Elements of Solar Energy Conversion
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Lecture – 11

Hello and welcome back to this series of lectures on Elements of Solar Energy Conversion. Today, we are at the 11th lecture and so far we have covered the basic outline of the course and the basic ideas about sun and earth relationship. And, now we are into the more detailed analysis of the angles their interrelationships, and today we are going to complete whatever we started last class and we will start a new topic today ok.

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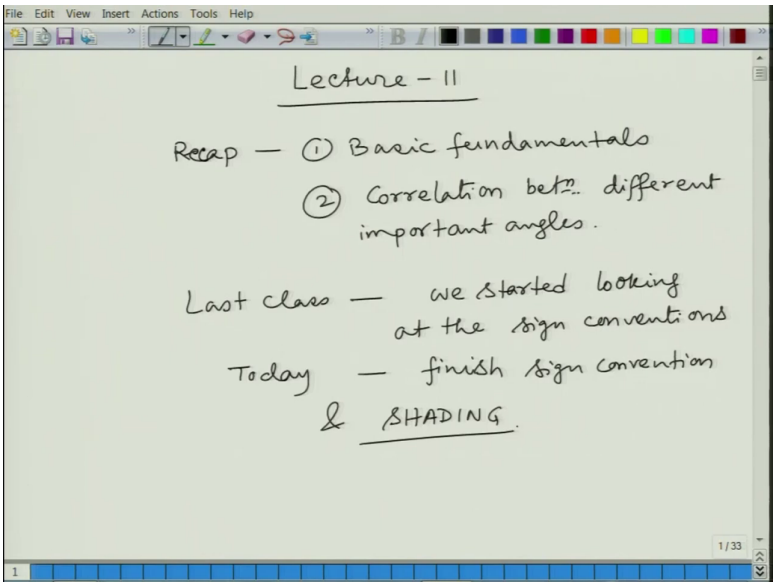

So, here we are at lecture number 11; and we have covered the basic fundamentals, then we started the correlation between different important angles ok. And, in the last class we started looking at the sign conventions.

This is a very important thing because every time whenever we look at certain angle, we should know what the available values that we it can take, and what is the range of values and, as well as what determines its sign, whether it is positive or negative; what determines that. So, today we will finish this sign convention and we will start talking about a very important topic, which is shading ok.

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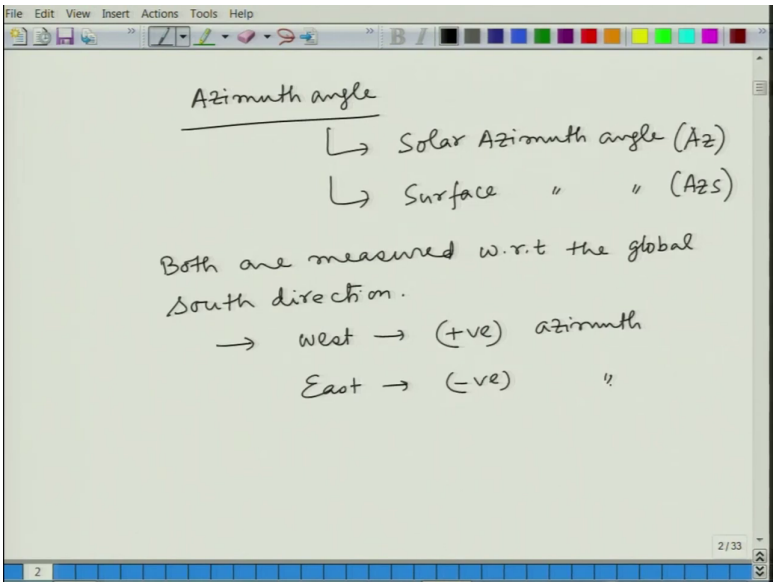

So, let us start with the sign convention ok. So, we have talked about the azimuth angle and there are two types of azimuth angles right; one is the Solar Azimuth angle and the other is

the Surface Azimuth angle. Solar azimuth angle is designated as A z and surface azimuth angle is designated as A z S ok.

For both of these; what we have both are measured with respect to the global south ok. And, for from south direction, if you go west it is taken to be positive azimuth ok; and if you go east it is taken to be negative azimuth ok and that that is true for both the solar and surface azimuth angles.

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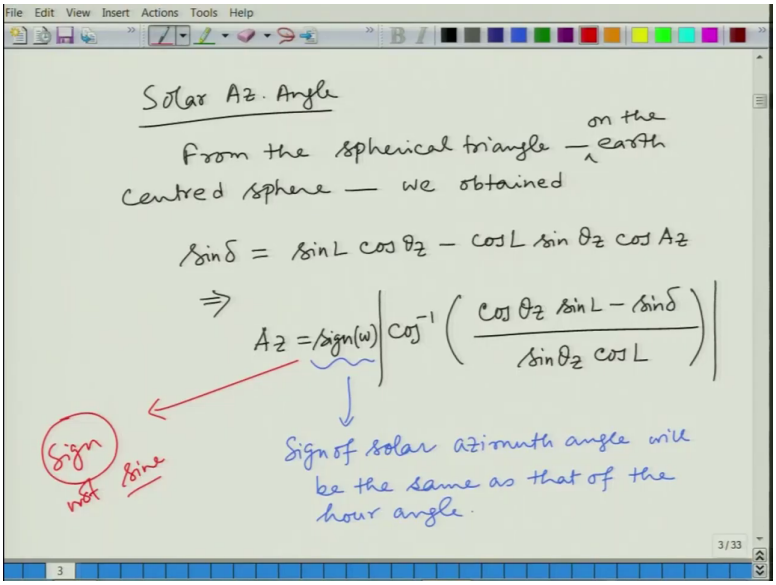

For solar azimuth angle we have not yet derived or written any clear cut expression for this solar azimuth angle ok. So, let us first do that. From the spherical triangle which is; earth centered spherical triangle.

So, this spherical triangle on the earth centered sphere, we obtained the following relationship, sin of declination is equal to sin of latitude, cos of zenith angle minus cos of latitude, sin of zenith angle and then cos of solar azimuth angle ok. So, this gives you an expression for the azimuth angle in terms of the other angles ok.

So, what you can write; this A z is cos inverse cos of theta z sin of latitude minus sin of declination angle divided by sin of zenith multiplied by cos of latitude ok. But, this particular expression can have both the signs right from just knowing the value of these angles will not tell you; what would be the sign of this solar azimuth angle right.

So, we need to have something sign. So, this gives just the modulus or the value of it. And, the sign will be the same as the hour angle ok. So, this means what sign of solar azimuth angle will be the same as that of the hour angle ok.

So, here a word of caution that please remember this is sign ok, not the trigonometric sine ok, not s i n e, but s i g n; so this means, the sign of the hour angle ok. So, this please remember and do not get confused.

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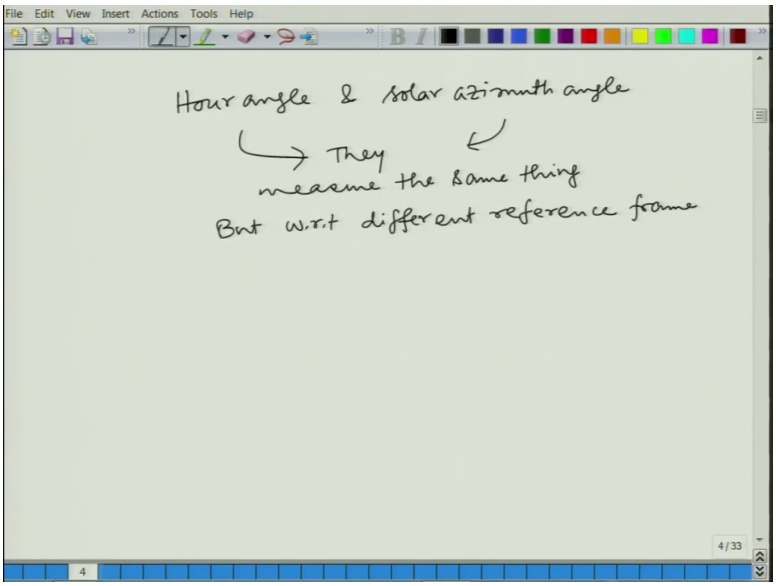

Now, one thing I want to mention here is that, this hour angle and I should say solar azimuth angle. They actually measure the same thing right; it measures where the sun is radiating normally and with respect to the location or solar noon at the, so they measure, they measure the same thing but, with respect to different reference frame, that is the difference reference frame ok.

So, it is expected that both will have the same sign ok. So, I am not going to go in detail of this, how it will change from the different hemispheres and all, you can use this formula.

And, try to find out what would be the relation for at the solar noon, or at the morning, what would be typical variation of these two angles the value wise, and you will get a clear picture how these two angles are related. But, the concept that these two are measuring the same thing with respect to different reference frames, that is important ok, that intuition you should get ok.

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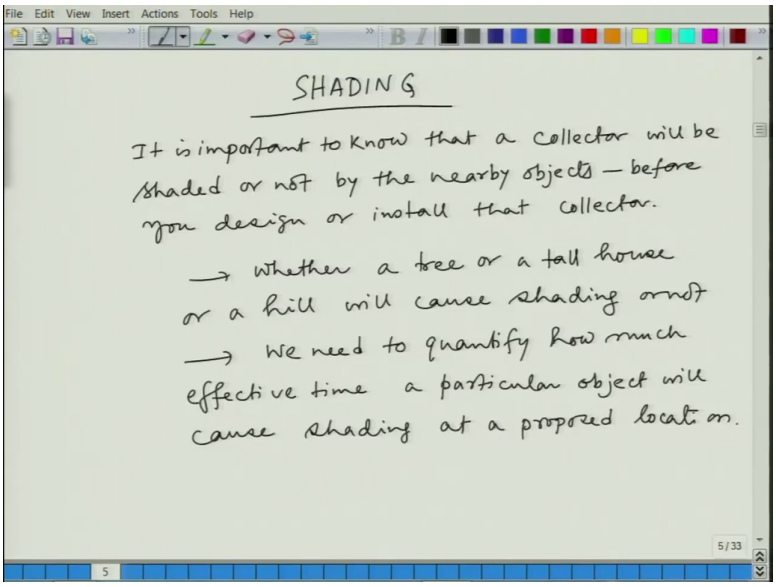

Now, we are going to start the next topic which is shading. And, all these relationship that we have used or derived so far, this will be used very much in understanding this topic shading ok. So, what does it mean? So, first it is important to know that a collector will be shaded or not by the nearby objects before you even install anything. Before you design or install that collector. What I mean? Suppose on your roof top you are trying to place a or you are thinking of placing a solar photovoltaic panel ok.

So, if that is the case you would like to know, whether the big tree that is just beside your house, whether it will shade that particular location of the panel most of the time in the year. If, that is the case you should not even try it or you should choose another location, where that shading will not happen, or maybe a building large tall building just across the street, whether that creates a shade for the most of the effective hour in the afternoon.

So, that you have to know right before you can decide otherwise you place it, you install it, but you get lot less power that you would anticipate ok. So, that is why we need to know like whether a tree, or a tall house, or a hill, will cause shading or not ok. So, not shading, but also we need to quantify; how much time, or how much effective time a particular object will cause shading at a; proposed location that is one thing.

Other thing why we need shading? Because, solar energy is not only a method to get you electricity; it also affects lot of other things in life right like; your home. How you design the building; that needs to incorporate the elements of solar energy ok.

Because, the windows that you are designing, if you are in India it is a hot country. So, the windows you need to design in such a way that, it reduces the amount of sun rays that is coming inside in the summer months ok. So, the orientation the area of the window and still you need to have enough light ok. So, all these things are interrelated and you should have some idea about them. So, that is why this topic is important.

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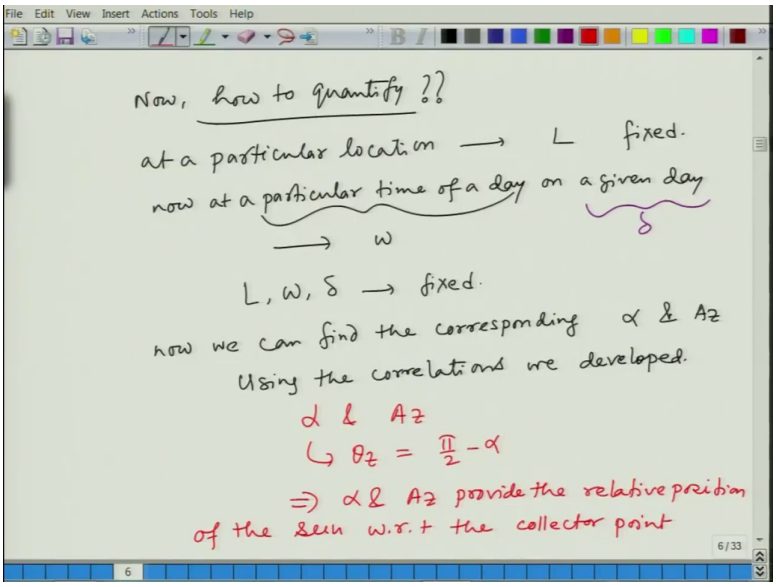

So, now, how to quantify this? We can understand that it is required to be quantified, but how to do this? So, suppose at a particular location ok, you have a fixed latitude right this is fixed ok. Now, at a particular time of a day on a given day; what else is fixed? One is this hour angle, which tells you the particular time of the day and the other thing is a given day gives you a fixed delta, or the declination angle, right.

So, that is how if you want to know at a particular location, at a particular time, and on a particular day, what would be the fixed things; these are the fixed things. So, L hour angle and declination angle these are fixed ok.

Now, we can find the corresponding alpha, which is the altitude angle and the solar azimuth angle right so yeah. So, using the correlations we developed in earlier classes ok. So, these two we can find out, for a particular location, for a particular day, and for a particular time,

we can find out this alpha and A z and whenever we have alpha we have theta z right. Because, theta z is nothing, but pi by 2 minus alpha theta Z is the zenith angle and alpha is the altitude angle ok.

So, once we have that; so these two angles what do they do? Alpha and A z provide the relative position of the sun with respect to the collector point, where you are trying to see, whether there will be shading or not right. So, that is what it does alpha and A z will tell you; what is the relative position of the sun.

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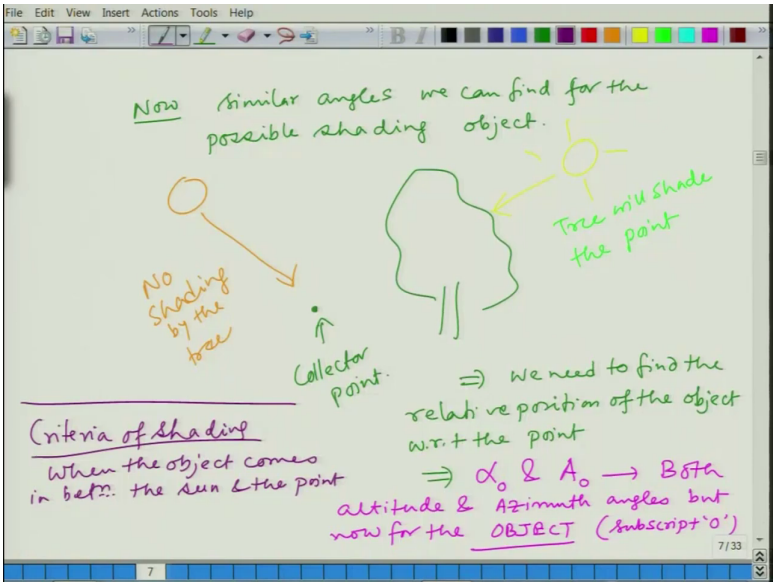

Now, similar angle or angles, we can find for the possible shading structure, or rather object ok. Suppose, this is the location you are interested in and you have a big tree here ok. So, at a particular time, if the sun is here so, there will be no shading right, by this tree. It may be something else here also, but by the tree you do not have any shading available ok. But, if sun

is here, then this tree will shade it ok. So, the tree will shade the point or this is the collector point ok.

So, we need to have some idea, what is the relative position of the sun with respect to the point and what is the relative position of the object with respect to the point ok. So, we need to find the relative position of the object here it is a tree with respect to the point right. So, and the same measurement we can have like, we will have alpha and A azimuth angle, but now we will put A subscript O for the object ok. So, both altitude and azimuth angles, but now for the object, and that is why the subscript O ok.

So, if that is the case then we have the relative position of both the sun and the object and what is the criteria of shading? So, we can write the criteria of shading when the point object or rather the object comes in between the sun and the point right. Just like the eclipse; eclipse is a shading phenomena right.

So, what happens there? The for the solar eclipse, the moon comes in between the sun and the earth ok; that is how the eclipse happens and for the lunar eclipse the earth itself comes in between the sun and the moon. So, here also when we have the object in between the point or the observer location and the sun, then the shading will happen.

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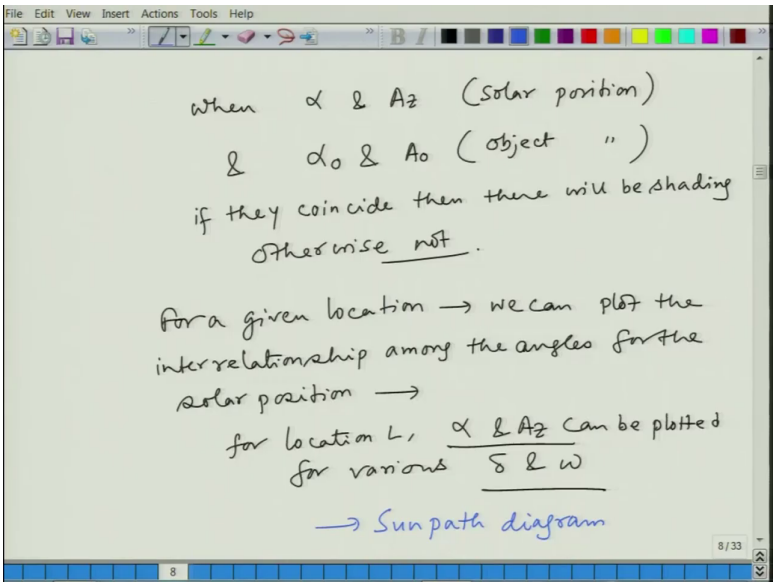

So, what we can take home from this discussion is that, when this alpha and A z, these are for solar position. And, alpha O and A O, which is the object position. If, they coincide then there will be shading, if they coincide then there will be shading otherwise not ok, otherwise not.

So, this is important thing to remember that, what we find out is the relative position of the sun as well as the object and in terms of the altitude angle and the azimuth angle. And, they will tell you whether the object and the sun are coming in the same line, then there will be shading, otherwise not ok.

So, for a given location, what we can do we can change or we can plot the interrelationship among the angles for the solar position. What we mean by that, for location L alpha and A z

can be plotted for various delta and omega right. And, so, these are the variable angles, but for a fixed location, we let us fix the location in terms of the latitude.

And, then let us keep 2 variables dependent and 2 variables independent ok. That is what we do this is the independent set, this is the dependent set, and what we find is called a sun path diagram. So, how the sun moves with respect to the observer location that is what is captured in the sun path diagram. So, let us look at such a sun path diagram ok.

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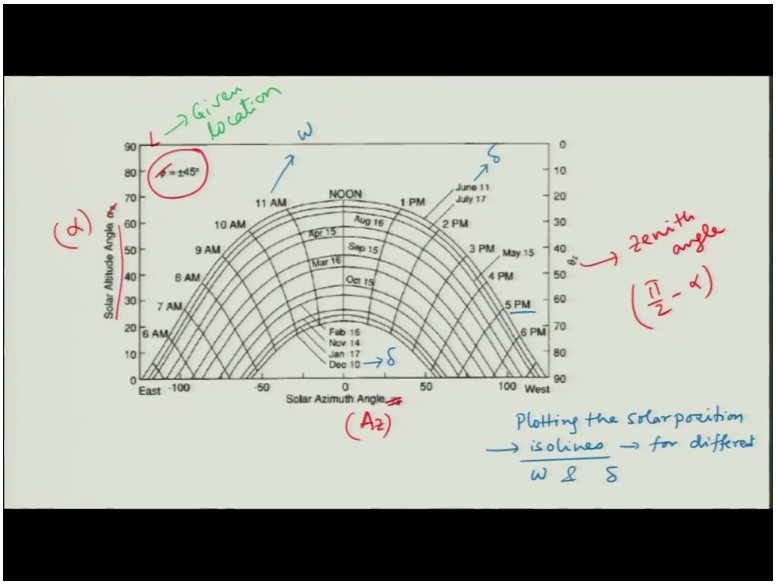

So, this is a sun path diagram on your screen which is for a particular latitude ok. So, for latitude we use this symbol L and here we see, that the two independent axis that we have is the solar azimuth angle and we write it as A z and the other one is the solar altitude angle, which we write as alpha.

So, these are two independent axis that we have and the other third vertical axis which you can see here, which is zenith angle, which is no new information is there, it is just pi minus 2 by alpha. So, both the vertical axis are basically giving you the same information, but the horizontal axis, that axis that is the solar azimuth angle A z.

And, what we are plotting here is; the solar position ok. So, what we are plotting here? Plotting the solar position ok. And, what are the fixed lines or values? So, what we are plotting are the isolines ok; isolines of the solar position; and for different hour angle, you can see here this 11 AM stands for a particular hour angle ok or 5 PM stands for a particular hour angle ok.

And, different dates ok; that means there are different declination angle. Such as this particular line is for a particular declination angle June 11, or if you take December 10, that is another particular delta.

So, in this plot what information you have is; the information is the alpha and A z for different omega and different delta ok. And, the whole plot is valid for a given location ok. So, this sun path diagram tells you the relative position of the sun with respect to the collector point ok. Now, we discussed here that we need both the solar position, as well as the object position.

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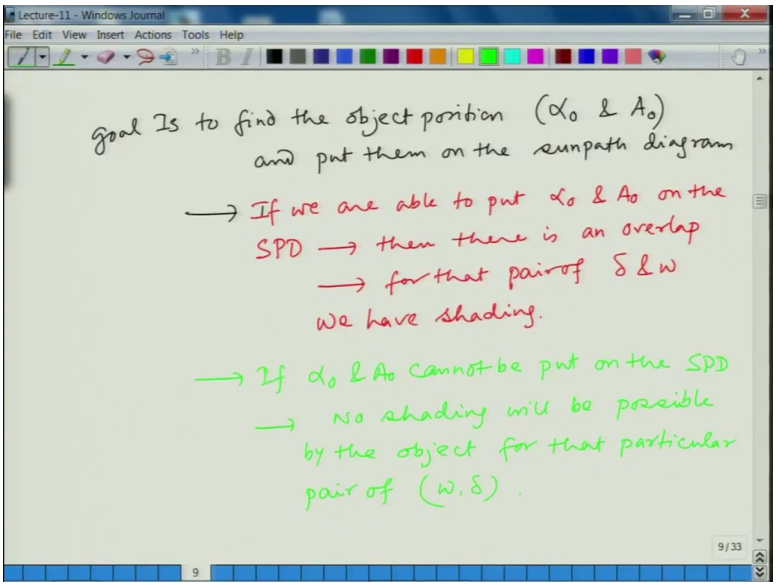

Now, it is solar position is obtained from the sun path diagram, now our goal is to find the object position. And, what would be the measurement of object position? They will be the altitude angle for the object and the azimuth angle for the object ok. And, these two angles we have to find out and put them on the sun path diagram. If you can put; that means, there is a overlap.

So, if you are able to put alpha naught and A naught on the sun path diagram, then there is an overlap ok; that means, for that pair of delta and omega, we have shading ok. And, if you cannot if alpha naught and A naught cannot be put on the sun path diagram, then no shading will be possible by the object for that particular pair of omega w clear ok.

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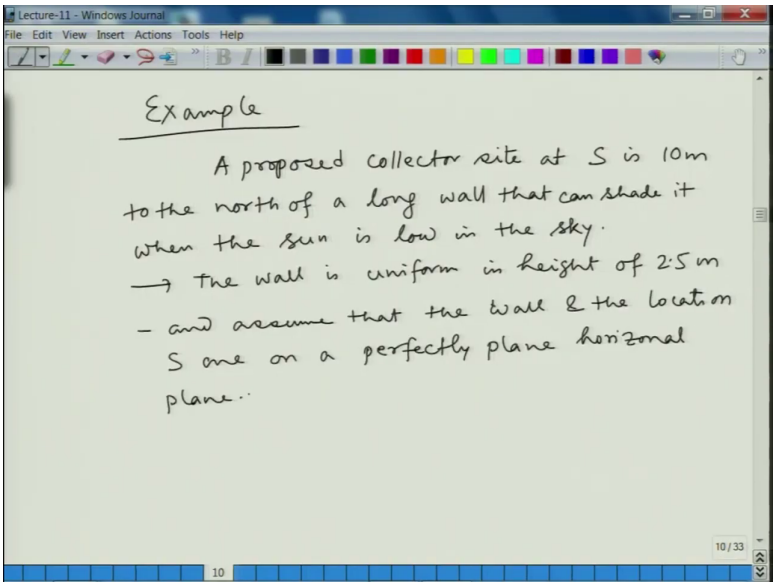

So, let us try to take an example; otherwise this becomes little hazy to visualize. So, let us take an example. So, what is the statement? A proposed collector site at S ok, let us designate that point to be S for solar collector is 10 meter to the north of a long wall ok. So, a possible object which can shade that location is a long wall, which is 10 meter to the north of that location. That shades it when or I should say, that can shade it when the sun is low in the sky ok. What does it mean?

That of course, when the sun is at the zenith of the sky, there is little possibility that a wall will shade that location, if the wall is not too high ok. So, when the sun is low in the sky, then only the shading possibility comes. So, what is given the wall is uniform in height ok.

Everywhere it has the same height and that height is 2.5 meter ok. And, assume that the wall and the location S are on a perfectly plane horizontal plane, perfectly plane horizontal plane ok.

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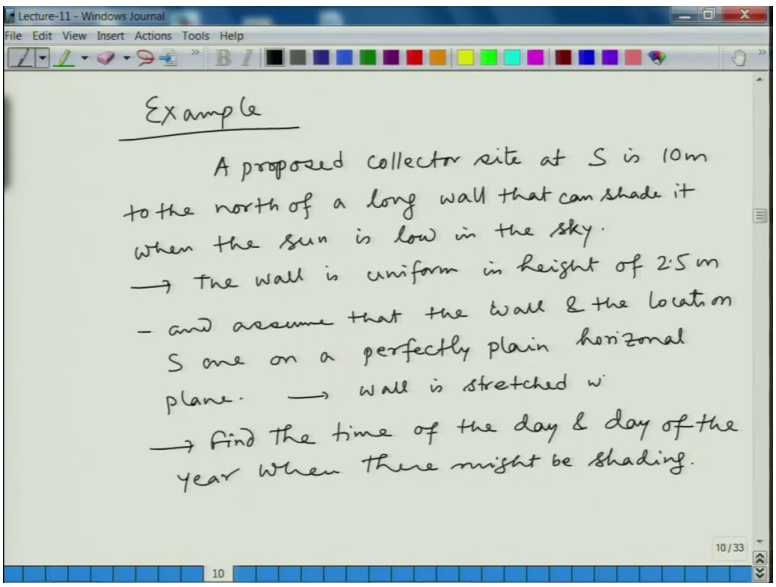

So, what we need to have here is to find the time of the day and day of the year, when there might be shading by the wall ok that is the problem statement.

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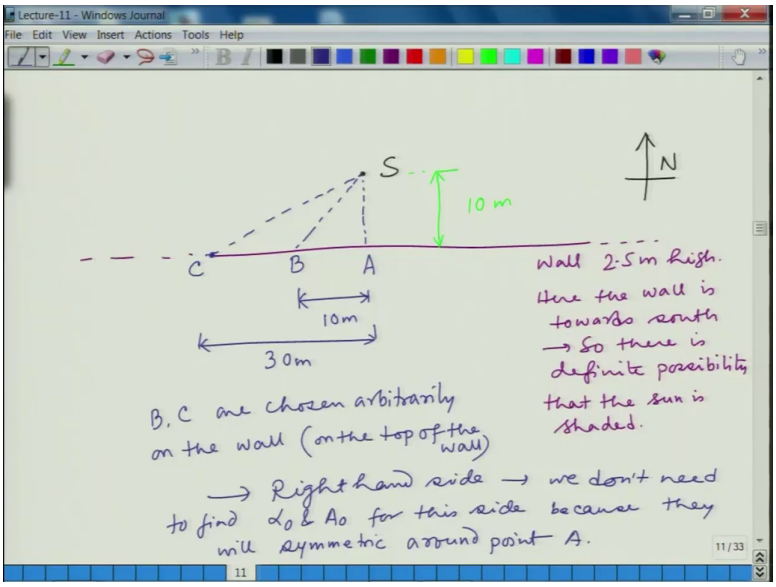

So, if we simply put this point, if we want to draw it let us say this is the point where the proposed locator will come ok. And, let us say this is the wall is a very long wall going towards east and west ok, another thing in the problem statement itself we should mention; the wall is stretched between or the wall is along the east west direction ok.

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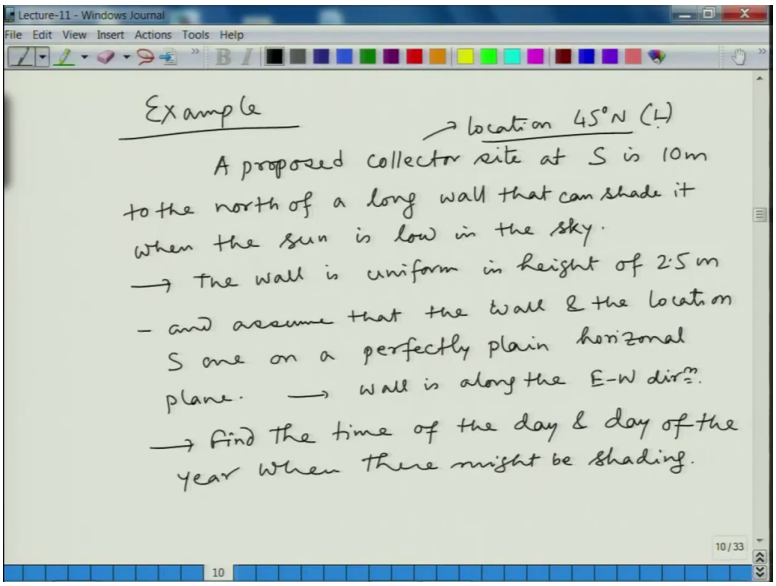

So, first north and south we have to locate ok. So, it is given that the location proposed location S is north of the wall. And, we should always draw any figure that is the convention that we use even in maps you see that north is towards the top of the page ok. That is the typical direction of north ok. And, this is the wall which is 2.5 meter high ok. And, this distance is also given this distance is given to be 10 meter ok.

So, first even if you even before you jump on solving this example problem, what you should think of certain intuition you have to develop in terms of whether you need to do all the calculation for this problem or not. So, what I mean by that?

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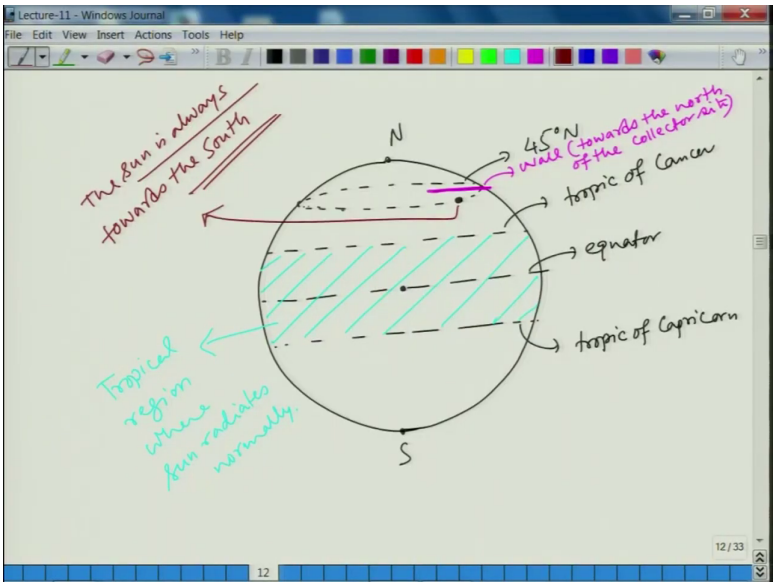

So, let me take another page here. So, suppose you have a location and the location is given I think for this example, the location is given location is given to be 45 degree north ok, that is the latitude ok. Now, suppose this is the earth and you have a location here, suppose this one only 45 degree north. So, this is about 45 degree so you can locate that, 45 degree north line ok.

So, you know the sun radiates; so this is our North Pole, and this is South Pole, and we know where that tropics lies right. So, this is our equator ok, this is the Tropic of Capricorn and this is the Tropic of Cancer right. So, now for this location anywhere on this 45 degree North line, if you have a wall which is north to this particular location.

Suppose, we have a wall here towards the North, so, this is hugely exaggerated version of the distance, because we are looking at the earth centers reference frame. So, if this is the wall,

wall is placed towards the north of the collector site. If, that is the case, then what do you think, will sun ever be shaded by this wall? Please think on this, because this is important intuition that you have to develop.

So, by this figure what I want to show you that the sun radiates only in this region right, radiates normally right; this tropical region where sun radiates normally ok so for 45 degree North, the sun will always be towards the south right.

So, for this location, for this location, the sun is always any time of the year, any time of the day, it is always towards the South right. So, anything towards its north, whatever it may be it is a big Mount Everest is there it can never shade the sun right, because sun is always towards the South. So, that is the intuition you have to bring along when you look at a shading problem.

Now, coming back to this problem here, here the wall is towards south. So, there is a possibility that, the sun will be shaded. So, there is definite possibility that the sun is shaded ok. So, to approach this problem we need to first pick few points. Because, you cannot find the azimuth angle or the altitude angle for the whole wall the all along the wall, we have to take few points and then we have to generalize ok.

So, let us take some point, which is one point the obvious choice is just directly closest point from the wall. And, let us take another point here which is point B, which is again this distance is 10 meter ok. So, this is again B is chosen arbitrarily you have you could have taken one point which is 15 meter, so just now we will do that 1.

So, let us say another point, point C which is 30 meter ok, let us say this is 30 meter. And, these choices are arbitrary choices B C are chosen arbitrarily on the wall, and importantly on the top of the wall, on the top of the wall ok. Because, that is the critical point which can shade the sun.

So, if that is the case, then one thing we can write that the right hand side, we do not need to explicitly calculate, because whatever happens towards the left will be symmetrical towards

the right as well. So, we do not need to find alpha O and A O for this side, because they will be symmetric around point A ok. What do you mean by that? It will be more clear when we actually solve the problem.

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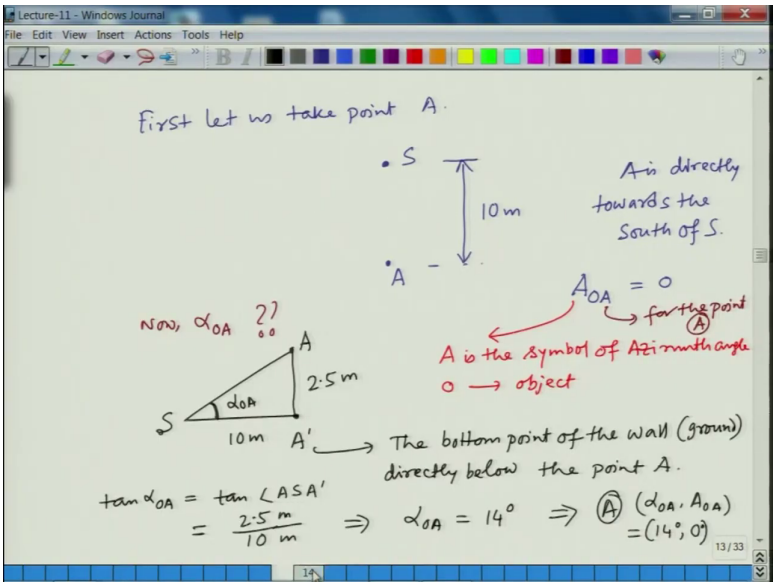

First let us take point A ok. So, this is our point S, this is our point A, we are singling out it and this distance is given this is 10 meter and the A is directly towards the South of S ok. So, if it is directly towards the South, what we can directly say? That the azimuth angle will be 0, right. So, what we can write, that A azimuth of object which is at A will be 0 ok.

So, let me just specify what we mean by this symbol, this capital A is the symbol of azimuth angle ok. This O stands for object ok, and the other A, this A for the point A. For point B we will have A OB this point A ok. So, this azimuth angle we obtain very easily, because it is directly towards the South.

Now, what would be alpha OA, which is the altitude angle of the object A how will we get it? Ok. Now, you think of this angle or this triangle rather. So, when you look it from the side, what will you get you will get this is the S, this is A, which is top of the wall and let us say, A prime is the bottom of the wall directly below point A.

So, this A prime the bottom point of the wall. So, this is on the ground which is directly below the point A. So, whenever we use prime; that means, it is directly vertically below that point A prime is vertically below point A. So, what are the dimensions of this triangle one is given that A A prime is our height of the wall that is 2.5 meter right. And, this distance is also given SA prime, that distance is 10 meter right.

So, what we have this tan and this angle is the alpha, this is the altitude angle right, alpha OA. So, tan alpha OA is nothing but tan of angle ASA prime ok. And, that tan is our 2.5 divided by 2.5 meter divided by 10 meter ok; from here you can get this alpha OA is nothing but 14 degree ok.

So, the point A is represented with two coordinates now; one is the alpha OA and the other one is the A OA the azimuth angle. So, alpha OA and azimuth OA will be nothing but 14 degree comma 0, 0 degree right. So, that is the coordinate location of point A with respect to the position the collector side position S.

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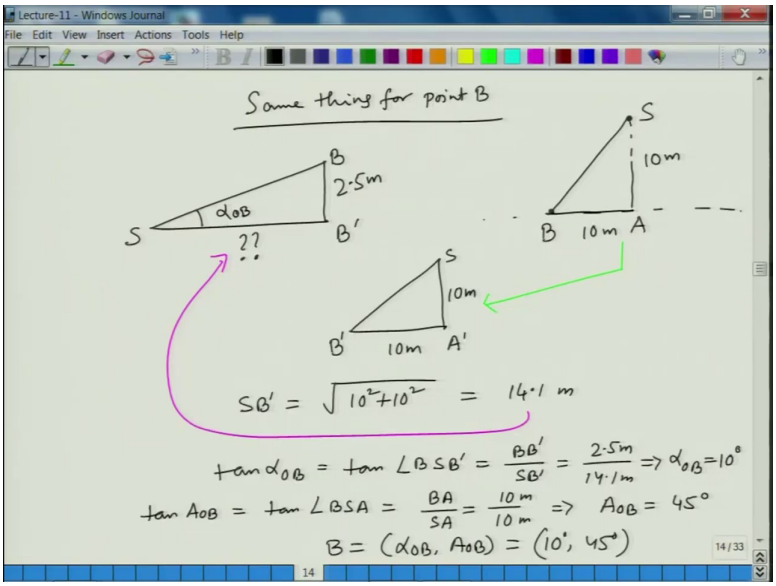

Now, the same thing we will do for point B ok. So, when we talk about point B what we have here S, and then we have a line here and B is not directly south but both these dimensions are 10 meter ok; so that is what is given. So, now, the side view angle what we can write here is another triangle where we have B prime, which is the vertically bottom point on the ground.

So, what are the dimensions? This 2.5 is given for the wall, this angle is our alpha OB, but we do not know this SB prime right, we do not know this. So, how to know this? We need to invoke another angle, where we have this ok. So, basically from this particular figure you can get it here, if you only look at the plan view on the plan on the plane of the point S, what you can have this SA prime B prime. And, here what we have? We know this SA prime is 10 meter and A prime, B prime is also 10 meter ok.

So, what we can find? That SB prime is nothing but square root of 10 square plus 10 square right from a right angle triangle; so this is the value ok. Now, you take this value and substitute it here. So, what we get is tan alpha OB is nothing but tan of B S B prime, which is

equal to BB prime by SB prime that is 2.5 by 2.5 meter by 14.1 meter. So, this will give alpha OB will be equal to 10 degrees ok. And, we need another angle which is the azimuth OB ok.

Now, the azimuth OB the tan of that will be tan of BSA ok. Azimuth is the how east or west it is with respect to S. So, that is from this triangle you have the BSA. So, if you can yeah you can write it to A.

So, this BSA this triangle is nothing but or this tan is nothing, but BA over SA that will be 10 upon 10 meter, which is which will give you A of OB is 45 degree ok. So, B is now represented by this coordinate system alpha OB A OB this will be 10 degree 40 45 degree ok. So, this is the location of B with respect to position S ok.

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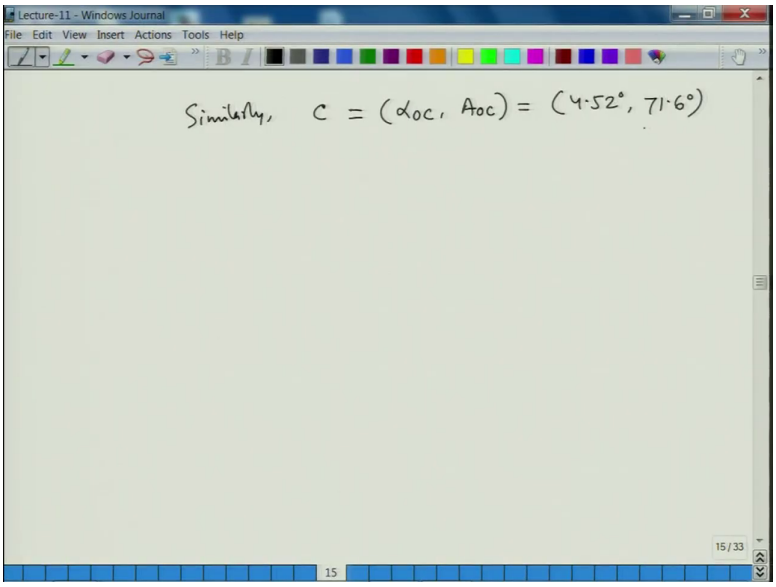

So, similarly we can show for C we will get alpha OC, A OC will be 4.52 degree and 71.6 degree ok. So, what we can do? Now, on the sun path diagram, we can place all these values and can see what is the overlap that we are getting. And, that is what we will do in the next class and today I will stop here.