Refrigeration and Air Conditioning
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Lecture No. # 40
Cooling and heating Load Calculations

Welcome back, this lecture is a continuation of my earlier lecture. And the specific objectives of this particular lecture are to introduce solar radiation through fenestration, define solar heat gain factor and shading coefficient discuss effects of external shading, introduce ventilation and infiltration and discuss estimation of heating and cooling loads due to ventilation and infiltration.

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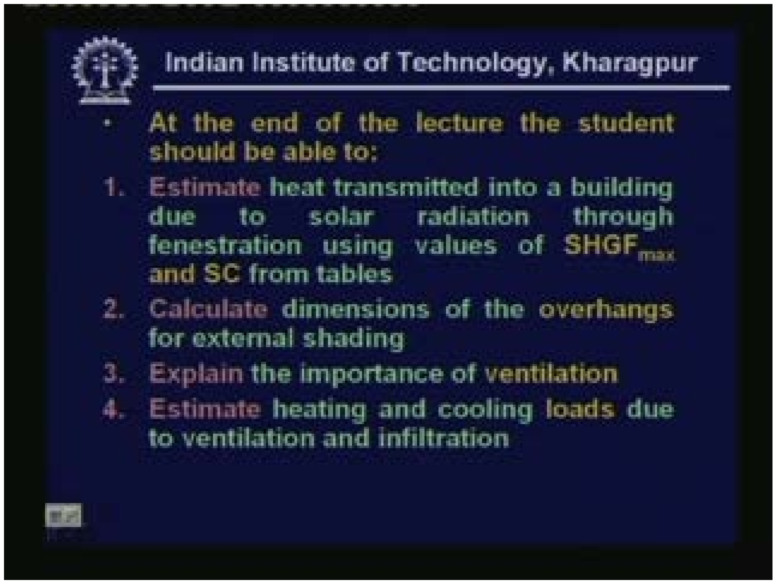

So at the end of the lecture you should be able to estimate heat transmitted into a building due to solar radiation through fenestration using values of solar heat gain factor and shading coefficient from tables calculate dimensions of the overhangs for external shading, explain the importance of ventilation and estimate heating and cooling loads due to ventilation and infiltration. Before that let me just work out an example.

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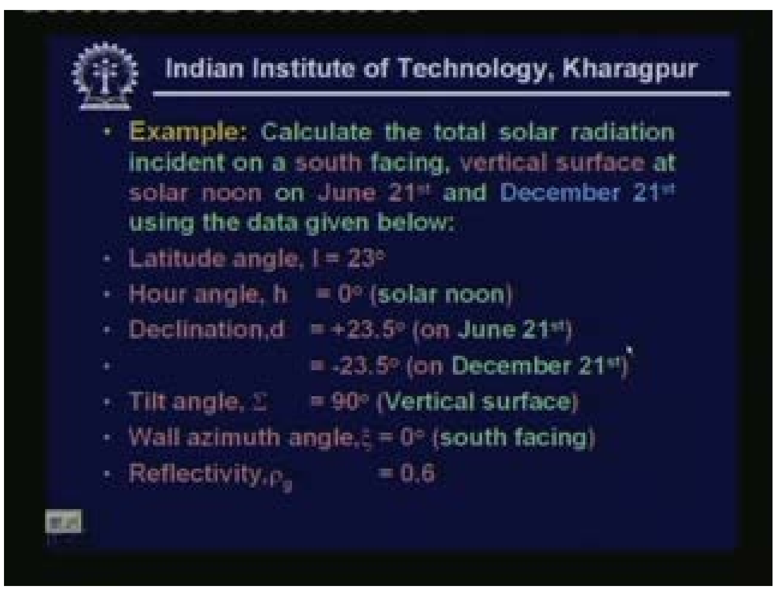

On calculation of solar radiation on a south facing wall the example is like this you have to calculate the total solar radiation incident on a south facing vertical surface at solar noon on June twenty first and December twenty first using the data given below the latitude angle is given to be twenty three degree centigrade and the hour angle is zero degrees because it is at solar noon okay.

This is not given but you have to infer this from the given information and the declination. Declination is plus twenty three five degrees on June twenty first and minus twenty three point five degrees on December twenty first and the tilt angle, tilt angle here is ninety degrees because it is a vertical surface and the wall azimuth angle zeta is zero degree centigrade. Because the wall is south facing and finally it is given that the reflectivity of the ground is point six. So this is the information given and based on this we will have to calculate the total solar radiation.

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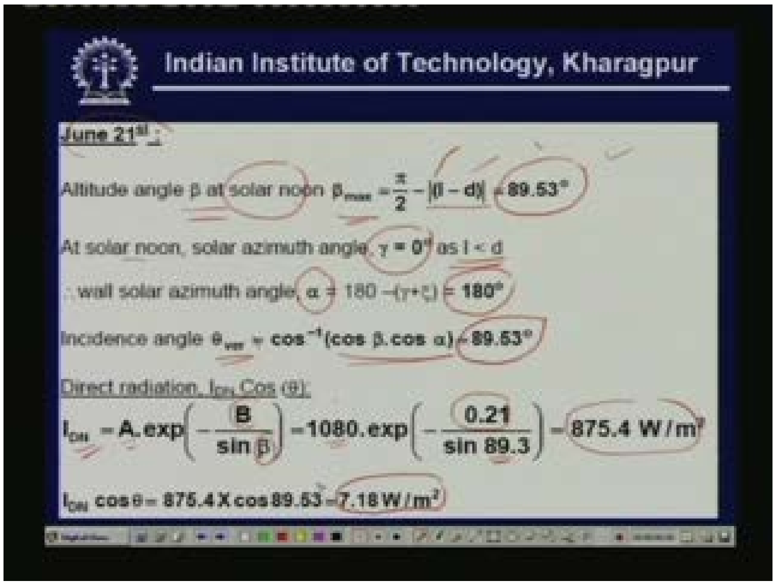

Okay. So here step wise procedure is shown first what we do is we find out the altitude angle beta since we are doing the calculations at solar noon beta is nothing but beta max. Thus we given by pi by two minus absolute value of l minus d where l is the latitude and d is the declination so you find that the altitude angle works out to be eighty nine point five three degree degrees. First I am doing the calculation for June twenty first okay. Here I take the declination as twenty three point five degrees next at solar noon we have to calculate what is the solar azimuth angle since we are making the calculations at solar noon the solar azimuth angle is either one eighty degrees or zero degrees. It is zero degrees if altitude is less then declination. So you have to take solar azimuth angle to be zero degrees in this case okay.

And next we have to calculate what is so wall solar azimuth angle alpha in the wall solar azimuth angle alpha is given by one eighty minus gamma plus zeta and here you find that gamma is zero and zeta is also zero. So you find that the value of alpha is one eighty degrees for this particular case okay. Once you know the value of alpha and the value of beta calculate the incidents angle since this is vertical wall the incidents angle is given by theta vertical is cos inverse cos beta into cos alpha beta is eighty-nine point five three degrees and alpha is one eighty degrees. So from this you find that the incidents angle is eighty nine point five three degrees once you know the incident angle they can calculate what is the direct radiation on the surface the direct radiation is given by Idn cos theta.

So first let us find out Idn from the ASHRAE model Idn is given by A multiplied by exponential within bracket minus B by sin beta where beta is the altitude angle that is eighty nine point five three degrees and a is ten for summer. So the take the value of A as ten eighty and B which is called as the extinction coefficient it takes a value of point two one for summer this aspects have discussed in the last lecture okay. So you take this values of ten eighty for A and point two one for B and substitute the value of beta you find that the direct normal radiation is eight seventy five point four watt per meter square.

So we have to find out what is the direct radiation on the vertical surface. So that you have to find out by multiplying this with cos theta where theta is the angle of incident okay. That is the eighty-nine point five three degrees so if you find that then you will find that Idn cos theta works out to be seven point one eight watt per meter square okay. Next we have to find out the diffuse radiation.

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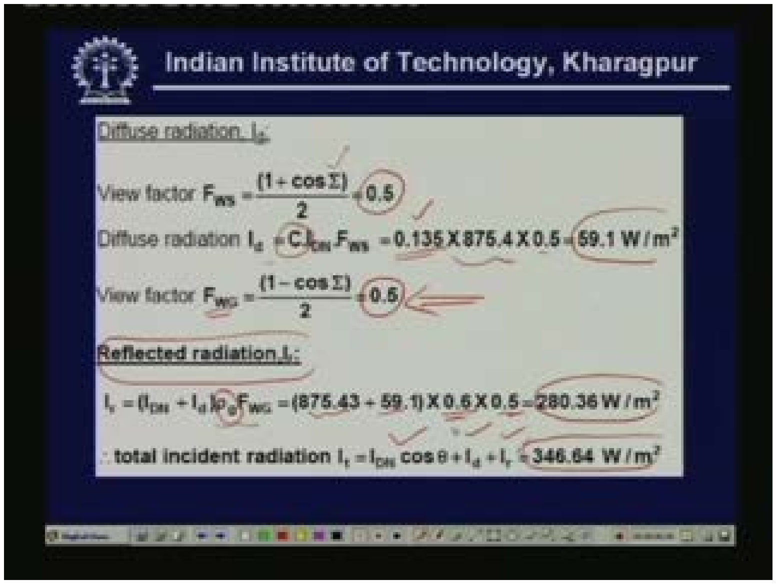

Diffuse radiation for that we have to find out the view factor view factor is given by one plus cos epsilon by two and this ninety degrees so you find the view factor is point five okay. This is for the diffuse radiation once you know the view factor diffuse radiation given by again based on the ASHRAE model Id is equal to C into I subscript Dn into F subscript ws where t c takes the value of point one three five for summer. Since I am making the calculations for June I take a value of point one three five and Idn v what is so to be eight seventy-five point four as shown in the last slide and Fws is point if substitute all these values you if substitute all these values you find that the diffuse radiation is fifty nine point one watt per meter square.

Next we have to find out the reflected radiation reflected radiation also have the view factor between the ground and the wall. So first let us find the view factor between the ground and the wall that is F subscript wg this one that is given by one minus cos epsilon by two. So this what so to be point five then based on the ASHRAE model the reflected radiation from the ground is equal to Idn plus I diffuse multiplied by rho g into Fwg where rho g is the reflective of the ground which is given as point six and Fwg is point five. So if you substitute the value of Idn and I diffuse you find that the reflected radiation works out to be three eighty point three six watt per meter square. So the total incident radiation is nothing but some total of direct radiation contribution diffuse radiation and reflected radiation. So the direct radiation total radiation works out to be three forty six point six four watt per meter square okay. So this is a fatedly straight forward procedure.

This is for a vertical wall if the surface is inclined then you have to use the tilt angle and if it is facing any other direction other then south then you have to use proper surface azimuth angle okay as explained in the last lecture. The same manner you can calculate the all this parameters for December twenty first okay. For December twenty first the declination angle will be minus twenty three three point five degrees okay. So now let me show a table where the solar radiation results for June twenty first and December twenty first are given.

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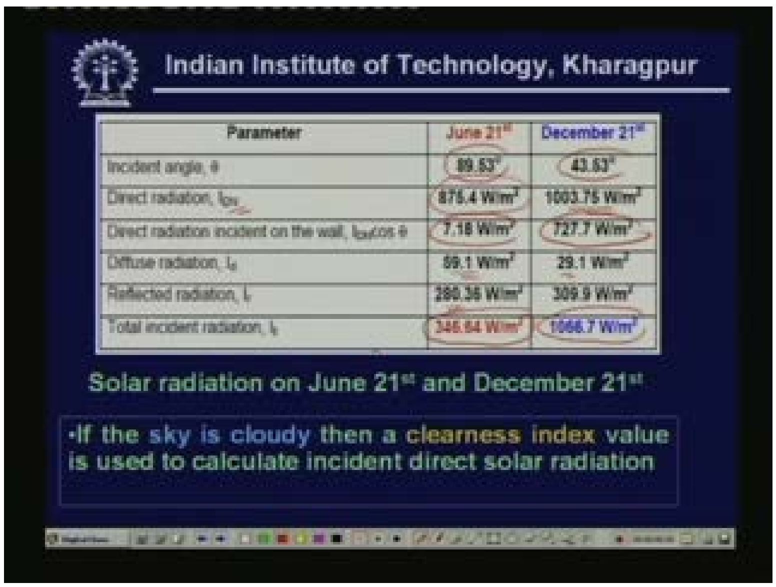

So this table shows the comparison between June twenty first and December twenty first June twenty first you find that the incidents angle is eighty-nine point five three whereas for December twenty first it forty three point five three the direction radiation Idn is eight seventy-five point four watt per meter square. In case of June twenty first and its thousand three point seven five ion case of December. Similarly the contribution of direct radiation is nothing but Idn cos theta is seven point one eight watt per meter square for June seven twenty seven point seven watt per meter square for December okay. And the diffuse radiation is fifty-nine point one and twenty nine point one and reflected radiation is two eighty point three six and three nine point nine in case of December. So the total incident radiation on the vertical surface is three forty six four watt per meter square on June twenty first and ten sixty six point seven watt per meter square on December twenty first okay.

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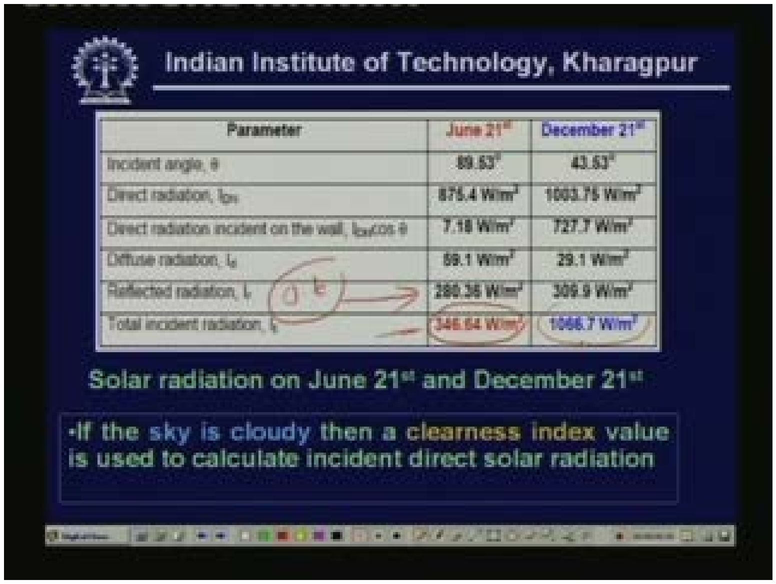

This example actually gives us some useful information that information is that this is a south facing wall you observe here that for south facing wall. If you get the total radiation incident on the wall is three forty six point six four watt per meter square in summer. Whereas it is almost eleven hundred watt per meter square in winter okay. And here for summer this value is coming because of the reflected radiation. Because we have taken point six as observe reflectivity of the ground if the ground is not so reflective you find that the total incident radiation on the vertical surface on June will be very small whereas it is very high on the December twenty first or that is in winter okay.

So this tells us this gives us an important information that is that for south facing walls the solar radiation incident on a vertical surface is much less in June whereas it is much higher in winter okay. So since we want to reduce the load heat load on the building during summer and we want to maximize the heat transfer to the building during winter it is always beneficial to keep windows doors etcetera on south side okay. So that the radiation part will be small in summer and it will be large in winter. So your cooling capacity requirement will be small and the heating capacity requirement also will be small okay. So this is actually this is a principle generally used in passive cooling and heating techniques okay. Use the south wall properly and of course these results hold good for northern hemisphere okay. Because the altitude is twenty three degree north the results will be.

If you are talking about southern hemisphere okay, and so for this ASHRAE model in fact if you remember I have mentioned in the last class that this model assumes that the sky is cloud less okay. But if the sky is cloudy sometimes what is done is a clearness index value is used to calculate the incident direct solar radiation okay. The clearness index value is one if the sky is clear and it will be less than one if the sky is cloudy and the clearness index value for different reasons during different seasons are available okay. So from that data you can calculate what is the radiation during a cloudy day okay.

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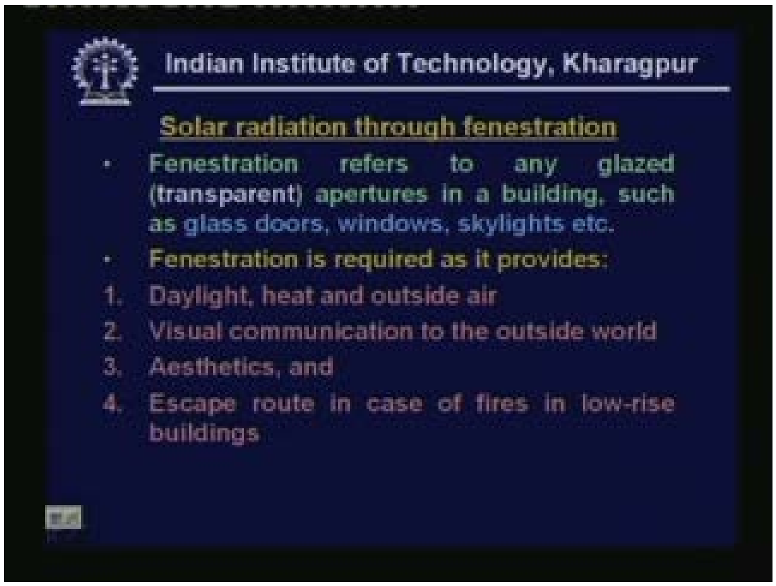

Now next let us look at solar radiation through fenestration first. So all what is fenestration refers to any glazed apertures in a building such as glass door windows skylights etcetera. That means it refers to all those transparent surfaces such as doors windows skylights etcetera okay. All these are called as fenestration we need fenestration all buildings have fenestration why do we need fenestration it is required. Because it provides day light heat and outside air and fenestration also provides visual communication to the outside world it also improves aesthetics and finally it provides a escape route in case of fires in low rise buildings because of all these factors almost all buildings will have some amount of fenestration. That means you will have some amount of glass windows or glass doors etcetera okay. Because of the four reasons mentioned here.

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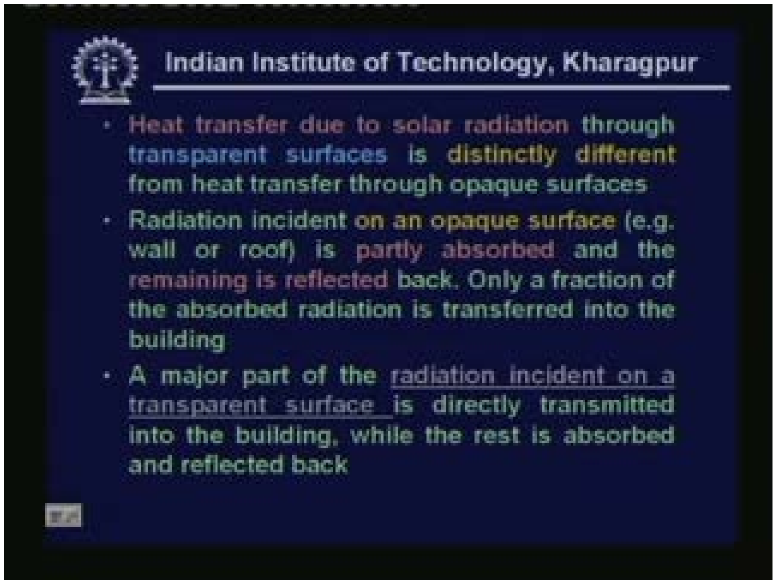

Now let us see what is the affect of this on the cooling and heating loads heat transfer due to solar radiation through transparent surfaces is distinctly different from heat transfer opaque surfaces. This is one important thing to note okay, what is the difference radiation incident on an opaque surface for example a wall or a roof is partly absorbed and the remaining is reflected back because it is opaque surface. So its transitivity is zero. So whatever radiation is incident either it is absorbed or it is reflected. That means or it is reflected that means it is partly observed and partly reflected and out of the observed part only a fraction of it is transferred into the building this aspect we will discuss in the next lecture.

So ultimately whenever radiation is incident on an opaque building some of it is observed and some of it is reflected back and out of the observed portion only a part if finally transferred to the building. That means only a part of the radiation incident on a opaque surface finally becomes a load on the building okay. This is as far as the opaque surface is concerned. Now let us look at a transparent surface for a transparent surface a major part of the radiation incident on a transparent surface is directly transmitted into the building while the rest is observed and reflected back we this from our basic physics that all transparent surfaces have high transmissivity okay.

So whenever radiation is incident on the surface most of it is transmitted through the surface right transmitted through the glass and only a small part of it is observed and a small part of it is reflected back. So this is the major difference between the transparent surface and opaque surface and this has a huge affect on the heating and cooling loads okay. First let me, let us look at a reference surface and see what happens to the radiation okay.

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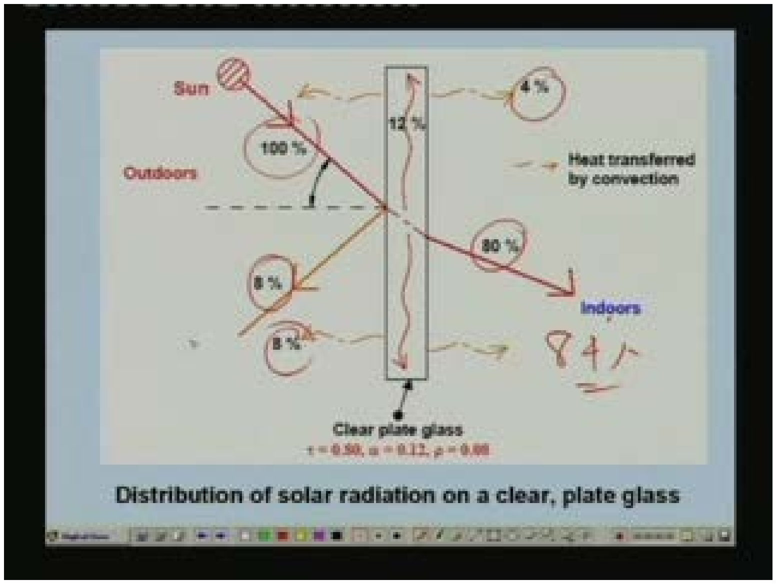

This is a distribution of solar radiation on a clear plate glass okay. On a clear plate glass clear plate glass has these optical properties it has a transmittivity of point eight it has an observitity of point one two it has reflectivity of point zero eight okay. So these are the values for the solar radiation solar radiation these are the values now since it has a tranmittivity of point eight if hundred percent of solar radiation is incident on this window okay. Which is nothing but your window made of clear flat glass plate glass eighty percent of it is directly transmitted to the indoors okay.

Because it has as transmittivity of point eight right and twelve percent of it is observed by the glass while eight percent of it is reflected back. Okay. This is based on the optical properties of the clear glass now of the twelve percent absorb what happens to this twelve percent the radiation observed by the glass this will increase the temperature of the glass. That means glass temperature increases due to absorption okay. Absorption of radiation right once the glass temperature increases it reject some heat by convection to the outside and some part of it is rejected to the indoors okay. For example typical values are this particular glass will reject about eight percent to the outside and about four percent to the indoors.

So final you see that out of the hundred percent solar radiation incident on the surface eighty percent plus four percent that is eighty four percent is directly transmitted to the building or to the indoors while sixteen percent is transmitted to the outside okay. This is for a clear plate glass and these values will be different for different type of glasses okay.

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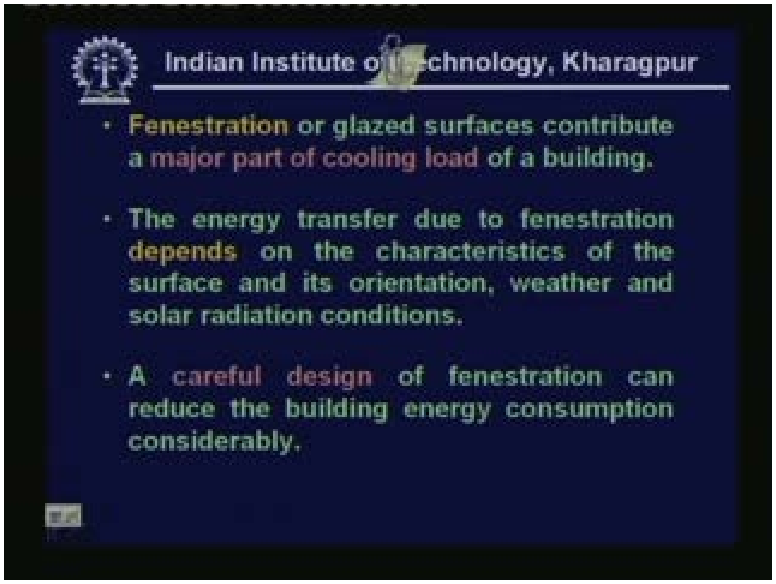

Now what is the importance of fenestration and glaze surfaces, why do we have to consider this seriously? Fenestration or glaze surfaces contribute a major part of cooling load of a building. So the energy transfer due to fenestration depends on the characteristics of the surface and its orientation, weather and solar radiation conditions. So careful design of fenestration can reduce the building energy consumption considerably okay. So if you are, if you design it properly then fenestration can help you introducing the initial and running cost. But if you do not design it properly then you will have to pay both in terms of initial and running cost. For example if you design the fenestration properly that means if put the glass windows doors etcetera, properly on proper direction and with proper orientation you will find that the radiation transmitted to the building during summer can be reduced very much whereas it can very much increased during winter.

As a result the cooling load on the building can be reduced during summer and the heating load on the building can be reduced in winter okay. So the required cooling and heat capacities will be less so your initial and running cost will be less okay. So if you are that is if you are using the fenestration properly okay. Instead of that if you are putting glass left and right just to increase the ethictics or anything you will find that both heating and as well as cooling loads will increase okay. Ultimately you have to pay for this in terms of initial and running cost okay. So they, that, why it is very important to understand the importance of fenestration and the issues involved in the design of fenestration for buildings.

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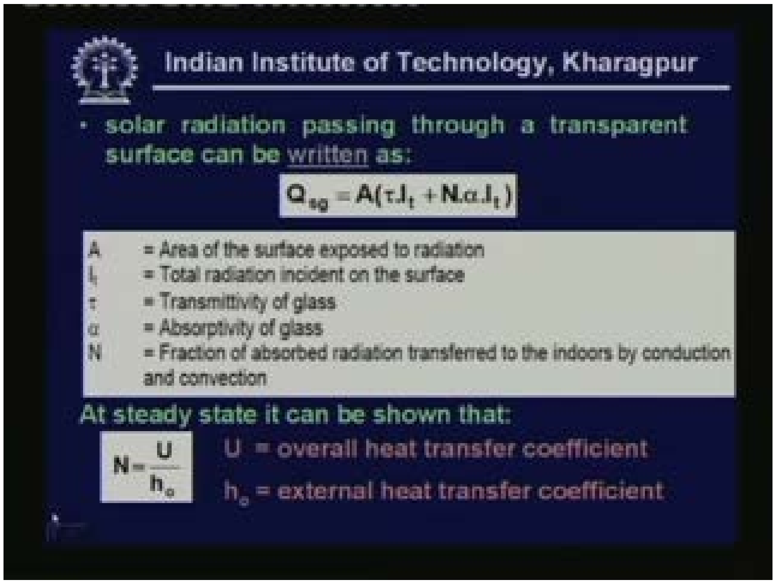

Now let us look at simple model for calculating solar radiation passing through a transparent surface okay. So this model is based on these assumptions the assumptions are like this.

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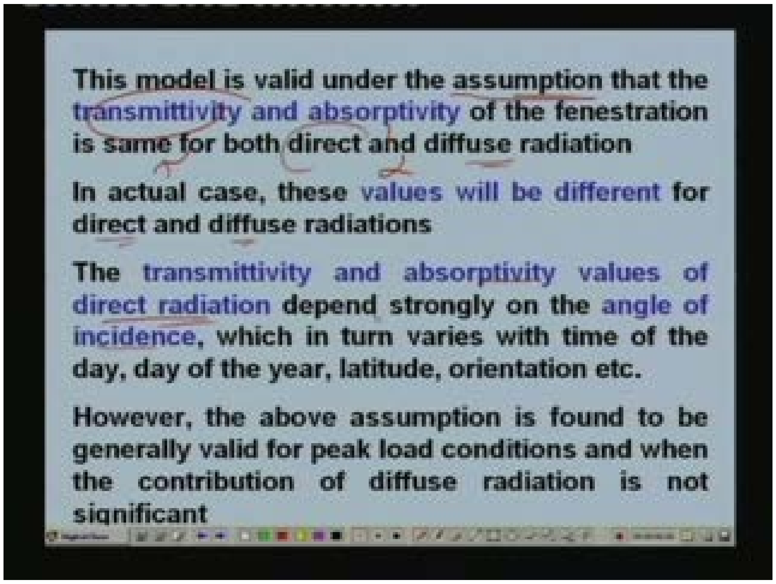

So this is valid under the assumption that the transmittivity, that is a tau value and the absorptivity that is alpha value of the fenestration is same for both direct as well as diffuse radiation. This is an important point to be remembered in actual case you find that the transmittivity and absorptivity of the glass will be different for direct radiation and diffuse radiation okay the values will be different and the transmittivity and absorptivity values of direct radiation okay. It depends strongly on the angle of incidence right. So this is again a very important point to be remembered the transmittivity and absorptivity of the glass for direct radiation is not a constant okay.

So it is a function of the angle of incidence and as we have seen the angle of incidence itself various it varies with the altitude, it varies with our angle, it varies with declination and with orientation etcetera right. So the, based on this the transmittivity and absorptivity of the glass also varies whereas the transmittivity and absorptivity of the diffuse radiation remains more or less constant okay. However the model that I am going to present which is taken actually from ASHRAE hand books, it is based on the assumption that the transmittivity and absorptivity values are same or constant. And they are same for both direct radiation as well as diffuse radiation. However this assumption is justified because normally we do the calculations for the peak load conditions okay. And at peak load conditions you find that the contribution of direct radiation is much larger compared to the direct diffuse radiation, I am sorry.

So direct radiation is much larger than the diffuse radiation. So the, if you are assuming that the tau values and alpha values are same for both, you will not be making a huge error okay. And besides it simplifies the procedure however it is not necessary that you have to assume them to be same okay. With a little bit of extension you can take different values of tau and alpha for diffuse radiation and direct radiation and do the calculation separately okay.

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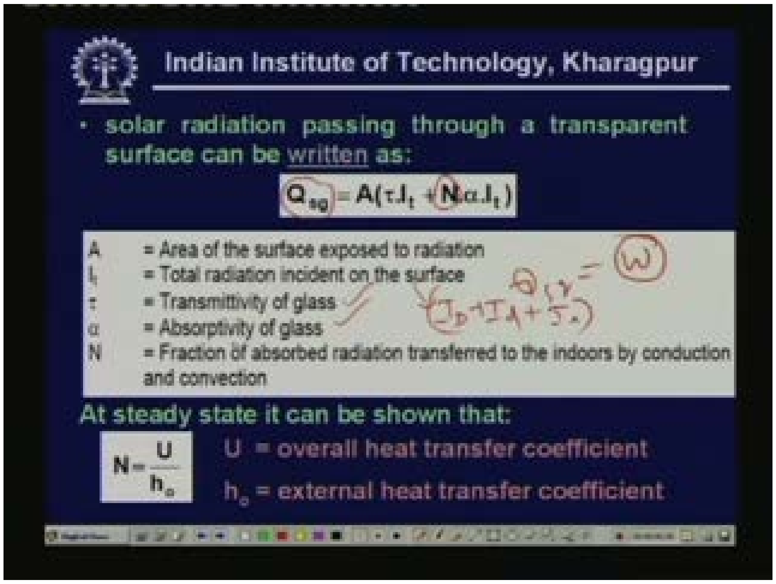

So under these assumption you can write the solar radiation transmitted to the building Q subscript sg okay, is equal to A within multiplied by within brackets tau into I subscript t plus n multiplied by alpha multiplied by I subscript t here, as I said Qsg okay, is the radiation transmitted to the building and the units are watts is SI units okay. And A is the area of the surface exposed to radiation in meter square It is the total radiation incident on the surface. So this includes both direct plus diffuse okay. Of course you can also include reflected radiation normally reflected radiation will be small part.

So this includes the total radiation incident on the surface and tau is the, as you know is the transmittivity of the glass alpha is the absorptivity of the glass. And what is n? n is a new parameter and this is the fraction of absorbed radiation transferred to the indoors by conduction and convection. In fact I was mentioning that when the glass absorbs radiation its temperature increases. So because the temperature between the glass and the surroundings they will be heat transfer due to convection okay. So this factor n takes into account this heat transfer that means the heat transfer due to convection because the temperature difference between the glass and the surrounding air okay.

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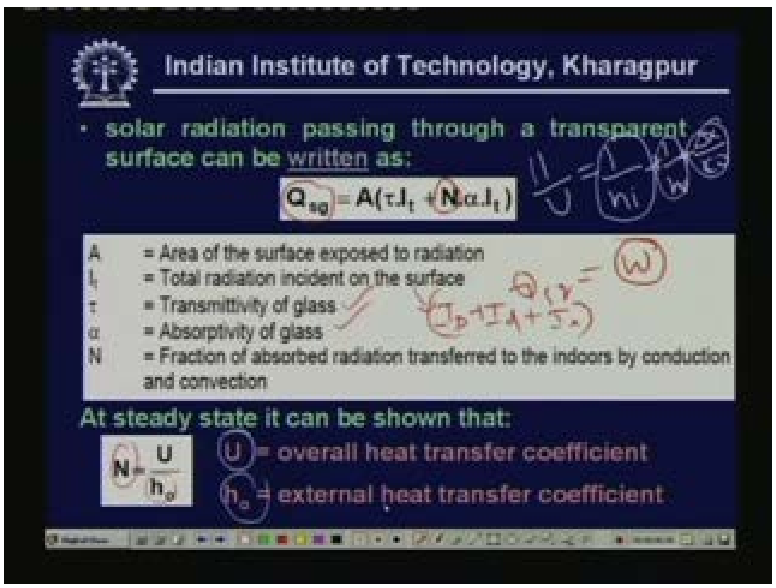

And it can be very easily shown that at steady state the value of N is given by U divided by h naught where U is the overall heat transfer coefficient okay and h naught is the external heat transfer coefficient. So U is the overall heat transfer coefficient for a flat glass one by U you know that the expression one by U is one by hi plus one by h naught plus delta x by k wall okay.

This is the resistance of the wall this, the convictive resistance on the outside this is the convective resistance of the inside.

So you can calculate overall heat transfer coefficient and h naught is the external heat transfer coefficient okay. So if you know the overall heat transfer coefficient external heat transfer coefficient properties of the glass and if you can estimate the total radiation incident on the surface. As you have shown in the example last example you can calculate what is the solar energy transmitted to the building okay, through a fenestration.

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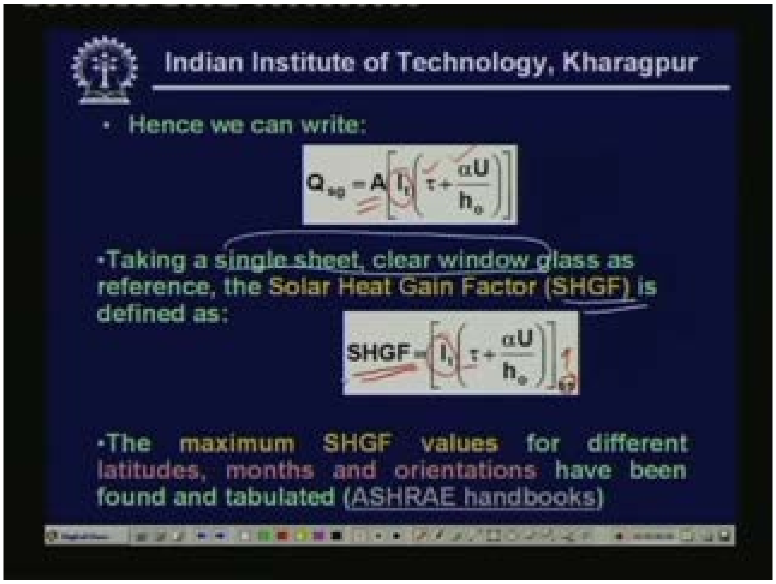

Now what we can do is, from the last expression we can write Qsg like this okay, A and take out A and you can also take out It. So you can write Qsg is A into within brackets It multiplied by within bracket tau plus alpha U by h naught as i said tau is the transmittivity alpha is absorptivity U by h naught is your fraction n okay. Now what is done is, a single sheet clear window glass okay single sheet clear window glass is taken as a reference and a factor called solar heat gain factor or SHGF is defined as follows okay. So taking the single sheet clear window as reference we define a solar heat gain factor as this is nothing but total radiation incident on the surface multiplied by within brackets tau plus alpha U by h naught okay.

And the subscript stands for subscript ss stands for singles single sheet clear window glass. That means it is for the reference glass okay. You will see immediately what is the advantage of defining this, the advantage is that the maximum solar heat gain factor values for different altitudes months and orientations have been found and tabulated. For example ASHRAE hand books gives the maximum solar heat gain factors for different altitudes months and orientation etcetera. So once you know the solar heat gain factor maximum solar heat gain factor of or from the table for given altitude for a given orientation for a given a day then you can calculate what is the energy transmitted into the building if the glass is made of reference glass. Because the energy transmitted is nothing but area multiplied by SHGF right. So let me show a typical table adopted from ASHRAE hand books.

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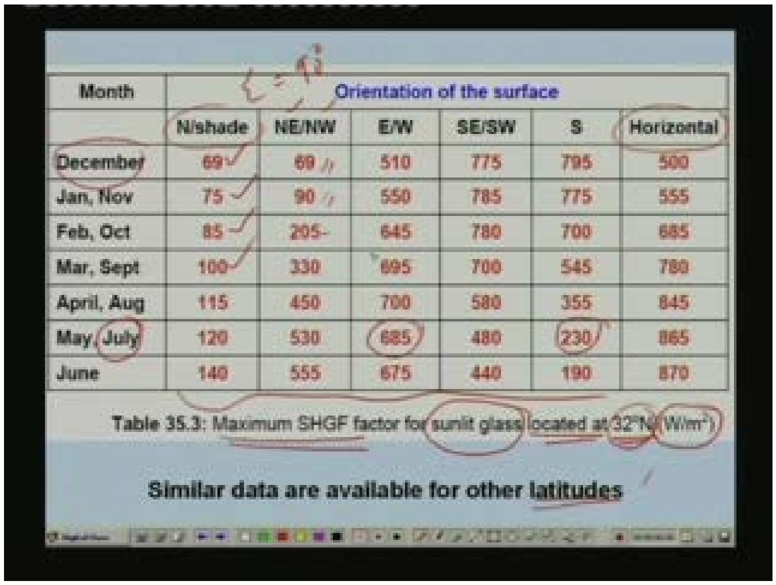

Month	Orientation of the surface					
	N/shade	NE/NW	E/W	SE/SW	S	Horizontal
December	69	69	510	775	795	500
Jan, Nov	75	90	550	785	775	555
Feb, Oct	85	205	645	780	700	685
Mar, Sept	100	330	695	700	545	780
April, Aug	115	450	700	580	355	845
May, July	120	530	685	480	230	865
June	140	555	675	440	190	870

Table 35.3: Maximum SHGF factor for sunlit glass located at 32°N (W/m²)

Similar data are available for other latitudes

Okay this is the, this table gives maximum solar heat gain factor for sunlit glass okay. Located at thirty two degrees north latitude and the units here are watt per meter square okay. For example for month December okay, orientation of the surface if the window is facing north or window is shaded then you find that the maximum solar heat gain factor is sixty-nine watt per meter square in December, it is seventy five watt per meter square in during January and November it is eighty five during February and October and hundred during march and September like that. Similarly for north east and north west. That means the window is facing north east or north west direction then during December this is the value during January and November this is the value February this is the value like that okay. Like that it gives the solar heat gain factor maximum solar heat gain factor for all orientation for different orientations okay.

The eight orientations and also for horizontal orientation for all these we are assuming that the glass is vertical okay. That is the tilt angle is ninety degrees okay. That means on a vertical wall right and this data is valid for thirty-two degrees north latitude ASHRAE hand books gives this similar data for other latitude also. For example twenty-four degrees forty degrees like that right. So from this table you can calculate what is the maximum solar heat gain factor. For example I would like to find out during the month of July, I want to find out what is the solar heat gain factor through a south facing window okay. That value is given by two thirty right during east or west facing window it is six eighty five like that we can find out the SHGF maximum.

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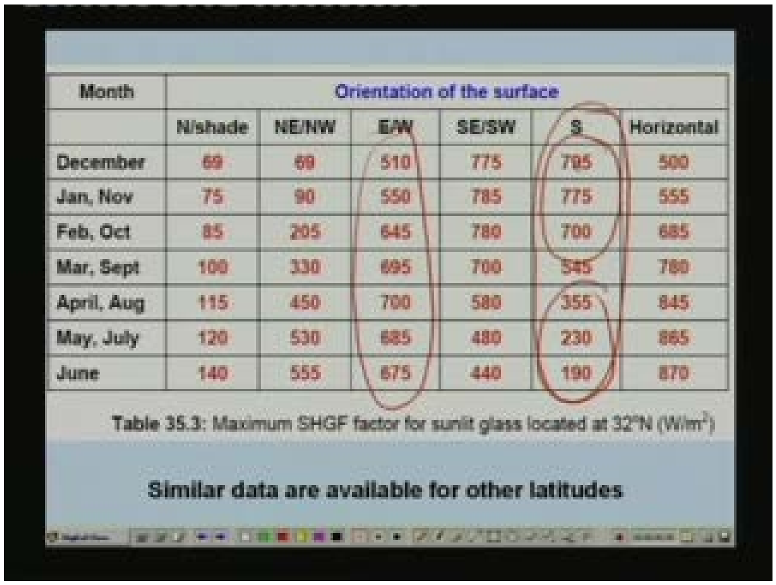

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Table 35.3: Maximum SHGF factor for sunlit glass located at 32°N (W/m²)

Similar data are available for other latitudes

One interesting thing you can absorb here is the benefit of putting the window on the south side. As I was mentioning in the last example you can see that for south side windows okay. The maximum solar heat gain factor that means radiation transmitted into the building because of solar radiation through the glass is very small during summer whereas it is large during winter okay. What we want is, we would like to heat the buildings in winter using solar radiation okay. And we do not want any solar radiation into the building during summer right. Because that way you can keep the building cooler during summer and you can keep the building warmer during the winter.

So using the solar radiation right, so this is very beneficial and this is very beneficial only when you put the windows on the south side. Because you see for the south side there is practically not much radiation during summer whereas there is lot of radiation during winter okay. Whereas for other directions like east west you find that is almost same during throughout the year. So you should not put look ta the table for east west the solar radiation is almost constant throughout the year okay. May some twenty thirty percent variation is there. That means you should never keep windows on east or west direction because on east or west directions during summer. You will receive lot of radiation. Of course during winter also you receive radiation but not as much as you receive if you put the window on the south side okay.

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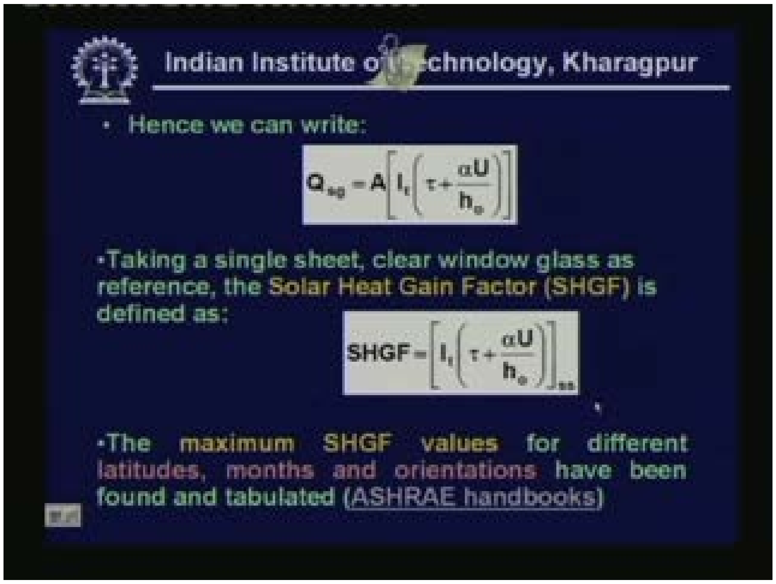

So this kind of hand book, a data are available in the hand books.

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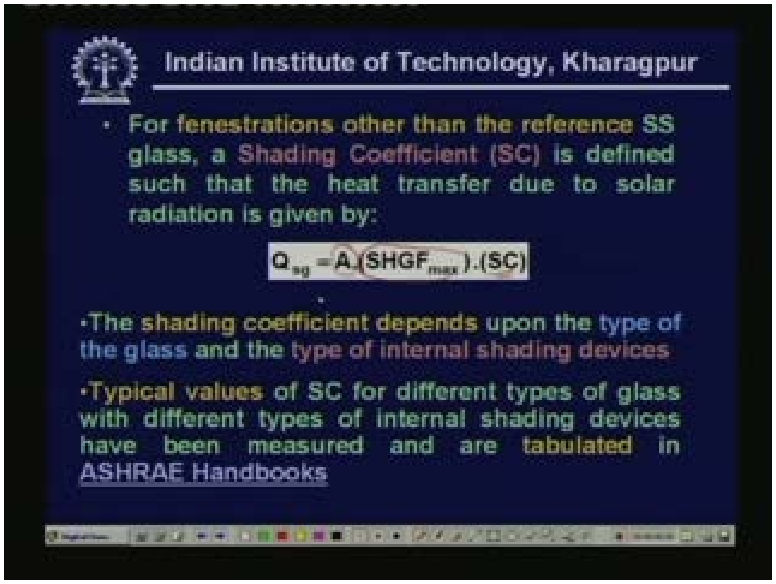

Now this data is for a standard reference glass. How about other glasses for fenestrations other then the reference SF glass a shading coefficient is defined okay. This shading coefficient is defined such that the heat transfer due to solar radiation is given by Qsg multiply that is equal to area A okay multiplied by SHGF maximum of the standard glass multiplied by the shading coefficient. So finally you find that shading coefficient is nothing but the heat transmitted through the actual glass divided by the heat transmitted through a standard glass okay.

That is how the shading coefficient is defined and the shading coefficient depends upon the type of the glass and also on the type of the internal shading devices okay. You can use a wide variety of internal shading devices. As you know very well, as I want to shade the window from radiation you can use curtains you use venetian blinds roller rollers like that okay. So the shading coefficient depends upon what kind of internal shading device you are using and it also depends upon what kind of glass your using whether it is a double or a single glass etcetera okay. And typical values of shading coefficient for different types of glass with different types of internal shading devices have been measured and are tabulated for example in ASHRAE hand books okay let me show a typical table.

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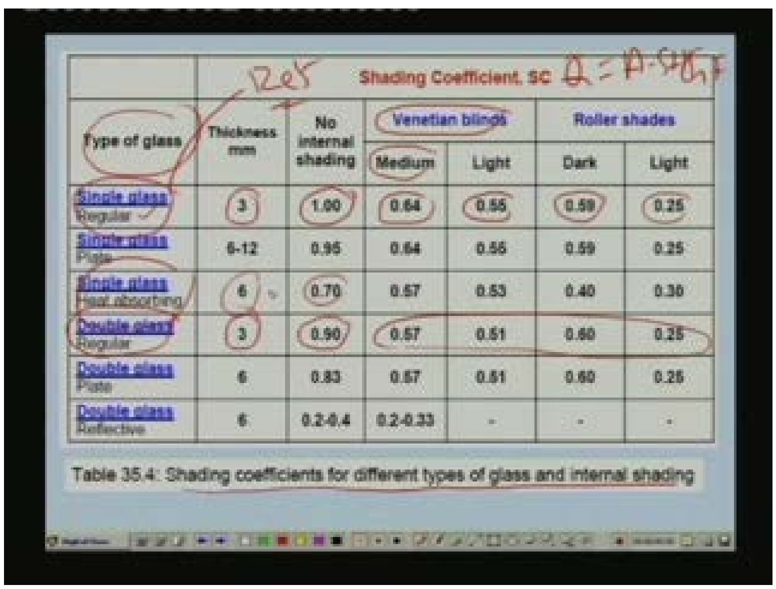

Type of glass	Thickness mm	Shading Coefficient, SC: No internal shading	Venetian blinds: Medium	Venetian blinds: Light	Roller shades: Dark	Roller shades: Light
Single glass Regular	3	1.00	0.64	0.55	0.59	0.25
Single glass Plate	6-12	0.95	0.64	0.55	0.59	0.25
Single glass Heat absorbing	6	0.70	0.57	0.53	0.40	0.30
Double glass Regular	3	0.90	0.57	0.51	0.60	0.25
Double glass Plate	6	0.83	0.57	0.51	0.60	0.25
Double glass Reflective	6	0.2-0.4	0.2-0.33	-	-	-

Table 35.4: Shading coefficients for different types of glass and internal shading

Again this is taken from ASHRAE hand books this table gives shading coefficient for different types of glass and internal shading for example for type of glass for a single glass okay. Single sheet regular glass this is the standard glass if it has a thickness of three mm and if does not have a no internal shading the shading coefficient is one the shading coefficient one because this glass is taken as the reference okay. So for this glass the Q is simply A into SHGF maximum that you get from the table right. However if you are using internal shading internal shading device. For example if you are using venetian blinds and the venetian blinds are of medium type you find that the shading coefficient reduces to point six four and if you are using light venetion blinds then the shading coefficient becomes point five five. If you are using roller shades and dark roller shades shading coefficient is point five nine if it is light roller shade it is point two five this is for a single glass similarly for different types of glass.

For example if you are using a double glass a regular double glass of three mm thickness you find that without internal shading the shading coefficient is point nine whereas for the single glass which one and with internal shading these are the values right. Other types of glasses are, you can also have heat absorbing glass of six mm thickness you find that are heat absorbing glass for six mm thickness the shading coefficient without internal shading is point seven. That means thirty percent less compared to a regular glass okay. So that how if you have this kind of information then you can select the proper shading coefficient value from these tables and once you know the shading coefficient value you can calculate what is the heat transmitted into the building through this glass okay.

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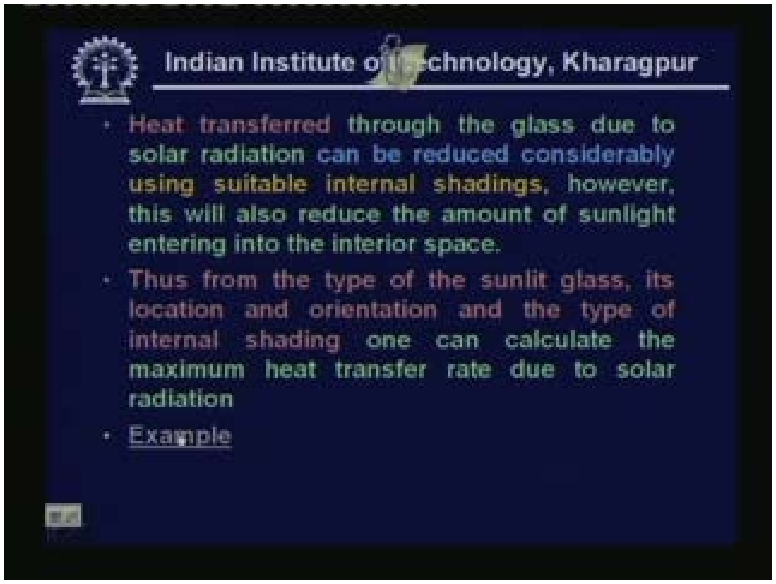

Now heat transferred through the glass due to solar radiation can be reduced considerably using suitable internal shadings okay. You might have noticed that when you are using internal shadings. The shading coefficient is less than one okay. That means amount of heat transmitted is less than one okay. So with this we know everybody knows that if you want to reduce the radiation you can simply put a curtain or you can simply use a venetian blinds okay. There by you can cut down the amount of radiation enter entering into the building okay.

So that is good as far as the cooling load is concerned. Of course there is a negative aspect to this when you are using a dark curtain or venetian blinds etcetera; the light that is entering into building also gets reduced okay. So light is not sufficient then you may have to use some artificial lighting so you have to pay for the artificial lightings. So again you have to see the balance you have to balance between the requirement for the light and requirement for reduction in the cooling load okay and from the type of the sunlit glass its location and orientation and the type of internal shading one can calculate the maximum heat transfer rate due to solar radiation. Let me give a small example this is very simple example.

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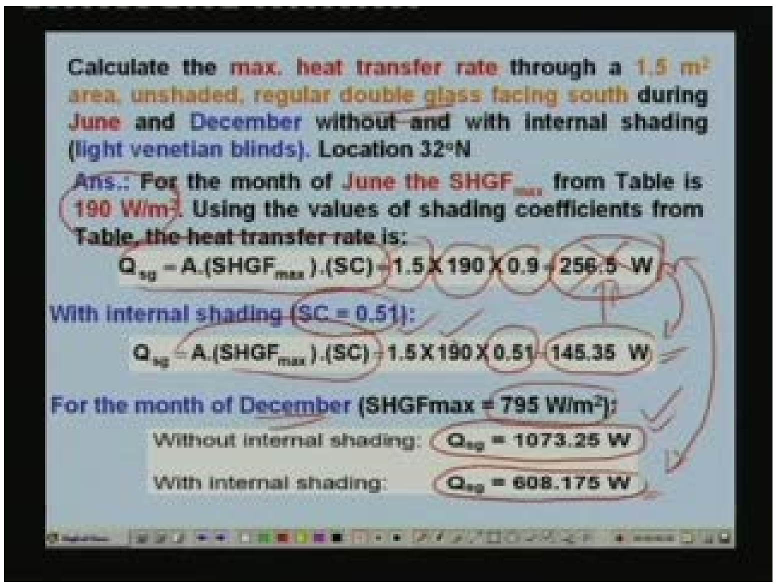

We have to calculate the maximum heat transfer rate through a one point five meter square area unshaded regular double glass facing south during June and December without and with internal shading oaky. The internal shading is light venetian blinds and the location is thirty two degrees north right. So the data given is you have to calculate during June and December okay. So first let us do the calculation for June for the month of June the SHGF max from table is one ninety watt per meter square okay. So this is solar heat gain factor for the standard glass okay. Then using the values of shading coefficients from the table that heat transfer rate is given by this si. The expression Q is A into SHGF max into shading coefficient if you are not using any shading coefficient any internal shading sorry. Then you find that area is one point five meter square and SHGF max is one ninety watt per meter square and shading coefficient for the double glass is point nine from the table.

So you find that Qsg is two fifty six point five watt on June okay, and with internal shading. That means if you are using venetian blinds then for the same date right. Find that the maximum energy transmitted is again given by the same formulae area is same SHGF of max is also same but the shading coefficient is different now it is point five one okay. So find that the total or at the rate at which energy is being transmitted the maximum transmission rate is given by one forty-five point three five watt. So from these you can see that with venetian blinds you can reduce the energy transmitted considerably it is almost fifty percent compared to without internal shading and if you do the same thing for December okay.

So you find that the SHGF of max for December is seven ninety five watt meter square. So without internal shading Qsg is ten seventy three point two five watts with internal shading this is six hundred eight point one seven five watt okay. Again you can see here that because this is a south facing glass the energy transmitted during summer is much less where whereas it is much higher during winter. Of course, obviously during winter you should not use any internal shading because you want this whereas during summer you should use internal shading because you don't want this okay.

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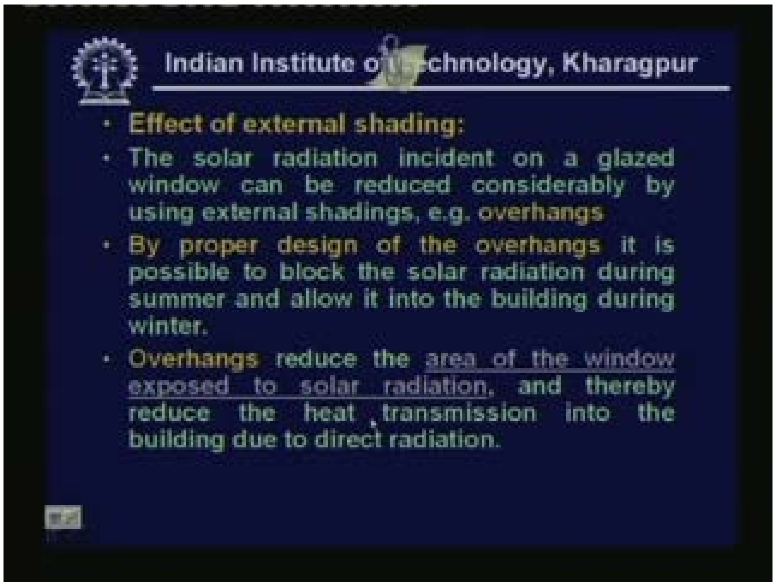

Now let us look at effect of external shading. So for we can been assuming that the window is not shaded externally. That means the full area of the window is exposed to radiation okay. But most of the times we find that most of the windows will have some kind of an external shading okay. For example in over hang right this over hang provides external shading that means not all the area of the window will be exposed to solar radiation part of it is exposed and part of it will be in shade okay. So this will have a bearing on the heat transferred to the building okay. So let us see what is the effect of this.

The solar radiation incident on a glazed window can be reduced considerably by using external shadings. For example over hangs of course the external shading can also be provided by let us say a tree or an adjacent building right. But here am I assuming that it is based on the over hangs okay. So by proper design of the over hangs it is possible to block the solar radiation during summer and allow it into the building during winter okay. There by you can reduce the cooling load and also the heating load. So what is the affect of over hangs as we know that over hangs reduce the area of windows exposed to solar radiation and thereby reduce the heat transmission into the building due to direct radiation okay. Let me show this.

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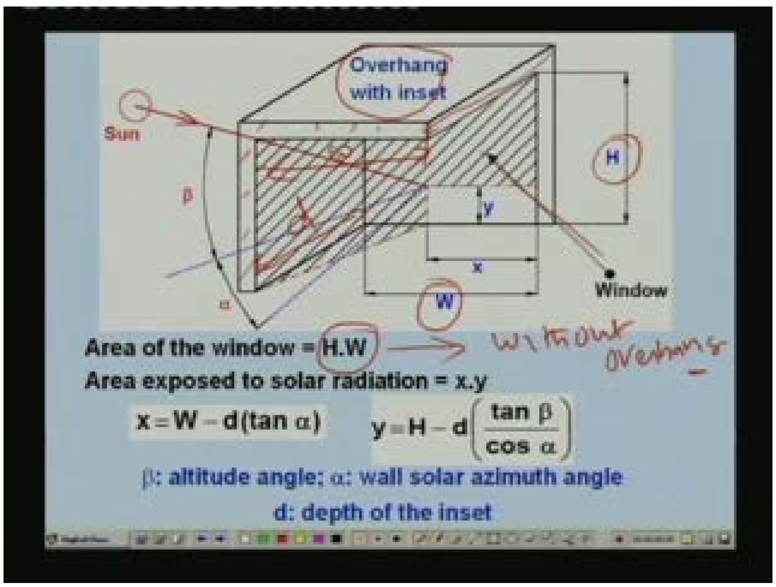

So this is the window oaky. So window as the dimensions of height H and width W so area of the window is given by H into W right and area exposed to solar radiation is equal to this without over hang okay. Because the entire area is exposed to solar radiation. But if I am using a overhang with inset that is I am using a overhang with inset this the overhang with inset the red hatched portion. So you have the certain length of it certain it has certain width and it has certain depth okay. Depth of the inset is this okay, and width is this right. So if you are using an overhang you find that, this hatched area at this particular incident when the sun is at this particular position this area is not exposed to direct radiation that means this is in shade okay. Only this much area is exposed to solar radiation oaky.

That means without over hang the entire area is exposed to direct radiation whereas width over hang only the small portion is exposed to direct radiation and this small portion is given here as multiplication of x into y okay and at any point you can calculate x and y because this is related to your solar geometry. For example this is related to your altitude angle beta and it is also related to your surface azimuth angle surface solar azimuth angle alpha okay. What is the relation?

You can find that at any point x is given by this relation x is equal to w minus d into tan alpha whereas y is equal to H minus d into tan beta by cos alpha. As I said beta is your altitude angle alpha is your wall solar azimuth angle. Whereas is the width of the window which is equal to width of the overhang and d is the depth of the inset that means this dimension okay. So if you know the dimensions of the overhang, what is the width of it? What is the depth of the inset and if I want to find at any particular incident how much area of the window is shaded, how much area of the window is exposed? Then you can calculate it very easily if you can calculate the altitude and wall solar azimuth angles okay. Let me give a small example here.

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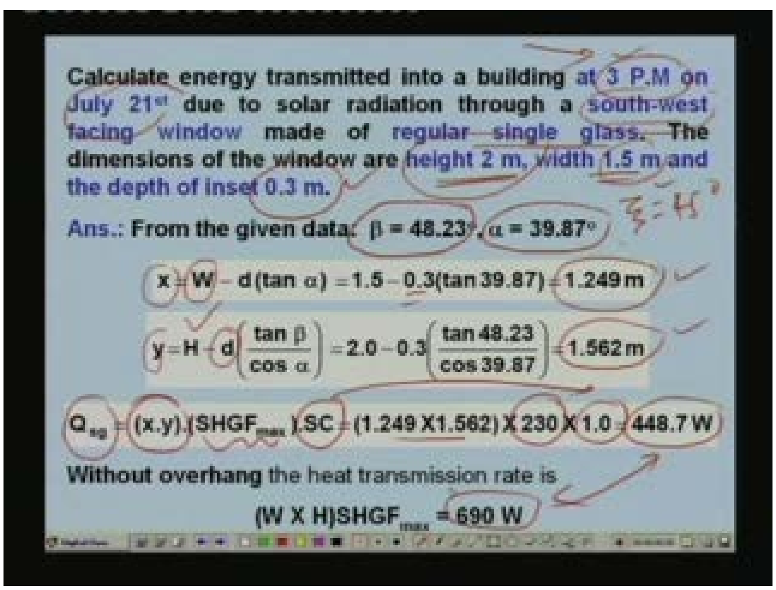

We have to calculate the energy transmitted into the building at three pm okay. On July twenty first due to solar radiation through a south west facing window made of regular single glass. That means it is made of the reference glass the dimensions of the window are, height is two meters and width is one point five meters and depth of the inset d is point three meters okay. Now from the given data that means at three pm that means hour angle is forty five degrees July twenty first you can calculate what is the declination on July twenty first and it is facing south west. So your zeta is forty five degrees okay.

So from the hour angle zeta and declination you can calculate the altitude angle and if you do the calculation you will find that the altitude angle works out to be forty-eight point two three degrees oaky. Similarly you can also calculate the surface solar azimuth angle which works out to be thirty nine point eight degrees. So this is the first step you have to calculate these angles once you calculate this angles you can calculate the dimensions x and y okay x and y is the length and height of the unexposed area I am sorry of the exposed area right. So x is given as w minus d into tan alpha where w is the width of the window which is given as one point five meter okay and d is the depth of the inset that is given as point three oaky. So you find that x is equal to one point two four nine meters and y is equal to h minus d into tan beta by cos alpha where h is two meters d is point three tan beta is forty eight point two three and alpha is thirty-nine point four eight seven.

So if you substitute this value you find the y is equal to one point five six two okay. So now you can calculate what the transmitted energy because of solar radiation is. So that is now given by SHGF max multiplied by the shading coefficient multiplied by the exposed area okay, is exposed area is x into y. So that is given by one point two four nine into one point five six two okay. This multiplied by this and SHGF max from your ASHRAE table works out to be two thirty watt per meter square okay. Because this thirty two degree north latitude okay and the shading coefficient is one shading coefficient is one because this is a standard glass.

So you find that the radiation transmitted is four forty-eight point seven watts okay. If you do not use the overhang you will find that the energy transmitted is w into h into SHGF of max that is six ninety watts okay. You can see that with over hang it is about four forty-nine with without overhang it is six ninety. So there is a considerable reduction in the energy transmitted to the, into building because of the absence of overhang. So over hang is beneficial right.

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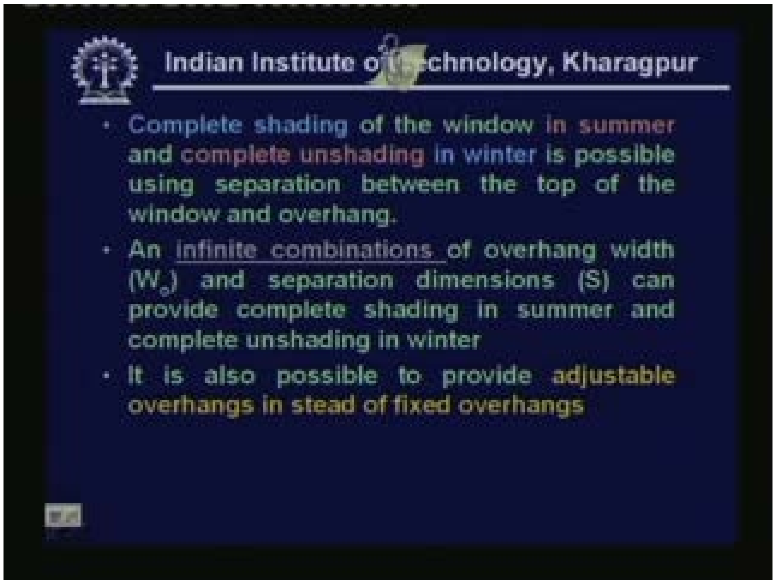

Now complete shading of the window in summer and complete unshading in winter is possible use separation between the top of the window and overhang okay. So ideally we would like to completely shade it in summer because we do not want any heat in summer whereas we want lot of heat in winter so you want complete unshading okay. So complete shading and unshading is possible using what is known as the separation is nothing but the distance between the top of the window and the overhang and an infinite combinations of overhang width and separation dimensions can provide complete shading in summer and complete unshading in winter okay. so let me show this.

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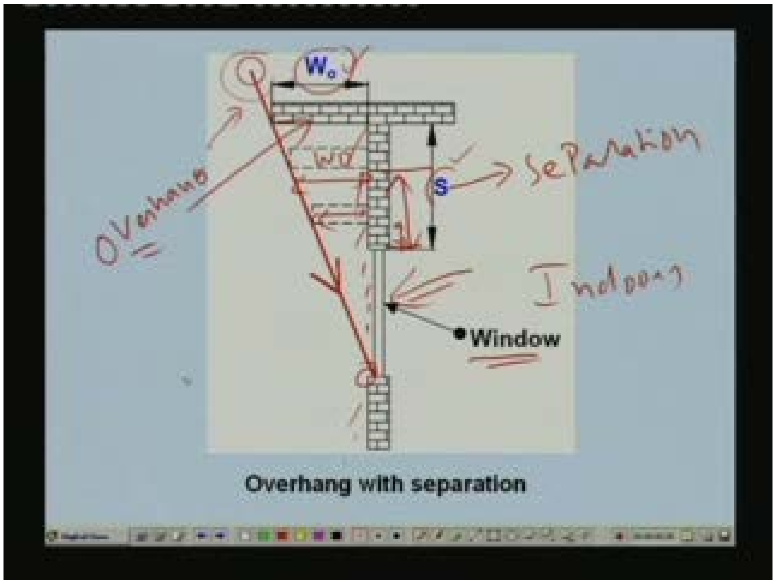

Okay, one thing I would like to mention here is that the position of the sun will be varying continuously okay. So when I am saying that this over hang can completely shade this window it can only complete shade at a particular point okay. It cannot complete shade all the time right. Because the position of the sun varies continuously. So normally what you have to do is you have to find out the point at t\which the load is likely to be peak okay. And the design overhang in such a way that during summer the window is completely shaded at this particular incident oaky and during winter it is completely unshaded.

So this is one thing you must remember again all these dimension and all will be varying between latitude to latitude. Because the solar geometry is varying from latitude to latitude and it also varies from the orientation to orientation okay. These things again you have to keep in mind. Now you can see from this figure that suppose you have this dimension w naught and this is what is known as separation okay. So this is your window if you provide this separation and this mush width of the overhang. Because this is your over hang right you can completely shade this window because the sunlight is falling at this point. So the entire portion this entire thing is in shade okay whereas the, whatever is below this is unshaded.

So no solar radiation is entering into the indoors which are on this side right. If you take this w naught and this S you can also take for example this w naught okay and this S. Then also you can completely shade the window or you can take this w naught and this S oaky. Again you can completely shade the window. That means a large number of combinations of w naught and S are possible which can result in the complete shading or unshading of the window okay. Of course there are certain limitations of fixed overhang.

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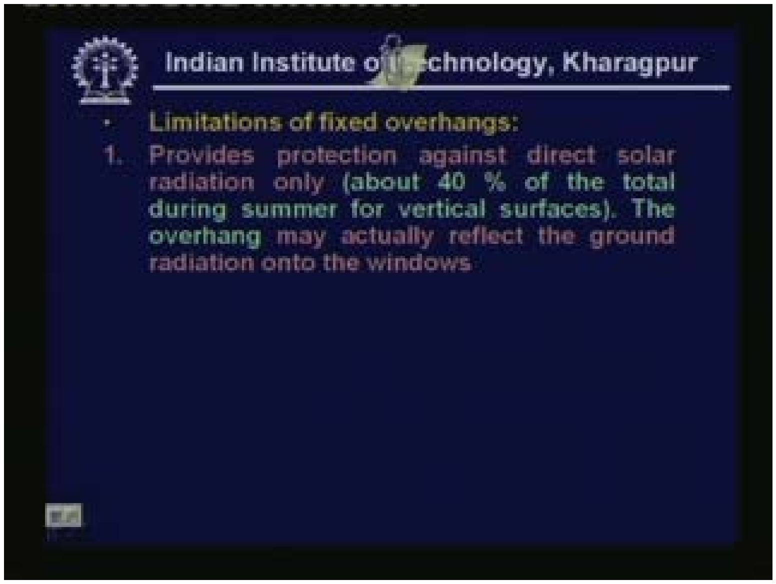

So far we have been discussing about fixed over hang it they have certain limitation what are the limitations any overhang provides protection against direct solar radiation only okay. It cannot provide any protection against diffuse or reflected radiation and you find that because of the variation of the transmittivity with incident angle during the peak summer time you find that for a vertical surface only about forty percent of the total solar radiation consists of the contribution of direct radiation okay. That means about forty percent of the total during summer is because of the direct solar radiation and provision of overhang can only reduce this right. That means it can only handle the forty percent rest sixty percent cannot be handled by the overhang. Because rest sixty percent consists of diffuse as well as reflected radiation and overhang cannot reduce diffuse and reflected radiations okay. External over shading right and you find that sometimes over hang can work in a negative manner. For example the overhang may actually reflect the ground radiation on to the windows right.

So it is a bit it may look like a paradoxic, that you provide an overhang. You find that there is more heat in the room oaky. This happens because if you are ground is highly reflective right then first the radiation will be reflected from the ground on to the overhang and from the overhang on to the wall on to the window right. So ultimately because of these reflections you will find that there is lot of radiation entering into the building not through direction radiation but through reflected radiation okay. Then over hang is working in a negative manner okay. So this one of the limitations of the fixed over hang and during mornings and evenings when the sun, so low in the sky that over hangs can provide only minimum protect okay. So they are not really very useful during mornings and evenings and over hangs are truly affective for windows facing thirty to forty five degrees of south okay, if over hangs are not very useful on east and west direction.

For example why because during on east and west direction the maximum radiation occurs during morning for east and during evening for west and during morning for east and during evening for west the position of the sun is very low right when the position is of the sun is very low. That means the latitude angle is very low the overhang cannot block the direct radiation okay. So it is not of no use the only way of blocking solar radiation east and west faces during morning and evening is to use something else like a wall or a tree or an adjacent building right. But not overhang this is the, another limitation of overhang right in spite of all these limitations overhangs are widely used because they also provide protection against rain. So overhangs are highly recommended okay.

So this is as far as the effect of solar radiation and how to calculate the cooling and heating loads this requires little bit of extension. But how to calculate the energy transmitted into the building due to solar radiation first through opaque surfaces and next through transparent surfaces again the for the transparent surfaces with and without external shading so from the discussion we can calculate all these things.

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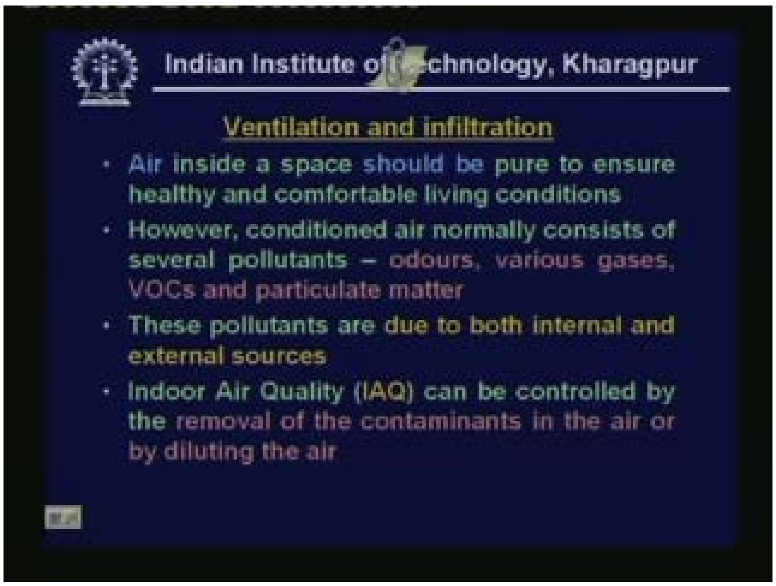

Now let us look at another aspect of cooling and heating load calculation that is ventilation and infiltration air inside a space show okay, should be pure to ensure healthy and comfortable living conditions however conditioned air normally consist of several pollutants okay. So what are these pollutants? these pollutants are orders various gasses such as carbon dioxide and volatile organic compounds or VOCs and particulate matter okay, see, you find that any conditioned space will not be hundred percent pure.

But it will consist of these impurities and if these impurities if the concentration of these impurities goes beyond a certain level you find that the indoor environment is not, neither it is healthy nor it is comfortable for the occupants okay. So these pollutants are due to internal and as well external sources internal sources are human beings appliances etcetera whereas the external sources are the outside air itself. And indoor air quality abbreviation is IAQ can be controlled by the removal of the contaminants in the air or by diluting the air. That means you can maintain the purity of the air inside a conditioned space either by removing the contaminants or by diluting the air okay.

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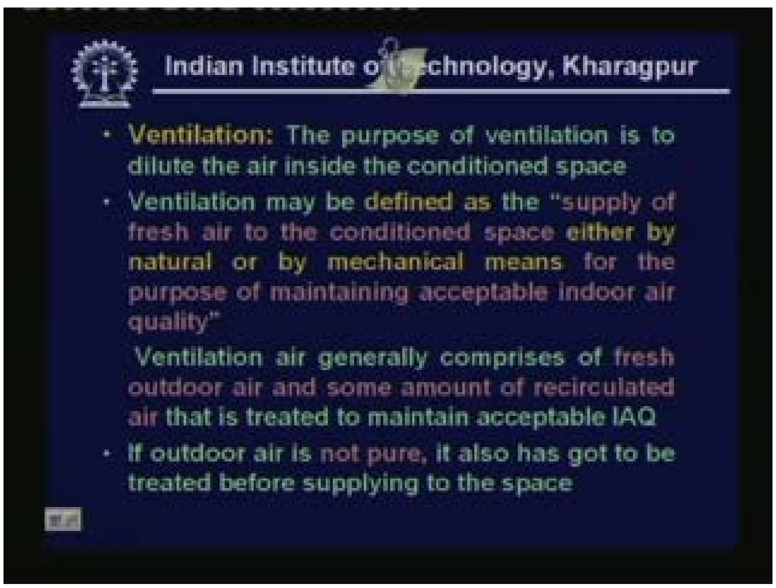

There are you can use the both of these techniques now with reference to this indoor air quality. What is ventilation, what is the purpose of ventilation? The purpose of ventilation is to dilute the air inside the conditioned space okay. There by maintain required indoor air quality and ventilation is defined as the supply of fresh air to the conditioned space either by natural or by mechanical means for the purpose of maintain acceptable indoor air quality okay. So the whole purpose of ventilation is to maintain required indoor air quality which is very much essential for comfortable and healthy living conditions and this consist of supplying fresh air and either by natural means. That means either by natural ventilation or by mechanical mean that means either by using an exhaust fans or blowers etcetera okay.

This is the definition of ventilation and ventilation air generally comprises of fresh outdoor air and some amount of re-circulated air that is treated to maintain acceptable indoor air quality okay. So the ventilation air need not to be all outdoor air it can be a part of outdoor air and some part of it can be re-circulated when you are using re-circulated air for ventilation purpose you have to treat it first then use it for ventilation okay. And if the out outdoor air is not pure that means outdoor air itself is dirtied consists of lot of dust then it also has got to be treated before supplying to the space.

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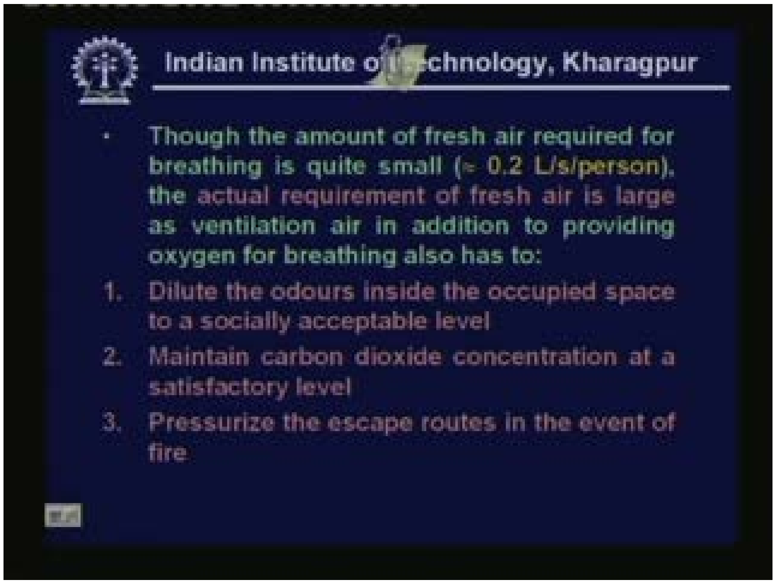

Though the amount of fresh air required for breathing is quite small that means its amount of fresh air required is about point two liter per second per person from breathing point of view the actual requirement of fresh air is large as ventilation air in addition to providing oxygen for breathing also has to serve the following purposes. So only one of the purposes of ventilation is to provide oxygen. In addition to providing oxygen ventilation air also as to dilute the orders inside the occupied space this is very important to a socially acceptable level okay. So odor dilution is a important function of ventilation second important function is to maintain the carbon dioxide concentration at a satisfactory level and the third practical requirement is that it should be able to pressurize the escape routes in the event of fire okay. So these are the other important functions of ventilation air.

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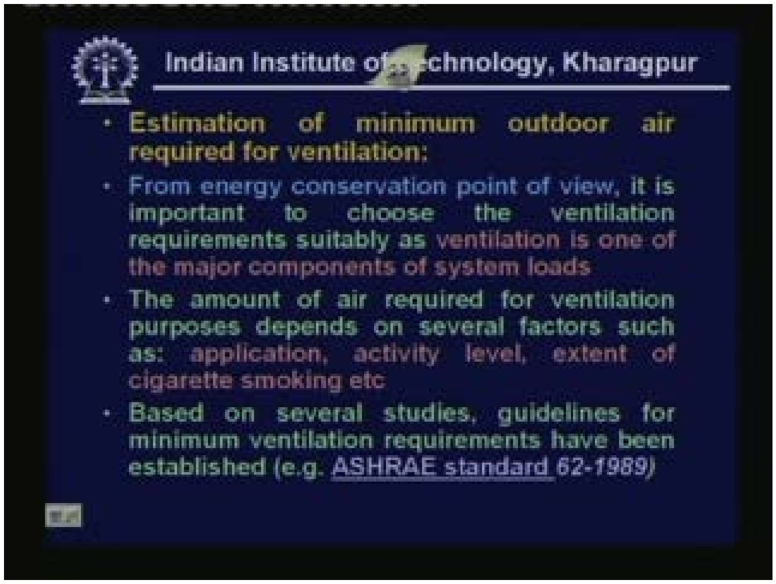

Estimate, let us look at the estimation of minimum outdoor air required for ventilation how do we find how much air is required for ventilation from energy conservation of point of view it is important to choose the ventilation requirement suitably as ventilation is one of the major components of system load s oaky. So it is very important to choose it properly you cannot have lot of ventilated air then you have to pay in terms of running cost the amount of air required for ventilation purposes depends on several factors such as application activity level extent of cigarette smoking etcetera.

So several factors affect the amount of required air okay. And based on several studies extending over several years guidelines for minimum ventilation requirements have been established for example one of the guidelines is ASHRAE standard sixty two bar nineteen eighty nine.

Let me give a small example of this ASHRAE standard what is it say this is a typical outdoor air requirements for ventilation adopted. From ASHRAE standards you can see that for offices if the occupancy level is seven people for hundred meter square floor area and if it is smoking zone you require ten liter per second per person and if it is a non smoking zone you require two point five liter per second per person okay.

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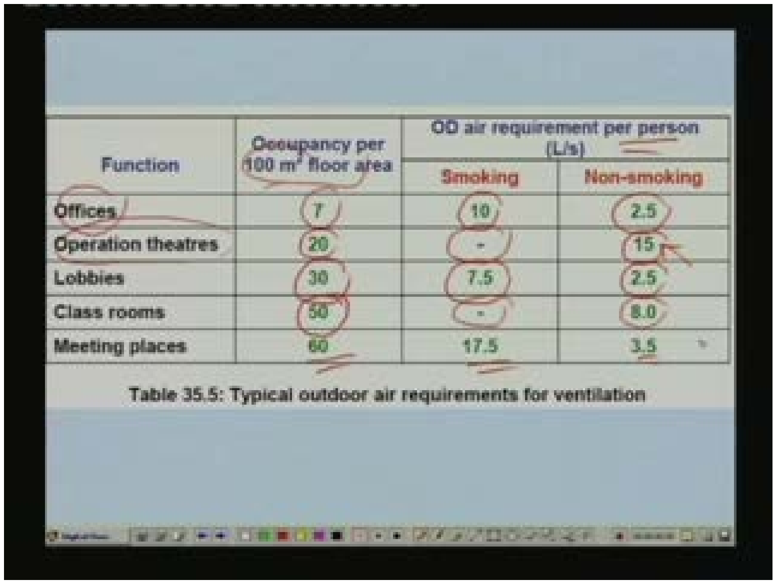

Function	Occupancy per 100 m² floor area	OD air requirement per person (L/s)	
		Smoking	Non-smoking
Offices	7	10	2.5
Operation theatres	20	-	15
Lobbies	30	7.5	2.5
Class rooms	50	-	8.0
Meeting places	60	17.5	3.5

Table 35.5: Typical outdoor air requirements for ventilation

And for operation theatres you require high levels of ventilation and the occupancy will be twenty persons per hundred meter square and normally smoking is not allowed but still you require high ventilation air. Because you have to maintain high level of purity and for lobbies where the occupancy is slightly higher thirty persons per hundred meters square floor area and if smoking is allowed you require about seven point five liter per second per person. And if the smoking is not there then two point five liters per second.

And for class room for example where the occupancy is still higher hundred person per fifty persons per hundred meters square floor area and normally smoking is not allowed. And the required ventilation is eight liter per second per person okay. And for meeting places these are the values so one thing you can notice here is that as the occupancy level increases the required amount of outdoor air are increases. Similarly if you are allowing smoking then outdoor air also requirement also increases okay.

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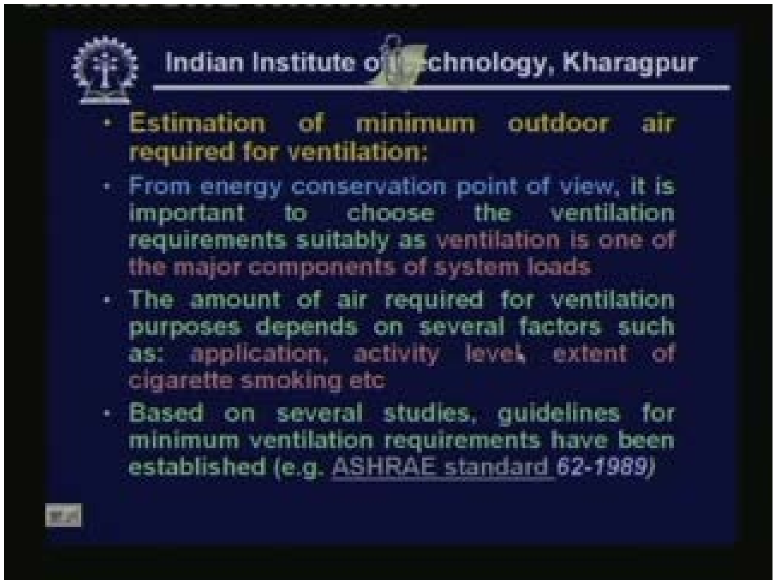

So based on, if you have this kind of data you can decide what is the outdoor air requirement. Let us see how to estimate infiltration. Now, so for I have been discussing about ventilation and let us see what is infiltration and how to estimate infiltration loads first of all infiltration it is defined as the uncontrolled entry of untreated outdoor air directly into the conditioned space okay.

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So you have to carefully note the different between infiltration and ventilation both involve supply of outdoor air. Whereas ventilated air is in complied in a controlled manner infiltration is uncontrolled entry okay. You have no control on that and infiltration of outdoor air takes place. Because of two effects one is what is known as wind effect and the other one is what is known as stack effect. As the name implies the wind effect means infiltration due to the wind blowing over the building.

So whenever wind blows over the building pressure difference are created because of these pressure differences outside air enters into the building and air from the building leaves the building okay. This is what is known as wind effect and the second effect is what is known as stack effect this is nothing but the entry of outdoor air because of the effect. So the affect is created because of the temperature difference between the inside and outside whether it is summer or winter the inside temperature will be different from the outside temperature you have a some temperature difference.

So because of this temperature difference there will some density differences between the outside air and inside air and if your building have some openings. Because of the density differences there will be entry of outdoor air into the building and some amount of or same amount of air leaves the building okay. So this is what is known as stack effect. In commercial buildings even though infiltrations supplies outdoor air in commercial buildings effect are made to minimize infiltration. Because it is uncontrolled and unreliable you cannot make any design depending upon infiltration because it depends upon unreliable factor such as wind and stack okay.

So generally it is reduced and so what are measures to reduce this, these measures? As you know very well are the use of vestibules or revolving doors use of air curtains building pressurization if you pressurize the building. And if the inside pressure is higher, then the outside pressure no outdoor air can entry. So there by you can reduce infiltration and also you can use proper ceiling of doors windows etcetera thereby you can reduce the infiltration loads.

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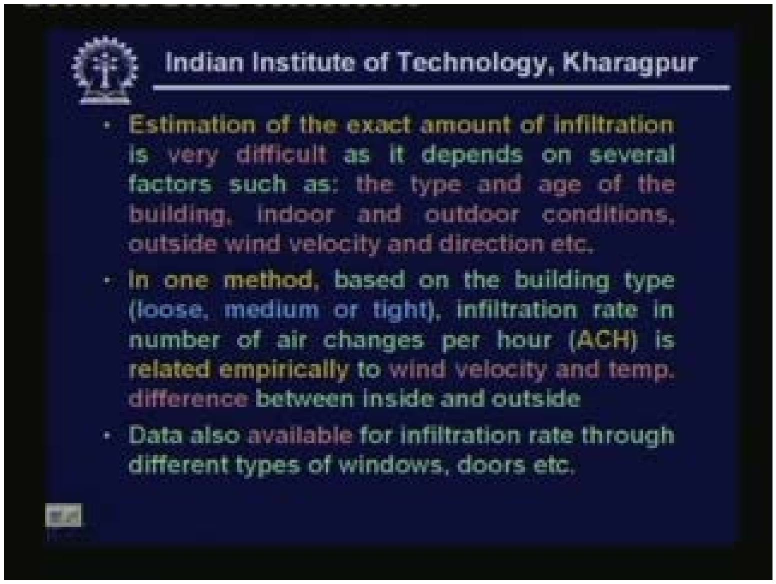

Now the estimation of the exact amount of infiltration is very difficult as it depend on several factors such as the type and age of the building indoor and outdoor air conditions outdoor outside wind velocity and direction etcetera okay. So analytical estimation is very difficult there is several methods are used one method is what is known as a air changes per hour in this method depending upon the building type whether it is lose building medium building or tight building infiltration rates are specified or rated empirically to win velocity and temperature difference. So if you know the wind velocity and temperature difference using the empirical equations you can calculate the infiltration rates and data is also available for infiltration rate to different types of windows doors etcetera okay.

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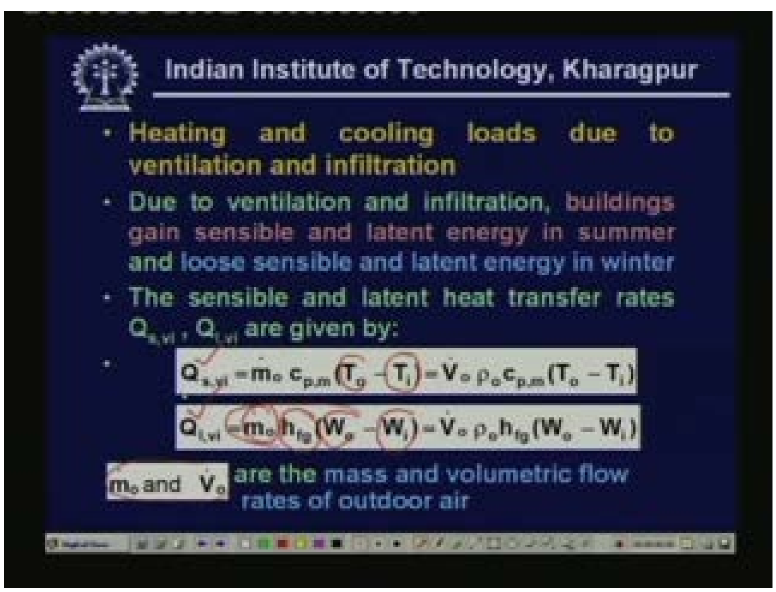

Now let us look at heating and cooling loads due to ventilation and infiltration due to ventilation and infiltration buildings gain sensible and latent energy in summer and lose sensible and latent energy in winter.

So you have to note here that the energy transfer is both in the form of sensible as well as latent modes okay. And the energy is gained in summer and it is lost in winter and sensible and latent heat transfer rates are simply given by Q sensible is m dot Cp into delta t which is, you can write in terms of volumetric flow rate that is v naught into density into Cp and latent heat transfer rate that is this okay. Here hfg is the latent heat of ha vaporization m dot o is the air flow rate due to infiltration or ventilation and w o and w i are outside moisture content and inside moisture content and t naught and t i are the outside dry bulb temperature and inside dry bulb temperature. And as I have written here m dot and v naught are mass and volumetric flow rates dye to infiltration and ventilation.

So if you know the infiltration ventilation rates and outdoor and indoor condition you can calculate what is the essensible heat transfer because of ventilation because of ventilation infiltration what is the latent heat transfer rate because of infiltration and ventilation okay. So that is how we can calculate but one of the major difficult is to find out the infiltration rates okay. At this point I stop this lecture and we will continue this discuss in the next lecture.

Thank you.