Solar Energy Technology
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Lecture - 4
Measuring Instruments

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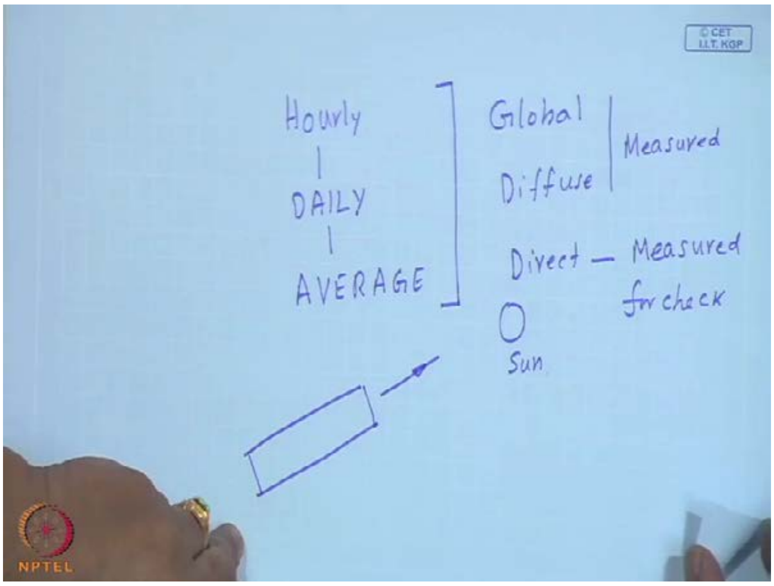

So, we recalled the necessity of certain measurements of solar radiation, which may be on a hourly time scale which we already discussed from where you construct or calculate the daily values from which you may come over with various averages. It could be average hourly value or average daily value or average monthly value or even yearly values. Most of the time it is a global and diffuse components measured direct solar radiation component is measured for check.

So, essential that means once in a while you can go through that not that is prevented to measure the direct component radiation. Simply, when once you have about typically you focus the instrument towards the sun any small error in focusing towards the sun.
We lead to a large error in fact it may go out of the range of the sun. Consequently a lot of care has to be exercised in using the direct radiation measuring instruments or not only in tracking and even in seeing; that the tracking is well maintained.

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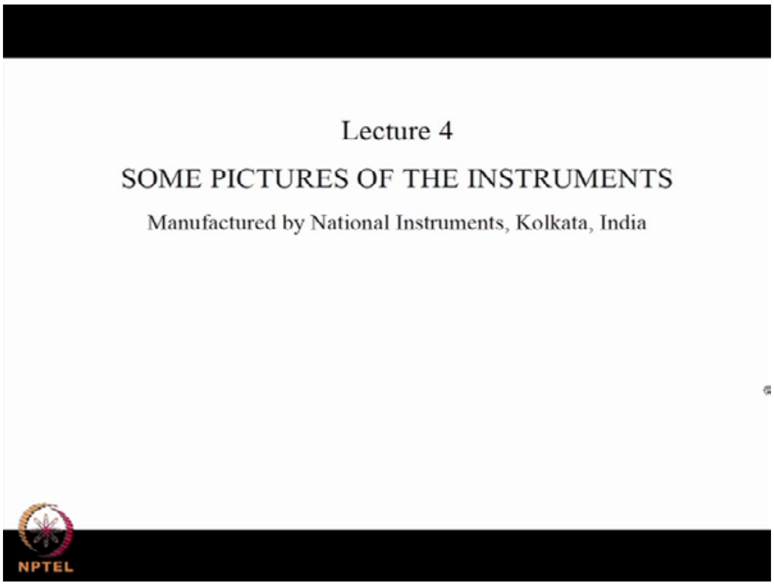

So, I shall show you some pictures of the instruments, you will have a better idea of how they work and all the details of cross-sections I cannot show, because the instruments are working they could not be broken, and these are manufactured by national instruments in Calcutta in India.

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And right now, I believe the company is not working anymore however these instruments were brought sometime back. First you will see a pyranometer and you will see on the glass bowl in the middle.

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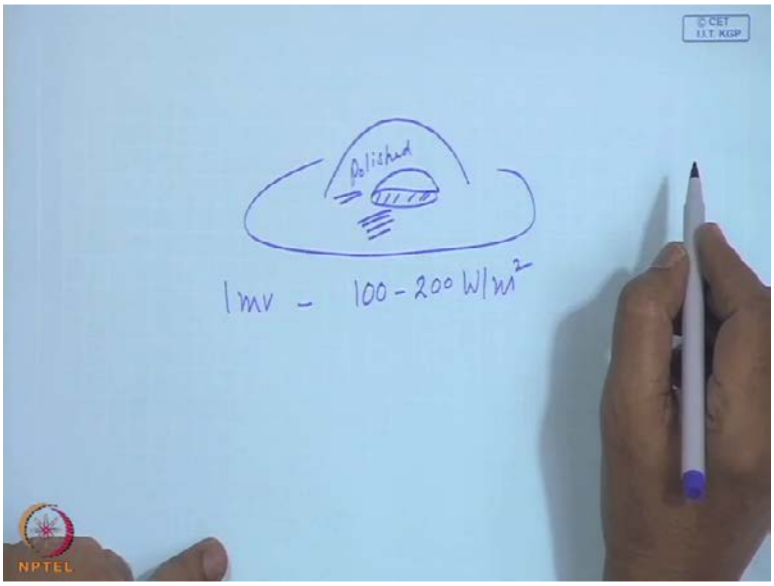

There are two concentric hemispheres with that portion black at the middle, and this is polished. Under that surface is a Thermopylae, which is basically thermo couples in series, which will produce a higher milli volt output for a given radiation input. As, I said typically there are around 100 to 200 1 milli volt for about 100 to 200 watts per meter square.

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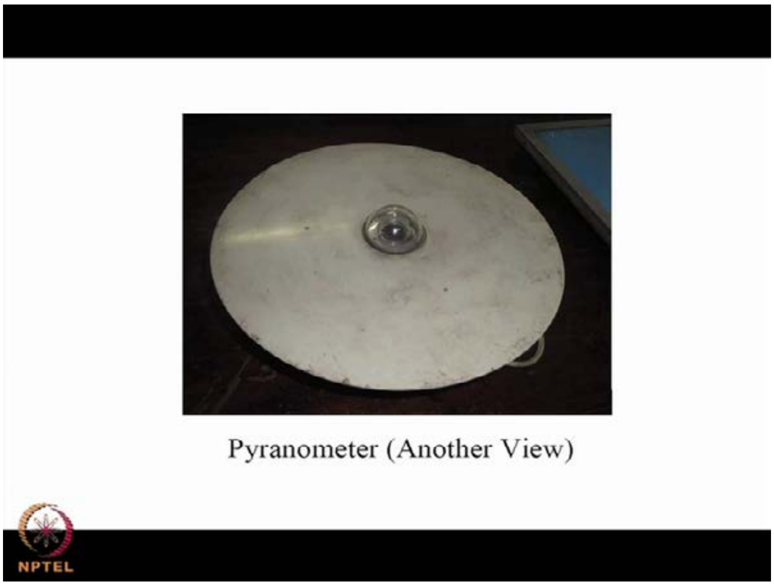

This is another view and you must be wondering, why so far I have not mentioned about the surrounding disk and this surrounding disk. Shall have the no other radiation being reflected onto the sensor. So, that it will be measuring only the total radiation or global radiation falling onto the sensor.

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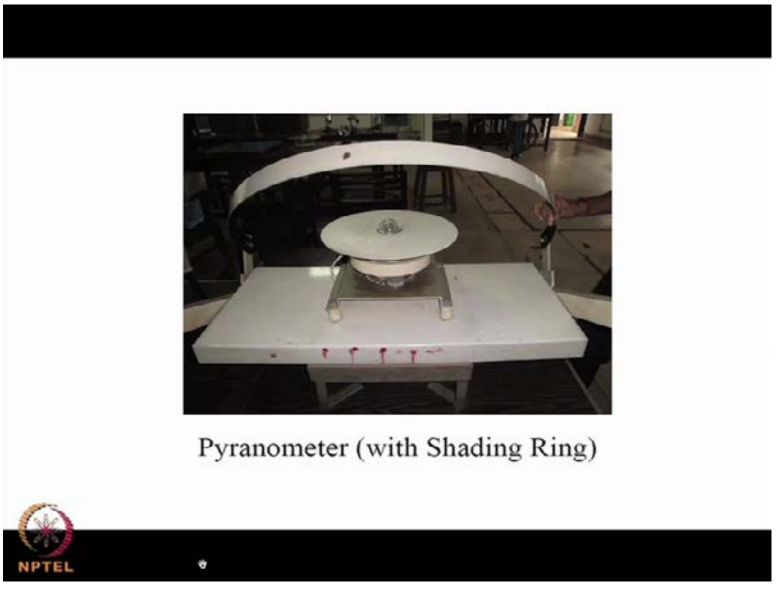

Now, this is to measure the diffused radiation and basically you cans see that the instrument is the same, but there is a large ring which you can see and that ring shadows the sensor which is the ball over here.

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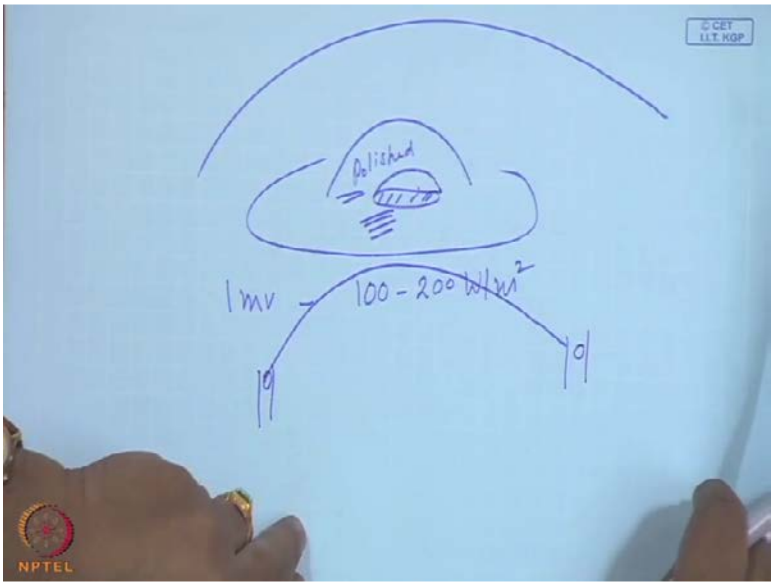

Now, you will also find an arrangement that it is inclined and the inclination can be changed by there are two nuts on which this ring is mounted, you can see like this and that can be turned depending upon the location of the sun.

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In another view you will find a scale for example, it is 0 and it goes to 23 degrees sun one side and another 23 degrees, and that slide can move to the positive side and the negative side of the angle; depending upon the declination of the day you move that.

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And then you will adjust to shade the sun that is falling so that the sensor is shaded from the sun's direct rays. So, thereby it will measure only the diffuse radiation.

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Now, this is a short tube pyrheliometer, and as I said that you cannot see the details at the bottom of that a long tube you have a sensor which gets heated due to the solar radiation, and that cap when it is removed is directed towards the sun, and then the rays falling on the sensor will heat that.

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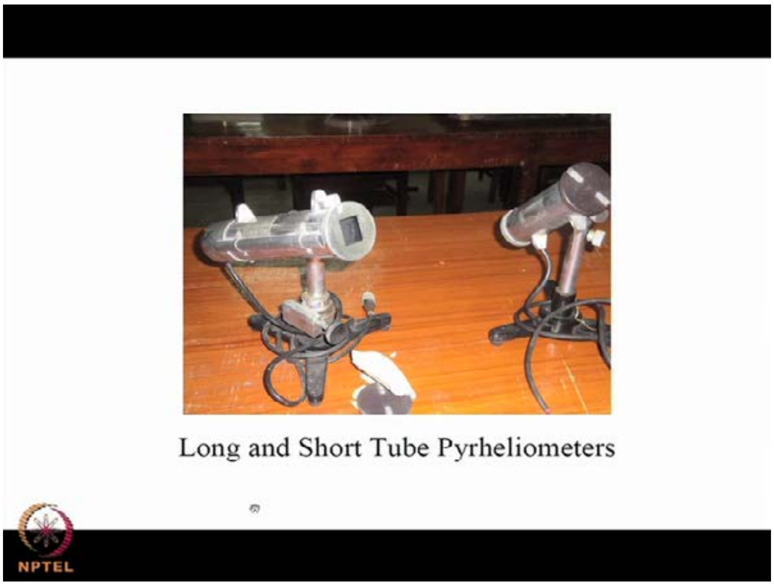

This is just to show you the difference between the long and short tube pyrheliometers; the long one is uncovered that seal is removed through which the solar radiation enters, and the long tube will have a lesser subtended angle and measures the radiation emanating from the sun only, and the short tube one will have a higher subtended angle consequently.

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It measures certain amount of radiation that is also coming from around and surrounding the sun. So this is a angstrom pyrheliometer basically the sensor mechanism is different in the sense it uses a non-detective system, like if your or in electrical technology post office box.

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Sunshine Recorder

If I remember right my undergraduate electrical engineering you try to balance so that the current passing. Through a particular circuit zero thereby giving you a measurement of the voltage generated and the electric power that is consumed. Now we come to your dependable sunshine recorder; it does not require any power and this is a view of course, there is a lot of reflection, but this is a better view and there you will find that black strip at the bottom of this glass bowl.

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Sunshine Recorder with charred Strip

And you see onto the right a little bit of charred portion which I am also showing it in a in larger view, somewhere in this area you will find a black charred bosh. So, if you will measure all the length of this charred portion that will give you the number of hours of bright sunshine and this strips basically you will have about three lengths to suit summer to winter variation, because though you may not feel much of a difference in lower latitudes, as you go to higher latitudes the daylight can be as much as something like 15 hours in summer or to may be 6, 7 hours in winter.

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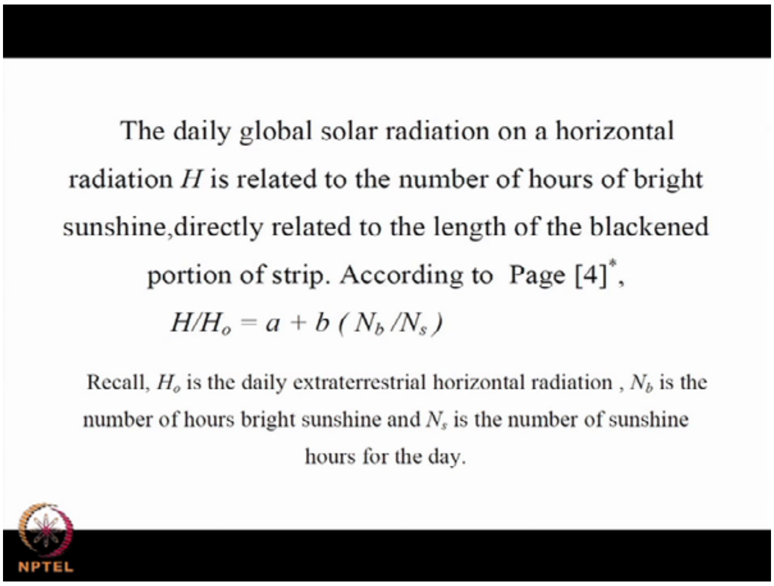

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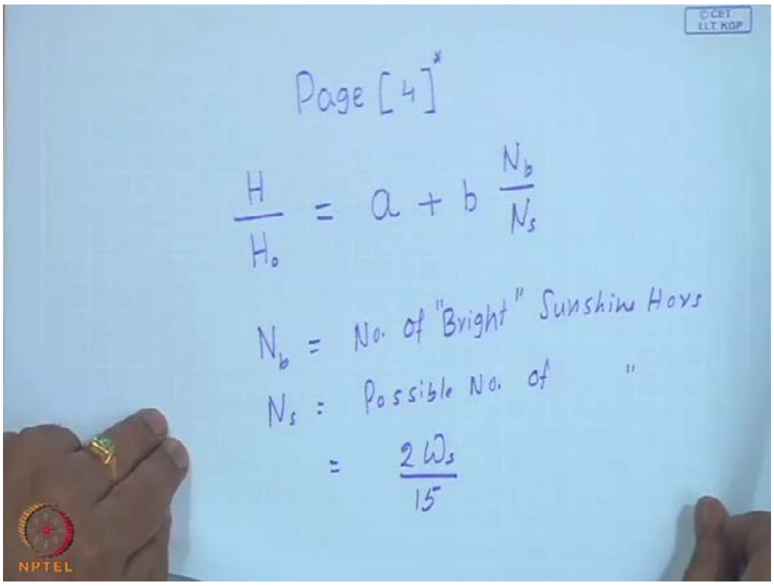

So, you will find the length needed in summer will be much longer, than the length needed in winter months. Now, doing all this what is the use and how is this used so page is a early researcher in the area of solar energy at that point of time the measurements available were small this 4 is a reference if you look at your notes you can find out the details.

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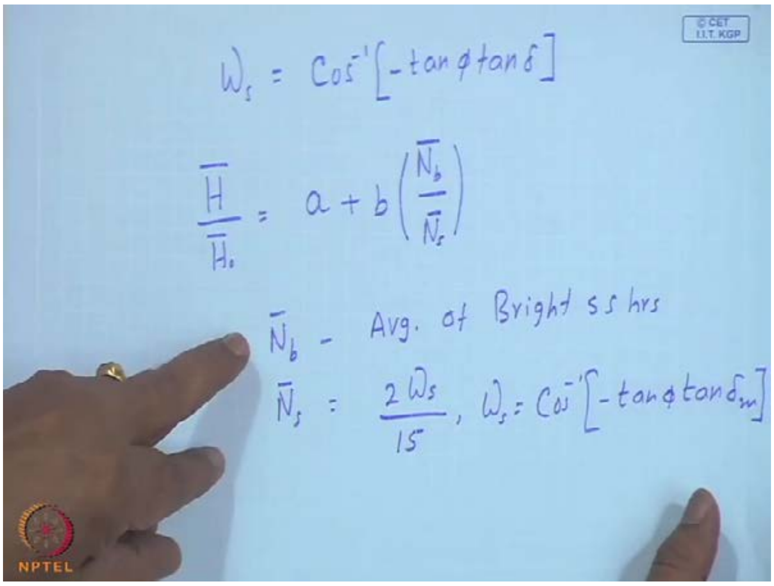

We were talking about the terrestrial radiation by the extra terrestrial radiation. This is linearly related to a constant a plus b to n b upon n s, n b is the number of bright sunshine hours obtained from the sunshine recorder. And n s is the possible number of sunshine hours, which we know equal to twice omega s by 15, which we have derived the formula in the other class where omega s is so called sunset hour angle, which is related to latitudinal location and the declination, and later on this is a plight to the monthly average daily value as in fact these constants need not be the same n b bar n s bar, where n b bar is the average of bright sunshine hours, and n s bar is twice omega s by 15, where now omega s is cos inverse minus tan phi tan delta mean.

We have got recommended mean declinations for each month, so we use that and this need not only be the average of n b bar and n s bar; it could be total number of bright sunshine hours by the total number of possible sunshine hours, even then it will be equal to the ratio of the average.

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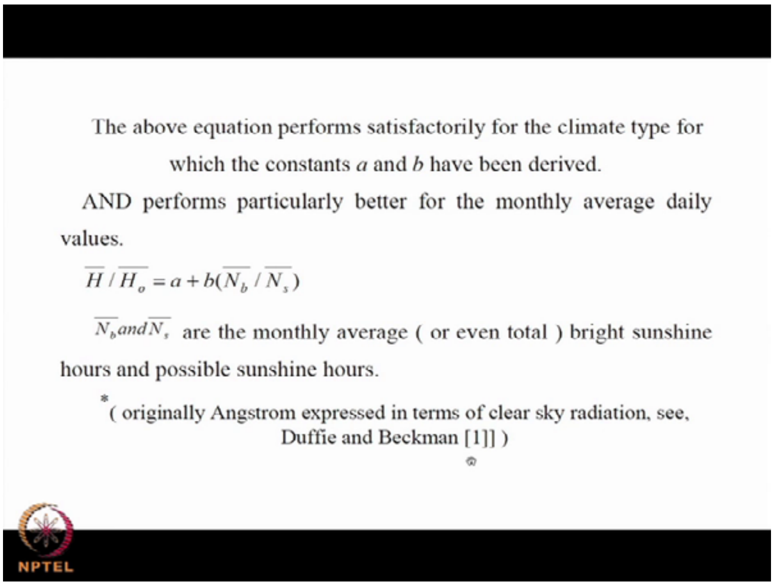

And, here I have to add a note. This angstrom type of relation originally angstrom expressed in terms of clear sky radiation, and you can see the book by Duffie and Beckman for the details.

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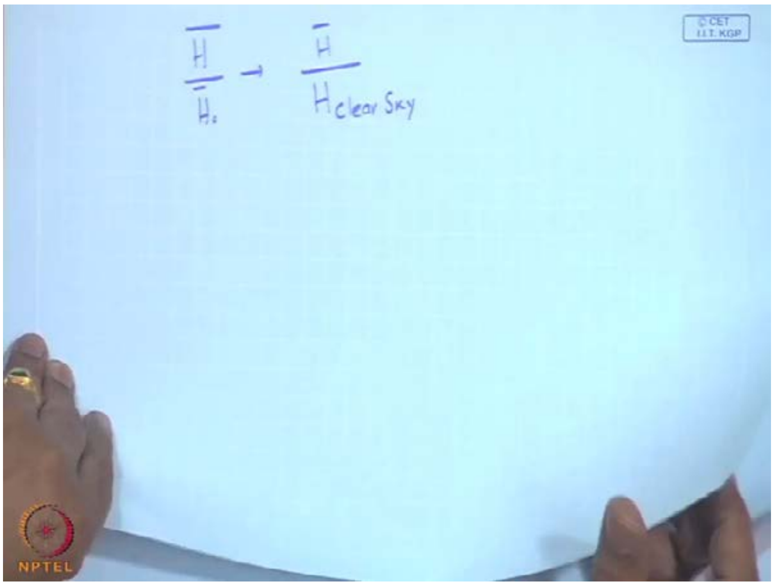

In other words it is instead of H bar upon H 0 bar; it is H bar upon H clear sky. There is a certain vagueness in defining clear sky, because that needs to be estimated depending upon certain features of that measure.

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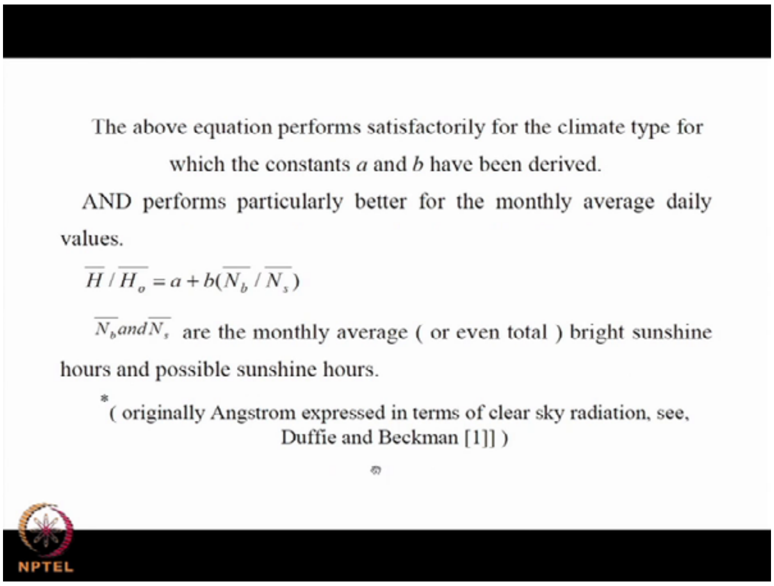

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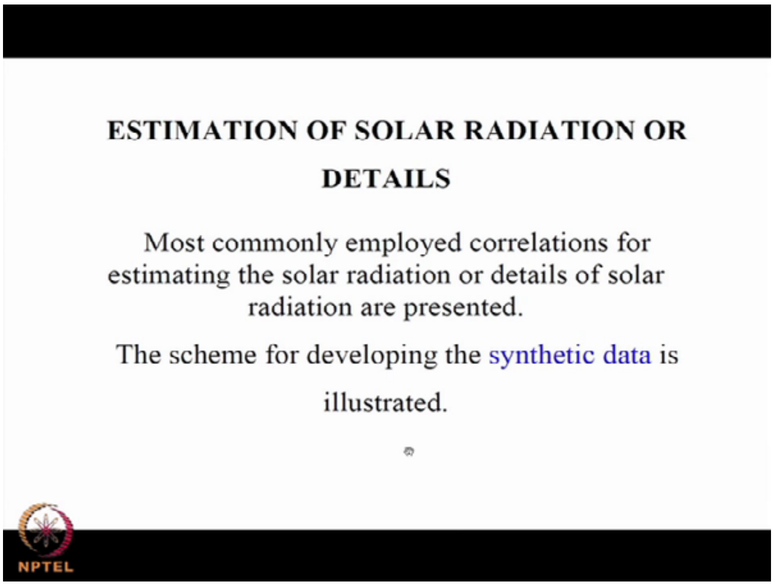

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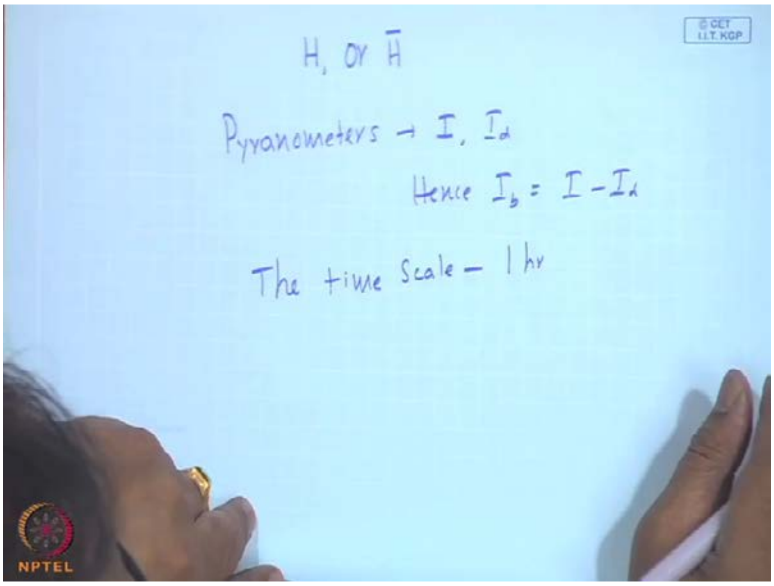

So, now where do we start we have a method of estimating H or H bar and if you make use of detailed instruments like pyranometers. We may have I and Id and hence I b equal to I minus I d; so most of the time the time scale is about one hour. And few measurements are available at smaller intervals that is the reason is for a well distributed day.

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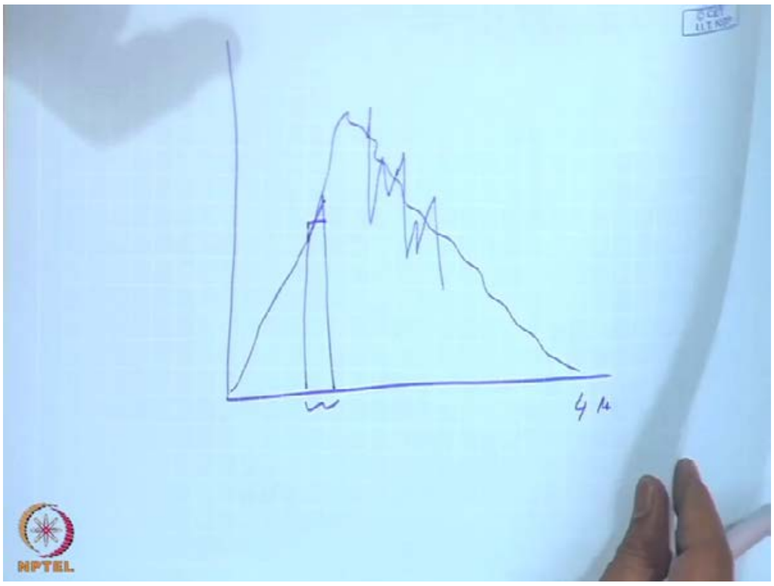

We have seen the solar spectrum to be something like this up to four microns, and if you take a 1 hour interval unless, there is a certain cloud cover or rain, are the chances are you may not have such a well vectorational. So, if you take this is approximated by a straight line or you can make it an equivalent rectangle, and if you have one hour radiation by a known distribution like linear or parabolic you can distribute it into quarter hours or half an hours. Though one has to think about whether that accuracy is needed or called for depending upon the model that you employ to estimate the performance of a solar collector or a solar energy system in general.

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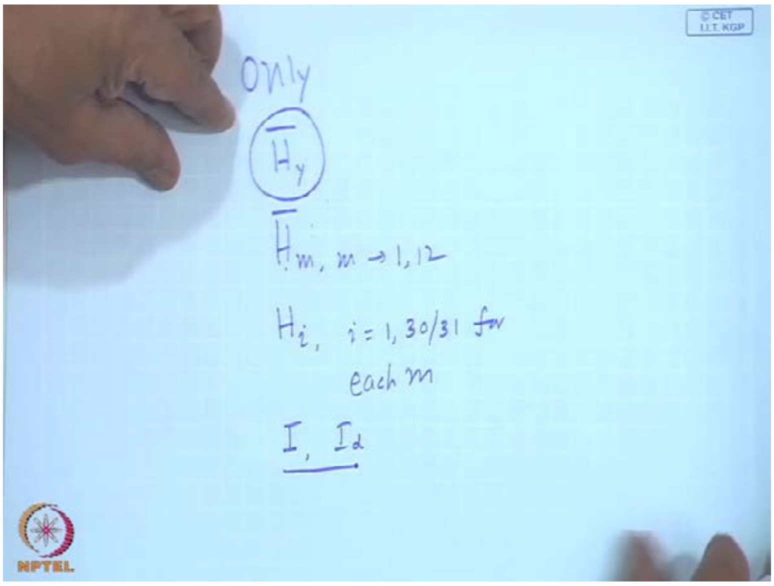

So, now if you do not have all the details you may have only H y bar. I am making the broadest possibility or you may have that is the yearly average radiation from which you have got H bar for each month, and 1 to 12 or you may have H I, I is equal to 1 to 30 or 31 for each m then of course, you may have got I for each day and I d for each day, I do not keep on saying I b can best made from these two. So, if you have got this data you can go to H I you can go to H m bar and you can go to H y bar, but though it is uncommon when you calculate from H bar you can total up and find out H y bar.

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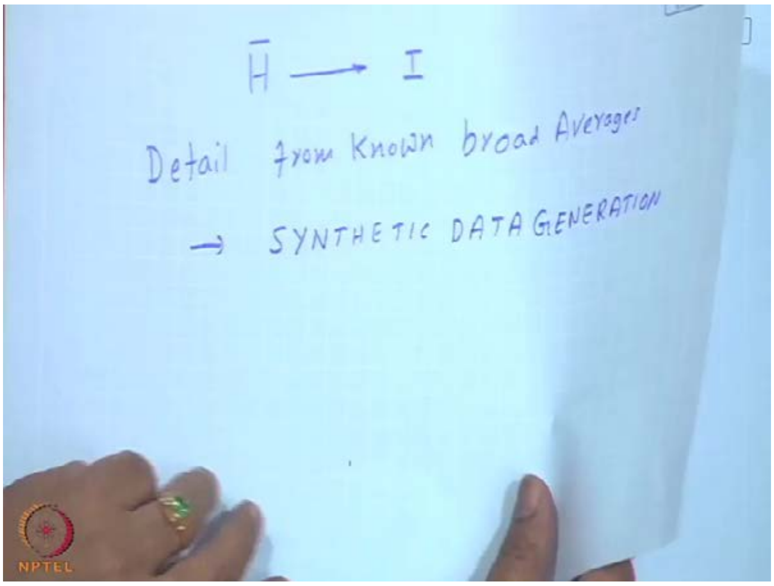

If I start with a something like monthly average radiation can I come to distribution of I. So, this is at different points if time the correlations are being coming in 1960, Leon jordan and as well as it is 1990 or 2000. They are continuing to come better and better relations then what they were existing. In written aspect getting the detail, from known broad averages, we may call it the latest terminology synthetic data generation. You may wonder what is synthetic data generation and in fact some people get upset with this term nevertheless this has got certain attributes the data generated from no matter what is the source the monthly average or the yearly average.

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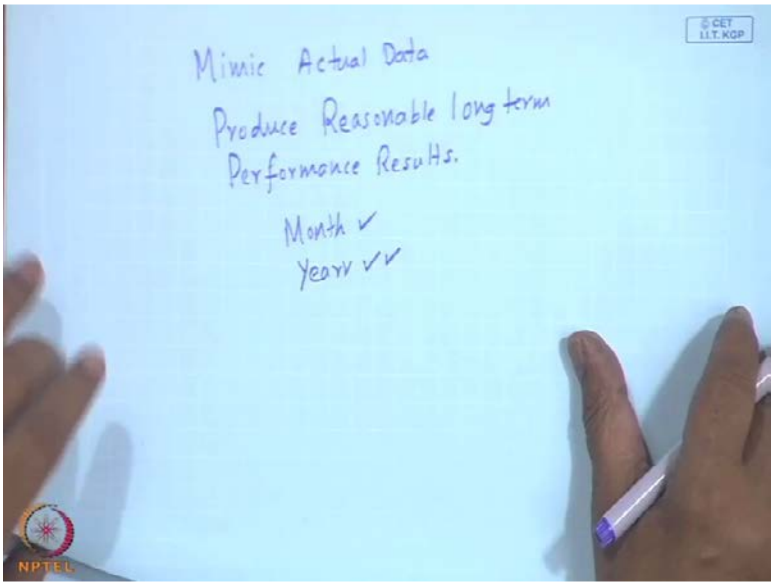

It will mimic actual data and produce reasonable long term results. What we mean is if you want to predict the performance of a solar energy system for a day for a particular hour, it may not be highly accurate, but for a month for a year it may be when more. So since our economics is likely to be based upon year and if it mimics the month distinction let us say between winter and summer reasonably well our job is done it is not essential how much is exactly produced on January one second third fourth like that, and if I can have a genuine average it is good enough because in any case next year it is not going to be reproduced and even if you use the actual data that actual data also belongs to somewhere or average of few years.

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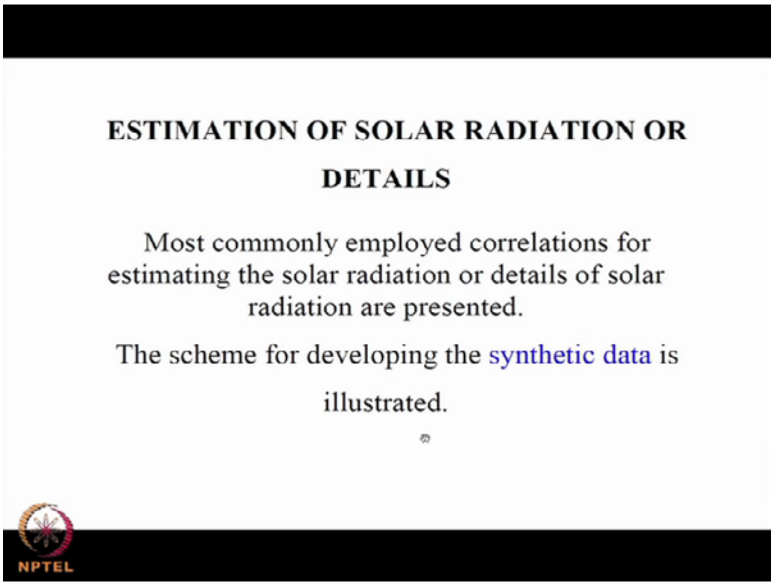

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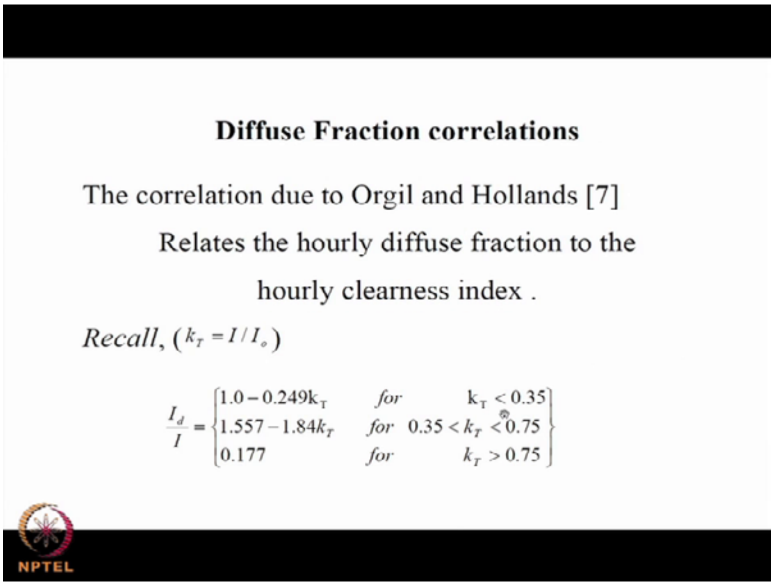

So, that scheme again towards the end of this lectures we will come to that in detail, but at the same time I just gave an introduction to whatever classically available can be considered as part of a synthetic data generation scheme.

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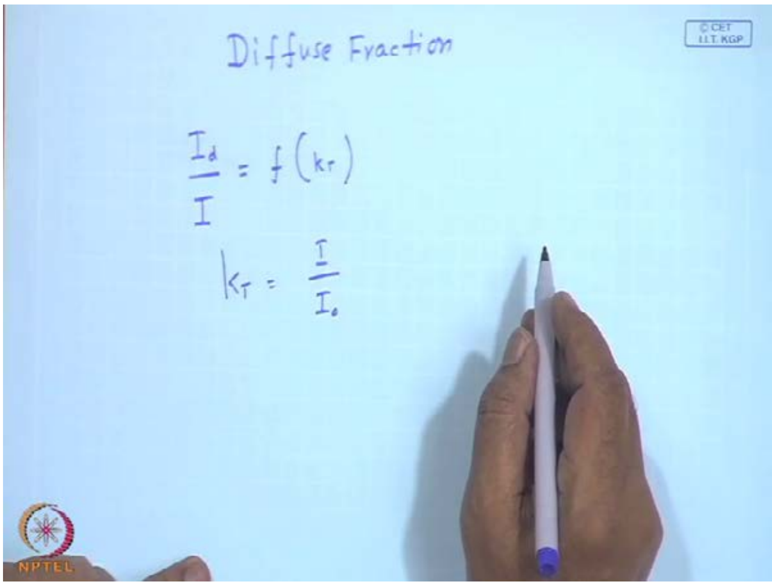

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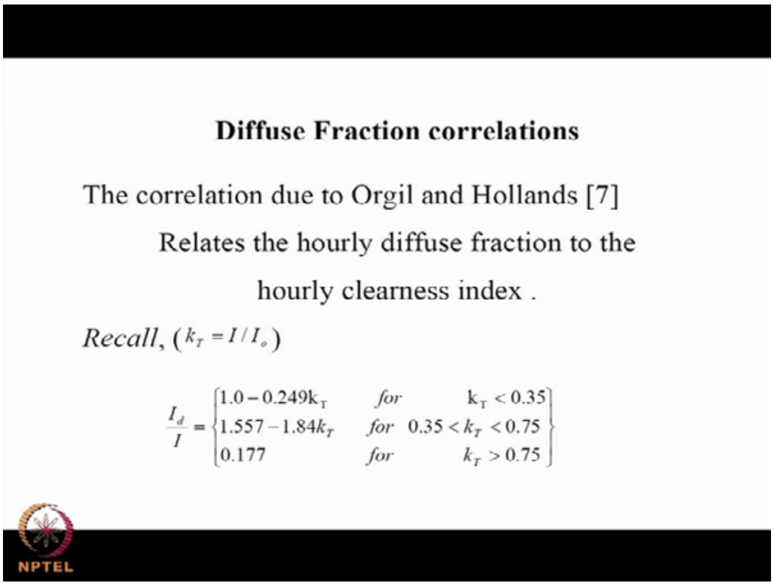

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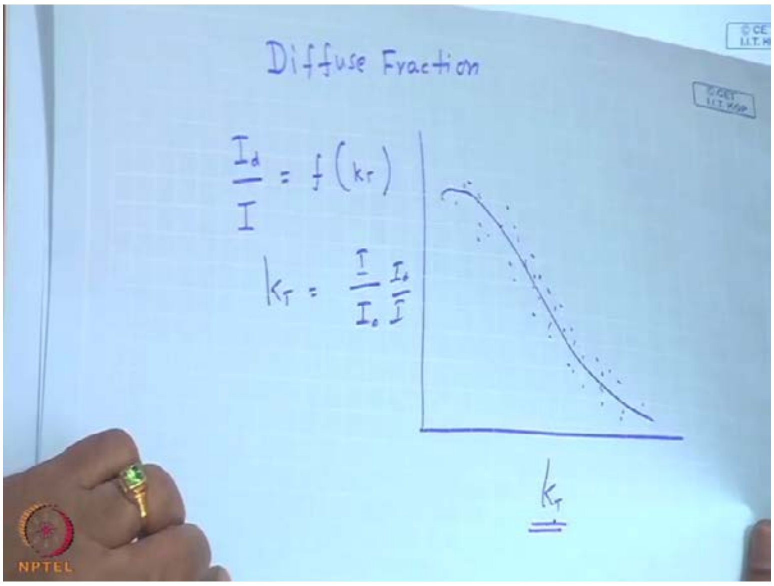

Original diffuse fraction correlations, Orgil and Hollands, expressed the ratio of diffused radiation to the global radiation as a function of hourly clearness index, which you may recall is equal to I upon I 0, which we have discussed in detail. Of course this relation I will not reproduce here I d by I is 1 minus 0.249 k t, depending upon the value of the k t similarly, another relation for k t between 0.35 and 0.75, and you have a 0.77 for k t greater than point one. So, if you try to plot this you will get some result like this; these are the equations, but if you plot the data there will a be lot of scatter. Now, that scatter may be due to k t only being not the correlating parameter or it may be some sort of measurement error, and most scientific reason is that the climate can be little bit erratic consequently one may not be able to correlate with a single variable.

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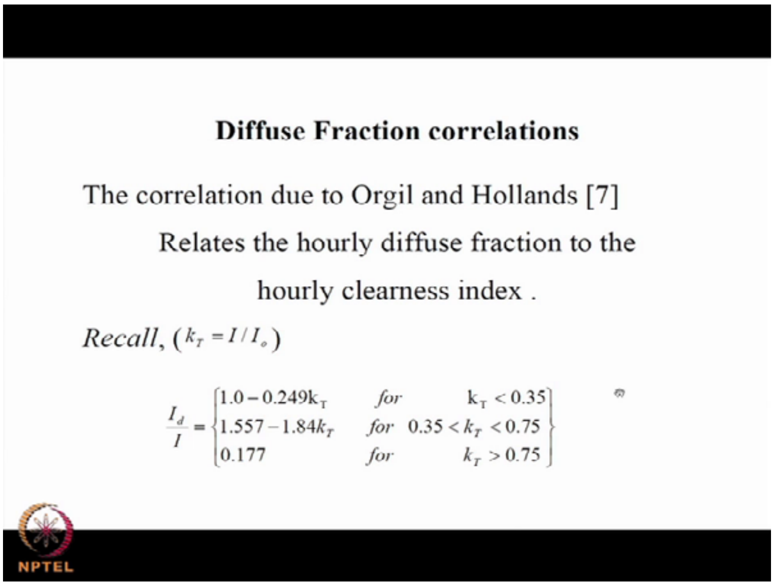

Now, you understand why we spend considerable time in introducing the so called clearness index.

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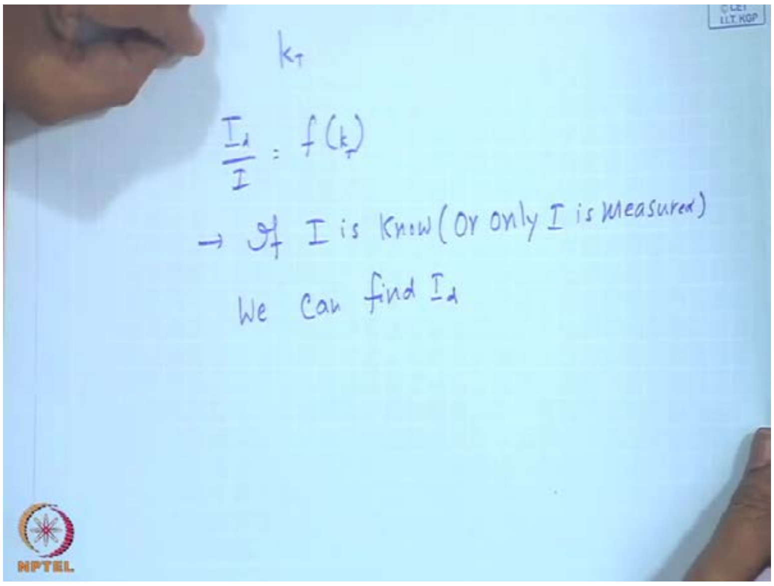

Now, you will see that this I d by I is a function of k t reasonably well represented and that correlation has been given by Orgil and Holland’s. Of course, you will ask what is the use of it the use of it is if I is known, in other words or only I is measured. We can find I d; this is one is that means the number of measurements that we are trying to make or reduced, but at the cost of of course, some accuracy, but later on we will see some 10 percent 15 percent difference in the estimated I d value. May or may not make much difference, whether it will make lot of difference or not we will find out from the relevant formula that we will be seeing in a little while.

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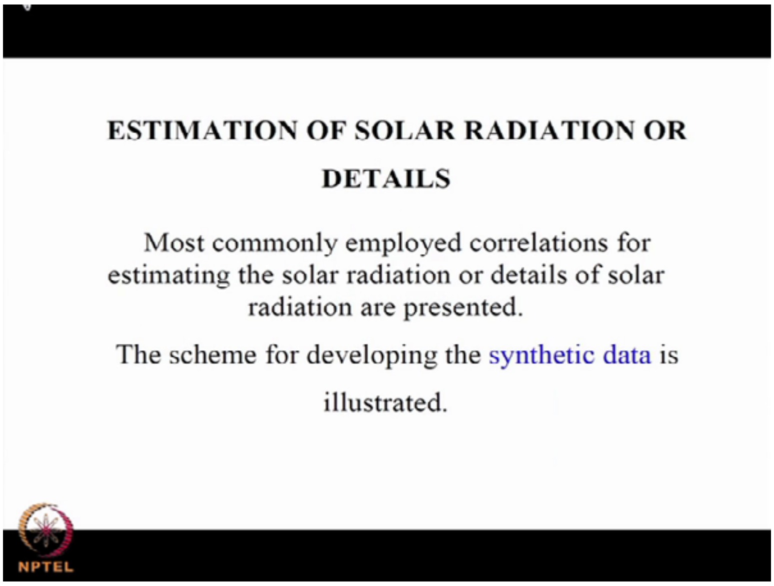

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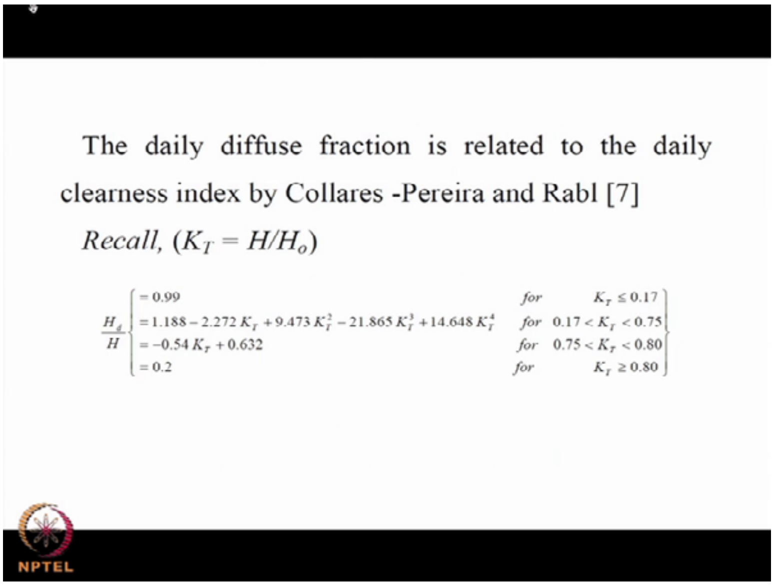

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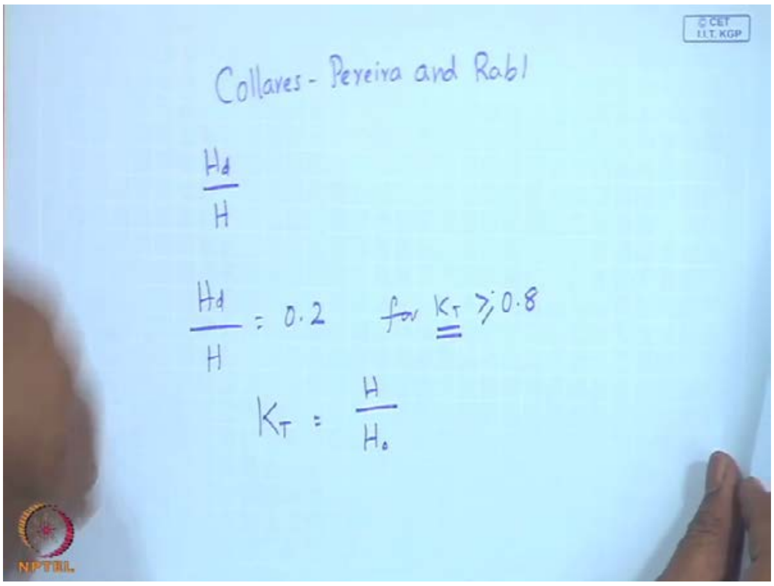

Similarly, Collares-Pereira and Rabl, they proposed a relation, similar ratio for the daily H d by h, again you can see at the screen, where there are four relations depending upon the value ofclearness index in the range of 0.17 in the range of 0.75 and up to 0.8 and K T greater than 0.8, and H d by H is a simple constant 0.2 for k t greater than or equal to 0.8, remind you this is the daily clearness index and that we know is H upon H 0. So, this means the number of days available with capital K T greater than point eight or far and few consequently, one may not be able to find much of an accuracy the global use a value of point two.

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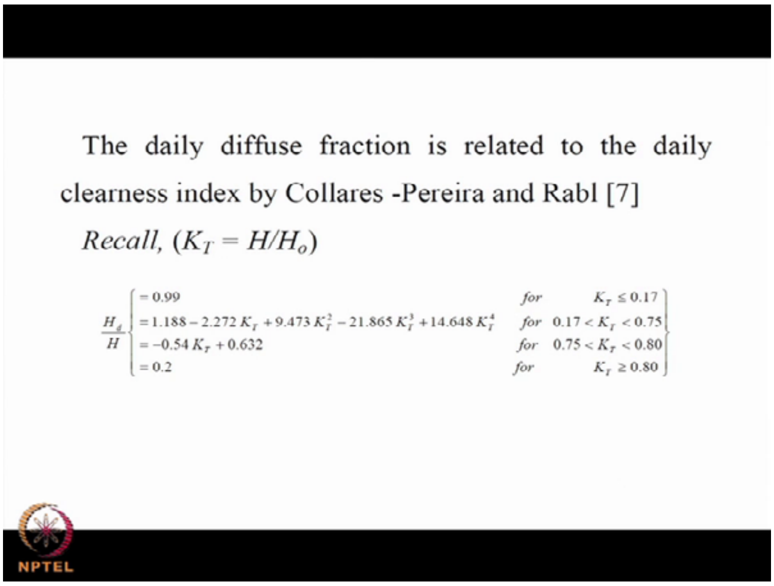

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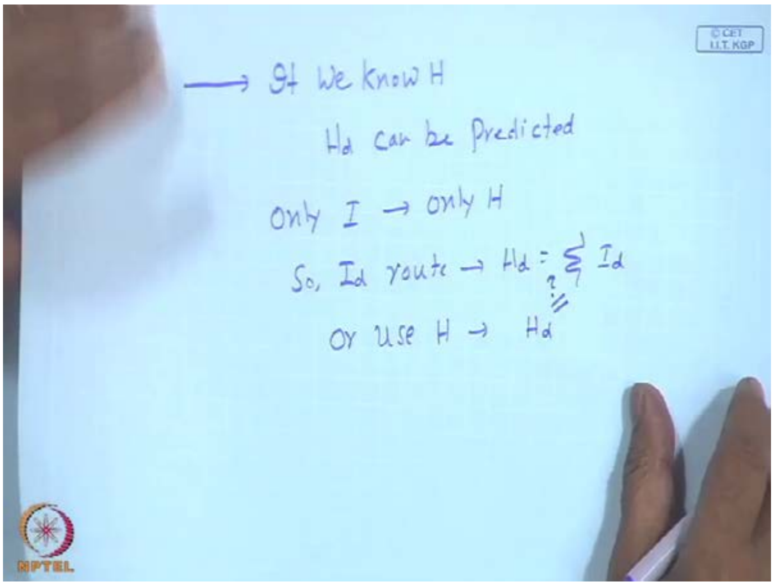

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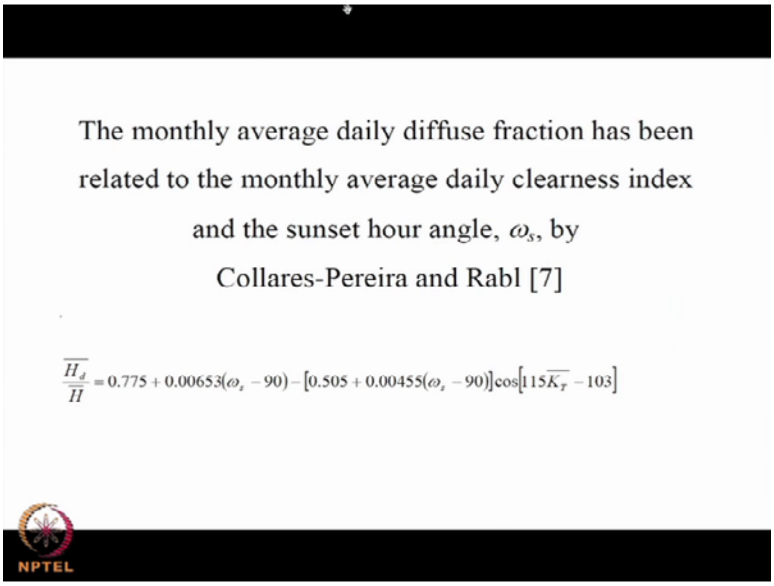

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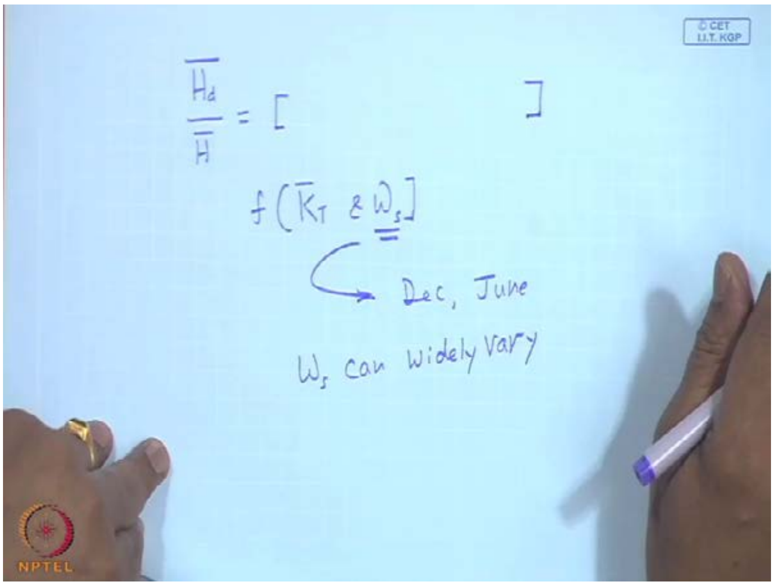

So like the hourly clearness index, this daily clearness index also has a role in predicting the daily or diffused fraction values, which again translates into, if we know H. H d can be predicted. Of course, we should realize that there will be a difference from an actual measurement and a correlation that is being used that means a consequence of only I gives us only H. So, I can go through I d route keep on predicting I d from the values of I or then get H d as a summation of I d or use H, and get H d. Now, there may be a difference between these two or this two equal, this could be a somebody can investigate this and find out which is a better one to use.

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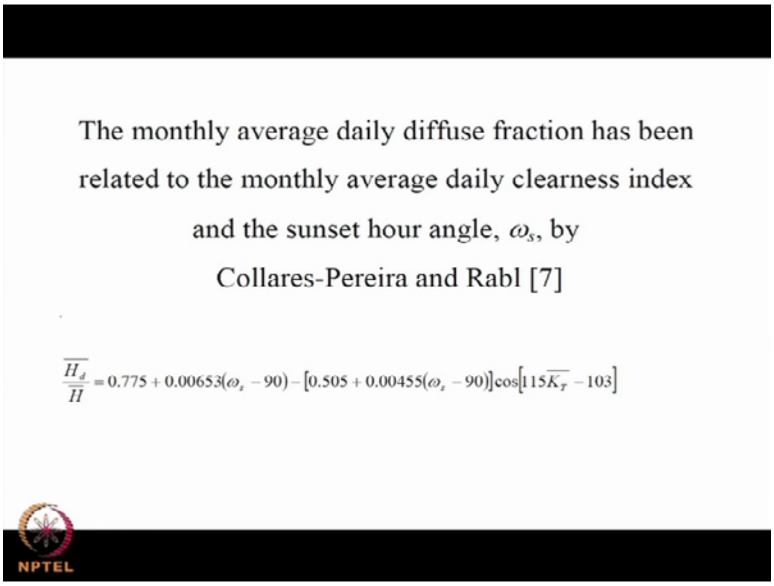

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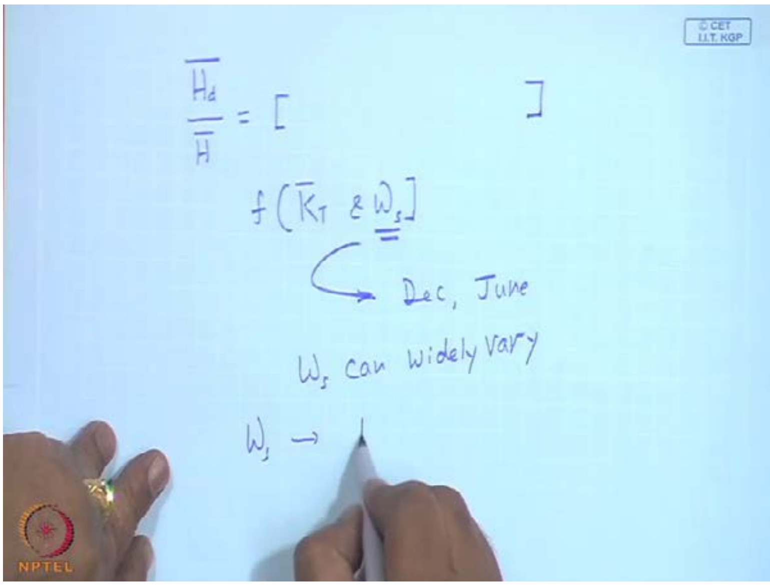

So, you can also see the previous correlation has about four parts, and the next correlation by Collares-Pereira and Rabl gives the monthly average daily diffuse fraction, as on the single equation which again you can see on the screen right, and now this is a function of K T bar and omega s. If you see this December and June omega s can widely vary. Consequently, if you have a large omega s like in summer; then H d by H value will be or you can calculate I think it will be lower and if you have a small omega s, you may have a higher diffused fraction. So, you can just check up for a value of omega s. Let us take 120 omega s 80, and find out what is H d bar by H bar then as a food for thought, you can try to explain on a physical basis why H d by H is larger or smaller if you have a higher or smaller omega.

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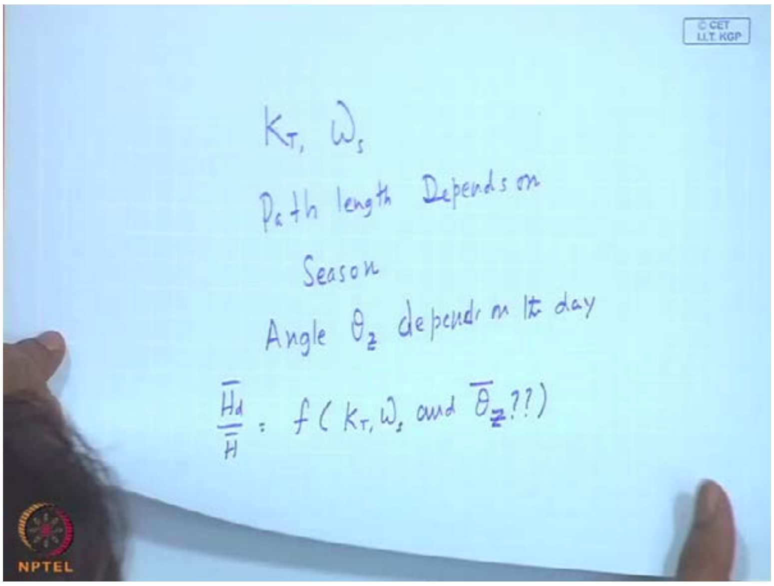

Also again some sort of a task for you to set you thinking, if you have got a function of K T and omega s, we know that, path length depends on season right, also your angle theta z depends on the day. So, I just propose your H d bar by H bar, may be a function of K T omega s and theta z bar. How I define this average angle of incidence for a horizontal surface, I do not have a ready answer, but somebody can think about it.

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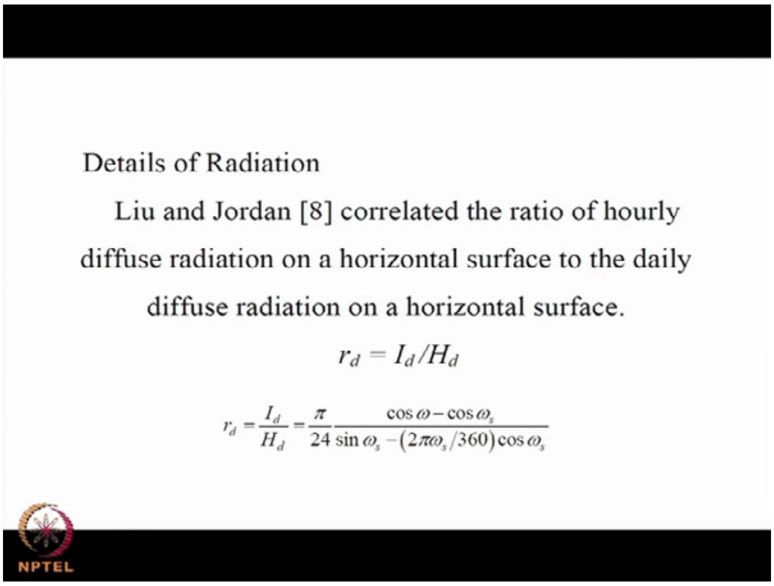

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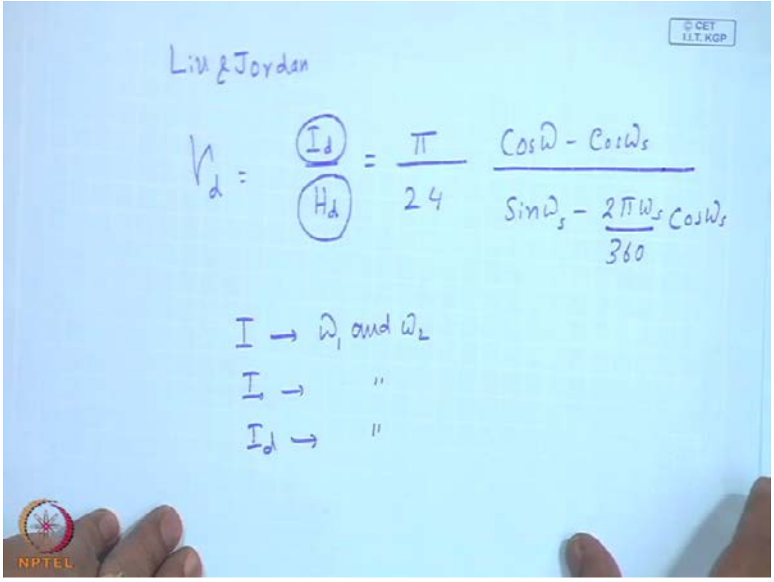

So, now again I can find out the diffused fraction for the monthly average day given the monthly average global for similarly, for the day and similarly, for the hourly values. Then originally Liu and Jordan, they proposed a ratio r d which is I d upon H d, please note that this is a ratio of hourly diffuse radiation to the corresponding daily diffused radiation, right. And this is simply given by I will write this is a smaller equation. There is a purpose I shall move this a bit here, so you can see that relation. Now, typically my I is between omega 1 and omega 2, I 0 also the same consequently I d also within omega 1 and omega 2.

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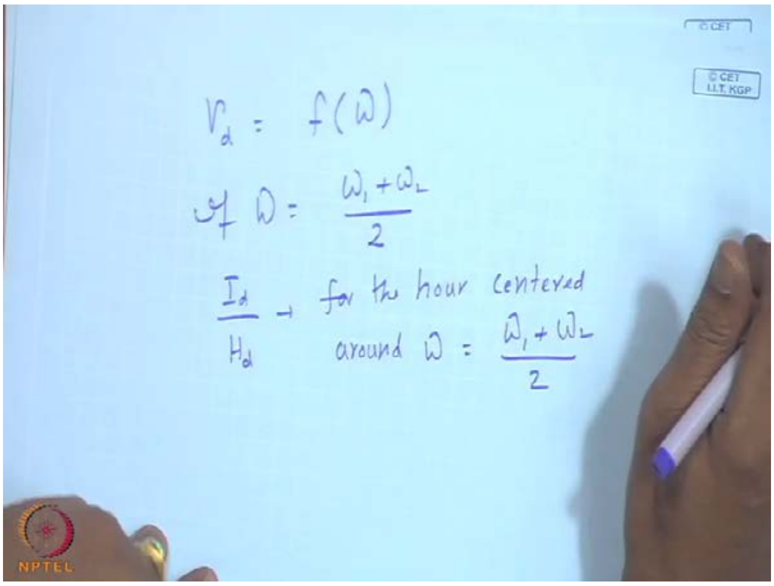

But, now r d is a function of omega, a single value of omega not an interval. So, if omega is the midpoint of the particular hour under consideration. My ratio of I d by H d will be for the hour centered around omega equal to omega 1 plus omega 2 by 2 In other words it is a continuous function and if you give a value of thirty two it will give you between 25.5 to 39.5 degrees. So, it is not necessarily exactly 1 hour from noon etcetera. But, depending upon the value of omega give you; it is expected to give you an hourly value.

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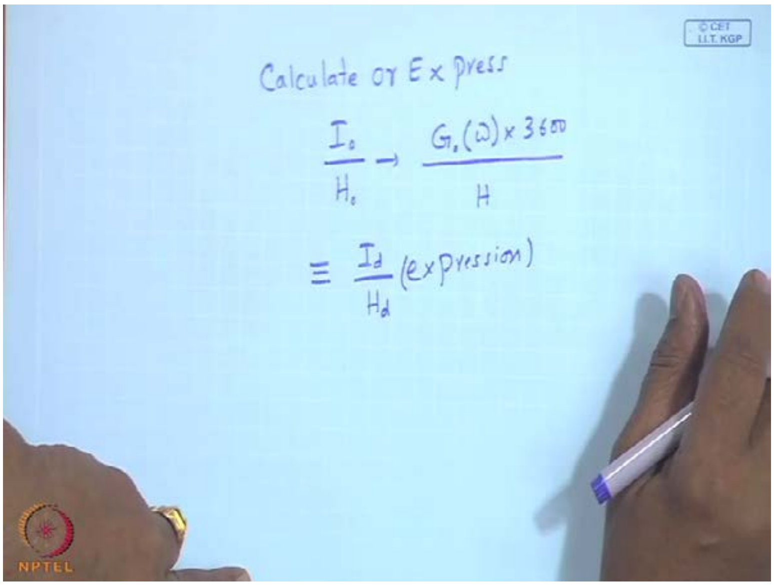

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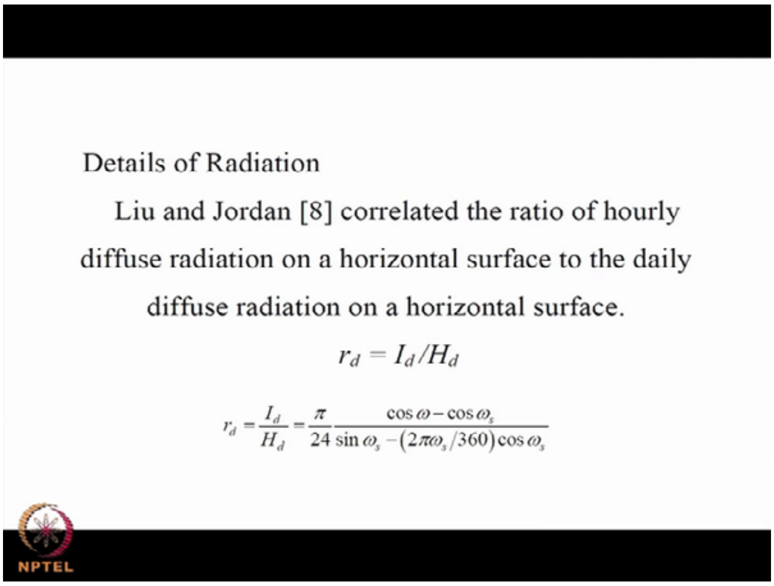

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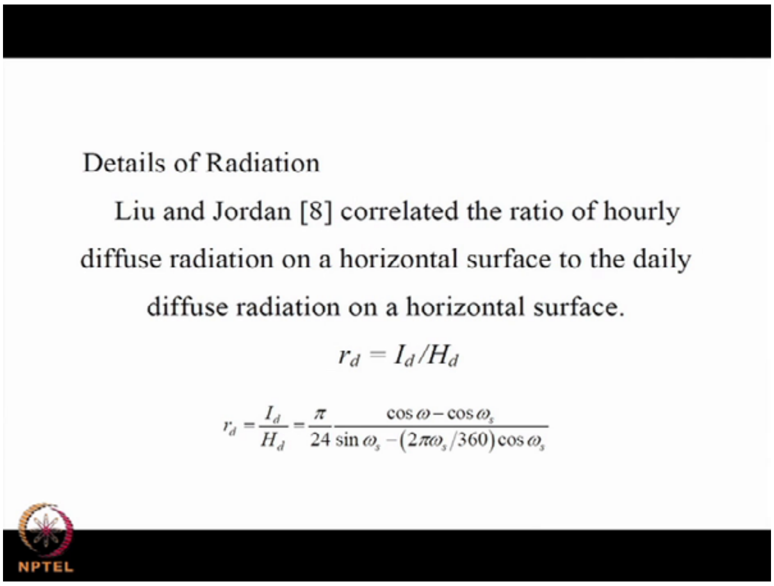

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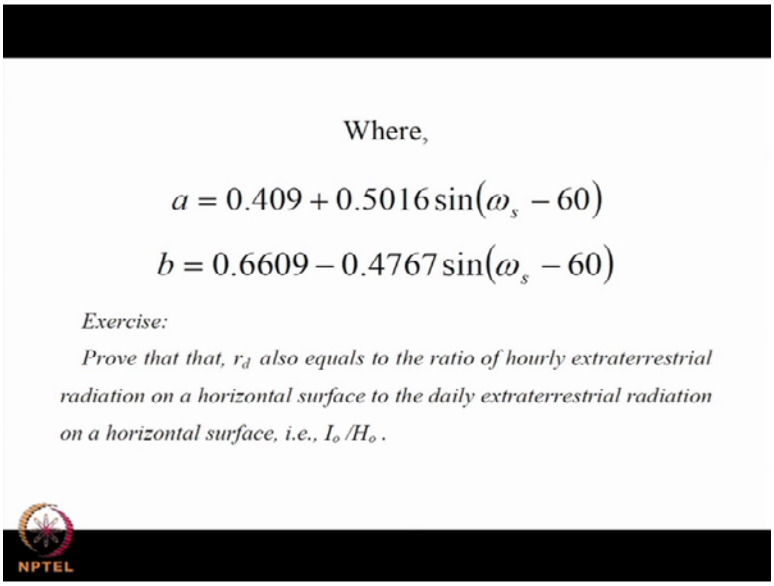

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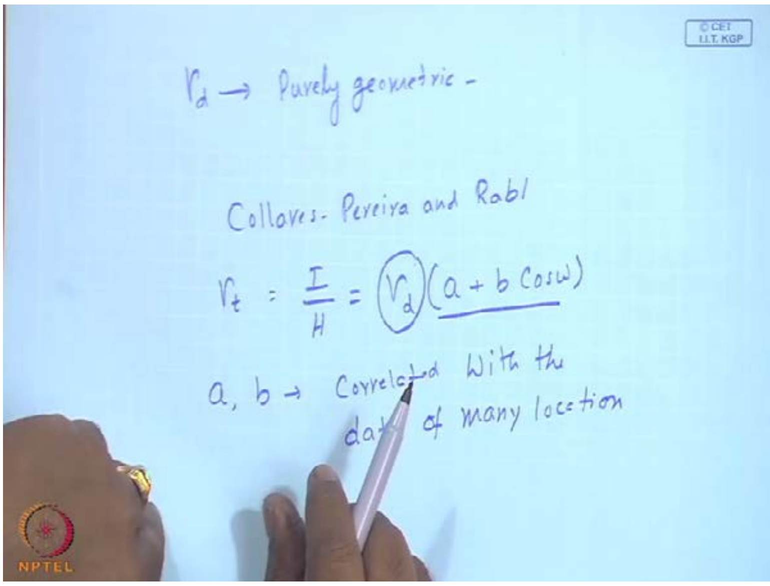

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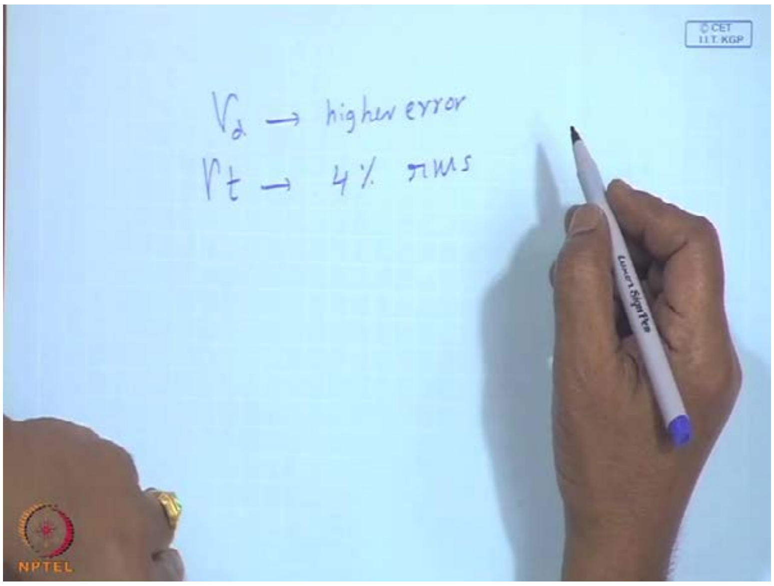

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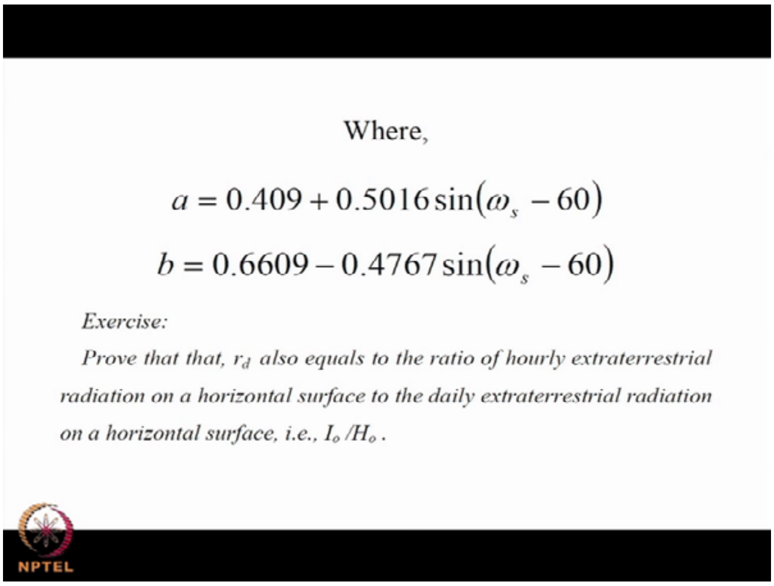

And one more comment is in order you calculate or express, I 0 by H 0 which is g zero at omega into 3600 because, we are calculating the midpoint by H zero this will be identically equal to expression, not numerical values not necessarily the numerical values This cos omega minus cos omega s by sin omega s minus 2 pi omega s etcetera, that is derived just one can take extra terrestrial radiation ratio it will be equal to I d by H d. This at one point of time was a bit surprising.

Later on certain issues were resolved, now you will also find that r d purely geometric factor, in other words no matter what your clearness index is and if you are having a particular day length and omega, you will have exactly the same ratio. So, this is something that makes you feel uncomfortable however more things will follow little later.

Again Collares-Pereira and Rabl, express r t, which is the ratio of hourly global radiation to the daily global radiation; it is I will write it for simplicity as r d into a plus b cos omega. Where a and b are given in terms of certain constants and the sunset hour angle, so interestingly this is also geometric, but these a and b are correlated with the data of many locations. In other words, if you attenuate this theoretical ratio sort of by a factor changed by omega s, with these constants you will get a expected distribution of I by H. Now, you can expect r d in general as a higher error, and r t is typically about 4 percent r m s, you have to understand the root mean square error meaning or that is actual errors can be larger, but that is the sort of an average error or whatever I was mentioning I left it as an exercise over here, prove that r dalso equals to the ratio of hourly extra terrestrial radiation on a horizontal surface to the daily extraterrestrial radiation on a horizontal surface. That is I 0 by H 0 I gave you sufficient hint you can just verify and make sure that what I said is right.

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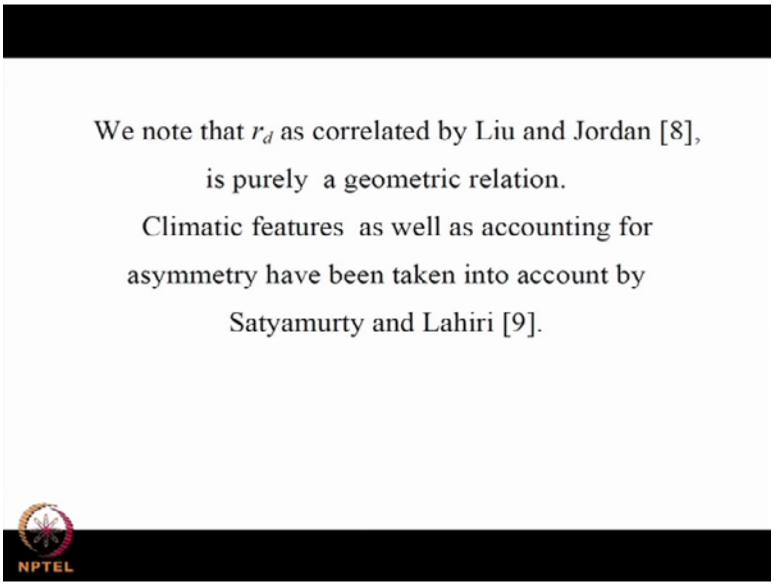

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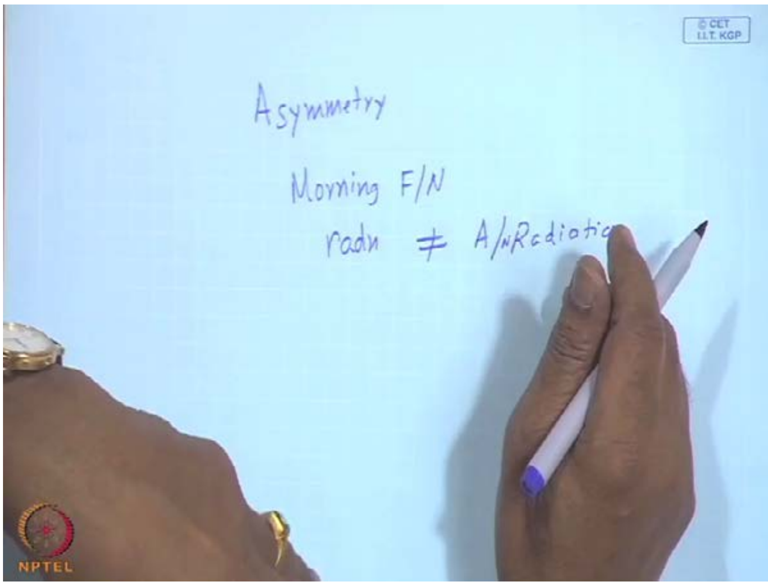

So, later on work at energy lab at, Kharagpur has taken into certain climatic features in developing correlations for r t and r d including a symmetry; a word about the symmetry because that is a very advanced topic less than understood, not yet possible to really formulize it. Generally morning that is fore noon radiation is not equal to afternoon radiation. If you look at these correlations it looks like solar radiation distribution is symmetric around solar noon whereas, or in reality the morning may be higher than the afternoon radiation and vice-versa there is no specific geometric bias, but both kinds of locations are observed it has got to do with a lot of meteorology, which is responsible for the formation of orographic clouds which sometimes, will produce more diffused radiation or more cloud cover affecting the radiation in the fore noon part or in the afternoon part.

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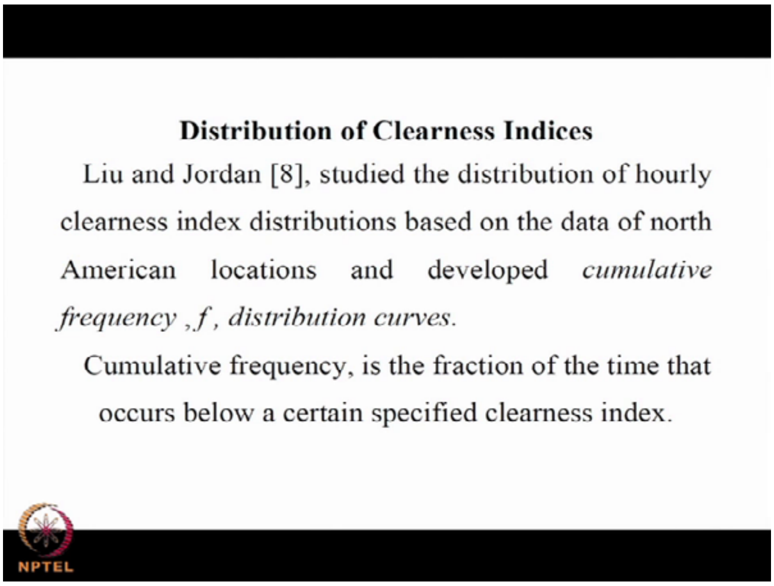

Now, we will go to what is meant by distribution of clearness indices. So, based upon the North American locations again, Liu and Jordan.

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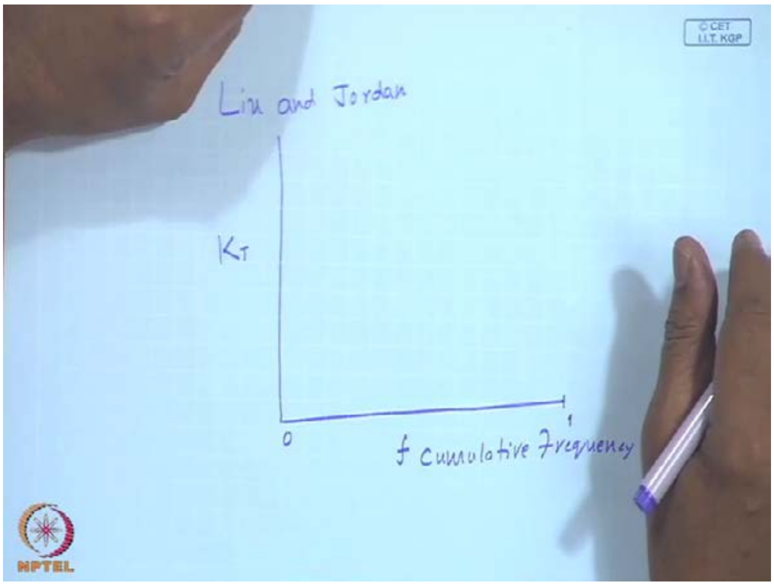

They developed a curve for clearness index versus cumulative frequency, which will vary between 0 to1, I will explain in a minute what is meant by cumulative frequency, this is nothing but the fraction of the time that occurs below a certain specified clearness index.

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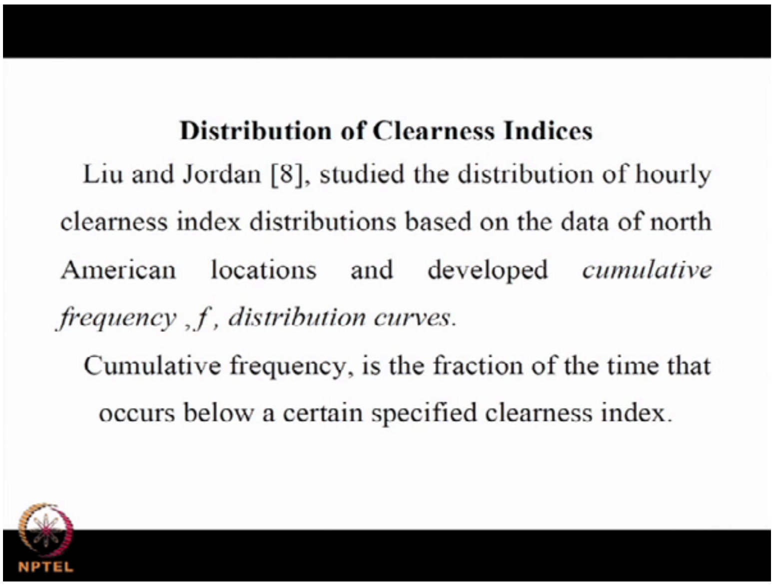

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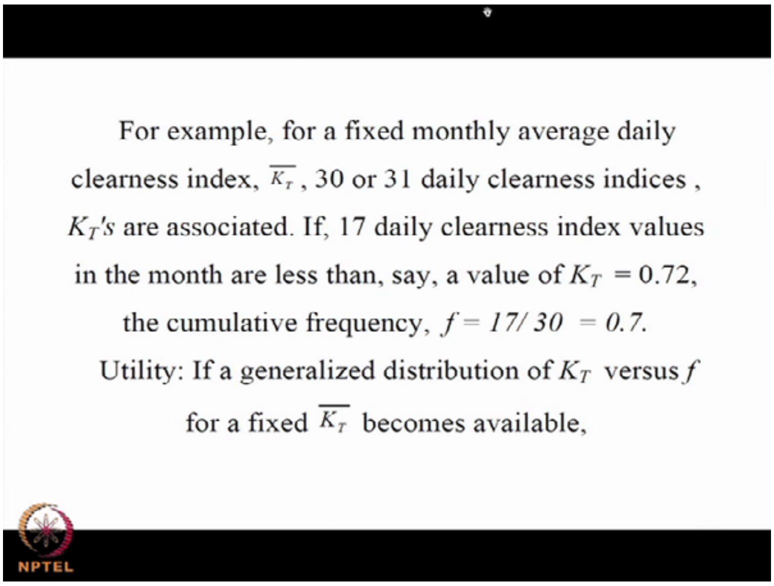

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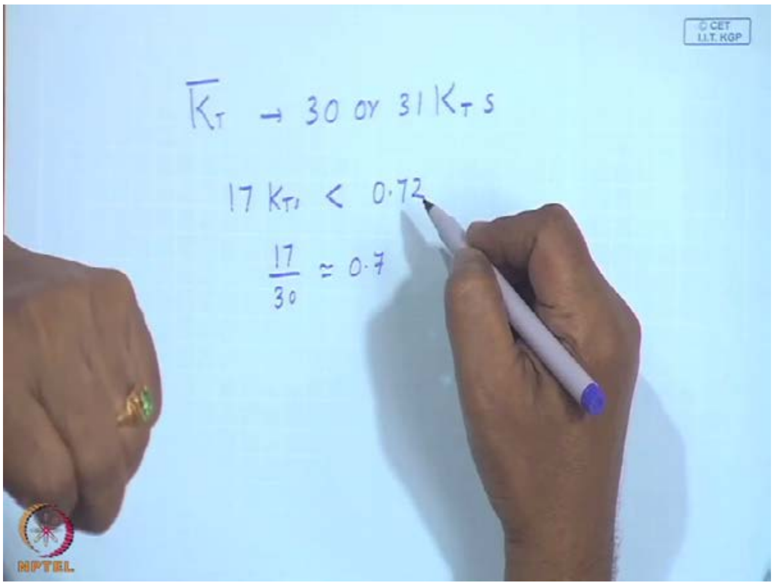

So, translated in simple terms, if you consider a monthly average daily clearness index of K T bar, there are thirty or 31, for a given K T bar, you have got 30 or 31 k Ts. Now, we find 17 K T is less than 0.72, so the fraction is 17 by 30, which is about 0.7. So, my cumulative frequency is 0.7, if your capital K T is 0.72; that means 77 percent of the days will have a clearness index less than 0.72.

This you can more easily understand in terms of the percentile of the marks if you have got 20 or 30 students and the minimum is let us say 21 percent and maximum is 76 percent, and if you find out how many people got below 22, 23, 25 like that, compared to the total number if students will be the cumulative frequents of occurrence.

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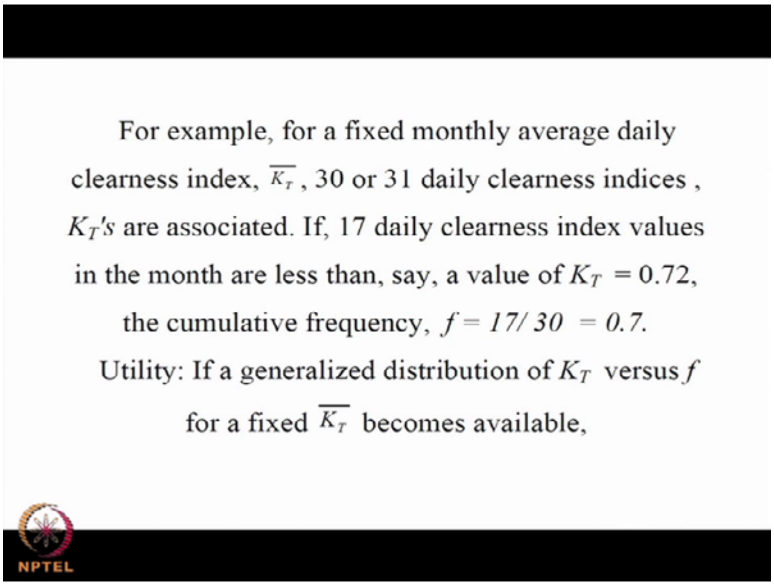

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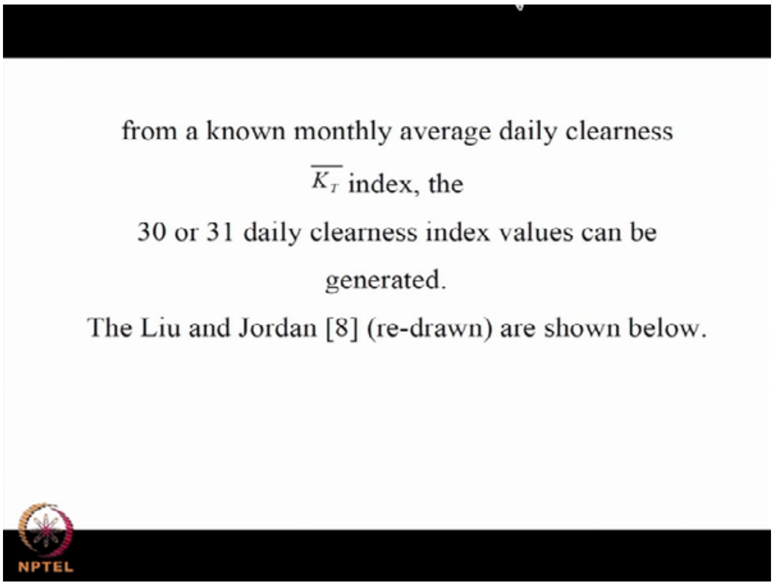

So, the utility is if you have a generalized distribution of K T versus its cumulative frequency, you can generate all the 30 values, in other words.

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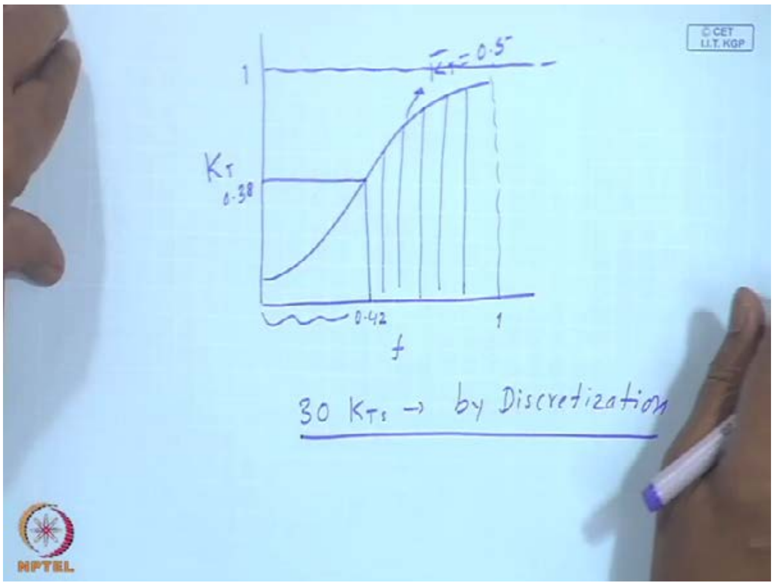

This is f, this is capital K T, this one curve this may be belonging to K T bar is equal to 0.5, obviously this will be 1 this may be slightly less than 1, because this K T 0.9 or 0.8 will be a very high value. So, if I choose a point for to mark and go this may be point, let us say 38, we can say that 42 percent of the time the clearness index is less than 0.38, so this many days or this much fraction of the time, we will have a clearness index less than this value of point 38. So, if you discretize it into 30 parts, I will have 30 K T s.

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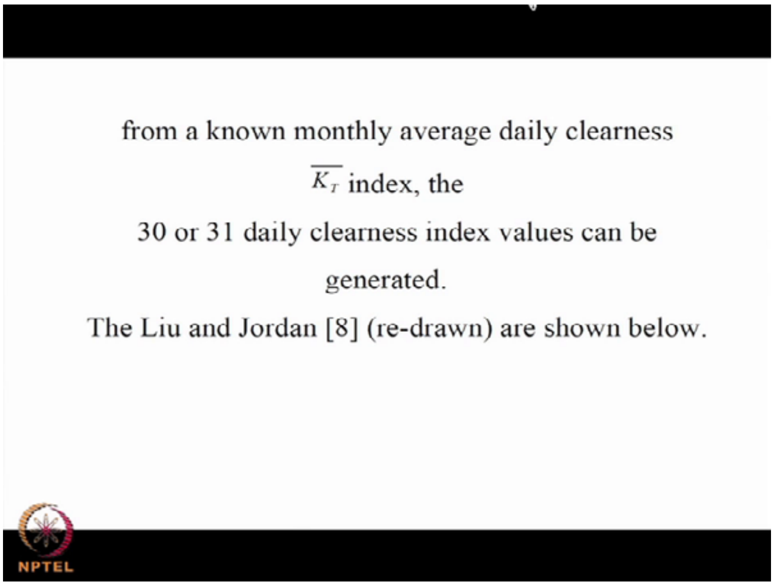

This is of course, in general can be told in terms of the fraction of time, but for the ease of understanding for easy understanding, I just made it a each day because that is the way the daily clearness indices were drawn developed.

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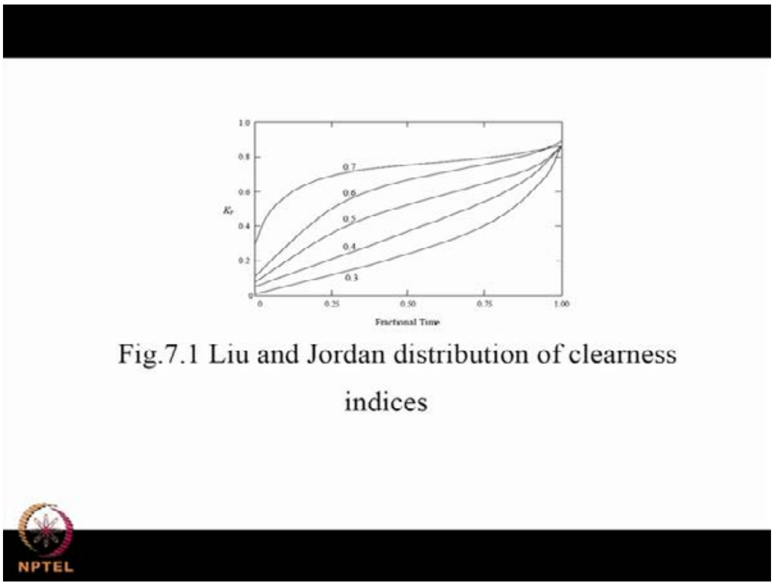

So, this is redrawn figure of Liu and Jordan, you will find that interesting features.

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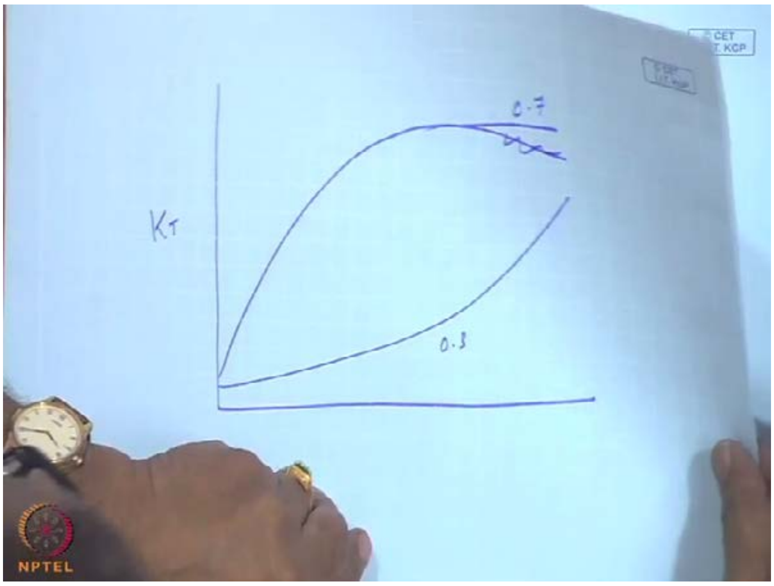

If you take a low average clearness index of 0.3 and then a higher clearness index of 0.7, sorry it does not groove down it should go up 0.7, you will find that there are more number of values towards the lower end and there are more number of values towards the higher end once again you can easily understand, if the average number of marks in a class is 92 percent. Many students must be having a higher percentage and if the average is 38 percent many students must be having lower numbers.

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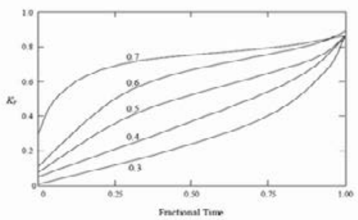

Fig.7.1 Liu and Jordan distribution of clearness indices

So, this is the trend that can be expected, and what you will find is that minimum K T at zero f is quite a bit where in between like something like points 0 to 0.3, though not so much the higher end of 0.9, which is also understandable if the average is low or high, the minimum value of the clearness index can vary a lot whereas, the maximum there may be a single day with a 0.8 or 0.9, so they coincide.

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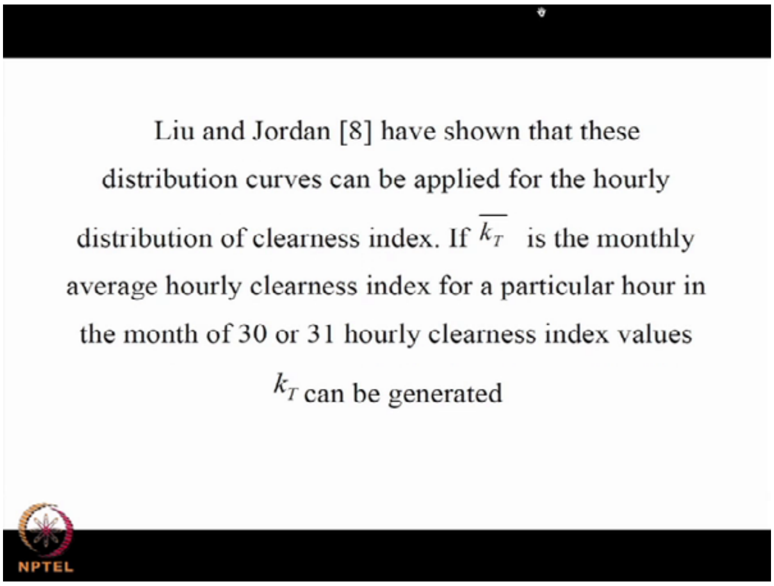

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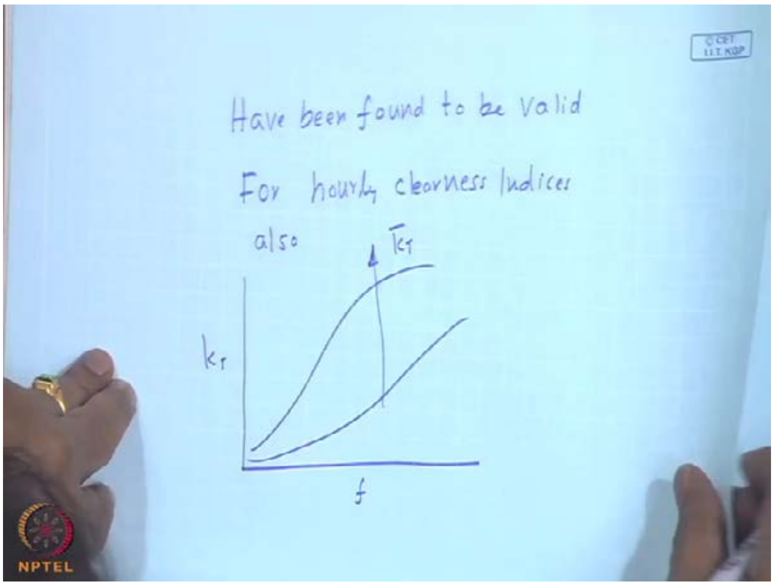

So, these curves have been found to be valid for hourly indices, also in other words you just have the same set of curves f, we make it small k T here, and this is small k T bar. So for a given numerically equal hourly average clearness index to the daily average monthly average of daily clearness index, you have the same frequency distribution.

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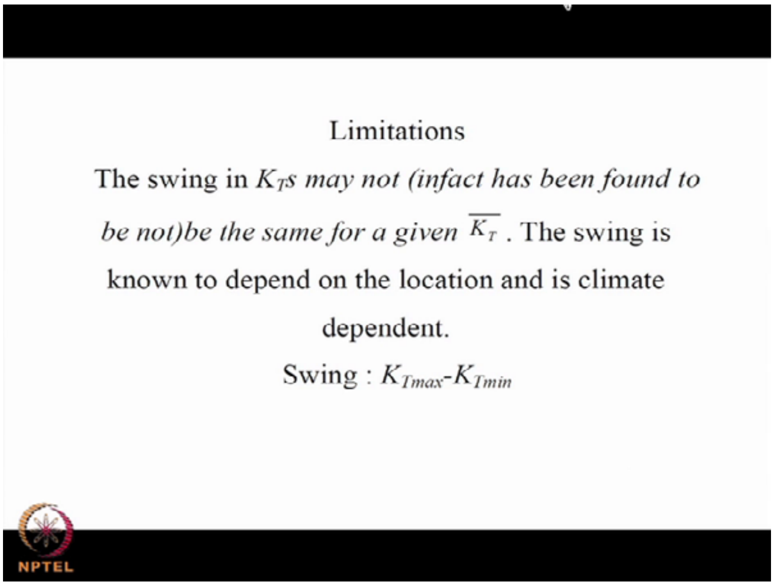

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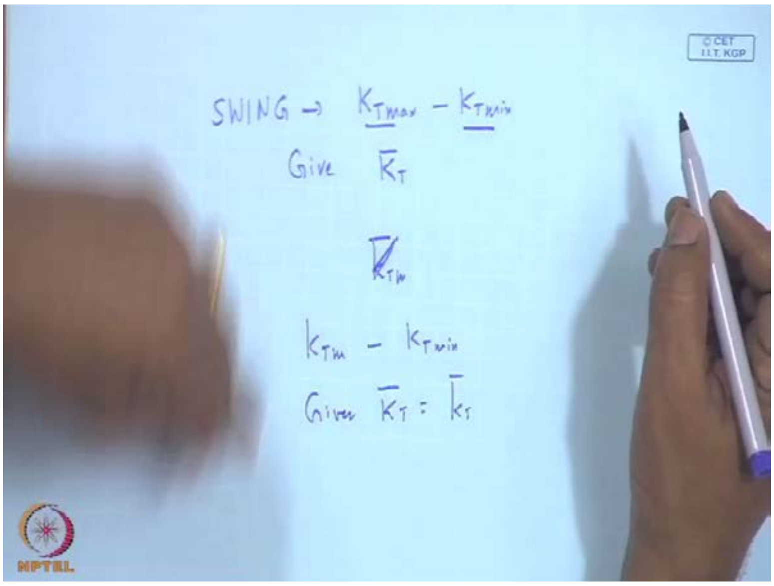

This comes as a bit surprise and could further be examined, the reason is if you have the daily values and I define the swing as, first thing I can think of this swing can be different for different locations and even different seasons. For example, if you consider a tropical climate like Chennai for example, and more or less all the days are uniform so the swing will be smaller and whereas, if you consider a similar average value but, at a higher latitude, there may be one cold day there may be a rainy day then; the variation between maximum to the minimum is likely to be different this much can be said from location to location.

Similarly, if we have oh sorry hourly K T maximum minus hourly K T minimum given K T bar for numerically equal hourly average and daily average values. The swing in the hourly values I can expect to be little higher than the swing in the your daily values. So, these features can still be considered and examined.

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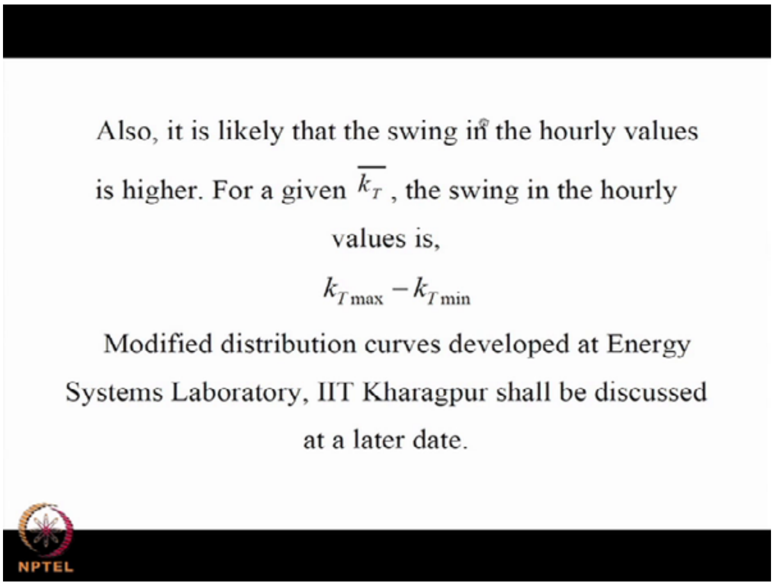

And we have developed some modified distributions and which will be discussed as a part of a advanced topics.

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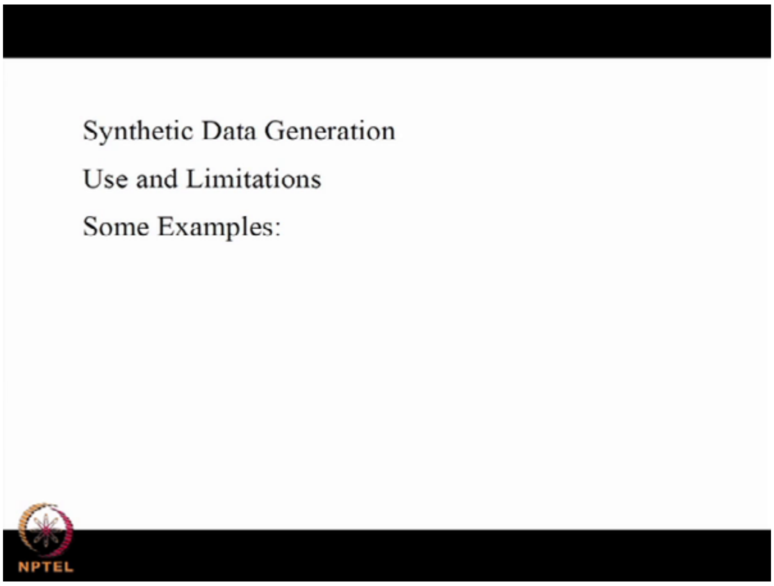

Which maybe skipped for a under graduate person and then we will go ahead with these things for the whatever textbook are directly available.

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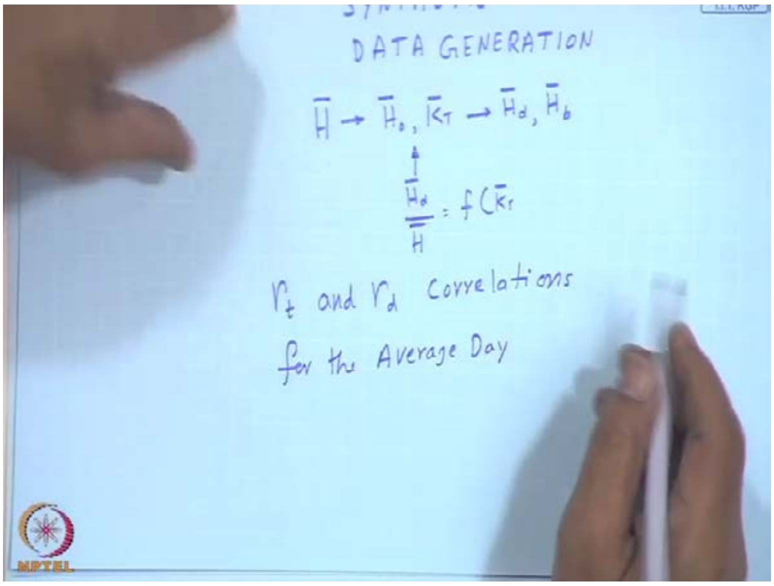

So, now I shall go to utilizing all the correlations, which we have written as a part of also synthetic data generation. We may not have all the missing links, but some links which we use; so I shall show from the sort of a flowchart you start with H bar on the right hand side I will be showing that you can calculate what is H 0 bar and K T bar, from there you can calculate H d bar, diffused part. And also of course, H b bar. If you want how we have the correlation for H d bar by H bar; so the input I can show it like this H d bar by H bar is a function of K T bar. Now, I use r t and r d correlations for the average day.

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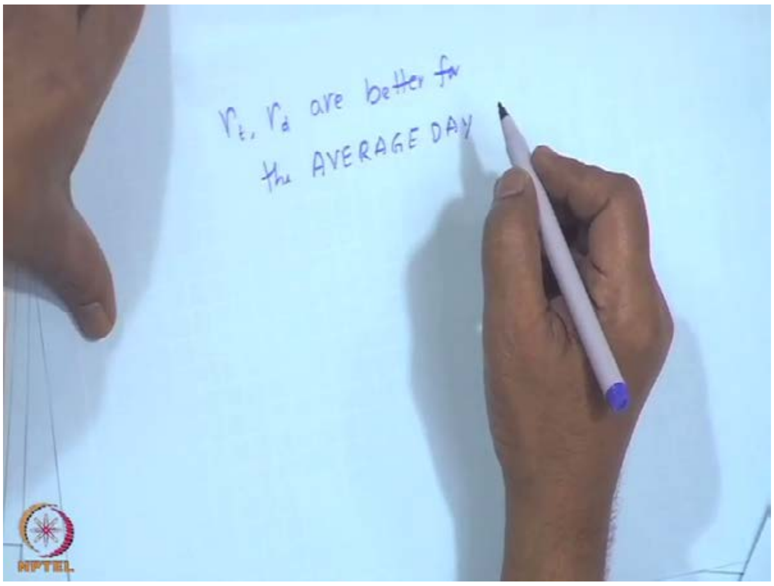

In fact, these correlations we can expect, that these r t and r d correlations to yield better accuracy, when applied for the average day than for a single day, because the averages will be smoothing out the hourly values, and it will generate a pretty good distribution and that is what you have.

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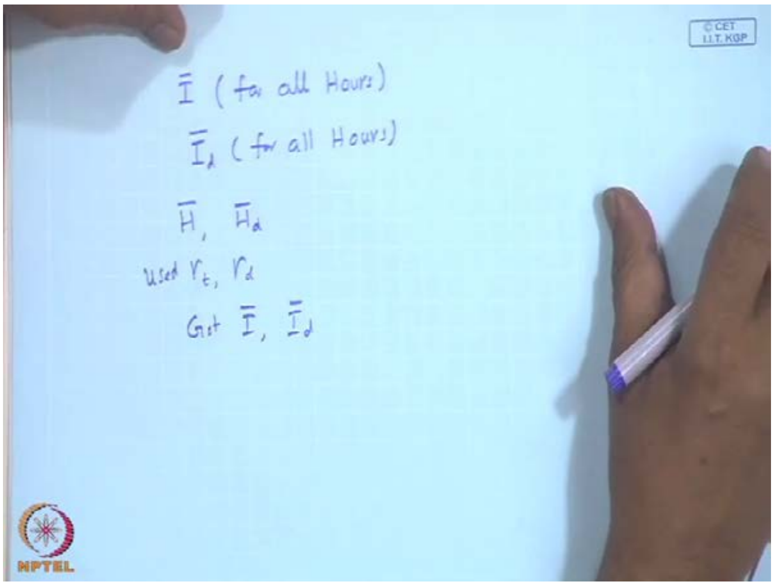

So, if I use r t and r d correlations then I can have what we defined, earlier I bar for all hours, and then I d bar for all hours. So, let me recalculate I used H bar obtained H d bar then used r t r d got I bar and I d bar. In other words form the given simple monthly average daily value, we could generate the hourly average of course, hourly values of global radiation and the diffused radiation right. When once we know the formula, which we will we will appreciate even more why these things become necessary and why we are trying to talk about more of I and I d and trying to get it from H or H bar and I.

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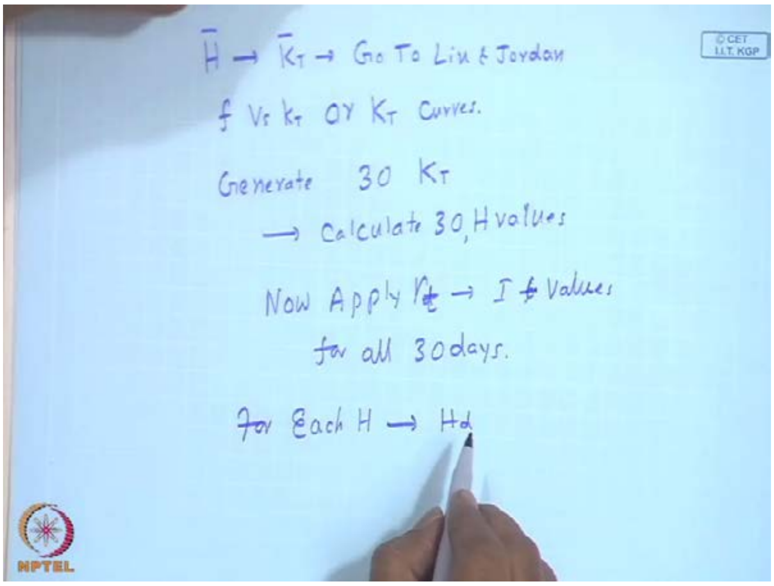

Similarly, from H bar since I know K T bar, go to Liu and Jordan f versus K T or capital K T curves generate, 30 K T; so from this calculate 30 H values, when once you have now apply r k sorry r t correlation, which will have I values for all 30 days. Now I have one part for each H I can get a H d by applying Collares-Pereirarabl’s correlation for the day, not the monthly average.

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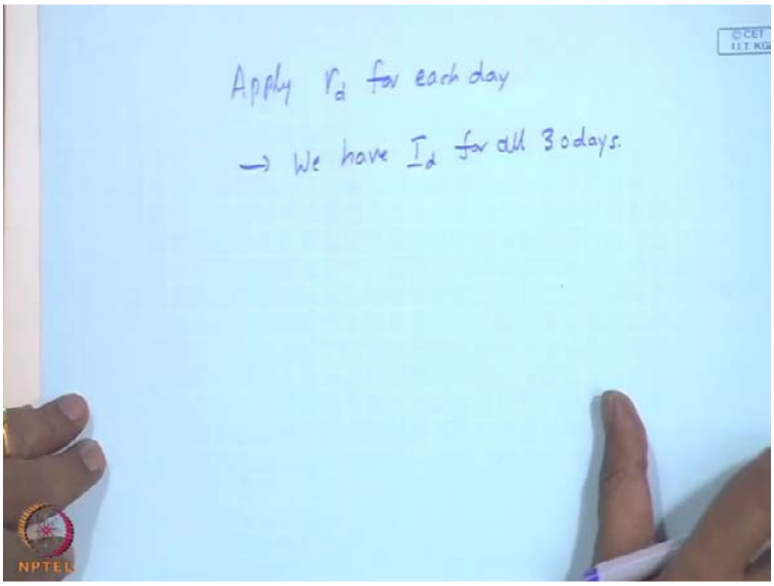

And apply r d for each day, so we have I d 30 days. So, in summary we should be able to say given the monthly average clearness index or monthly average daily radiation, we can make use of Liu and Jordan’s cumulative frequency distribution curves. And apply r t and r d correlations for individual days or for the monthly average day and generate, the needed hourly values for the 30 days. So, in this process we cannot assign a sequence what is January 1 or January 2, but we can generate a sequence of 30 numbers, which we will may able to randomize, and then use for our simulation studies.