Elements of Solar Energy Conversion

Prof. Jishnu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture – 06

Welcome back. We are going through this course of Elements of Solar Energy Conversion and we are here at lecture 6.

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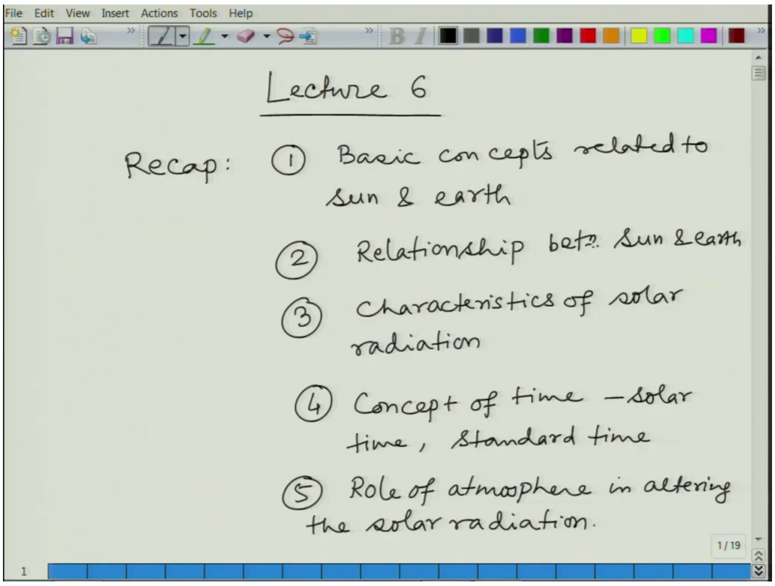

So, in first five lectures, what did you see? Let me just give you a quick recap of the topics. We have seen the basic concepts related to sun and earth ok. And, then we have looked at relationship between these two celestial bodies between sun and earth.

Then we have looked at the characteristics of solar radiation and then we also looked at the concept of time – the solar time, standard time etcetera ok. And, then we finally, what we looked at is the role of atmosphere in altering the solar radiation ok. So, these are the topics we have seen in first five lectures.

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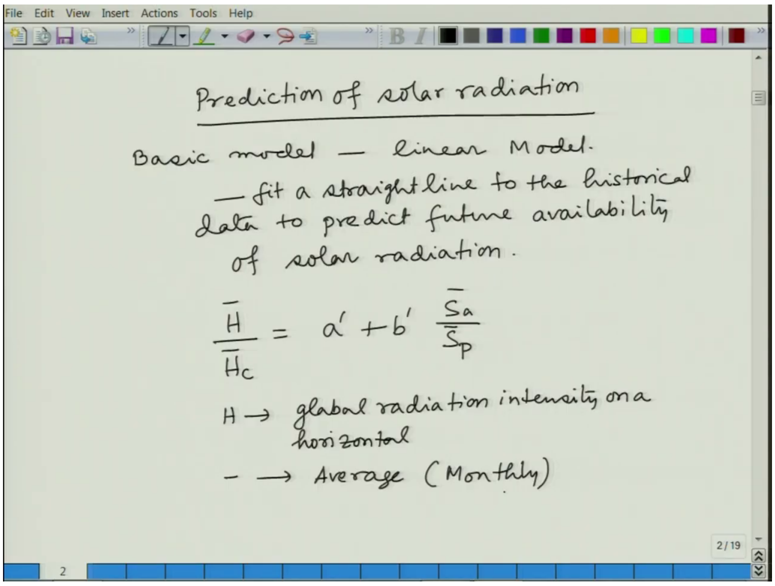

And, at the end of the fifth lecture we started talking about the prediction of solar radiation. We have seen why we need to predict it; because for any design purpose you have to know, how much you will actually get, how much solar radiation you will actually get, how much of that can be converted.

What would be the characteristic of that radiation and all those things that you have to predict right and then only your design will be perfect and it will behave as you wish. So, that is why solar prediction is important.

And, there the most basic model that is often used that is the linear model. So, what we do? We fit a straight line to the historical data to predict future availability of solar radiation ok. So, this we started looking at. So, the basic equation that we have used is this one.

So, now, we have to know or we have to understand what these different terms mean ok. So, these H that we have talked about, H means the global radiation intensity on a horizontal surface. So, H you can relate to horizontal surface and that is why the symbol is taken and whenever you see a bar on top; that means it is average and this particular average is most often done monthly. Over a period of month we average the radiation values ok. Now, this let me go to the next page.

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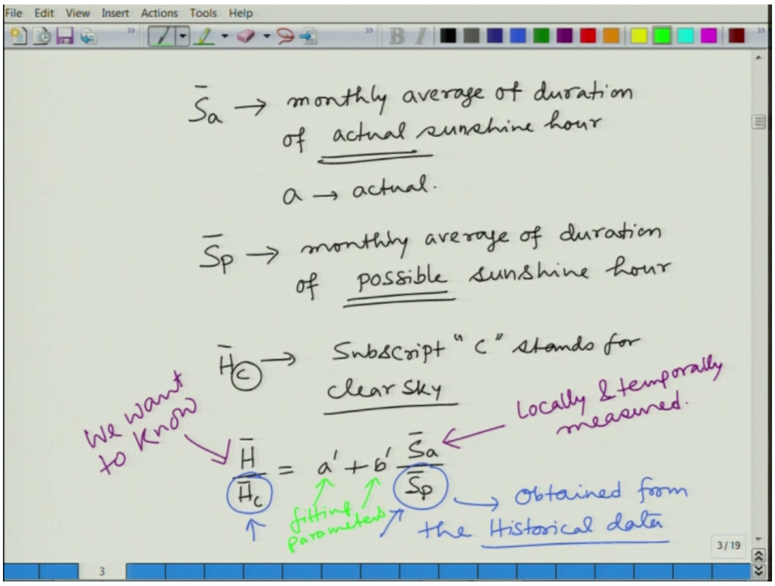

And, explain what we mean by this S a bar. S a bar is nothing, but monthly average of duration of actual sunshine hour ok. So, this actual term is the key point here and that is why this a the subscript a stands for actual and sunshine hour what do we mean by that? For how long sun is actually radiating that is the sunshine hour.

Similarly, this S p bar this stands for monthly average of duration of possible this p stands for possible sunshine hour ok. So, what do you mean by actual and what is meant by a possible? Possible is what theoretically you can expect a particular point of interest will receive sunshine for. So, that is the possible length of sunshine hour ok, but actual is what you are actually getting.

So, for a particular latitude or longitude you can exactly determine for a clear sky all through what would be the possible sunshine hour, but in reality you will not get that because of many factors like you have to take into the what is around that particular location – what is the altitude, what is the relative altitude with surrounding buildings, trees, anything else; because all of those things will actually tell you whether sun rays will be able to reach that location or not ok.

So, that is why we distinguish between this actual and possible sunshine hour ok. Now, another thing I need to mention here this subscript c. So, this subscript c stands for clear sky ok. So, whatever monthly average we are taking H c and bar that is taken at the clear sky condition. So, that assumption is being represented through that subscript c ok. So, and ok. So, what is given and what we want to know. So, let me write that equation once again.

So, here we have these two denominators which is H c bar and S p bar these two denominators are related to or rather we obtain them from the historical data. Historical data what do we mean by that? We place we have some observatories where we place these horizontal planes with some radiation measuring instrument and we find out what is the total radiation that is being absorbed or being available to that particular plane throughout a day and for each day for a very long time.

So, that is a continuous process for all these observatories we keep those data and those are the data which are being used for calculating this H c bar and S p bar ok. Now, these two are available from the historical data. Now, what we want is this quantity right. We want this is we want to know or rather predict ok. Now, this quantity S a bar, that is what we measure for a particular location for which we are interested in, ok.

So, this is locally and temporally measured. So, on this basis we will actually get the H bar and what are these? These are fitting parameters and we will see that for different locations we will have different fitting parameters and those are the space area or the location specific information that are there in those a prime and b prime. Now, one thing that we need to talk little bit about is that clear sky assumption.

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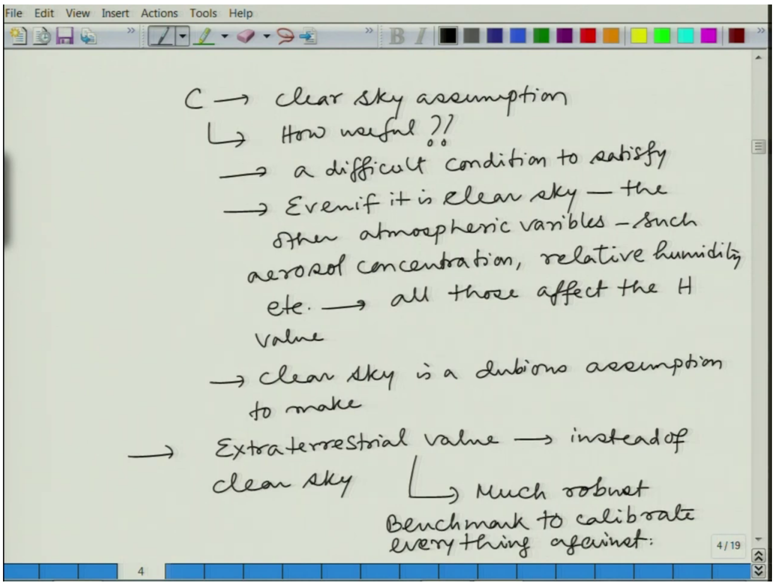

Clear sky assumption – how valid is that or how useful is that rather. Valid does not mean much, but how useful. First of all it will not be possible to obtain all those days in clear sky condition ok. So, difficult condition to satisfy. So, lot of data you have to discard just due to not a clear sky condition ok. So, that is not a good thing to have and other thing is that even if it is clear sky, the other atmospheric variable such as your aerosol concentration, relative humidity etcetera these are not constant, right.

Even if you do not have any sky sorry, even if you do not have any cloud then also you can have significant variability in terms of this aerosol concentration or relative humidity or some particular gas concentration. All of those all those affect the H value or the energy received on a horizontal plane that value is affected by all these things.

So, clear sky is a dubious assumption to make that is why later initially for long time this clear chi assumption data were maintained and used ok. But, recently for past few decades we are using extra terrestrial value instead of clear sky value. Why do you use that extraterrestrial value? Because extraterrestrial thing is independent of anything that happens in the atmosphere, ok.

That is why you have a solid benchmark which will not change due to anything in the atmosphere whether it is clear sky, whether aerosol concentration is more or less it does not matter. That is why this extraterrestrial value is a much robust benchmark to calibrate everything against ok.

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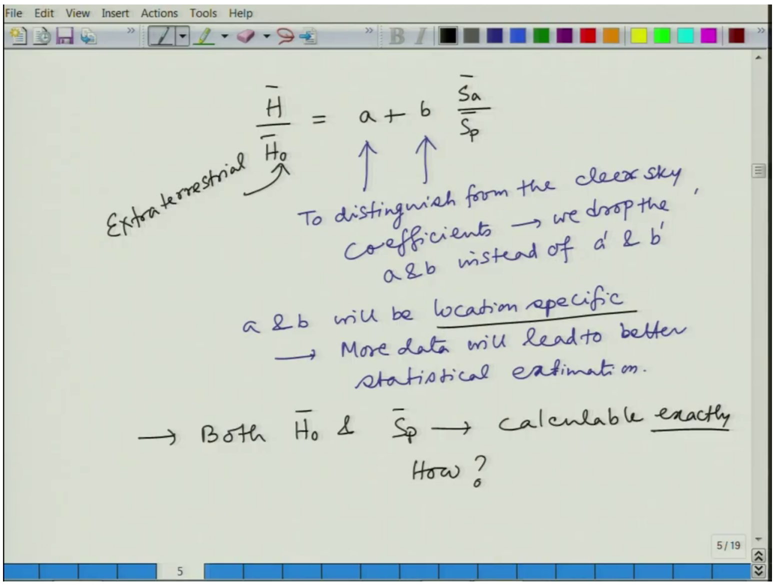

So, the equation form does not change what we change is now we change that with the extraterrestrial value. So, now, you can see this o stands for extra terrestrial and also we name these coefficients differently, ok. So, to distinguish from the clear sky coefficients we drop the prime rotation ok. So, a and b instead of a prime and b prime ok, you get it?

So, now the equation form does not change, everything stay same. We only take have taken out one of the key variable that can change the whole scenario. So, we have taken a extraterrestrial value instead of clear sky value, and that way the a prime b prime they have changed to a and b ok.

So, of course, again this a and b will be location specific and the more the data you have the better estimate you will get from this equation. So, more data will lead to better statistical estimation ok. So, this is the basic form. Now, one thing is that whenever we use this extraterrestrial thing we have certain advantageous as well.

Now, both this H prime naught and S prime naught we can calculable exactly we do not have to depend on data, but we can calculate it exactly. Of course, the more data you take a and b coefficients will be much more stringent; because anyway whatever you value whatever value you take in the denominator for extraterrestrial or clear sky assumption the a and b coefficients those coefficients will of course, depend on the atmospheric condition and location, right.

That is why we call it location specific ok, but now we have better plane to stand on where the H naught prime H naught bar and S p bar both of them we can calculate exactly. Now, we will see how we can calculate that.

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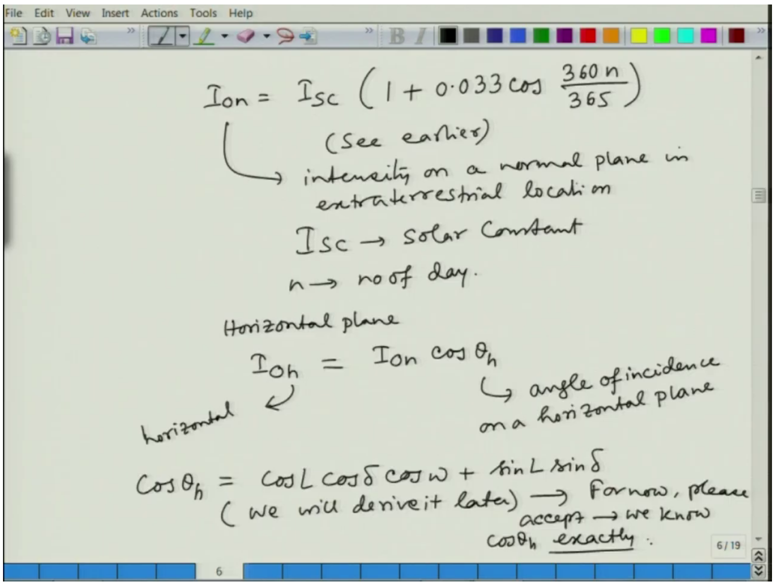

So, from earlier classes you have seen that the intensity on a normal plane in the extraterrestrial condition that we can write exactly in terms of I o n which will be function of the solar constant I s c and multiplied by this factor 1 plus 0.033 cos 360 n divided by 365 this we have seen earlier. So, please look back the earlier videos and you will find this particular equation.

So, basically this ion is the intensity on a normal plane in extraterrestrial location terrestrial location, and I s c is the solar constant and you can see there is a variability which is taken from this taken by this cos function cosine function and n is the number of day which starts from January 1, ok.

Now, this is the intensity on a plane which is normal to the sun ray ok. Now, we are interested in a horizontal plane, right. So, let me write h to be o h, ok. Here note the difference this is h for horizontal ok. Now, how will this I o h be related to I o n? This will be related to I o n into cos of theta h ok. Theta h is the you can say this is the angle of incidence on a horizontal plane.

You can keep a horizontal plane in an extraterrestrial location or you can like hypothetically keep it and you can find what would be the angle of incidence on that horizontal plane and the intensity will be just the I o n the normal intensity multiplied by the cosine of that angle of incidence theta h, ok.

So, later may be next class only we will see that this cos theta h we can estimate it exactly in terms of other angles. So, this is we will derive it later. But, for now, you just accept that this cos theta h can be obtained exactly in terms of other angles. For now, please accept we know cos theta h exactly ok.

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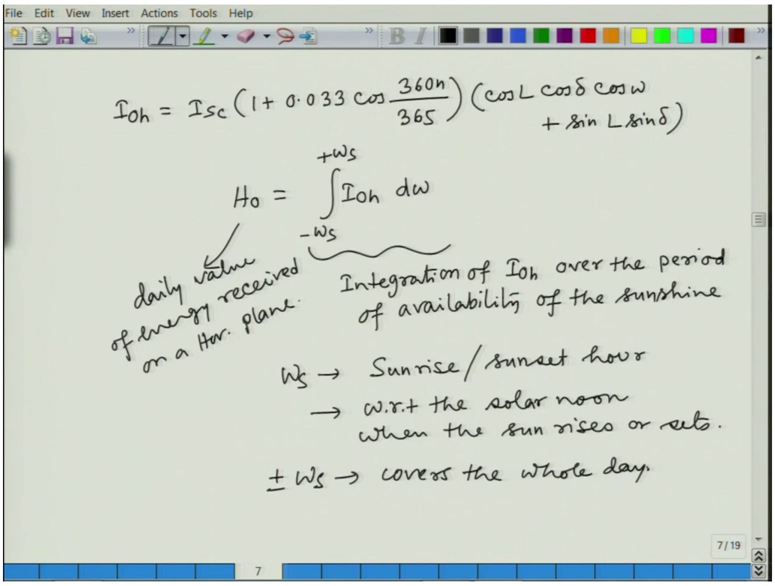

Now, if that is the case then what we can write this I o h will now be I s c 1 plus 0.033 cos 360 n by 365 that will be multiplied by this cos theta h. Just do not bother about the cos theta h expression, what are those angles we will go into detail in future classes, ok.

Now, once we know that what we can find this H naught is related to this I o h, right. What is that? H naught is nothing, but integration of this whole I o h with the duration of sunshine hour ok. So, this is nothing, but the integration of I o h over the period of availability of the sunshine because this is the daily value daily value of energy received on a horizontal plane right. So, this is just the integration throughout the day.

Now, here we have introduced few new things without mentioning; so, let me just say that this omega s is nothing, but the sun rise or we can also call sunset hour which is basically with respect to the solar noon when the sun rises or sets both of them are equal.

If we consider the solar noon, then if the sun rises 5 hours from the solar noon it will set after 5 hours from solar noon ok. So, that way this w s that is why this plus minus w s this covers the whole day.

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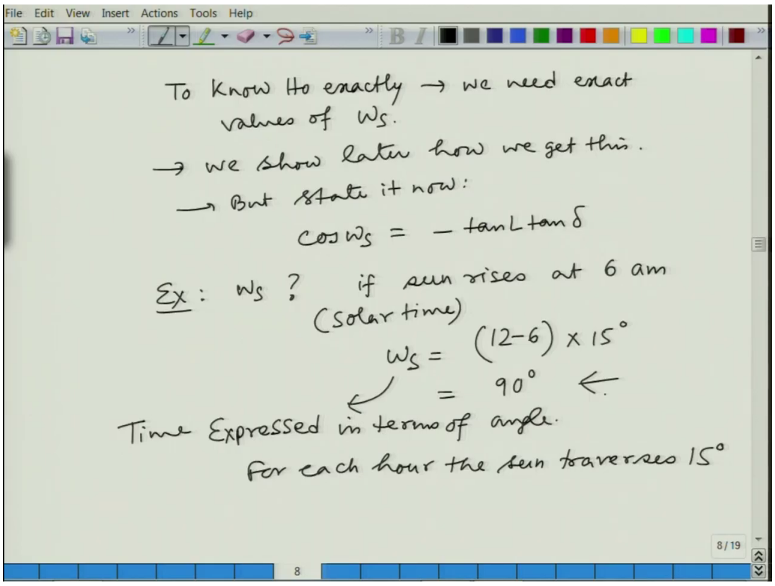

So, to we said that H naught prime or H naught bar is exactly calculable. So, for that we need to know H naught exactly right. So, to know H naught exactly we need exact values of w s ok. So, again we will show later, but right now let me just state them how we get this.

But, we can state it now that is this omega s is known in terms of cos omega is s is equal to tan L tan delta ok. So, this is also known exactly for a particular case. Now, just to give you a idea so, what this omega s is because otherwise you would not feel comfortable.

So, we can say that if sun rises at 6 am and we are talking about solar time ok. So, with respect to the motion of the sun if it crosses the horizon at 6 am then this omega s is nothing, but 12 minus 6 multiplied by 15 degree which is 90 degree ok. So, basically this is expressed in terms of angle and so, basically time expressed in terms of angle and when you have a gap of 6 hours from 12 noon to 6 am, 6 hours.

And for each hour the sun traverses 15 degree ok. In 24 hours it traverses 360 degree, of course, this is apparent motion ok. This I will not repeat every time, but by this time you have got the idea that sun traverses means the apparent motion of the sun actually the earth is rotating with respect to sun ok. So, that is how you get this w s or omega s ok.

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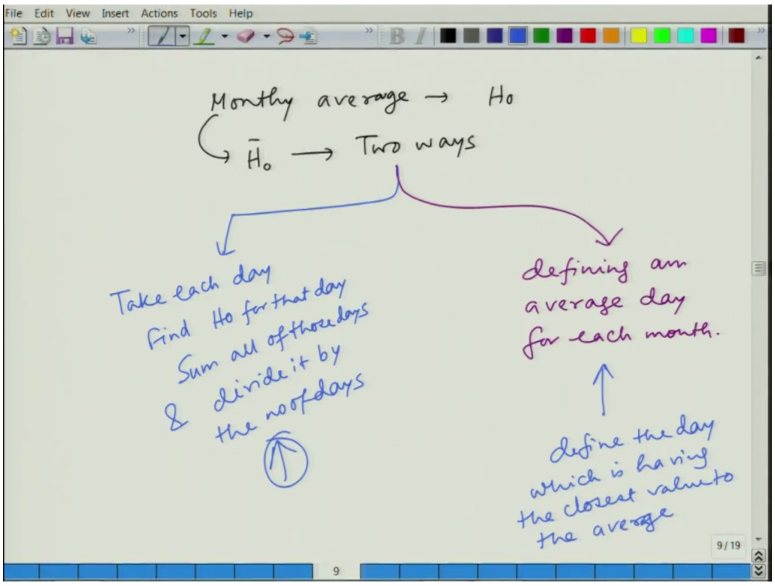

Now, once we know that then what we need to do? We need to take monthly average right monthly average of this H naught values. So, that is how you get this H naught bar. Now, there are two ways by which you can do this monthly averaging. One is take each day, find H naught for that day, then sum all of those days and divide it by the number of days ok, that is the most common way to do it.

But, there is one more like little sophisticated way to do it is by defining an average day for each month, what do you mean by that? For suppose for take the example of the month of

January. So, for month of January you do the averaging by the first method, and check which day of the month was actually the closest to the average value, ok.

So, you define that particular day define the day which is having the closest value to the average and that will be your average day of the month ok. So, and that way, what you are doing? You are saving a lot of time, every time you do not have to do the averaging for the whole month. What you do? You just find out the H naught for the average day.

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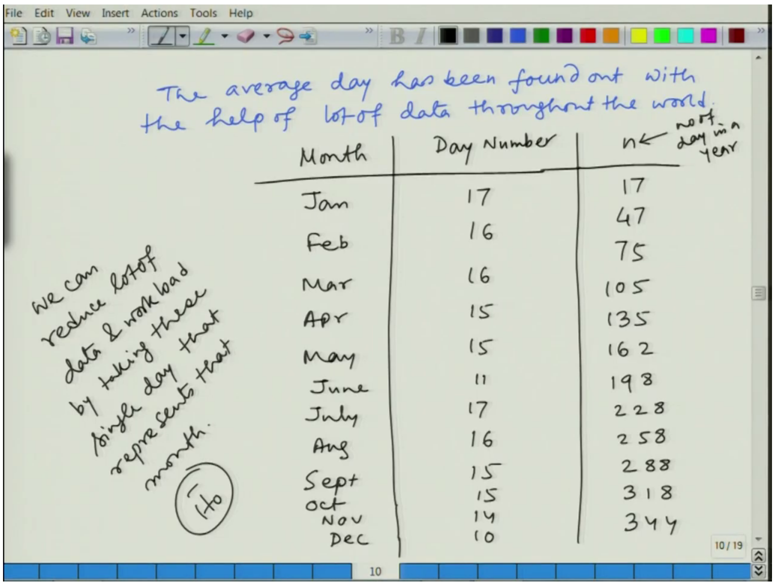

So, that way you reduce your work load very very significantly ok. So, the average day has been found out with the help of lot of data throughout the world ok. Globally, there are lot of measurements and we have incorporated all of them and for each month we have taken a average day ok. So, what are those average days that is important to know.

So, let me just write the average days ok. So, what we can write? So, this is month and this is day number. So, for January it is 17, for February it is 16, March 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14 and December 10 ok.

These are the globally accepted values for the average day of the month and correspondingly you can write what would be the value of n for those particular days. So, this is what you have seen that this n appears in many of these equations that we are using. So, this n is the number of day in a year. So, January 17 is easy, n will be 17 because the n counting starts from January 1 ok.

So, for other let me write the days because this will be quick reference for your computations. These are the values ok. This I made a mistake here. This will be 198. So, if we take these average values or average days of the month, then we are we can we can reduce lot of data and workload by taking these single day that represents that month. That is how this H naught bar is calculated ok. Now, in the whole scheme of things we have seen that how we can get the H naught bar exactly.

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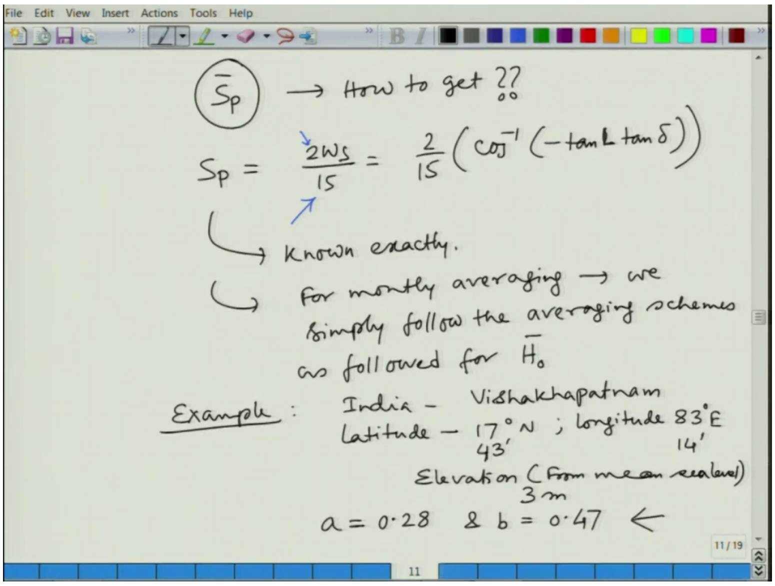

But, we also need to know how to get this particular S p bar exactly. So, how to get that? Now, actually for any day S p you can write in terms of this omega s which is the sun rise or sunset hour and you multiply it by 2; because you have sunrise and sunset and this 15 degree, 15 is coming to make it in hour.

So, as we know that what is the value of omega s we can write. So, again we know this exactly. So, known exactly; that means, now for monthly averaging we simply follow the averaging schemes as followed for H naught bar ok. So, after that it is straight forward ok.

Now, one thing we can show you an example not the calculation example, but how these data are maintained. Let us say one location in India and that location is Visakhapatnam ok. Now, for that the latitude is known to be 17 degree north and longitude is known to be 43 degree sorry 83 degree east. So, actually this is 17 degree and 43 minute and this is 83 degree 14 minute ok.

So, these are the location of that or the latitude longitude of that location Vishakhapatnam and the elevation is also of course, this is average elevation from the mean sea level from mean sea level that elevation is 3 meter it is close to the coast. So, the average elevation is low 3 meter. And, for that what we have calculated based on this curve fitting this coefficient a is 0.28 and coefficient b is 0.47 ok.

So, these we calculate now if we fit or if we use that equation H bar divided by H naught bar equal to a plus b into S a bar divided by S p bar in that equation if we put these particular a and b then we will get that equation will tell you the predictive model for the location Vishakhapatnam.

That is the way all the other places are also tabulated and if you have something in between suppose you have something in between Delhi and Kanpur ok. Suppose, you have data for these two places and you have to interpolate in between to get the value for that location ok.

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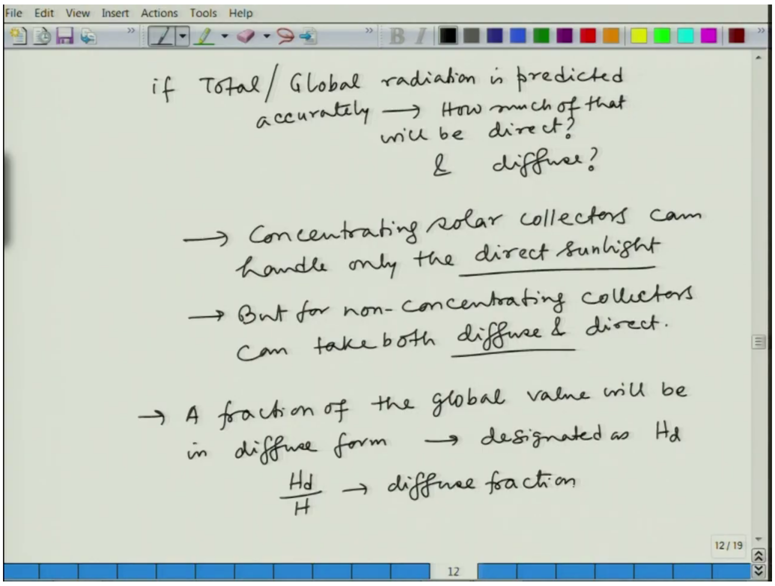

Now, another important question is that the total or often called global radiation. So, if this total or global radiation is predicted accurately and how much of that will be direct and how much of that will be diffuse? This is an important question, right.

You will understand or you will appreciate this even more when you will actually look at the concentrating solar collectors because this concentrating solar collectors can handle only the direct sunlight. Direct sunlight means what? Which is coming from the sun without getting any change in direction without getting scattered, that is what it means the direct sunlight. And, the concentrating sunlight the concentrating collectors can only take this direct sunlight, it cannot take the diffuse.

But, for non-concentrating ones collectors can take both diffuse and direct. It is not only the solar collector that distinguishes between this diffuse and direct sunlight, it also determine the heat load of a building or how much radiation is available to a plant. So, this solar radiation data needs to be predicted for several purposes so, for that and also lighting.

So, for direct for the inside lighting of a building if you want to use the solar energy often we use only the diffuse part not the direct part ok. So, for that also we need to have some idea whether it is diffuse or direct ok. So, now. So, a fraction of course, a fraction of the global value will be in diffuse form ok. So, what is that fraction? So, let us say diffuse is often designated as this H d small d stands for diffuse. So, H d divided by H this is the diffuse fraction.

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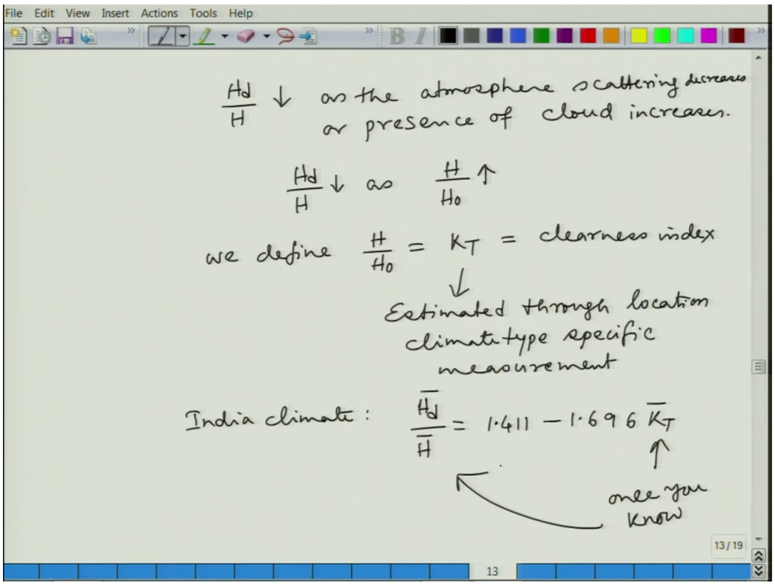

Now, intuitively you can see that this diffuse fraction will decrease as the atmospheric scattering or presence of cloud increases right. Sorry, atmospheric scattering decreases or presence of cloud increases. So, basically we can relate this that H d by H will decrease as H by H naught increase right; H naught is extraterrestrial value.

So, if you have cloud then H by H naught will decrease and in that case H d by H will increase, right. So, we define this particular thing this H by H naught to be a quantity called K T or clearness index ok. Clearness index tells you how much cloud or aerosol concentration is there ok.

Now, you can estimate this again through lot of measurement estimated through location as well as climate type specific measurements and the accepted value for Indian condition. So, Indian climate the accepted correlation is this is this H d bar divided by H bar. So, basically the average diffuse radiation fraction, that is, 1.4 minus 1.696 K T bar ok. So, once you know K T once you know you can find this diffuse fraction ok. So, that is how the diffuse radiation is I mean calculated.

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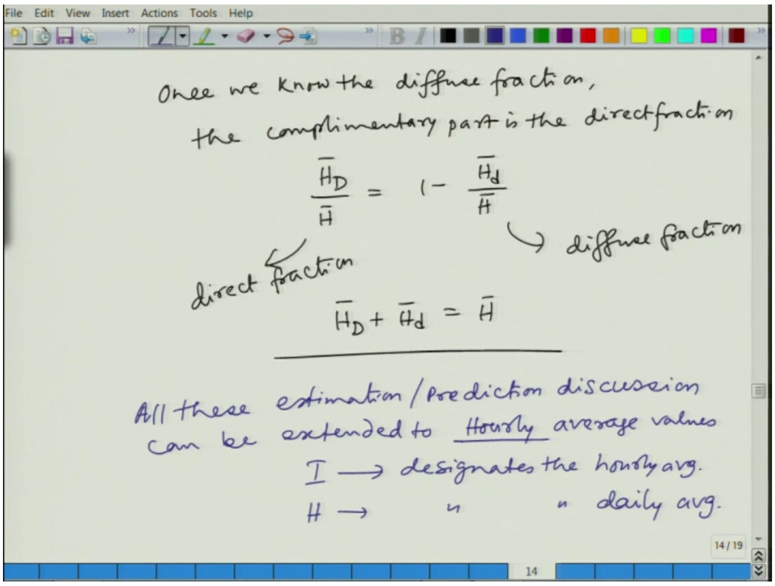

Now, let me just write. Now, once we know the diffuse fraction the complimentary part is the direct fraction ok; that means, this H direct is usually designated with capital D this is 1 minus H ok. So, this is direct fraction and this is diffuse fraction because this is direct plus diffuse gives you the total radiation or global radiation, right. So, that is how we get.

So, these two important things we have seen – one is how to estimate the total global radiation on a horizontal plane and then how much of that will be diffused and how much of that will be direct because some part will be useful by some particular device and the other part will be useful by other devices and few are few can utilize both the diffuse and direct portions ok.

Now, all these discussions can be all these estimation or rather prediction discussions can be extended to hourly average values. What do we mean by hourly values? Because often we want to know for a particular day how the radiation is distributed for individual hours ok. It is not always that the for the whole day we want to know the total radiation that is available.

We often need to break it down into hourly values and that is why we need this and this we designate it with I can be confusing with intensity and the hourly values. But, I designates the hourly average and H designates the daily average ok. So, this and then it is important to connect these two.

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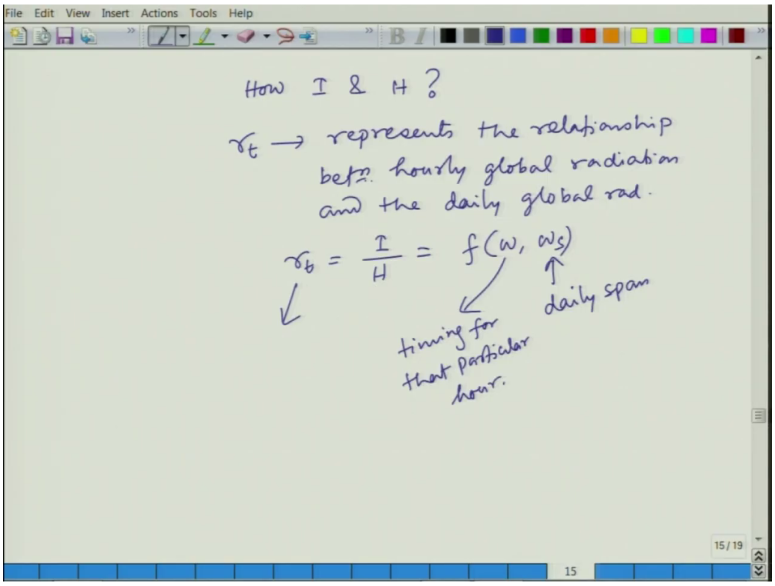

How I and H will be connected ok? So, we connect this by a ratio of r t this represents the relationship between hourly global radiation and the daily global radiation ok. Basically, r t is nothing, but I by H and you can imagine that this will be a function of this hour as well as the total span of the sunshine hour for that whole day w s ok. This gives the daily span and this gives the timing for that particular hour ok.

So, now, again this r t we can find out exactly. And, we will see that in the next class how we can find it out and that way we will be able to define or you will be able to predict the hourly values for each day for a particular location. So, we will see that in the next class.

Thank you very much for your attention.