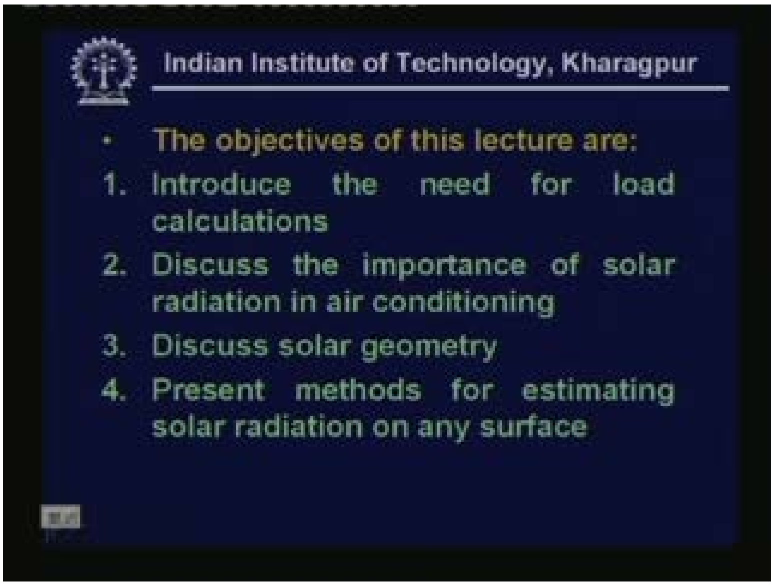
Refrigeration and Airconditioning
Prof. M. Ramgopal
Indian Institute of Technology, Kharagpur
Department of Mechanical Engineering
Lecture No. # 39
Cooling and Heating Load Calculations: Solar Radiation

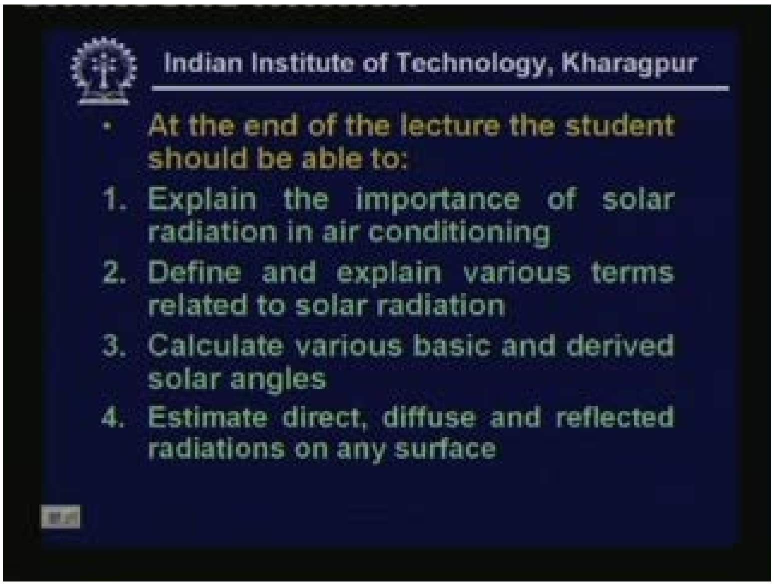
Welcome back in this lecture I shall begin a very important topic in air conditioning that is heating and cooling load calculations. I shall begin this lecture with discussion on solar radiation.

(Refer Slide Time: 00:00:59 min)



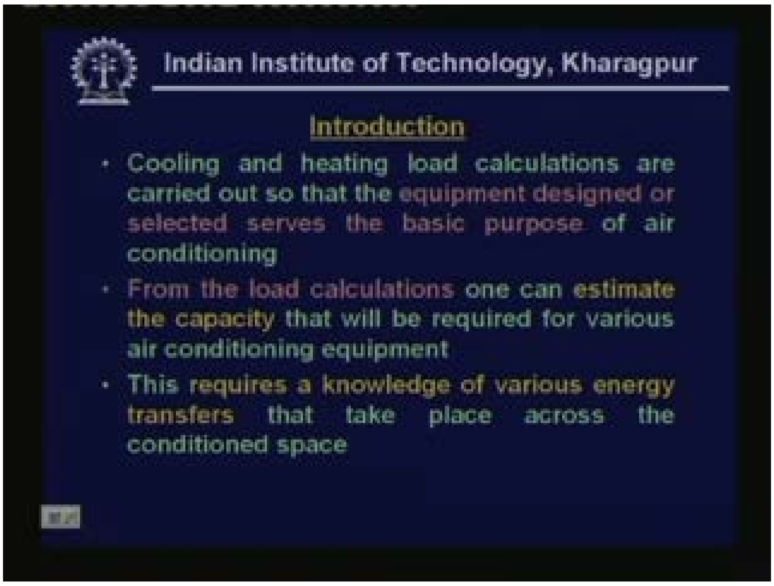
So the specific objectives of this particular lecture are to introduce the need for load calculations discuss the importance of solar radiation in air conditioning discuss solar geometry present methods for estimating solar radiation on any surface at the end of the lecture you should be able to.

(Refer Slide Time: 00:01:17 min)



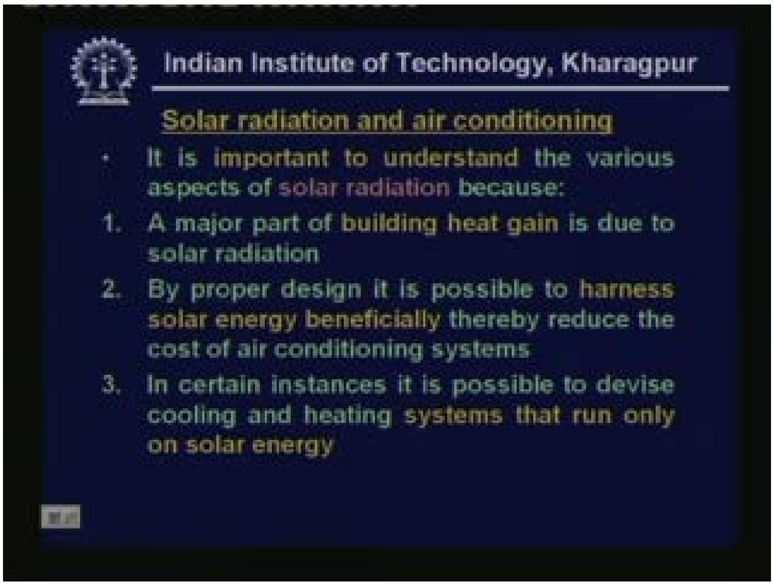
Explain the importance of solar radiation in air conditioning define and explain various terms related to solar radiation calculate various basic and derived solar angles and finally estimate direct diffuse and reflected radiations on any surface. So let me give a brief introduction.

(Refer Slide Time: 00:01:37 min)



Why do we have to carry out cooling and heating load calculations cooling and heating load calculations are carried out. So that the equipment design are selected serves the basic purpose of air conditioning. So this is a very important activity from the load calculations one can estimate the capacity that will be required for various air conditioning equipment. And actually cooling and heating load calculations is a way step wise procedure it is a systematic step wise procedure you have to have certain inputs like the specifications of the building the load pattern and all that and from these specifications you have to calculate various energy flows across the building okay. For example energy transferred to the building or energy transfer from the building energy generated inside the building etcetera okay. So from these at the end of these this step wise procedure what you get is the total load on the building okay. So this total load on the building is required in order to estimate the capacity of the cooling or heating equipment okay. This is the purpose of cooling and heating load calculations okay.

(Refer Slide Time: 00:02:49 min)

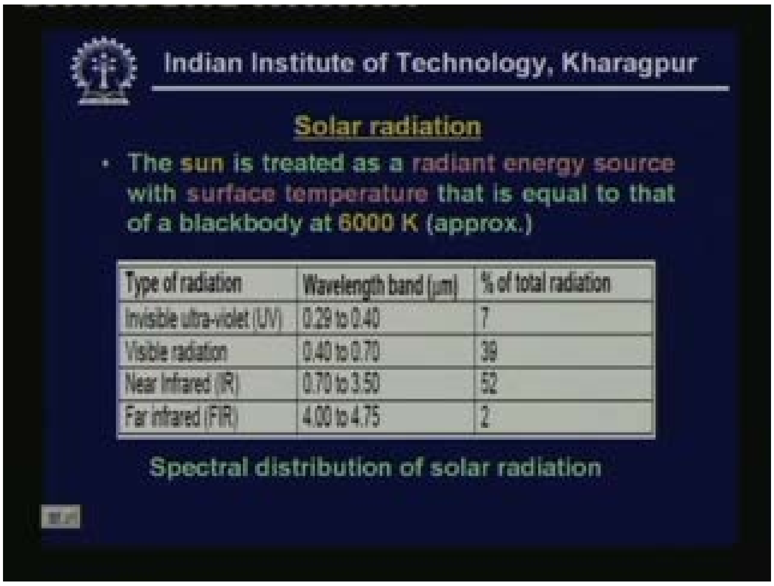


So why do we have to bother about solar radiation in air conditioning? What is the importance of this? It is important to understand the various aspects of solar radiation. Because a major part of building heat gain is due to solar radiation. So in order to estimate cooling and heating loads one has to take solar radiation into account and second reason is that by proper design it is possible to harness solar energy beneficially thereby reduce the cost of air conditioning system this very important reason also and the third reason is that in certain instances it is possible to device cooling and heating systems that run only on solar energy okay.

So this is a very important this very important as for as energy conservation is concerned. Because it is possible in some cases where you can have a cooling system. For example using an absorption refrigerant system you can device an air condition system which runs only on solar energy okay it doesn't require any other energy input. So this is a very beneficial as far as certain remote areas are concerned and it is also very good from energy point of view and also from environment point of view. Because solar energy as you know is renewable and it is very non polluting okay.

So you have to understand the solar radiation properly so that you can use it properly to reduce the load on the equipment. The load on the heating and cooling. So that you can go for a smaller equipment which will reduce the initial and running cost and you can also design systems which use solar energy okay.

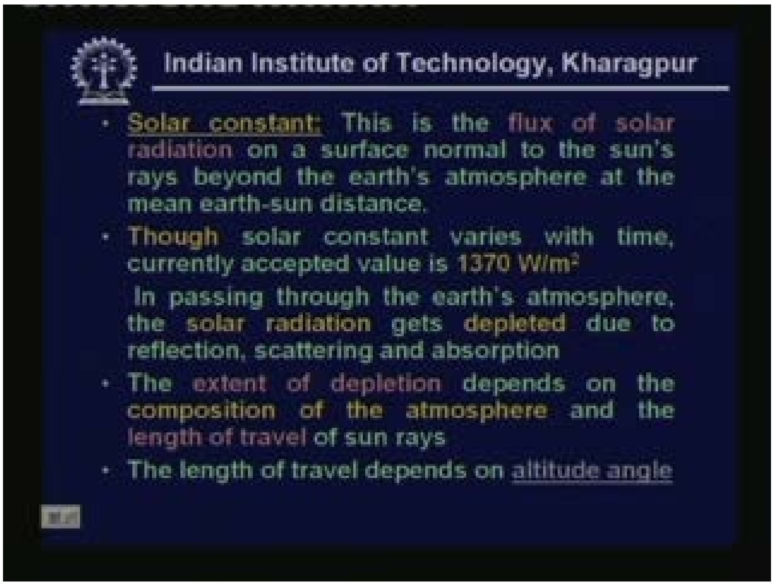
(Refer Slide Time: 00:04:29 min)



Type of radiation	Wavelength band (μm)	% of total radiation
Invisible ultra-violet (UV)	0.29 to 0.40	7
Visible radiation	0.40 to 0.70	39
Near Infrared (IR)	0.70 to 3.50	52
Far infrared (FIR)	4.00 to 4.75	2

First let us, let me give a very brief introduction to solar radiation as you know very well the sun which is a nothing but a star is treated as a radiant energy source with surface temperature that is equivalent to that of a black body at six thousand Kelvin okay. So this is equivalent to a black body of surface temperature which is approximately equal to six thousand Kelvin and on the spectral distribution of solar radiation is given in the table here. So you can see here that the solar radiation stretches form about point two nine microns up to about four point seven five microns and it consist of invisible ultra violet radiation which lies in the wave length band of point nine microns to point four microns and it it consist of about seven percent of the total radiation and the visible radiation which lies between point four to point seven microns consist of about thirty-nine percent of total solar radiation and the near infrared radiation which is in fact gives rise to heating affect lies in the range of point seven to three point five microns and it consist of about fifty-two percent of the total radiation and finally you have far infrared or FIR radiation which lies in the range four to four point seven microns and it consist of two percent of the total radiation so you can see that the majority of solar radiation lies in the range of visible radiation and near infrared radiation okay so all most ninety-one percent that's the reason why so sun is the major source of light as well as heat okay

(Refer Slide Time: 00:06:04 min)

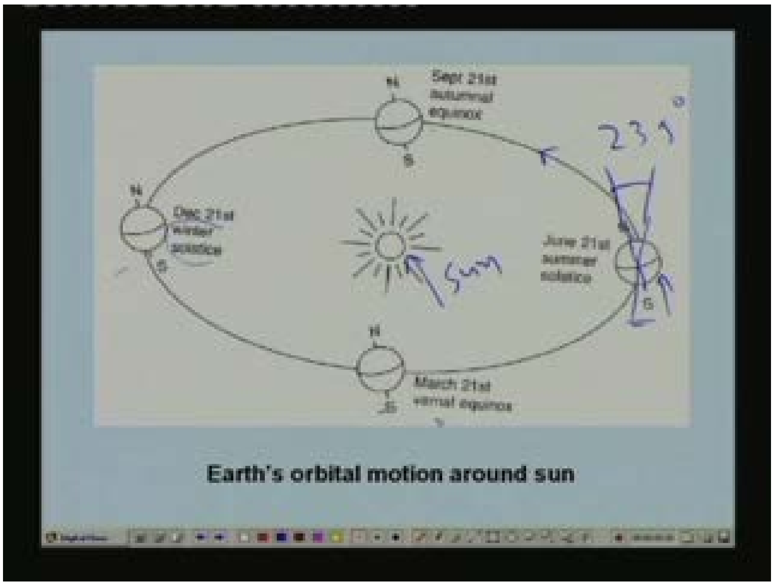


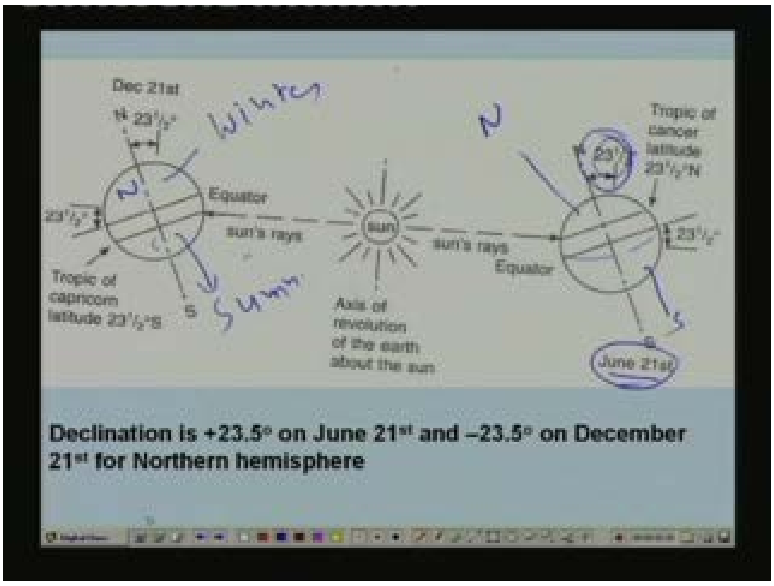
Now let me define what is known as the solar constant. A solar constant is the flux of solar radiation on a surface normal to the sun's rays beyond the earth's atmosphere at the, mean earth sun distance okay. It is important to understand this definition it is nothing but the solar radiation per unit surface which is kept normal to the sun's rays and which is kept beyond the earth's atmosphere okay and at the mean earth's sun distance. Though this solar constant value varies with time from day to day the currently accepted value is about thirteen seventy watt per meter square okay. So you can use this value in calculations and what happens to the solar radiation as it enters into the environment or is as it enters into the atmosphere in passing through the earth earth's atmosphere the solar radiation gets depleted due to reflections scattering and absorption.

So we know very well that the atmosphere earth's atmosphere consist of various gasses it consist of water vapour it consist of several dust particles of several sizes okay. So atmosphere consist of all these things. So as a solar radiation enters the atmosphere and as it passes through the atmosphere it gets reflected it gets absorbed it gets a diffracted okay. So it under goes all these processes as it passes through the earth's atmosphere okay. So ultimately the end result is that even though the solar radiation or the solar constant is thirteen seventy watt per meter square beyond the earth's atmosphere as it arrives at the earth it gets depleted considerably because of the presence of the atmospheric gases atmosphere dust particles water vapour etcetera okay.

And the extent of depletion depends on the composition of the atmosphere and the length of travel of sun's rays okay, obviously the composition of atmosphere has a great effect on the extent of depletion. And it also depends upon the length of the travel of sun's rays and the length of travel depend on what is known as altitude angle. So I will define this altitude angle a little later.

(Refer Slide Time: 00:08:11 min)



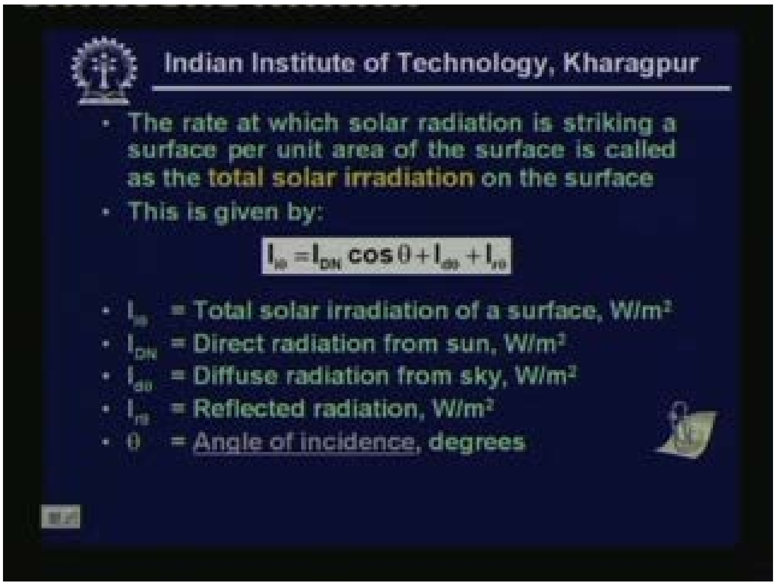


Now let us briefly look at sun earth relationship we know that the planet earth makes one rotation about its axis every twenty-four hours and one revolution about the sun in a period of about three sixty-five point two five days earth's equatorial plane is tilted at an angle of about twenty-three point five degrees with respect to its orbital plane this is very important. For example in this figure you can see that, this is the sun okay. And this is the earth, so earth is orbiting around the sun not in a circular this thing is lightly elliptical and it is tilted at about twenty-three point five centigrade with reference to its own axis. So it is not perpendicular you can see that it is lightly tilted okay. This is the pole north south pole of the sun. So it has a tilt right. So this angle is about twenty-three point five degrees okay. And you can see the position of the, if you take the sun as a reference then you can see the position of the earth at different day.

For example at on June twenty-first its position is like this and on September twenty-first it is like this on December twenty-first, it is like this and on march twenty-first, it is like this okay. And June twenty-first is known as summer solstice and September twenty-first is known as autumnal equinox and December twenty-first is known winter solstice and march twenty-first is known as vernal equinox. Now if you look at this figure you will find the tilt and what is the effect of the tilt okay. For again you can see that is the, this angle is twenty-three point five degree centigrade and on June twenty-first this is your northern hemisphere. And this is your southern hemisphere okay. So on June twenty-first the northern hemisphere is tilted towards the sun okay whereas the southern hemisphere is tilted away from the sun. So as a reason you find that the northern hemisphere experience a summer during this season okay.

Similarly when you come to December twenty-first December twenty-first this is the northern hemisphere this is a southern hemisphere okay. Northern hemisphere is tilted away from the sun whereas southern hemisphere is tilted towards the sun as a result this experiences winter okay. The northern hemisphere whereas the southern hemisphere experiences summer okay. So the seasonal variations are mainly because of the tilt angle okay. So as you know very well the earth's rotation is responsible for day and night whereas its tilt is responsible for the change of seasons since the distance between earth and sun is very large for all practical purposes. It can be considered that the sun's rays are parallel to each other when they reach the earth okay. The distance is about ninety-three million kilometres. So it is very large so you can consider the sun's ray to be parallel when they reach the earth.

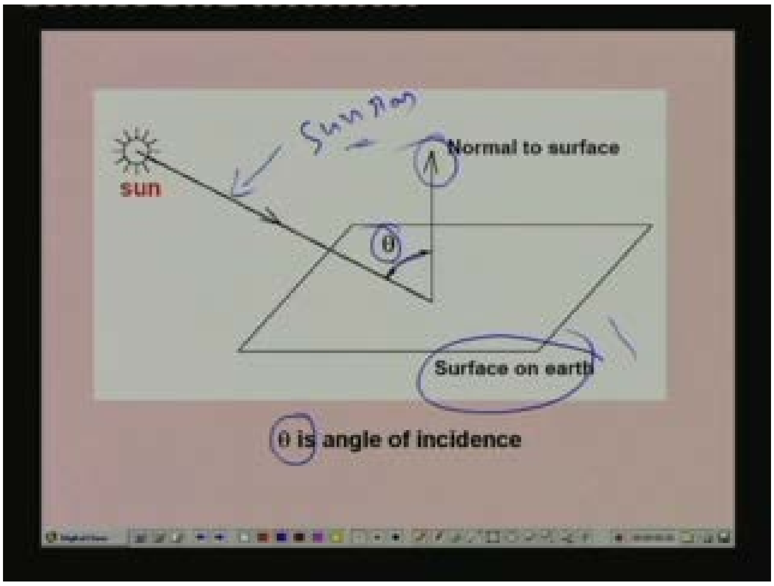
(Refer Slide Time: 00:11:12 min)



Now there are, we are interested in the solar radiation striking a surface as far as the air conditioning load calculations are concerned. So let us see how to calculate this the rate at which solar radiation is striking a surface per unit area of the surface is called as the total solar irradiation on the surface. And the total solar irradiation on the surface is given by this equation I subscript i theta is equal to I subscript dn cos theta plus I subscript small d theta plus I subscript r theta. And as you can see here I subscript i theta is the total solar irradiation of the surface in watt per meter square and I subscript capital DN is the direct radiation from sun and I subscript small d theta is the diffuse radiation from sky and I subscript r theta is the reflected radiation and theta is known as angle of incidence okay.

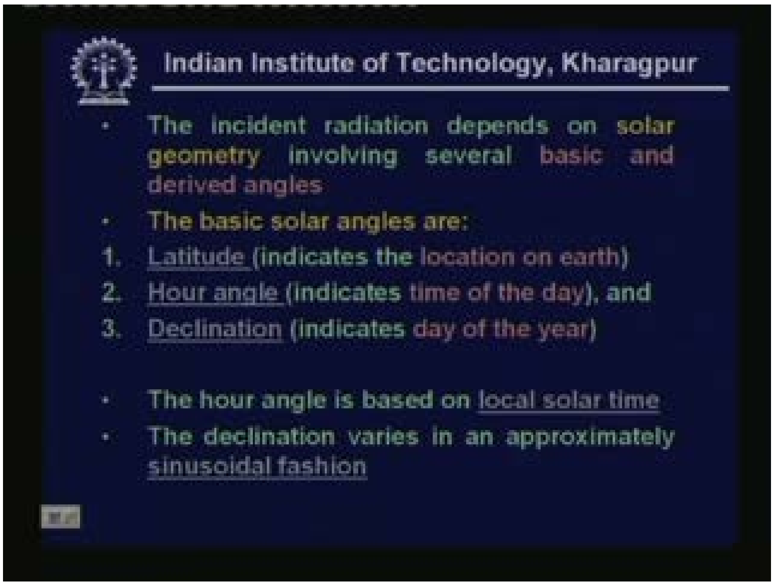
So you can see that the total radiation incident on any surface consist of basically three parts one is the pick of the direct radiation the second part is pick of the diffuse radiation from the sky and the third part is pick of the reflected radiation okay, from the ground and from the surrounding surfaces on a cloudless day. That means when the sky is cloudless you find that the contribution of the direct radiation is about eighty-five percent. So the of the total radiation, so the contribution of diffuse and reflected radiation is quite small on a clear day okay. Whereas on a cloudy day you find that the importance of or the contribution of diffuse radiation increases where as the contribution of direct radiation reduces okay. Now what is the angle of incidence how is it defined.

(Refer Slide Time: 00:12:50 min)



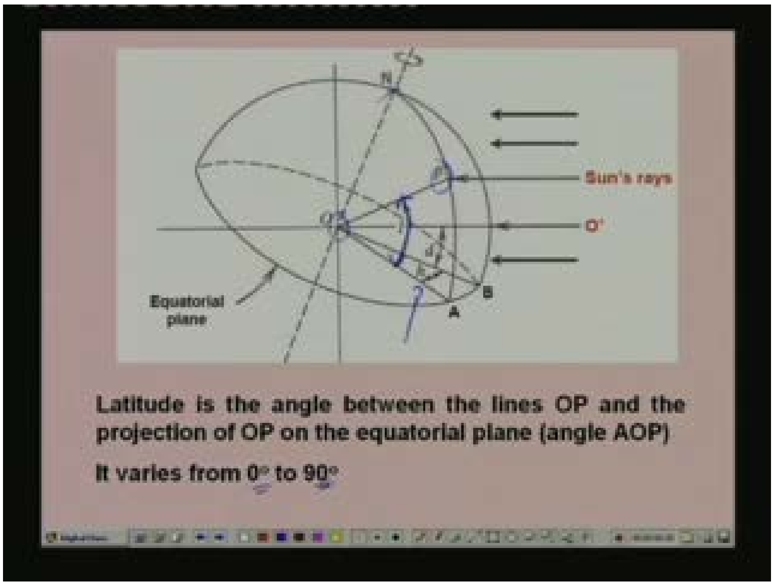
You can see that the angle of incidence is nothing but the, this is the sun's rays okay. This is your sun ray okay. And this is the surface on earth you can see here and this is a normal to the surface okay. So the incident angle is theta, theta is nothing but the angle between the sun ray and the normal to the surface okay. So this is this angle right.

(Refer Slide Time: 00:13:18 min)



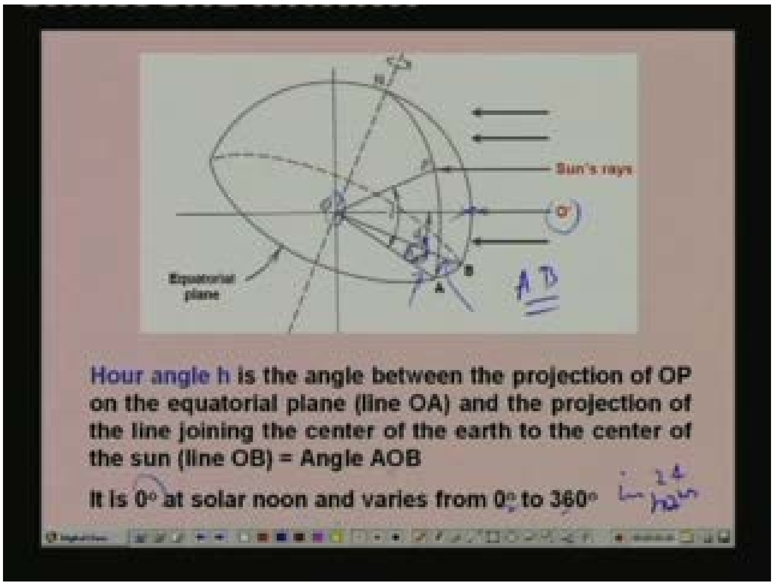
Now the incident radiation depends on solar geometry involving several basic and derived angle. So it is important to understand these angles and what are the basic solar angles the basic solar angles are the first one is what is known as latitude and the latitude indicates the location on earth. So what is this latitude?

(Refer Slide Time: 00:13:39 min)



The picture here shows northern hemisphere, this is your northern hemisphere; this is your equatorial plane okay. So this is your equatorial plane and O is the centre of the earth and O dash is the centre of the sun and as I have mentioned for our calculation purposes we can assume that the sun's rays are parallel okay. So they arrive parallely on earth okay and point P is any point on the surface of the earth okay. Maybe it is a point of the observer right now with references to this we define all these solar basic solar angles starting with the latitude. Latitude is defined as the angle between the lines OP okay. Line OP is nothing but the line joining the centre with point P okay. Line OP and the projection of OP on the equatorial plane the projection of OP on the equatorial plane is nothing but OA okay. So the latitude is nothing but angle between OP and OA that is nothing but angle AOP that is this angle oaky. As you know the latitude varies from zero degrees to ninety degrees when is at zero when the point P lies on the equatorial plane obviously the latitude is zero okay. And when the point P lays on the pole this angle becomes ninety degrees. So this is how the latitude is defined. And latitude along with the longitude completely specify the location of any point on earth the second basic solar angle is what is known as our angle and this indicates the time of the day. So how is this defined?

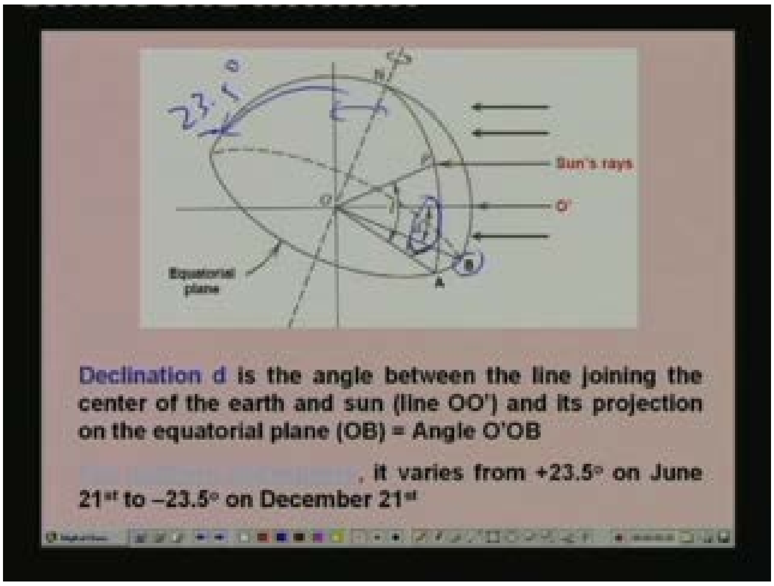
(Refer Slide Time: 00:15:13 min)



Again referring back to the same figure oh here the hour angle h is defined as the angle between the projection of OP on the equatorial plane OP is nothing but the line joining point O that is the centre of the earth and the position of the observer P okay. And its projection is, as I have said is OA. So our angle is nothing but the angle between OA and the projection of the line joining the centre of the earth to the centre of the sun now point O is the centre of the earth and point O dash is the centre of the sun okay. So the projection of O O dash on the equatorial plane is nothing but AB okay. So that is the projection of O O dash on the equatorial plane. So our angle is nothing but the angle AOB okay, that an angle between OA and OB okay.

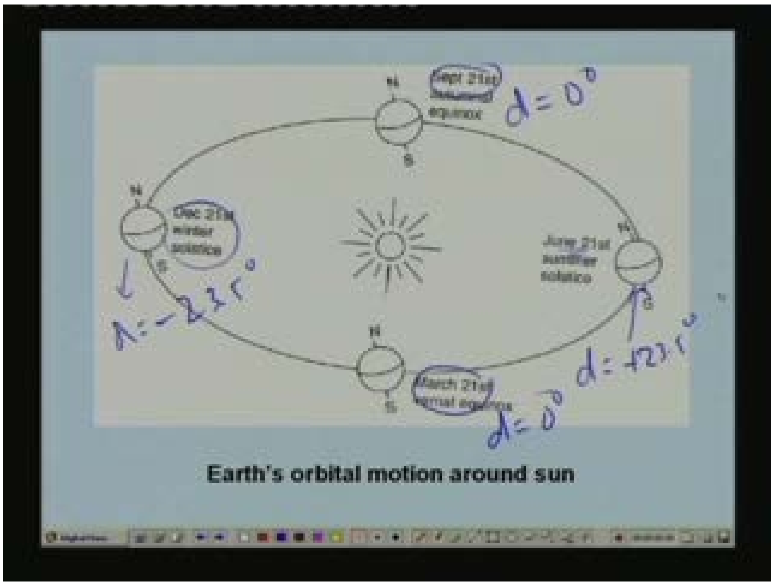
That is this angle right now at solar noon when the earth rotates and when point P become comes at this point you find that the our angle is zero okay. And the our angle varies from zero at solar noon to three sixty degrees okay. Because it rotates in one day right three sixty degrees in twenty-four hours okay. It may makes one rotation in twenty-four hours the third basic angle is what you known as declination an declination indicates the day of the year.

(Refer Slide Time: 00:16:38 min)



Again we refer to the same figure and declination d is the angle between the line joining the centre of the earth O and sun okay. That is nothing but the line O O dash and its projection on the equatorial plane the projection of line O O dash on equatorial plane as i have already discussed is OB okay. So declination is nothing but angle between OB and O O dash that is nothing but angle d okay. And since this angle that means earth is tilted a twenty-three point five degrees okay. You have an angle of tilt of twenty-three point five degrees you find that for northern hemisphere the declination varies from plus twenty-three point five degrees on June twenty-first to minus twenty-three point five degrees on December first and this will be exactly reverse for the southern hemisphere okay. This will be clear with the help of this picture.

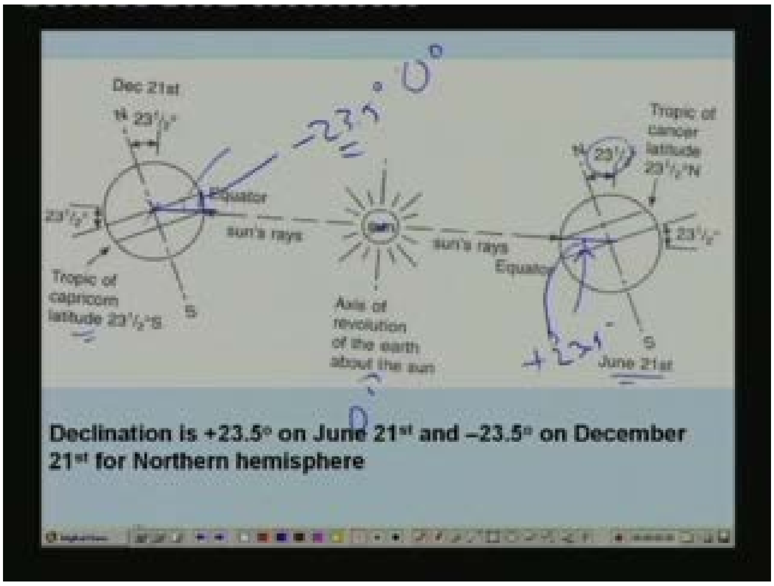
(Refer Slide Time: 00:17:33 min)



As I said, this is the orbital motion of earth around the sun and this is the summer solstice that is on June twenty-first on June twenty-first. As I said for northern hemisphere your angle of declination is plus twenty-three point five degrees and on September twenty-first and on March twenty-first. That means at the two equinoxes the declination is zero degrees okay.

And on December twenty-first. That means on winter solstice you find that the declination d is minus twenty-three point five degrees oaky. This as I said remember that this is for northern hemisphere this is this will be very clear if you look at this picture.

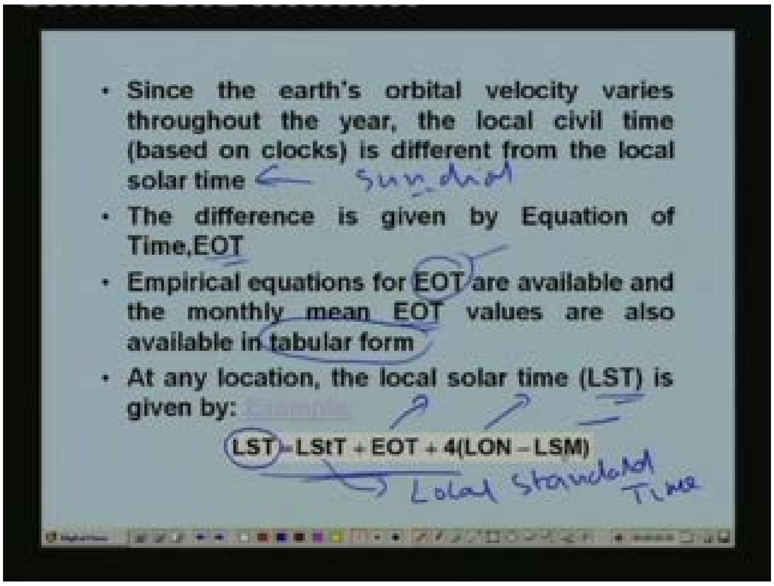
(Refer Slide Time: 00:18:15 min)



For example take just summer solstice and winter solstice that is June twenty-first and December first this is the equatorial plane of the earth okay. And since this angle is twenty-three point five this angle is tilted as twenty-three point five the declination is nothing but this angle okay. So this is also twenty-three point five degrees okay. So by convention we take this as plus twenty-three point five degree centigrade and on winter this is your equatorial plane. And this is your angle of declination okay. The line joining point O and this and its projection on equator okay. So this angle is minus twenty-three point five on December twenty-first okay.

So it varies from plus twenty-three point five to minus twenty-three point five through zero degrees and it is zero degrees at the two equinoxes and the hour angle. So you can see now the basic solar angles depend upon three important parameters. That is what is the location of the surface on earth which is indicated by the latitude and what is the time of the day time of the day is specified by the hour angle and what is the day of the year okay, day of the year is indicated by our declination. So location time of the day and day of the year these three define three basic solar angles latitude hour angle and declination okay. And the hour angle it is very important to keep in mind that the hour angle is based on what is known as local solar time.

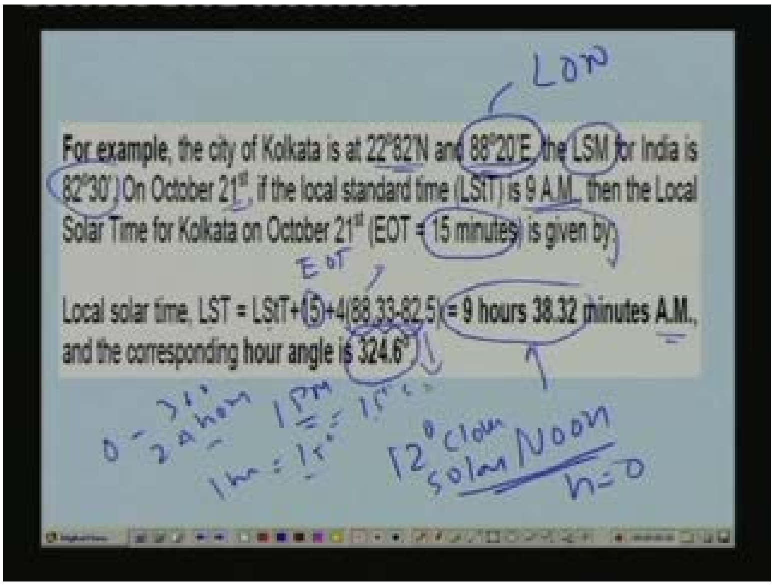
(Refer Slide Time: 00:19:57 min)



What is local solar time since the earth's orbital velocity varies throughout the year the local civil time, which is based on our clock say the mechanical or a, or electronic is different from the local solar time so local civil time is what is the time shown by your watch whereas local solar time is, for example time shown the time shown by let us say a sun dial okay. So this is the time shown by a sun dial you will find that these two will be different okay. They are not exactly equal and the difference between the local civil time and the local solar time is what is known as equation of time or EOT okay. And empirical equations for EOT are available. So if you know the day of the year you can calculate what is the equation of a time for a particular day okay.

It is taken as constant for a particular day. So you can calculate EOT as a function of the day of the year okay. If you know the number of the day you can find out EOT and the mean monthly mean values of EOT are also available in tabular form if you look at ASHRAE handbooks or anything you will find the values of EOT okay. And at any local at any location the local solar time LST is given by this expression LST is the local solar time which is equal to LStT. This is the local standard time okay. EOT as you know is nothing but equation of time plus four into LON minus LSM LON is nothing but the local longitude LSM is a local standard meridian okay. I will let me give a very simple example.

(Refer Slide Time: 00:21:45 min)



For example for the city of Kolkata, is located at twenty-two point eight two latitude north latitude and its longitude is eighty-eight degrees twenty minutes east okay. This is the longitude right and the local standard meridian for India is eighty-two degrees thirty minutes eighty-two point five degrees okay. So this is the data and we would like to find out on October twenty-first if the local standard time is nine am okay, then what is the local solar time for Kolkata okay.

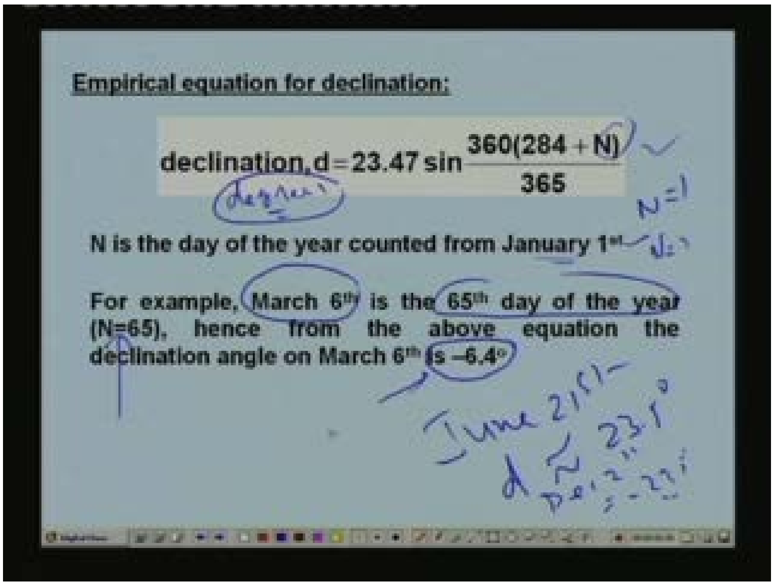
So for this particular day that is October twenty-first from the empirical equation for EOT or from the table for EOT you will find that the equation of time is given by fifteen minutes okay. So EOT is given as fifteen minutes so the local solar time is nothing but local standard time plus fifteen minutes fifteen minute is your EOT okay. Plus this is the correction for longitude variation between the LSM and LON okay. So our local longitude is eighty-eight point three degrees whereas the local standard meridian is eighty-two point five degrees okay. So this is the correction for that.

So if you substitute the values you find that local solar time is nine hours thirty-eight point three two minutes whereas the local standard time is nine am okay. Since this is nine hours thirty-eight point three two minutes in the morning the corresponding hour angle is three twenty-four point six degree centigrade. How did I calculate the hour angle? As I said at noon okay, noon means let us say twelve o'clock okay. Twelve o' clock solar time solar noon your hour angle is zero okay. For example at one pm the hour angle is equal to fifteen degree centigrade how is it? So because it makes the hour angle various from zero to three sixty degrees in twenty-four hours okay.

So one hour is equivalent to one hour is equivalent to fifteen degrees. So if it is, if you are starting with noon then after noon it will be you starting with zero at noon afternoon hours will be let us say three pm means forty-five degrees okay. Four pm means sixty degrees like that and if you proceed in that manner you find that in the morning. For example nine am. Nine am means three hours before, so solar noon okay. That means it i three sixty minus forty-five that is three fifteen degrees centigrade okay. So now the local solar time in this example is nine hours thirty-eight point three two minutes. So the solar angle is three twenty-four point six degree okay.

So that is how you can calculate the hour angle. So what you have to do to calculate hour angle is to first find out what is the local longitude. And you also should know what is the local standard meridian right and then you if you know the local standard time and equation of time then you can calculate first you should calculate the local solar time. And once you know the local solar time you can calculate the hour angle because one hour is equivalent to fifteen degrees okay. So the hour angle, as I said is based on local solar time and the declination varies in an approximately sinusoidal fashion. I have mentioned that the declination varies from plus twenty-three pointy five degrees to minus twenty-three point five degrees and the variation is almost sinusoidal okay. So you can fit an empirical equation.

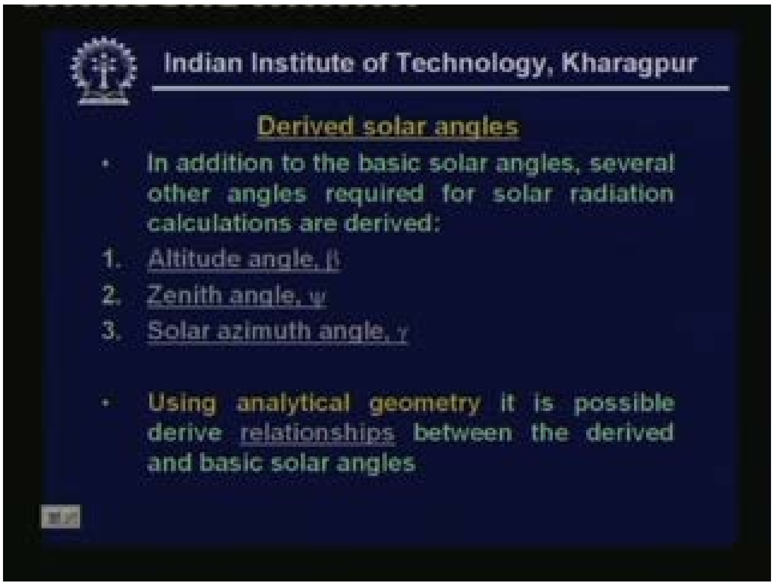
(Refer Slide Time: 00:25:19 min)



So this is an empirical equation for declination okay. Declination d in degrees this is degrees. It is all the angles are in degrees okay. So this is very important keep it in mind okay. So unit should be consistent so declination degrees is given by this empirical equation twenty-three point four seven into sin three sixty into two eighty-four plus N divided by three sixty-five what is N N is the day of the year counted form January first. That means January first n is equal to one January second n is equal to two like that. So December thirty-first n becomes three sixty-five okay.

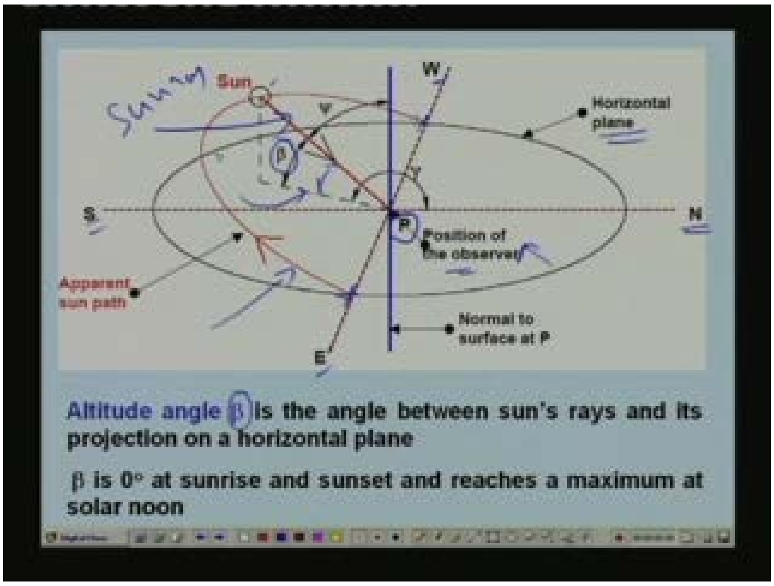
So if you know the day of the year you can easily calculate the declination using this equation okay. And where from this equation you will find that on June twenty-first okay. On June twenty-first you find the declination d is approximately equal to twenty-three point five degrees and on December twenty-first okay. This is equal to minus twenty-three point five degrees okay. For example I want to calculate the declination for March sixth okay. March six happens to be the sixty fifth day of the year. That means N is sixty-five. So all that you have to do is substitute the value of N here. So you will find that the declination on March sixth is minus six point four degrees okay. From the above equation okay so these are the basic solar angles.

(Refer Slide Time: 00:26:46 min)



Now let us look at derived solar angles in addition to the basic solar angles several other angles required for solar radiation calculations are derived first one is what we known as altitude angle. So let us see what is this altitude angle.

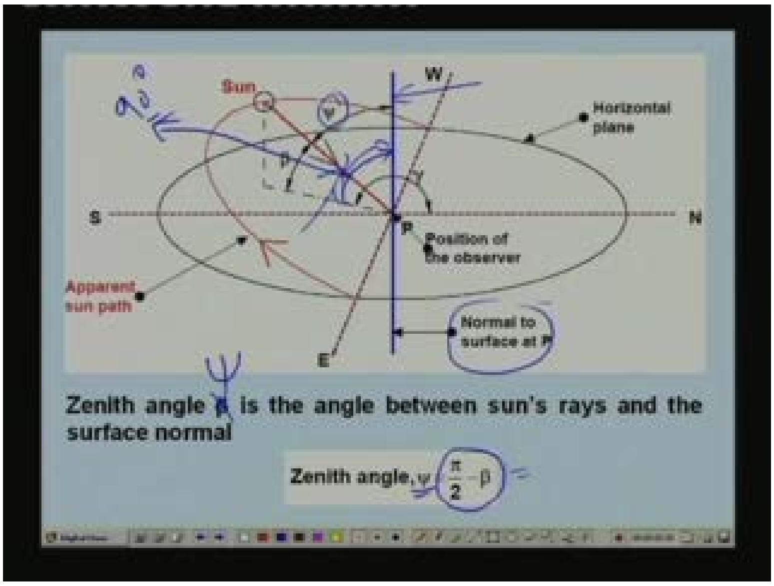
(Refer Slide Time: 00:27:02 min)



Okay, let me explain this figure. Let us say that, this is a horizontal plane okay. So this is the point P is the position of the observer okay. And let this be the north and south sides and this is the west and east sides okay. So you have north south east west right and this is the path of the apparent sun path. That means this is the path of the sun as it appears to the observer who is located at point P. So as you can see that sun rises at this point okay sun rises in the east and follows this path this a this is for a particular day okay. This path is not constant it varies again form day to day, so for a particular day let us say that this is the sun path so it rises in the east and it sets in the west okay. Now with reference to this figure what is the altitude angle altitude angle is given by beta is the angle between sun's rays and its projection on a horizontal plane.

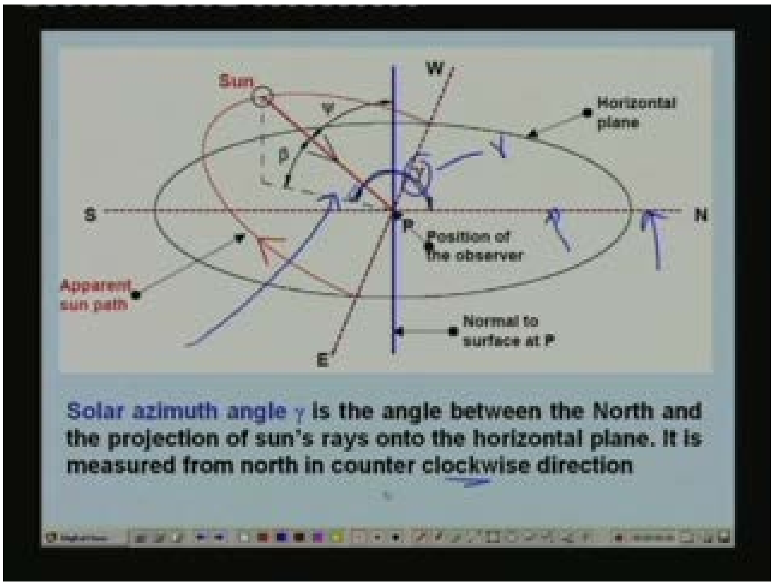
So this is your sun ray this is your sun and this is the sun ray. So beta is nothing but the angle between this sun ray and its projection on the horizontal plane the projection of the sun's ray on horizontal plane is this okay. So altitude angle is nothing but this angle that is beta okay. As you can see that beta is zero at sunrise okay. So at this point the sunray directions of the sun ray and its projection coincides. So beta will be zero similarly beta will be zero at sunset okay. So at these two points beta will remain zero and it reaches maximum at solar noon okay. In fact that is the definition of solar noon at solar noon you will find that the altitude angle is maximum. So this is the first angle the second angle is what is known as zenith angle.

(Refer Slide Time: 00:28:56 min)



So zenith angle I am sorry this should have been psi this okay, zenith angle is given by this symbol is the angle between sun's rays and the surface normal okay sun ray's. As I have again I said this is the sun ray and the normal to the surface at point P is this okay. So the zenith angle is nothing but this angle okay. So this is zenith angle obviously zenith angle plus altitude angle should be equal to ninety degrees okay. So this angle is equal to ninety degrees. That means zenith angle is equal to ninety minus beta. So if you know the altitude angle you can find out the zenith angle easily next important angle is what is known as solar azimuth angle.

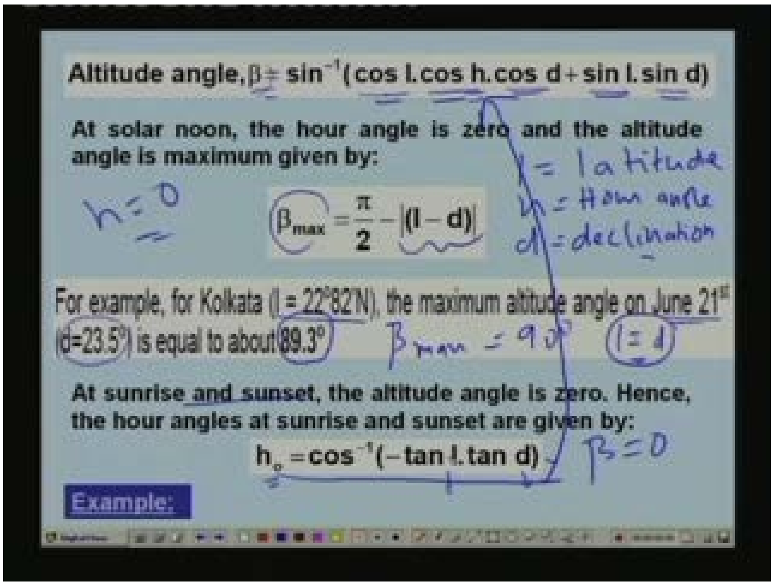
(Refer Slide Time: 00:29:46 min)



Again we refer to the same figure and the solar azimuth angle gamma is the angle between the north and the projection of sun's rays on to the horizontal plane okay. So what is, so as I said this is your north direction okay. So azimuth angle is nothing but this and the projection of sun's rays on to a horizontal plane the projection of sun's rays on to a horizontal plane is this line okay. So the azimuth angle is the angle between this line and this line okay. So as you can see that is nothing but this angle okay. This angle is given by gamma and this is measured in counter clock wise direction of course this varies this convention varies from text book to text book some people define the solar azimuth angle with reference to the south direction okay.

Some people define with reference to the north direction and sometimes it is defined in terms of the clock wise direction from north and in some books. It is defined in terms of anticlockwise direction from the north and in some other books it is defined for forenoon it is in the clockwise direction and for afternoon it is the anticlockwise direction. So the definitions vary but basically once you have this diagram it is easy to understand. And it is easy to change from one convention to the other convention okay. So in this particular lecture I am following the convection of measuring it from the north in the counter clockwise direction okay. So this is the solar azimuth angle gamma now using a analytical geometry it is possible to derive relationships between derived and basic solar angle. This is important the relationships between various angles.

(Refer Slide Time: 00:31:41 min)

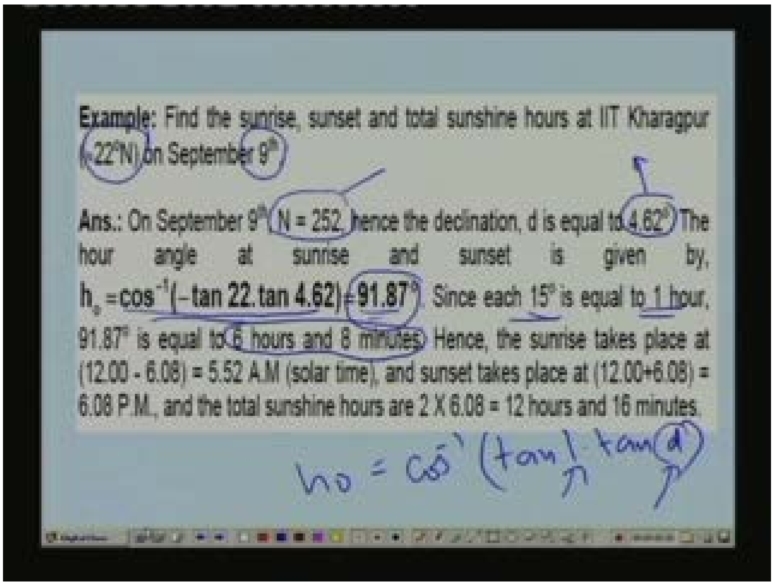


Okay, so altitude angle beta. So beta it can be shown that beta. The altitude angle beta is equal to cos l multiplied by cos h multiplied by cos d plus sin l multiplied by sin d, where l as I have already discussed is latitude h is hour angle and your d is declination okay. So you can see that the altitude angle is simply related to the basic solar angles of latitude hour angle and declination. That means the altitude angle depends upon the, a day of the year time of the day and the location of the point okay. And as we know at solar noon the hour angle is zero that means cos h is equal to zero right.

So when h is equal to zero as you know cos h is one okay. Then you find that the altitude angle is maximum and that value is given by beta max. Beta max is simply equal to pi by two minus l minus d okay. This is your absolute value of l minus where l is the latitude and d is the declination okay. So once you know the latitude and declination you can calculate what is the maximum altitude angle on any given day. For example for Kolkata again take the example of Kolkata for Kolkata the latitude is twenty-two degrees eighty-two minutes north. And I want to find out what is the maximum altitude angle on June twenty-first okay. And as we know on June twenty-first the declination d is twenty-three point five degrees okay. So beta max is nothing but pi by two minus twenty-two point eight two minus twenty-three point five okay.

You have to take the absolute value of that then you will find that this is equal to eighty-nine point three degrees okay. This is the maximum altitude angle is almost close to ninety degrees okay. On June twenty-first for Kolkata and you can see that the beta max is equal to ninety degrees when l becomes d okay. So d as we know is, that means when the latitude becomes equal to declination the beta max becomes ninety degrees okay. Next you, that is another important information that you can get from this equation. That is, that at sunrise and sunset we know that the altitude angle beta is zero okay. So beta is zero at sunrise and sunset. As I have already explained to you so we can find out what is the time of sunrise and sunset using this equation okay, how, if you substitute value for beta zero here you can find out the hour angle at which sunrises and sunsets okay. And that hour angle is given by this expression this is derived from this equation okay. This is derived from this equation by taking beta is equal to zero so h naught is the, at hour angle at which the sunrises or sunsets. That is given by cos inverse minus tan l into tan d where l as you know is the altitude and d is the declination okay let me give a small example.

(Refer Slide Time: 00:35:03 min)

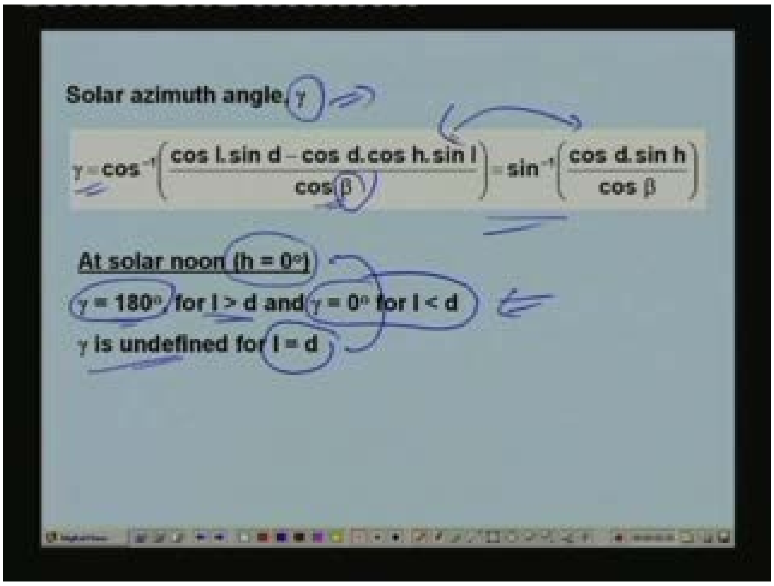


For example I would like to find out the sunrise sunset and a total sun shine hours at IIT Kharagpur on twenty on September ninth okay. So I would like to find at what time the sunrises and the sunsets and what is the total sunshine hour. That means how many hours the sunshine is available at this particular location which has a latitude of twenty-two degrees okay. That means l is equal to twenty-two degrees twenty-two degrees north okay. So first as you have seen h naught from the earlier this thing is tan okay. As you can see from this expression h naught is cos inverse tan l into tan d. So we have to find out what is the latitude you have to find out what is the declination latitude is given as twenty-two degrees. So I have to find out the declination on this particular day September ninth. So all that I need to know is what is the number of the days.

So if you start counting from January first you will find that September ninth happens to be the two fifty second day of the year so n is equal to two fifty-two. So if you substitute n is two fifty-two in the expression for declination you find that the declination angle is equal to four point six two degrees okay. So if substitute four point six two degrees in this expression you find that the hour angle at sunrise and sunset is equal to ninety-one point eight seven degrees okay. Since each fifteen degrees is equal to one hour ninety-one point eight seven degrees is equal to six hours and eight minutes okay. Right, so the hour equivalent to six hours and eight minutes what is the meaning of, this means that the sunrise takes place at twelve minus sixth six point zero eight that is five five point five two hours in the morning this is the solar time and sunset takes place at twelve plus six point zero eight that is six point zero eight pm right.

So sun rises at five point five two am and sunset is six point zero eight pm okay. And both are with reference to solar times and the, so total sun shine hours are nothing but two into h naught two into h naught by fifteen. Let us say since it is not in degree this will give you the total sunshine hours okay. So you can see the usefulness of this equation okay. This is simple and elegant equation can be used to find out at what time the sunrises or sunset at any location on the earth on any particular day okay. And you can also calculate the total sunshine hour this information is very useful in the design of several solar energy equipment and it is also useful in air condition for load calculations okay. So this is the relationship between altitude angle and the basic angles and the usefulness of this equation.

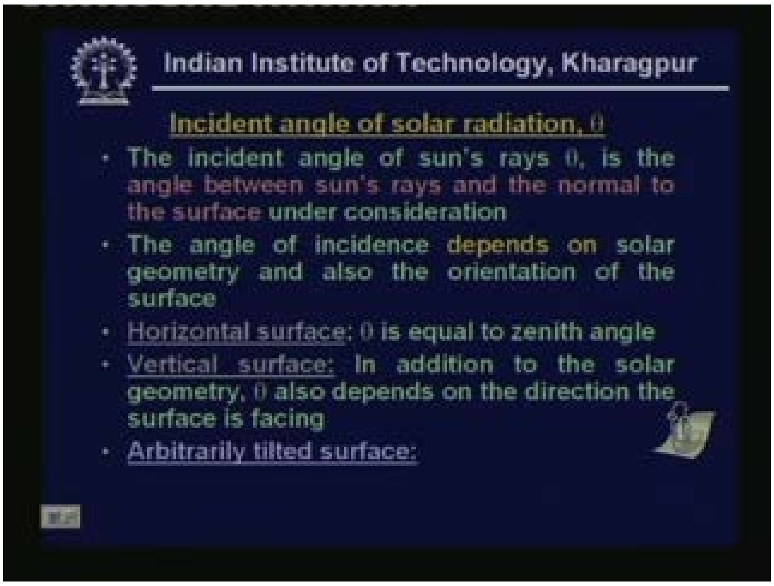
(Refer Slide Time: 00:38:04 min)



Now let us look at the other equation that is the equation for solar azimuth angle in terms of the basic angles. So solar azimuth angle this as I have mentioned is a, as measured from north in a counter clockwise direction right. So that is the if you take that convention, then this is given by gamma is equal to cos inverse cos l into sin d minus cos d into cos h into sin l divided by cos beta. As you know again l is the latitude d is the declination h is the hour angle and beta is the altitude angle okay. So this defined in terms of again. That means this is again a function of the basic angles only because beta is a function of basic angles l d and h right.

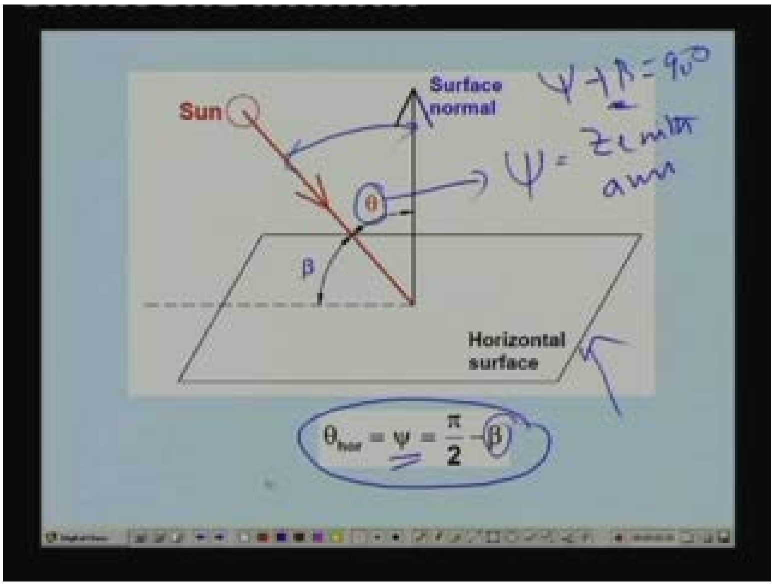
So this you also have an alternate expression. This is also equal to sin inverse cos d into sin h by cos beta these two expression are equal. So that you can easily prove by using your trigonometric relations okay. So this, the relation between solar azimuth and other angles and one important thing to note here is at solar noon. That means when h is equal to zero gamma is one eighty degrees for l is greater than d. That means when the latitude angle is greater than the declination angle. Then we have to take gamma as one eighty degrees and gamma is should be taken as zero degrees for l is less than d okay. So this you must keep in mind okay. So only for solar noon you have to keep this information and a gamma is not defined for l is equal to d at solar noon from this equation okay.

(Refer Slide Time: 00:39:45 min)



Now let us look at incident angle of solar radiation that is theta. So as I have already mentioned the angle incident angle of sun's rays theta is angle between sun’s rays and normal to the surface under consideration the angle of incidence theta depends on solar geometry and also on the orientation of the surface. For example let us look at the horizontal surface theta is equal to zenith angle this can be shown very easily if you look at this figure.

(Refer Slide Time: 00:40:13 min)

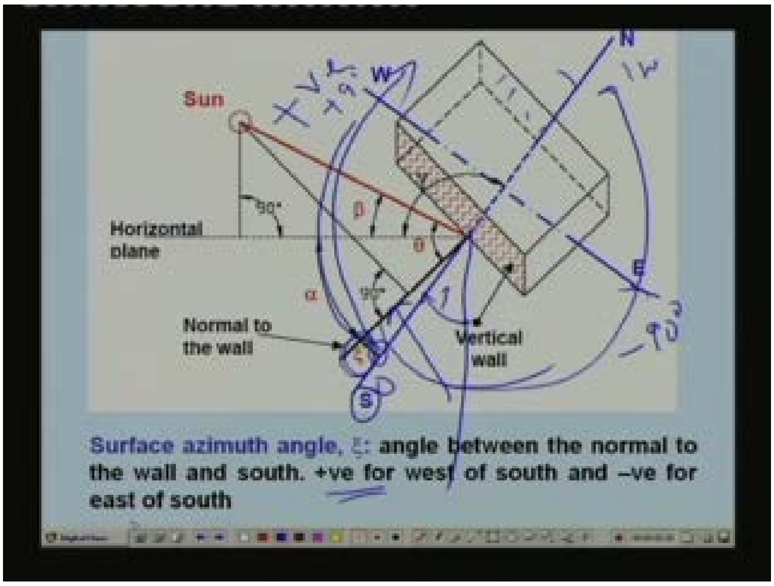


So this is your horizontal surface and by definition theta is your angle of incidence. So which as I said is defined as the angle between the sun's rays and the surface normal okay. Since this is the horizontal surface this is the surface normal and this is your angle of incidence. And it is, so happens that the angle of incidence for horizontal surface is all also equal to your zenith angle okay zenith angle. And as we know psi plus beta is psi plus beta is ninety degree centigrade ninety degrees. So theta is equal to pi by two minus beta okay. So if the surface is horizontal then once you know the altitude angle you can easily find out what is the angle of incidence.

How this information is useful, for example I want to calculate what is the radiation incident on the roof on a flat roof okay. A flat roof means it is a horizontal surface. So all that I have to do is on a particular day at a particular time because it is a function of the time of a day location of the surface and the day of the year okay. So all these things, for these, once you know these things all that you have do is you have to find out what is the altitude angle okay. So calculate the hour angle from the time of the day calculate the declination from the day of the year.

And from the latitude information calculate the altitude angle okay. Once you know the altitude angle the angle of incidence is nothing but ninety minus altitude angle. So you can straight away get the angle of incidence for a horizontal roof okay. Now let us look at vertical surface the calculation of angle of incidence for a vertical surface is little more complicated compared to horizontal surface. Because here in addition to the solar geometry we also have to consider the direction the surface is facing whether it is facing east side or west side or south side these things will come into picture okay. Let me explain that with the help of this picture okay.

(Refer Slide Time: 00:42:14 min)



So in this picture this is the shaded surface is the wall okay, or surface under consideration okay. I want to find out what is the radiation incident on this particular surface okay, which is shaded in red right and this is your south and north direction okay. And the wall is arbitrarily oriented right. So this is north and south this is your east and west directions and let us say that at a particular point on a particular day the sun is at this position. And this is your horizontal plane okay. And this line is nothing but the projection of sun's rays these are the sun's rays' on to a horizontal plane.

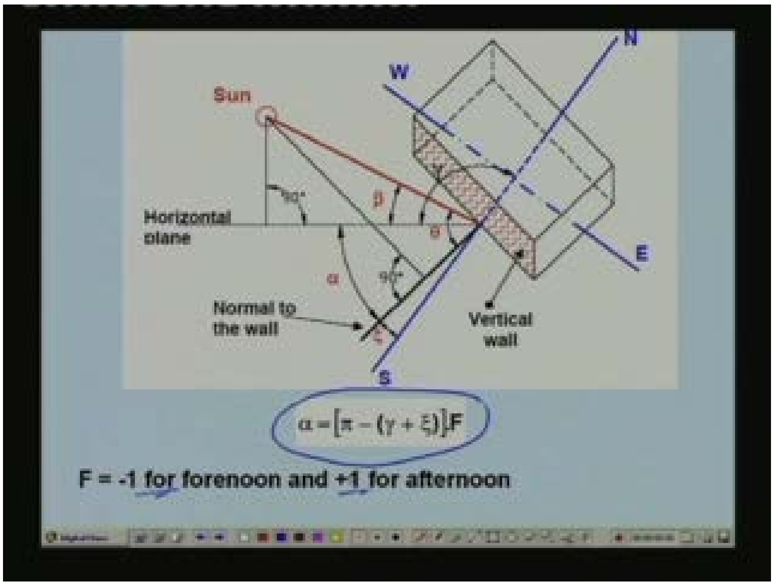
So this is ninety degrees so the, from definition we know that this angle is beta okay, which is nothing but the angle between the sun's rays and its projection on the horizontal plane okay. So we have already defined that angle beta and we also have defined the incident angle incident angle is nothing but the normal to the surface this is your normal to the surface okay. And the sun's rays that means this angle. So we have defined these two angles already that is beta and theta okay. And we have we have also defined solar azimuth angle gamma which is nothing but the angle between north and the projection of sun's rays on a horizontal plane that is this angle.

So these three angles have already been defined. So I introduce here two new angles that is one is what is known as wall solar azimuth angle alpha and the other angle is surface azimuth angle zeta okay. Now first let us look at wall solar azimuth angle alpha wall solar azimuth angle alpha is defined as a angle between the normal to the wall. That means this line this thick line and the projection of sun's rays on to a horizontal plane the projection of sun's ray on to a horizontal plane is this okay. So alpha which is called as wall solar azimuth angle is nothing but this angle that is the angle between the normal and the projection of sun's rays on to a horizontal plane. So that is alpha and I said we have also defined another angle called zeta that is what is known as surface azimuth angle zeta okay. Surface azimuth angle zeta is nothing but this is defined as a angle between the normal. That mean this line this thick line normal to the wall and the south is this okay.

So for this particular picture the picture I have taken in this is your zeta if the normal is somewhere here. Let us say then the zeta becomes this. That means zeta is always defined with reference to the south direction and the normal to the surface okay. The normal to the surface obviously depends upon the orientation of the surface and the direction in which the surface is facing okay. And the convention here is that it is taken as positive for west of south. That means all for all these direction this is the south so of on all these directions you take zeta as positive okay.

That means zeta varies from zero degrees when it the normal coincides with the south to one eighty degrees when it coincides with the north okay. That means, for this one it is one eighty degrees and a in this direction if it is facing in this direction it varies from again zero to one eighty degrees through a negative this thing. That means this become for example if you take east is minus ninety degrees okay, whereas west is plus ninety degrees okay. Similarly by if you consider let us say southeast okay south east is minus forty five degrees whereas southwest is plus forty-five degrees okay. Like that, so if you know the orientation of the surface you can easily find out what is the value of zeta and remember the convention followed that is positive for west of south and negative for east of south.

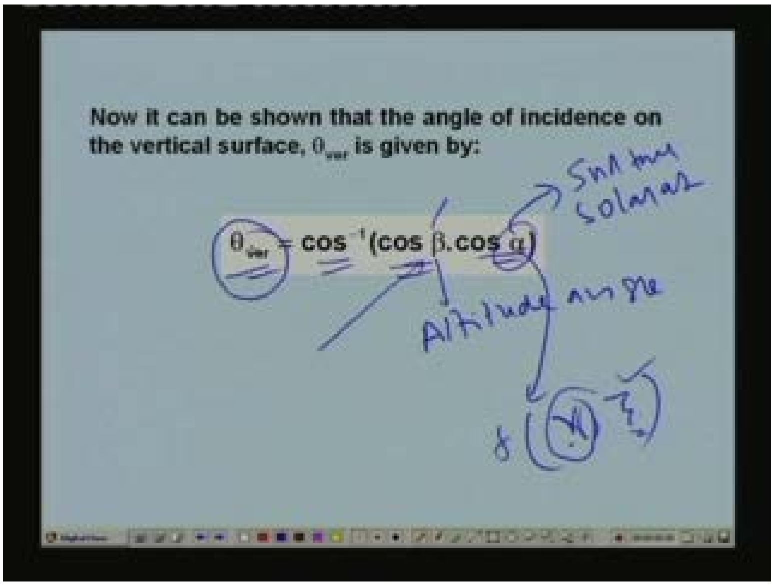
(Refer Slide Time: 00:46:07 min)



Now you can find a relationship easily between alpha that is surface solar azimuth or wall solar azimuth angle alpha. And the solar azimuth angle gamma and surface azimuth angle zeta okay. So if you look at this picture this is one eighty degrees this total angle okay, is one eighty degrees. So one eighty degrees is equal to gamma that means this angle plus alpha that mean this angle plus zeta okay, for this particular case. So for this particular case which happens to be the afternoon because the sun is towards the west okay. It has crossed the solar noon okay. So this example is for after noon right for afternoon you find that gamma plus alpha plus zeta is equal to one eighty degrees okay. That means alpha is equal to one eighty minus gamma plus zeta right.

Now for forenoon the sun will be on this side towards the south okay. Sun will be somewhere on this side then you will find that gamma is equal to one eighty plus alpha plus zeta okay. In such case you'll find that alpha is given by one eighty minus gamma plus zeta into minus one okay. So that is why you have given this equation. Now this is the relationship alpha is equal to F into pi minus with in brackets gamma plus zeta where F takes the value of minus one for forenoon and plus one for afternoon okay.

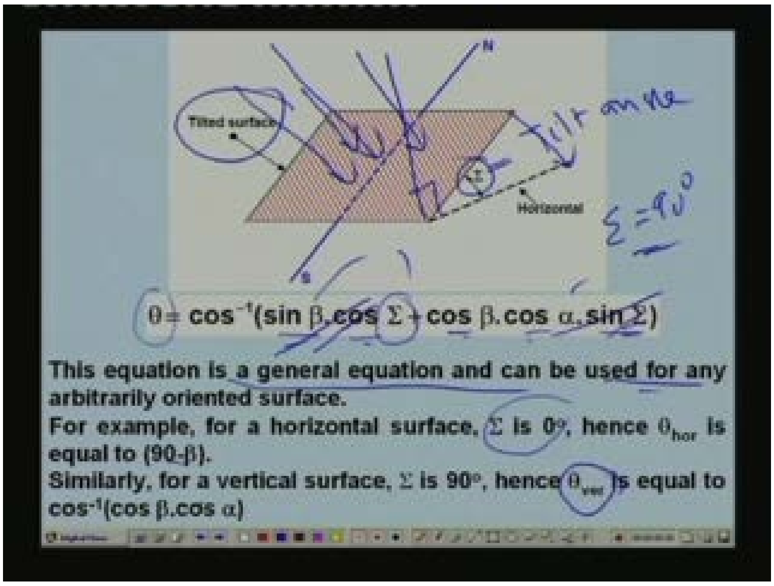
(Refer Slide Time: 00:47:52 min)



Now it can be shown that the angle of incidence because ultimately this is what is important to us on a vertical surface is given by this relation theta vertical is equal to cos in inverse within brackets cos beta into cos alpha cos beta. As you know is, altitude angle and alpha is your surface azimuth surface solar azimuth angle okay. And the expression as you, this you have seen is the function of your gamma and zeta right. So if you know the orientation that means oriental surface zeta and I should know beta and other angles you can find out gamma. So from gamma and zeta you can find out alpha and from your basic latitude hour angle and declination you can find out beta. And from this information you can find out what is the angle of incidence on a vertical surface theta vertical and where do you use this information. This information is required to find out what is the solar radiation incident on a vertical wall okay.

So both horizontal orientation and vertical orientation are very frequently encountered in air conditioning calculation. Because many most of the buildings will have horizontal roofs and all the buildings generally have vertical walls okay. So you have vertical walls and horizontal roofs. So you have to use these two expressions for finding the angle of incidence of solar rays okay. Now let me give a very general expression for arbitrarily tilted surface okay. Any surface it can be horizontal vertical or tilted for this arbitrarily tilted surface.

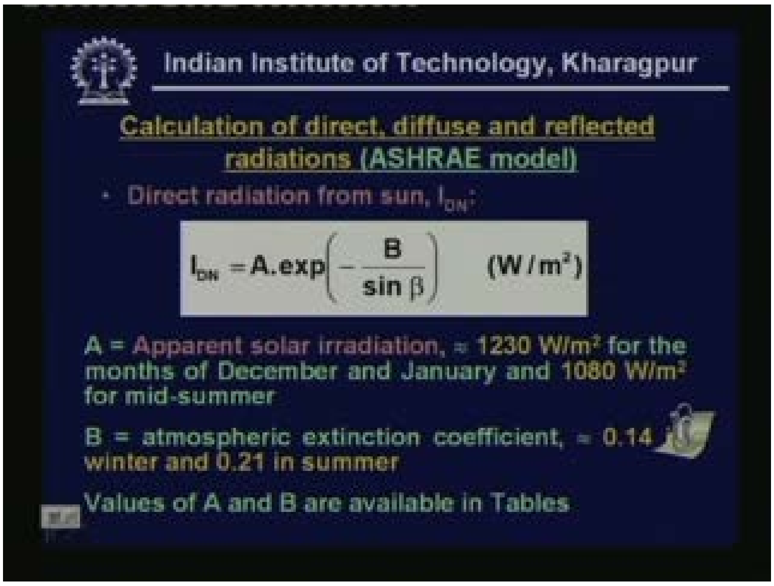
(Refer Slide Time: 00:49:34 min)



It can be shown okay. First this is arbitrarily tilted surface and here we define another angle called as tilt angle okay. That is sigma this is a tilt angle okay. And this is the surface which is exposed to your solar radiation okay. So solar radiation is falling on this surface right, so tilt angle is nothing but the angle between the horizontal and the surface okay. That you can see here and it can be shown that the angle of incidence on any arbitrarily orientated surface is given by theta is equal to cos inverse sin beta into cos sigma plus cos beta into cos alpha into sin sigma okay.

So in addition to your beta and alpha you also should know what is the angle of tilt in order to calculate the angle of incidence of sun's rays on any surface okay. As I said this is a general equation and they can be used for any arbitrarily oriented surface for example for a horizontal surface this tilt angle becomes zero right. Because this coincides with this it comes here so sigma is equal to zero once sigma is equal to zero this vanishes and this becomes one. So you will find that theta is nothing but ninety minus beta okay. So this as simplifies down to this expression and for a vertical surface sigma is equal to ninety degrees for vertical surface. Because this surface becomes like this okay, ninety degrees. So when sigma becomes ninety degrees cos sigma becomes zero. So you will not have this term and sin sigma is one. So it can be you can easily find that theta vertical is equal to cos inverse cos beta into cos alpha okay. So if you remember the expression for the tilt angle on any arbitrary oriented surface then you can simplify it to other surfaces like vertical or horizontal surfaces okay.

(Refer Slide Time: 00:51:33 min)

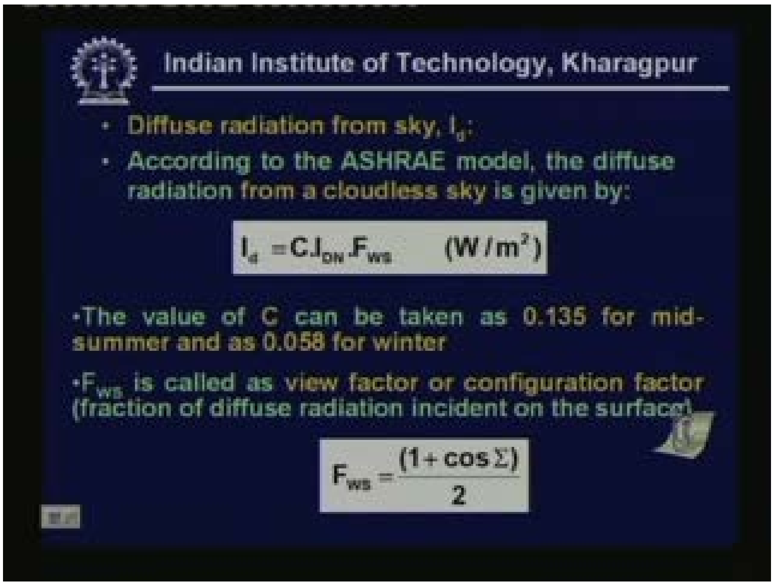


Okay, so calculation of a angle of incidence is one major part of a solar radiation calculations okay. So once you calculate that is required because you want to calculate what is the radiation incident on a surface but in addition to the if you remember your earlier expression in addition to the angle of incidence. We also have to find out what is the direct radiation what is the diffuse radiation and what is the reflected radiation several models are available several solar radiation models using which you can find out direct diffuse and deflected radiations in air conditioning calculations.

Normally we use what is known as an ASHRAE model this is the model suggested by ASHRAE based on their data okay. The data collected by ASHRAE and they are fitted empirical equations to their data and they have suggested certain correlations for estimating these radiations okay. So this is a very popularly used model as far as air conditioning calculations are concerned okay. So in this lecture I will discuss ASHRAE model. So first look at direct radiation direct radiation from sun is given by I subscript capital DN that is equal to A into exponential within brackets minus B by sin beta and the units are watt per meter square here A is what is known as apparent solar irradiation. And it takes the value of twelve thirty watt per meter square for the months of December and January. That means basically for winter in winter air takes a value of twelve thirty watt per meter square where as during summer.

That means during say may June July air takes a value of about ten eighty watt per meter square okay. So if you want to do the solar radiation calculations for winter you can take a value of twelve thirty for air whereas for summer you can take a value of ten eighty and the constant B is known as atmospheric extinction coefficient and it take a value of point one four in winter and point two one in summer. So if you know the values of A and B then you can calculate I direct radiation of course you also have to know the altitude angle beta okay. Because here sin beta is there so beta is the altitude angle. So from the knowledge of altitude angle and A and B you can calculate the direct radiation on a surface and the values of A and B are available in tabular form when ASHRAE gives the values of A and B for each month. And they calculated this fro twenty first day of each month and these values are tabulated and they are available on ASHRAE handbooks okay.

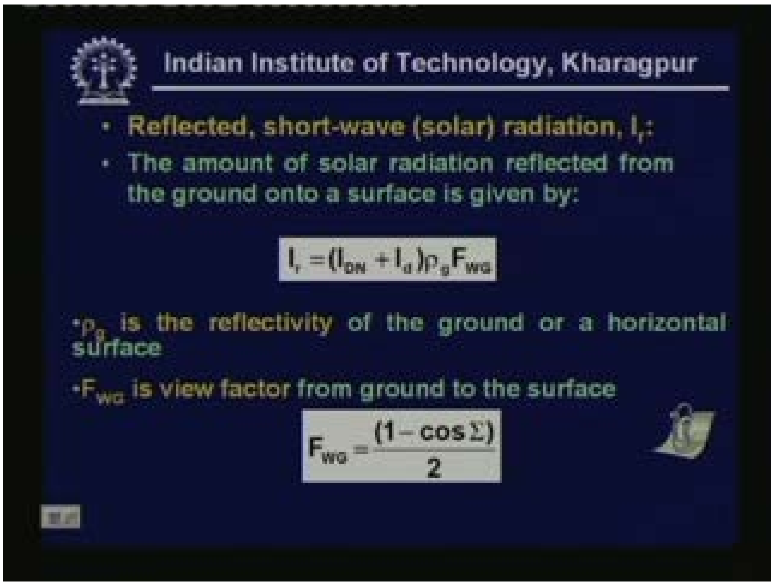
(Refer Slide Time: 00:53:58 min)



Next comes your diffuse radiation from sky diffuse radiation is I subscript d and according to the ASHRAE model the diffuse radiation form a cloudless sky is given by id they relate this to the direct radiation. And what is known as an angle factor. So id is equal to C multiplied by I subscript DN multiplied by F subscript WS where C is a constant. And it can be taken as point one three five for midsummer and point zero five eight for winter okay. And F subscript WS is called as view factor or configuration factor and this is nothing but the fraction of diffuse radiation incident on the surface. Here I would like to tell one thing this ASHRAE model assumes that the sky is cloudless okay.

The, that means the calculations are strictly valid for a cloudless sky this is this assumption is required. Because this model is based on the assumption that the diffuse radiation arrives at the surface uniformly okay. It you it arrives at the surface uniformly this is valid only when the sky is cloudless if the clouds are there in the sky then the diffuse radiation will not be uniform okay. And this factor as I said the view factor is nothing but the fraction of diffuse radiation incident on the surface. And it can be very easily shown that F subscript WS that is the view factor is equal to one plus cos sigma by two where sigma is the tilt angle defined earlier. So for a horizontal surface the tilt angle is zero so the view factor is equal to one that means it sees all the radiation it receives all the diffuse radiation whereas for a vertical surface sigma is equal to ninety degrees. So cos sigma becomes zero and the view factor becomes point five. That means the vertical wall receives only fifty percent of the diffuse radiation from the sky whereas the horizontal surface receives all the radiation from the diffuse radiation of the sky okay.

(Refer Slide Time: 00:55:47 min)



And the values of cr again available in tabular form finally we have this reflected short wave radiations from the ground or from the surrounding surfaces. The amount of solar radiation deflected from the ground on to a surface is given by Ir is equal to IDN plus Id. This is nothing but direct radiation plus diffuse radiation multiplied by rho g multiplied by F subscript WG where rho g is the reflective of the ground which depends upon the surface nature of the ground. Or a horizontal surface and F subscript G WG is what is known as view factor or configuration factor from ground to the surface okay. Again by definition this view factor is nothing but how much fraction or what fraction of the reflected radiation is received by the surface okay.

If the surface does not receive any of the reflected radiation then its view factor is zero if it receives all the radiation then its view factor is one right and it can be easily shown that FWG is equal to one minus cos sigma by two where sigma is equal to tilt angle. As you know and for a horizontal surface facing upwards sigma is equal to zero okay. So sigma is zero means your view factor is zero whereas for a vertical surface sigma is equal to ninety degrees. That means view factor is point five okay. So this is how using the ASHRAE model you can calculate direct diffuse and reflected radiations from the known data okay. Once you know these things and once you know the angle of incidence you can calculate the total radiation incident on any surface okay. At this point I conclude this lecture and I will give an example on how to calculate the radiation in the next lecture.

Thank you.