you have got it is as if the collector is rotating along with the earth.

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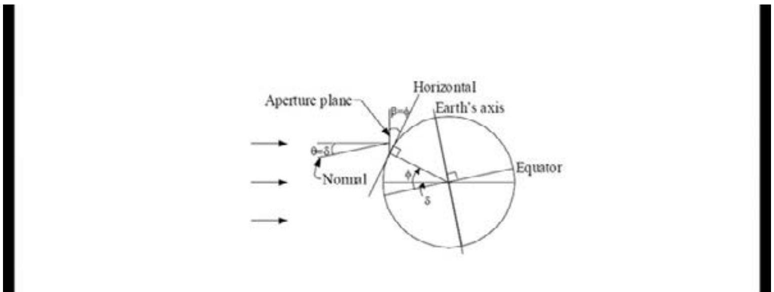

$$\cos\theta = \cos\delta$$

And cos theta is given by simply cos delta the figure is shown over here and you can see that depending upon the equator and the plane of rotation which differ by an angle delta my cos theta will be equal to cos delta. Which is pretty good compared to perfect tracking where you have got cos theta is equal to one.

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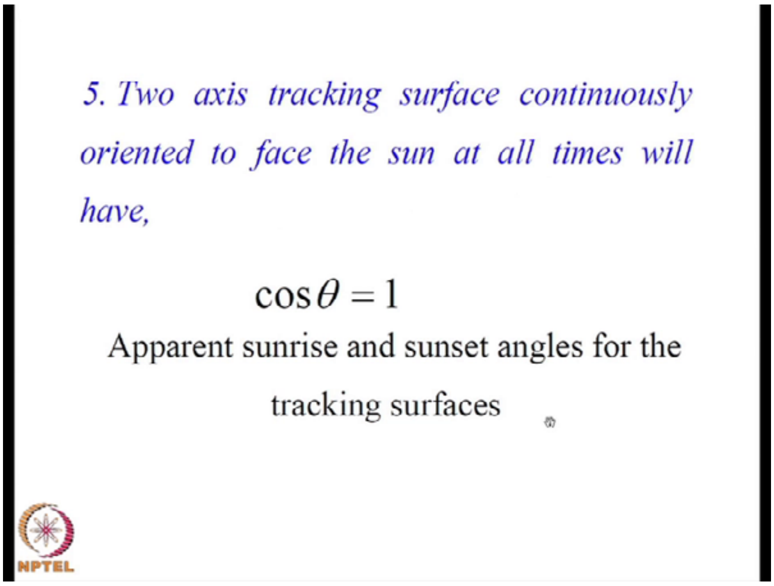

Because, delta maximum is only 23 degrees and which will be almost 0.95 or. So, consequently cos theta being about 0.95 or higher compared to cos theta being to equal to 1 that is not much of a loss in having its only single axis tracking compared to perfect to axis tracking. So, in all these cases we need to calculate the what I shall say the apparent sun rise and sun set hour angles for each mode

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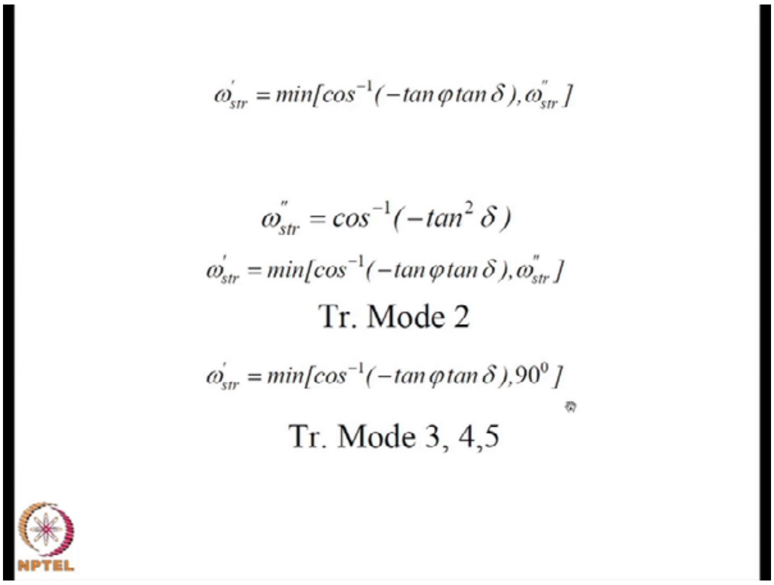

1 2 3 4 5 they are given by setting theta is equal to phi by 2 you will obtain those numbers.

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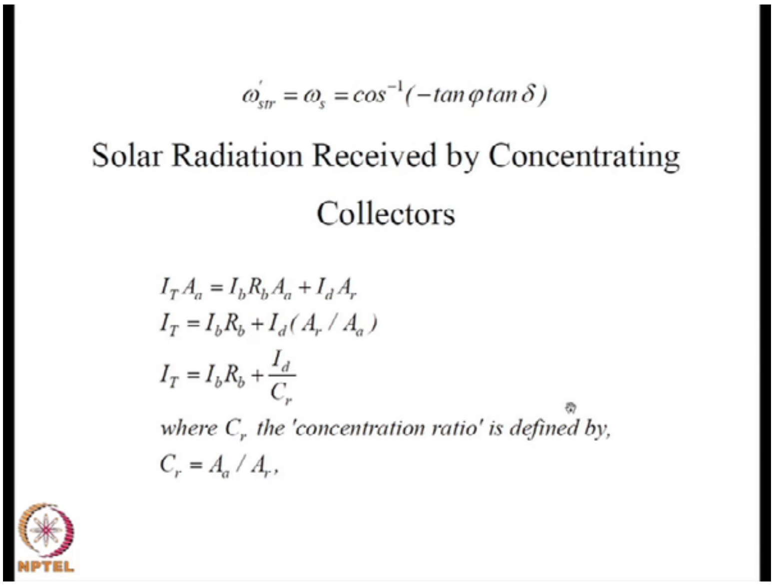

So, we shall continue with the remaining of the summary in the next class and I shall just go through the remaining relations. So, that you will be confident and these are all at one particular place for you. So, that we can always refer to them and once again my offer is open if you point out any mistakes they will be corrected and the correct answer will be I shall communicate to you. Thank you.