Solar Energy Technology
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Lecture – 30

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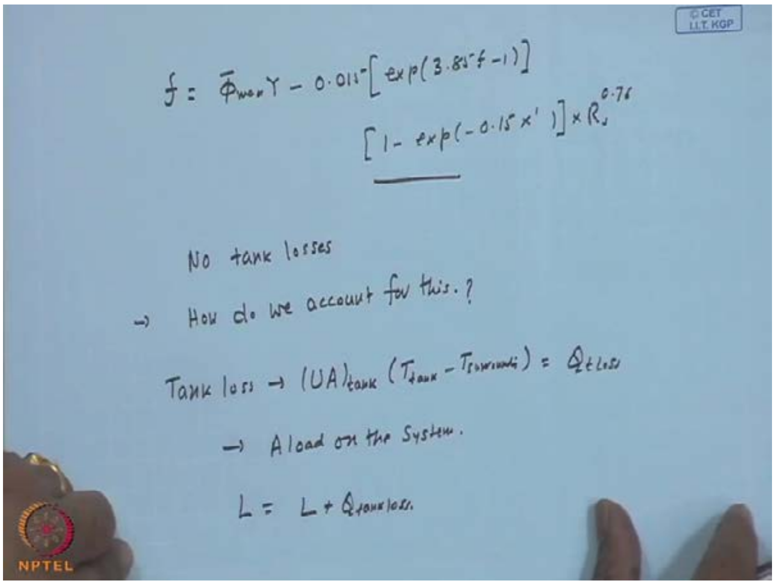

We shall continue with the phi bar of chart method and for the sake of continuity, the solar load fraction is given by phi bar max Y minus 0.015 exponential 3.85 f minus 1 times 1 minus exponential minus 0.15 x dash times R s to the power 0.76. I shall quickly go through. R s is the ratio of the stranded storage to the actual storage and solar load fraction, this correlation is an implicit relation and your (( )) which combines the solar radiation statistics to the operating parameters that to be evaluated, and all the collectors are in parallel and it operates at a constant critical level. Lastly, this assumes an infinity heat exchanger and no tank loses.

So, how to take care of the tank losses? How do we account for this? So, tank loss something like UA of the tank times T tank minus some T surroundings. As far as this, I may call it Q t loss. This is a load on the system. So, I shall change l to l plus Q tank loss.

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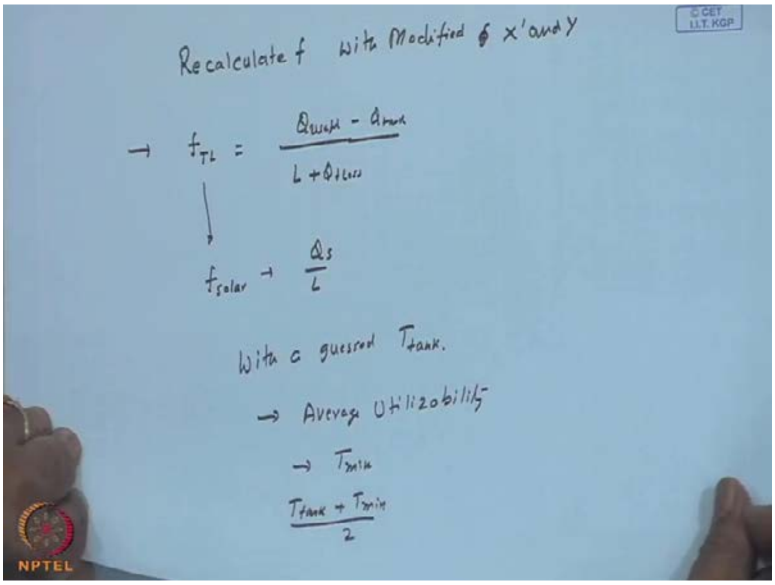

Then, re calculate f with modified x dash and y. So, the solar load fraction that will be obtaining with, this shall be, I will write as f T L. This actually can be written as in the low. I will have l plus Q tank loss and in the numerator, it will be Q useful going to the system, ok. Then, from this we should calculate f solar that is what is Q upon L which can be, and I am deliberately not giving the details here. The purpose will be best solved through an example. The basic philosophy of accounting for the tank losses is considered to be tank loss to be a load on the additional load on the system. So, the parameters x dash and y will change.

Now, the solar load fraction can be the load fraction calculated is inclusive of the tank losses, out of which we pick up the load that is going into or rather or whatever it is, minus Q tank loss that will be the one that close to the system. So, I can calculate what is Q s by l, right, but this is with a guessed T tank, right. So, this will correspond to some average utilizability. So that will correspond to set another T minimum.

So, the collector will be having an input something like T tank plus T minimum by 2. So, you iterate until the difference become small at to a point 1 degree at point north y degree, whatever is the accuracy you require. Let me repeat to take in to account to the tank losses. You assume a tank temperature from the manufactures classification, calculate the loss from the tank and guess 1 with T tank minus T surroundings into U a tank that is added to the load. So, now recalculate your x dash and y and obtain the load fraction. That will be load fraction, where the energy is going to beat not only the system load, but also the tank losses.

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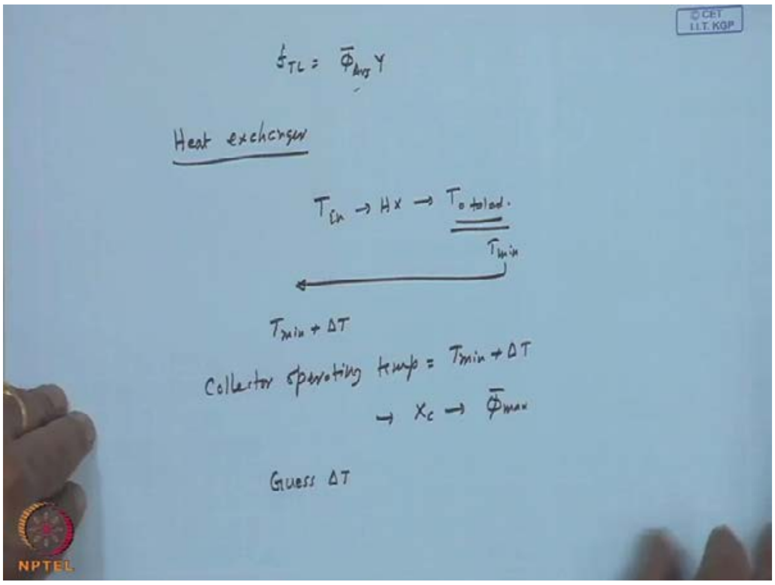

So, from that we need the solar load fraction correspond to that load fraction f TL. You have an average utilize. In other word, if I say that f TL is just like we have an equated phi bar max f TL is some phi bar average times y. So, this will be corresponding to average inlay temperature to the collector which will produce this utilizability and from there, the real will be something like the minimum of the temperature T minimum and the T tank or the average temperature. So, again T minimum plus T average by 2 and see whether, it is close to the initial guess or not.

How do you take to the heat exchanger? This also I shall only indicate if there is a heat exchanger, so that T in to the heat exchanger will come out to load. So, if this is to be at T minimum, ultimately collector will be operating at T minimum plus delta T. So, my collector operating temperature is T minimum plus delta T. So, this change by X c and that change by phi bar max. So, guess delta t.

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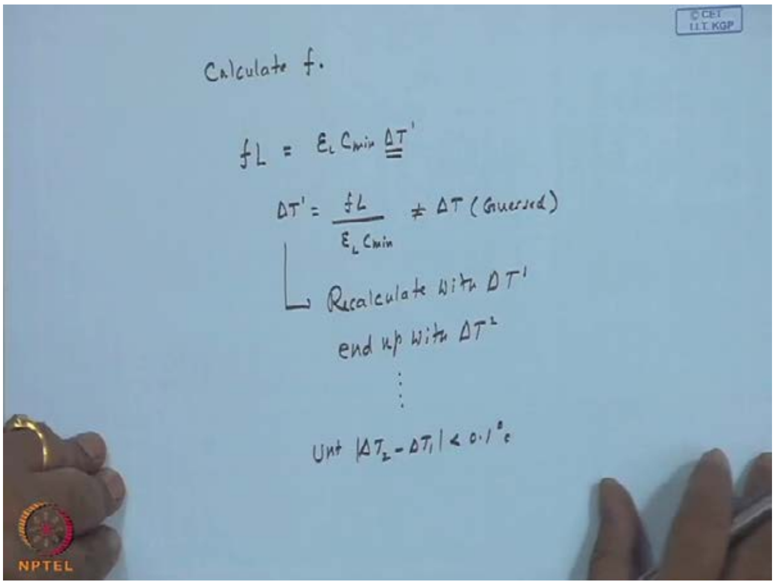

Calculate solar load fraction because your non-dimension critical level has changed. You utilize ability change, so f will change. If this is f multiplied by L should be equal to epsilon L C minimum into delta T. Correct? If this is the effectiveness at the heat exchanger multiplied by this minimum and the delta T available across the heat exchanger should be equal to the energy gain. So, from this I will get a delta T equal to f L by epsilon L C minimum, which I will call it L not equal to delta 2 which would guess recalculate with delta T 1 and end up with let us say, delta T 2 and continue with the procedure until delta T 2 minus delta T 1 mode is less than 0.1 degree or whatever accuracy.

So, basic philosophy is you include the tank looses as a part of the load which will modify your x and y, and this strategy will give you a solar load fraction as if the tank loss is also a part of the load from which we can pick up. What we call this solar load fraction? It is the amount of energy that is going to meet the load upon the total load. Subsequently, if you want to take into an account the heat exchanger effect, you assume that the heat exchanger is responsible for operating the collector at a higher temperature T minimum which modify my X e bar minimum phi bar maximum and hence, f.

So, the amount of energy deliberate is f into l. That should be supply it by the heat exchanger which calls for a delta T dash which may not be equal to the guessed delta T. So, you iterate upon these two while this come closer.

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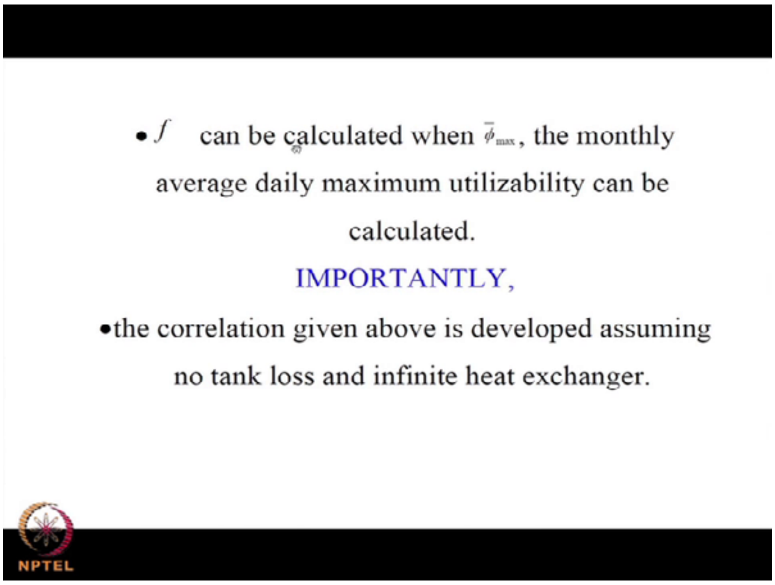

We will do one example including the tank loss and the heat exchanger effect, then that should be even more clearer. So, still with standing the calculation procedure of the monthly average utilize ability.

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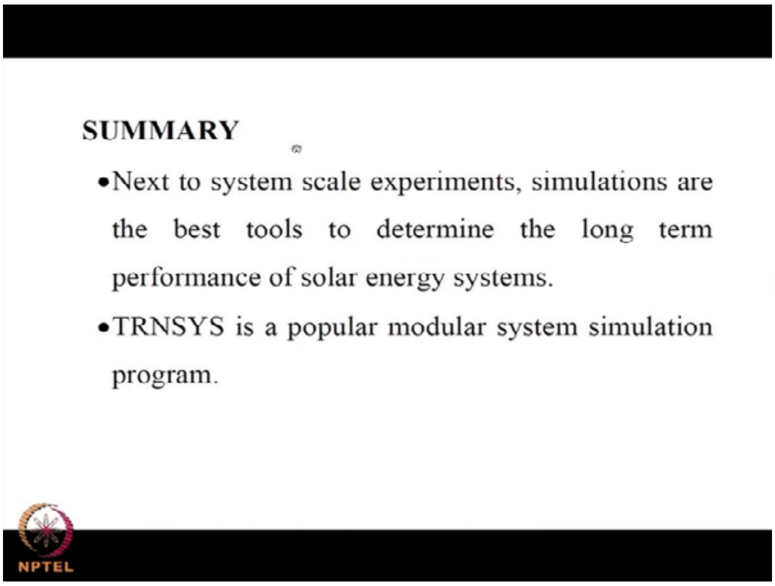

First we review the methods that are available to have long term performance, prediction of solar energy, thermal system and we realize long term performance is the indicator of the performance of the solar energy systems because your medical cycle repeats itself in one year and also academic analysis can be made, and next two system, k l experiments which are popular expense and time consuming. Nevertheless, the importance isn't identifying the system operating difficulties and there are other popular stimulation programs.

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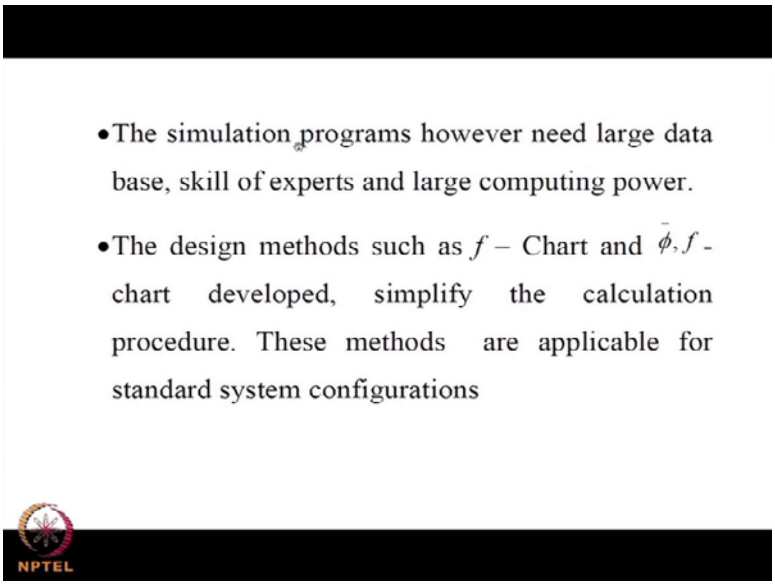

The simulation programs also have some disadvantages. They need the skill of experts and large data base and cost of the simulation could be quite significant. If you are doing small system scale simulation, then to respond to stranded system which may be 50 percent, 60 percent, all the total number of like domestic, water heating, spills heating or service heating system or process industry requirement the design method, such as f chart and phi bar f chart has been developed.

F chart supplies energy eta about 20 degree Celsius which is based for base collectors as well as recruit based collectors and phi bar f chart method can be taken to account the temperature at which energy delivery is desired. That is given as an implicit relation in terms of another parameter in addition to the non-dimensional collectors loss and non-dimensional absolve energy, namely the monthly average daily utilizability. The monthly average daily utilizability is nothing, but the solar radiation available to us above the critical level throughout the month, and that combines this statistics of the solar radiation as well as the operating conditions of the system. All these are applicable for stranded system configurations.

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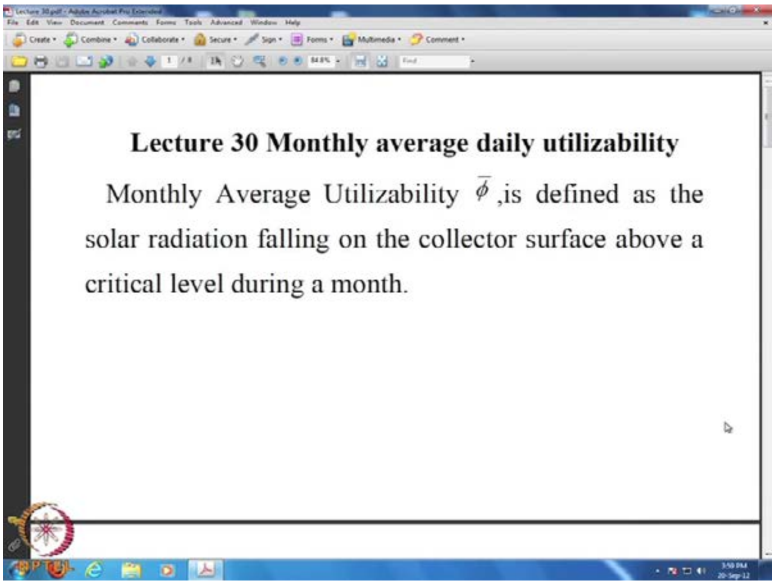

Now, we shall go try to predict monthly average daily utilizability.

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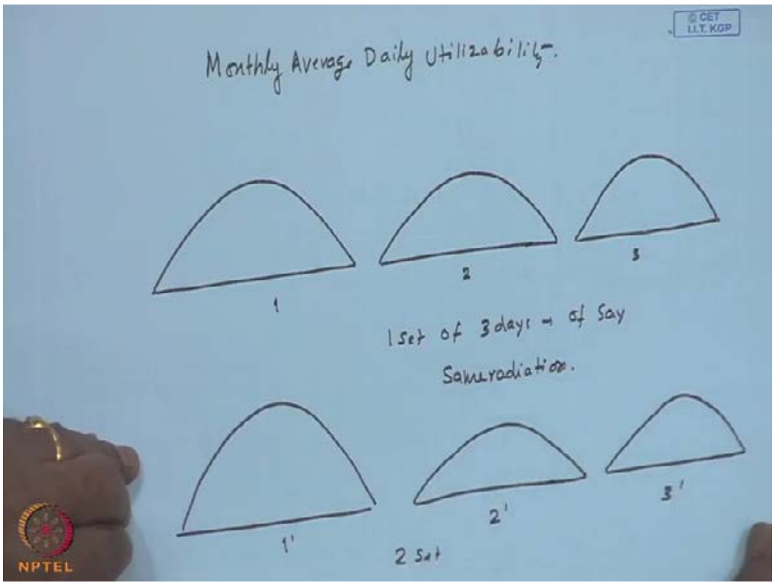

So, definition we have understood. It is nothing, but the solar radiation available to us above a critical level. Now, first let me consider three typical days in a month just to bring out certain features I wanted, so that you will develop understanding of what is utilizability and what sort of a function it is. This is the first set of three days, though they do not look identical of say same radiation 1, 2, 3. Later on, I will consider here a brighter day, a cloudy day and sort of average day. So, this is second set. I will call it 1 dash, 2 dash and 3 dash.

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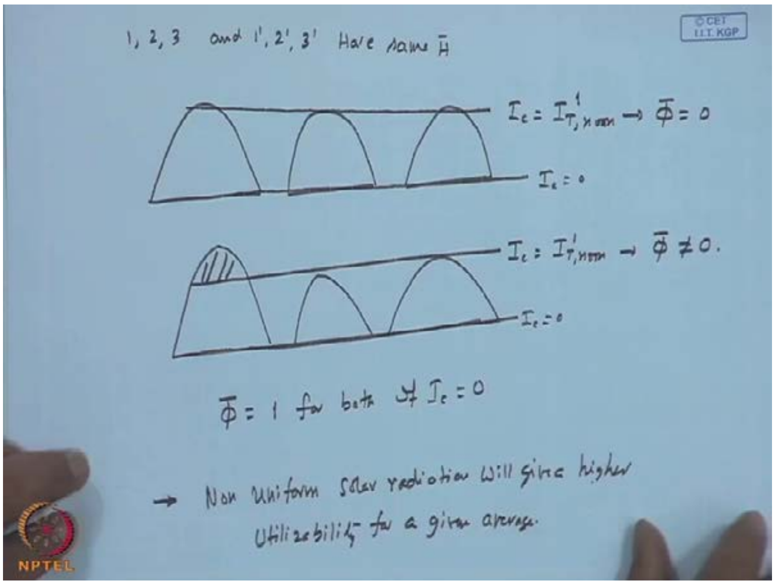

1, 2, 3 and 1 dash, 2 dash, 3 dash have same H bar. Let us say, the average day relation of all the, both the sets is 3 days. Typically, I just want to illustrate the point. They have the same average, but one across more or less uniform solar radiation and the other one with a high radiation, a cloudier radiation and sort of an average radiation, right and to further exaggerate, so that I will make this scale bit less and you can see the point more clearly continuous.

So, now zero critical level here. Also, it does not require great mathematics. That way, utilizibility will be 1 if the critical level is 0 or whatever will be the distribution, ok. This is anyway issue even the numbers are different, average are different, the monthly average, daily utilize available to be 1, if I C is equal to 0.

Now, if I reach this, I T at noon of set one for this my phi bar is 0 whereas, I C equal to I T noon because they are all equal, that is the same value phi bar is not equal to 0. This negative contribution do not contribute, this does not subtract from this. So, I have this positive. So, it looks like I can make a generalization. If you do not mind non-uniform solar radiation from day to day basis will give a higher utilizability for a given average. That is very clear about it.

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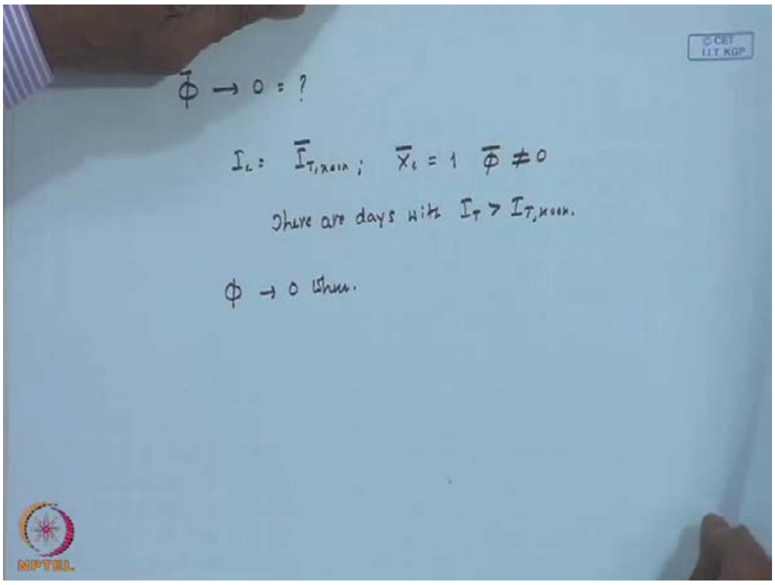

So, if you have got a cleanness index distribution which is more non-uniform, now stranded deviation is more, then another distribution, you will have a higher utilizability, particularly at higher critical levels, because there will be at least one day that will be contributed to the useful energy, though the one with the uniform or more uniform solar radiation levels will be contributed equally of course at low radiation levels, but at higher critical radiation levels re-contribution will be less. Then, when will it be 0? For a practical distribution, right. If you say that I C equal to I T noon of the average day, right that means, X c bar as we had defined equal to 1 phi bar is not 0 because there are days with I T greater than I T noon. So, one property is my monthly average daily utilizability which is related to my X c bar. If X c bar is equal to 1 is not equal to 0.

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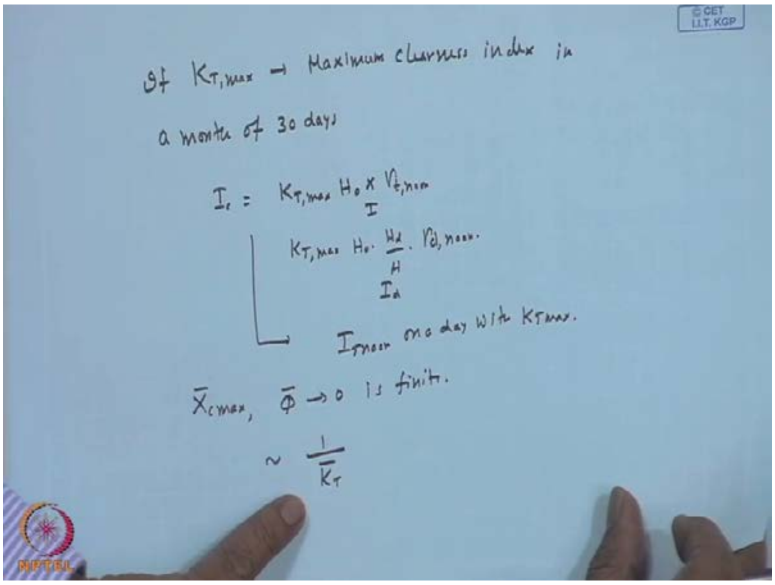

Now, phi bar when will this be 0? So, we can have a quick estimate. If K T max is the maximum, clearness index in a month of 30 days or 31 days, it does not matter. Then, if my I C equal to K T max multiplied by H 0, that will may give the horizontal radiation multiplied by R T at noon that give me I at noon. Then, again I can find out K T max into H 0 into H d by H will give me the diffuse radiation multiplied by R d noon. This shall give me I d from which I will calculate I T noon on a day with, excuse me K T max, ok. So, X C max for which phi bar is 0 is finite. So, approximately in fact you can, it will be approximately put on the K T bar.

If average clearness index is equal to 0.5, if the non-dimensional critical radiation level is 2 almost, phi bar will be 0 that is if you assume that K T max can be maximum 1. So, the solar radiation at the noon time will be twice that are the solar radiation on the average day. So, the ratio of X C bar should be 1 upon K T bar is a simple logic. You equate the noon time radiation based upon the average. What should it be? How many times it should be the noon time radiation of the day with the K T max? If K T max is 1, this much, otherwise it will be K T max by K T bar ratio. Some approximations are involved. This is the finite number 1. It should work as a ball per value. You do not have to calculate utilizability beyond this value, but utilizability does go to 0 for a finite value of X C bar.

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$$\bar{\phi} = \frac{\sum_{hrs}\sum_{days}(I_T - I_c)^+}{\sum_{hrs}\sum_{days} I_T} = \frac{\sum_{hrs}\sum_{days}(I_T - I_c)^+}{\sum_{days} H_T}$$

$$= \frac{\sum_{hrs}\sum_{days}(I_T - I_c)^+}{N\bar{H}_T}$$

Klein [53], (Solar Energy, Vol.21, p.393, 1978) a correlation to calculate the monthly average daily

So, this is the definition for the simple thing first Klein has correlated.

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utilizability for south facing flat plate collectors in terms of

- A non-dimensional critical level, $\bar{X}_c$,
- A geometric parameter $R_n/\bar{R}$ and
- Three constants which are related to the monthly average daily clearness index, $\bar{K}_T$.
- Klein's [53], correlation is given by,

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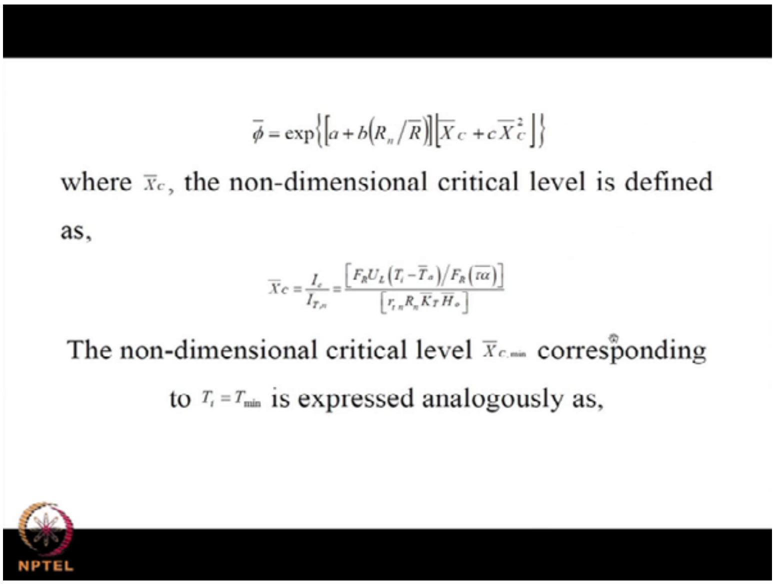

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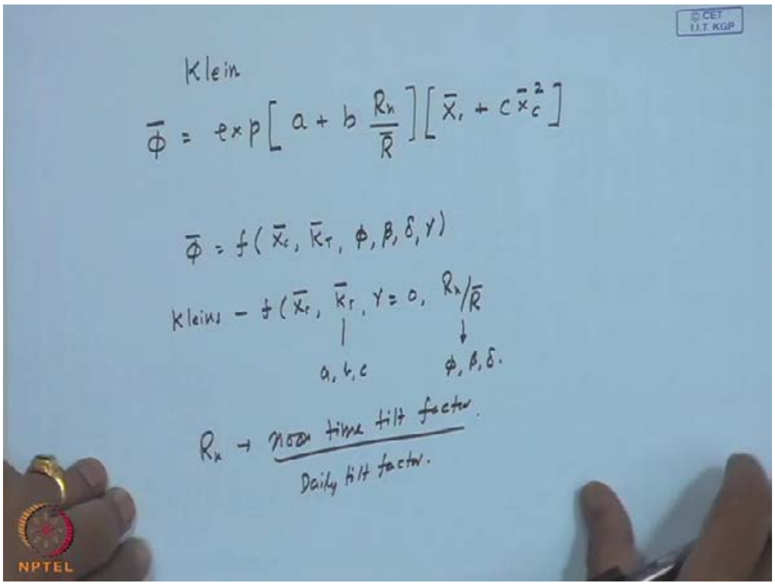

The monthly average daily utilizability as exponential, a plus b R n upon R bar. I wanted to write down relation first and then, let us examine how satisfactory, what are the parameter that has been taken care off? If you do not have the relation, I would expect my phi bar to be a function of obviously X C bar, very strong K T bar very strong because K T bar will decide the sequence of the clearness indices are the frequency distribution uniform. T is non-uniform that the clearness indices as we have already demonstrated a non-uniform distribution is like you to give us a higher utilizability. Then, that of the uniform distribution particularly at higher particular levels and please understand this automatically does not translate into higher useful energy phi bar max is high or phi bar max is low is different from phi bar max multiplied by H t in S i are low, ok.

If you have a clearness index, the uniform of the K T satisfied. So, the non-dimensional utilizability may be lower, but the actual energy gain may be more, but less proportional. Then, the increase in the K T. So, when we talk in general, solar energy is heat if we talk about non-dimensional number. Let us talk just non-dimensional number increases or decreases rather than mixing up with the real physical variable. These two may not be synonymous or equal into each other all the time and X C bar K T bar and the latitude because it will have some effect definitely on what will be the noon time radiation compared it to horizontal radiation or the tilted radiation compared to the horizontal radiation, the slope delta declination demand because my this R b are factor strongly depend upon this and of course, gamma if it is non surfacing.

So, Klein correlation is as f X C bar K T bar is there. This comes through a b c. Of course, he has chosen gamma equal to 0 and instead of R n upon R bar is in place of phi beta delta. So, this is R n is the noon time tilt factor to a daily tilt factor, ok.

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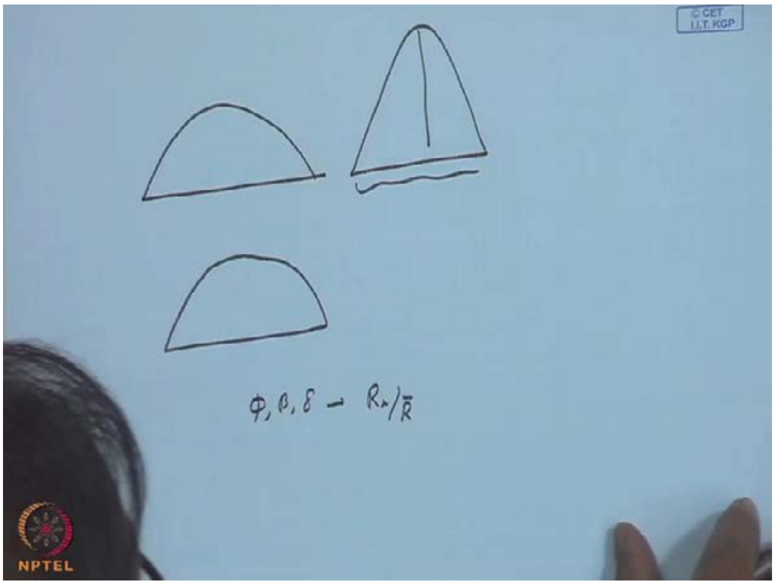

Basically, it is very difficult to show only in one picture, but you can understand the spirit of it. If this is the horizontal radiation, a particular lower intension, we make a steep radiation at the noon time and another distribution makes it larger throughout here.

R bar may be large and then, R n is not so large. Here, R n is very large; R bar may not be so large. So, what he is trying to say is the effect of the phi beta along with the month will stretch to a larger extent or to illustrate extent, though it may overall increase total solar radiation or decrease solar radiation depending upon the length of the day etcetera.

For example, few examples we have calculated noon R b factors in general for favorably oriented surfaces towards south or higher in winter. That means R b n will be higher in winter, then R b n correspondingly in summer, ok. So, he expects that the correlation very successfully phi beta delta which are three parameters or combine into single parameter R n and R bar. The logic behind that is you will know how much the stretching took place to overall inflation you call it or increase of the solar radiation.

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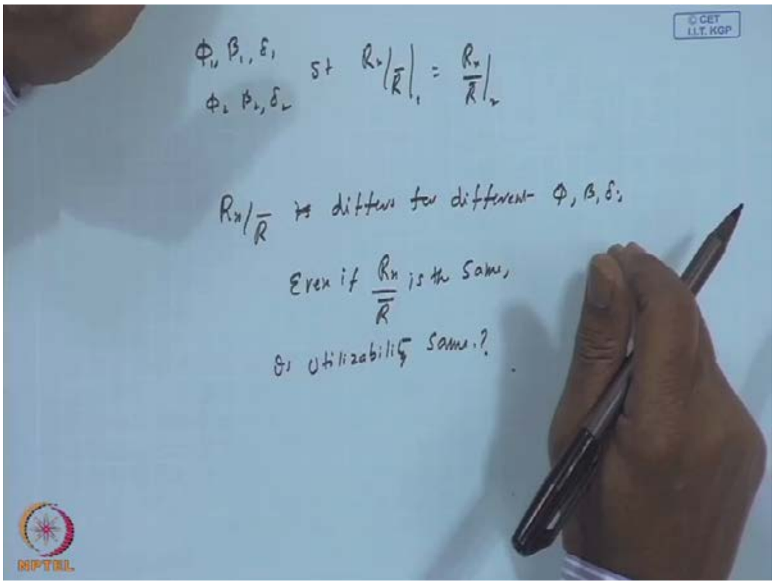

However, if you go through little detail calculation, not always I have not trying to say this correlation does not work. It works well and if you choose phi 1, beta 1, delta 1 and phi 2, beta 2, delta 2, such that R n by R bar 1 equal to R n by R bar 2. This will pass because I have R 3 variables phi beta 1 delta 1. This arbitral I will choose, find out R n by R bar, assume a particular phi 2 beta 2 R phi 2 delta 2. Delta 2 is not in my hands. Find out beta, such that these two variables are equal. So, two of them are free. So, consequently two of them can be fixed, such that this ratio is equal to this.

So, if you examine a large number of sets of phi 1 beta 1 delta 1 of n being general phi and beta 2 and R n by R bar is deferrers for different phi beta delta, this is obvious, but even if R n by R bar is the same, E is utilizability same. So, according to that correlation for a given K T bar of course, and X C bar, they are the same, but they will not be the same or they will be the same which we have to find out from the data. So, such strategies we are done under certain conditions. The utilizability, they can be different even if R n by R bar is the same for two different sets of phi beta delta. Of course, you have to really set the acumination because your K T should be the same; X C bar should be the same, etcetera, but nevertheless in general.

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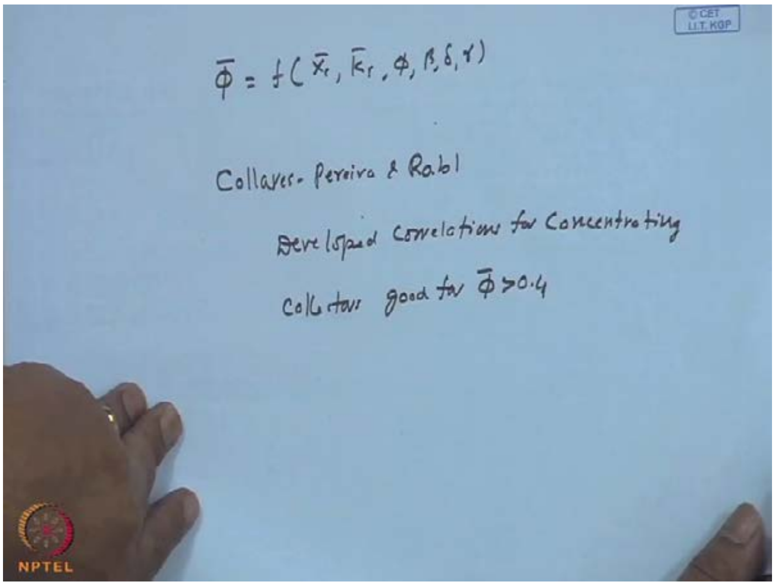

If this is a, you may have a method to get my phi bar in general valid for X C bar K T bar phi beta delta gamma. So, this is a complete picture even if we take non-south facing surface. For example, Klein's correlation valid for flat plate collectors and Collares-Pereira and Rabil developed correlations for concentrating or focusing collectors good for phi utilizability greater than 0.4. That means for higher utilizability.

So, generally, some approximate have been made the argument has been concentrating collectors, unless your operated high utilizability efficiency, if he cannot be felt or cannot be realized. So, in a relation for phi bar above 0.4 is good enough or of course, there are other limitations, but that we shall not go in this course.

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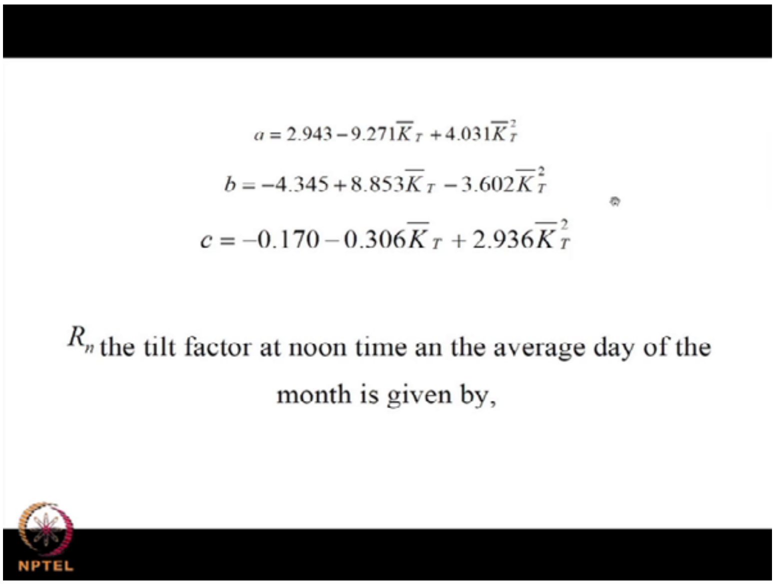

So, the constant a, b and c very correctly.

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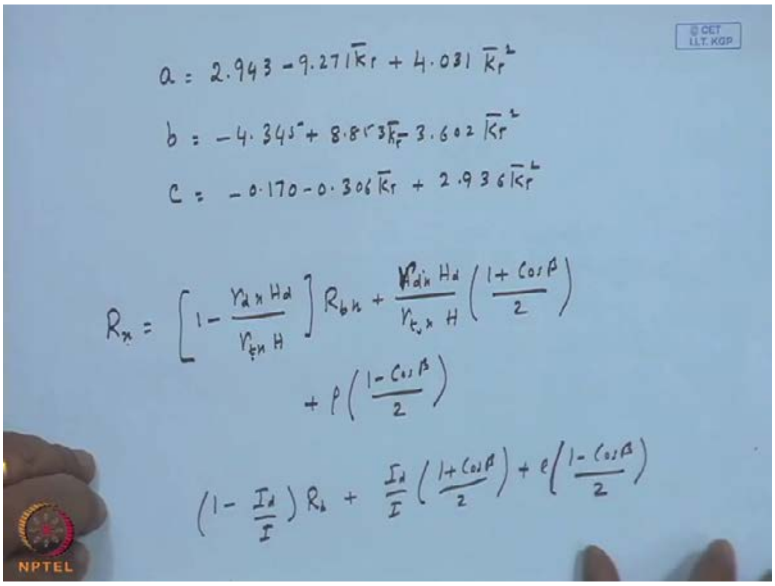

It is a function of a clearness index and b is minus 4.345 plus 8.853 minus 3.602 K T bar square and the constant c minus 0.170 minus 0.306, there should be a K T bar plus 2.936 K T bar square. So, this is a nice variation. You have got utilizability in terms of X C bar a b c constant with taken to in this index and one factor to represent 5 beta delta which works reasonable, quite satisfactorily and that R n, the noon time tilt factor, which usually again recall can be written as, it is written in terms of those quantities that we know and which we not like to use in our day our data. Since, this being a monthly design method R d n, sorry 1 plus cos beta by 2 plus ground effective times 1 minus cos beta by 2.

You remember in our long form or whatever in the terms of the data, you see the 1 minus I d by I times R b in general plus I d by I times 1 plus cos beta by 2 plus rho times 1 minus cos beta by 2, ok. Now, noon times, this n n n comes into that because it sets a particular time.

Now, you will see that R d n by R t n is I d by I. This is I d by H d multiplied by H d I d. This is multiplied by H. So, this is nothing but I d by I. So, here I d by I and this is nothing, ok. So, what we try to do is express in terms of the diffuse fraction and the R t and R d correlation to estimate the solar radiation at the noon time. This is some of the average day of the month, you recall in the differentiation of the non-dimensional critical I t n R n. In the denominator, we need the noon time radiation on the average day to calculate that unit R n R n is given by this expressed in terms of R t and R d.

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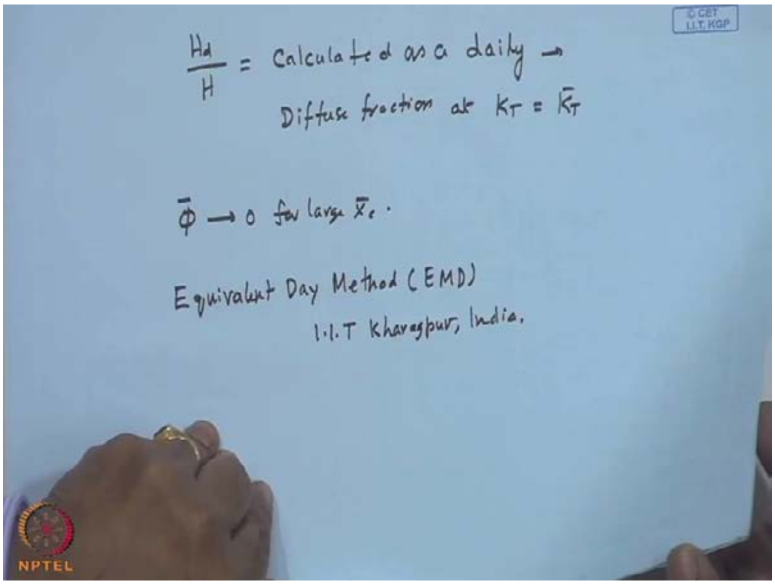

H d by H is calculated as a daily diffuse fraction, though it is the average day of the month at K T numerically equal to K T bar. So, we know that we are making the calculation on the monthly average day, but the diffuse fraction for some days, not the other is calculated with the clearness index numerically equal to the monthly average daily clearness index.

The possible reason could be it a single day when the critical level reaches the noon time acts like, though it is an average day, acts like a single day. Possibly this is logic I am trying to give and hence, H d by H is calculated with K T numeric equal to K T bar instead of H d bar by H bar or this simply correlates better and hence, this is used.

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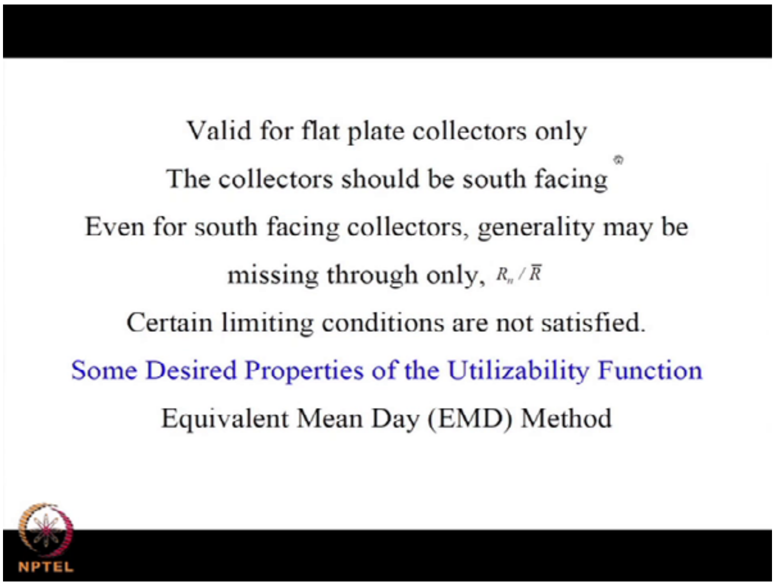

So, once again, yes this phi bar does not go to 0 for large X C bar. So, since it is being explanation relation, this shall not go to 0 of high values of X C bar even X C bar tends to infinity. So, if you want to have certain limitations, first of all collectors satisfactory utilizability method need to be formed and then, non south facing surfaces needs to be found and whether, R n by R bar adequately represents phi beta delta needs to be done. It will be nice if phi bar goes to 0 at finite X C bar since we know that and some of these properties of the utilizability function are to be satisfied and there is what is mean by equivalent day method that is EMD. This is done at IIT, Kharagpur India.

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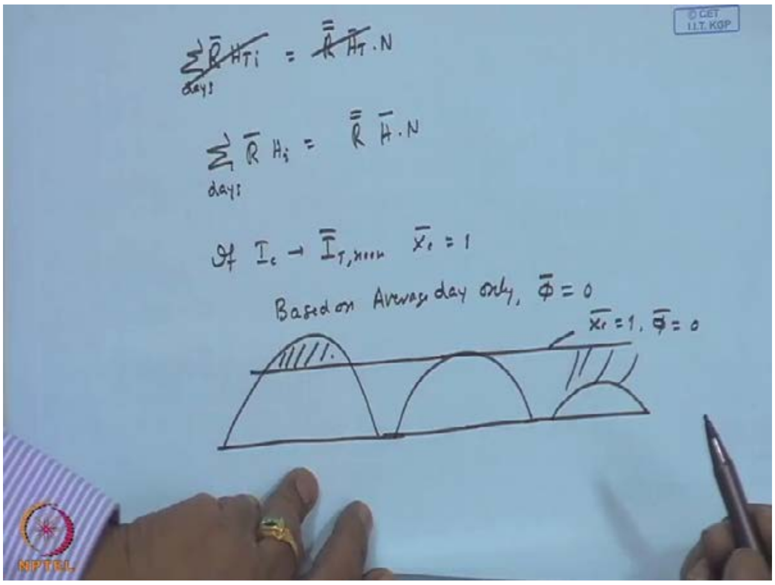

So, now if we ask our self a question, what can't we follow the methodology like estimating the solar radiation. That is for example, R times H d submission over all the days equal to R. We call it double bar, does not matter H t bar. One average day, solar radiation, you take it multiply by and find out the tilted radiation. This should not be T s sigma R bar H i over days should be equal to R. So, one single day characteristics, this is between 3 to 4 percent or 5 percent difference and there is no apart from a numerical difference. There is no quality to error in the step of the calculation. This works for R b, works R b bar R b bar day R b bar month and in general, R bar and in fact, even for bar for the day average day value will be the monthly average value pretty closely.

Why not for the utilizability? That is because if I C equal to I T bar noon X C bar is equal to 1 and based on average day only by utilizability will be 0. So, like the three diagram, I am showing if you visit on, this is the average day, this is X C bar is equal to 1. If I calculate only based upon this and phi bar is equal to 0 which is not true because I have got a positive energy contribution on the day with the higher K T. So, this is the reason all the days do not contribute two useful energy whenever the solar radiation highest available is less than the critical level. Still the average day would have worked if I had taken these negative things into account, but negative things are not given a penalty, right. This is treated as 0, I T minus I T plus only summed up.

So, this has to be taken into account, but not this deficit. So, the average rate will not work. So, if you realize that the average concept why it fails for calculating new monthly average daily utilizability is because basically, you do not take into account a negative contribution whereas, in the case calculating R bar power of bar, a day with a higher K T may have you higher to be compensated with the day with a lower K T may have a lesser by you or higher by you to be compensated with a day lower K T or higher K T. That does not happen here.

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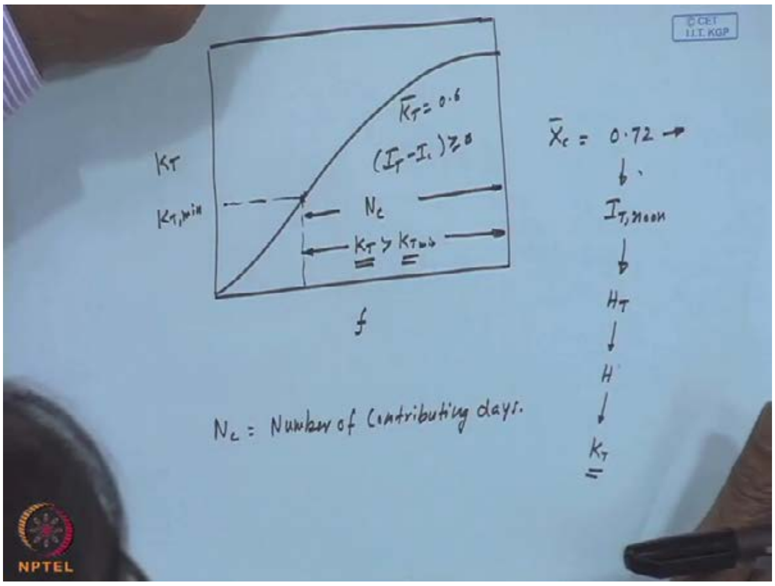

So, what we can do is if we have accumulated to frequency distribution like this that we know from Leon Gordon, this is let us say at K T bar is equal to 0.6, ok. So, X C bar has some value 0.72. So, this corresponds to Saturn I T noon, this corresponds to Saturn H T and H and K T.

I have calculated for a system based upon the solar average radiation which is X C bottom 0.7. I can calculate from the correlation, all right but if you want to do some other averaging technique, I will just say that this correspond to the I T noon 0.72 multiplied by whatever is f for you l divided by I will get a noon time solar radiation; from which I can get the filtrate radiation or the horizontal radiation and clearness index. So, I can say this one is sort of K T mean corresponding to by X C bar mean and these many days will have a K T greater than K T mean or this much of fractional time will have the clearness indices early basis or daily basis higher than the noon time radiation, when it is just equal to mix c bar number. So, these things I will call it NC, the number of contributing days.

Let me just repeat because the concept is a little tricky. If you have a Saturn one dimensional critical level based upon the conventional definition, that will correspond say particular I T noon and hence, on the average day K T bar is K T bar known to me. I can find what the critical level corresponding clearness index to that X C bar is. So, as long as the critical clearness index is higher than this minimum clearness index, all these things, my I T minus I C is greater than or equal to 0. This will be 0 and here onwards, it will be positive ok.

So, now these days need not occur. This is not day number 1 of the month and this is not day number 31 of the month, ok. Sequence, it can be anything, but there are certain NC number of days for which my solar clearness index is higher than the minimum clearness index that will meet the critical level that we have decided.

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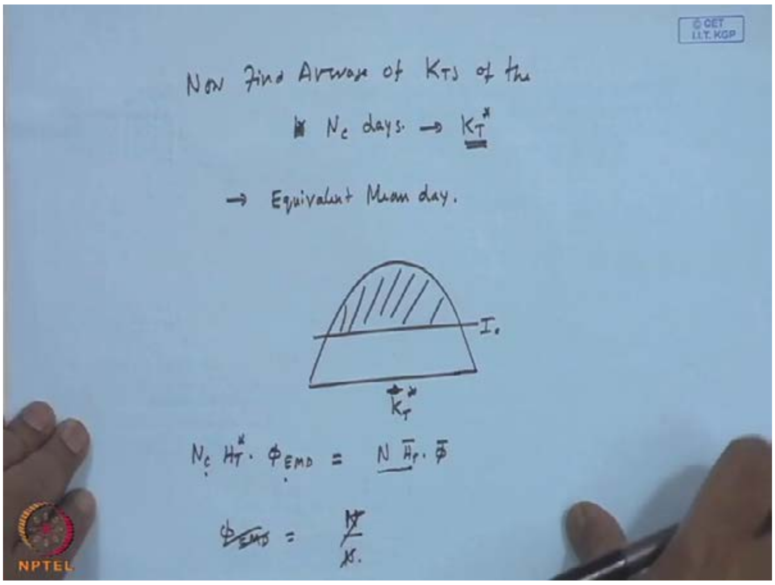

So, now find average of K TS of the N C days. So, what it is clearness index average for the days for which the K T is greater than K T minimum. This is for sake of some notation we will call it K T star. So, now I will define this as the equivalent mean day. So, now I have got only day with particular K T bar star. So, this is the distribution, this is I C, this is the energy gain on the average day. So, if NC is the number of contributing days and I have got H T star as the radiation on the tilted surface on the day with K T star, sorry this multiplied by phi EMD. Somehow, I calculate for a single day equal and mean day utilizability that multiplied by the solar radiation multiplied by the number of contributing days is the energy contributed, right.

So, this should be equal to all the days times H T bar multiplied by phi bar. This is my conventional definition which when multiples the total radiation on the surface will give me the radiation above the critical level. What I was trying to say here is if for this equal and mean if the singe days EMD is this that multiplied by the solar radiation on the equal and mean day that multiplied by the contributing number of days because the other ones are 0. The energy coming from these things should be equal to the total energy based upon the monthly average daily utilizability from the conversion definition. So, now phi EMD will be N by, sorry what I want is phi bar.

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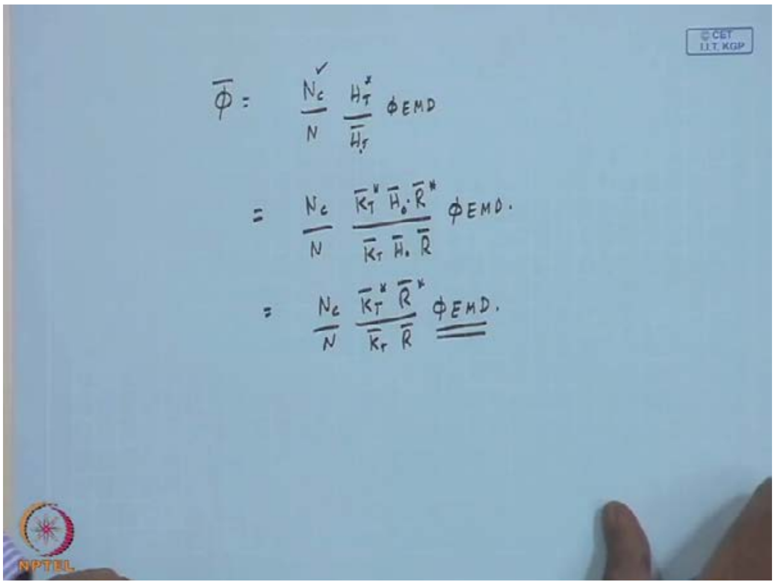

So, phi bar will be N C by N times H T star by H T bar times phi EMD phi is equal to phi EMD. That is it. N C is known for that I need the Leon Gordon clearness index distributions. Then, H d star into H d bar. So, this can be simplified for their N C by N times K T bar star H 0 bar into R bar star upon K T bar H 0 bar that remains the same more or less times R bar times phi EMD. So, this shall be equal to N C by N times K T bar star R bar star by K T bar R bar phi EMD.

So, I can calculate the monthly average daily utilizability if I can somehow calculate the single days utilizability. That single day being the equal and mean day, which we have defined as the day having the clearness index of average of the day is with the critical level higher than the lower than the noon times radiation of N number of N C number days in their month. We should continue with this in the next class.

Thank you.