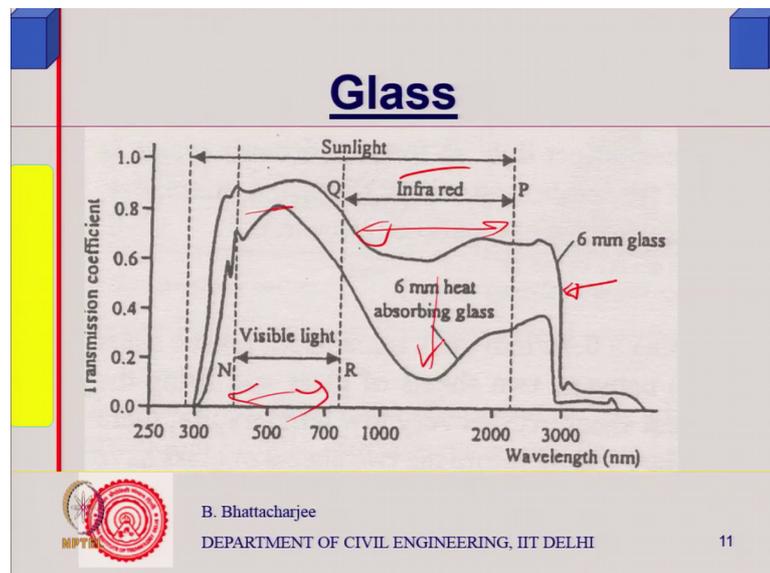**Energy Efficiency, Acoustics & Daylighting in building**
Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture - 23
**Thermal Design of Unconditioned Building**

So, we continue with glass, where you stop last class right.

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And that is what we said that when you look at the transmission coefficient over the solar spectrum, then what we see is, got actually high absorptivity within the visible range visible range right and then this is the heat radiation infrared radiation this is heated in and this is 6 millimeter normal glass, this 6 millimeter normal glass. But if you have an heat absorbing glass then this gets reduce somewhat, but this is significantly reduced right.

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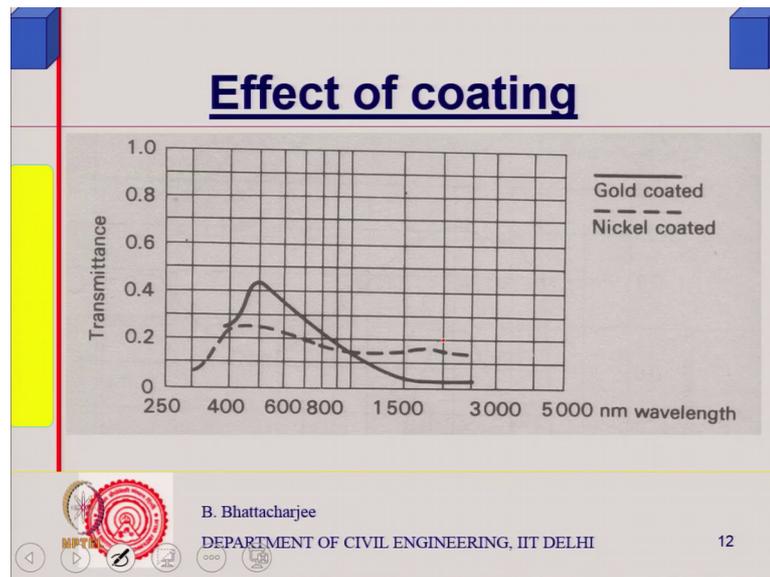
And net effect of course, we see in solar gain factor which usual see in a moment. If you have gold coated glass then overall transmission you know transmittance reduces, but of course, infrared radiation significant reduction will be there beyond this, you know this infrared region.

Nickel coated is somewhere here. So, by coating you can reduce down the heat absorption right visible light some reduction some places it would be there. Photo chromatic glasses they are usually with bromides there. So, what happens is they are sensitive their transmitivity or transmission coefficient depends upon the amount of light falling in. So, that is a function of you know, so that is kind of intelligence sort of a thing. So, if there is too much of light it will not allow if there less light it will allow. So, photo chromatic glasses can be something like this.

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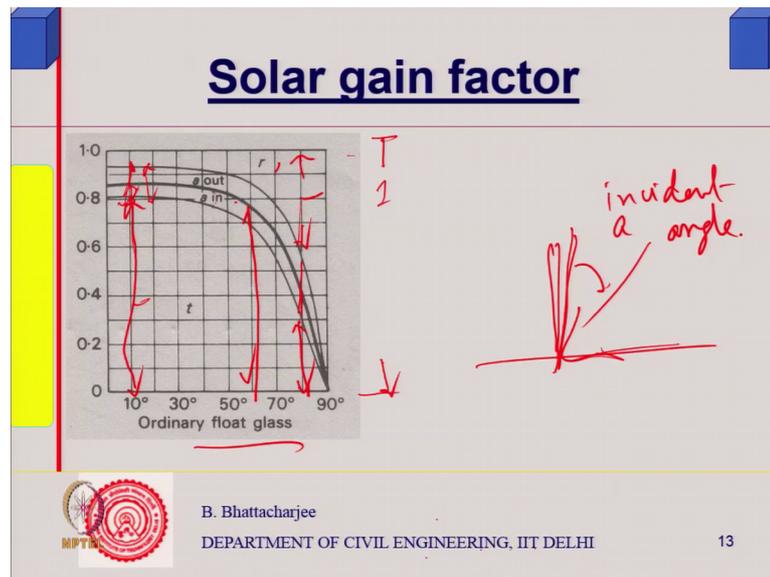
And we know that it is solar gain factor though which we quantify this. Now, solar gain factor if you look at it this axis is it total amount of you know the fraction of radiation, this range represents the reflection at any angle of incidence say 80 degree this is the reflectance r, this is transmitted say 10 degree angle of incident this is what is transmitted through it and this is what is absorbed.

So, part of the absorbed is actually transmitted back. So, in other words theta at any point of time is given by this central line some will be in some will be out. So, theta the solar gain factor is given by the central line, central line. This is fully transmitted absorbed light part of it is transmitted, this is the absorbed light which goes out and reflected is thrown out. So, this is this is what is you know.

So, this is one total is one out of which this fraction is reflected this fraction is directly transmitted and this fraction is absorbed part of it is then transmitted again and this is a function of angle of incidence also. Obviously, you can understand if it is coming parallel to the surface nothing will be transmitted everything will just pass by right. So, that is why at 90 degree angle of incidence because normal to the surface the angle the race makes with normal to the surface that is actually your angle you know incident angle, incident angle, incident angle. So, it depends upon incident angle as well.

Therefore, you can understand that it will vary with time to time because solar radiation will be incident at different angles at different time. So, it will be you know it will vary.

However, we can take a single value as an approximation or you can take theta varying with time if we can estimate them for the type of glass that we are using for the glass that we are using right. So, that is what is the solar gain factor for glasses, solar gain factor for glasses right, solar gain factor for glasses alright.

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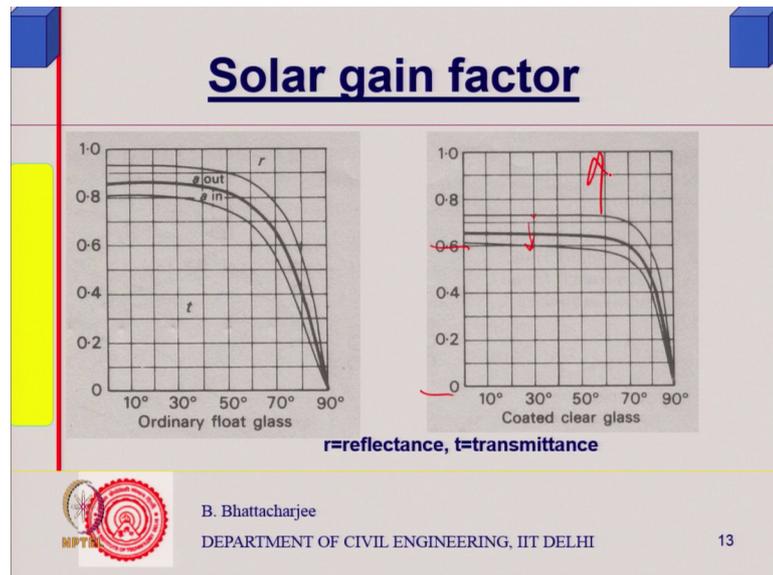
So, will go to the next one let say this is coated clear glass this is coated clear glass. This is what is transmitted relatively less as you can see, absorption is similar, but large amount of it is reflected as well, large amount of it is reflected as well. I mean in a way talking of the totals spectrum of solar radiation right. So, that is how all right; reflectance transmittance etcetera etcetera.
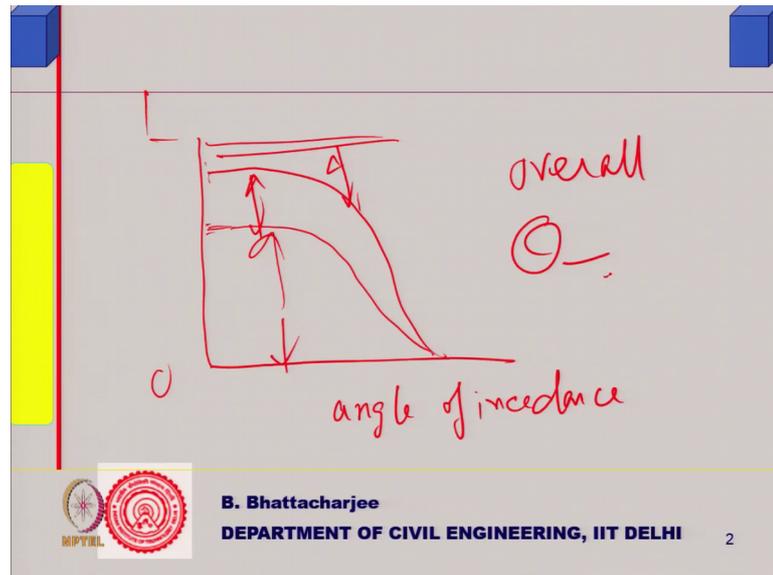
So, this is what related to glass if this is your angle of incident, angle of incidence and this is 0 to 1. So, highly absorbing glass will be somewhere here, which will absorb quite a bit and this is reflected this portion is reflected. So, absorption high more absorption means this, more reflection obviously, would mean this and this is the transmittance. So, glass can be chosen based on the solar properties you know. Overall theta is what is overall theta is what is important overall theta that is important for us. So, choice of glass should be based on theta.

Alright, coming back to next thing is, but you go to find out how much will be the radiation and you can see obviously, we know how to calculate the amount in details we have seen how to calculate the amount, at any point, at any location on any surface on a given day at a given time you know. So, we have already seen that. But if you see the radiation pattern varying that is give you a kind of good idea.

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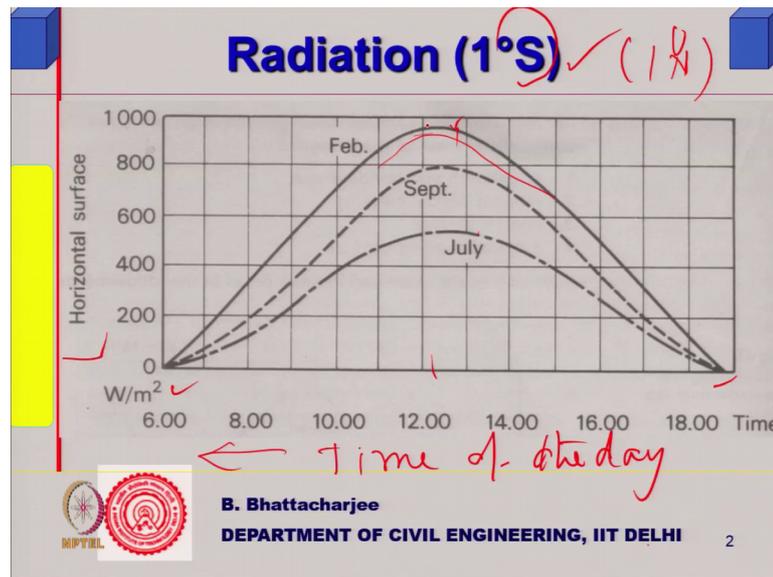
So, for example if you look at 1 degree south latitude you find that if this is a time of the day, time of the day 6 to 18 now 1 degree south latitude. So, you find that maximum radiation is received in February which is summer there, you can see similar 1 degree north the only difference will be instead of you know instead of July.

Student: It will be July.

July will go summer there February will come down then. So, September is summer there actually near equator this is a kind of variations you will find 1 degree south or 1 degree north, this is actually horizontal surfaces around 12 noon you find maximum radiation, 12 noon you find maximum radiation right.

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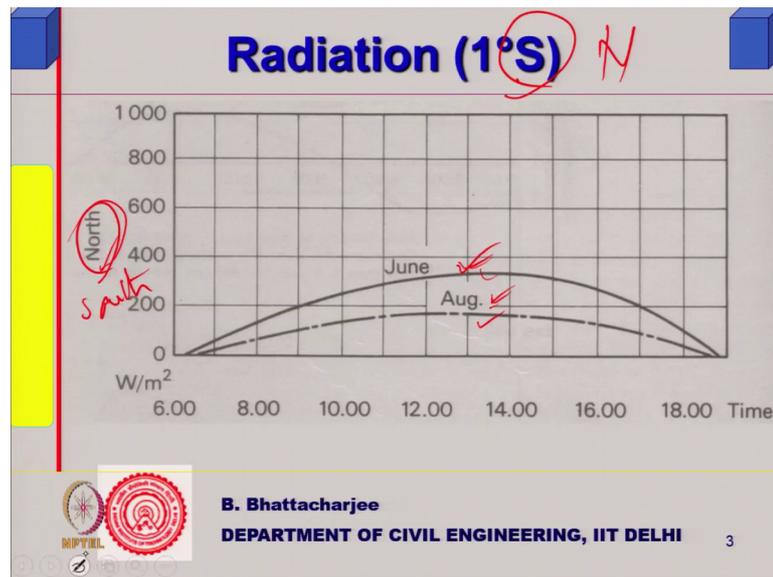
And if you do for north surface, if you do for north surface you get this is during August and during June, but if you take 1 degree north right then this will become.

Student: Opposite

South surface because north in southern hemisphere gets receives radiation, but north in northern hemisphere do not received radiation while south does because banking of the sun is towards the south. So, this is one degree north if it is, if it is north then this will be south surface and months will also change accordingly. So, you get say for example, in south surfaces winter months suns altitude is less.

Student: Less.

So, south surface gets lot of radiation, but in summer month it will get less radiations right. So, winter months it keeps on getting. So, here it is the summer months actually for northern you know southern hemisphere north surface is here actually winter months sorry these are winter months their corresponding ones in our case should be reverse order. So, this gives here some idea I will I will summarize this little bit more once we look at them.

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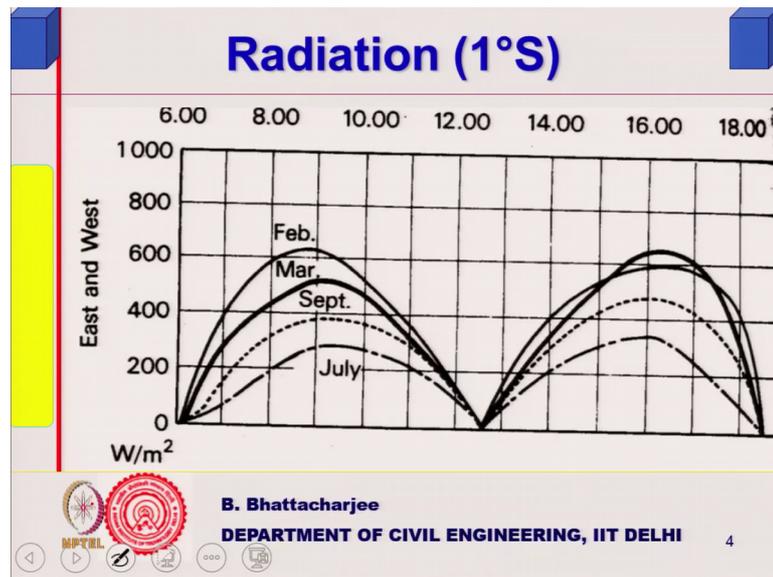
And this is on east and west surfaces. So, east and west surfaces you find that during summer you get lot of radiation this is a east surface early in the morning, early in the morning till 12 and this west surface right and this is September, this is September. So, close to equator the tendency is to get radiation, tendency is to get radiation you know this variation is order also you can see this order of the order one 600 watt per meter square this is the order and if you go from this to let us say; and you know south, in our case it will be north I will come back to this again.

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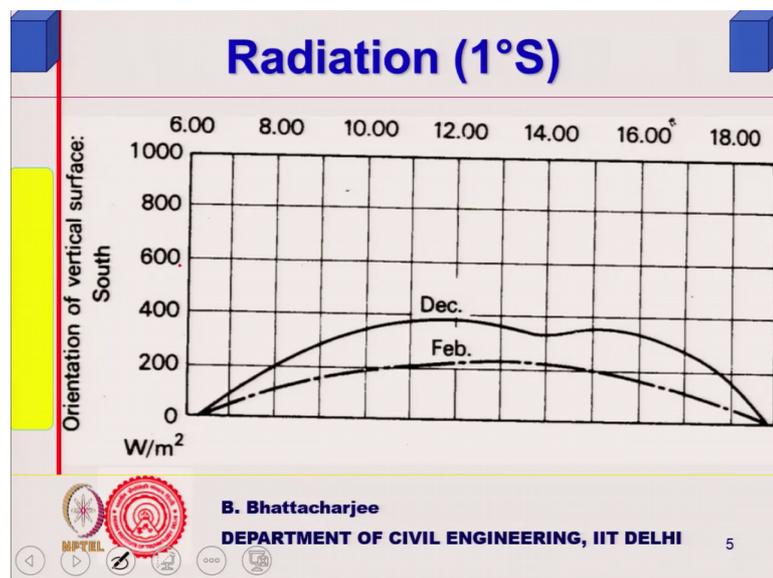
But, what I am trying to if you compare this with the let us say some higher latitude 33 degree south.

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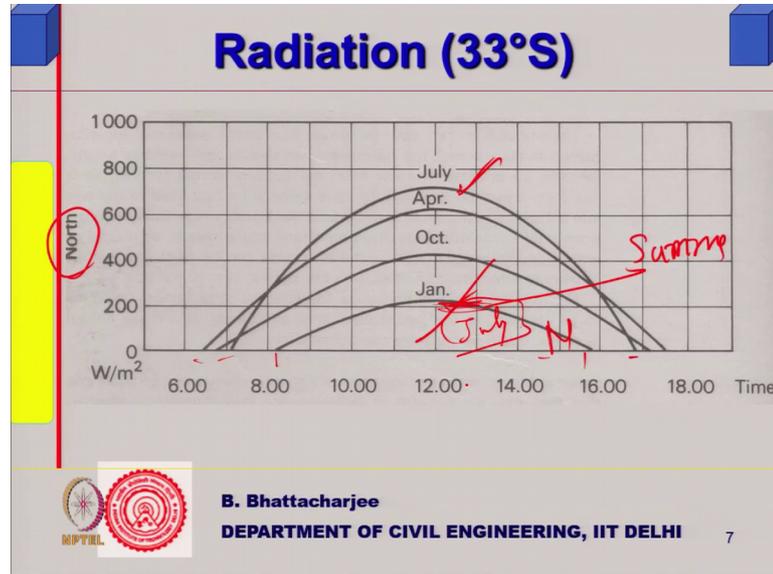
So, in summer this peak is much higher in horizontal surface just compare this and we obviously, know how to calculate this out, but we have just compare this horizon surface. So, summer months this was very much there right and 33 also this is high. So, a horizontal surface always receives high radiation, horizontal surfaces in summer months. But winter you see which has got down significantly, even the time, time of sun you know during the sunrise to sunset is now day is smaller, here day is very large, summer months day is large radiation received on horizontal surface is also large as good as lower latitude close to equator right. But winter days small. While this was not the case in 1 degree, 1 degree, 1 degree, 1 degree you know. So, day and night was more or less.

Student: Similar.

Similar both in summer and winter, both summer and winter right. And in winter also it get sufficient radiation there is of the order of a around 4-500, but if you see this one compare this with this one compare with this one you find that this is somewhat less.

Less than yeah similar although peak is because its horizontal surface, but day time becomes less. So, total radiation received will be less while, this we understand anyway because it is a function of latitude and declination as we have seen earlier. If you see

north surface in this case which is equivalent to south surface in northern hemisphere right, this is in winter months, this is in summer months. So, at higher latitude south surfaces in northern hemisphere will receive low radiation in summer while in.

Student: (Refer Time: 11:28).

Southern latis hemisphere in north surface in this is summer, this is summer, this is summer if I put it equivalent January you know you put it equivalent it would be somewhere in the July or something like that in our side July or June July, July around that time and July scenario in northern hemisphere. So, it would receive much less radiation during summer months south surface.

And winter months it will receive maximum radiation maximum radiation and duration also duration; obviously, the day become smaller, but still its comparable I mean in summer months practically much less duration during which south because in you know altitude angle of the sun is much lower, much lower at such latitude because altitude is also a function of declination latitude you remember that it is a function of declination latitude and of course, hour angle.

Student: Hour angle.

Hour angle yeah. So, that is on north surface that is on north surface in 30 degree south and this is an east and west surfaces.

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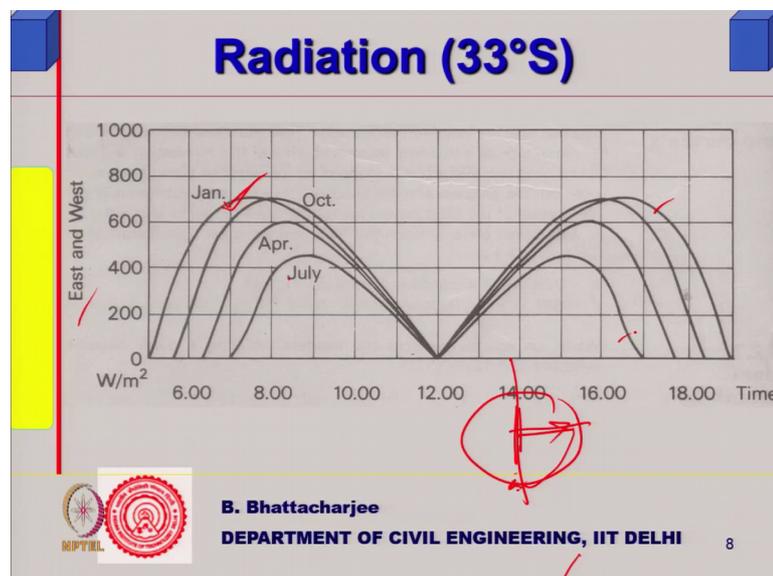
Now we can see again the summer months they get it the east surface. It will just get reverse in our northern hemisphere. It will get on the east, you know it will gets slightly July will become January and January will become July otherwise all fine. So, this is the summer months, this is again January and this is July.

So, in summer months in higher latitude what you find that you get some radiation in the north surface also and in northern hemisphere and southern hemisphere south surface also get some, I mean east surface sorry east and west get radiation in summer months because the day is longer. So, you get early in the morning till 12 you get some radiation and afternoon you get radiation. Horizontal gets radiation all the time summer months its get higher winter months its get less because day time becomes longer. So, this type of variation is important from the point of view of understanding. Next what we have going to discuss.

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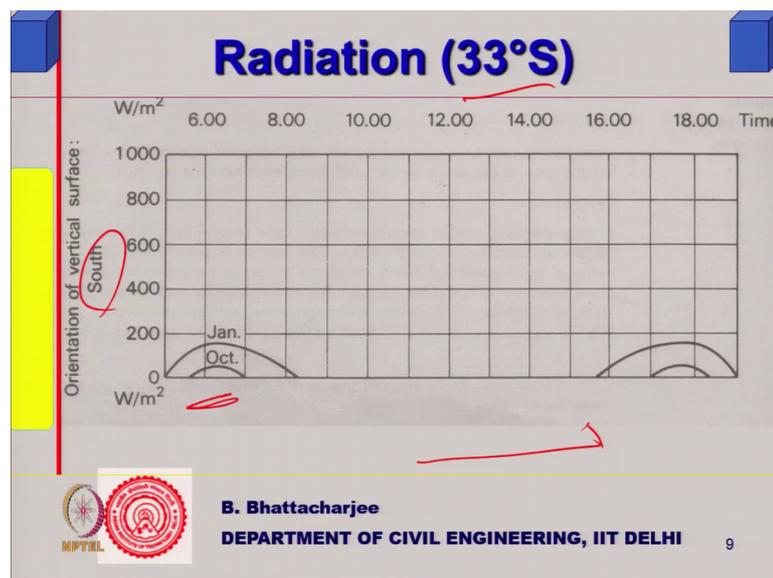
So, this again you can see saying 30 degrees south in you know south means, south means it will only get some radiation because sunrises somewhere beyond the east in higher latitude day is long in summer. So, sun will rise not east, but somewhat beyond the east actually a little bit depending upon where it is which hemisphere it is, it is the day is longer than 12 hours. So, even the south surface in southern hemisphere receives some radiation in the morning and you know in the evening also afternoon just before sunset.

Same case will be the northern north surfaces in northern hemisphere because sun will rise early to meet north of the due east, because day is longer not twelve hours slightly more. So, north surface will also get a little bit of radiation in the morning early in the morning and also in the afternoon. Now, what is important here is because of these kind of variation I can actually block the sun by providing something like overhangs, this is horizontal overhang over the window.
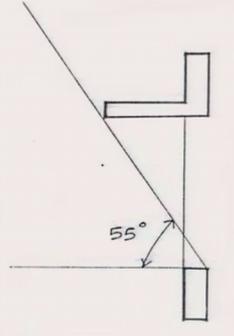
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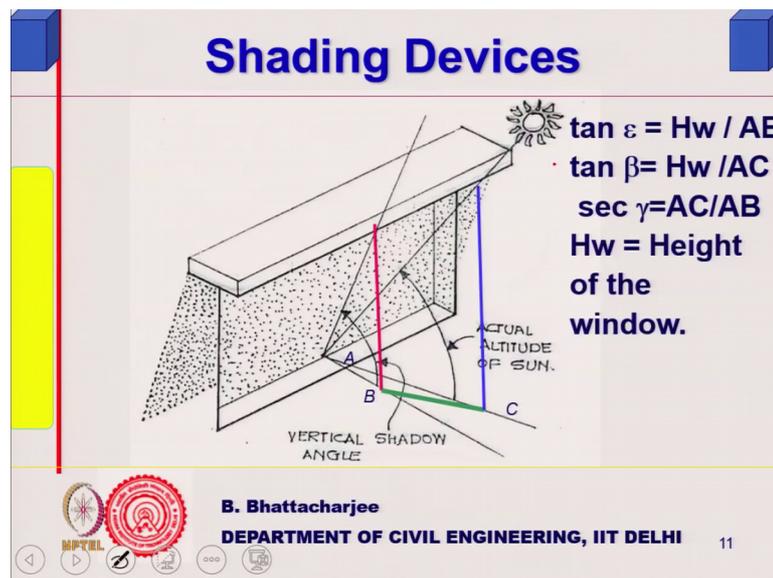
So, this is the window or openings I can provide, so since you know I can design then in such a manner in let us now talk of I have given you explanation through southern hemisphere. But let us understand because we are in northern hemisphere it would be easier to understand the northern hemisphere scenario. In northern hemisphere of course, in near equator 1 degree north or in above 10-12 degree close to it actually, altitude angle of the sun may not be that low in winter as we have seen, but as you go away from it altitude angle of the sun is quite lower right.

So, what you can do is you can provide this overhang such that summer sun is blocked, but it tell us winter sun to go through right, winter sun to go through. So, this will be, this will be for south facing windows in northern hemisphere or north facing windows in southern hemisphere right. So, you can allow winter sun to come in and these are this we called shading devices, this we call a shading devices. This is a horizontal shading device this is a horizontal shading device. Now, I can have a vertical shading device also I will

come to this angle and all that later on, I can have this is horizontal shading device and this angle. I will come to little bit later on.

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And this is you know, this is, this is horizontal shading, this is a vertical shading device.

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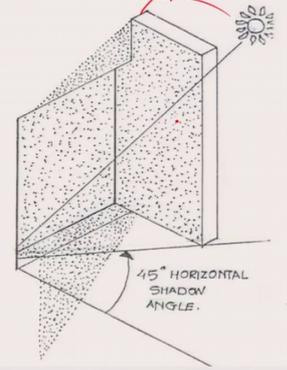
Now, when will you need vertical shading device you know when the early in the morning or in the evening because you see you should block from this side, it should block from this side right. It should block from this side for south facing surfaces in south facing surfaces in northern hemisphere or east facing surfaces you can put it on

east facing surface will receive, but altitude angle of the sun is lower. So, you all have to see that how work it out. So, this is called vertical shading device because it is vertical while that is called horizontal shading device. You can have combinations, you can have combinations will define this angle a little bit later on.

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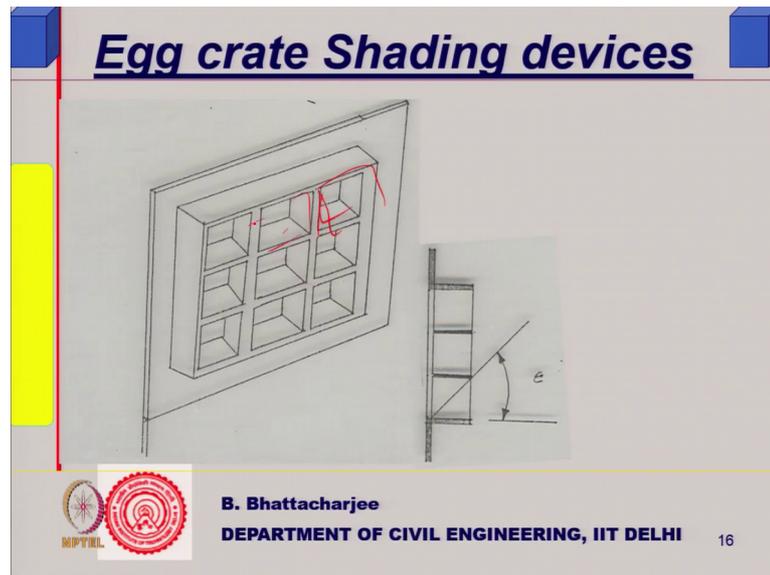
You can have combinations this is called egg crate shading device, that is which looks like an egg crate. So, you will have combination of; like in hotel rooms you will see quite often each room will have this kind of you know total; I mean balconies and may be openings of the kind such that sun is blocked. So, it can be systematically done these are called a crate shading device and you can have all kind of combination you can have inclined shading device also.

So, let us go back to them some then how do you look at this a little bit more, define them through some angles, define them through some angles. So, therefore, we can utilize the shading devices effectively to cut down the unwanted solar radiation during summer and allow them because the length will govern this. So, we define certain angle these angles are first of all you see I can draw a normal to the window or wall normal to the window or wall right, normal to the window or wall.
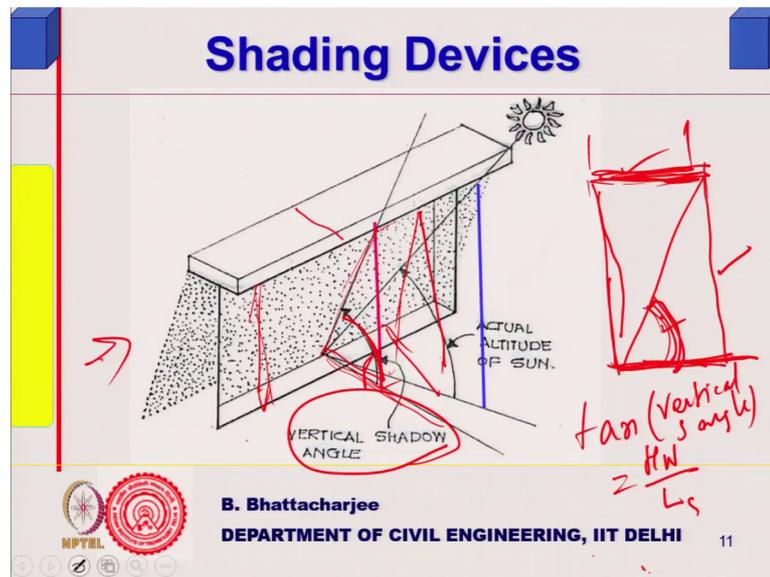
And if this is the shading device then maybe I have a diagram let me see if I have a diagram right. So, I can just drop it down from any point, drop it down from any point, this is normal to the window. So, this is nothing, but height of the same height as a window height, same height as a window height right. This is same height as a window height and this angle this angle this is 90 degree, this is 90 degree because I have dropped it down and we define actually something called vertical shadow angle, and this is the vertical shadow angle, this is the vertical shadow, angle vertical shadow angle.

So, what is vertical shadow angle? It is a angle the tip of the shading device makes with the normal in horizontal plane. You know a line joining the tip of the shading device to the point on the window interior point on the window right with the normal drawn from that normal to the window itself. So, this is what it is, you know this is what it is. So, I mean this will be same elsewhere if I draw. So, anyway anywhere I will get the same one. So, at any point, any point you can take.

So, basically this if this is your this is your shading device in vertical plane this angle I am talking of, I am talking of this angle. This is you know if I see from this direction I see this is a shading device shade overhang, this is overhang, this is the window height and normal to the window is this. This angle in vertical plane I call it vertical shadow angle, is the characteristics of a horizontal shading, is the characteristic of a horizontal shading. So, characteristics of horizontal shading is vertical shadow angle right.

And how would how would I find it out? It is simply this distance you know supposing I want to find out this is say cos of this angle, I want to find out this is simply this height divided by or tan is very simple tan of this angle, let me say I want to find out I define it as epsilon I will just come to that. So, tan would be, tan of this angle would be equals to vertical shadow angle vertical shadow angle, angle will be equals to this height that is window height, height of the window divided by.

Student: (Refer Time: 21:24).

Length of the.

Student: (Refer Time: 21:25).

Shading. shading device horizontal right. So, I can find out this one right now I got to related it with the sun I got to relate it with the, I got to related it with the sun you know I got to relate it with the suns position. Now, suns position if I want to related it to, suns position if I want to relate it to, suns sun will be at some inclined it will not be not necessarily be normal to the window it can be at some angle.

Sun ray will be at some angle I mean know it may not be parallel to this it may not parallel to this not necessarily. So, this is the sun ray and its projection on to the horizontal plane is this, its projection onto the horizontal plane is this; projection on to the horizontal plane is this. So, this is the, this is the what is this angle then. What is this angle?

Student: Altitude angle.

Altitude angle of the sun, altitude angle of the sun so, this altitude angle of the sun and therefore, this you know if I look at it because I am dropping it down it is normal, just normal to the horizontal plane. So, this is, this is normal this also normal. So, I can get a relationship between I can get a relationship between.

Student: Vertical shadow angle.

The shadow angle and altitude angle shadow angle and altitude angle. Now, this line must be parallel if I join this line, now this line because this is same or in other words not this, I join, if I join this my drawing may not be very good because it should have been

something like this may be may not be very good. So, if I join like this right this is drop down from the top I mean I have dropped one down from the top and this I have drop another down from the top, this is another down from the top you know the angle sun rays of course, somewhat inclined.

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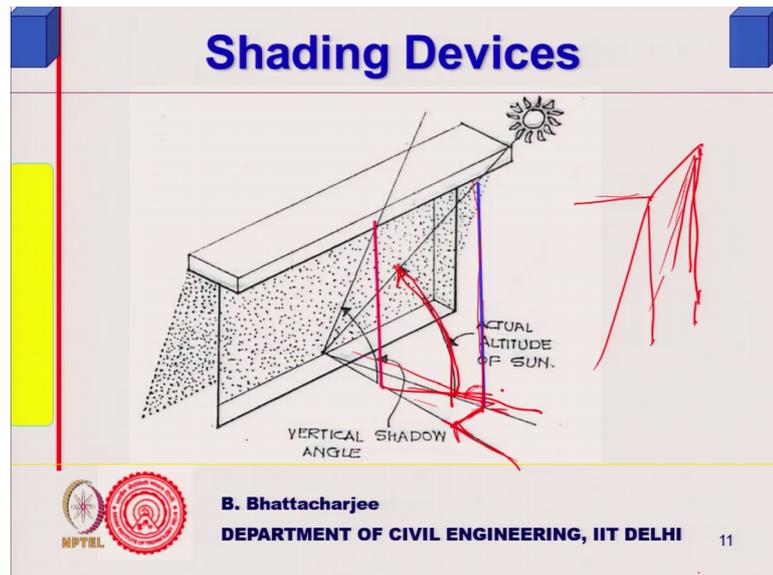
So, I can actually this is the distance or maybe I have a better diagram. Well, this is the line this is the line which will be parallel to suppose to be, parallel to this, it will be parallel to this and this is normal you know all this. So, this line is parallel to this, this is normal to that line. So, this is actually 90 degree, this is actually 90 degree, this is actually 90 degree right, because this line green line is parallel to that black line I mean parallel to this line and its normal to this is normal to this one. So, this should be 90 degree. In other words you know I can get relationship relating this to how do I get it.
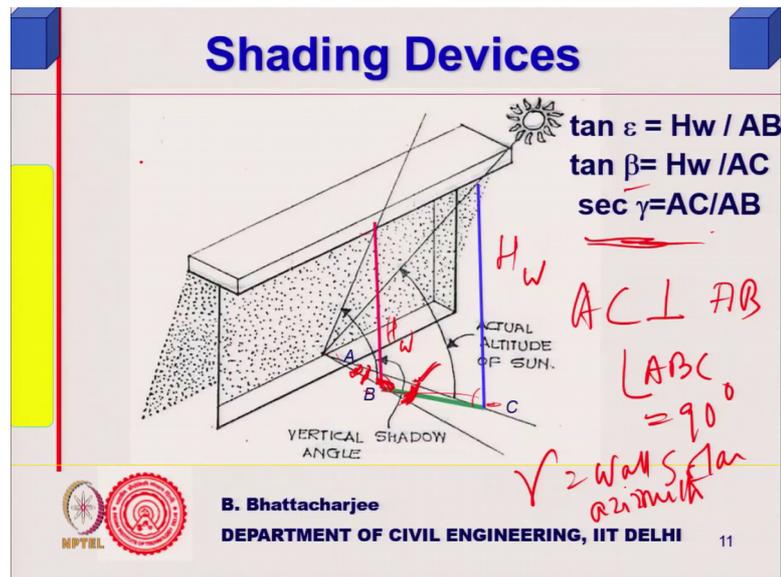
Student: (Refer Time: 24:08).

Angle tan epsilon is Hw by AB that is what we have said already tan Hw is the height of the.

Student: Window.

Window, and tan beta altitude angle will be again height of the window Hw by.

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Student: AC.

AC, Hw by AC, Hw by AC. So, this is Hw, this red line is also HW. So, Hw by AB and Hw by AC. Now, I want to find out relationship between length, you know relationship between length. So, sec gamma, now what is this? What is this angle? What is this angle?; Angle between normal to the sun ray in horizontal plane and angle between normal to sun ray in horizontal plane and normal to the wall.

Student: Wall solar.

Wall solar azimuth.

Student: Wall solar azimuth.

Wall solar azimuth. So, this is gamma is the wall solar azimuth. So, wall solar azimuth will be nothing, but because this is ninety degree this is wall solar azimuth and this you know, this distance I mean this distance I cannot find out actually AC by AB, AC by AB will be equals to AC is a hypotenuse AB is the this angle. So, cos angle will be AB by AC, sec will be AC by AB sec of secant of gamma will be equals to AC by AB because this is the wall solar azimuth; this is the wall solar azimuth.

This is the, this is 90 degree, this is normal to that one. So, AC is normal, AC is normal to line AB, AC is you know this is 90 degree or angle ABC, ABC is 90 degree angle

ABC is 90 degree. So, AB by AC is cos AC by AB is and gamma is a wall solar azimuth, wall solar azimuth, wall solar azimuth right, wall solar azimuth.

So, therefore, now I can related this actually, I can relate this AC by AB. So, this I can relate actually sec gamma will be equals to you know tan epsilon by.

Student: Epsilon by tan beta.

Tan beta. So, this is what I have done, sec gamma will be equals to height of the window anyway this we have seen already, we have define already Hw is the height of the window and tan epsilon is equals to Hw by Ls tan beta sec gamma. So, did I write it beta the same? Yes, tan beta right sec gamma is equals to tan epsilon.

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So, tan epsilon can be written as Hw by Ls, tan beta sec gamma height of the window length of the devices. So, length of the device can be related to, length of the device or tan epsilon or what you call vertical shadow angle, tan of vertical shadow angle is related to altitude angle and wall solar azimuth, wall solar azimuth, at any point of time.

So, you know the time at which you want to block it, you can actually, you know you can actually find out because at any time you will be able to find out first of all solar azimuth. So, wall solar azimuth, altitude angle of the sun. So, what is the Ls require to block, the sun at that point of time you can find out because tan epsilon you can find out.