Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 02
Solar radiation

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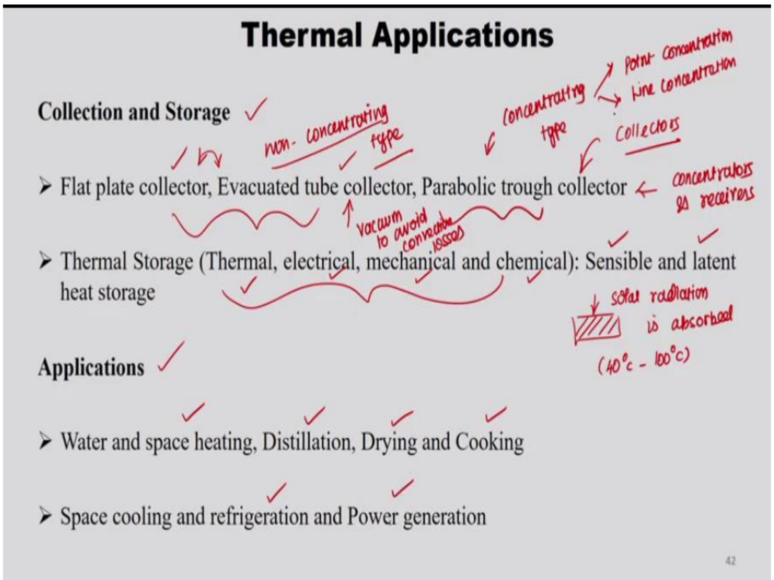

Good morning everyone. So, today we are going to continue yesterday's lecture on solar energy, overview of thermal applications. So, yesterday, we discussed about the basics of solar energy, as well as the sun, earth, and their geometrical relationship. So, today we will review about thermal applications of solar energy. And we will continue lecture two on how to calculate solar radiation parameters.

So, as we discussed the solar energy the major challenge would be in collection and storage. And we are also going to review about their applications. So, in terms of collection, the device used is collectors solar collectors. So, there are two major categories. One on non concentrating type and the other one is on concentrating type. So, the non concentrating type we do not give any special effort to concentrate the solar energy.

So, the major collectors used in this category are the FPC flat plate collector, and then evacuated tube collector. Both works on the same principle that if we have a black surface that absorbs the solar radiation. Solar radiation is absorbed. So, these both collectors work on the temperature range of around 40 degree centigrade to 100 degree centigrade. And then there are special arrangements to insulate them to avoid the heat loss.

And then we also have glass covers to trap the solar radiation. Anyway that we will see in detail in your fourth and fifth lecture of second week, but here we are just introducing. And what is the difference between them? FPC and ETC is that to avoid convection losses here we create a vacuum inside the tube, vacuum to avoid convection losses. And in parabolic trough collector, we take special effort to concentrate solar radiation.

In that way you would be having concentrators and as well as receivers for collection of solar energy. So, this may be of two types one is point concentration. Another is line concentration. And then, thermal storage, as we said, not only collection is important, we need to store them for the **(()) (03:45)** hours. So, in that way there are many types of storage is available, kind of thermal, electrical, mechanical, and then chemical.

So, if you take thermal storage. There are two types again sensible and latent heat storage, so sensible and latent heat. So, sensible normally done with rock solid material, solid materials and kind of pebbles. So, there are liquid materials, also we can use to store sensible heat. So, here in latent heat we use phase change material, so this solid materials normally used for solar air heaters.

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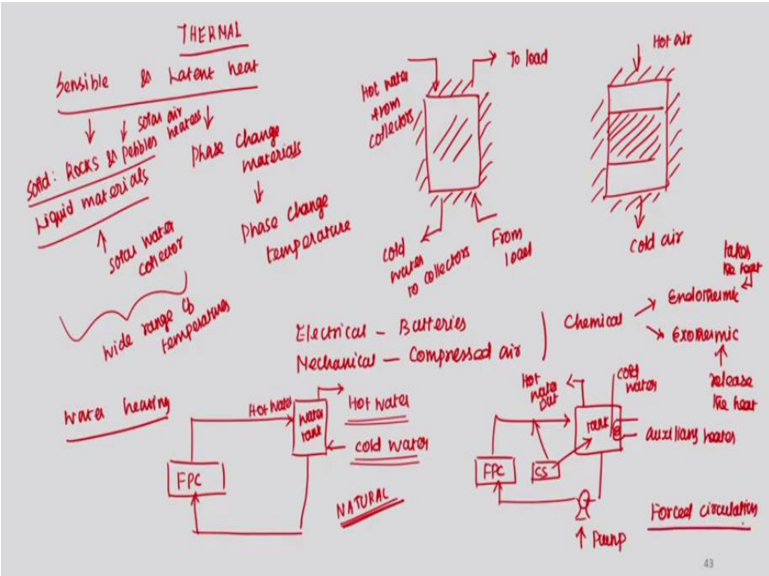

Liquid materials normally we use for solar water collector. And sensible heat can be done for wide range of temperatures. But in phase change materials you need to be careful about the phase change temperature of the material at that point only you would be able to use them as a storage material. So, for example, you will have a insulated tank. Here for solar water collector you would get a hot water from collectors.

So, after releasing its heat so you would get cold water. So, that is going to collectors. So, from the load, there would be another fluid, which comes and takes this heat and goes to the load. And in terms of sensible heat storage, again you will be having insulated tank. So, in which there would be a screen meshes. So, in inside, you can fill the solid material, the hot air from solar air heater comes and leaves it heat lose its heat, and go back to the collector.

So, this way the storage can be done. This is thermal part. But, if the conversion is done here, the solar radiation is converted into thermal. If it is electrical, then you would be having you would be storing in batteries. And if it is a mechanical storage, you can use probably example as compressed air. And in chemical, you would use the concept of endothermic and exothermic. If the reactions are endothermic, you would give the heat.

And when they convert back to the reactants, then they will release the heat. So, in that way you can store, takes the heat and release the heat. So, that is all about the storage and then we will review some of the applications, water and space heating applications, distillation, drying, cooking. All can be done by solar energy. And the space cooling and refrigeration application also solar energy can be used, and then power generation also.

So, all are thermal applications, for example, in water heating. So, you have a FPC that is flat plate collector. So, here you have a water tank. So, this is a cold water so that comes and go to flat plate collector and gets heated and hot water goes into the tank. So, whenever in use, you would take the hot water out. So, to compensate, you may send the cold water sorry not hot air it is a hot water.

So, you would fill it with the cold water so this works natural circulation mode. But you can do it with the forced circulation as well. So, the same arrangement, you would be having FPC, your hot water goes to tank. And you would be having provision for cold water replacement, and if you want you can use axillary heater, as well. From this you can take hot water out, but how to get the hot water so that you would be using the pump.

And it is pumped to FPC, and also you can have a provision of control system. So, which checks, both when our water comes out of FPC whether it is at particular temperature. And within that tank, the hot water is at its required temperature or not you can check with some particular control system. So, here, since we are using pump. So, this is forced circulation system. So, here, we would be having **(()) (10:45)** effort due to gravitational effect.

And also, here if you see hot water density is less so it remains in the up and cold water is density is high, so it remains in the down so that way we manage with natural circulation itself. So, here we use pump to pump the fluid through the collector, and then the hot water goes to the tank. So, this is forced circulation system. And then space heating applications.

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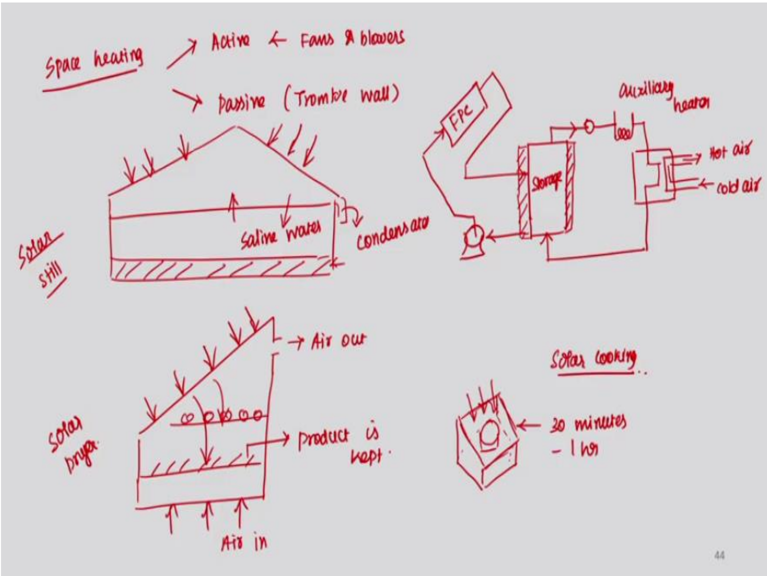

So, here too, we have two method one is active where we use fans and blowers. And the second one is passive method by natural circulation, the famous concept of Trombe wall **(()) (11:41)** from passive method. So, here to, just to review about, we have a flat plate collector, from which your hot water comes, goes to storage. From here it is taken using pump and goes to FPC, and from here you can take it out.

And then you can if you want to use an auxiliary heater. And then goes to some heat exchanger, goes back to storage system. So, here you can send your cold air and take it as hot air out. So, this is your auxiliary heater, if the temperature is not required enough. So, in that way, space heating can be done. And then the next application is the distillation. So, instead of normal distillation, for example, you are having always remember the storage and all that it should be properly insulated.

Here, we are just reviewing about applications. So, I am not going into detail, because, to avoid losses, we need to take care of that part. So, here you are, just to make you understand how it is being done. So, that is what we are discussing here. And then, for example solar distillation, so we call them as solar still. So, here you have a insulated arrangement, so where you fill the still with the saline water.

Then you would be having the arrangement to trap the solar radiation. So, due to which the water gets heated, and then you will have provision to collect the condensate and clean water, and this salt would be deposited in the dome. So, this is nothing but solar still. And after that you will have a thermal application in terms of drying solar drying. So, there also you have a collector arrangement where your solar radiation comes in.

And you will have inside there are perforated trays where your product escaped. So, you will have provision for air circulation as well, somewhere here. This is air out. So, directly the product gets heated by solar energy and then its moisture gets removed and it gets dried. So, this is solar dryer. So, and then the solar cooker is also that there is a box type so where you keep your food material in the shallow container.

And you would be having the upper one as a glass cover, where it absorbs the solar radiation and directly it gets heated. The food get heated but it is like one time keep and forget it kind of thing. You cannot make normal chappatis, rotis and all, because, you need to also stand in the sun. So, in that way, the food which you can keep it and fire about 30 minutes to one hour, it can be cooked in that range.

So, in that way, solar cooking also can be done using solar energy. And after that, there is a refrigeration unit as well. You can do space cooling and refrigeration using solar energy. So, the famous application is vapor absorption system. So, here, the main elements are generator. So, this generator is attached with FPC. So, here always we need to remember. Here we are taking FPC as a example.

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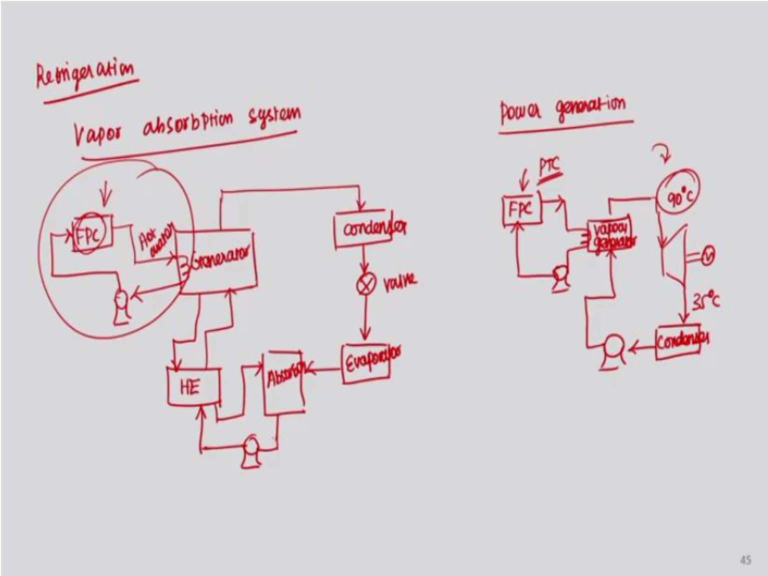

If you want to have higher temperature, then one may need to go to concentrating type collectors which is nothing but parabolic trough collector PTC. So, it depends purely on the application side. So, at what temperature you would be required. For example in the generator you would be producing the refrigerant vapors.

So, which refrigerant you use or at what temperature you would need your vapors to be produced based on that you would be supplying the hot water, hot water or hot fluid whatever. So, based on that, you would be selecting the collectors. Sometimes it may not be FPC in the sense like it is not one collector you would be having array of collectors as well. So, based on the temperature range and temperature, what you require.

So, this is pumped. So, always say should be in upper. So, this is the generator where you get the refrigerant vapors. So, this refrigerant vapors goes to. So, this is something called a heat exchanging. So, here, you would be having condenser, where you get the high pressure liquid, and then you throw out alert and go to this is a wall throttle wall. And then it goes to evaporator. And then goes to absorber so where it is mixed with the salts.

So, this is pumped goes to heat exchanger. So, from the salt solution comes back and heats the incoming solution from the absorber and goes back. So, this after gaining heat it will go to generator. So, it provides the hot water. Hot water, which is required to create a refrigerant vapors out of salt solution. So, in that way, the solar energy can be used to produce the heat effect in the generator.

And then we can use it for power generation as well the same solar energy. So, here in power generation, so what you would be having is a turbine. From there, you take a electricity. So, here you would require the vapor. So, that comes from vapor generator, for example, 90 degree centigrade. So, this goes to, again, condenser and then pumped back, go to vapor generator. So, this is to get that.

So, you can directly use collector arrays, and give them the heat. So this is pumped back to FPC. So, remember again here we generated the vapor around 90 degree, so if you require more temperature for example if you want to create 120 or 130, then you might be using the, it would be wise idea to use PTC parabolic trough collector so which can cater the need of higher temperature. So, that is all about the overall thermal applications of solar energy.

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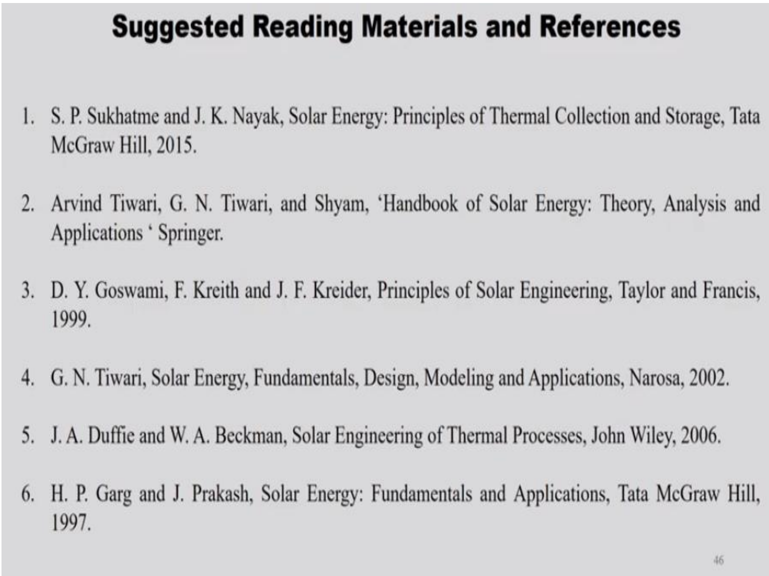

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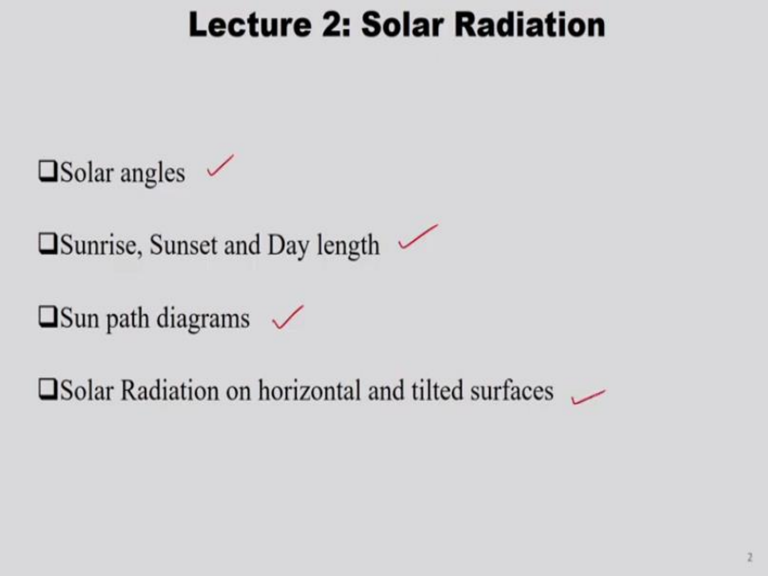

So, these are suggested reading materials and references to refer for this particular lecture. We are going to discuss about Lecture 2 Solar Radiation. Here basically we are going to learn about how to calculate solar radiation parameters. So, in this lecture, we are going to see about solar angles; sunrise, sunset and day length; sun path diagrams; and solar radiation on horizontal and tilted surface.

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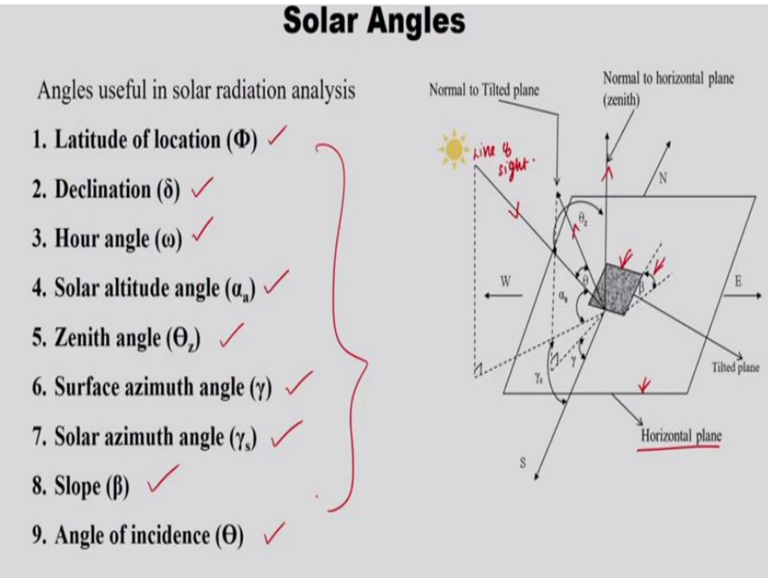

The solar angles, there are 9 various angles we suppose to be comfortable with to analyze solar radiation parameters which are latitude of the location, declination angle, hour angle, solar altitude angle, zenith angle, surface azimuth angle, solar azimuth angle, slope, and then angle of incidence. So, this diagram says about the horizontal plane, which is this, and then the tilted plane is the way we tilt the plane to absorb solar radiation maximum.

So, that angle is tilt angle we call it as a beta. So, this particular line is normal to the horizontal plane. So, we call it as a zenith. And this particular line is normal to the tilted surface, and then based on which various angles are defined, we will see one by one. So, this particular rays, sun rays. So, we can call it us line of sight as well. So, based on this horizontal plane, tilted plane, normal to tilted plane, normal to the horizontal plane, and then line of sight, or sunrays, we will define these 9 angles. So, we will see one by one.

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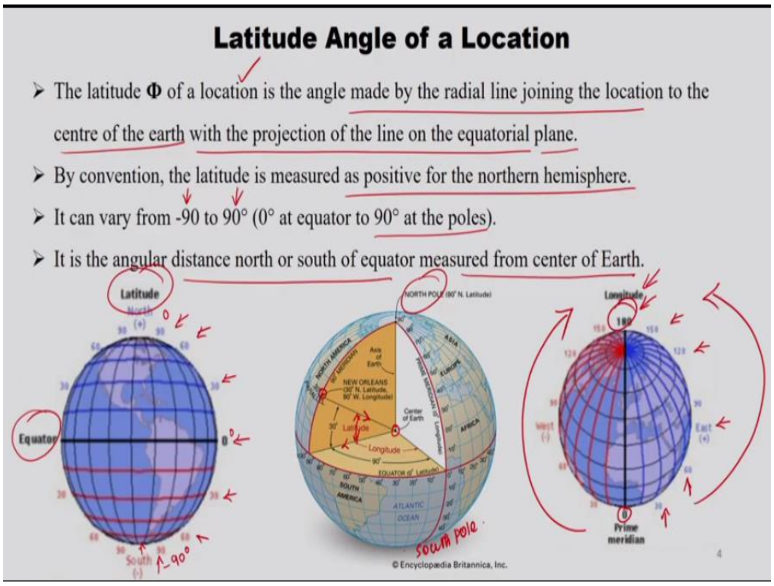

The first one is latitude angle of a location, the latitude angle of your location is the angle made by the radial line joining location to the center of the earth. So, that is this particular line. So, this is nothing but our location where we suppose to calculate the latitude. So, this is center of earth, so this is the line joining these two points with the projection of the line on the equatorial plane. So, that is this particular line.

So, this angle is nothing but latitude of the location. So, by convention, the latitude is measured as positive for the northern hemisphere. And then it can vary from minus 90 to plus 90, 0 at the equator and 90 at the poles, the poles are north pole, and then this particular thing is south pole. So, this is nothing but, equator, which is measured at 0 degree, and then north pole is measured as positive 90, and south pole is measured as minus 90 degree.

So, this is in this way. So, this is 0, 30, 60 and then 90. So, this is minus 30, minus 60, and then minus 90. So, this particular way latitude is measured, but if you see longitude. So, latitude is measured from equator and the longitude is measured from the meridian. So, this particular 0 and 180 is prime meridian. So, from this 30, 60 and then 90 and then 120, 150 and then 180 so this way, it is east, it is positive, and then west it is negative.

So, this way longitude is measured. So, apart from latitude, we also define longitude for the location. So, this may be useful when we calculate solar time. So, we will see how to calculate that. So, it is the angular distance north or south of the equator measured from the center of the earth here is that is the line joining equator.

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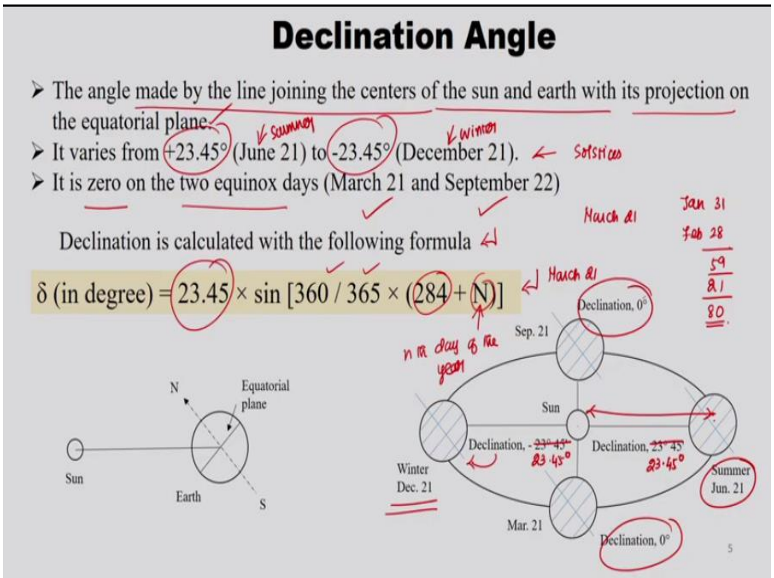

The second one is declination angle. So, this angle is nothing but, made by the line joining centers of the earth and sun with its projection on the equatorial plane. So, it varies from plus 23.45 degree on June 21 to minus 23.45 degree on December 21. So, these both we call it as a solstice, solstices. So, this is winter solstice. So, this is summer solstice. And this particular delta declination angle is 0 on 2 equinox days, one is on March 21 and another is on September 22.

So, the declination angle is calculated using this particular formula, which is nothing but 23.45 degree into sine of 360 upon 365 into 284 plus N. So, this N is nothing but nth day of the year. For example, March 21. So, in Jan, we have 31 days and in Feb, we have 28. So, normally, the leap year is not taken into account, so this way 9, 59 days, 59 + 21. So, it is 80th day, so, if we substitute 80 to calculate March 21, what should be the declination angle?

So, for March 21, we will substitute here as 80, and then calculate delta. So, here it is a winter solstice. So, declination is it is 23.45 degree itself, 23.45 degree. So, this is summer solstice.

So, this is declination is 0 on September 21 and March 21. So, this is sun. So, this is earth. So, the distance between them is one line and then its projection on equatorial plane so that is second line. So, the angle made by these two lines is called declination angle.

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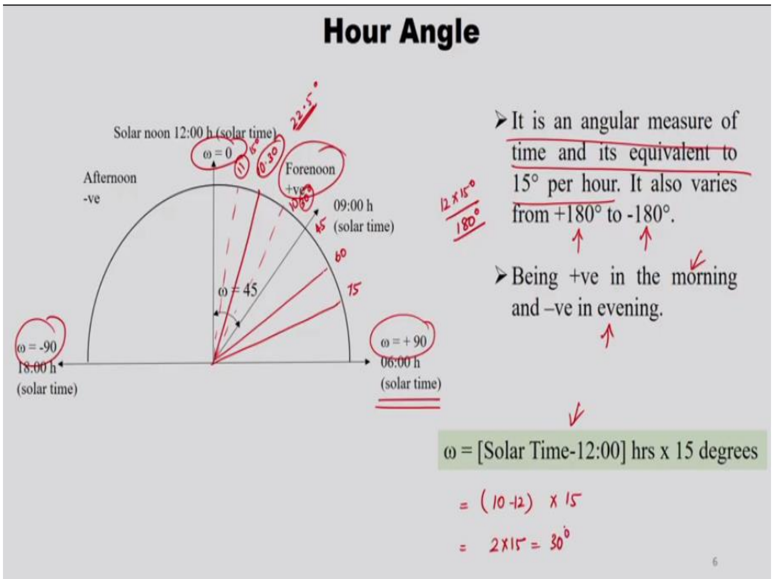

The next one is hour angle. It is an angular measure of time and is equivalent to 15 degree per hour. So, we have 12 hours from sunrise to sunset. So, 12 hour into 15 degree around 180, so sunrise to sunset again sunset to sunrise. So, it varies from plus 180 to minus 180, so being positive in the morning and negative in the evening. So, for example, here, the 6 hours in the morning. So, this is measured as 90 degree and solar time solar noon, which is 12 hours.

So, that is measured as 0. So, this is morning time for noon time so it is considered as positive. So, for example, this is 9 hours, this is 12 hours. So, if we want to calculate it, 10.30, so then we suppose to calculate like, so this is 10, so this is 11. So, this is 12 hours is 0, 11 hours is 15 degree, and then 10 hours is 30 degree, and then 9 is 45, 8 is 60, 7 is 75, and then 6 is 90. So, 10:30 if you want to calculate, so at 11, it is 15; at 10, it is 30; so it is 22.5 degree.

At 10:30, it is 22.5 degree. So, in this way for noon, it is calculated as positive; in the afternoon, omega is minus 90; in the evening, that is 6 o'clock in the evening; and then in the afternoon, it is 0. So, in between, if you want to calculate you suppose to calculate the same way in minus. The formula is Solar Time minus 12 in hours into degrees. So, for example, Solar Time is 10 minus 12 so into 15. So, 10 hours it is two, so if it is 10 hours in the morning, then you are supposed to calculate plus as a plus, so it is 30 degree.

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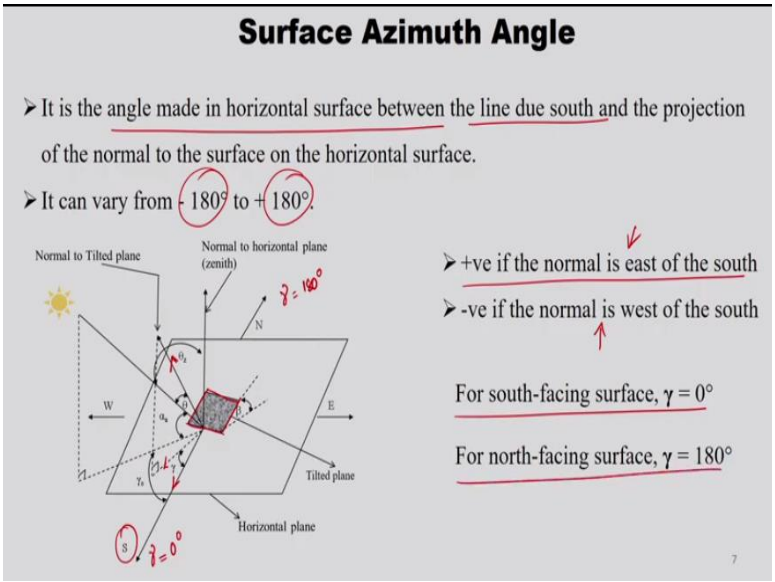

The next one is surface azimuth angle. So, it is the angle made in horizontal surface between the line due south. So, this is the line due south, so this particular line, and the projection of the normal to the surface on the horizontal plane. So, for example, so this is the tilted plane, as we have seen already, so the normal to the tilted plane is this particular line. So, it is projection of the normal to the horizontal surface.

So, that is this particular line. So, the angle made between these lines is called surface azimuth angle. Again, it varies from minus 180 degree to plus 180 degree in due south. This is referred as a gamma. So, this is 0 degree, and due north gamma is nothing but 180 degree. So, it is considered as positive if the normal is east of south. It is negative, if the normal is west of south. And then for south facing surface, gamma is 0, and for north facing surface, it is 180 degree.

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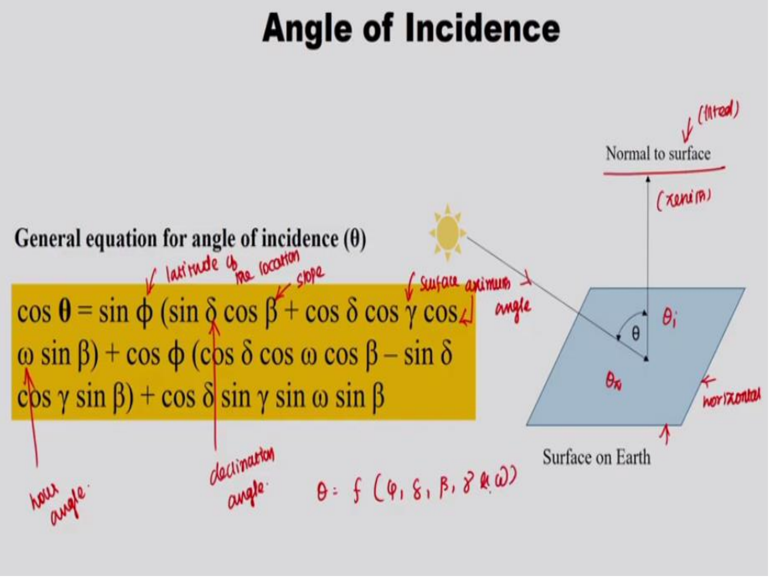

Next one is angle of incidence. So, this is suns ray or the line of sight, so this is considered as horizontal surface. So, this is normal to the surface. So, this angle made between the line of sight and the normal to the surface is called theta. So, if this surface is horizontal one, so then normal to that, we call it as a zenith. An angle made this zenith angle or normal angle of incidences, so this, if the surface is tilted one.

So, this is normal to the surface that is tilted surface. So, then in that way, angle made is theta i, that is angle of incidence. So, that is given by this particular formula, cos theta is sine phi. So, the phi is nothing but here the latitude of the location. So, delta is declination angle, beta is the tilt angle of the surface or slope; declination angle and gamma is surface azimuth angle, omega is hour angle. So, theta here mentioned as a function of phi, delta, beta, gamma, and then omega.

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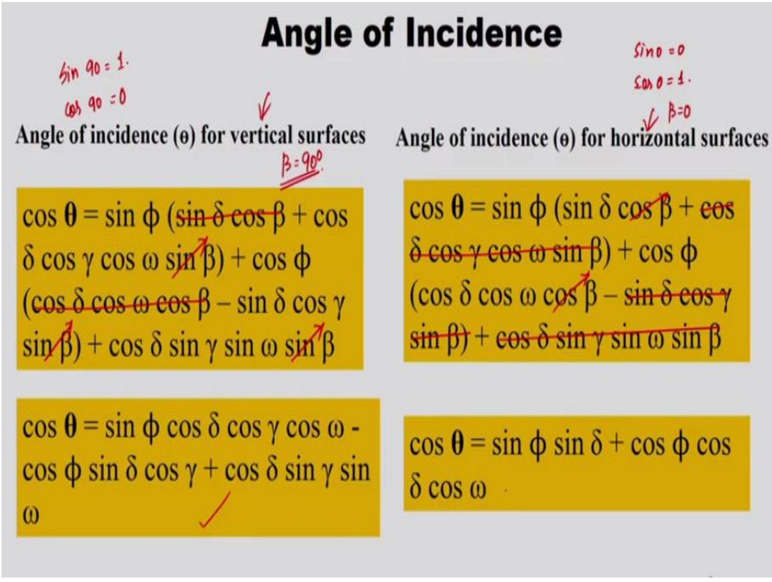

So, from the basic equation general equation we can derive it for different surfaces. So, vertical surfaces, beta equal to 90 degree, which is nothing but slope. So, we have this convention, sine 90 is 1, and cos 90 is 0. So, if we see the first term, so this will go cos 90 0. And then here, sine beta this becomes 1. And then so we have cos 90, so this particular term will go. And then we have sine beta, so this become 1.

And so here if you see, again, sine beta, so this becomes 1. So, first term would be sine phi cos delta cos gamma cos omega. The second term would be cos phi sine delta and cos gamma. The third term is cos delta sine gamma, and then sine omega. So, here if you see horizontal surface, beta is 0, so, sine 0 0 and cos 0 is 1. So, here if you see, cos 0, it is 1, and then sine 0, so this becomes nullified. And then, cos 0, this is 1, and then sine 0. So, this term vanishes. So, here also this term also goes. So, we have sine phi sine delta, and then cos phi cos delta cos omega.

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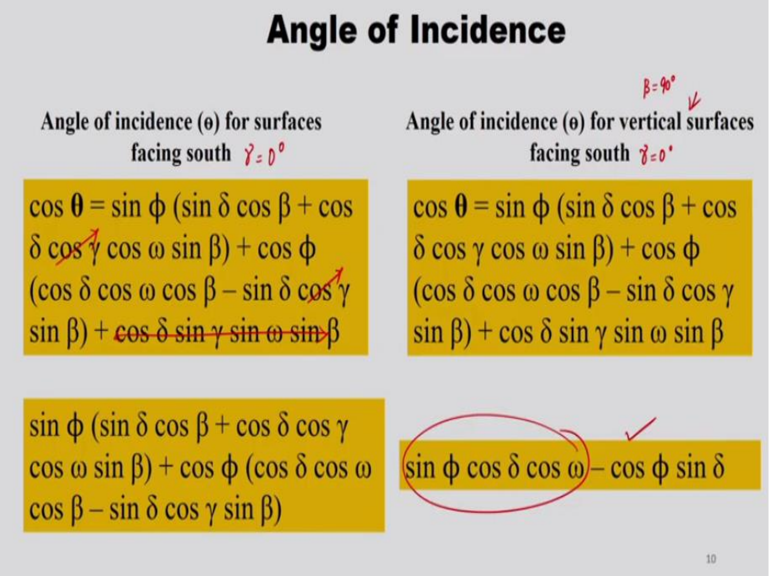

So, the next one is angle of incidence for surfaces facing south, as we already said azimuth angle is 0 degree. And if we substitute that, then this particular term would go because sine 0 is there. Other than that here cos gamma, so this becomes 1. And then, here also cos gamma, so this becomes 1. So, sine phi sine delta cos beta, and then cos delta cos gamma, that is 1 anyway we can override there is no harm in that.

So, cos omega sine beta and cos phi cos delta cos omega cos beta. Here minus sine delta, cos gamma sine beta. So, this becomes 0 so that term goes. So, here facing south, gamma is 0. And then vertical surface, so that is beta is 90 degree. So, for beta 90 degree we have already here. So, in that if we substitute gamma is 0, so this particular term may go. So, what we would be having is the first term is there.

Alright, sine phi cos delta cos gamma is anyway 1, and then cos omega so that particular term is here. And then, if you see here, the cos gamma again 1 so cos phi sine delta would be there, cos phi sine delta minus sine is there. So, sine gamma sine 0 0, so this term also goes. So, in that way, so we can find it. So, based on, like what you were asked so you had surfaces due south or due north that is inclined to particular angle or inclined to vertical surface or horizontal surface, you can plug in and play with that particular general equation.

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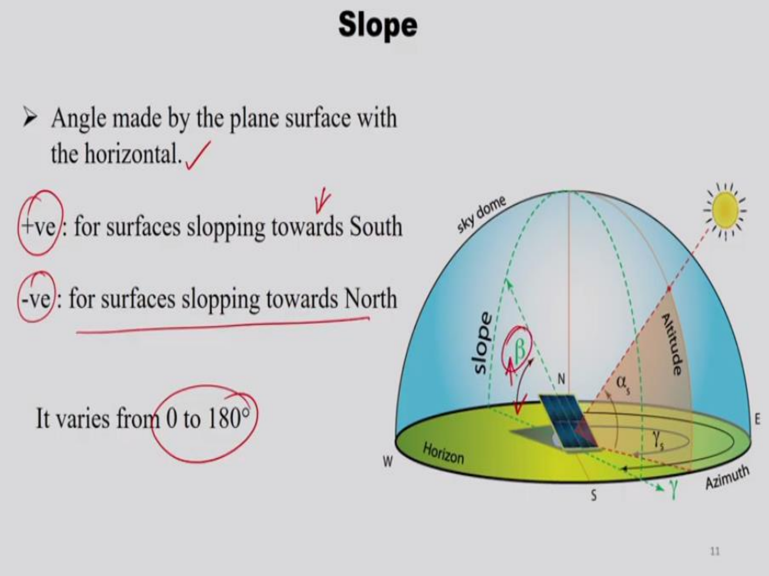

And then the next is slope, angle made by the plane surface with the horizontal. So, it varies from 0 to 180 degree. If the surface is sloping towards south, it is calculated as positive 0 to, 180, and for surfaces sloping towards north, so it is negative. So, in that way it is calculated as 0 to 180 with the negative sign. So, this is here, mentioned us beta. So, this is horizontal, this is inclined surface. This particular angle is slope.

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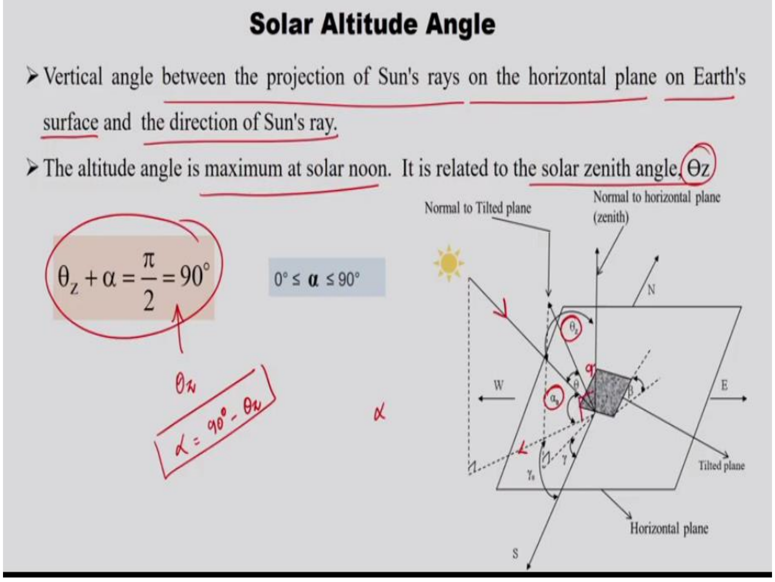

And then solar altitude angle, which is defined as alpha, vertical angle between the projection of sun’s rays on the horizontal plane on earth’s surface, and the direction of the sun’s ray. So, this is sun’s ray and its projection of sun’s rays on the horizontal plane as this. So, this particular angle made between these two lines is called solar altitude angle. So, this is maximum at the solar noon, and it is related to the solar zenith angle theta z.

How it is related. So, theta is a plus alpha which is equal to 90 degree. So, if we know the zenith angle, then from that also we can calculate solar altitude angle which is nothing but 90 minus theta z, so this also varies between 0 to 90 degree. So, here if you see, so this is alpha a. So, this is theta z. So, this particular total angle is 90 degree.

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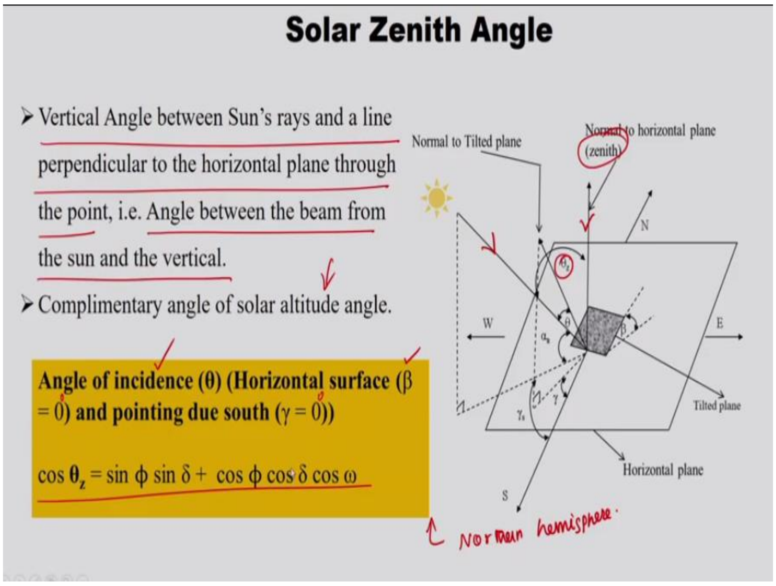

And then, solar zenith angle, vertical angle between sun's rays and a line perpendicular to the horizontal plane through the point. So, this is that line which is normal to the horizontal plane. And then this is the line of sun's rays. So, the angle made between these two lines is called zenith angle, or it is called us angle between the beam from the sun, and the vertical. Vertical is nothing but zenith.

So, it is also, as we have just to see, it is a complimentary angle of solar altitude angle in the general formula of angle of incidence, we can substitute since it is a horizontal surface where there is no tilt, beta is 0 degree, and then which is pointing towards due south, gamma equal to 0 degree. So, this is all calculated for northern hemisphere, if you substitute so we can get the zenith angle as sine phi sine delta cos phi cos delta and cos omega.

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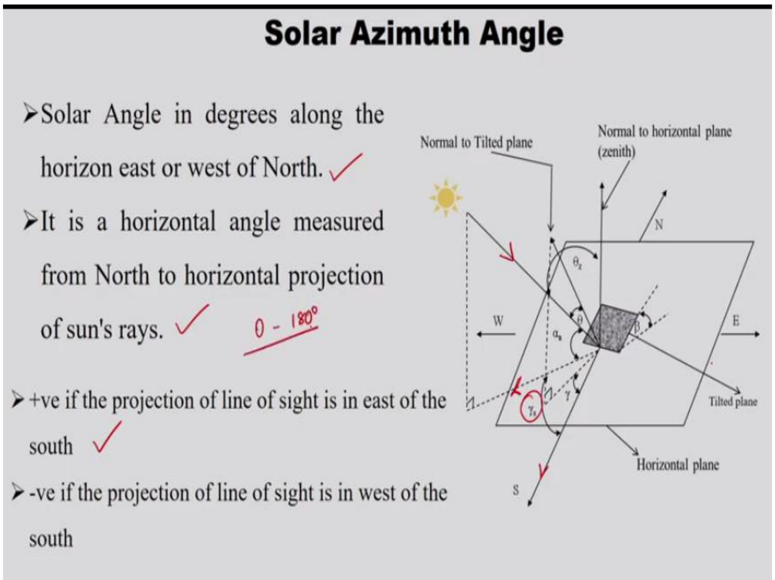

The next one is solar azimuth angle. Solar azimuth angle is nothing but gamma s, so solar angle in degrees along the horizon east or west of north. It is a horizontal angle measured from north to the horizontal projection of sun’s rays. So, the horizontal projection of sun’s rays, this particular line and this is the line due south, due south line.

So, the angle made between these lines is called solar azimuth angle. Positive, if the projection of a line of sight is in the east of the south, so this direction. And if it is calculated as negative, if the projection of line of sight is in the west of the south, this also varies from 0 to 180 degree.

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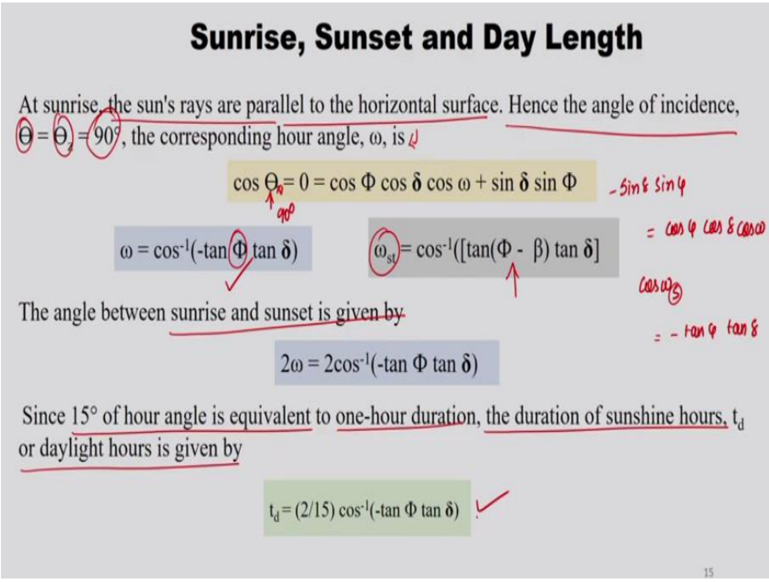

Then sunrise, sunset and day length. How to calculate them? So, at sunrise, the sun’s rays are parallel to the horizontal surface. So, angle of incidence would be theta, theta z which is equivalent to 90 degree. So, the corresponding hour angle omega, how to calculate, so the cos theta or cos theta z which is 90 degree if you substitute theta as 90 degree. So, then it becomes 0. So, this is cos theta z formula.

So, cos phi cos delta cos omega sine delta sine phi. So, in this particular equation, if we substitute theta z which is zenith angle is 90 degree, then it would become 0. So, it will be like, sine delta sine phi minus which is equivalent to cos phi cos delta, and then cos omega. So, if we want to calculate cos omega or sunrise or sunset, that is a subscript s is added.

So, sine upon cos so that is minus tan phi, and then tan delta sine upon cos so that is this one. So, if we have tilted surface, then with the latitude, we will subtract the slope angle, which is nothing but beta. Ah, the angle between sunrise and sunset is given by 1 omega is cos inverse of minus tan phi and tan delta, but here total day length we suppose to calculate so 2 omega will come.

So, as I said earlier, so that is nothing but 2 cos inverse of minus tan phi tan delta. So, 15 degree hour of angle is equivalent to 1 hour duration. So, that duration of sunshine hours, t d or daylight hours is given by 2 upon 15, so this is to 2 upon 15 cos inverse of minus tan phi tan delta.

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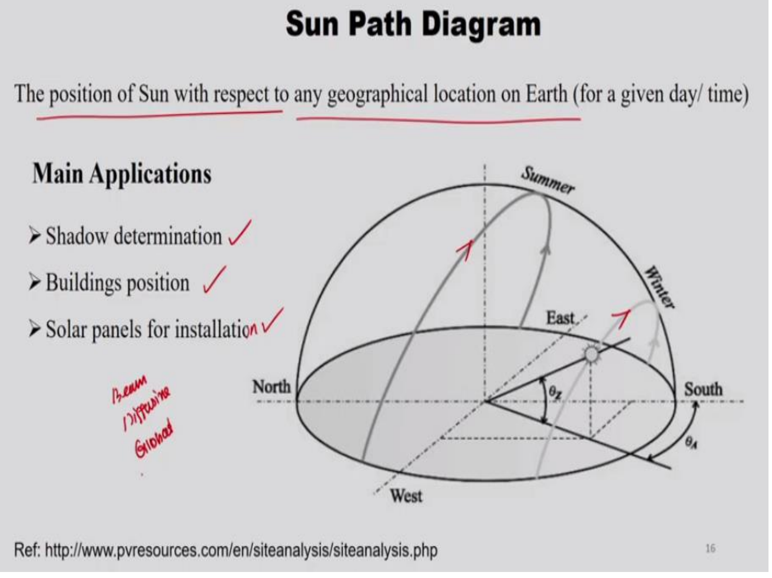

So, the next one is sun path diagram so this is nothing but the position of the sun with respect to any geographical location on the earth for a given day time. So, this is particular sun path during summer time. So, this is during winter time how the sun travels from sunrise to sunset in a day length. So, the main application, shadow determination, buildings position, and solar panels for installation, so for that we normally see sun path diagram, and then calculate various angles. And from there we will calculate the radiation, the beam, diffusive, and then global radiation.

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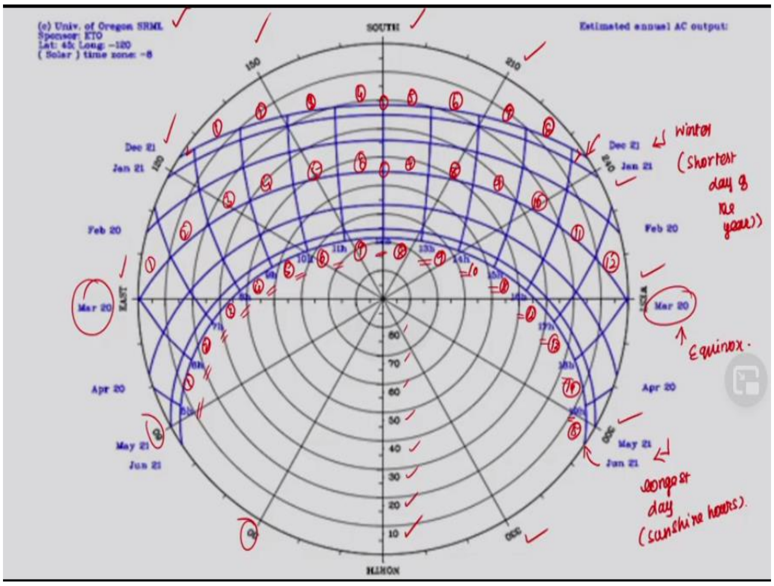

So, this is just an example also taken from University of Oregon so that particular sites website. Ah here if you see, normally we think that it rises in the east and sunsets in the west so that happens only exactly on March 20th. So, we call them as Equinox days. So, before that, so this is a diagram so this is divided into 10, 20, 30, 40, 50, 60, 70, 80, 90 degree. And this is nothing but meridian.

So, this is starts from 30, 60, 90, 120, 150, 180, then, 210, 240, 270, 300, 330 and 360. So, this is divided in this manner. So, these are hours to 7 hours, 8 hours, 9 hours, 10 hours, 11 hours, 12 hours are considered to be noon and then, 13, 14, 15, 16, 17, 18, 19, that way it goes. So, as I said earlier, equinox days it exactly rises in the east and comes in the west.

So, if you see this is 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, exactly when noon come, and then 7 hours, 8 hours, 9 hours, 10 hours, 11 hours and 12 hours. And we have 2 solstice days, one is on June 21st that is this line. And then another is on December 21, so this is winter time. So, this is suppose to be the shortest day of the year. So, this is we get longest so that means sunshine hours.

So, if you see here, in the December 21st, 1 hour, 2 hours, 3 hours, 4 hours, within 4 hours, **(()) (46:42)** would come, then 5 hours, 6 hours, 7 hours, 8 hours. So, day length would be around 8 hours plus **(()) (46:50)** things are here. And then if you see in the June 1st, so this is 1, 2, 3, 4, 5, 6, 7, so then 8, 9, 10, 11, 12, 13, 14, and then around 15 hours **(()) (47:17)**. So, with this sun path diagram, one can determine all this information or one can get all this information.

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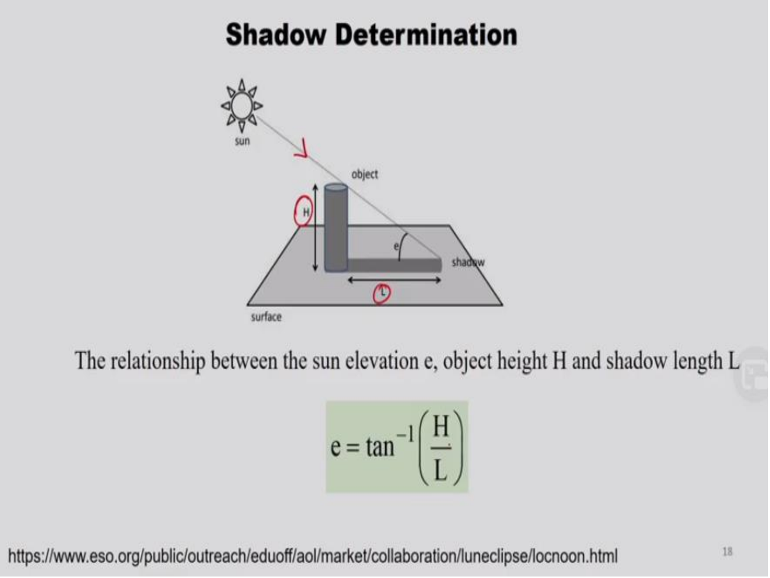

And then shadow determination. So, this is most of you know already, so this is nothing but an object, and its height is H and its projection is L, and this is nothing but elevation, suns elevation. So, in that way, tan e is nothing but H upon L, so e is tan inverse of H upon L. So, this way, the shadow determination can be done.

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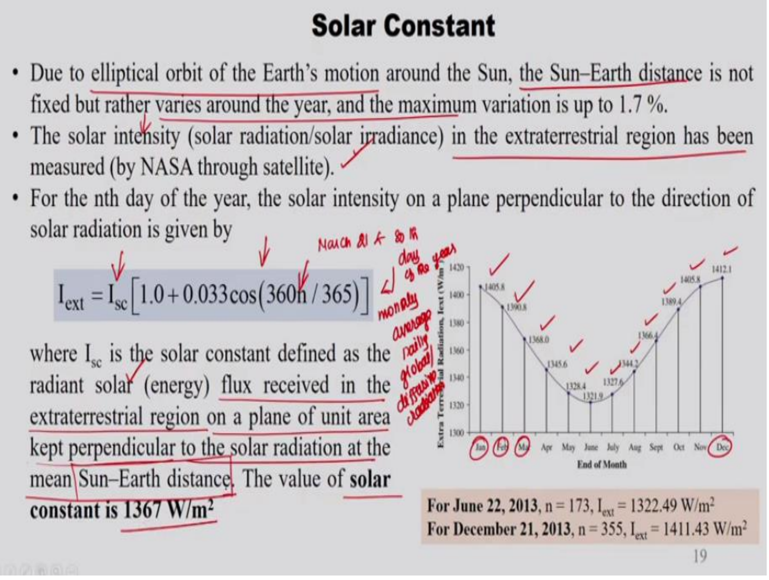

And then the solar constant, actually solar constant is defined as the radiant solar energy flux received in the extraterrestrial region on a plane of unit area kept perpendicular to the solar radiation at the mean sun earth distance, the sun earth distance is not same throughout the year because of the fact that the earth's motion is in elliptical orbit.

So, in that way we do not get the same distance throughout the year because of which we calculate mean sun earth distance. So, solar constant is flux received in the extraterrestrial region on a plane of unit area kept perpendicular to the solar radiation at the main sun earth distance, its value is 1367 watt per meter square. So, this is being used to calculate the extraterrestrial radiation value.

So, this we will be using it to calculate the monthly average daily global diffusive radiation. So, due to elliptical orbit of the earth's motion around the sun, the sun earth distance is not fixed but rather varies throughout the year, and the maximum variation is up to 1.7 percentage.

So, the solar intensity or radiation or irradiance in the extraterrestrial region has been measured by NASA through satellite. And there is a correlation given our formula given to calculate the same. So, for nth day of the year, so that is this the solar intensity on a plane perpendicular to the direction to the solar radiation is given by the extraterrestrial radiation I, which is equivalent to solar constant into 1 + 0.033 cos 360 into n upon 365.

So, this is for example we calculated March 21st so that is 80th day of year. So, in that way, it is calculated here, the mean value is given for various months, Jan to December. So, the radiation varies the extraterrestrial radiation varies in this fashion. So, but however the I sc is taken as a mean value that is 1367 watt per meter square.

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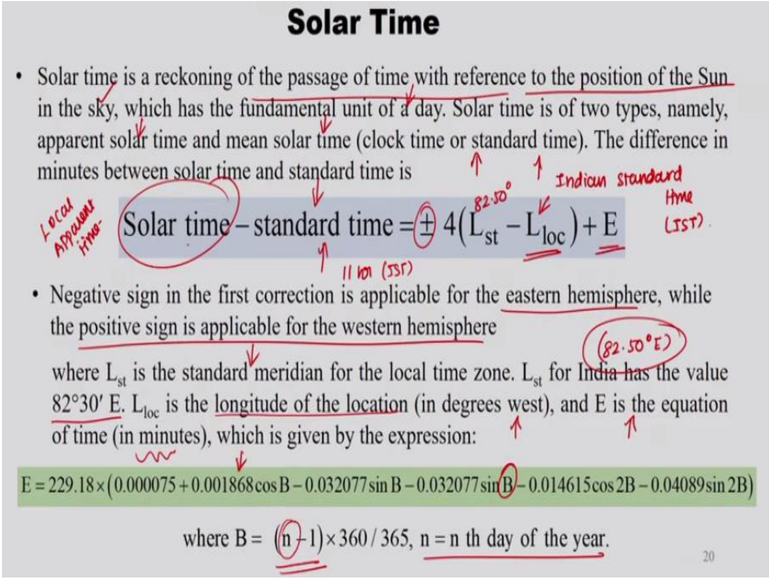

The next one is solar time. Now, solar time is the reckoning of the passage of time with reference to the position of the sun in the sky which has the fundamental unit of the day. So, there are two types of solar time, with which we can measure. So, one is apparent solar time so this we call it as a local apparent time. The second one is mean solar time, so which is nothing but a clock time or standard time.

So, for India we can call it as the Indian standard time, IST the difference between them in minutes is given by this particular formula solar time minus standard time which is equivalent to plus or minus 4 into L st minus L loc plus E. So, what is this LST? LST is the standard meridian for the local time zone and LST for India has the value of 82 degree 30 minutes in the east, so are 82.50 degree in the east. And L loc is the longitude of that location.

So, for which we suppose to calculate the solar time, and in degrees west or east, and then E is the equation of time, which is in minutes, which is given by the expression below. So, in this expression, there is a term called B. So, B is calculated as n – 1 into 360 upon 365. So, n is nth day of the year. And here if you see there is a plus sign as well as minus sign. So, the negative sign is for eastern hemisphere and positive sign is for western hemisphere.

So, in this way, we can calculate the solar time, if the standard time is given, for example, 11 hours in the morning. That is the Indian Standard Time IST and LST is nothing but, for India, this is the fixed value 82.50 degree in the east, and longitude of the location we suppose to find it out which location you want to calculate the solar time. And you, we suppose to substitute here, and **(()) (53:11)** is nothing but, which day you want to calculate the solar time. So, if we substitute we can calculate solar time.

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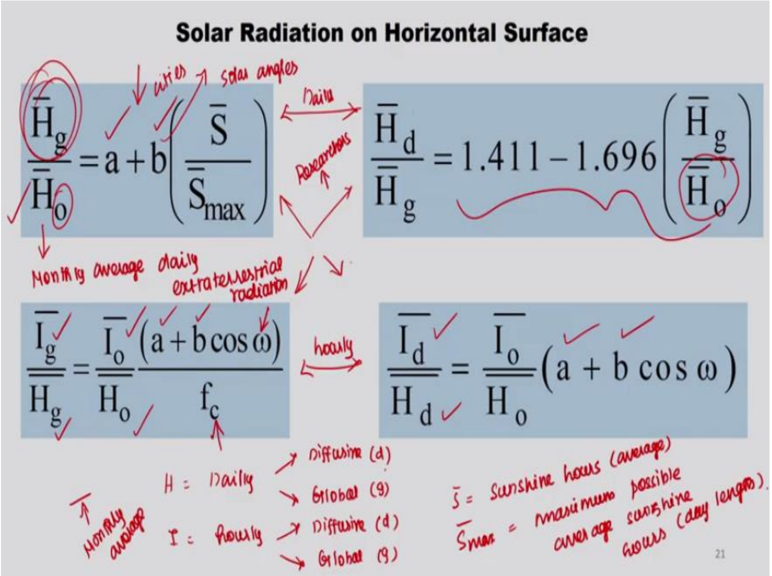

And then solar radiation on horizontal surface, so here it is mostly with all correlations. So, here this H refers to daily diffusive or global radiation, I refers to hourly diffusive and global radiation. So, this is d. So, this is g. This is d. This is g. So, this bar refers to monthly average. And then here if you see there are S bar which is nothing but, sunshine hours for a day. And S max is nothing but, maximum possible.

So, this is bar S average, maximum possible average sunshine hours or we can call it us day length as well. So, apart from that what we have. So, this o, so this is nothing but, monthly average daily extraterrestrial radiation. So, these all these correlations were given by the researchers anyway, this we will see in detail when we do the problems. So, which correlation is being used for which case?

So, here if you see so this is the global radiation that is related to the originally it is related to the H c that is monthly average daily radiation under clear sky, but we cannot define what is clear sky with certain definition, which is applicable for all locations. So, in that way it is converted to that H c bar is converted to H naught.

So, H naught is nothing but the daily extraterrestrial radiation, then on particular day of the month, so the monthly average daily extraterrestrial radiation is equivalent to daily extraterrestrial radiation in that way by applying that particular assumption, then this formula is given us H g upon H naught, which is equivalent to a + b S bar upon S bar max. So, these are fitting constants.

So, this is given for certain cities, and some researchers has given this a, b in terms of other solar angles. So, that way also one can calculate once you get g, then H d upon H g is given using this particular formula, so, again here, which is monthly average daily extraterrestrial radiation. So, these two are calculated for daily. So, the same way, hourly radiation also can be calculated.

The same way, this is hourly global, this is nothing but daily global hourly global is connected with daily global and using this particular formula. So, I naught H naught is extraterrestrial, a b also formulas are, how to calculate a b is given, or it is directly given for a particular location, omega is nothing but hour angle, f c is a correction factor. And from after calculating H I g, then we can calculate I d as well, that is diffusive radiation.

So, that is calculated using this particular formula, again a, b are fitting constants we can calculate using some other correlations. So, this we will see in detail. These are either formulae or correlations that we will see in detail when we do problems. The next one is solar radiation on an inclined surface. So, for any inclined surface, there are three types of solar radiation, one is beam, diffusive, and then reflector solar radiation from a horizontal surface, and the surfaces surrounding it.

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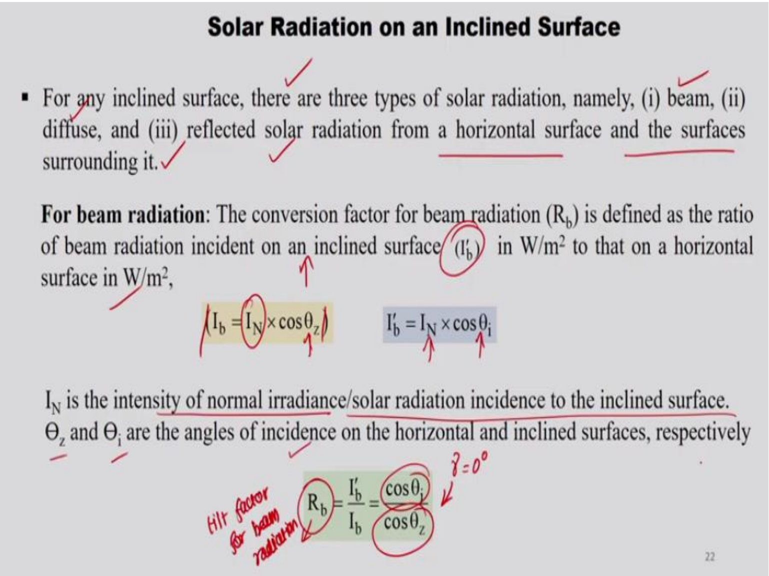

For beam radiation, we calculate the R b, which is nothing but the tilt factor or conversion factor. Tilt factor for beam radiation. So, the here R b is defined as the ratio of beam radiation incident on an inclined surface which is nothing but I b dash in watt per meter square to that on a horizontal surface, which is also in watt per meter square. So, I b is for horizontal surface, which is nothing but I N that is the beam flux into cos theta z.

So, this is zenith angle and I b dash for inclined surfaces, again I N and cos theta i. So, if we calculate the I b dash upon I b, so you will get us cos theta i cos theta z. And if the surface is due south, then gamma is 0 degree. So, substituting in the angle of incidence formula you would get.

I N is the intensity of the normal irradiance or solar radiation incidence to the incline surface theta z, theta i are the angles of incidence on the horizontal plane and inclined surfaces, respectively. So, horizontal is nothing but zenith angle. So, in that way we can calculate the tilt factor for beam radiation.

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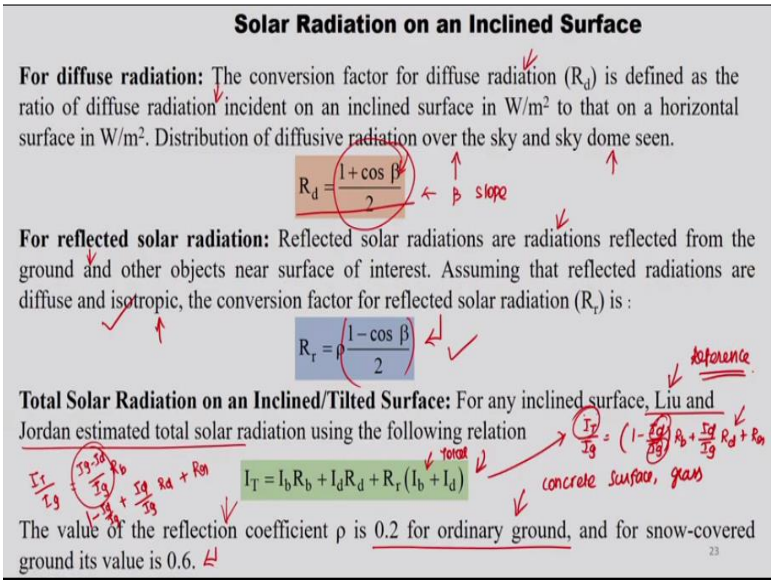

And, for diffusive radiation, so this is again, diffusive radiation is defined as the diffusive radiation incident on an inclined surface, which is again in watt per meter square to that of the horizontal surface again watt per meter square. So, usually, this is based on distribution of diffusive radiation over the sky, and sky dome seen from the tilted surface. So, this is defined as R d is 1 plus cos beta upon 2.

So, beta, here is slope and for reflected solar radiation, so this is again the radiation is reflected from the ground, and other objects near the surface of interest. Assuming that reflected radiations are of diffusive and isotropic this I have told you in first lecture itself. So, many radiation models considered them as a isotropic in nature, though they are **(()) (1:00:31)** because the diffusive radiation comes from various directions, may not be uniform.

So, the conversion factor for reflected solar radiation R r is defined as rho into 1 minus cos beta upon 2 so that is **(()) (1:00:45)** because here are the diffusive radiation is taken as 1 plus cos beta upon 2. So, remaining the reflected radiation is 1 minus cos beta upon 2 that is multiplied with rho, which is nothing but reflection coefficient. So, this is 0.2 for ordinary ground or concrete surface, as well as grass.

So, this can be taken as 0.2 for snow covered ground that is 0.6 around. So, R d is defined, R r is defined. And here, this R b when we calculate we need to be careful, which angle of incidence and zenith angle which surface, or whether it is a horizontal or inclined surface or which is having certain inclination angle and theta z also we have given the formula for northern hemisphere, so that we should keep in mind.

But, this R d, R r would be same for all surfaces because it includes only beta. But here, it includes angle of incidence as well as zenith angle. So, to calculate one should be careful. Then, total solar radiation on an inclined or tilted surface. Liu and Jordan, so he estimated using this particular relation. So, this particular reference we would give when doing when we do the problems. So, I T is I b R b I d R d and I b I d, so this is total into R r.

So, if we divide this equation by I g I T upon I g, that is global radiation, then it would be I b upon I g. So, I b upon I g into R b plus I d upon I g into R d plus I b plus I d is nothing but I g. So, then we need not put divided by I g that becomes 1 R r. So, here also in the I b we can write it like I g minus I d. Total minus diffusive. So, in that way, the total this particular term can be written as 1 minus I d upon I g.

So, in that way, this formula also can be written as I T upon I g which is equivalent to 1 minus I d upon I g into R b plus I d upon I g into R d plus R r. So, in that way, we have used the correlation for d and g. Already we have seen, there are many correlations and formulae to calculate diffusive and global radiation. So, if we know that, then we can substitute just by calculating tilt factor and substituting that values we will be able to calculate the total radiation falling on an inclined surface.

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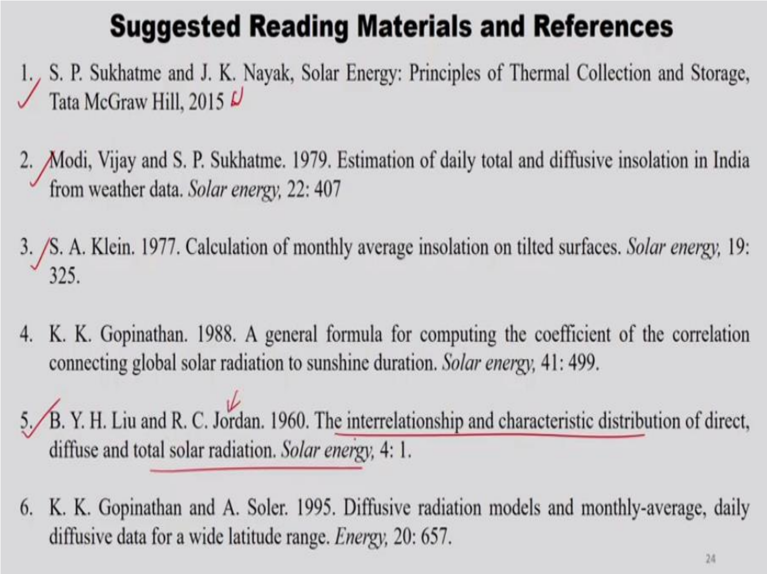

So, that is all about solar radiation parameters. So, we have used this, these references, so Sukhatme and Nayak is the basic reference material, and this is the journal paper with which that particular correlation has been taken, Liu and Jordan. Other references are also used in this lecture. Thank you.