Elements of Solar Energy Conversion
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Lecture - 12

Hello and welcome back to the series of lectures on Solar Energy Conversion ok. So, so far we have covered 11 lectures and today we are going to see the 12th lecture and in these 11 lectures what we covered.

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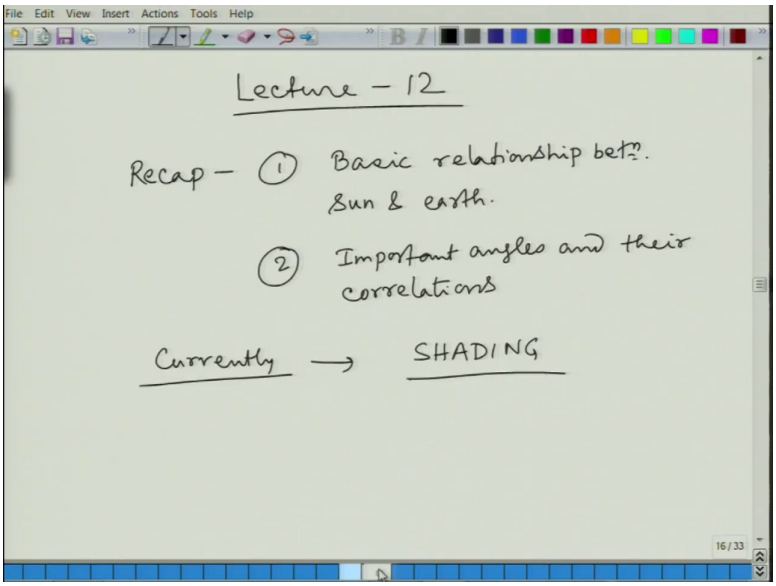

So, this is lecture number 12 ok. So, what we covered so far? We have covered the basic relationship between sun and earth and its implications. And 2nd major topic that we covered is the important angles and their correlation.

So, these 2 major topics we covered and the currently what we are doing is we are looking at another important topic which is shading ok. How a particular location will be shaded by the

nearby objects; trees, buildings and other things that is the topic that we are now discussing. So, in the last class, where we stopped?

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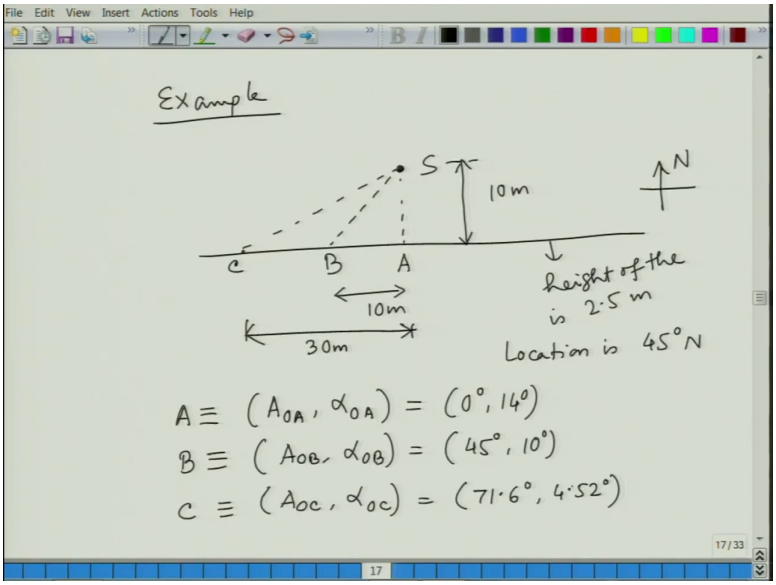

We were looking at one example where we were trying to understand whether a particular location S will be said shaded by a vertical wall plates placed towards its south ok. So, what we did? We have taken one point directly towards the south then another point here B and another point C here ok.

And these distances where this was 10 meter and this was 30 meters and this distance was 10 meter again ok. And the height of this wall is 2.5 meter ok. And what else is given? The location; location is given to be 45 degree north that is the value of the latitude.

So, this is the problem that we are looking at. And what we obtained in the last class that the A point was represented through its azimuth angle, the object azimuth angle for point A and the altitude angle for point A and that we obtained to be 0 degree and 14 degree, ok. Similarly for point B we needed to do little more trigonometry calculations to obtain the same thing which is the azimuth angle as well as the altitude angle ok.

And, what where the values? It was 45 degrees and 10 degrees ok. And we did not do explicit calculation for the point C, but we mention the values because the C point will be calculated very similar to how we calculated for point B ok. So, for point C what we will get at the azimuth angle and altitude and that value is triangle 71.6 degrees and 4.52 degrees ok. So, each of these points now can be placed on the sun path diagram right.

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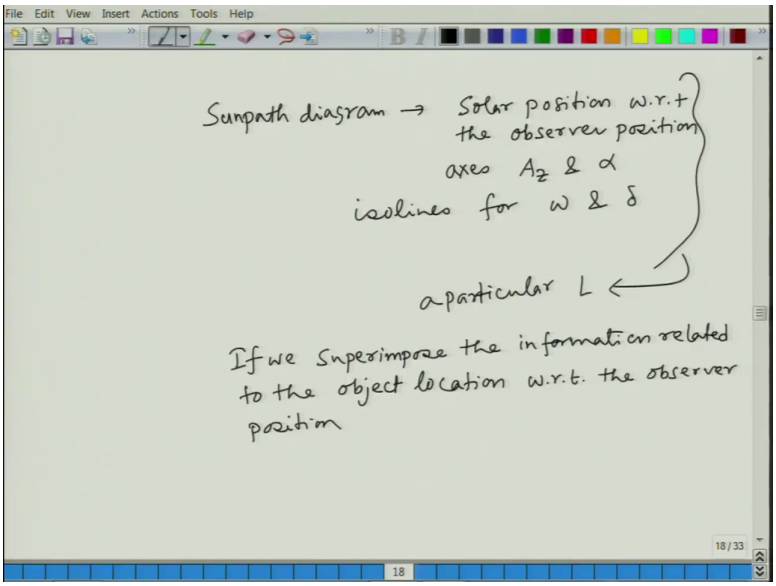

Sun path diagram tells us; so, just to recap a little bit. So, sun path diagram gives us solar position with respect to the observer position right. And the axes are azimuth angle solar azimuth angle and the solar altitude angle right. And the isolines are drawn for different hour angle and different declination angle right. And everything we get for a particular L or latitude ok. This is what the sun path diagram is.

Now, if we superimpose the information related to the observed or the object location; object means, the one that has a possibility of shading the particular location. So, the object location with respect to the observer position ok. If we do that then we will find what would be the shading probability or shading possibility at a particular hour angle and particular delta or declination angle. So, let us go to the sun path diagram ok.

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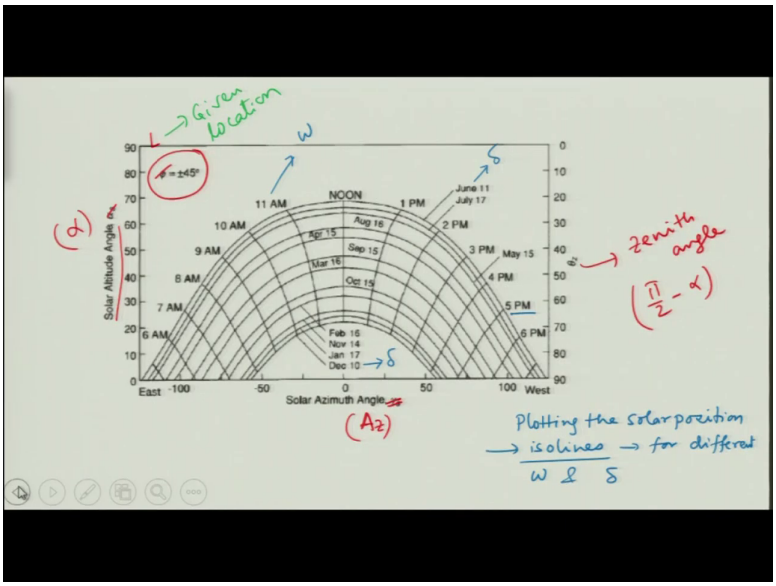

So, this is the sun path diagram that we have looked at earlier. So, here we will try to superimpose the information regarding A, B and C on top of this diagram ok.

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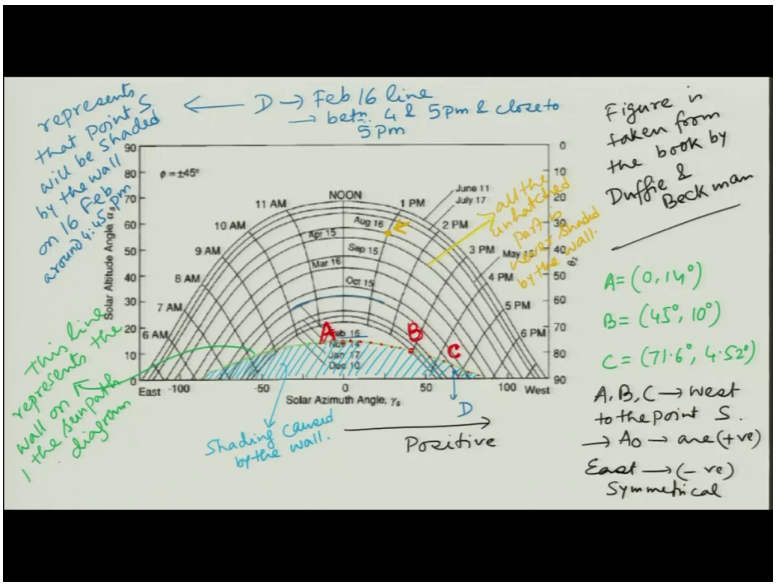

So, here I should mention that this particular figure is taken from the book by Duffy and Beckman ok. So, this is a book that I referred to in the introductory video, please look back. So, this is a book that you should follow and this figure is also taken from there ok. So, fine.

Now, what we can do? We can place the points related to the wall object points on this particular solar sun path diagram. So, what we have seen that let me just repeat it. That A is represented by 0 and 14 degree, B is represented by 45 degree and 10 degree and C is represented by 71 degree 71.6 degree and 4.52 degree

So, if we try to place these points where these points will be? Ok. So, 0 and 14 degree, so, it will be somewhere here ok. Let us write that this is A and then 45 degree and 10 degree this will be somewhere here ok. Let us write this point to be B ok. A and B we located and the third point is 71.6 and 4.52. So, this will be 71.6 and 4.52. So, somewhere here, ok.

Now, so, these are tentative, you can be as accurate as you can be ok. But, what we can do? The whole wall can be represented on the sun path diagram by such a line ok. One side of the wall will be represented by such a line and the other side. So, this is for the west. So, all A, B and C are west to the point S and west you know azimuth angle is positive that is what we are getting azimuth angles are positive that is the sign convention we are using. So, that is why everything here that we got is positive

Now, the well is extended to the east side also right. So, the east will be will be negative, but it is exactly symmetrical. So, what we can logically deduce? That this particular line that we have drawn this green line will be mirror imaged on the other side as well ok. So, that is the line which will tell us that ok; this line represents the wall on the sun path diagram right that is what we got. So, what we can see here?

That anything that is lying under this curve, so, let me hatch this part. So, this whole part will be shaded ok. So, this part represents the shading caused by the wall ok. So, if you look closely you can see. Suppose you take this particular point ok. Let us say this point is D ok. So, D is what?

D is basically on the February 16 line ok. So, this is the February 16 line ok, here it is written February 16. So, D is on that line. So, it is February 16 line and it is between 4 pm and 5 pm close to 5 pm. So, between 4 and 5 pm and close to 5 pm right. So, what you can say here?

That on 16 February of any year around 4:45 the wall will shade that location S ok. So, this point D is shaded or rather D represents that point S will be shaded by the wall on 16 February around 4:45 pm. Does not it? So, that is the use of this sun path diagram. And now under this hatched area, you can take any point and you can find out whether what is the time

and date for that particular location which will tell you which part, I mean that will tell you that at that point it will be shaded.

And the rest of the curve like everything here ok all the unshaded part is never or unhatched part is never shaded by the wall. So, what does it mean? Suppose you take this point ok; August 16 at 1 pm that particular point S will not be shaded by the wall that is what it means ok. So, this is August 16 at 1 pm it will never be shaded ok. So, how useful is this sun path diagram?

Quite useful right and one point I should make here that we have taken three points to represent the wall; A, B and C, but in principle you could have taken in any number of point that you we would like to calculate for. So, you could have several points along this line and you could get this shape of this particular hatched area much more accurately if you have taken more points on the wall.

But here we are doing this for representation purpose and we are not trying to be quantitatively exactly accurate that you can see that on a graph like this you cannot be quantitatively super accurate right. So, that is what we just restricted ourselves into three points.

But, if you have a complicated geometry like not a straight wall, but a varying height wall straight wall, but varying height then you have to take several different points to get this shape of this hatched area much more closely ok.

So, that tells us important things about the sun path diagram ok. So, far what we have seen? That one kind of shading problem which will tell you that a particular location is how prone it is to be shaded by the nearby objects that is one kind of shading problem we often encounter.

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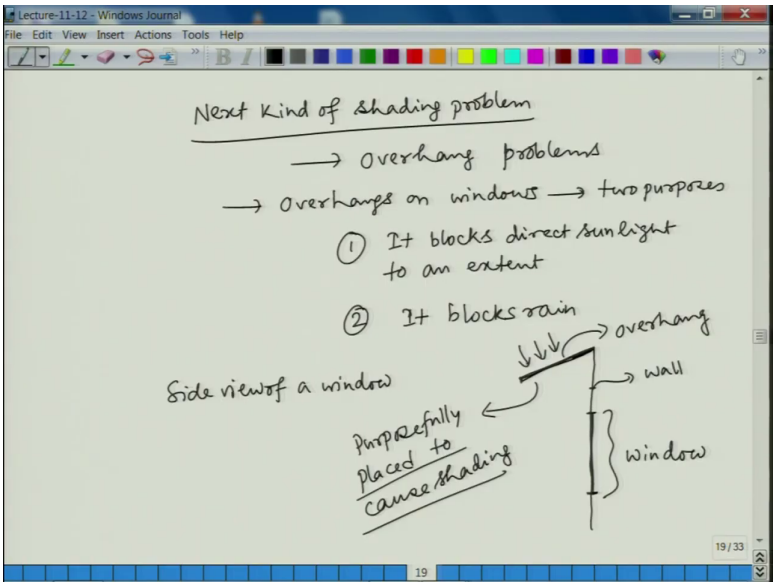

The next kind of shading problem that we will talk about we will talk about is called overhang problems ok. We will see that it takes into account a variety of actual or practical shading problems that we encounter in the solar conversion fields ok. So, first let me tell you why this is called overhang problems. So, I am sure that you have seen these overhangs on windows ok.

So, it serves two purposes. 1 is it blocks direct sunlight to an extent ok and the 2nd purpose it serves is the so, it blocks rain as well ok. So, two purposes it serves. So, what is that if we take a side view of a window then we can draw something like. So, often this overhangs has some slope as well. So, that the rain is not accumulated and it is on a wall a vertical wall. So, let us say this is the or this is the portion which is open as a window.

So, this is the window, this is the wall and this particular extension is called overhang. It hangs over the window that is why it is called overhang ok. So, what does it do? It covers rains as well as direct sun rays to reach the window ok. So, how does this overhang actually affects the solar radiation that is what we are going to do. So, this is actually purposefully placed to cause shading ok.

Earlier problem we have seen that we want to predict some undesirable shading on the location of the solar collector right. Here we are placing something which we intentionally place it. So, that it cause shading and it also represents a class of problem which will see that gives us the shading possibility in case of the rows of different solar collectors ok.

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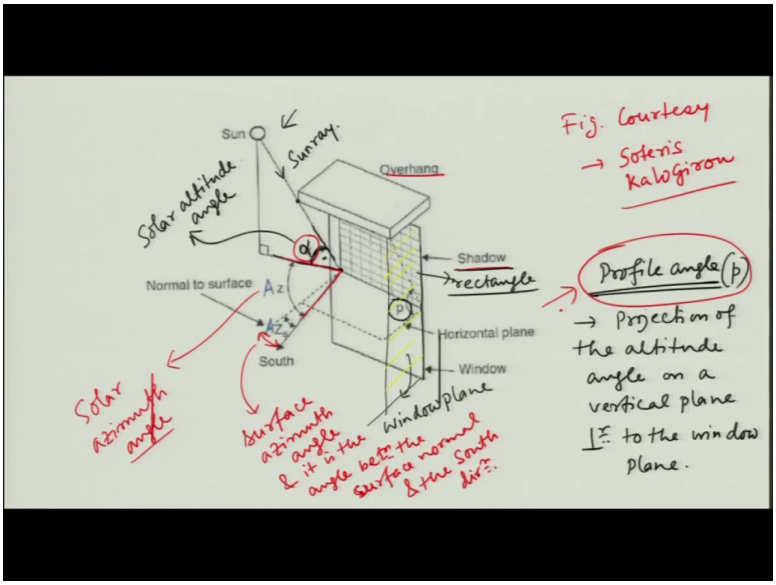

So, let us look at it ok. So, this is a much cleaner picture of a overhang on a window and it also tells you several of the important angles that we are looking at ok. So, this is our

overhang and this is the shaded portion that you see that is the shadow it makes on the window or the wall ok.

And again I should give the figure courtesy it is from the book by Soteris Kalogironi ok. So, again this book is mentioned in the introductory video which we are also following in this course. So, this particular figure is taken from this book ok. Now, in this figure please see that for this is the sun position and this is the sun ray that is falling on the or that is the direction of sun ray that is coming to the window.

Now at this particular tip we will have a critical sun ray that will reach this particular point on the vertical wall which will be one end of the shadow rectangle. So, the this hatched area is the shadow rectangle, this part shadow rectangle and this point represents the one angle of or one corner point of that particular rectangle. And what does it do?

So, this particular angle this angle ok is our solar altitude angle ok. Because, this is the angle between the sun ray and its projection on the horizontal plane, that is why it is called solar altitude angle ok. So, what we will see here that this particular solar altitude angle will not give us the angle that we require for calculating the shading.

The particular angle that we require is called profile angle; profile angle often designated with the symbol p and it is shown here. What angle is that? It is the projection of the altitude angle on a vertical plane perpendicular to the window plane ok. So, here you can see this particular altitude angle is projected to a vertical plane.

So, this is the window plane right, this is the window plane. And a vertical surface that you can consider at this particular location which is also perpendicular to the window plane. So, it will be somewhat like this ok. So, this particular plane is a vertical surface which is perpendicular to the window plane.

And we are projecting this particular angle alpha ok to this yellow shaded vertical plane and whatever angle we are getting that is our profile angle ok. What other angle can we see here is the solar azimuth angle. So, this is the solar azimuth angle. Why it is solar azimuth angle?

Because, it is the angle between the projected sun ray on a horizontal plane, that makes with the south direction.

So, that is why this is solar azimuth angle and the other angle this particular angle is the angle between or this is called surface azimuth angle and it is the angle between the surface normal and the south direction ok. So, all these angles we can see and will see how this profile angle is super important to find out the shading ok.

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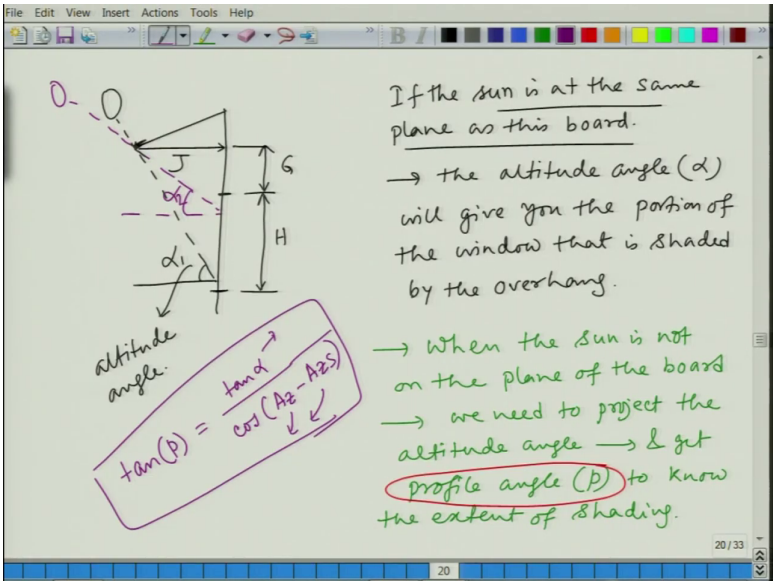

So, if we look at the overhang picture again. So, this is the typical picture of it and let us say puts let us put some dimension. This is the J and then we have this window opening here. So, let us say from the top of the overhang the top of the window opening is G distance down and the window opening itself is of length H or height H ok.

If this is the distance ok, so, if the sun is at the same plane as this board ok; the writing that we are doing if it is the same plane sun is on this plane only then we can see that we can project it on the wall across the overhang. And what we will get is the angle and this angle will be the altitude angle right.

And whatever that angle is if the sun is here and it makes this angle ok, so, that will give you this alpha 2 this is alpha 1. So, altitude angle itself will give you how much of the window will be shaded ok. So, in that case if the sun is at the same plane as the board the altitude angle alpha will give you the portion of the window that is shaded by the overhang.

But, how can you ensure that? I mean you cannot simply ensure that because the sun is moving towards east and west as well. So, it has two directional motion, ok. So, you cannot just the sun cannot be on a single plane, it has to cross the plane. So, that is where this profile angle becomes important.

When the sun is not on the plane of the board, we need to project the altitude angle and get profile angle p ok to know the extent of shading ok. So, that is where this profile angle becomes important ok. Let me write the formula for profile angle before we go to derive it.

So, how we are how we can get tan of this profile angle will be tan of alpha divided by cos of the solar azimuth angle minus the surface azimuth angle. So, here we are seeing that by these two azimuth angles we are taking the solar movement out of the plane of the window that is what we are doing. And the altitude angle is still there in the picture ok. So, let us try to derive this from the geometry.

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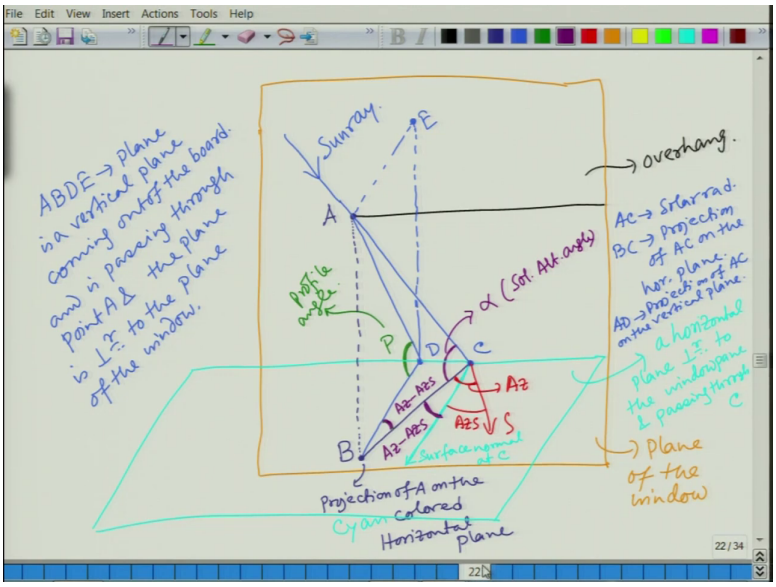

So, let me draw this figure. So, let us have that we have a let me use a faint color here for the whole. So, let us say this is the plane of the wall on which the window lies and let us say that this is the overhang ok. So, this is the plane of the window and this is the overhang ok.

Now, for any position of sun what we can write? We can draw a ray which will pass through this and hit the plane of the window ok. Let us name this point C ok. And at this point what you can draw? You can draw a horizontal plane which is parallel to the overhang and perpendicular to this plane of the window. So, let us say this is the horizontal plane which is perpendicular to in the window plane and passing through this point C.

So, this particular plane is horizontal plane perpendicular to the window pane and passing through point C, ok. So, this point if we extend this is the sun ray right and this is the point where the sun ray is hitting the window pane. Now, you have to visualize this because it is

not possible to draw a three dimensional figure that is why you have to use your imagination to visualize this ok.

So, I will try to be slow so that you can follow now let us name this point this tip of the overhang to be A, ok. And here we can drop a vertical line which will be on the plane this horizontal plane ok. So, if we say this point is B, so, this is projection of A on the this line ok, this plane or let me use this cyan colored horizontal plane clear ok.

Now, what we can draw? We can connect these two points B and C and we can also drop a projection of this point. Let us name this point E and that projection let us name that D ok. So, basically D point it is this E point is not very I mean we are not dropping projection on this. Let us do it differently.

Let us say that this AC line that is the sun ray direction right. So, we can project it on the vertical plane which is the window plane which is AC. So, AC is the solar radiation ok. Now, what we can do? We can project this AC on the horizontal plane. So, BC is the projection of AC on the horizontal plane ok. And we can also project this AC on the vertical plane and that is how we will get this D ok.

So, AD is the projection of AC on the vertical plane and that vertical plane is perpendicular to the window plane ok. So, that is how we get that vertical plane and it will be somewhere here, ok. So, let us name that point E. So, this is the thing that you have to visualize.

This ABDE, this plane is a vertical plane coming out of the board. Board is same as the plane of the window ok. So, this particular plane is coming out of the board and this vertical plane is passing through is passing through point A and the plane is perpendicular to the plane of the window ok. So, if you can visualize this, now the angles will be easy to visualize.

First one is this BCA, this angle is what? AC is the solar radiation and BC is the horizontal projection of this and angle between them will be alpha or solar altitude angle ok. Now, the projection of that particular alpha onto the vertical plane is the profile angle right. So, let us

name. So, this particular angle ADB this is the profile angle ok. Now, if that is the profile angle what angle do you see here is the this particular angle ok.

This particular angle we will see, but let us say that this is our south direction suppose. So, what is this angle? This angle is nothing but or this angle is our Az or the solar azimuth angle right. And we can draw a vertical or on this horizontal plane we can draw a perpendicular which is the normal to the plane ok.

So, surface normal at C; surface means the window surface. So, what is that angle? This particular angle is Azs right. So, surface normal making with the south direction ok. So, if that is the case then this angle is nothing but z minus Azs. Agree? This particular angle ok. And by reciprocity rule this particular angle is also Az minus Azs. Is not it? Now, let us try to find out the relationship between these angles ok. So, let us look at the relationship between these angles. So, let me remove some part of it, so that I can write, ok.

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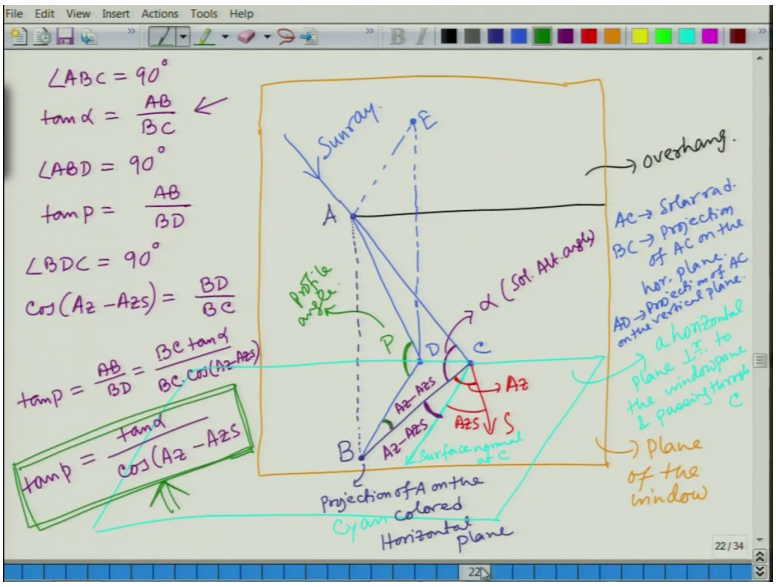

So, note that this angle ABC is 90 degree right because that is the in two different planes. One is AC is on the vertical plane and BC is on the horizontal plane. So, what we can write? That tan alpha is nothing but AB divided by BC ok. Similarly, this angle ABD that is also a right angle 90 degree ok. So, what we can write? tan p is our AB divided by BD ok.

Another angle we can see here this BDC is also a right angle. So, these all three angles or all three triangles are in different planes ok. So, please try to visualize that and ensure that you agree with me that which one is the right angle then only you can tell the correlation ok. So, here what we can write? This cos of this Az minus Azs this is our BD divided by BC. Make sure you follow all of these different relations ok.

Now, we are after tan p right. So, what we can write? That tan p which is AB divided by BD that we can write. This AB is nothing but BC into tan alpha which is coming from here ok

and the other one BD is BC into cos of Az minus Azs right. So, what we have? BC cancels out and we have tan alpha divided by cos of Az minus Azs tan p, ok.

So, this is the relationship we were after right? What is the relation between the profile angle and the altitude angle and it will or it must involve the solar azimuth angle as well as the surface azimuth angle that is what we are seeing here ok. And that is what we wrote here that will be the profile angle ok, well and good. Now, let us go to the use of this profile angle. We have found the profile angle from all the relations, now how to use it.

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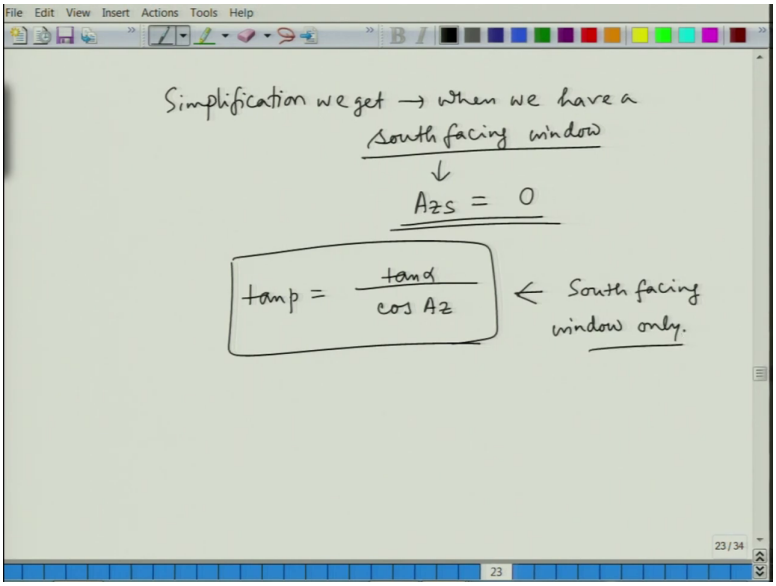

So, one simplification we can have simplification we get when we have a south facing window. This you must have heard that in India, we talk about the south direction is from where the light and wind everything comes right. That is the most favored direction for your airy and enough light room if you want to have then that is why we place the windows.

So, we often get this south facing window and for south facing window what we can directly write this surface azimuth angle will be 0 right because the surface normal is already facing towards the south. So, angle with the south will be 0. So, if this is the case then the profile angle becomes little simplified. We have tan alpha divided by cos Az right because Azs is 0 and that is for south facing window only ok.

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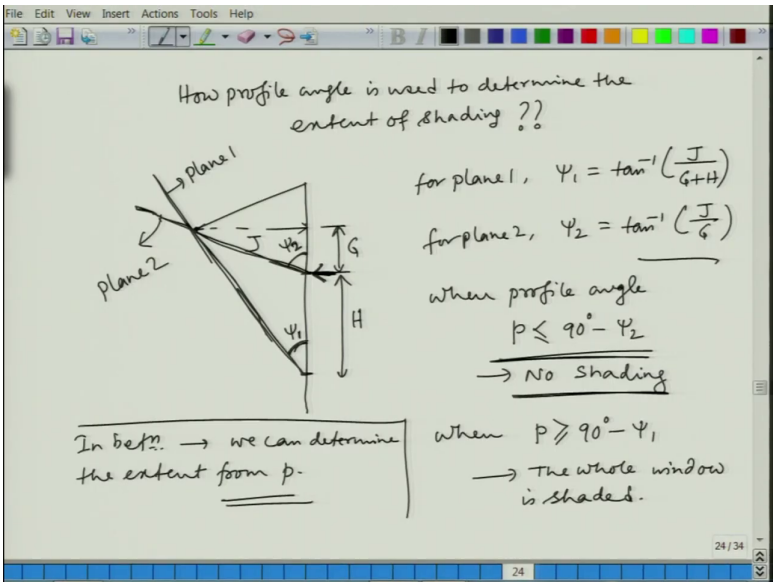

So, that is a simple change that you can make other than that how we are going to use it, how profile angle is used to determine the extent of shading? Right. So, we all we did to find the profile angle is to get how much of the window will be shaded right. So, here is the formula.

If we have this particular overhang that we have drawn earlier, so, this is this distance is J and this distance is H sorry G and the height of the window is H this we drew earlier right so, ok. So, here we can draw two planes. One is this one and other one is this one right. So, let us

name this particular one to plane 1 and this one to be plane 2, ok. And what angle does it make? Let us say this angle is psi

So, the plane 2 makes psi 2 and plane 1 makes psi 1 ok, the psi is the angle between the this plane and the window. So, for plane 1 we have psi 1, which is tan inverse J over G plus H right, this is straight forward and for plane 2 psi 2 is tan inverse J by G ok.

So, to find out the extent of shading profile when profile angle p is less than equal to 90 degree minus psi 2 ok then there will be no shading. Sorry, I made a mistake here. This 1 and 2 I made a mistake. So, this is plane 1. So, corresponding psi is phi psi 1 and this is psi 2 ok.

Now, this these are fine, psi 2 is J by G yeah ok. So, when your profile angle is less than equal to 90 degree minus psi 2 then there will be no shading because the sun ray is coming at the top of the window. Here sun ray is coming at the top of the window. So, the whole window is getting sun rays. So, there will be no shading ok.

And on the other hand when this p is greater than equal to 90 degree minus psi 1 then the whole window is shaded ok that is how it appears. And whatever happen in between we can determine the extent from p right. So, the relationship between p and psi this will tell you how much of the window will be shaded ok. So, that is how the profile angle is used.

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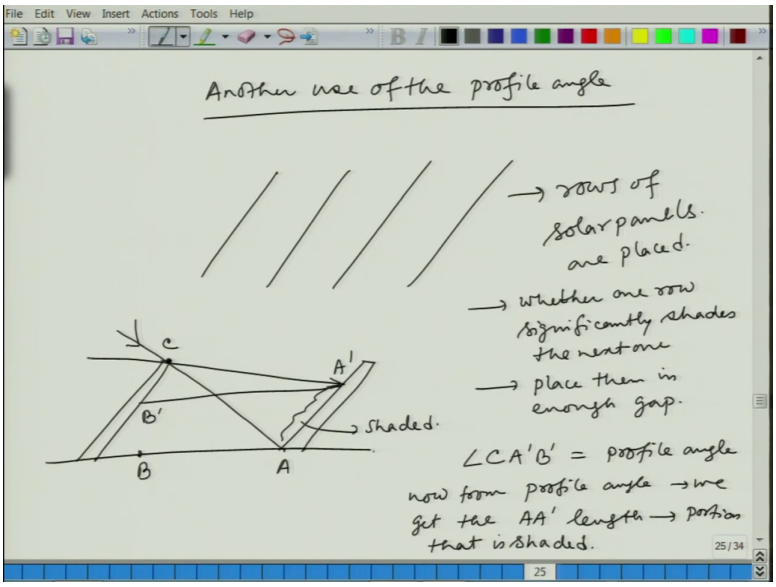

Now, let us look at another use of the profile angle. This is where we this is the one that actually relates to the conversion technology, like when you have rows of these solar panels. If you have seen a solar panel field then you will see that there will be rows, parallel rows all are placed towards facing towards the equator that is how the rows of solar panels are placed ok.

Now, it is important to know whether one row significantly shades the next one right. It should not happen and that is why you should place them in enough gap. So, how to find this gap? See if we have two rows and this is the horizontal level then if we can say that this is the top. So, when we have sun ray coming like this then there will be no shading right and when we have sun ray coming like this then this portion will be shaded right.

So, to find out it is just like a case of the profile angle. So, we can say, so, it let us say this is A, this is A prime and a parallel line will give you B prime, here it is B. So, when or rather this C A prime B prime is your profile angle ok.

Now, from profile angle we get the AA prime length. So, the portion that is shaded ok. That is how the profile angle is used. So, here we stop and we finish the discussion on shading. In the next class, we will talk about how the radiation is measured and how what are the different components when we talk about a tilted surface.

Thank you very much.