Sustainable Architecture

Prof. Avlokita Agrawal
Department of Architecture and Planning
Indian Institute of Technology, Roorkee

Lecture – 39
Energy Efficiency-IV

Good morning. Welcome to the 4th lecture on Energy Efficiency as part of the online ongoing course on Sustainable Architecture. In the previous three lectures of this week we have discussed about the various terminologies related to energy efficiency. We have looked at the different properties and concepts which need to be kept in mind while designing energy efficient buildings. We have also seen how each one of these concepts will be used in building design to improve its efficiency.

So, we saw that it is the building design in the first place which should be considered for example, what should be the orientation of the building, what should be the surface area to volume ratio of the building, what should be the geometry of the building and so on. And, then we also saw what are the different properties of the materials thermal properties of the materials which we should consider which will help us to improve the energy efficiency for example, we talked about the U values, the SHGC values.

So, we understood the fundamental concept of each of these properties and how does it affect the performance of the building, the building physics aspects of that. In today's lecture we will be talking about what are the compliance options. So, when we are talking about the different properties of the materials, the different factors, the different parameters related to building energy efficiency how do we go about them to comply as per the rating systems, as per the codes.

So, in this case when we are talking about the Indian scenario, we have our code which is called Energy Conservation Building Code. And, the requirements for energy efficient buildings come from this code which is ECBC. When we are talking about ECBC and when we are talking about the building envelope at large, there are few components distinctly which we have also seen in the previous lecture. So, we have opaque walls and roofs and then we have fenestrations and skylights, all of these together form the building envelope; other factors include lighting, what kind of lighting, what is the wattage, what is the efficacy.

So, lighting power density is largely what we are talking about and then we also have HVAC, pumps, electrical power and all the electrical systems, electrical and mechanical systems. So, we will start dealing with each of these components one by one and see what ECBC prescribes.

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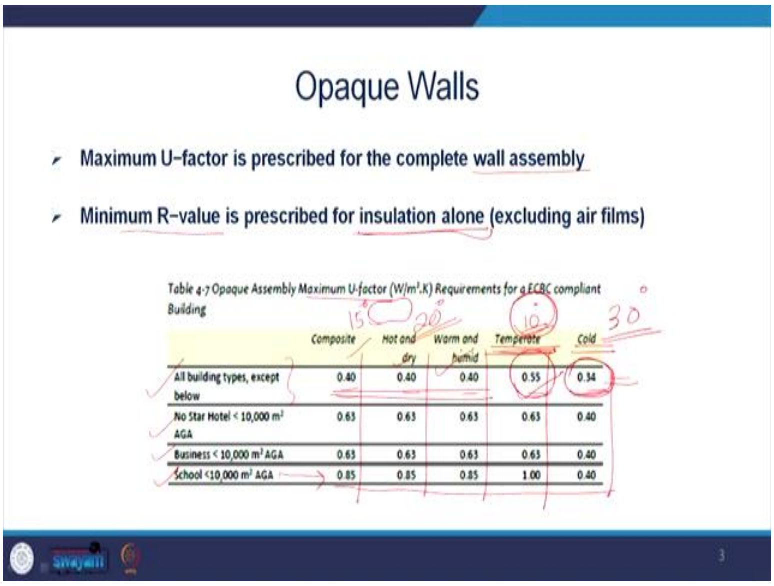

So, first of all we take the case of opaque walls. Now, when we are talking about opaque walls ECBC prescribes the maximum U value or U factor for a complete wall assembly. So, when we say a complete was wall assembly, it implies there will be a plaster on one side of it and then there will be a brick wall. There might be an insulation in between, then another cladding may be a wall or another hard material and then another layer of plaster or finishing material.

So, this entire set of materials is the wall assembly, it is the complete wall assembly and when we are talking about the properties of this wall; we are talking about the properties of this complete wall assembly and not an individual material. So, we can look at the complete U value of this wall assembly or alternatively we can also look at the minimum R value which is the resistance value which is prescribed for insulation alone.

So, only the R value of insulation can also be met with, this is the prescriptive approach; so, where these values have to be met. So, if you look at these values; so, the U values have been distinctly defined for buildings depending upon their purpose, depending upon their function.

So, these offer all building types except hotels, business purpose buildings and schools all other building types have these specified U values for walls as this. So, we see for composite, hot dry and warm humid climates, the U values are 0.4. For temperate climates the U value is prescribed to be higher. Now, if you remember the concept of U value, the U value which is the thermal transmittance property of any material or an assembly of materials is the property by virtue of which the heat is transferred from one side to the other side based upon the temperature differential. So, if we look at the composite climate, hot dry climate and warm humid climate the temperature differential is quite high. At times it is in the range of the in peak summers which may be in the range of 20 degree centigrade, but this is only during the peak summers. In extreme winters it may be around 15 degrees and rest of the time of the year, it may be somewhere in between them, where it may be as less as 5 degrees or it may be as high as 20 degrees.

When we are looking at temperate climate, now temperate climate if you remember our discussion on climate and weather; the temperate climate has very less diagonal range. So, the difference between indoors and outdoors will often be less, very less. So, we are looking at a time temperature range, the difference between indoor and outdoor in the range of a 0 to 10 degrees only; so, maximum is 10 degrees. So, having very low U values will not affect much because anyways the temperature differential is going to be much lesser.

While, when we look at the cold climates the extremely cold season in cold climates has a higher temperature differential between indoors and out, the outdoors may go sub-zero. So, we may be having temperatures which are like minus 10, minus 5 degree centigrade while indoors we may be wanting to maintain a temperature of around 20 degree centigrade. Thereby, the temperature difference increases to around 30 degree and therefore, we would see that the for all the buildings the maximum, if emphasis is on U values for cold climates and they have been prescribed to be the lowest.

With this we can see that different buildings have different, different building types have different U values where for school buildings which are going to be occupied largely during the day; they have been provided with most lenient values, but the difference from climate to climate that variation remains the same.

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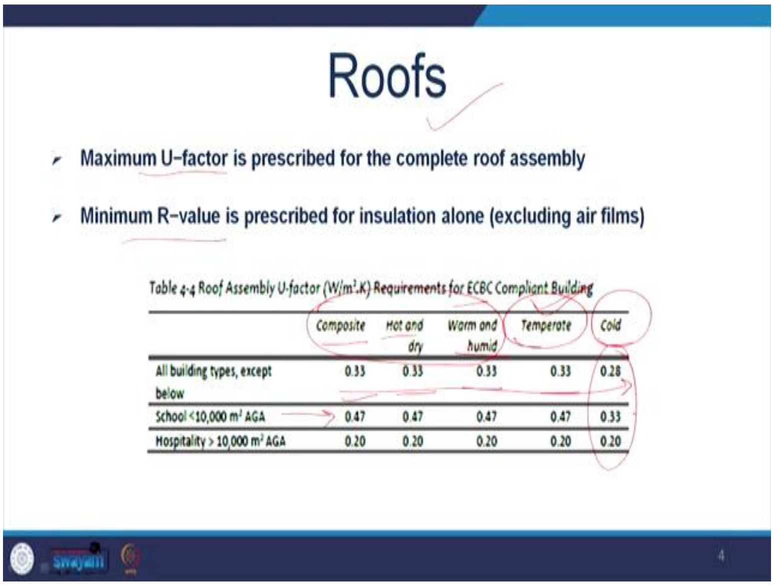

Another opaque component is roof and for roofs also which is also opaque maximum U factor and my minimum R value is prescribed exactly same as that for the walls. And, we can see the same trend following here for the climate variation. Now, here we would see that there is no difference between these three and temperate as well because, the roof receives the heat is largely because of the solar radiation falling onto the surface.

And, in temperate climates the heat received because of solar radiation is same as that of these 3 climates and hence no variation in U value for these 4 climates. While, in cold climates again the temperature differential is quite high. Therefore, the U value assembly U factor is proposed to be low as compared to all other. Again we would see that the school building since there are daytime use buildings they are proposed to have relatively higher U values. So, more lenient properties are allowed for roofs of school buildings, opaque components of school buildings.

Now, how do we calculate this U value? So, often the U values the resistance or conductivity values for individual materials are available, but for the assemblies it is not available.

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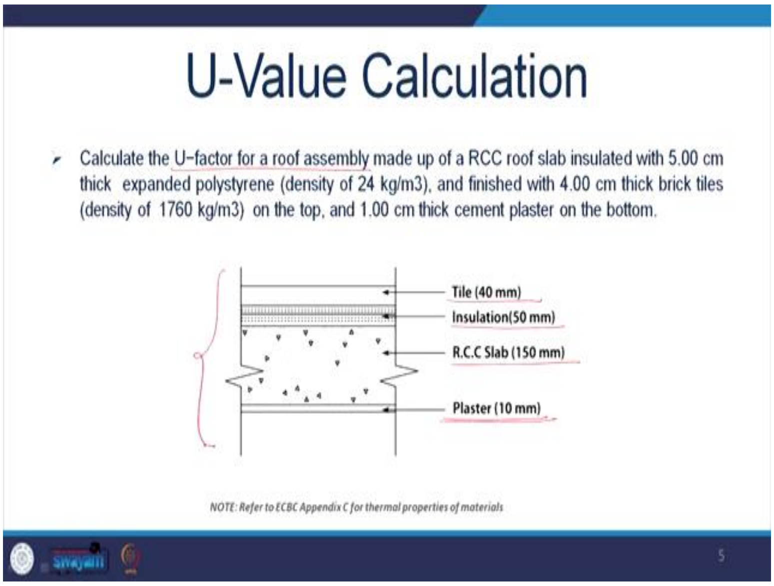

So, in ECBC the method for calculating the U value for an assembly is also given, let us quickly look at this calculation here. So, what we have to do is we have to calculate the U factor for a roof assembly which is made up of mainly RCC slab which is 150 mm thick. It has an insulation of 5 centimeter 50 mm on top of it and which is the expanded polystyrene XPS. And, then on top of it we have tiles which is 40 mm thick and in the bottom on the inside it has a plaster which is 10 mm thick. So, we have to calculate the collective U value for this roof assembly.

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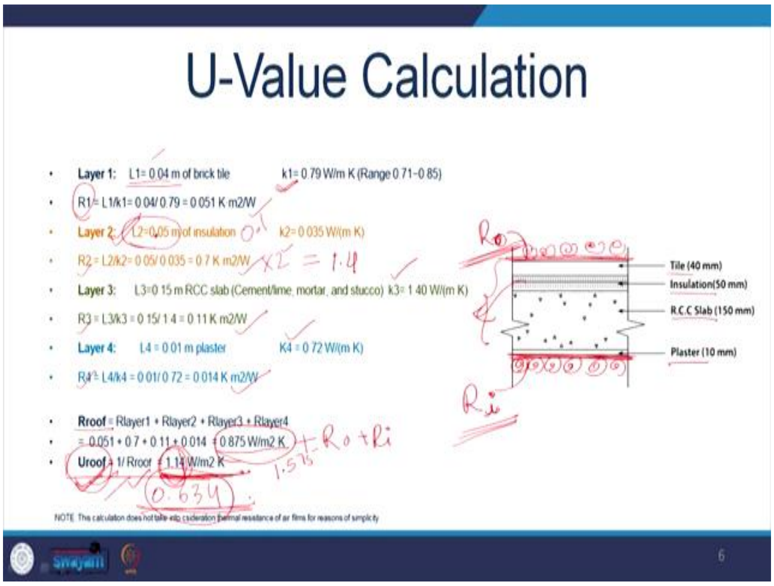

Looking at ECBC, ECBC also has annexure where individual properties for these materials separately are given. So, if we look at this for each of these 4 layers; for each of these layers we first write down the thickness of this material in meters. And, from ECBC annexure we note down the conductivity value for the given materials. So, this is for tile, this is for insulation, this is for the RCC slab and for plaster. First of all we calculate the resistance values for each of this by dividing the thickness of the material by its conductivity value.

So, for each material its resistance values will be calculated, once we have calculated the resistance values we calculate the total resistance offered by the roof which is the sum total of all these different resistances. Now, here for simplicity we are taking the resistances offered by these 4 layers only, 4 layers of materials. But, when we look at it scientifically and as per the definitions there is a thin layer of air above the style and also beneath this. On both sides there is a thin layer of air which also offers resistance to heat transfer.

Now, whenever we are calculating the overall resistance offered we would also calculate R 0 and R i. So, this is R outside resistance offered by air outside and resistance offered by air inside and that is dependent upon the speed of the air. So, small eddies are formed on the surface of this layer, both the sides. This is dependent upon the air speed and based upon that the resistance offered by the air is calculated.

These values are also given in ECBC and we can take it from there. For the ease of a calculation for simplicity we have not taken these into account, but ideally, we will be taking these two resistances offered also into account and add them here. So, R o and R i will also be there, the total resistance of the material then calculated the inverse of it 1 by R will give us the overall U factor of the opaque assembly, here it was for the roof. So, this is how the U value will be calculated.

Now, when we are looking at the compliance using prescriptive method; so, we have to achieve the U value less than the U value prescribed for the wall assembly or the roof assembly as per ECBC. So, if they prescribed U value for the roof assembly has been given to be 0.3 we have to achieve a U value which is less than or equal to 0.3; because that is the maximum U value which is prescribed. If you look at the code, this is much higher than what is prescribed in the code which implies that either the insulation needs to be increased.

So, if we increase the thickness of this insulation from 0.05 meter to say around 0.1 meters. So, instead of this if we increase it to 0.1, this will be increased by 2 and we will get a resistance of 1.4 Kelvin meter square per Watt. And, when we add it up here, it is further added to make it approximately 1.575. And, if we calculate the inverse of it, it comes out to be 1 by 1.575.

So, we get a U value of 0.634 which is still higher than the U value which is prescribed by the code, but we can see that just by increasing the thickness of insulation the U value has substantially reduced. So, we have to do those permutation combinations to achieve the U value of the root within the prescribed limit.

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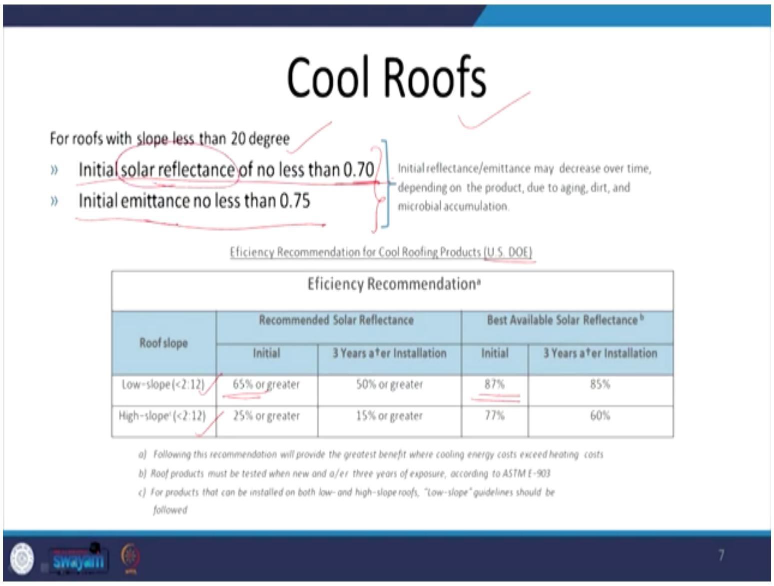

The next prescription is about the cool roofs, we have also seen how cool roofs work. So, for India the prescription is that the initial solar reflectance should not be less than 0.70 and the initial emittance should not be less than 0.75. This is for the roofs with slope less than 20 degree, for roofs which have slope higher than 20 degree the values would vary. The reflectance values especially would be much lower because, they are more the high slope is more likely to cause the glare on surrounding buildings.

So, this is one of the prescriptions as per the US DOE, where they have prescribed the initial solar reflectance for different slopes, where the initial solar reflectance has been prescribed to be higher than 65 percent for the low sloped roofs initially. And, the best available solar reflectance in the US market is around 87 percent. So, when we are talking about cool roofs, we are actually looking at the solar reflectance and the emittance of the material.

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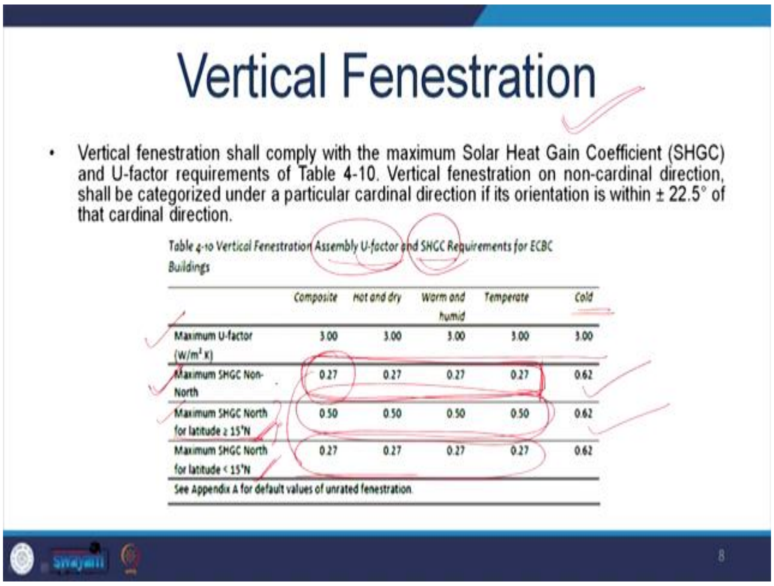

The next component which is also very important and lot of work is required here, because a lot of heat transfer is possible through the vertical fenestration. We are talking about largely glazed windows here. So, when we are talking about vertical fenestration, we have two requirements. One is the assembly U factor which is the U factor taking into account both glass and frame and we also have the SHGC requirements for the same fenestration.

The as per the ECBC the U factor and SHGC requirement are given for the fenestration based upon the orientation and latitude. So, we have U value irrespective of the latitude and orientation and for SHGC we have SHGC maximum values of SHGC prescribed for the non-north windows. And, maximum SHGC prescribed for the north facing windows based upon their latitudes greater than equal to 15 degree north and less than 15 degree north. This is based upon the amount of solar radiation, the direct light which is received on the northern side.

So, based upon this the U values and SHGCs are given, this is the maximum value of it. Again if we see the U value for all the windows in all the climates they have been prescribed to be same, because we have also seen that the larger percentage of the total heat gained through a fenestration is because of SHGC. So, greater emphasis has been placed here for SHGC. If we see for all the non north windows the SHGC in 4 climates has been prescribed to be quite low 0.27, implies only 27 percent of the direct solar radiation, the heat falling on the window is transmitted inside permitted inside. While, for cold climate the SHGC has been prescribed to be much higher.

So, the so that the window is able to allow maximum amount of heat indoors in case of cold climate. If we look at the SHGC for the north facing windows for latitude greater than equal to north 15 degree north, we see that higher SHGC values have been prescribed. Because, all the places with latitude greater than equal to 15 degree north will not receive any direct solar radiation from the north and hence there is no requirement to keep the SHGC low. However, for cold we still are keeping it very high.

In all other windows for places which are having their latitudes less than 15 degree north, the SHGC has again been prescribed the same as the non-north windows which is 0.27. So, when we are selecting the fenestration we have to meet the prescriptive requirement. Now, when we were having this discussion about the SHGC we talked about the availability of direct solar radiation onto the window. Now, if the shading is provided on top of this window outside, the direct solar radiation which is incident on the window, the fenestration, will reduce.

And, there the requirement for this SHGC may not remain that stringent, it will become lenient which we will see in subsequent slides.

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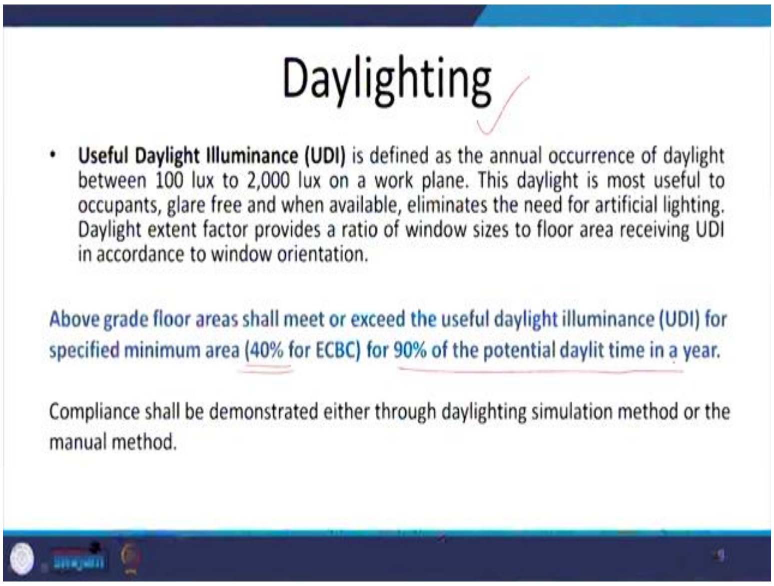

The next important factor here is daylighting, here we are talking about the amount of natural light available in a habitable space. So, we are talking about the amount of light daylight which is available on a work plane and useful daylight which is available on a work plane throughout the year. So, for 90 percent of the potential daylit time in a year.

So, when we are talking about compliance, we are talking about minimum 40 percent of the area, total floor area shall remain potentially lit, shall remain daylit for at least 90 percent time of the daylit time in an year. Now, when we are talking about the compliance here, what we are looking at is we are looking at the daylit areas.

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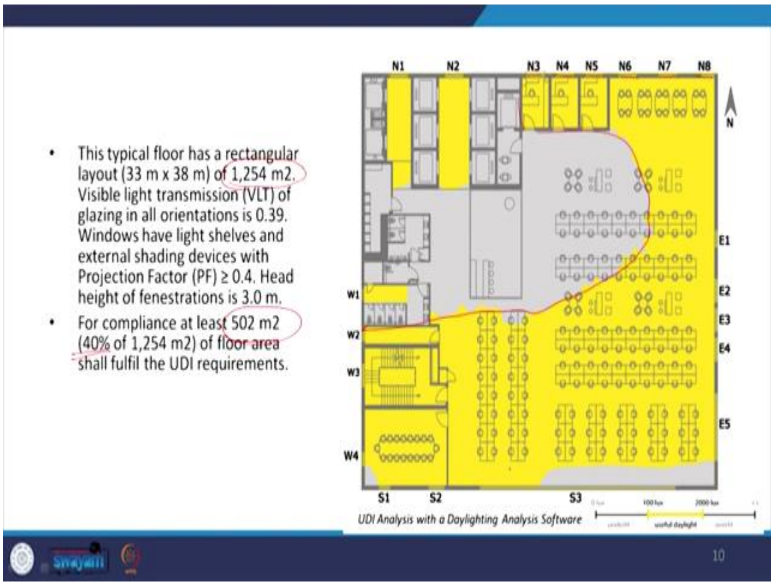

So, these are the windows if you can see. So, from these windows this particular plant is using a simulation software, where the daylit areas have been calculated. Now, these daylit areas have been calculated taking into account that this area remains day lit for 90 percent daylit time in the year and the minimum that is required is 40 percent. So, if the total floor area was 1254 meter square at least 502 square meter of this total floor area is supposed to be lit.

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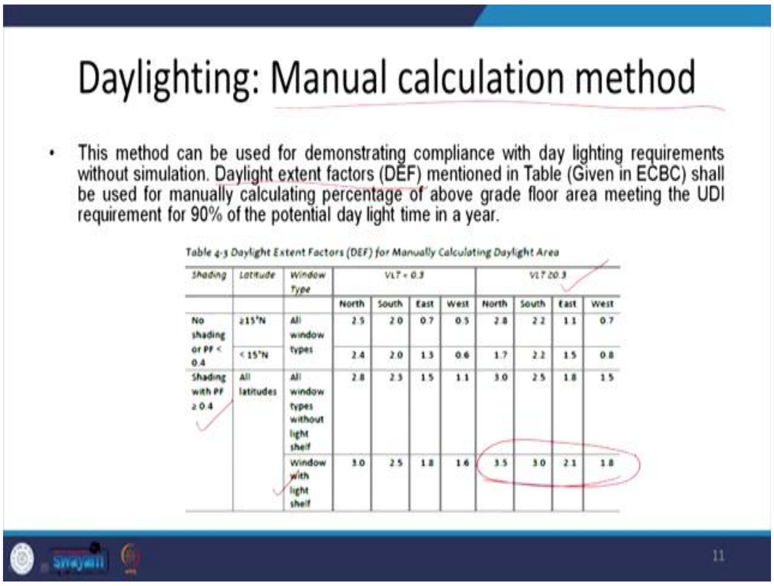

Now, how do we prove the compliance? So, one method is by using simulation tools which we will subsequently see in other portions of the ongoing discussion. When we are looking at the manual calculation method, we have to calculate the Daylight Extent Factors or DEF. Now, the values for these are to be calculated based upon the tables which are given in ECBC and the compliance criteria remains the same.

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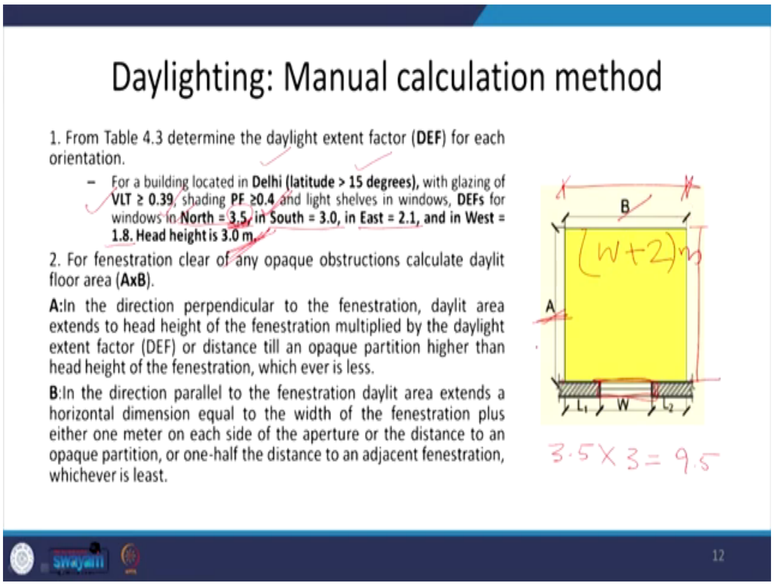

So, when we have to calculate the DEF, first of all we need to locate the latitude of the place. For example, in this case where we are discussing about the DEF, this is in Delhi which has a latitude greater than 15 degrees, next we have to know the VLT of the glass. So, the VLT of the glazing for this window is 0.39 here, this window also has a projection an overhang and the projection factor of it has been given to be 0.4. So, these are the basic components which we require, the latitude, the VLT, the projection factor and then we calculate the DEF based upon the table from the ECBC.

So, when we know that the VLT is greater than 0.3 and the latitude is greater than 15 degree north, here we are talking about window with a projection factor of zero point greater than equal to 0.4. Based upon this we would calculate the DEFs for all the windows on different orientations with and without light shelf, here it is with light shelf. So, we can see that this is the relevant numbers of DEF which is to be used in calculations here. Based upon this we get these numbers: north 3.5, south 3.0, east 2.1 and west 1.8.

And, the head height is also available as per the design, now based upon all this we have to calculate the area which will be daylit because of this window here. So, we have to know these dimensions A and B, A is the depth up to which the daylight will be available and B is the horizontal dimension up to which the daylight will be available; considering that there is no opaque partition in this given area. In case there is an opaque partition higher than the head height of the fenestration the extent will reduce.

So, once we have calculated; so, A which is the depth, it is in the direction which is perpendicular to the fenestration. And, the day light area extends to the head height of the fenestration multiplied by the DEF which we have calculated or the distance till an opaque partition higher than the head height of the fenestration appears. So, if we look at this particular case, we have a DEF of say 3.5 in north.

So, if we are calculating it for the north fenestration we would say we would see that this has a DEF of 3.5 and the head height is 3. So, we have A available as 3.5 multiply it by 3, that is 9.5. And, in horizontal direction it is equal to the width of the fenestration plus either 1 meter on each side of the aperture or the distance to an opaque partition.

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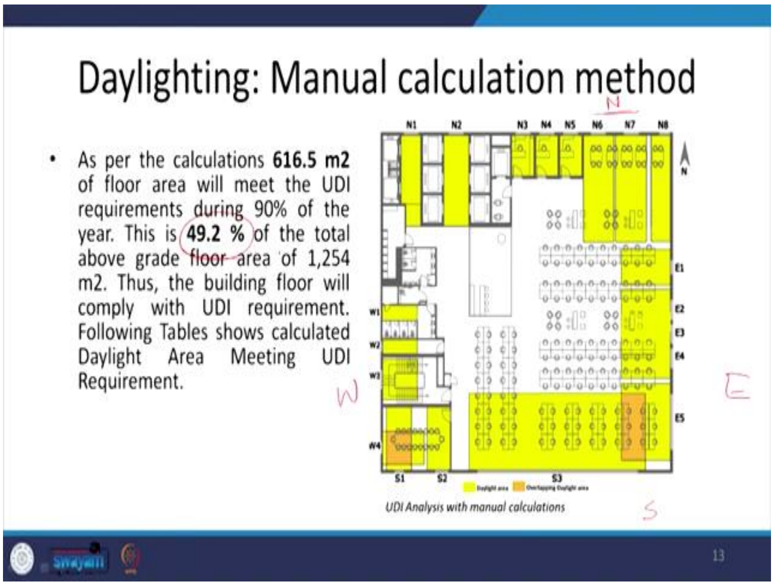

So, for B if this is W we are talking about W plus 2 meters. On the basis of this we will calculate the daylit area which is available for each of these windows on different directions, orientations. So, we will calculate it based upon the DEF for north and south east and west and together we will calculate the total area which is which will meet the UDI requirement, the usable day light requirements as per the prescriptions of ECBC.

And, as per these calculations this comes out to be 49.2 percent which implies that this particular plan, this particular design is compliant as far as day lighting requirements are concerned.

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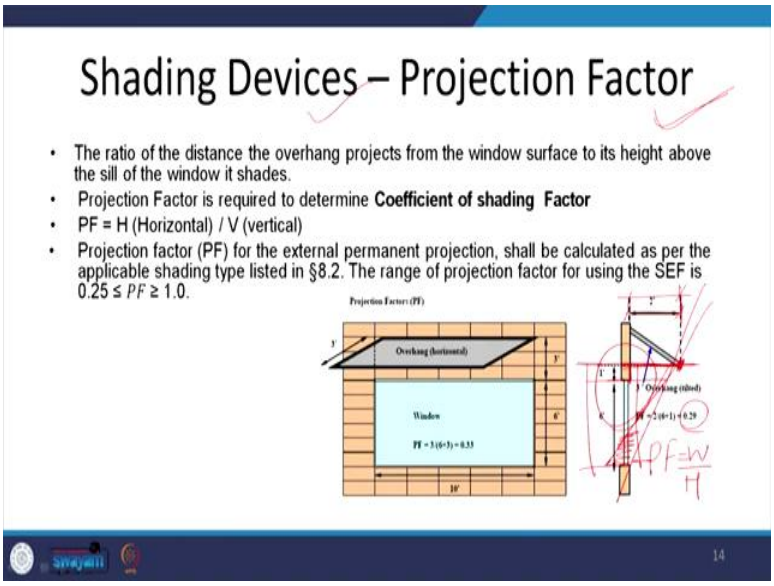

Next in continuation of the fenestration we are talking about the shading devices. So, we have very quickly in passing discussed about the projection factor which is PF. When we are talking about projection factor we are taking the shading which is offered by the by the projection. So, in this case the horizontal projection is 2 feet and the vertical and the height of the window is this height, where effectively the point at which the projection has been installed that, but a bottom most point we calculate the total height.

So, this is the W by H, where W is the width of the projection and H is the height of the window from its shelf to the bottom most point of the shading device. So, W by H is the projection factor and we calculate the projection factor with this given data. Now, whenever we have projection factor as we have seen in the previous lecture as well; it will limit the amount of sun which is falling directly onto the window, the glazing fenestration. So, this portion of the sunlight has already been cut off.

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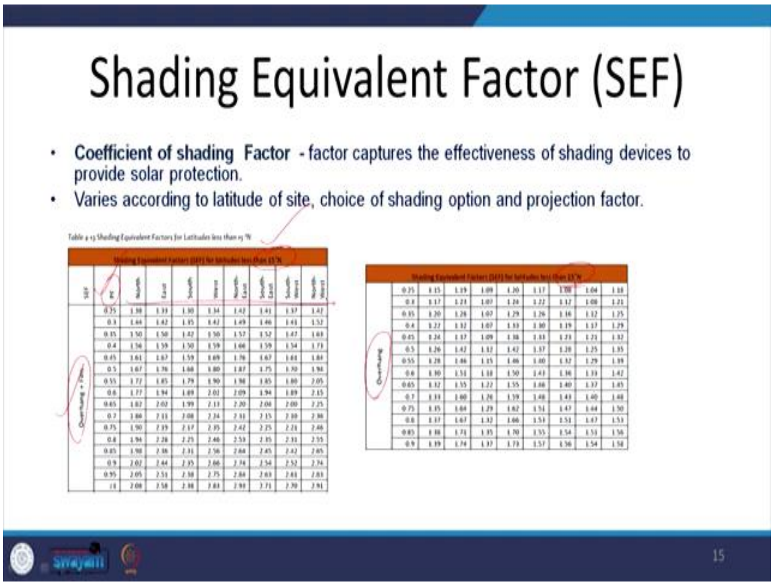

To account for this projection and this shading which is provided by this shading device, we take into account the shading equivalent factor. So, if we have a window which remains shaded because of the presence of an overhang throughout the year, there is no direct light falling onto it. And, practically the amount of heat which is transferred inside because of the direct radiation falling onto it will become very close to 0. There is not practically 0 because there is the diffused component of the solar radiation which is also available.

So, there is one direct component of the radiation which will be reduced to 0 close to 0, but there will always be a diffused component of the solar radiation which will always be incident on the glazing, on the fenestration. So, to calculate the shading equivalent factor we need to know the projection factor of the shading device. Once we know the projection factor and we also know what type of shading device it is, it could be an overhang or fin, it could be only an overhang or it could just be fin. So, depending upon the design of the shading device.

Then for different latitudes these tables are available in ECBC, based upon the latitude the projection factor, the type of shading device and the orientation, 8 orientations have been taken; SEF can be picked up from the tables given in ECBC.

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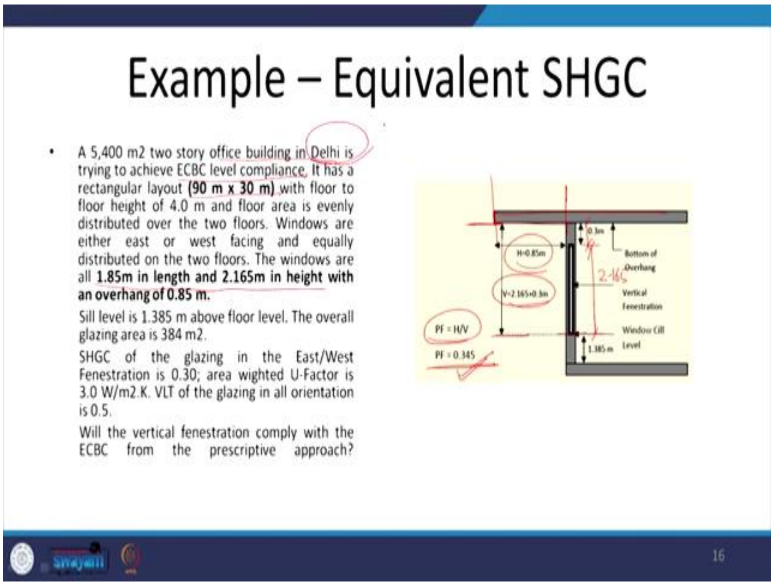

Once we have picked up from the table, here we are taking a quick example again. So, this is a two storied office building in Delhi again and we have to achieve an ECBC compliance. So, this has a rectangular layout of 90 meter by 30 meter and the windows are all 1.8 meter in length and 2.165 in height. So, we see that this is 2.165 and the projection of this roof slab is further 0.3 meter above the window. So, the total height of the projection, the shading device from the sill of the window is 2.165 plus 0.3 meter which is the vertical dimension and horizontal projection of this roof is given to be 0.85 meter.

So, we calculate the projection factor as H by V and this comes out to be 0.345. If we go back to the table which is given here; so, we have a projection factor of 0.345. So based upon this projection factor which we calculate here, based upon the latitude for Delhi which is greater than 15 degree north. And, the orientation of different windows; 1: we will have the SHGC which is prescribed as per the initial tables which we have seen and then we will calculate the SEF.

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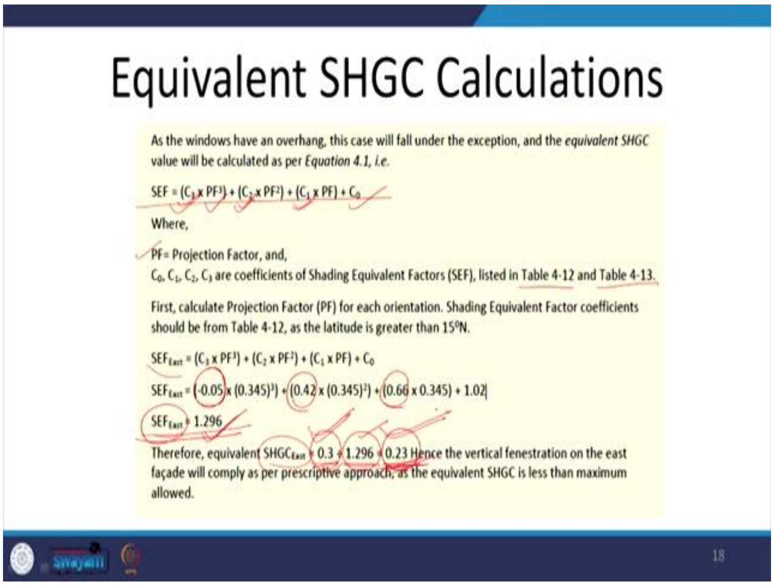

So, for calculating the SEF we will get the coefficients from the ECBC based upon this data. So, if we look at the projection factor and the latitudes following the table 4 dash 12 and 4 dash 13 we will calculate the coefficients C 3, C 2 and C 1. And, put it in this equation where we use the projection factor which is calculated and substitute the coefficients, 4 coefficients to calculate the SEF for each direction. So, SEF of east comes out to be 1.296. Now, this SEF of east will be multiplied by the SHGC which is prescribed in the prescriptive tables and we calculate the effective SHGC.

Now, this is the effective SHGC. So, once we have calculated the SEF we divide the SHGC which is prescribed for the given orientation as per the prescriptive tables and divide the SHGC by the SEF to obtain the effective SHGC of that fenestration. So, instead of using a fenestration which is having lower SHGC we can actually use an SHGC which is higher. And, still obtain an SHGC which is well within the prescriptive limits by dividing it with the equivalent shading factor the SEF and we can still comply with the requirements the ECBC.

So, once we have provided the shading compliance can be shown based upon these calculations as per ECBC. Now, so far this is all prescriptive requirement whatever is given in the code will be met with.

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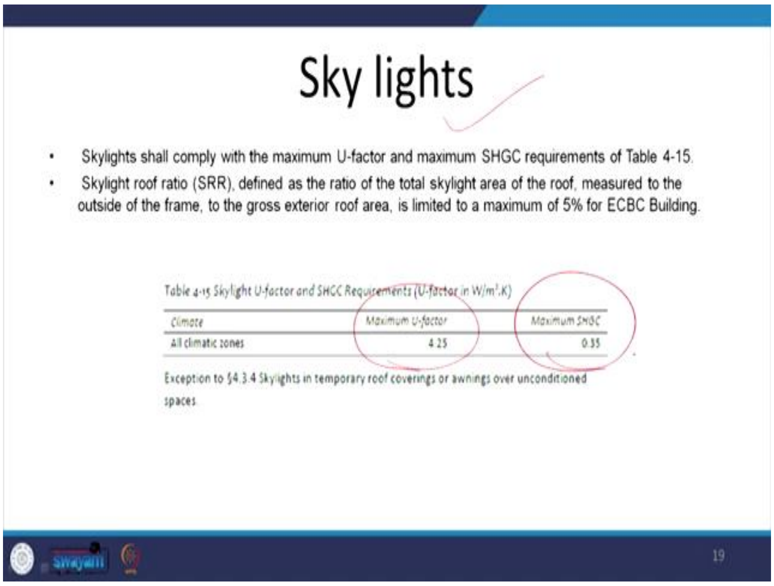

Again, we also have the prescriptive requirements for the skylights. So, for skylights for all climatic zones the maximum U factor and maximum SHGC has been prescribed. So, whenever we are going in for skylights we will use these U factors and SHGCs.

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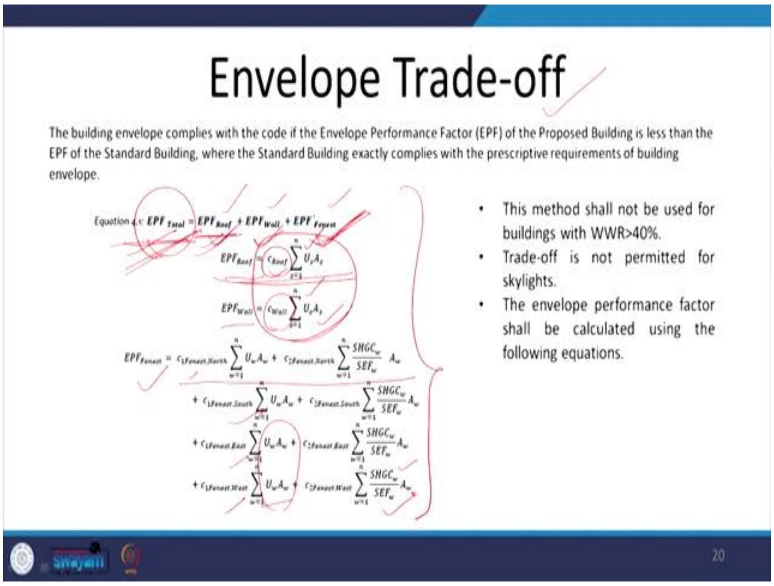

Now, this was how the compliance can be shown when we are talking about the prescriptive approach, where whatever value has been given in the code will be met. So, if we have to go ahead with the prescriptive approach and if you want to comply using it, a glass which has the U value as prescribed and an SHGCs as prescribed will be used. In case there is a shading device using SEF the compliance will be shown; all this is prescriptive. Now, sometimes we may decide that we will invest more in insulating the roof, but by virtue of the design there is not enough insulation which is required on say the northern side of the building.

Or, because there is another building coming up so, certain portions of the building will not even receive the direct solar radiation. So, the SHGC of the glass; so, the glass will be selected such that SHGC is much higher and we are not investing high on glass. So, how will the compliance be shown? In such a case we use the envelope trade off method, in this the energy performance factor of the proposed building will be compared with that of a base building. And, this overall envelope performance factor is a sum total of EPF of roof, EPF of wall and EPF of fenestration.

So, what we are doing here is fundamentally we are compensating for a reduced performance of one component with an increased performance of say another component. This is the trade off, but it is only between the components of the envelope. So, we are looking only at roof wall and fenestration here and using their performances and efficiencies interchangeably. So, when we are talking about an envelope trade off method, we will calculate the EPF of each of these components separately using these equations.

Here the coefficients for the roof or wall or the fenestration for SHGC and U values, they are taken from the tables given in ECBC. For the calculation of EPF of roof and wall, we multiply the U values with the areas and we calculate the sum total of it for different types of materials which has prescribed on the roof and wall. So, there may be combination of the materials which is used and then for EPF fenestration we calculate it for all the different directions.

So, we calculate it for the north, south, east and west separately; for both the properties that is U value and the SHGC with relevant SEFs. Using this the overall EPF of the building will be calculated and EPF of proposed case, proposed building has to be lesser than that of the base case. Now, this base case has the EPF calculated as per the U value given in the prescriptive approach method. So, the U value will be taken as what is given in the prescriptive tables and the area will be the total area. So, once we calculate the base case PEPF, we compare it the EPF of the proposed case.

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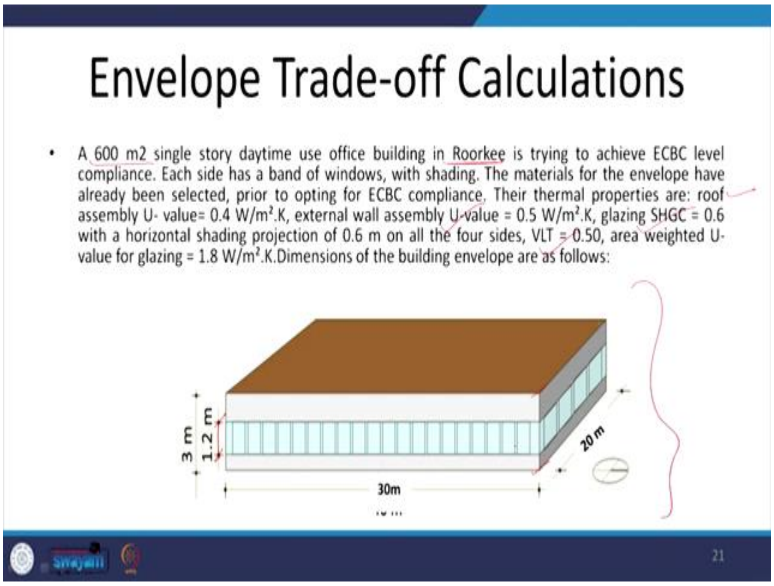

Let us quickly take an example here. So, this one is a 600 meter square single storey daytime use office building in Roorkee and here we are trying to achieve the ECBC level compliance. So, it has a band of windows; so, the height of the window is 1.2 meter, the total height of the building is 3 meters and there is no shading which is proposed.

And, the materials for the building are given; so, for roof, for external wall assembly, for glazing all the properties are given here. We also have the VLT given and overall the building is oriented in such a manner that the shorter dimension of the building which is the 20 meter side is oriented towards north.

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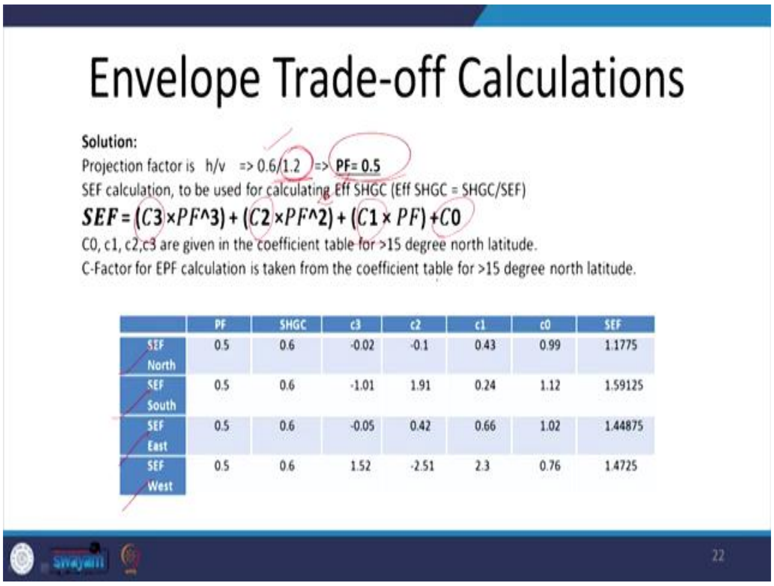

So, for the proposed case the shading device has been proposed here, in base case there was no shading device, while in proposed case there is an overhang of 0.6 meter proposed that is 2 feet. And, this is right above the window which is 1.2 meter high.

So, we calculate the projection factor as 0.5, based upon the tables we will obtain the coefficients substituting this projection factor here. This is the table which shows how the SEFs from the tables have been obtained and we calculate the effective SEF, the total SEF.

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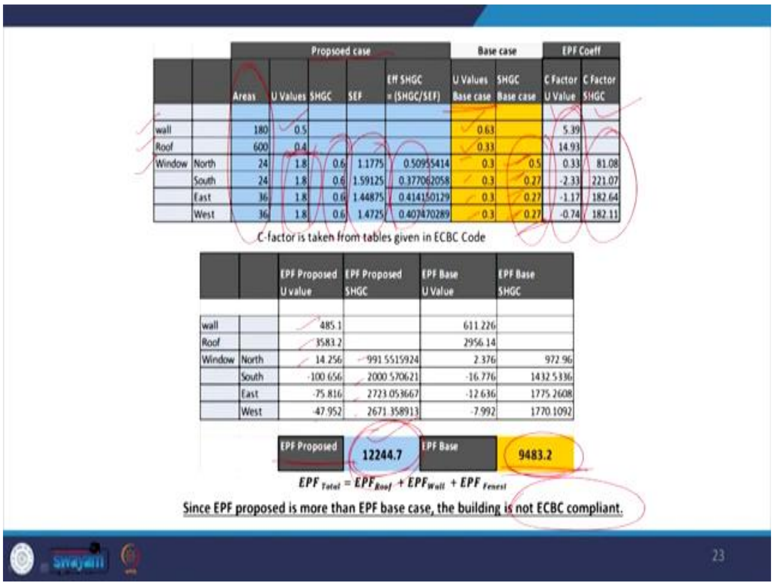

Now, here this very quickly shows how the difference between the base case and proposed case is. So, for the base case the U values are coming from the prescriptive tables. So, for wall 0.63, roof 0.33, for windows the U value is a 0.3 and the SHGC of the base case is as per the prescriptive tables. So, based upon these the coefficients have been identified and the total EPF has been calculated using the same formula. Now, for the proposed case the materials have been changed, here the areas remain the same for both the proposed case and the base case.

The U values have been altered, so, the U value of the wall has been increased, improved. So, more insulation probably has been added to the wall or thicker walls have been made, while there is a compromise on the roof. So, not enough insulation has been done on the roof. So, the walls have been improved, but the roof has not, also the U value of the window is substantially high. So, we see that the base case is far better than the proposed case because the U value is much higher here. And, the SHGC which has been considered is also higher than what is proposed in the base case 0.6.

But, there is shading provided so, we calculate the SEF and we calculate the effective SEF by dividing the SHGC of the window by the SEF as we have just seen. So, we calculate the effective SHGC and we see here that the effective SHGC is still higher than the base case SHGC. The C, the coefficient values remain the same for both the proposed case and the base case. And, we calculate the total EPF of the proposed case here individually of the EPF for each of these components and then the total one here.

Here we see that the EPF of the proposed case is higher than that of the base case and hence this building will not be an ECBC compliant building. So, by doing this, by taking this envelope trade off method we can see whether a trade off between the performances of these three factors would result in a building which has an envelope performance factor same as that of the base case or not.

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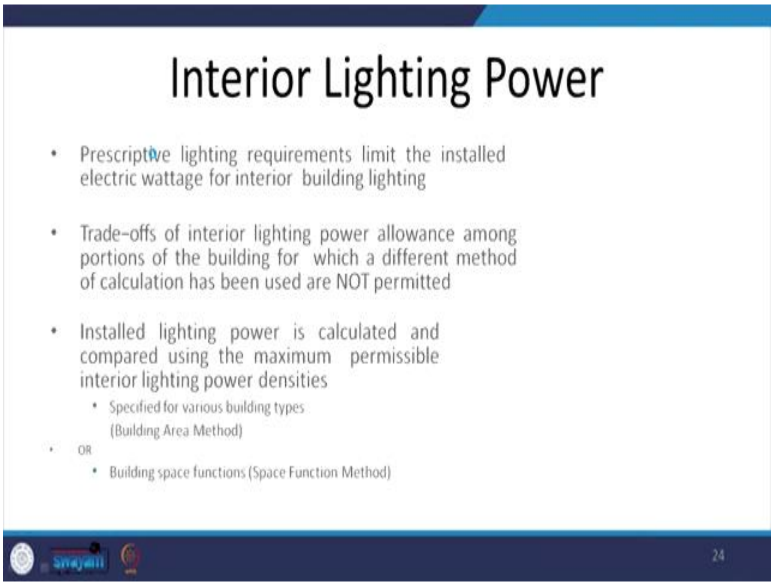

So, with this we have completed the two compliance approaches: one is the prescriptive approach of compliance and the other one is the envelope trade off method of the compliance. This is largely for the envelope, we have covered the envelope for energy efficient building so far. One more component which is left when we are talking about the energy efficiency of the building, it is the lighting power; the energy which is consumed by the buildings for artificial lighting.

So, in the next lecture we will be talking about the lighting power and we will also look at the third compliance approach, just an introduction of it which is the simulation approach, the whole building performance method. And, we will also learn about the net zero approach for the energy efficient buildings.

So, thank you for being with us in this lecture. See you again for the next lecture. Bye, bye.