**Sustainable Material and Green Buildings**
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**Lecture 32**
**Urban Heat Island: Radiation Concepts**

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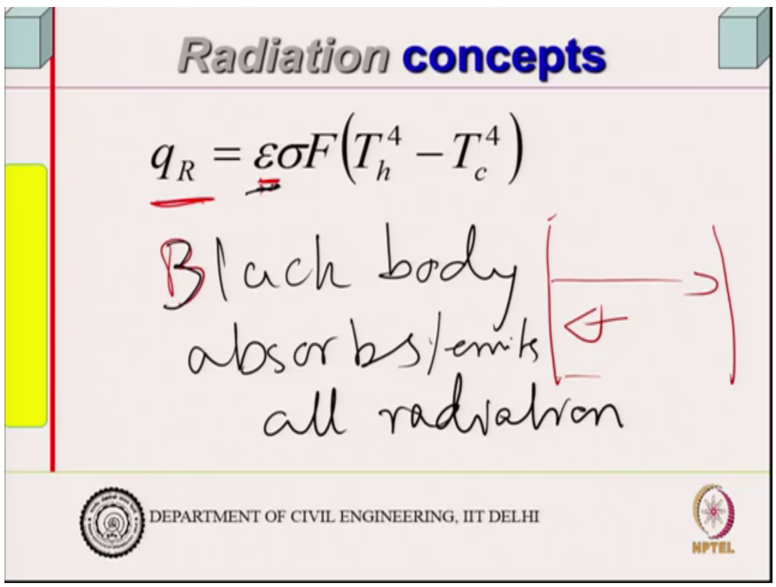


So welcome back. Now we will look into urban heat island right. Now to understand that first we must understand a little bit of radiation concepts which some few might be familiar, some you may not be. So radiation heat flux is written in this manner, there is a heat exchange between two surfaces per unit area, this will be in terms of watt per meter square, is given by equivalent emissivity of the two surfaces. For example, if I have two surfaces, supposing I have two surfaces, one like this another like that, So radiation heat exchange between these two surfaces is governed by equivalent emissivity of the two surfaces.

Now what is equivalent emissivity? Every surface has got you know it can absorb heat and once heated up it will radiate right. Everybody have this, if you supply energy to it, it will absorb and it will radiate if it is at higher temperature. So heat transfer from higher temperature to lower temperature takes by radiation which does not require any medium, which does not require any medium. Now a perfect black body is one, a perfect black body is one, you know a perfect black body is one which absorbs black body absorbs everything all radiation right.

So whatever energy comes it radiates, then when it emits it will also emit all radiation absorbs or emits all radiation. So but others bodies, other surfaces they absorb some therefore emissivity is a unitless, dimension less term.

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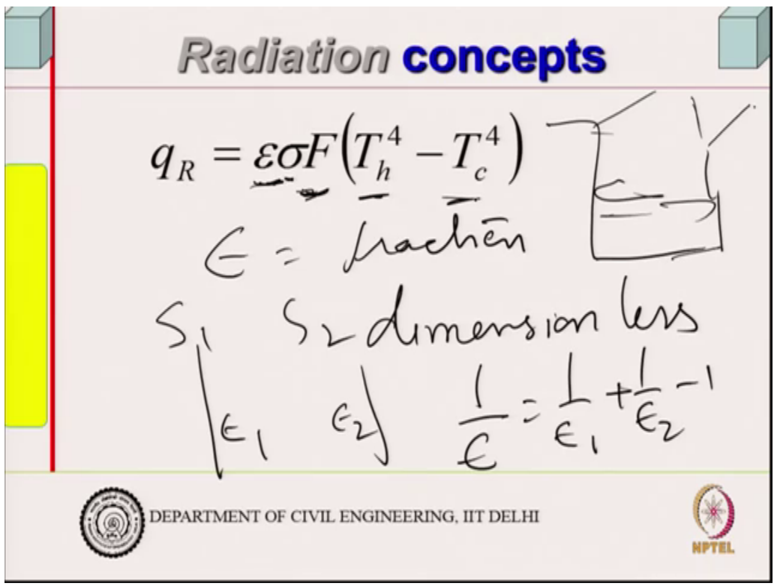


Which is basically epsilon is dimensionless term, the emission at a given wavelength by the body under consideration that divided by that of black body, perfect black body. So this is a fraction, fraction dimensionless. Now we did talk of two surfaces, one surface, surface 1 , surface 2 this has got epsilon 1, let us say this is epsilon 2. So 1 by epsilon the equivalent emissivity is given as 1 by epsilon 1, plus 1 by epsilon 2 minus 1. Emissivity of equivalent emissivity of these two surfaces are given by this equation right. So radiation heat flux is governed by equivalent emissivity of the surfaces this is Stephens Boltzmann constant because this is Stephen Boltzmann law and this is called configuration factor.

The surfaces as they see each other, for example if I surface like this you know its a surface 1 surface like this and there is another surface something like this and they see each other fully, then this value will be 1, face to face and they you know same area, so it is 1. But if it is inclined, if it is inclined then projection of 1 will be there on other. So f value will be plus, you know f value will be different, f value is the what you call configuration factor or it what one surface is the you know portion of what its sees or projection of one surface into the other.

And this is a temperature of the hot body in Kelvin and this is a temperature of the cold body in Kelvin, So that is the radiation heat exchange right. There is a radiation heat exchange I am not sure whether I told you this earlier.

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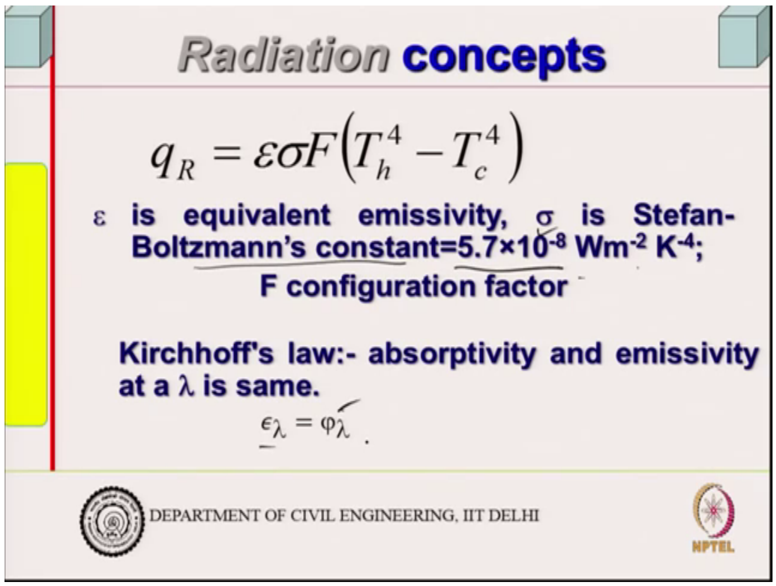


So Stephens Boltzmann law is like this, epsilon is equivalent emissivity, sigma is Stephen Boltzmann constant and this 5.7 into 10 to the power minus 8 watt per meter square and Kelvin minus 4 and this is called configuration factor right. So, Kirchhoff's law relevant to radiation concepts is absorptivity and emissivity at a lambda is same. Now if we denote this as the absorptivity and this emissivity because whatever it absorbs at same wavelength it will emit as well right.

A perfect black body does that and we are talking in terms of emissivity as the ratio of the energy emitted at a given wavelength by the body under consideration that divided by that of the perfect black body, so this is what it is right.

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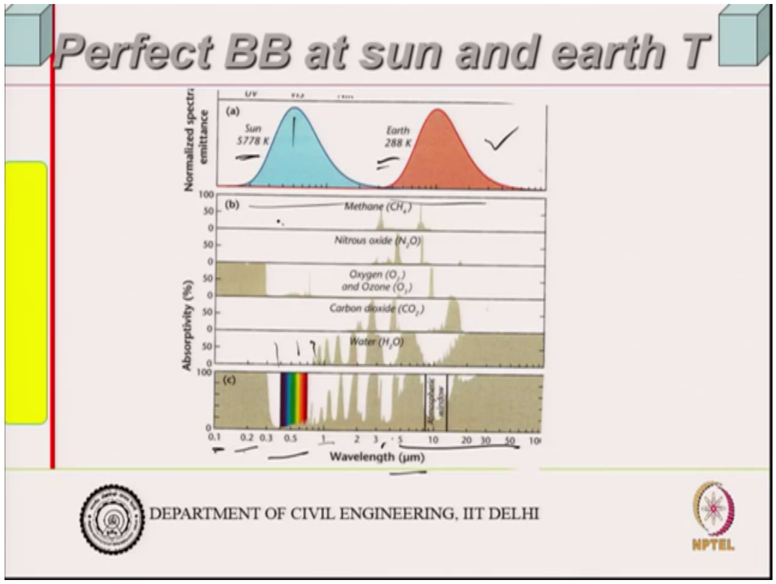


So if you look at consider sun as a perfect black body and earth as a (perfect black body) at different temperatures you know at their temperature, earth is the temperature, so you find sun is at 5778 Kelvin, the wavelength it radiates belong somewhere to this, these are in microns so 0.12 this you know so these are spectrum. And this is of the earth because the quality of radiation or the wavelength of the radiation is a function of temperature at which the body radiates. For example, you can understand this very easily, you take Iron and heat it up, heat up to that temperature when it becomes red rod and further heating it will be white.

That means it is radiating wider you know spectrum of wavelength when it becomes white, if you cool it, it is red that means its only radiating red wavelength corresponding to red color and still cool it its color is nearly iron black color, I mean iron you know normally that grey black color of the iron but it is still hot. So it is radiating only the heat radiation. So this is the quality of radiation is a function of temperature, quality of radiation is a function of temperature.

Now earth we are assuming that is around 25 degree Centigrade, 288 Kelvin. So the radiation quality of radiation is long wave radiation, so this is long wave radiation, this is long wave radiation, this has got short wave radiation out of which there is a small portion which is visible right. And this small portion where I have the peak again you know, so this is visible range, this visible range beyond that ultraviolent and infrared heat radiations are also there. But here it is all heat radiation at 288 Kelvin right.

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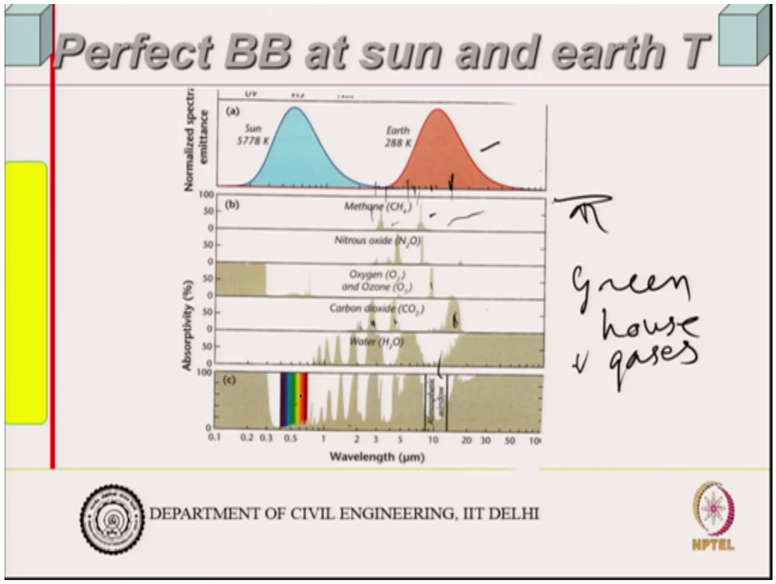


Now this shows, this part shows absorptions by Methane, because earth radiates in the nocturnal sky where sun is not there, radiation heat exchange between the earth and outer cosmos right and the methane absorbs most of this radiation, methane absorbs most of this radiation right at this level you know this is a peak, this is a peak as you can see there. Then if you look at nitrous oxide it is somewhere here, oxygen somewhere there, carbon dioxide you see it is quite a bit of big spectrum, good lot of heat absorbs, heat absorbs here and this also absorbs and this is also absorb and this is also you know it absorbs this, so it is a biggest spectrum.

And water vapor, so these are the greenhouse gases, these are the greenhouse gases, so these are greenhouse gases right. So they absorb you know, they absorb that is what they absorb actually most of this. Now if you will see this is absorptivity, these values are absorptivity right, so this is why you know these are the greenhouse gases which absorbs quite a bit of them and atmospheric windows through which actually it goes out this are the absorptions majority of it gets absorbed by the earth and so on. This is the visible portion and so on. So that is why you know now you get the better idea what is greenhouse, you know which and why they are greenhouse gases and the spectrum in which they actually absorb.

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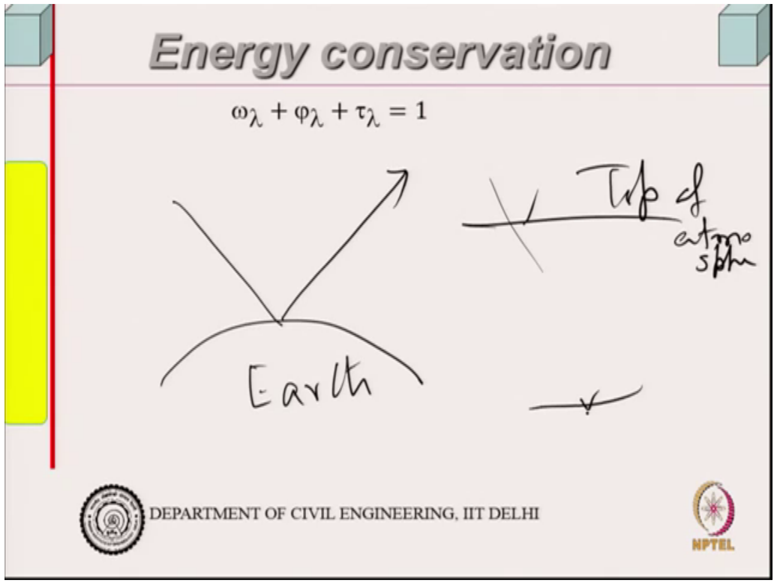


Now, ofcourse earth energy balance I think I might have talked to you sometime earlier or may not have but whatever is received by earth you know in a year it must go out. Whatever is received by earth in a year should go out. Actually 50 percent of it goes away straight from the you know, so if this is a top of atmosphere, top of atmosphere 50 percent of it does not reach the surface and I think I might have mentioned this earlier, this 50 percent over the year also goes out, some by evaporation, some by radiation, some by combustion to the upper layer and those. So heat balance of the earth is like that right but then absorption if occurs by those ones then they will trap it, okay. So but today we are not talking much about that.

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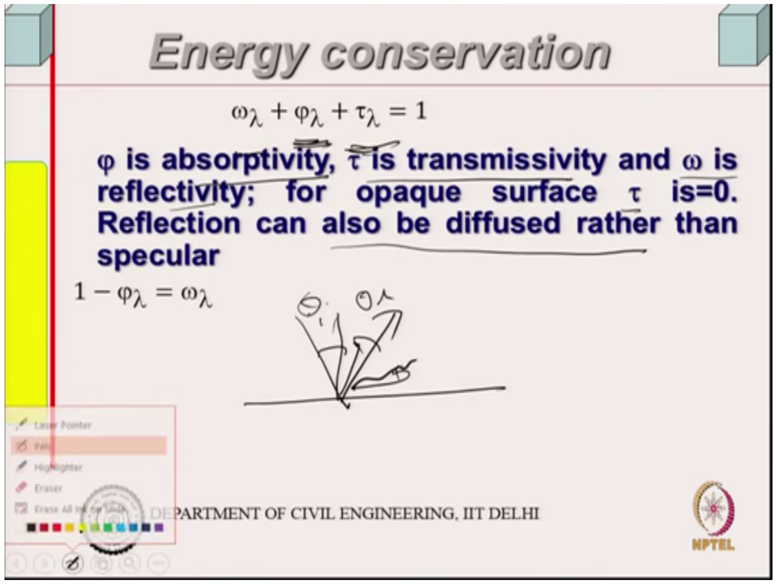


So let us say, now this is if we pick any of surface if it is transparent it will transmit some they are all fractions, reflect some and absorb some. So at a given wavelength any body transmission, absorption and reflection, refractions because absorptivity is defined as the fraction of energy absorb divided by total energy incident upon it. Reflectivity is defined in a same manner, fraction of energy reflected back right divided by energy you know incident and this is transmitted. So a transparent body ofcourse will transmit, so this is a sum total.

So this is absorptivity, this is transmissivity and this is reflectivity. For opaque surface t tau is 0, for opaque surface no transmission would occur. Reflection can also be, okay so this is what it is. Now this what we call as specular reflection, you know angle of incident theta, incident theta r these are same, this is related to specular reflection, this is related to specular reflection. But if it is diffuse reflection it will go in all direction, so reflection can also be diffused, reflection can also be diffused actually, okay.

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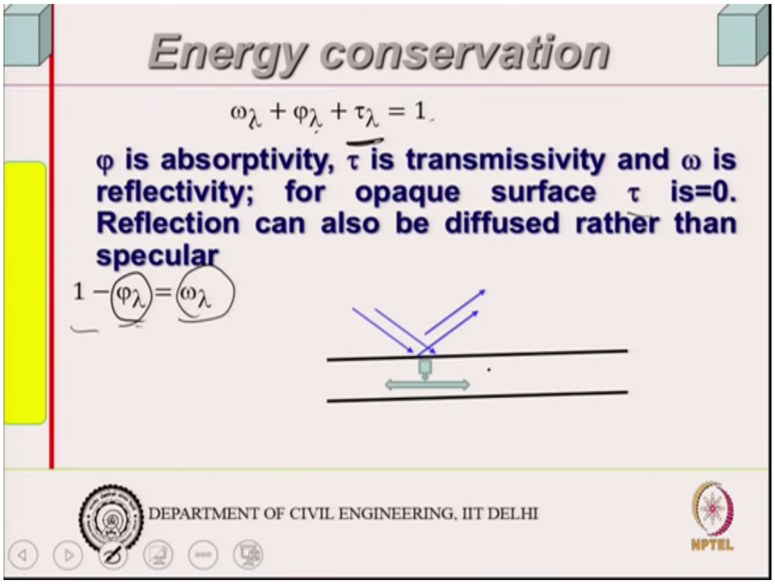


So 1 minus if it as opaque body this would be 0, this term would be 0 then these 2 sum must be equals to 1. So 1 minus this is equal to, 1 minus absorption must be equals to, 1 minus absorptivity must be equal to reflectivity we will use them later you know. So this is what it is whatever is coming in a body part of it is reflected, part of it is absorbed, part of it is absorbed and this is a sum total.

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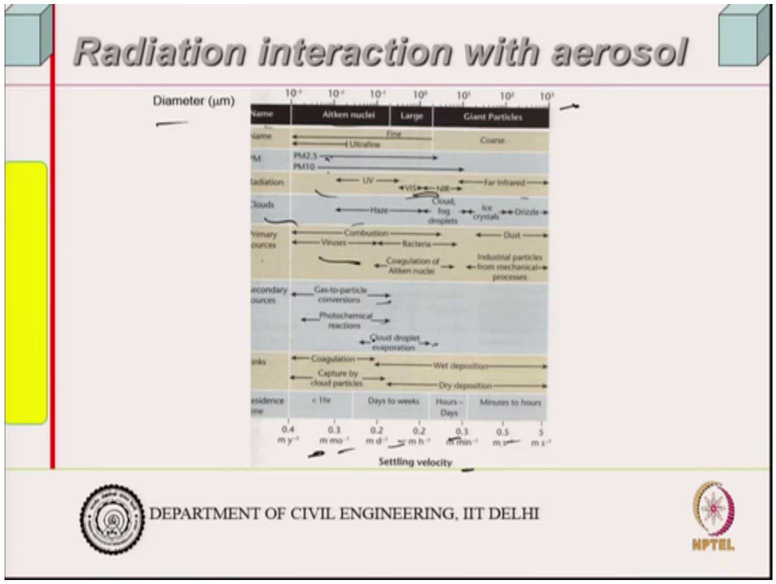


Now aerosol in the atmosphere, they are fine particles are spreaded in the air, you know air can have colloidal solution. So this you know solutions colloidal solutions, solution means what? Particles are of sufficient in small size and if there is a uniform solution you pick up from one portion, pickup from another portion you will find concentrations are similar, right if it is uniform solution. Suspended suspensions are larger sizes or colloidal solutions are larger sizes. So they are not exactly, you might find in a colloidal suspension concentration is more of solids let us say in water soil and water you make a turbid solution you find more particles at the lower level then at the higher level, so they try to settle.

So in air also same thing will happen particle can remain at suspension, so if you look at diameter in microns the equivalent Aitken nucleus they call it name right. So 10 to the minus 3 micron these are in microns to 10 to the power 3 microns which means 1 millimetre. So we are looking at these sizes, so this is a cloud then various combustion sources particles secondary, sources, gas particle, photochemical reactions, cloud droplet etc-etc. And there we have got settling velocity.

So particle size smaller than 2.5 micron, 10 micron you know and their settling time if you see less than an hour and some which are large particle they can be, they can take longer time too much longer time to days and weeks and hours to solute. So therefore radiation absorption is also there this one absorbs the radiation. For example, this range ultraviolent radiations are absorbed, in this range far infrared radiation are absorbed visible you know to a near infrared they are absorbed in this particles absorbs this. So particles also absorbs this (aero) you know the aerosol particle absorb this right. And they transmit them some to the outer cosmos and some to the ground right. So that what it is.

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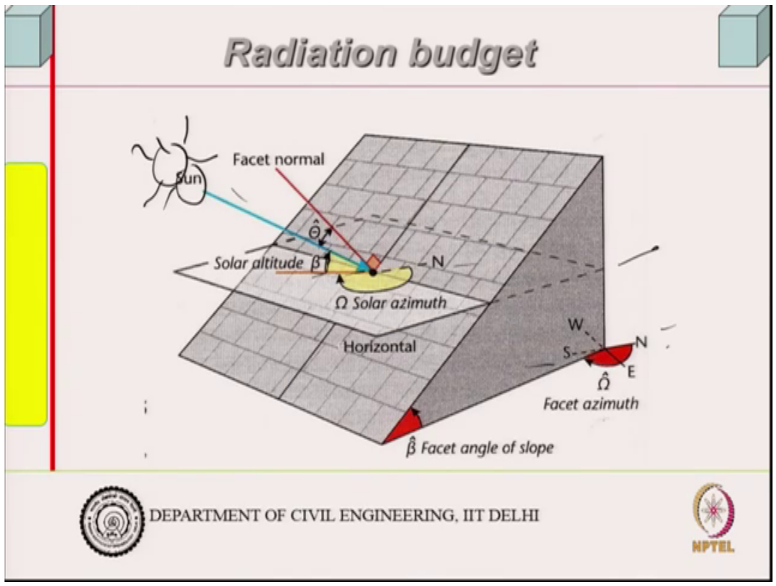


So they interact, now just to recollect some of you might have already done a course you know earlier building science of somewhere, you might have come across little bit of radiation issues. Supposing but then here you will be using this here as well as later on also may be. So to define certain angles, now this angles are first of all this is altitude angle, this is, this is altitude angle of the sun. So if I have the surface this is normal to the surface, sun's radiation, sun is somewhere here, sun is somewhere here sun's radiation come into the surface this angle we call it solar altitude angle, that is normal to the surface.

The angle the sun ray make with the normal to the surface this we call as altitude angle right and right altitude angle. So solar altitude angle normal we know this is a, this is a projection this is the normal to the surface is projection to the horizontal plane is this. So altitude angle is the angle between sun ray and projection of the normal to the surface on another surface, on horizontal surface. So that is this altitude angle right and this is called we call incident angle. Incident angle is a angle between normal to the surface and sun ray right, normal to the surface and sun ray. Now sun's position is defined by two angles, one is its altitude angle, another is azimuth angle.

Azimuth angle one convention and more commonly used convention is this, take geographical north and this is the ,you know this is a sun ray projection on to the horizontal plane, this angle we call as solar azimuth, this angle we call as solar azimuth. So you know this is the north direction, this is the north direction as shown here south, east, west an all that right. So this is a azimuth, solar azimuth, solar azimuth angle is the angle made in the horizontal plane from a reference line to the projection of the sun ray on to the on that plane. So this, this is diagrammatically these are like this

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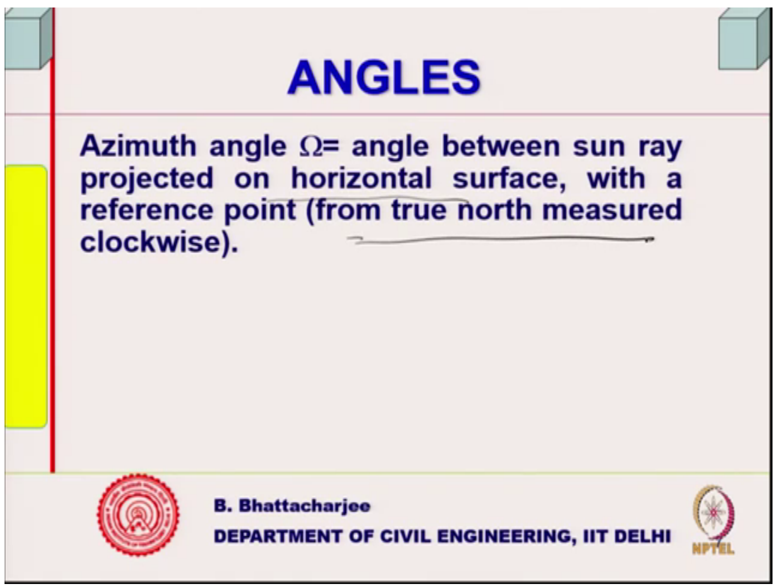


And if I write them out, so azimuth angle is angle between sun ray projected on horizontal surface with a reference point. Usually from north measured clockwise. So now from north measured clockwise.

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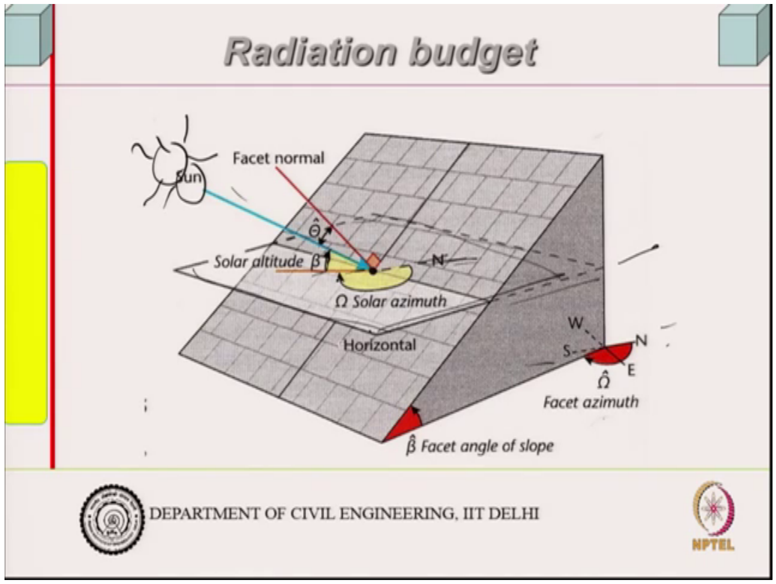


North measured clockwise, so this is the horizontal, surface this is the horizontal surface, this is the horizontal surface, this is in the horizontal surface this is the north direction, so from here to this we call as solar azimuth angle, solar azimuth angle right.

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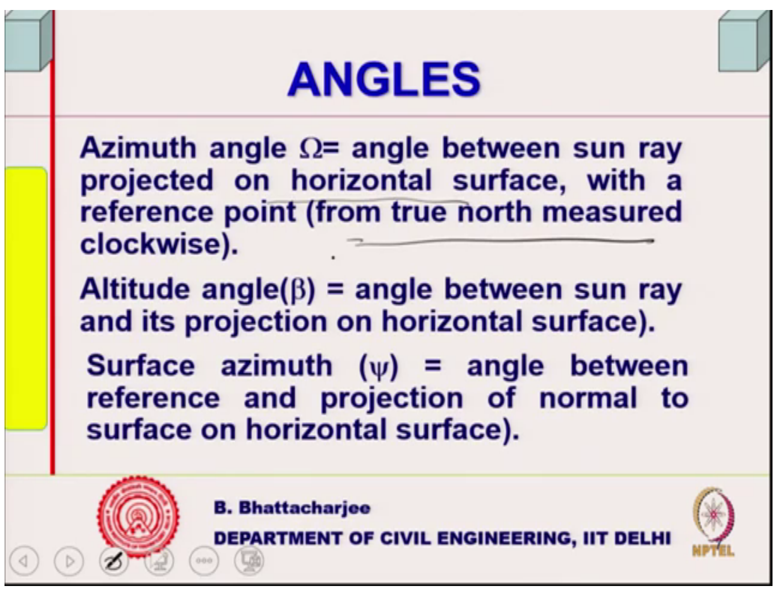


So measured clockwise, then altitude angle, angle between sun ray and its projection on horizontal surface, angle between sun ray and projection of, so this is the projection of the sun rays on to the horizontal surface and this is the sun ray, so this is your altitude angle, okay. There are some more angles all though I may not be using them surface azimuth, if you want to measure the surface azimuth which I may not require here but this angles I just taught so let there be their definition.

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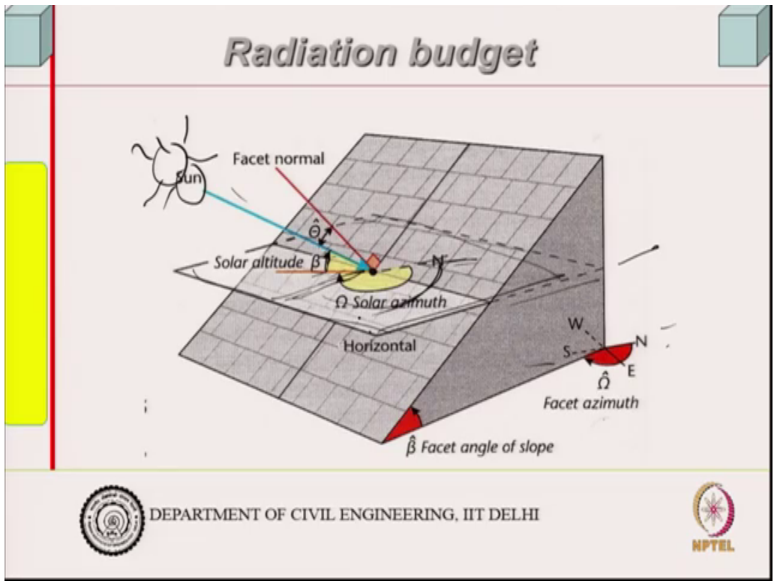


Supposing this is the normal to the surface if I project it on to the ground I will get some, some line you know some lines somewhere there. If I project this line, this is the projection of the sun ray here, projection of this line here so this angle I will call as surface azimuth. Azimuth of the surface normal to the surface projected onto the horizontal plane angle between that and the north direction measured clockwise we call it surface azimuth or in case of a wall I will call it wall azimuth.

For horizontal surface obviously this angle is not really relevant because normal to the, it will be normal to the surface it will be vertical and its projection on to the ground will be simply a poin, so that will be 0.

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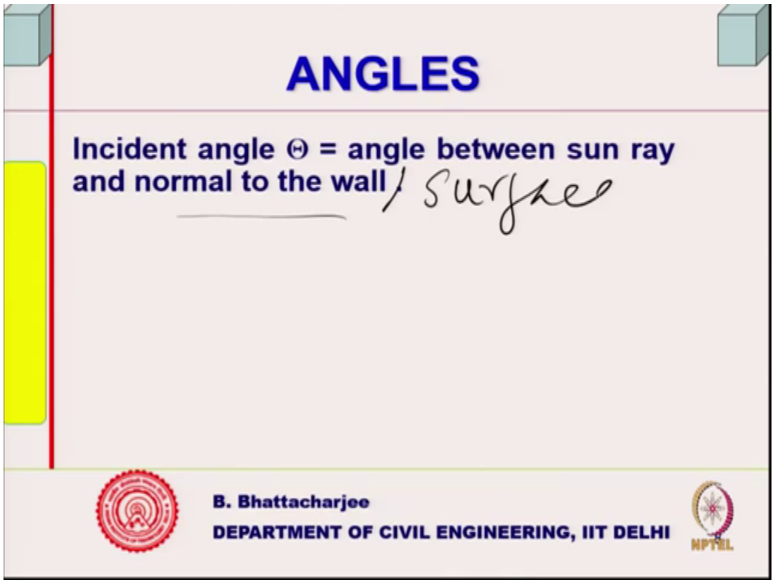


Then we define incident angle right, incident angle is the angle between the sun ray and normal to the wall or surface. So if you see this, this is what I defined, this is what I defined.

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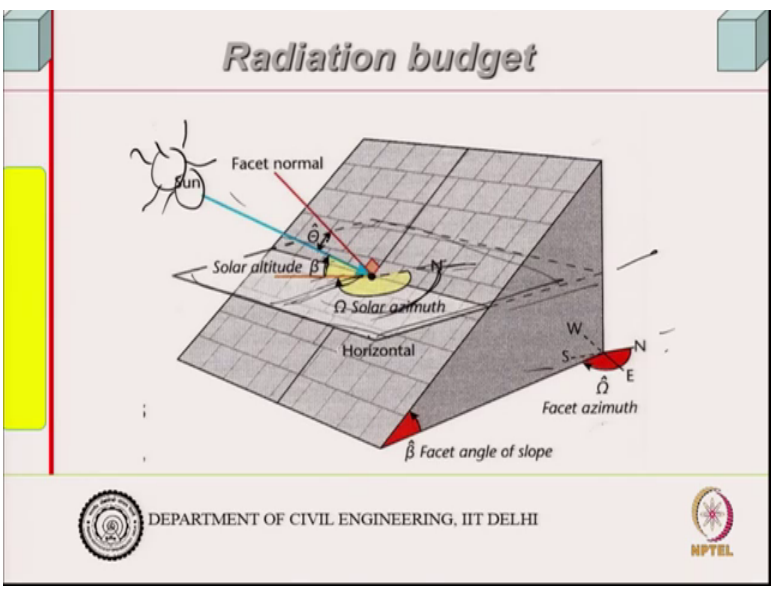


This is angle right, normal to the surface and sun ray that is incident angle, so this is incident angle right, this is incident angle.

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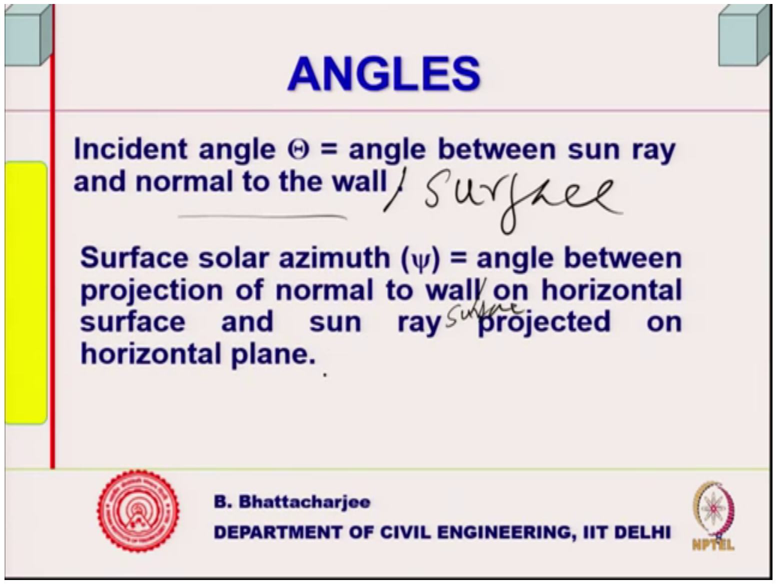


Then we define surface solar azimuth that is the azimuth angle between the two, although again it is not very important, angle between the projection of normal to the wall or surface on horizontal plane and sun ray projected on the horizontal plane.

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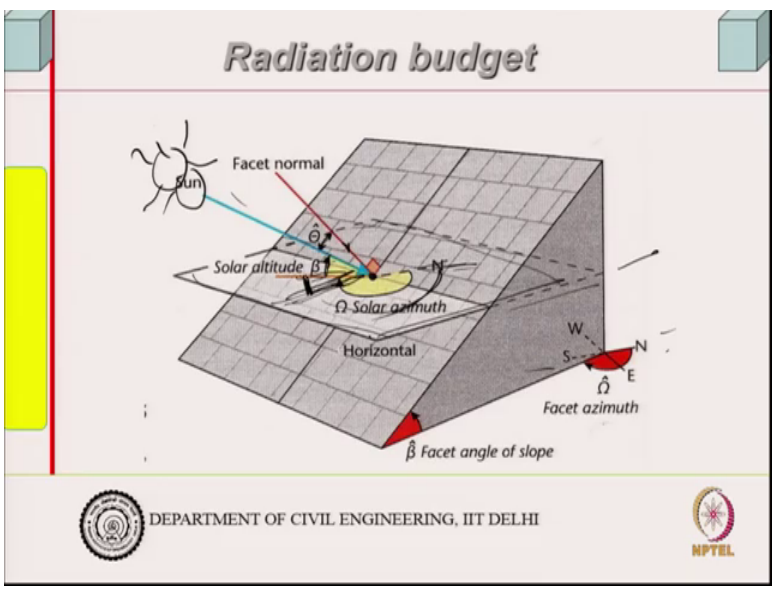


So this, this we will not need it here actually but supposing this, this is a you know projection of this line over ground, so projection of sun ray is here this is wall solar or surface solar azimuth. That is the azimuth difference between the azimuth of sun and the surface difference you know projection of the normal to the surface on to the horizontal plane, projection on to the sun ray on to the horizontal plane, the angle between them we call it surface azimuth. In case of wall we call it wall solar azimuth. If I am interested in finding out the radiation or incident angle for a wall or surface this becomes important right, this becomes important.

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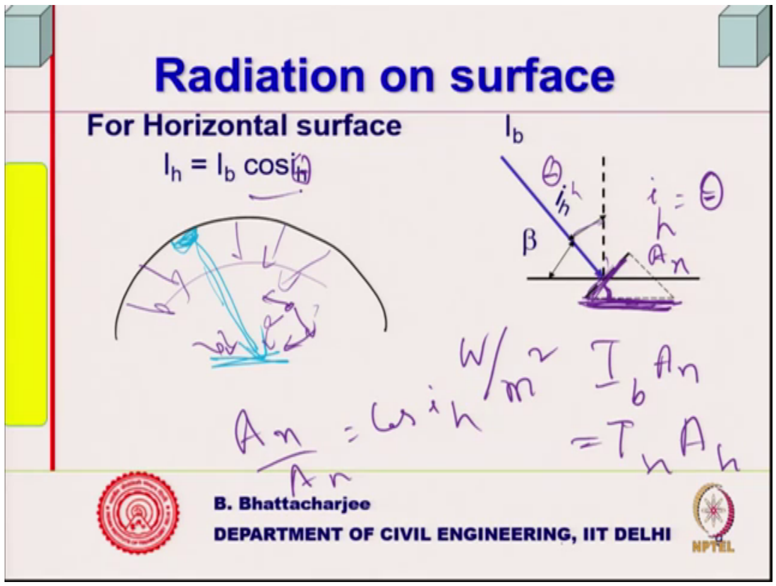


So for horizontal surface simple, if I have radiation falling like this I call it beam radiation because I said that radiation will be you know reflection would be two types, specular or diffused. Now in case of, in case of sky board the sun is somewhere, sun is in case of sky board sun is somewhere there, sun is somewhere there if this is the plane I am considering so I will get beam radiations like this. But radiation will also come from other places let us say from this portions also because atmospheric aerosol etc will absorb and they will diffused, it will go in all directions.

So if the particle here it will diffuse the solar radiation in all direction and I will get lot of diffused radiation from all here. So I have 2 types of radiation, one is a beam radiation another is diffused radiation. So let us look at the beam radiation. So this is a beam radiation so I will call it Ib, it is coming onto this surface is normal to the beam radiation is this right and this is the normal to the surface for a horizontal surface. So this angle, altitude angle is given as because its projection will go to the ground so altitude angle is given as projection of sun's radiation onto the horizontal surface and the sun ray itself. this is altitude angle.

This we call this is you know, this is the incident angle actually or you know you can write it like this for horizontal angle sources is 90 degree minus beta in this particular case. So this is incident angle or we can write it denote this by simply this. So lb because Ih nothing but equals to incident angle itself here. So lb Cos, Ib because this is what is I and angle between these two is ih. So the radiation falling here would be falling on larger surface same radiation because intensity of radiation in 1 per watt per metre square.

Now it is falling over a larger surface now, so the radiation that is falling on to this surface will be given by Cos into this angle because is angle is same as this is, this is normal to this and this is normal to this, so this angle is again right. So this surface length is horizontal surface, so Cos of incident angle. So it will fall onto a larger area therefore intensity will be less, you know the intensity if this is a area let us say normal area, so Ib normal area An is the total intensity coming that must be equals to ih you know and this is a area horizontal.

And area horizontal by area normal by area horizontal is nothing but Cos of ih. So ih is equals to incident angle in this particular case.

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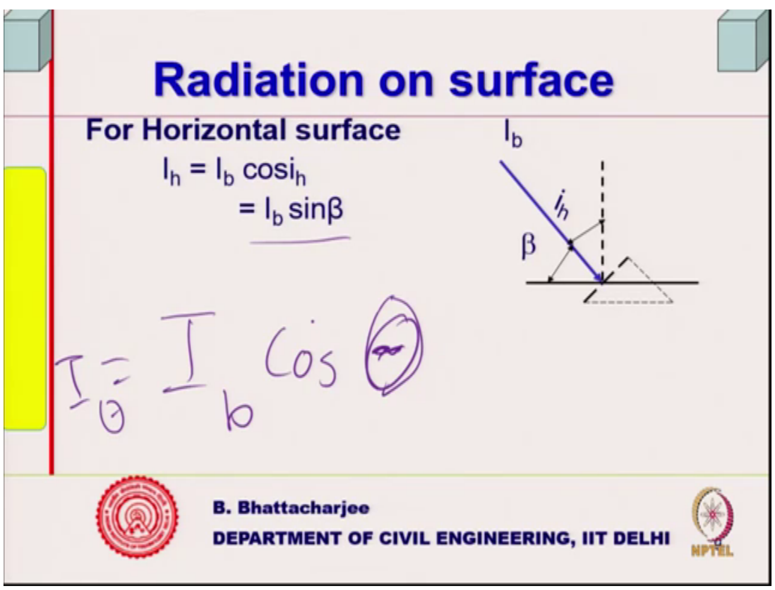


So Ib Cos h this is cosine law simple as that so ih is on horizontal surface it will be, in this particular case it will be sin beta because this is 90 degree minus beta so I b sin beta. So on horizontal surface any other surface it will be given as in this case ofcourse it is like this. For any other surface it will be given as Ib Cos of incident angle, Ib Cos of, so I on any angle would be given as I will be given as Ib Cos of incident angle, Cos of incident angle. That is how we define incident angle we defined earlier like this.  So Cos of incident angle for as (24:48) angle it is simply like that right, horizontal surface simply like that.

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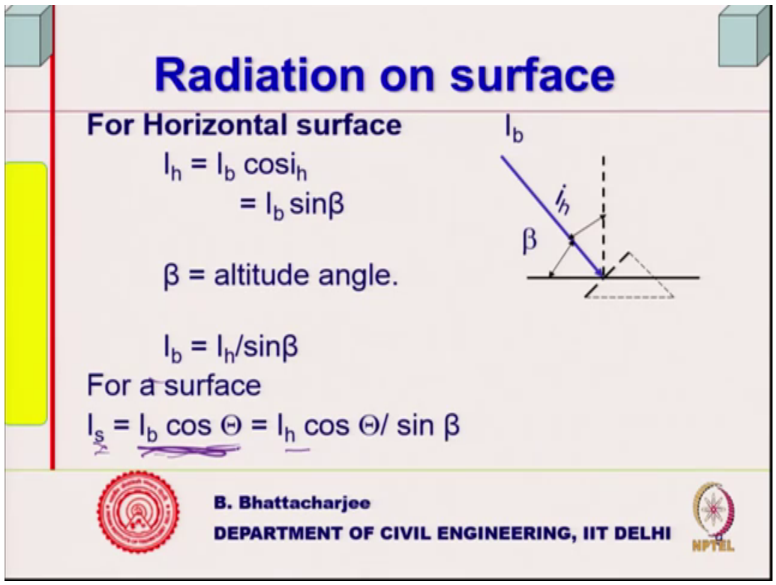


So I can actually measure or if I measuring horizontal radiation on horizontal surface is easy beam radiation can be calculated and I have not clearly into for a surface this is what it is Ib Cos you know on that surface Ib Cos so ih Cos theta by sin beta. One can find out this one as well. So this is what for any surface. So if this was an inclined surface as we have seen earlier, as we have seen earlier.

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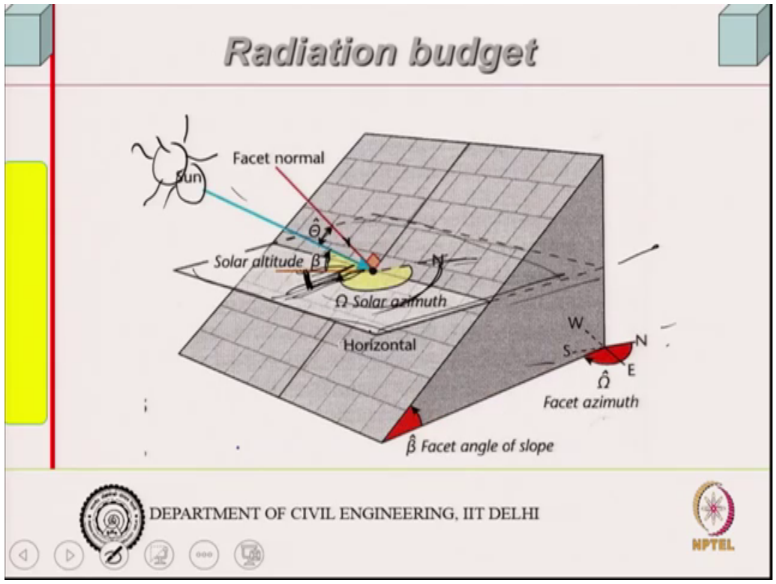


This is inclined surface, so this is whatever is the normal coming multiplied by Cos is a amount of radiation that will be falling on to that inclined surface it will be falling onto that inclined surface. okay. So that is it as far as surface radiation on surface we are concerned.

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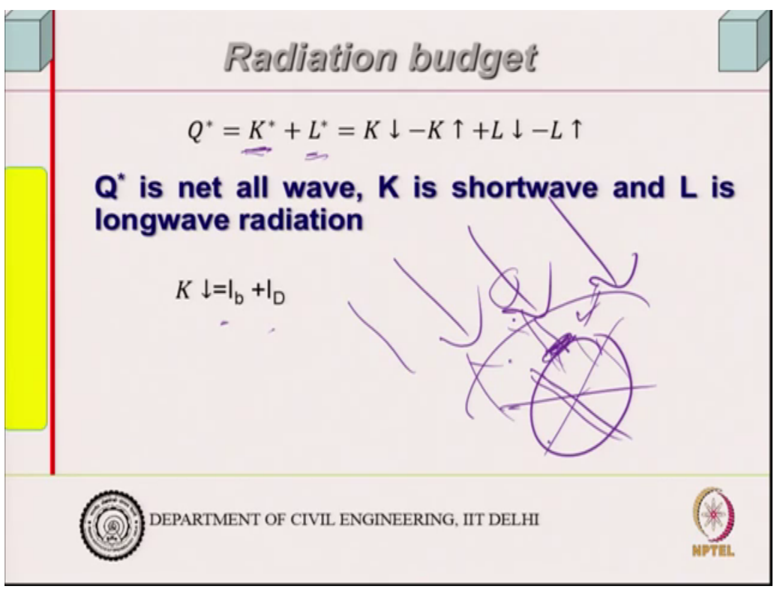


Now total radiation received by the, you know received on a earth is direct radiation, net direct radiation and net not sorry net short wave radiation and net long wave radiation. So the star denotes the net radiation received, Q star is the net radiation received by the earth, k stands for short wave, L stands for long wave. So Q is net all wave, K stands for short wave, L is long wave radiation. So this is downward what is coming in that must be equal to beam radiation plus diffused radiation as I mentioned, you know diffused radiation comes from all sides because particle will absorb and you know sun is very large compared to sun's ray falls like beam onto the whole surface of the earth. This is earth, earth is small so it comes from all directions.

So if this is your horizon this is you know this is your, this is your equator plane and at any point of time sun's radiation will come through you know come from all directions and is here ofcourse on the surface suppose you have (())(27:03) on surface here I will get normal radiation but I will also get radiation coming from, diffused radiation coming from all these direction as well. Because atmosphere will diffuse the direct radiation of the sun.  So always you have the long, short wave.

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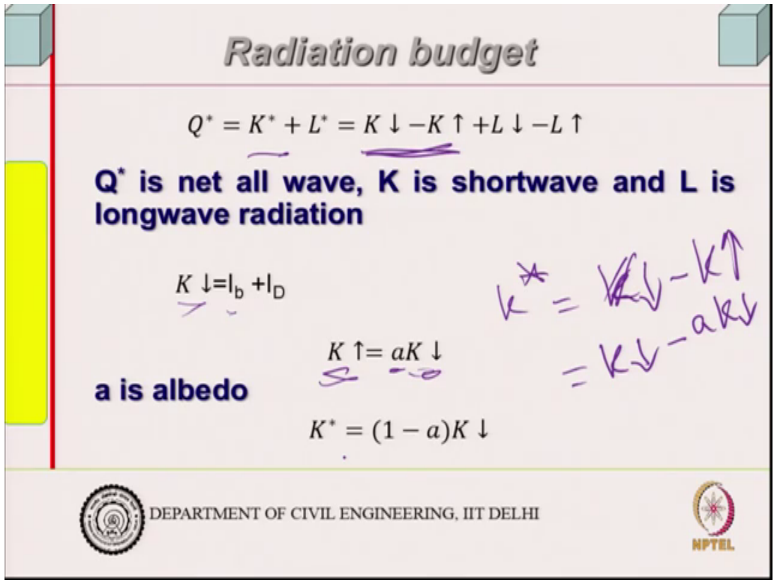


So if you look at short wave radiation I beam plus I diffused and if I look at some of it will be absorbed you know, some of it will be absorbed and some will go away. So this is going up, this going down. So is the (long) short wave radiations coming in, a fraction of it will go away, so this is called albedo. This a is called albedo, albedo denotes the fraction right which is the ratio between the radiation going out of the earth divided by radiations, short wave radiation incident. This is all for short wave radiation right I can combine for all wavelength and average we can take.

Now this would be, since you know K star is how much? Is a net, so it is difference between these 2 two,  K star was net, K star was net which is K downward minus K upward and this is nothing but k downward, so this is K upward is equals to K downward minus aK downward. So therefore I can write it like this. So net is 1 minus albedo K downward, what is received by the earth so right, what is this received by the earth.

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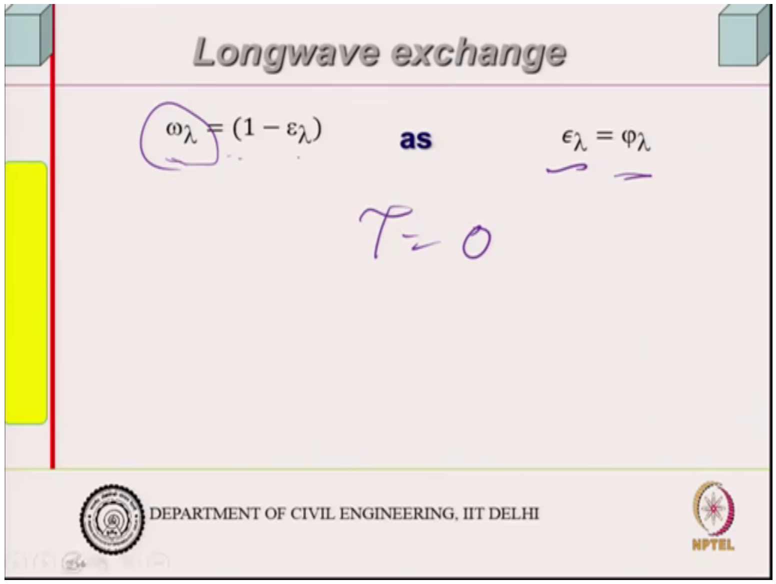


Long wave radiation, we have said that you know epsilon at given wavelength must be equals to absorptivity at same wavelength right, absorptivity at the same wavelength. Therefore reflectivity since earth we are assuming it is opaque, so whatever long wave radiation comes into it nothing will pass through it, it will be reflected back right. And that will be 1 minus absorptivity, 1 minus absorptivity and absorptivity is same as emissivity, so I can write as 1 minus emissivity, so reflectivity is nothing but 1 minus emissivity for a given wavelength.

Because we are saying absorptivity and emissivity is same and there is tau is equals to 0, since tau is equals to 0, so you know this can be so reflectivity is nothing but 1 minus emissivity.

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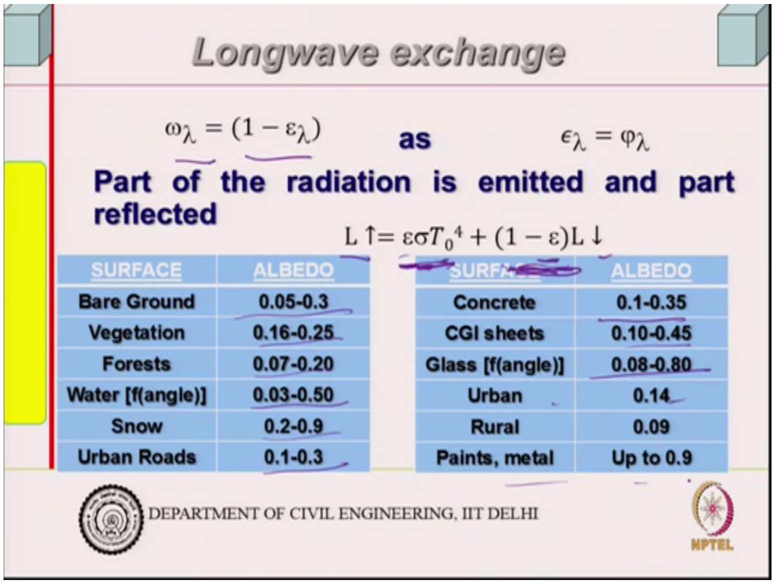


So part of the radiation emitted then part ofcourse reflected. Part is emitted, part is reflected. So we can write this, this the long wave radiation which is going out, part is radiated back, part is reflected, part is reflected and we have seen reflectivity is nothing but 1 minus this.

So this is a long wave emissivity whatever is coming in 1 minus that, that will be reflected back so this is a component reflected back, this is a component reflected back and this is the component going out by radiation. This is a equivalent earth temperature, we assume the cosmos is at negligibly small temperature or absolute 0 temperature or whatever it is, so therefore t to the power 0 that is the amount of you know heat that would go out, right

So this is epsilon and this seeing everything on the cosmos I mean totally (31:06) one can think in terms of this. So therefore the two things, one albedo released to shortwave radiation and emissivity of long wave radiation is important because 1 minus emissivity is again the reflectivity, 1 minus emissivity is again the reflectivity right. So if you see bare ground its albedo is somewhere the (0.5) 0.05 to 0.3 it would vary depending upon the weather it is at desert or just soil, rocky area. So we are looking at bare ground, no vegetation.

So this will vary and desert actually has got a higher value of albedo right, because you know (reflects) it reflects more, surfaces are it will absorb less, a soil will some of the other soil would might absorb more. Vegetation, this is the value right and forests, water, urban roads, snow. Snow gives your most of it right, snow gives because it is white so it will reflect, it will radiate everything. And concrete which is relevant for us 0.1 to 0.35, CGI sheet can go something like this, so they are various actually so there are ranges I just picked up the small portion of it and glass it will also depend on angle on incidence.

So is water, it depends on angle of incidence at 90 degree ofcourse it reflects maximum, lesser angle it will reflect relatively. Less, so albedo value is varies accordingly. Urban and rural, paints and you know paints and metals given up to 0.9. So albedo values varies depending upon the type of surface of the earth.

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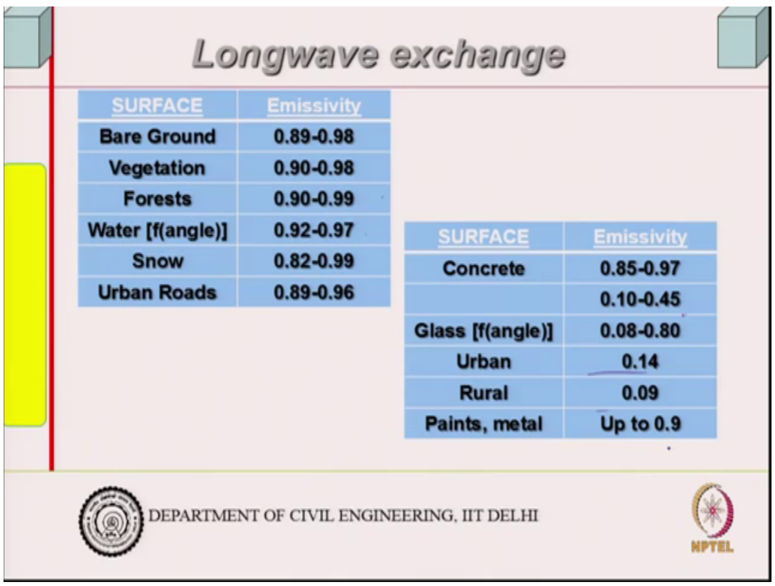


And if you will see long wave emissivity which is important that was for short wave, this is for long wave. So bare ground 0.89 to 0.98 so it emits good lot, you know it emits good lot vegetation something like this forests, something like this water most of it is actually emitted back. Concrete but you know some of the surfaces can be lower and glass, urban area, rural and so on. So that is what the albedo emissivities are. So emissivities are usually higher, emissivities are usually higher order of you know 0.8, 0.9 etc for most of the surface and albedo ofcourse varies depending upon surface. Snow could have much higher value, so that is what is related to absorption by the earth.