Energy Efficiency, Acoustics & Daylighting in building
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Lecture - 04
Introduction & Environmental Factors (contd.)

So, continuing from what we have done now I can calculate out the if I know the beams radiation and I know this is the beam radiation watt per meter square intensity of radiation as I told you earlier. We express it the unit is watt per meter square you know joules per second per unit area.

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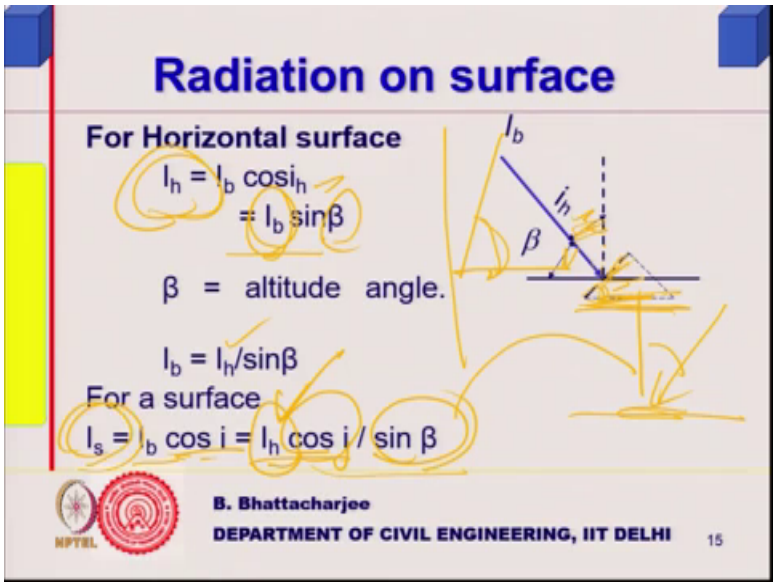

So, intensity is usually energy density, intensity quite often of any intensity when you are talking quite often we talk in terms of density energy density. So, here it is actually power density power. So, I b is in watt per meter square and that is the beam direct beam radiation normal to the direction of the beam itself, normal to the direction of the beam itself right.

So, that is search string normal and if its falling on a surface horizontal surface as I told you already earlier this is incident angle is this is altitude angle beta is altitude angle and this is in fact, incident angle for horizontal surface which is zenith angle same as zenith angle in this case. So, I h will be I b cosi h that is what we said earlier you said you know because the area this area is larger, this area is larger compared to this area, this area is

larger compared to this area this angle is beta. So, normal to this is this and normal to this is vertical you know like this, this I am interested in finding out this. So, normal to this is this and this will be 90 degree minus what is happening I b sin beta I h, yeah.

So, I h, this is this is normal to this surface, this is normal to this j and this is normal to this area. So, this is nothing, but i h. So, cosi h this surface will because i h and cosi h is nothing, but sin beta 90 degree minus so that is what it is. So, on horizontal surface if I know the beam radiation I know the altitude angle I can find out the radiation right. Beta is altitude angle, if I measure, but measuring we normally do it on horizontal surface because my pyranometer I will keep it on.

Student: Horizontal.

Horizontal surface. So, therefore, I can estimate the beam radiation from there. But remember this is all we are talking of direct radiation a pyranometer unless I have blocked, you know I have some way to block the diffuse radiation it will give me what we call global radiation because if I have a surface and its disaffiliation it will not distinguish whether it is a direct beam radiation or coming from sky work. For example, today outside you know if you see outside say all overcast there is no suns ray, but still you are getting some radiation that is diffuse radiation, that is diffuse radiation. So, it will not distinguish between diffused and direct radiation. So, what is done is you actually have an kind of a strip sort of a strip on top of the pyranometer sensing area and this strip can be moving which will block the suns direct radiation allowing most of the diffuse radiation to come.

So, normally two pyranometers are used together one measures the global which is the sum total of the diffusion direct radiation other measures only the diffused radiation because suns ray directional suns radiation is blocked. So, difference between this gives me beam radiation or direct radiation. So, this is one thing. So, for any surface of course, the amount of radiation intensity falling onto the surface is equals to I b cosi. Why? Because I is a incident angle, I is a incident angle that is what we have defined. So, on any surface it is for any surface suns radiation is falling like this, this is the incident angle is this. So, radiation falling onto the surface will be given by or if it is a vertical surface let us say radiation falling like this, normal to the surface is this. So, incident angle is this one the amount of radiation will be given or for that matter even for an

incline. So, it will be given as same cosine law will be valid. So, I b cos i for any surface cos incident here, here in this case for horizontal surface incident angle is i h, therefore, it will be I b cos i.

So, if I measure horizontal radiation or horizontal surface that multiplied by cos i divided by sin beta will give me the radiation that is received on any surface which is maybe inclined or whatever it is does not matter, but that is it. Because beam radiation multiplied by the cos of the incident angle we will give you the radiation that is falling onto the surface that is what we have saw seen in the beginning also for, I measured on horizontal surface find out the beam radiation relationship between horizontal radiation and beam radiation is given by this. So, measured one is horizontal radiation if I know the horizontal radiation incident angle an altitude of the angle of the sun for any surface I can find out the solar radiation.

So, that is radiation on any surface.

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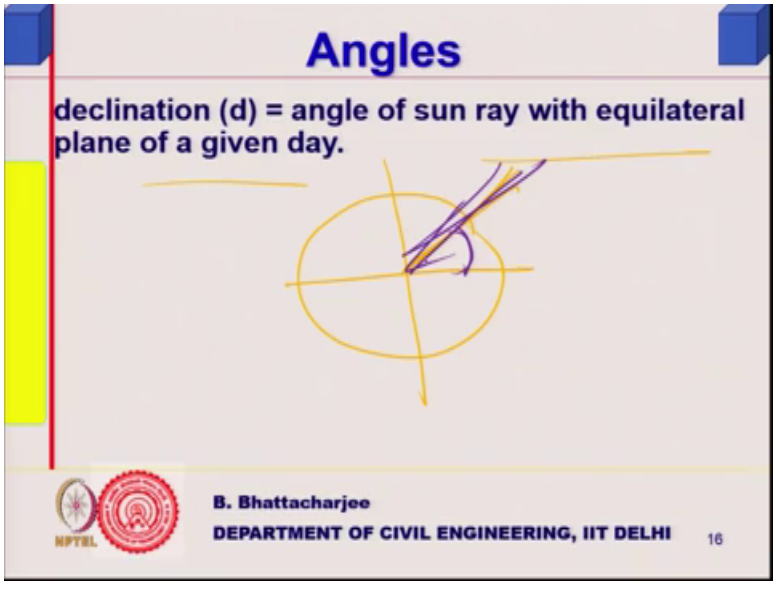

Now, I said that it varies from day to day. What varies from day to day? The altitude angle from an azimuth angle or it also varies from time to time of the day now let us say at a given time of the day 12 noon let us say. 12 noon is what solar time. What is 12 noon solar time? When the sun is right on top of your, you know it is maximum altitude on a given day it is at its maximum altitude right. So, that is your 12 noon it is at its maximum altitude. So, that is 12 noon, let us say at 12 noon.

Now, as I said for any latitude you know the altitude angle corresponding to 12 noon will vary from day to day because only one day even take. Let us say tropic of cancer only on a given day it is normal next day onwards it will keep on shifting. So, that we take account through an angle called declination, that we take account through an angle called declination angle. It is the angle sun ray make with the equatorial plane on a given day because this angle will be how much on 23rd June on tropic of can; 23rd June north tropic of cancer on 23rd June it is an equatorial plane. So, this is your equatorial plane let us say sun ray. Sun ray is falling like this, sun rays no color change I do not change the color this must be a change in color. Sun rays falling like this right this angle we call as declination angle right. So, what will be its value on 23rd June, 23.5 you know 23.5 and also on December.

Student: 23rd.

Same, only there it will be direction thing. In between, into declination where is from about 23.5 to plus 23.5 when it is done or not to minus 23.5, 23.5. So, this is what we define as declination as and I think I might have written yes, that is right. So, at 12 noon between minus 23.5 to 23.5 is a function of day of the year, there is a function of day of the year.

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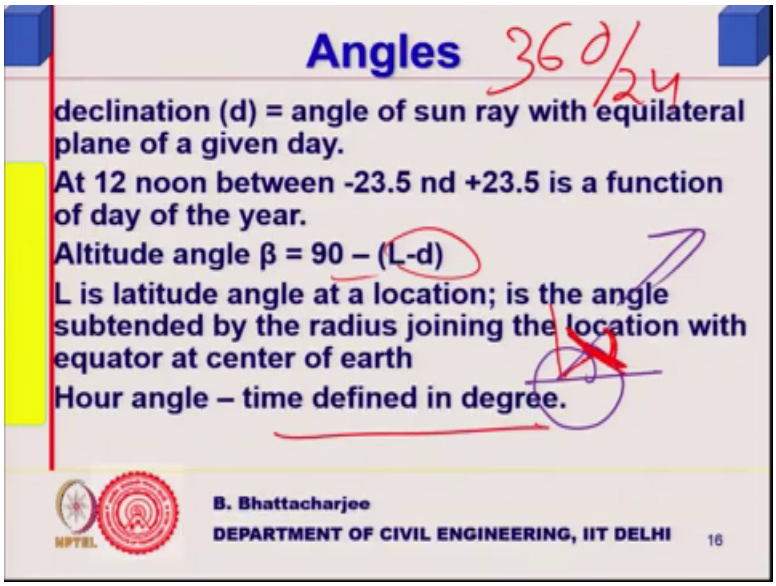

So, this angle you know, this angle I think I will come to this statement later on, but let me see if I have a diagram not really, not really, no. So, it is a function of day of the year.

Now, there are number of empirical equation to find out d as a function of N, capital N which is number of the year, number of the day of the year. I will give you only the simplest one there you know because its empirical again, it is angle where is in a periodic manner from 23.5 to 22.5, but if I want to rule because days are also since our calendar we have a leap here also.

So, its 365 days 6 and some hours and there are some more complicacy you want to go to more details you know it becomes more complex. So, I will be using a simple equation for declination with respect to day and let me see if I go to the first equation then I come back not really, not really you know let me see if I have they relationship not I think I will I will give you the formula than later on, I will come back to this formula. Now, I think if I look at this diagram, I said that this is the declination angle sun rays like that and for any surface here horizontal surface. It is you know suns ray is like this let us say its latitude is something of this kind right. So, 90 degree minus latitude minus declination is actually altitude angle of the sun because altitude angle of the sun is between these two horizontal plane and.

Student: (Refer Time: 10:31).

Suns ray, we will have more details of this we will come back to this. So, latitude L is an angle at a location we will come back to this and you will you know just do a little bit of geometry also. Let L is the latitude angle at a location subtended by the radius joining the location with equator at the center of the earth. I have already defined it formal definition is here. Now, we define it an angle to define the time of the day, we call it hour angle we call it hour angle right. Now, if I want to define time in terms of hour how much 24 hours will be equals to, how much angle it will be equal to?

Student: 360 degrees.

Right, it will be equals to 360 degree because every hour is 15 degree it completes the whole circle in cycle in 24 hours we have defined all I mean as a human being we have defined our you know in another unit it would be different traditional Indian unit it was different Paul something something you know what are those called I do not remember them right, now there are other I know. But the conventional time unit that we are using in SI units that second an hour. So, we divide this a day in 24 hour recycle. So, 360

degree corresponds to 24 hours. 1 hour corresponds to 15 degree 360 divided by 24, 360 divided by 24 corresponds to 15 degree right it corresponds to 15 degree.

Now, we take the starting point as 12 noon, we are looking at local time local solar time not the standard time. If we have standard time then there is an axis shift, so you have to do the correction. So, 0 hour angle corresponds to 12 noon and it would be you know I might take I mean I can use a given convention. So, convention could be 50 degree for every hour from 12 noon if it is 11 o'clock then it will be minus 15, 12 o'clock it will be.

Student: (Refer Time: 12:51).

0, 1pm, it is 15 degree plus. So, I can use that kind of a convention right. So, that is called time defined in degree. So, hour angle is the time defined in degree. So, that is another angle which you will be interested in.

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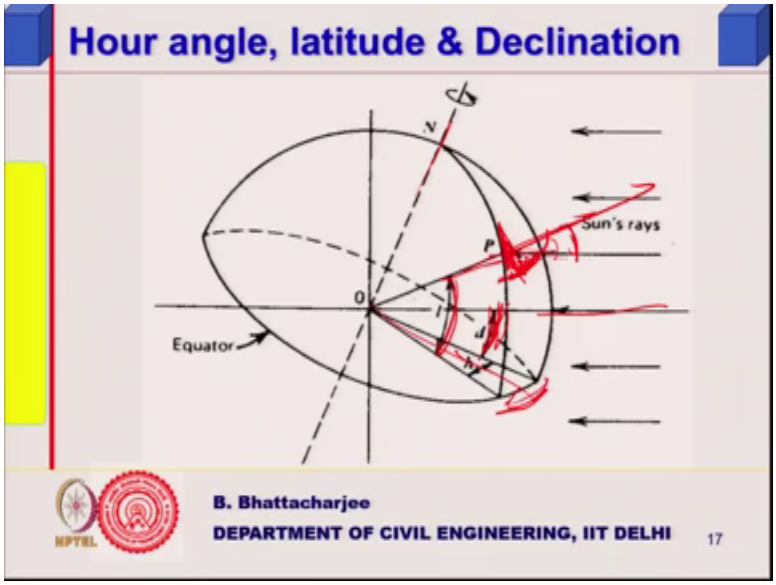

Now, you can see this diagram this is my north pole earth rotates about this axis suns ray is falling onto this. So, normal to this one is the equatorial plane. So, this is the declination, suns ray making this angle you know this is declination angle. This is the point P, this is the point P, so you know suns ray is falling like this. Now, this is the angle you know normal to this surface this is normal to the surface. So, the vertical will go like this.

If I join a line from radius to the surface of the earth that we actually represent the vertical at that point normal you know this horizontal surface is tangential to this one. So, normal to the surface in sun ray that would be normal to the surface at sun ray you know there will be 90 degree minus. So, basically horizontal and suns ray that is basically altitude angle horizontal and suns ray horizontal to sun ray that is altitude angle and vertical to sun ray that is zenith angle, vertical to sun ray. So, this angle is zenith angle this angle is your, this angle is your you know this is this zenith angle, this altitude angle altitude normal to between these two.

So, hour angle is now it earth rotates. So, there is a shift. So, hour angle will be defined here hour angle will be defined here. So, it is in the equatorial plane earth is rotating. So, hour angle will be define from 12 noon to later part. Let us see some more of this diagram make it more clear. So, this I already explained to you.

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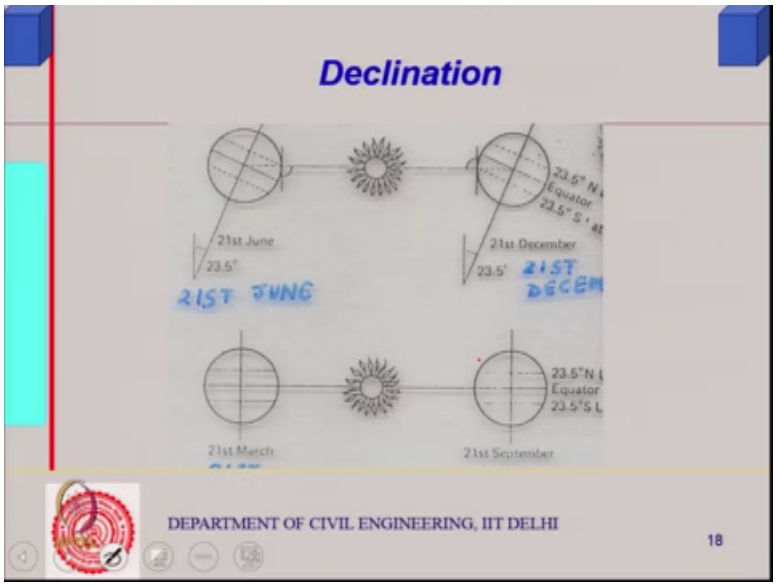

And this is showing same thing, declination how it is varying 23.5 to 22.5.

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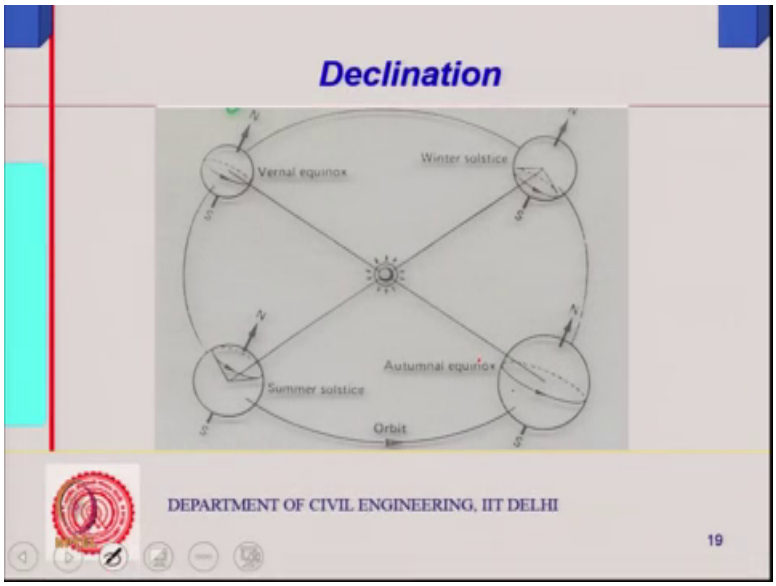

So, if this is the north, this is the equatorial plane, this is a simpler diagram that 90 degree minus theta. So, this is the suns ray and this is then declination angle, makes it clear.

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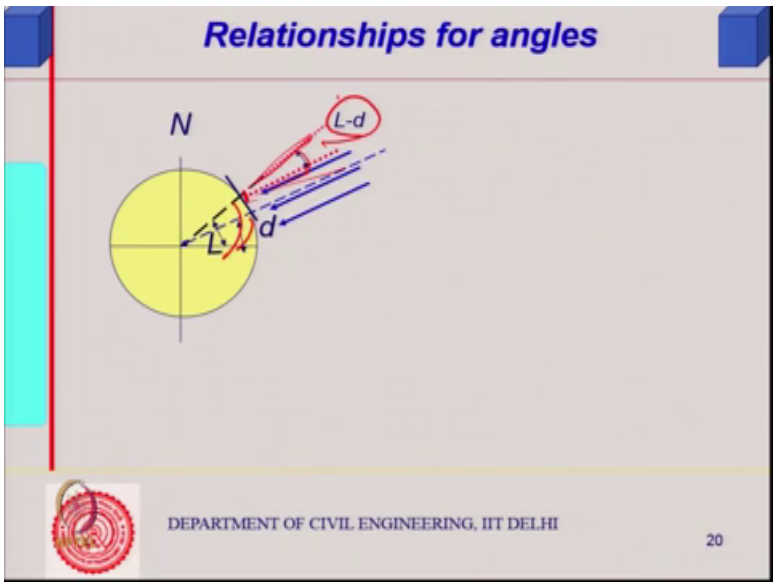

And if I am interested in a point somewhere here, this is a latitude angle, this is the latitude angle because it is also divided from the equatorial diameter. Now, I am interested in and. So, this is my horizontal surface at that particular location horizontal. So, angle between horizontal and suns ray is nothing but latitude angle you know, angle

between horizontal altitude angle. So, this is zenith angle vertical this is nothing, but vertical radius to that point and extended that line that is nothing, but vertical normal to the horizontal. So, this vertical and this is parallel this suns ray. So, this is nothing this angle is latitude this angle is declination difference between them is L minus d is nothing, but zenith angle. Zenith angle equals to L minus d this is only at 12 noon, at 12 noon zenith angle is equals to latitude minus declination. So, altitude is nothing but 90 minus latitude in declination, this is point clear.

If not, just let me make it clear again. You see what I am saying is this is my, let me make explain it again, let me explain it again. This angle, see this is my north direction geographical, this is my equatorial plane, suns ray coming like this, this is declination, there is no confusion on this, this is my location is location is this. So, latitude angle is this between these two point.

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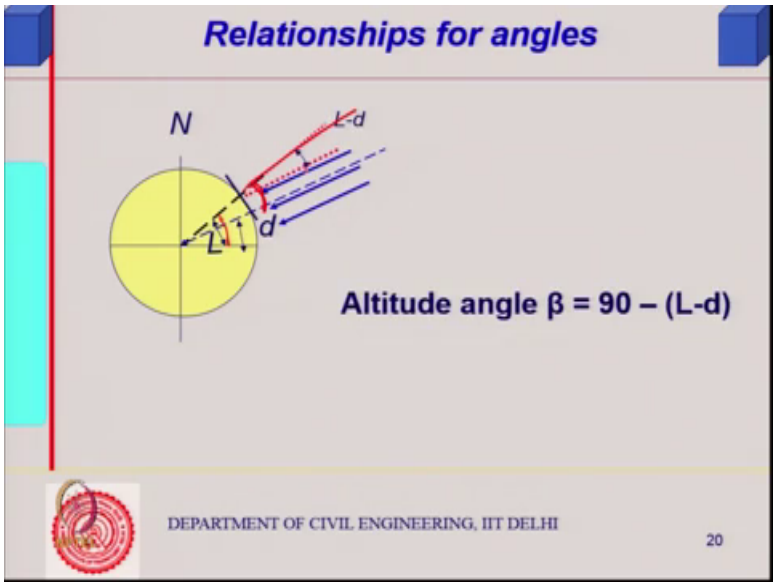

So, this angle is nothing, but latitude minus declination, latitude minus declination. What is this? This vertical this is suns ray, so angle between vertical and suns ray is nothing but zenith angle, 90 minus that is altitude angle that is what I was telling you earlier. So, it is at 12 noon 90 you know altitude angle beta is equals to 90 minus L minus d.

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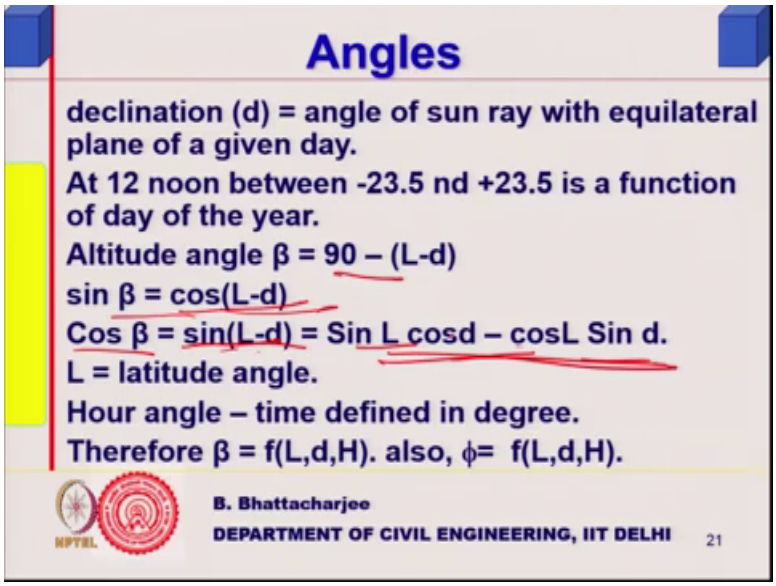

So, yeah this we have already defined. Now, supposing you know I take sin beta then this will be simply.

Student: cos (Refer Time: 17:30).

Cos and I can write it like this and cos beta will be written a sin L by d. So, I can write something like this. So, far I have not taken care of hour angle at all. So, at 12 noon this equation is valid, cos of the altitude angle is equal to sin of the latitude, cos of the declination this simple sin beta is equals to cos L by d cos L minus d and cos beta is equals to sin and L d you know because 90 minus L minus d and sin L cos d minus cos L sin d because sin L minus d can be written in this manner. So, at 12 noon this is simple relationship between altitude angle and declination and latitude is given by this. So, at 12 noon only if I would want to take hour angle that in becomes a little bit more complex which will look into that is right.

So, hour angle is time defined in degree I can that take that also into account. Therefore, beta is actually a function of latitude, declination and.

Student: (Refer Time: 18:29).

Hour angle; latitude, declination and hour angle right. Similarly azimuth angle is also a function of latitude, declination and.

Student: Hour.

Hour angle.

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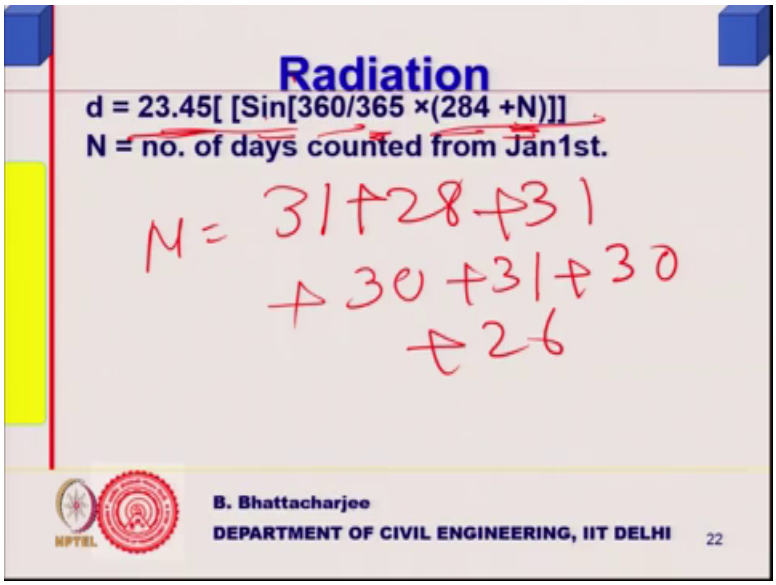

Simple empirical equation amongst many complicated equation this is one of the simple equation for declination. Simple equation is 23.45 sin of 360 divided by 365 multiplied by 284 plus N, where N is the number of days starting from first January, number of day in the year starting from first January right. So, number of days counted from first January. For example, if it is 25th July, 26 July, 26 July then it will be 31 days January 28 and not leap year 28 days February, then 31 days March, N will be equals to something like this 31 days March and then April is 30 days may is 31, June is 30 and plus 26 days of July right. So, that is what it is.

So, you can calculate this out when N is equals to 365, how much does it come to N equals to 1, how much does it come to. Actually it will vary between 23.5 to 23.45 to 23 point you know around this because sin of this angle will vary between you know it is yeah 0 to 1, minus 1 to plus 1. So, sometimes it will be minus 1 because it varies from 22.5 plus 23.5, 20.45. So, that is what it is. (Refer Time: 20:24) empirical equation there are more complex equation as I said, but we will be using this only.

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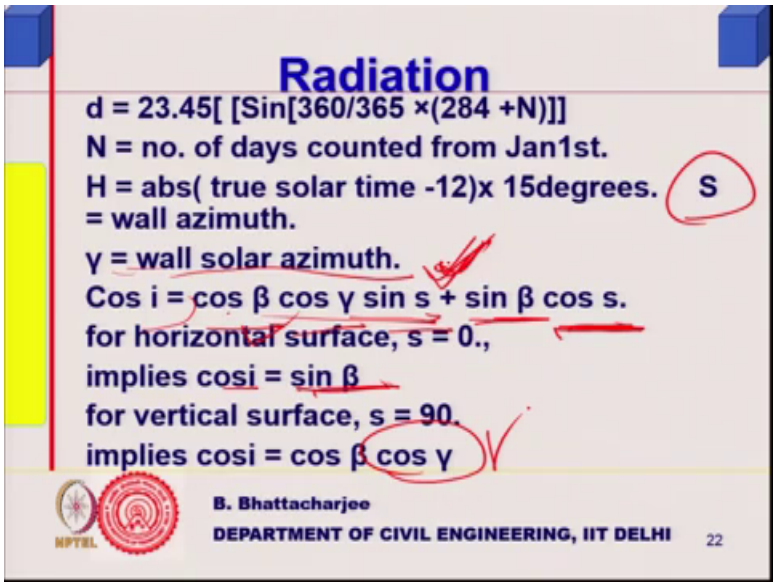

So, you can find out declination using this, maybe I have a small calculation. Now, hour angle as I said we defined absolute time true solar time minus 12, 15 degrees. So, sometime we do often use it absolute values not plus and minus. So, 15 degree hour angle both plus and minus because if it is you know depending upon the angle itself because cos of minus angle is as good as cos of plus angle. So, maybe it is related to that. And gamma is, so actually incident angle can be written in this formula, but I think I will go deeper onto this just for the sake of understanding supposing S is my solar, wall solar azimuth wall azimuth Y or it should be gamma wall solar azimuth then incident angle is given by cos beta, cos gamma, sin tilt angle or you know no solar azimuth sin beta cos gamma.

So, incident angular function of altitude angle, wall solar azimuth etcetera etcetera will derive them actually will derive them for tilt angle yeah this small s is tilt angle this.

This is tilt angle, wall azimuth is not coming here there is tilt angle. So, it is function of all this and for horizontal surfaces simply cos i is equals to sin beta, we will go more details into this actually we look into more details into this right. So, vertical surface tilt angle is 90 degrees so correspondingly changes. These are simple cases more complex cases we look into. So, when this tilt angle is 0 sin beta remains this term goes away. So, cos i is equals to sin beta cos of incident angle is equals to sin beta for when S is equals to 90 degree this term vanishes cos beta cos you know wall solar azimuth that remains.

This is actually should be gamma most of an, I am using gamma or Y similar. So, we will deal with this a little bit more.

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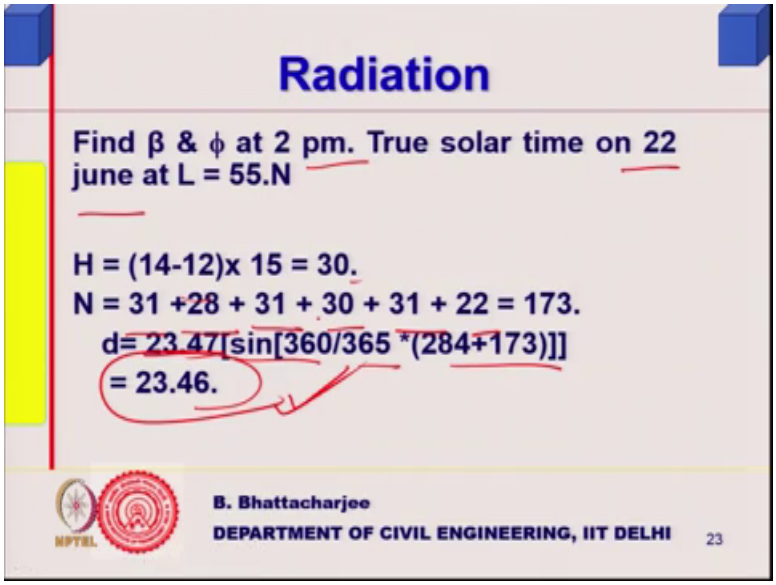

Supposing just for the sake of calculation I want to find out beta at 2 pm. True solar time on 22nd June at latitude 55 degree north. Now, why I have taken 55 degree north because this is same same problem is given in Marcus and Morris book, so we can verify that is why I have taken otherwise for a scenario of Indian condition or tropical condition I should have taken much lower, let it be, but the formula is same anyway. So, beta and phi want to find out hour angle is 2 pm, so 14 minus 12 into 15, 30 absolute value you can take, so 30; hour angle is 30. N is equals to how much? 22nd June.

So, 31 days, 21 days, February, March, April, May, 22 – 173. Capital N is equals to 173. So, my d value will be, how much will be d declination? 23.47 yeah this 45 or 47 I think there is you know this empirical formula. So, there is I think 23.47, sin 360 by 365 put it here and you get 23.46 right. So, beta you have found out beta you have found out and if you find out beta declination you have found out, you can find out well you can if you want to find out at 2 pm as it is you need more complex formula then the simple formula that I have given you earlier. So, let us look at that a little bit more in details now.

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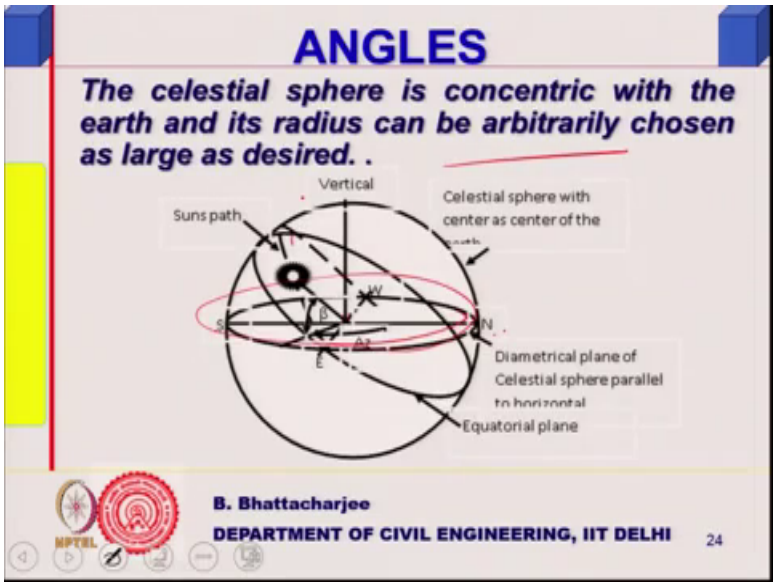

So, in order to look into the relationship between altitude angle, hour angle, azimuth angle, declination and all that now I want to find out altitude angle and the azimuth angle from latitude, declination and hour angle, because latitude defines the location, declination defines the day of the year, and hour angle which defines the time of the year. So, suns position I want to find out. Now, this comes from the principle of celestial, you know basically spherical trigonometry. So, the relationship I think I did not give you or maybe partly I have given you, but if you want to understand that completely then you have got to look into this concept of spherical trigonometry little bit more details.

Now, we define something called a celestial sphere is concentric with the earth as sphere if I make conceive which has got the same center as the earth and its radius can be arbitrarily chosen you know, so that is what is. So, in that if I can define this the geographical north on the horizontal, this is my horizontal surface, this is my horizontal surface right and this is north, this is south, this is east and this is west, this is vertical this is vertical. So, this is you know, this is a celesphere, celestial sphere with center as a center of the earth. So, this one itself you know this is a suns path this is the equatorial plane, this is a equatorial plane.

Now, you know if I look at the earth from the center I can draw a line towards the north direction towards the North Pole and also draw a line towards each direction east west and north south. So, these are this line right, these are these lines and this is a point on

the celestial sphere itself. So, altitude angle will be defined like this. So, celestial sphere first of all is a sphere whose centre is earth its dimension radius can be anything arbitrarily chosen. So, in that sphere I can find out because if you expand this diameter can be very large. So, sky volt can be included some where the suns position is there. So, I can locate the sun its position on the celestial sphere and you know directions also I can consider along in, geographical direction also I can put in there. Let us see how it is.

So, in this case O is the center of the earth this is you know in this one Os or maybe I have another diagram this will show you better.

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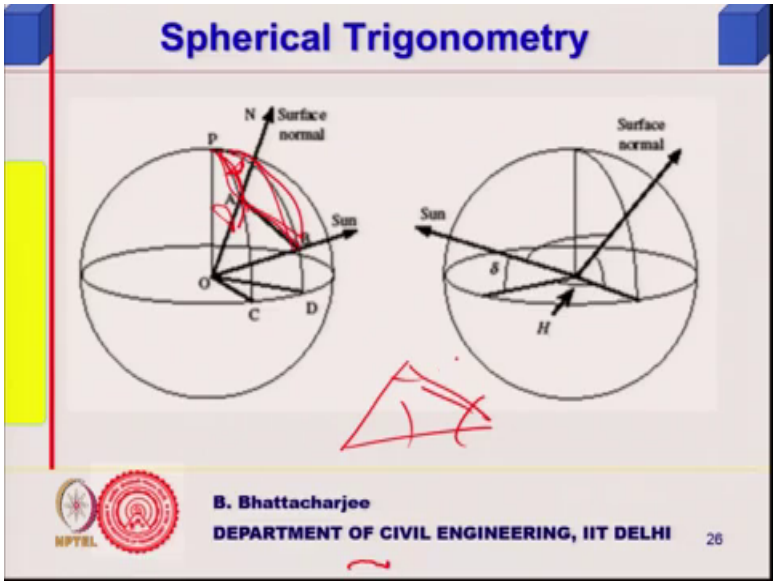

Now, before doing that let us understand a little bit related to spherical trigonometry. Compared to our you know, compared to our triangle in Cartesian coordinate a spherical triangle is defined by 3 arcs and the surface of the sphere in planar triangle I have in plane there will be 3 lines which will close the polygon and I have the triangle. Here I left 3 arcs, 1 arc another arc and another arc they will form a kind of a triangle on the spherical surface, kind of a triangle and the spherical surface and it is defined in terms of this, this arc is defined in terms of this angle.

So, sites are defined in terms of angle subtended at the center right and also there is an angle between, also there is angle between two of those surfaces you know from the radius from the center if I draw a line to one of those vertex, two of those vertices then I can get a plane and that is angle between these two planes subtended between these two

planes are the angles of the spherical triangle. Now, sum of these three angles can be more than 180 here, unlike the planar triangle where this sum is 180 here it could be different. So, we will see that. So, I think we will look into this concept of spherical trigonometry because that would give us proper understanding of all the angles that we are looking into.