Solar Energy Technology
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Lecture - 03
Terminology Extra-Terrestrial Radiation
Terrestrial Radiation

So, we shall talk about extra-terrestrial radiation, so that we will have an idea of the magnitudes in work from which, whether there is a possibility to predict or measure the terrestrial radiation.

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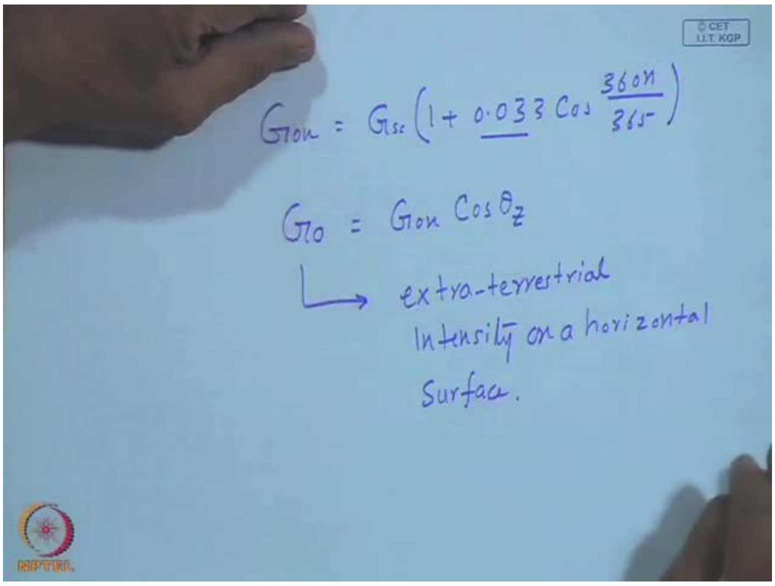

So, we just had the simple relation Go n is G s c 1 plus 0.033 cos 360 n by 365. So, this is nothing but the radiation normal to the plane. This is because we defined G s c as a solar radiation on a plane normal to sun's rays kept at a distance sun to earth mean distance. If I use the current distance, it gets modified by the elliptic nature of rotation of the earth by this amount, which is about plus minus 3 percent. So, from the angles we have defined so far, so if I multiply with the cosine of the zenith angle, I will get a horizontal surface. So, that is what I have recalled this equation.

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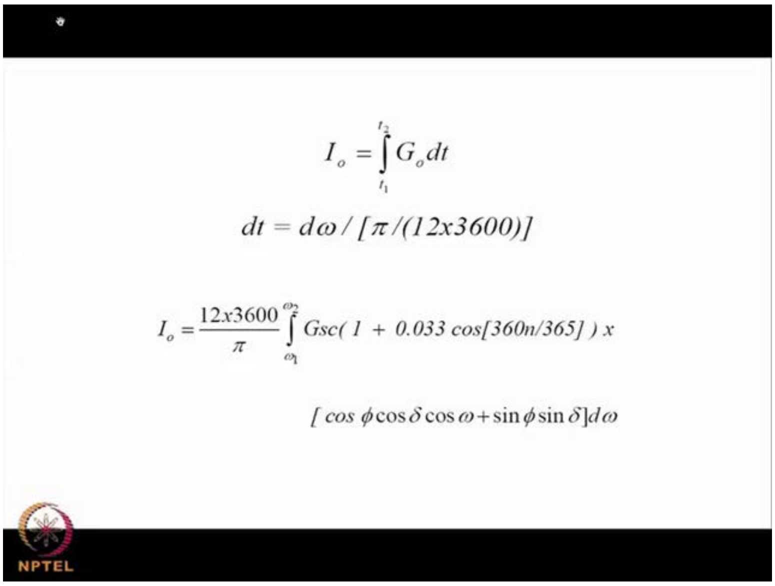

Now, this is the intensity. We know that intensity is varying with time. So, I want for any time interval.

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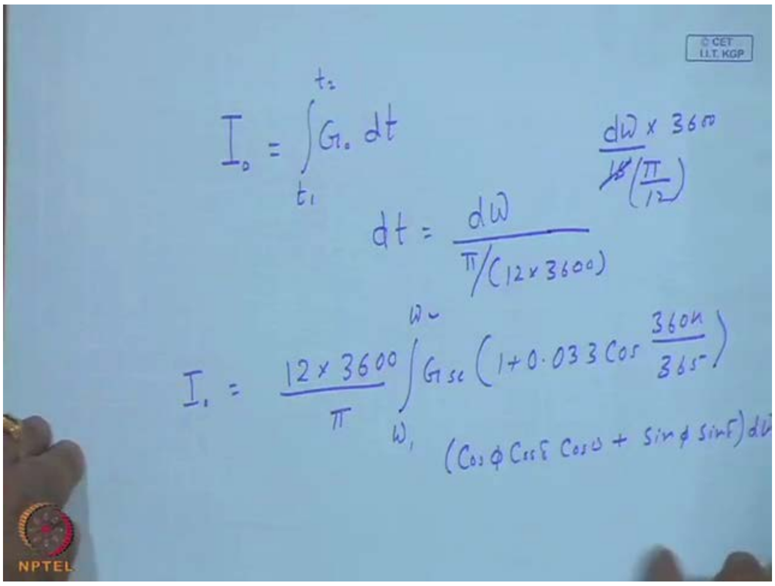

We have introduced this. So, if we integrate the G o. It is nothing but the G o n into cos theta z where G o n is G s c into that ellipticity passed. My function is in terms of the omega. So, d t can be nothing but d omega by pi by 12 into 3600. Actually, it is easier if you say that d omega by 15 is the number of hours multiplied by 3600 is seconds 15 is nothing but pi by 12.

So, that is how you will get that time converted into d omega s d omega divided by pi by 12 into 3600 within brackets. Then, I 0, I do not rewrite that expression. Its integration is this cos phi cos delta cos omega plus sin phi sin delta is nothing but the expression for cosine theta z.

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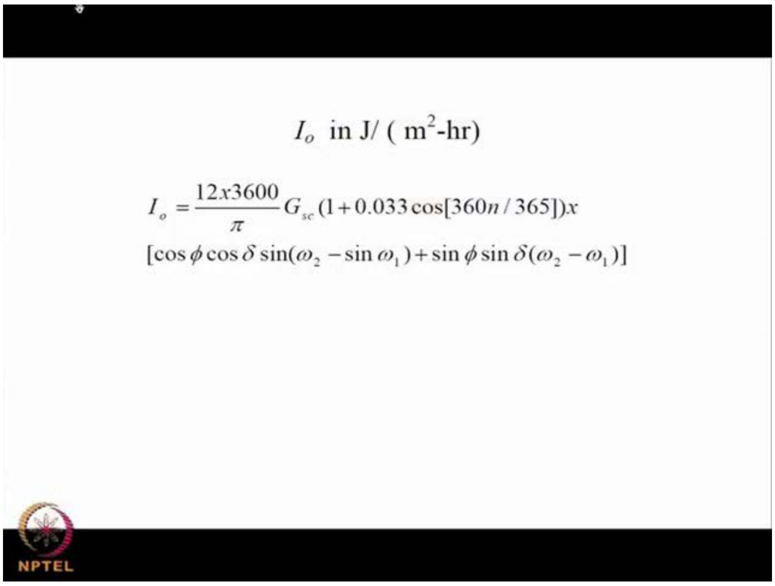

So, this can be easily integrated. You will get in terms of that cos omega integrated becomes sin omega in the limits. It will be this bracket should not be there. It should be sin omega 2 minus sin omega 1. You can just take it. Then, this is sin phi sin delta into omega 2 minus omega 1 agreed. So, this is I will rewrite as 0.

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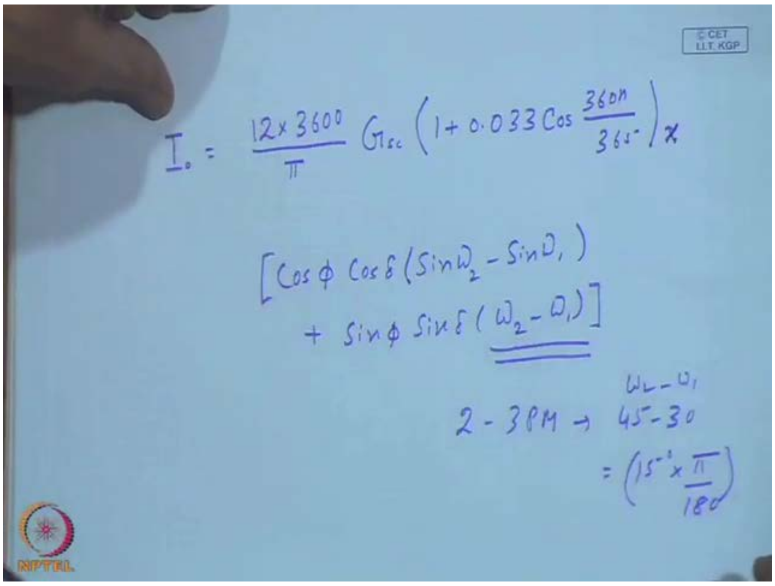

This x is a multiplication symbol because it split into 2 parts not x. so, this is the expression. So, this is almost a standard phrase that G s c into 1 plus 0.033 cos 360 n by 365 from which you can construct I0 H0, whatever it is by integrating over the appropriate time interval about radiance. This is where to be careful. Suppose that it is 2 to 3 p m. Then, this will be omega 2 will be 45 minus 30, 15 degrees. Then, I have to multiply by pi by 180; otherwise you will get a too larger number here.

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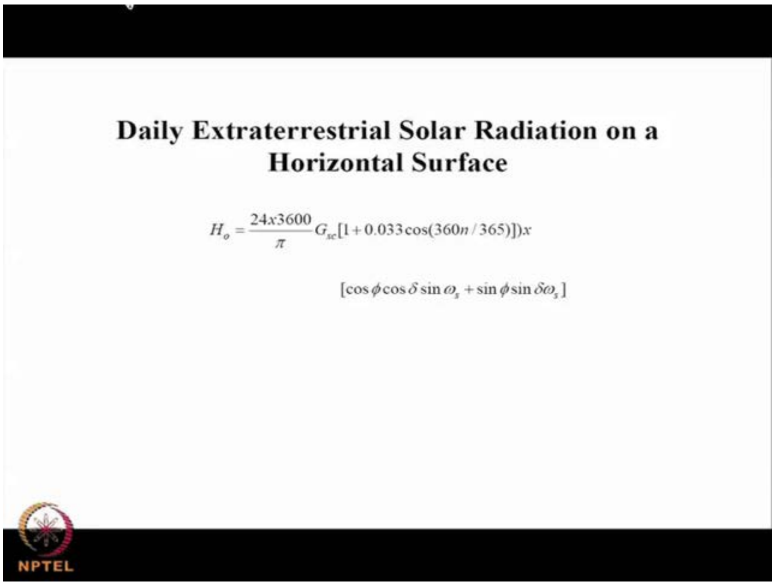

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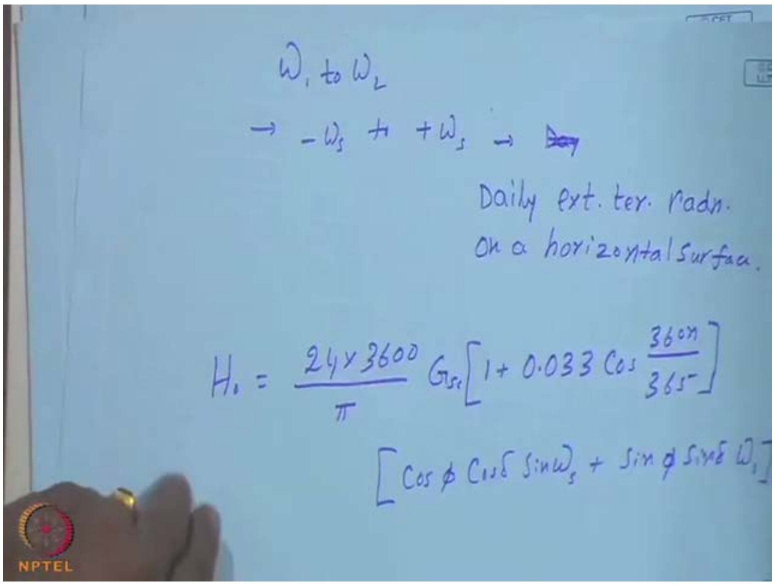

Now, if I choose omega 1 to omega 2 as minus omega s to plus omega s, then that will be there? This is because instead of that time interval being omega 1 and omega 1, if it is a symmetric function, you can write it as twice of 0 to omega s or minus omega s to plus omega s. That is how you will get a 24 instead of 12 and a sin omega s and here sin phi sin delta into omega s that too is observed in that 24. We will call it H0.

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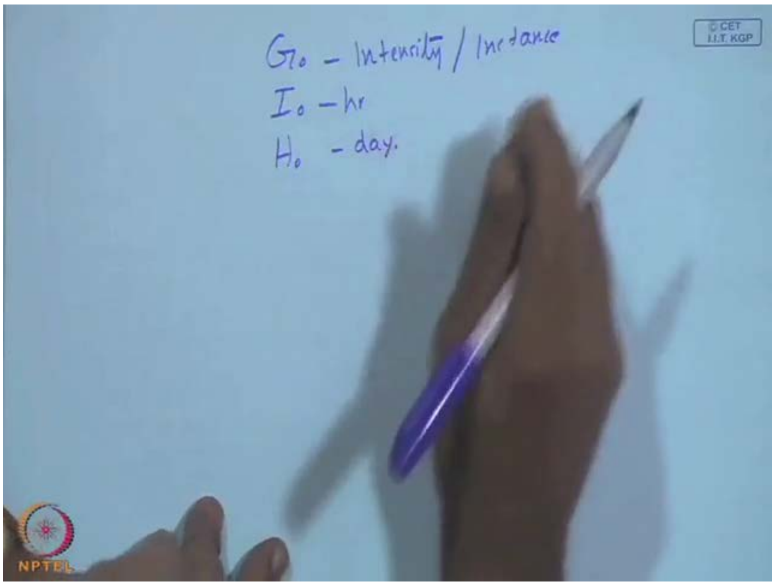

Now, what we can do? We can calculate G0 at any instant. I can calculate I0. I can calculate H0 for a re instant. For a given time of interval t 1 to t 2, it can be an hour. Generally, this is used for hour. This is in intensity or instance. This is day.

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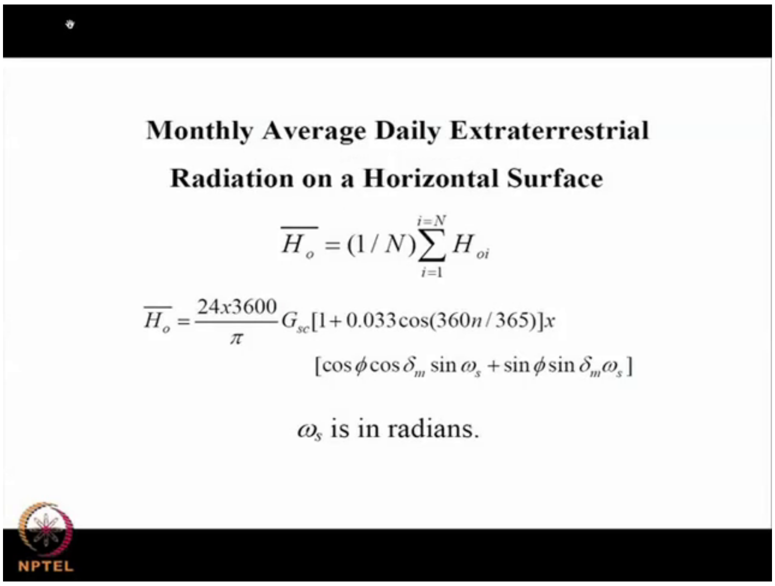

So, it is good if I can deal with daily values, if I know H0. Suppose that there is a relationship between what is H. That will be little more accurate than I0 to corresponding I, which there may be higher variation in a particular hour rather than for the entire day. That is one of the reasons why we try to go for longer time period. Then, we define these accompanying notes that will give you the exact full names because these are all long.

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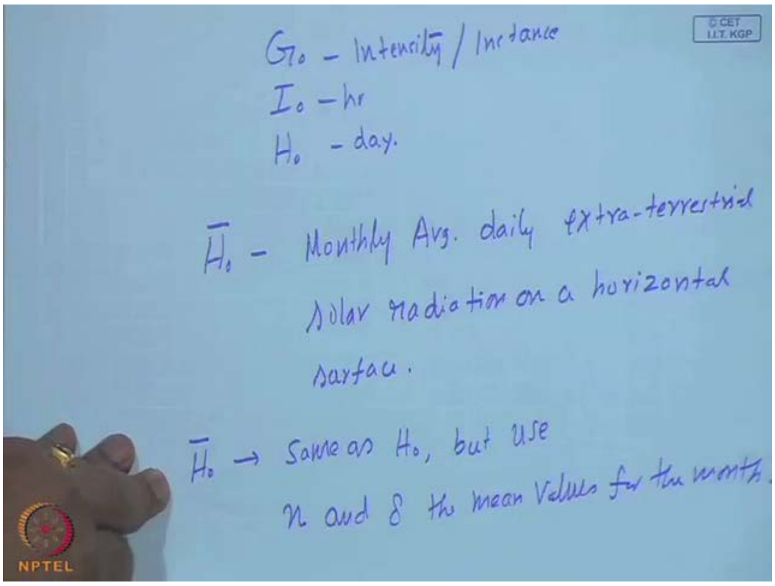

This is monthly average daily extra terrestrial if you want even solar radiation on a horizontal surface. So, generally these are bar alls. Bars are all averages and 0s are extra terrestrial. If t is tilted, if it is not there, it is on a horizontal surface. That is how we will later on distinguish and this H0 bar. I will make it simple same as H0M, but use.

So, H0 bar has been defined as summation of each daily extra terrestrial value divided by the number of days in the month. That can be easily calculated of the same formulas H0. You do not have to make 30 calculations and get the average and fairly accurately value. You will get it if you choose the midday of the month and the corresponding declination.

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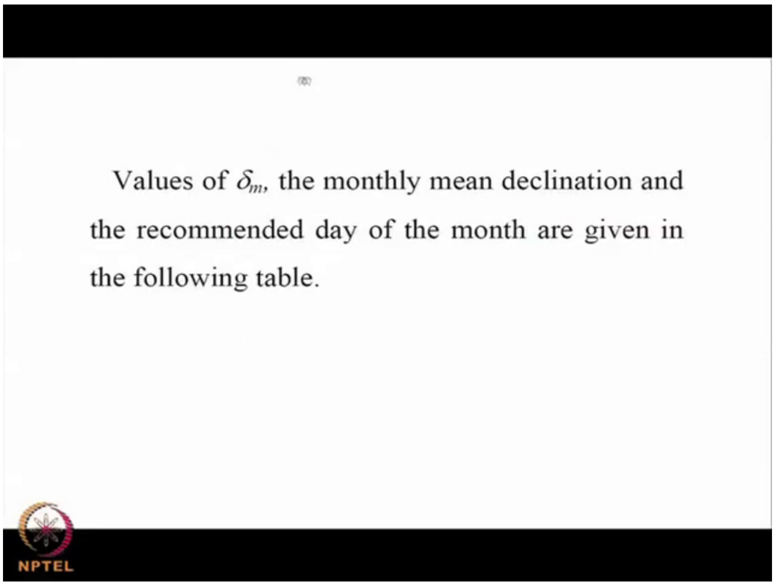

There is a small table, which gives you this delta m and the recommended days.

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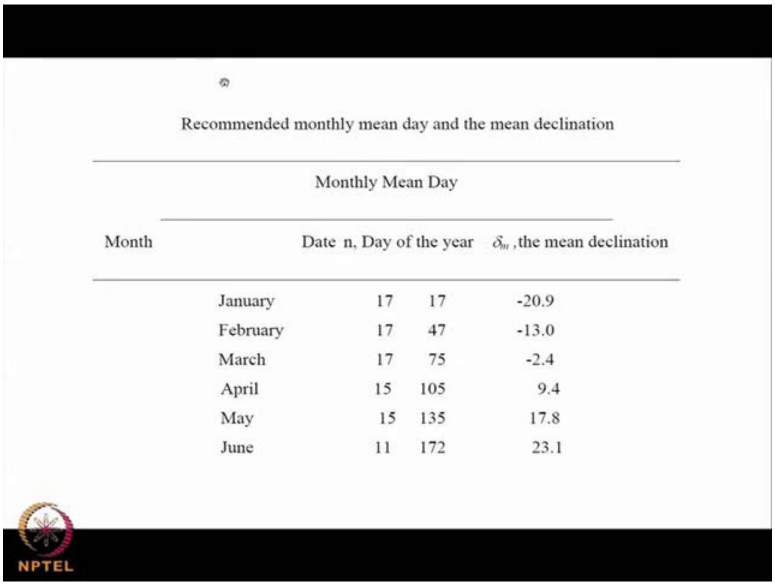

Recommended monthly mean day and the mean declination

Month	Monthly Mean Day: Date	Monthly Mean Day: n, Day of the year	δ_m, the mean declination
January	17	17	-20.9
February	17	47	-13.0
March	17	75	-2.4
April	15	105	9.4
May	15	135	17.8
June	11	172	23.1

I will come to you the history of it and how January day 17 and day of the year also 17. The corresponding declination is minus 20.9. For February, it is the total. These are all the Julian dates that 17, 47, 75 continuously number and the terms of this. We have almost around fifteenth of each month except June. It is eleventh, which you also can notice that the change in the declination is more non linear. Between May and June, there is almost 6 degrees change, which is not the case at other places.

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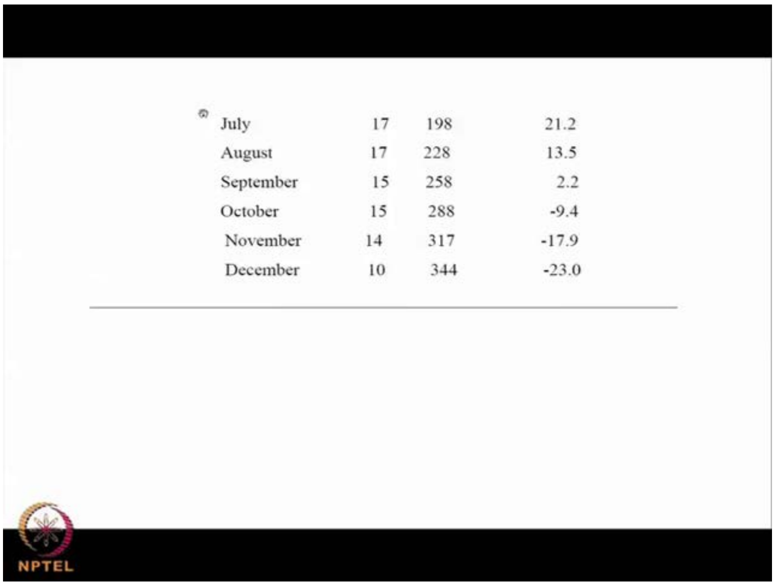

July	17	198	21.2
August	17	228	13.5
September	15	258	2.2
October	15	288	-9.4
November	14	317	-17.9
December	10	344	-23.0

So, like that, July and up to December, these are given. Actually, you do not need.

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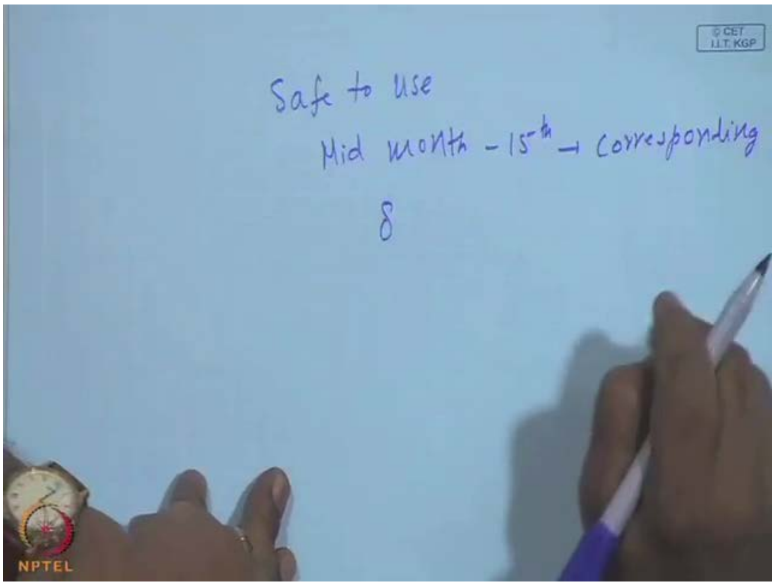

Safe mid month may be 15 and the corresponding. If you know these things, you are otherwise just the non linear. It is so small. It does not make any difference. Now, you might wonder how these numbers are derived, is it some mean day has been invented or defined or it is exactly sort of a back calculation. H0, I of each day has been calculated and the average has been found out. They found an untended delta, which gives closest value to that. So, you calculate for the month of January 30 H0 values find divide by 31.

You will get the average that turns out to be if I use n is equal to 15 and delta m is equal to minus 21.9, I will have the same number. It will lie closest in between 2 numbers. It will lie. Now, whichever it is close, it will be recalled mean declination and the recommended value. There is another advantage. Most of the time, for other processing of monthly average processing, you can use this midday concept and the mean declination.

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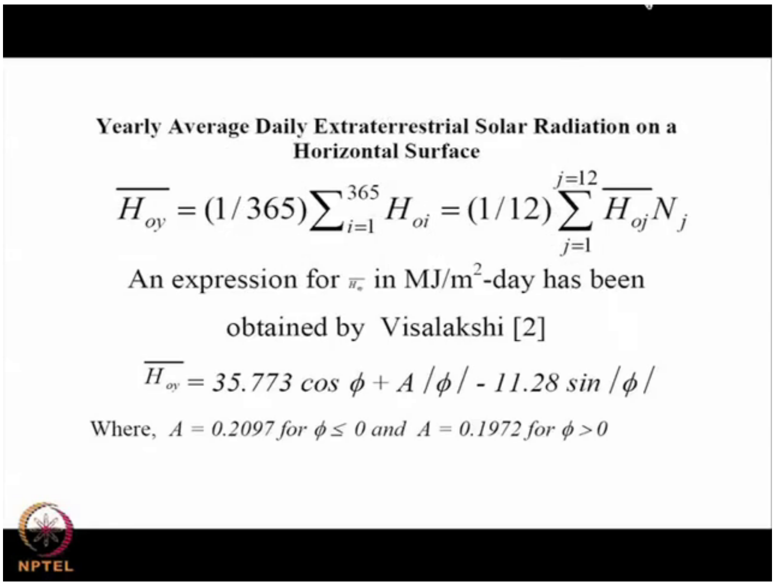

This is a little extension done here.

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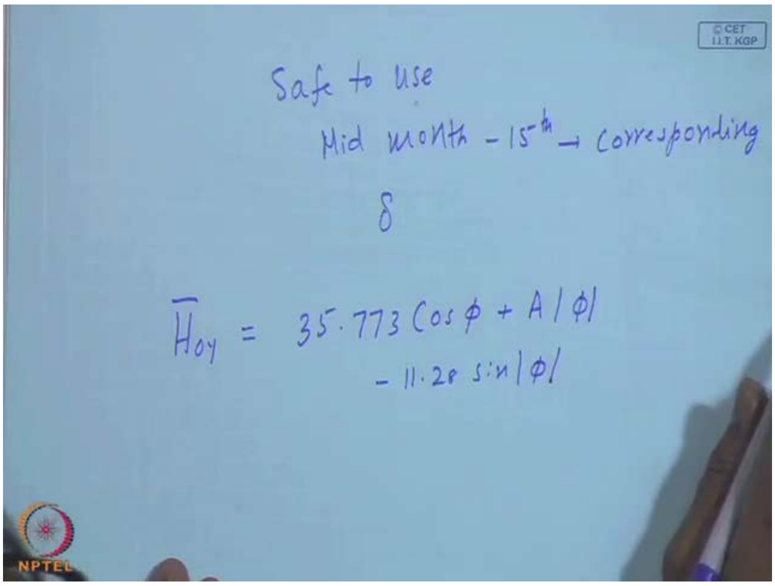

Similarly, I can define for the year average. This could be very useful if you want to make a single calculation for the entire year. So, that is what the solar radiation is falling on the root surface or other corresponding terrestrial value. You can use this. This is again defined as 1 by 365 plus all the summation or 1 by 12 of the averages of each month. You have a very simple expression given by H0 y bar is 35.773 cos of latitude plus A times modulus of phi 11.28 sin mod phi where A is for positive latitudes. It is slightly lower for negative latitudes slightly higher. In other words, southern hemisphere extraterrestrial radiation is slightly more.

This is because when the angles are favorable, the distance also is an error unlike hemisphere. This actually, it looks like a very empirical relation. Then, there was summation done from the expression from which the 35 of something can be derived some sort of. These are adding ons to take care of both southern hemisphere and the northern hemisphere.

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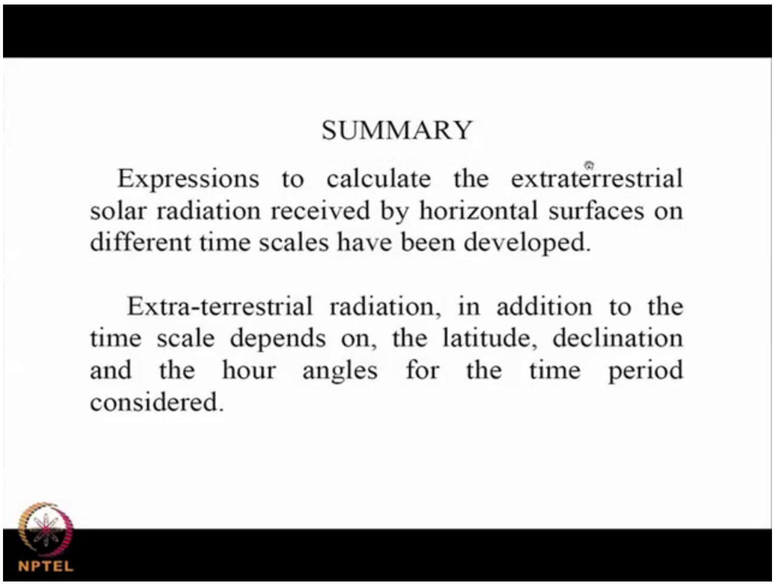

So, now what we achieved was on different time scales. I can calculate extra terrestrial value edge of the intensity on the horizontal plane or for a short period of time like our or a day, monthly average day or the yearly average day. With these, if we compare with what we are going to receive on the earth surface, we shall have some working method for the simulation calculations.

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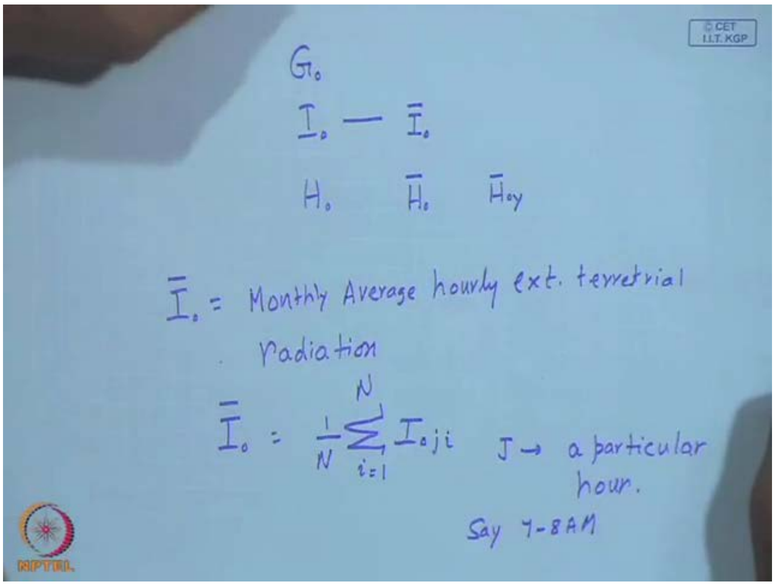

So, we have G0, I0, H0, H0 0 bar. H0 bar for the year 1 can also be defined. I0 bar that is you can call it monthly average hourly extra terrestrial radiation. So, we may define this I0 bar as it is the average of all the 30 days for a particular hour. It is not that day's value is divided into the number of hours, but it takes what is the extra-terrestrial value from 7 to 8 of all the 30 days. Then, we find out what is the average of that. There is a purpose.

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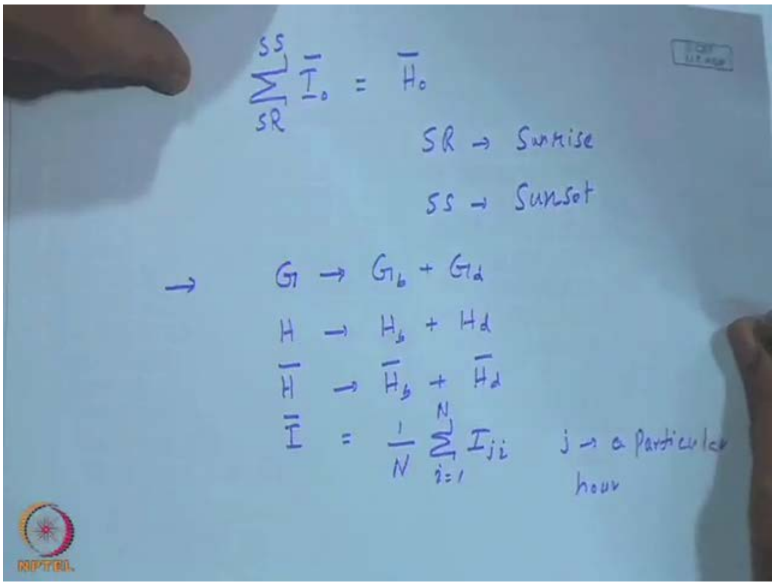

So, sigma I0 bar from let us stay instead of symbols from sunrise to sunset should also be equal to H0 bar. This is because H0 is the average of all the days. I0 is the average of each hour. So, that should comprise of the average day. So, sigma I0 bar sunrise to sunset. So, though we do not know the exact expressions yet, but physically SR can mean sunrise and SS can mean sunset.

Of course, we can go with a yearly average also, but that think is too much. We do not do this. So, when once we have define the terrestrial components, correspondingly G will be, G which will comprise of G b plus G d. then, a corresponding H will be comprising of H b plus H diffuse and H bar H b bar plus H d bar. We will not right now worry about the yearly part. Then, this is important. I bar is 1 by N sigma i j, i j a particular hour. I am only particularly repeating this average hourly value concept. It is an average of a particular hour for the entire 30 or 31 days in the month.

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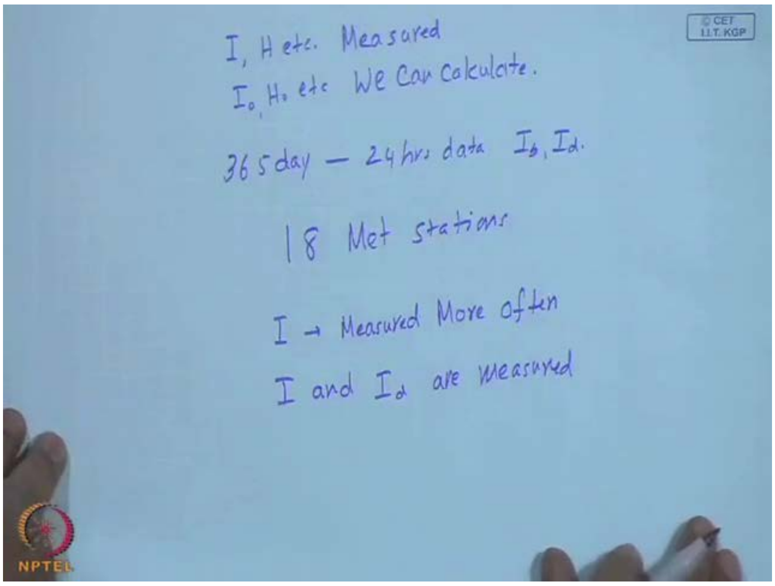

So, either you can have I, H etcetera measured. I0, H0 etcetera we can calculate. Now, when we are trying to go for the design of a system, one obvious simplification we would like to have is let us say I have got 365 days 24 hours data, just split into if necessary I b and I d. then, I may go with the stimulation and get the answer right apart from computational expense. If you are having a domestic water heating system, which may cost only 5,000 rupees, the stimulation cost may become comparable to that cost.

So, you may like to work with whether it gives 55 liters or 65 liters or whether it requires 2 square meters or 2.2 square meters, you may not be very particular. Most of the time in the production, depending upon the standard sheet sizes, one will go for either 1.5 square meters or 2 square meters, whatever the entire standard sheets available. So, as we go for standard systems and simpler systems, we would like to make the calculations as simple as possible.

Then, as we said, these 244 locations of t m are by 2. They are also not all measured information. Some of them are approximate measurements. Some of them are derived quantities from other measurements, which will deal with the type of instruments. In India, we have got only 18 meteorological stations. Most of them are what they call class 2 measurement stations. That means that they are approximate. So, with that data, a long term average is likely to give a more reliable information than data, which is less reliable measured more number of times.

So, apart from that the basic need is let us say if you look at a country like India, there are only 18 locations. Most of the time, these are all metros, Calcutta, Pune, Delhi Visakhapatnam and Bhopal and where the land is at premium. So, one may like to have say a solar energy system somewhere in bhadrak or baleshwar or smaller places where you may not have the data. Either you interpolate between 2 large stations are making approximation.

So, the other thing is if there is a meteorological station I, I b, I d, all 3 of them are very rarely measured. Most of the time it is I that is measured because to measurement of I b, you have to essentially go through tracking the sun and integrating the intensity values. This is because you have to be pointing out the instrument or I and I d are measured. So, that the difference is I b. You are not really worried about it.

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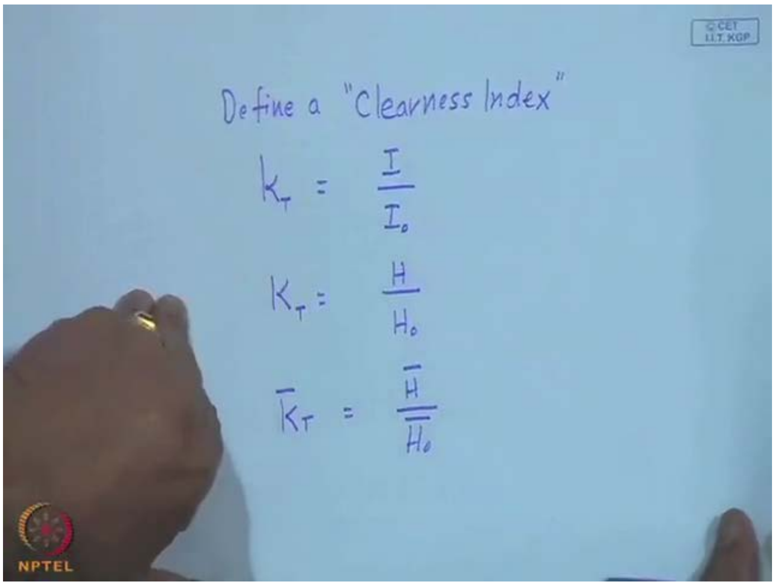

Now, what they have done is defined what is called a clearness index. Again, we have to follow the notation small k T actually is I, I0 basically. If clearness index is given to you, you can find out I. This is you know I0. But, of course, to get clearness index, you should know I.

So, the purpose of introducing a clearness index is something else other than that indirectly defined as a non dimensional number with respect to I0. Similarly, for the day, I can define it as H0. Correspondingly for monthly average day, you define capital K T bar as H bar upon H0 bar. Now, we have written those diffused components of radiation diffused fraction.

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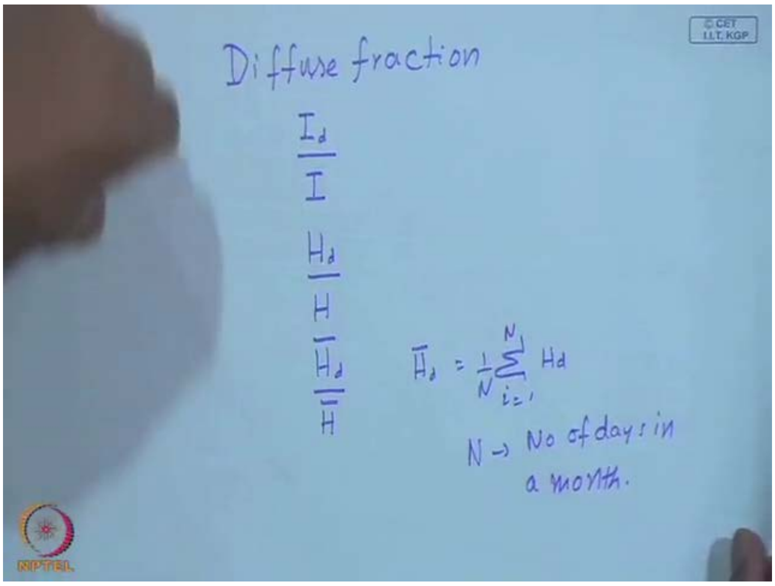

If I call it, what is a fraction of the diffused radiation compared to this global value? That means beam plus diffuse in the denominator and diffuse fraction in the numerator. Similarly, H d by H and H d bar by H bar, so again you define similarly. For example, H d bar is number of days in a month.

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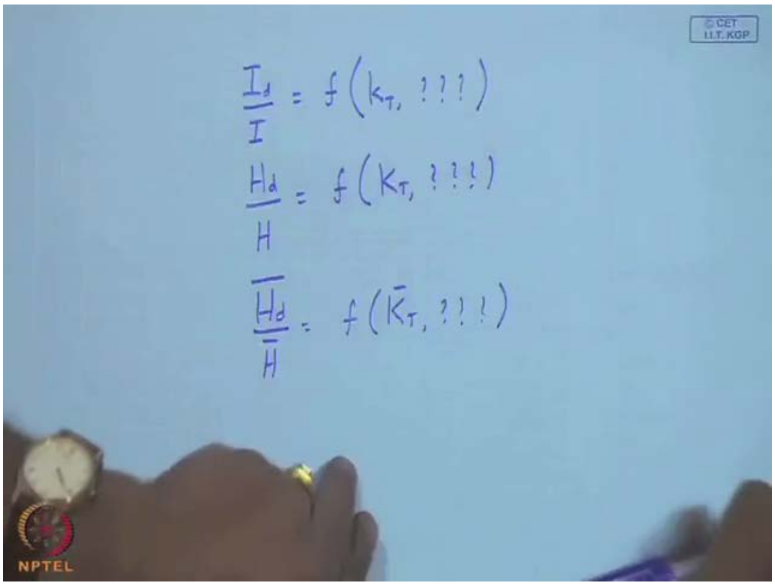

So, why we are doing all this? We are doing so that we can first hyper the size or postulate that this diffused fraction will be a function of the clearness index mainly. Though there may be other secondary variables, one might wonder why not I b by I instead of I d by I? Why not I b by I? When I was first going through that, why that is a beam direct radiation, 70 of that why not so? Then, there were measurements of I b or fewer definitely compared to diffused fraction. So, it happened that this diffused fraction co relates very well with this clearness index, which is nothing but the radiation available on the earth surface to the extra terrestrial radiation.

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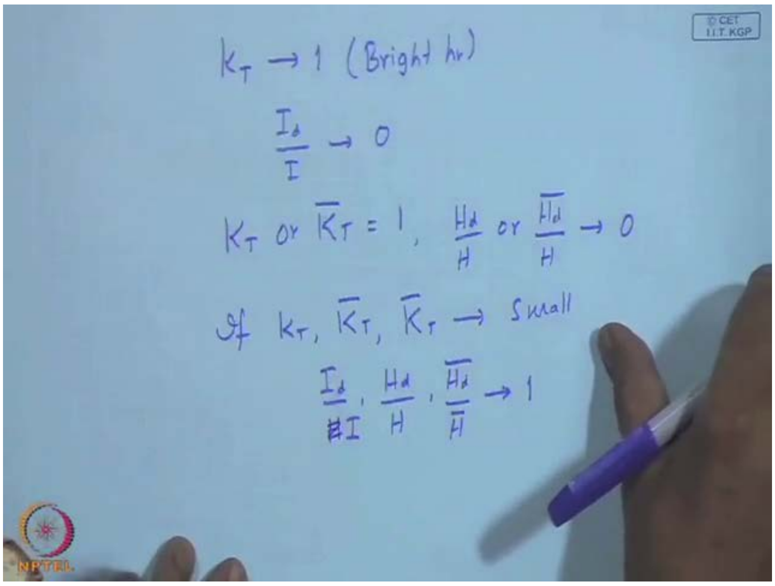

You can expect if K T is 1 that means it is a bright hour. In fact, actually it is called a clearness index. So, if it is equal to 1, it is very clear. So, diffused fraction should vanish that means if the atmosphere is 100 percent transparent, there is no diffuse radiation. All I is I b itself. So, by extension, if capital K T or K T bar or equal to 1, then my H d by H or H d bar by H bar tend to 0. If K T, capital K T I will not write 0, then I can expect this diffused fraction tends to be unity.

Why I did not say 0 is that I itself is 0. If I is 0, I d is 0. So, I will get into a mathematical difficulty of indeterminate form. If the clearness index is very small that means it is a very cloudy day, cloudy hour. Then, all the radiation that I am receiving is diffused radiation itself. Though it may be pretty small, but most of it will be diffused radiation. Consequently, we can say if the clearness indices are small, my diffused fractions are diffused fractions are close to unity. This is a physical thing that I can expect.

It has got a better relation with respect to the actual measurements of the diffused fraction co related with this parameter K T. So, I can calculate K T even. Once I have the measurement of I only, I can find out what is a diffused fraction from these relations.

When once we develop these things, we also have a slightly little more motivated thing, when once we have got this type of a non-dimensional quantity. There will be some sort of a distribution of clearness indices over a period of time. So, that also we can further explore to character as a month or character a particular hour. Like sufficient to say if we have got 30 or 40 students, if the average mark is 70 percent, chances are there will be 10 percent of the people. Above 80, 20 percent of the people, above 70 and 30 percent of above 60 like that there will be a cumulus to distribution. If the average is high, naturally more number of students should be getting higher marks.

So, this quality to features can be built into these distributions, which will effectively enable us to predict solar radiation depending upon broad values that may be available to us. Essentially, the prediction is what is likely to happen on a typical day in a month or the month average day in a month, not that we predict what it is going to be on tenth of tomorrow or eleventh of September 2012. No, that is not those types of prediction. This is an estimate based upon certain parameters. We shall start with continue terrestrial radiation components and clearness index.

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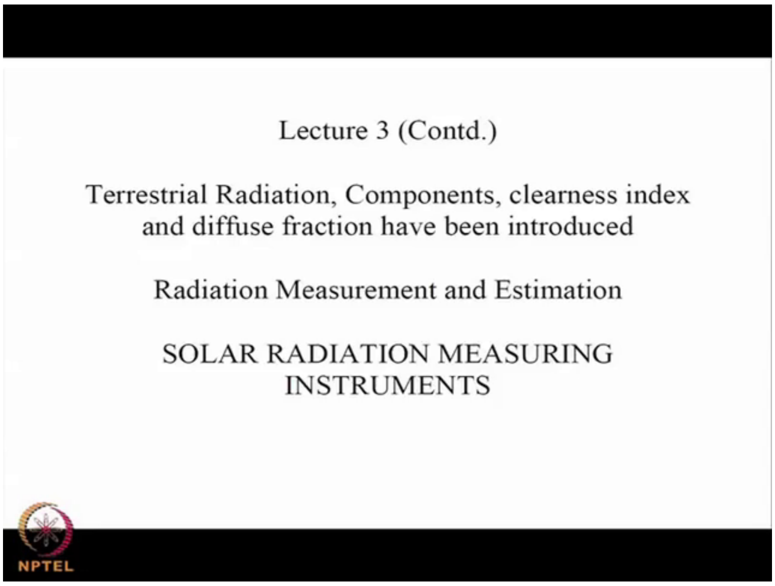

We have introduced in our last time the solar radiation under extraterrestrial conditions. That is as if atmosphere has 100 percent transmittance get set in the atmosphere reaches the terrestrial location comprising of direct radiation and diffuse radiation though we have not yet elaborated on how to measure these quantities. We also have defined a clearness index, which is a ratio of the terrestrial radiation upon the extraterrestrial radiation.

This clearness index also has been defined on different time scales like an hourly value or like a daily value or a monthly average hourly value. The whole idea is if the clearness index is known to us, we can estimate the diffused fraction thereby making the dependence on measurements lesser. It is requiring perhaps only the global component from which we can estimate the diffused component and subsequently the direct or the beam radiation component. So, before that, we need to know how to measure solar radiation or estimate it.

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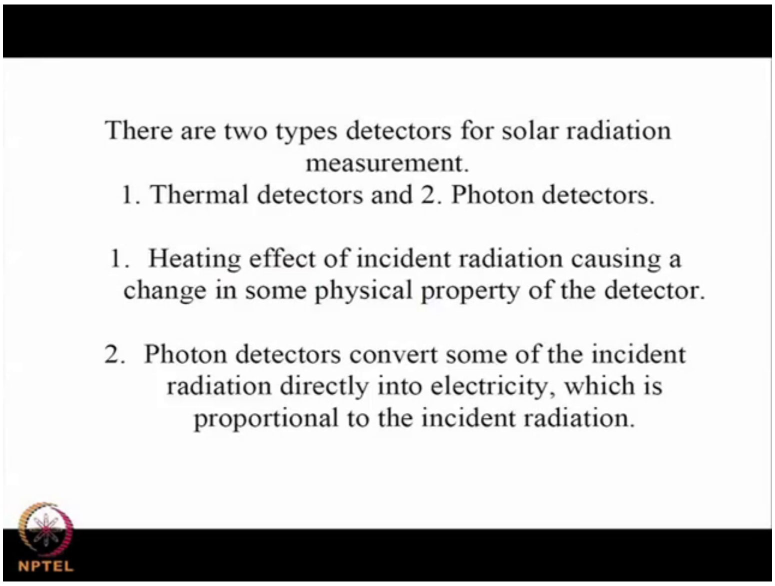

In terms of detector, perhaps more easily and more widely measured meteorological or other variables, basically the solar radiation measuring instruments make use of 2 types of detectors for solar radiation measurement. One type is the thermal detectors.

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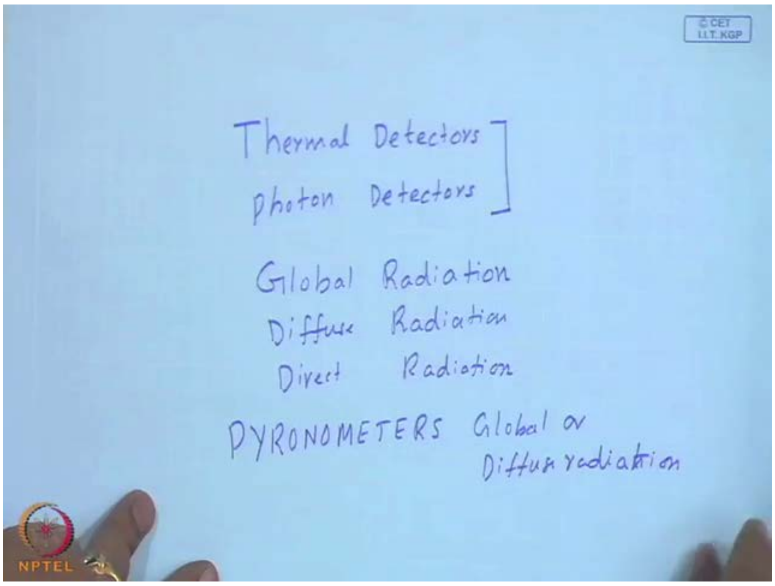

The other types are the photon detectors. The thermal detectors essentially produce a temperature differential between a heated part and not so heated part. The temperature difference is proportional to the solar radiation that comes onto the instrument, whereas the photon detectors directly convert the solar radiation to electricity. The amount of voltage generated is an indication of the solar radiation incoming. Alternately, the measuring instruments also fall into 3 categories. In other words, first we classified based on the type of detector that is employed.

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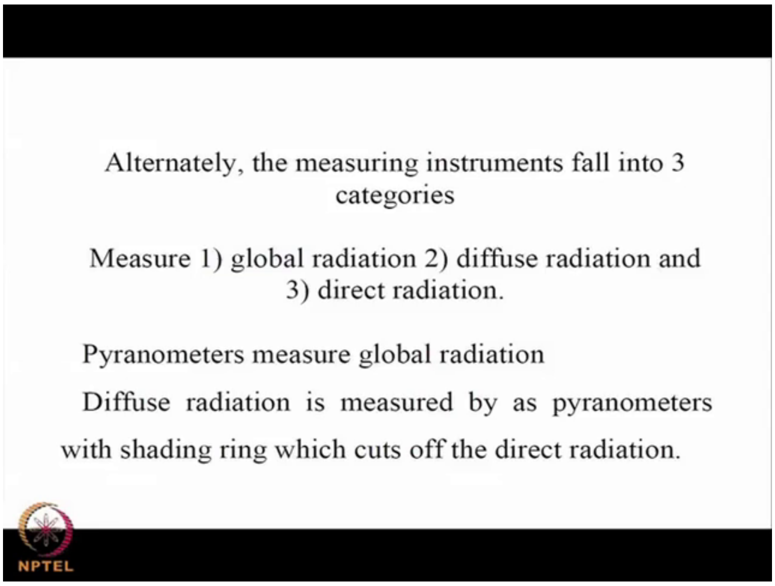

Now, depending upon the purposes, all the components fall into 3 categories. First is that which measure the global radiation, which is the sum total of direct and diffuse components of radiation. The third variety measures the direct radiation. We noted already that direct radiation needs to be measured by focusing the instrument towards the sun. Pyranometers, which are the most commonly used measuring instruments for solar radiation, they measure global or diffuse radiation. We shall find out the difference. How to use a pyranometer to measure the solar radiation, global or the diffuse component? Generally, the diffuse radiation is measured by the pyranometer with a shading ring.

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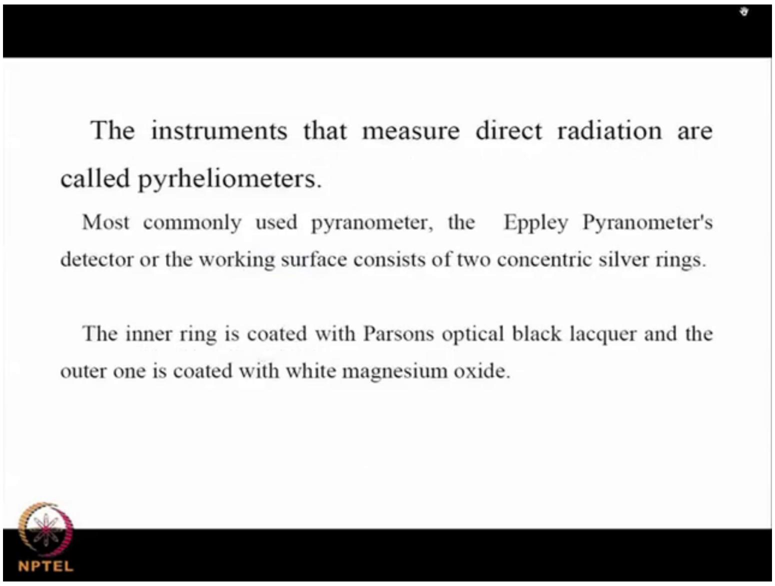

It basically shadows the sensor from the direct radiation making it record only the diffused component of radiation. You can understand the difficulty associated in measuring direct radiation is that the instrument has to be directed towards the sun. Such instruments are called pyrheliometers.

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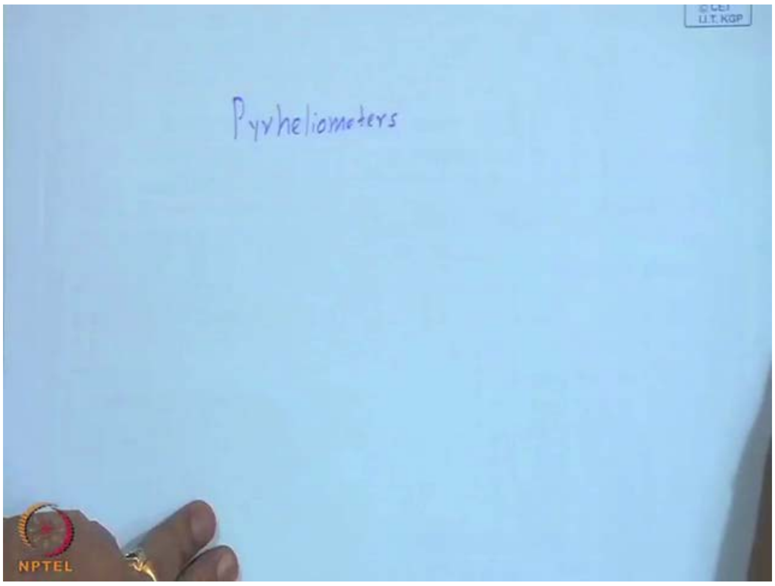

So, they should be continuously focused most of the time. Pyranometers are used to measure the global component and the diffuse component. The difference is the direct component, which is checked by measurements for a short while with pyrheliometers. The most common used pyranometer is the eppley type of pyranometer and detector. The working surface consists of 2 silver rings. We will come to the details along with the pictures. The inner ring is coated with parson's optical black lacquer. The outer one is coated with white magnesium oxide.

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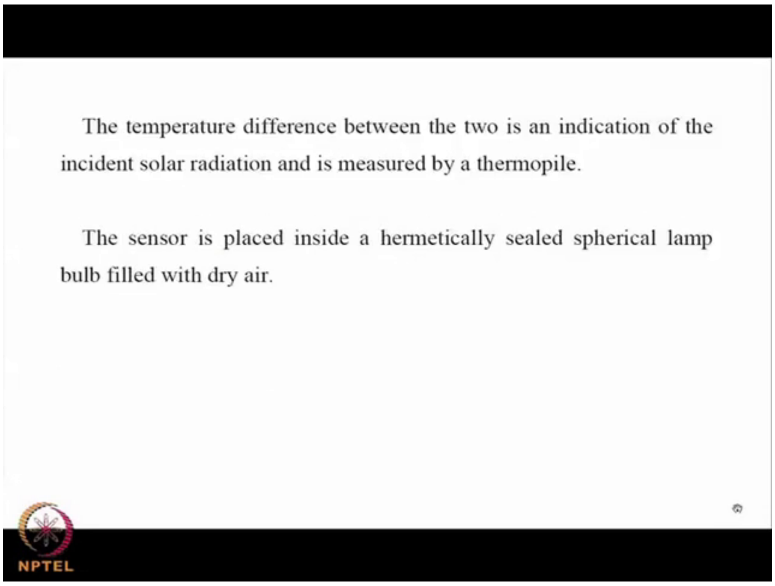

This produces a temperature difference between the black coated being at a higher temperature and the brightly polished material being at a lower temperature. The temperature difference is measured by a thermopile, which is connected to a measuring device like a microvolt meter or a milli volt meter.

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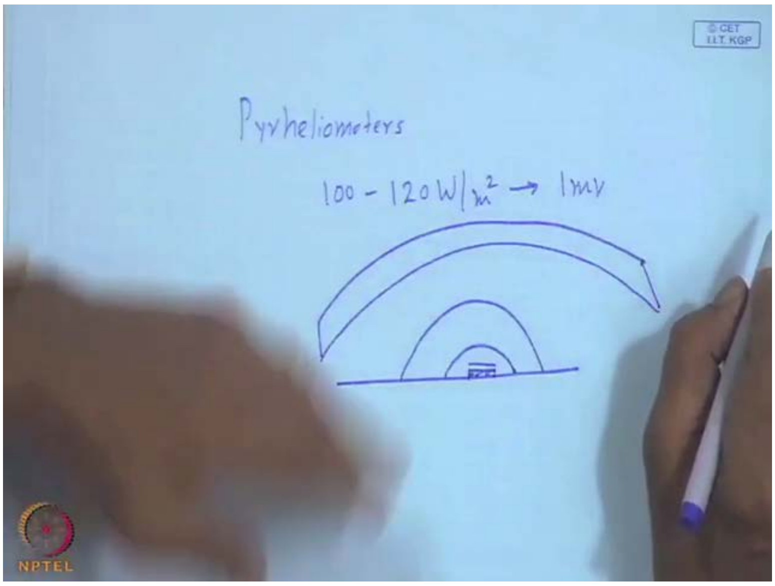

Most of the pyranometers, which are in commercial use produce about something like for 100 to 120 watts per meter square of solar radiation intensity. They generate about one milli volt. The sensor is placed inside a hermetically sealed spherical lamp bulb filled with dry air. This is to reduce your convective losses. The same instrument if I categorically show before, I show the actual instrument. This is sealed double bowl pyranometer with the sensor being at the middle. There is a shading ring of certain radius, which is calculated as per the requirement will make this shaded by blocking the direct radiation.

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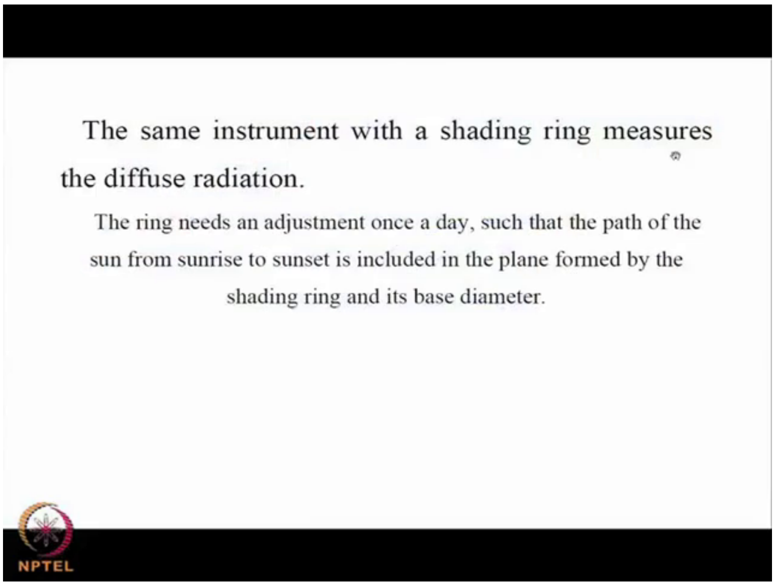

The same instrument with a shading ring to its base diameter has a certain ratio pre calculated ratio which will just shadow the particular sensor.

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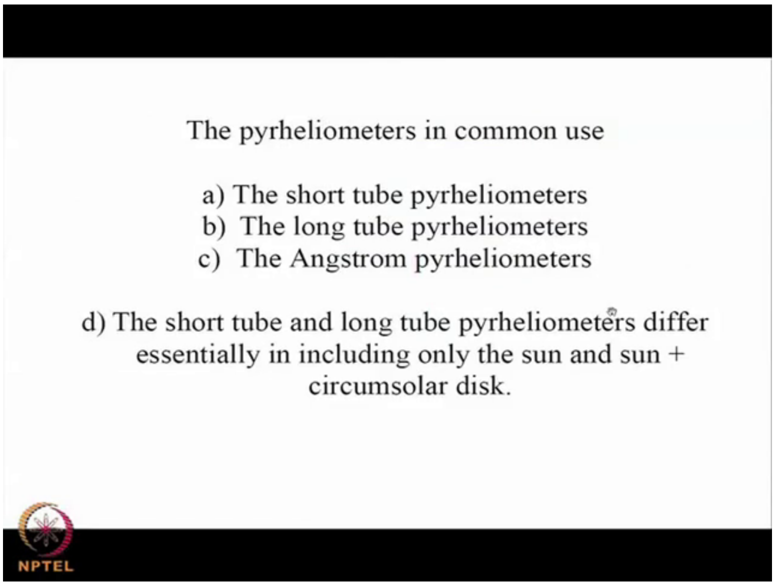

The pyrheliometer is basically of three types, the short tube pyrheliometer, the long tube pyrheliometer and the angstrom pyrheliometer.

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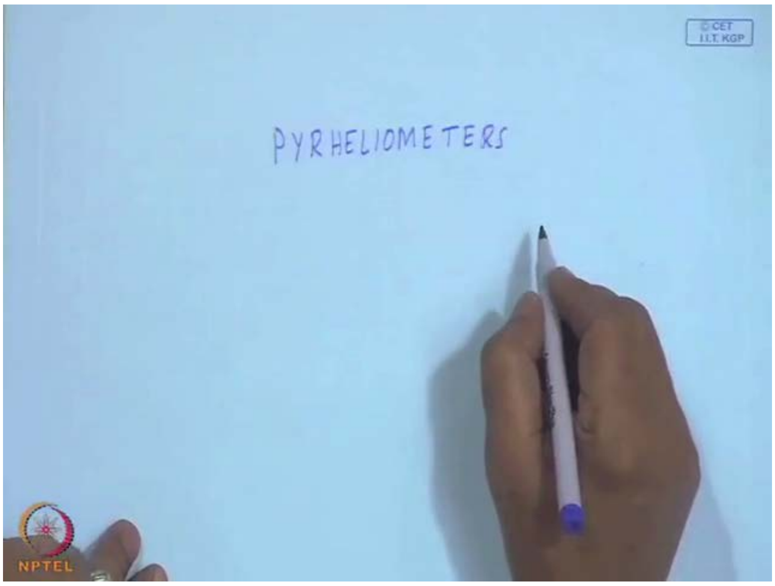

On the contrary, pyrheliometers are of basically 3 types.

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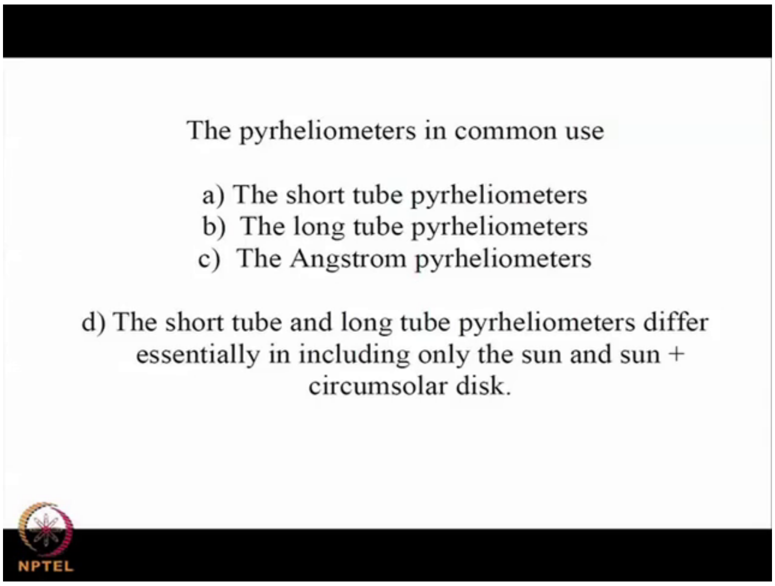

They are the short tube pyrheliometer, the long tube pyrheliometer and the angstrom pyrheliometer. The short tube and long tube pyrheliometers essentially differ in measuring either the direct radiation coming only from the sun or from the circum solar disc round the sun.

This is equal to the radius or diameter of the sun; otherwise the difference is the angle, which is included to include the sun or a little extra portion. That is what distinguishes the short term and the long tube. Angstrom pyrheliometer differs in using a dull null detection system.

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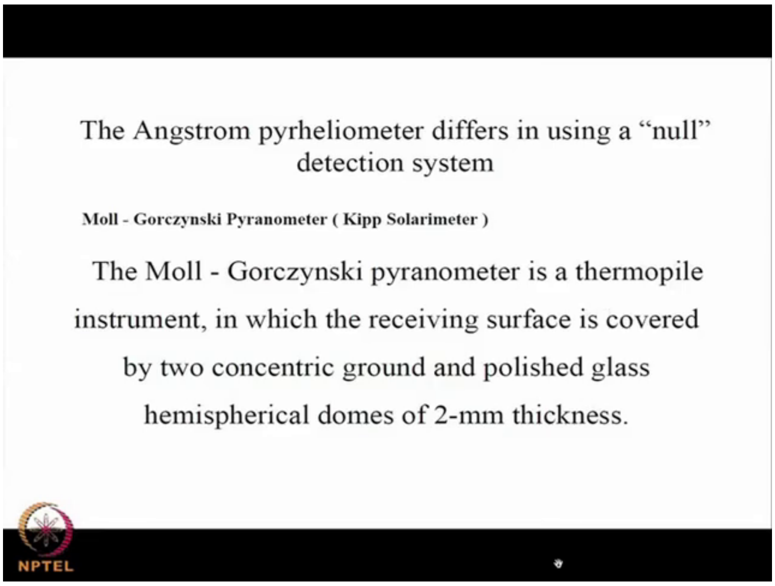

There are other types of pyranometers. This is moll gorczynski pyranometer or kippsolarimeter. This is a thermopile instrument, which has got of course, 2 concentric ground and polished glass hemispherical domes of 2 millimeters thickness.

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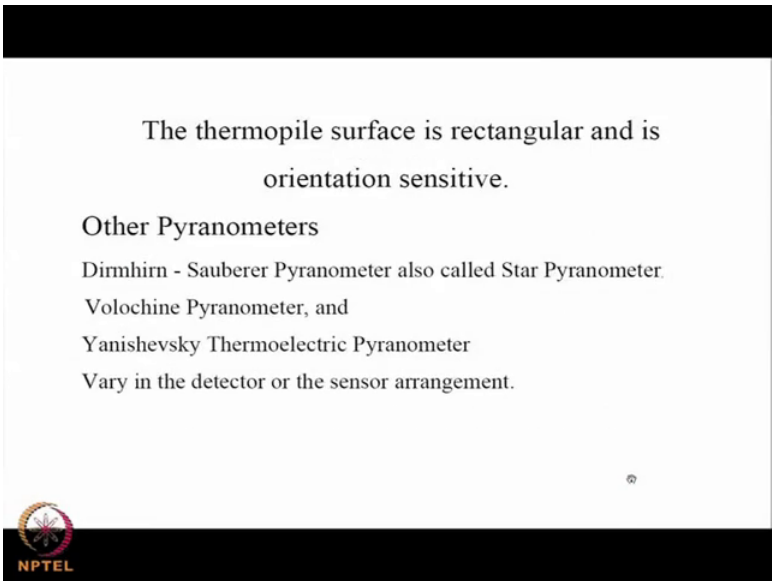

The thermopile surface is rectangular. Hence, it will be orientation sensitive. Normally, this is called a second category of instrument compared to eppley pyranometer. Of course, the primary standards are at very standard meteorological stations where the accuracy record is expected to be higher. You have got a lot of names of pyranometers. One can go through lots of websites, which will give the description and the companies that produce these.

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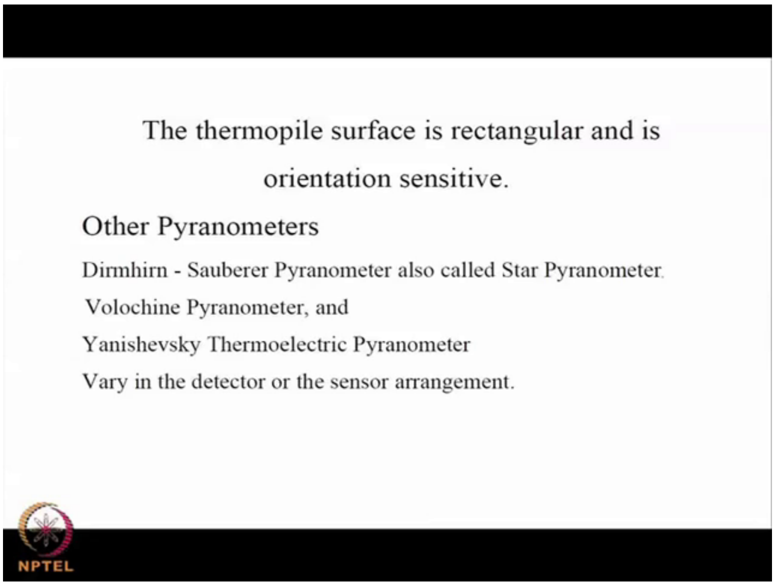

One is the Dirmhirn Sauberer pyranometer also called the star pyranometer or a Volochine pyranometer and yanishevsky thermoelectric pyranometer. They essentially vary in the detector or the sensor arrangement. The sensor could be rectangular sensor. It could be circular and the detector could be thermal detector or photon detector and sometimes circular.

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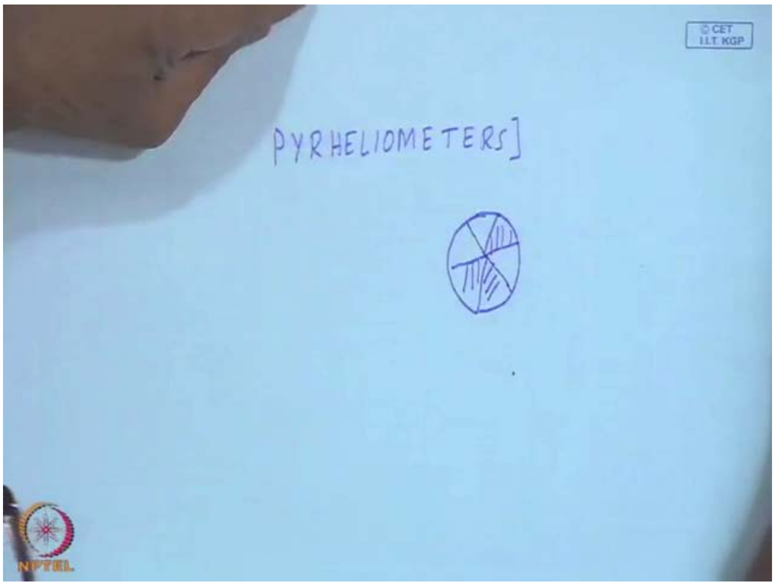

The circular disc, which is brightly polished instead of being surrounded by another black one, it is alternately painted black and white or polished. So, the temperature difference between these types of sectors is measured. So, this also basically is the temperature difference between the brightly polished and black painted surface.

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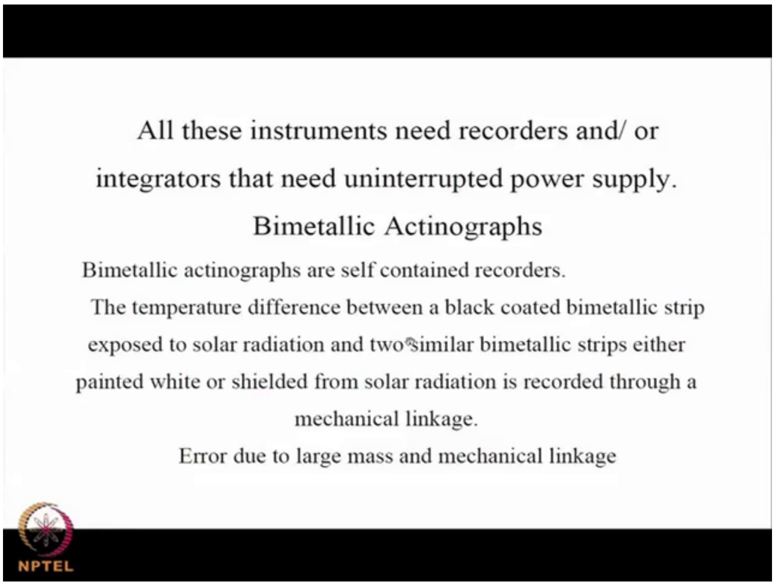
All these instruments need recorders and/ or integrators that need uninterrupted power supply.

Bimetallic Actinographs

Bimetallic actinographs are self contained recorders.

The temperature difference between a black coated bimetallic strip exposed to solar radiation and two similar bimetallic strips either painted white or shielded from solar radiation is recorded through a mechanical linkage.

Error due to large mass and mechanical linkage

There is another instrument called bimetallic actinograph. These are self contained recorders because essentially they depend upon the displacement of length of a black coated bimetallic strip exposed to solar radiation. The other bimetallic strip is painted white or shielded from solar radiation, which produces a mechanical linkage through which the solar radiation is indicated. This error is larger because of lot of mass of the mechanical arrangement plus also due to mechanical linkage.

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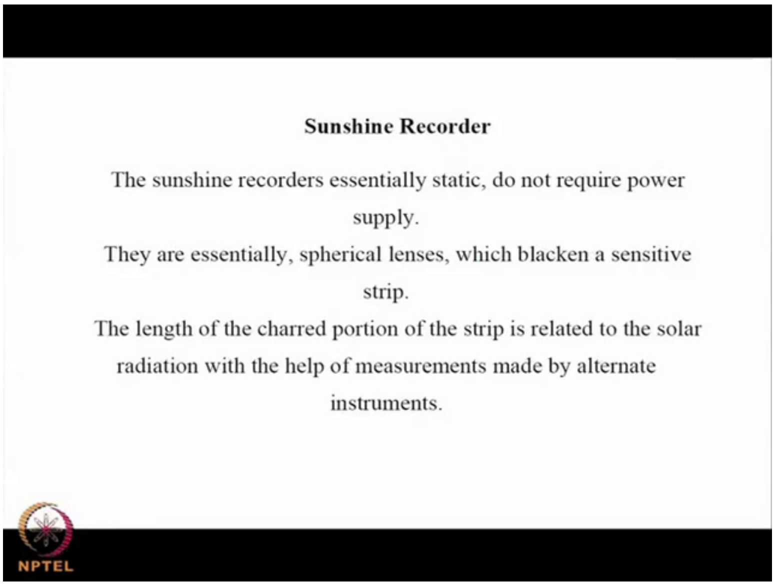

Now, we come to very commonly used in many meteorological stations.

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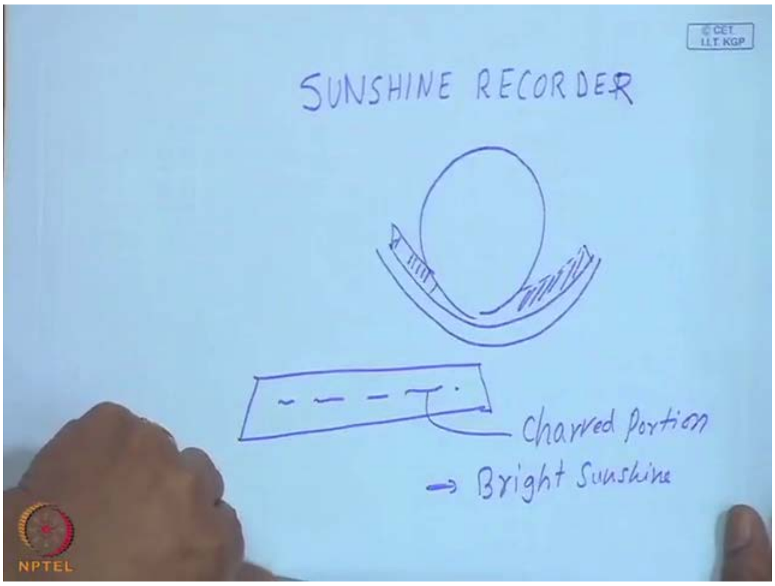

It also has a reliability though may not be as expensive. It may not be as accurate as the pyranometers or pyrheliometers. This is simply a spherical length arranged in a bowl and the bottom of which, we keep a stripe coated with a certain material. The material gets charred depending upon the intensity of the solar radiation.

So, if you look at straight that particular stripe, you will find depending upon the time of the day and the intensity, the charring will be a varying length. That means it is a bright sunshine out of a possible 12 hours or 13 hours of solar radiation. If somebody finds 6 hours to be of having bright sunshine, they can relate it to the total number of hours of sunshine possible on a particular day in the location to the total amount which is approximate.

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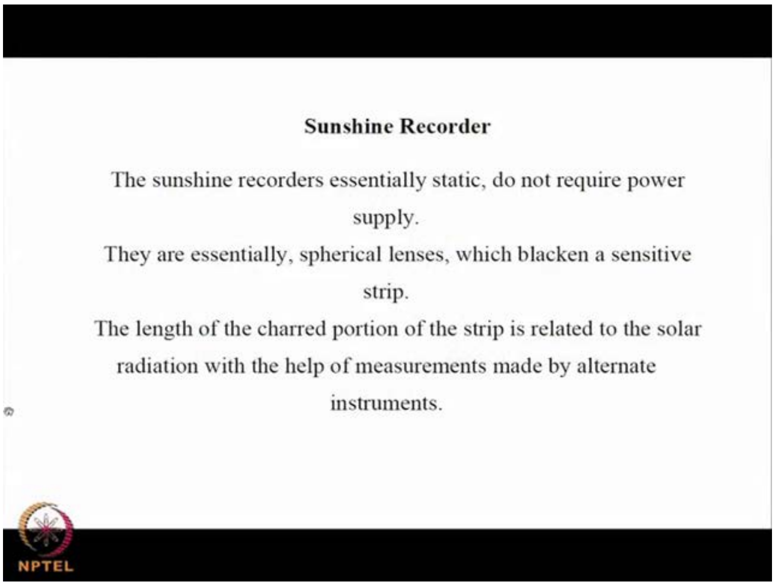

There have to be empirical constants usually derived based upon the location. So, these constants will give pretty accurate result for that location or the location with similar climate and other advantages.

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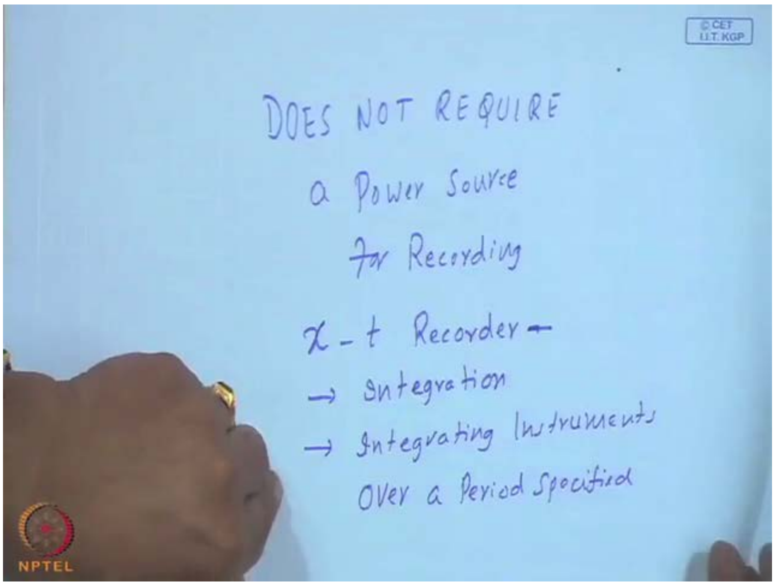

This does not require require a power source for recording. For example, if you have a pyrheliometer or pyranometer, the solar radiation needs to be continuously recorded. In the olden days, it used to be some sort of x t recorder. If one wants to get a value for 1 hour or 1 day, it goes through a painful integration process quite often mechanically or using a plan meter.

So, this recorder has to be operated with an external power source. If there is a power failure, then even though the instrument may be working, you will not have an indication of the solar radiation. The later generation pyranometers or couple to integrating instruments, which measure the intensity over a period specified and come out with cumulative values.

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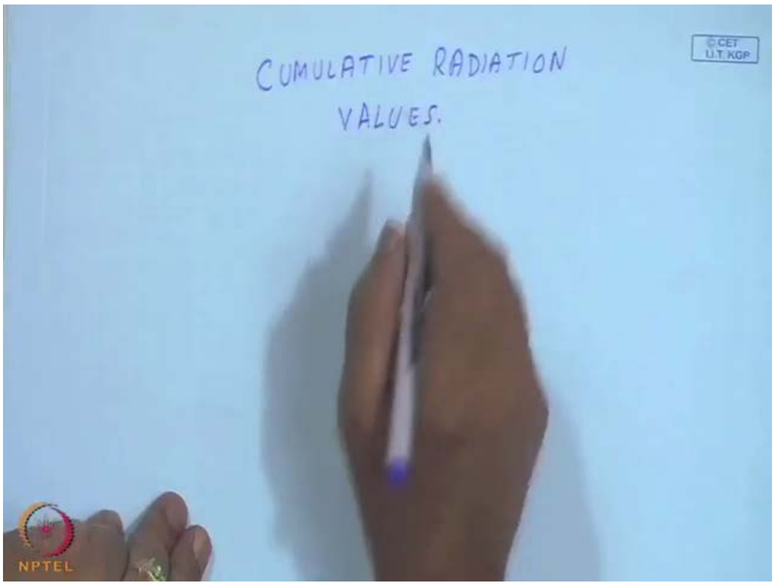

These are cumulative radiation values. So, again we have Campbell stokes recorder Jordan recorder.

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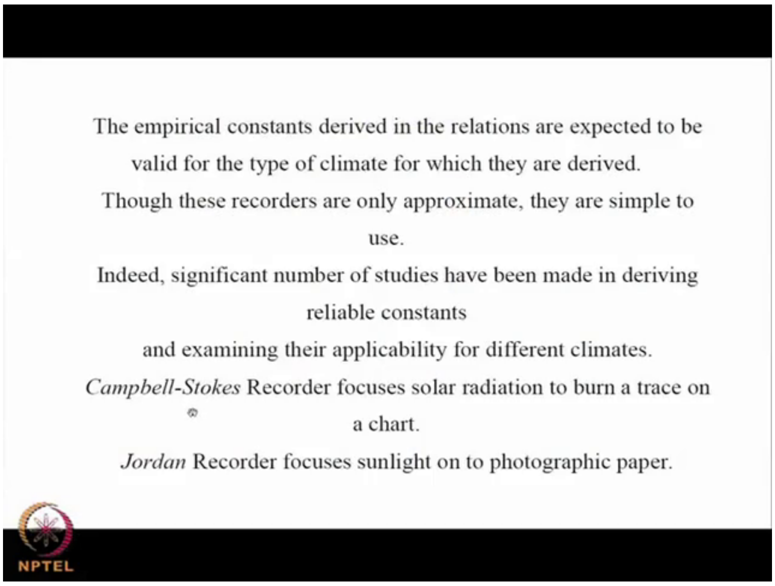

These are some of the popularly used sunshine recorders.

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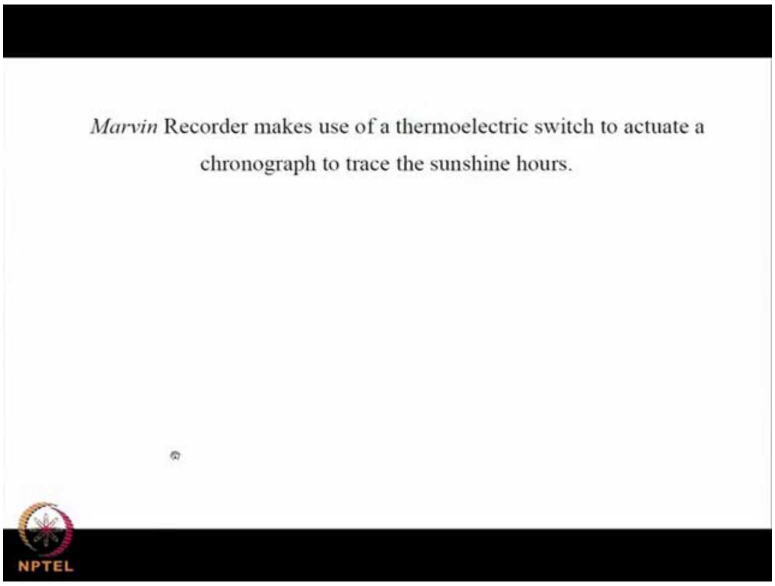

Marvin recorder makes use of a thermoelectric switch to actuate a chronograph to trace the sunshine hours.