Illumination Engineering and Electric Utility Services
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Lecture No. # 18
Lighting Calculations

Welcome to this course on illumination engineering and electric utility services.

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Today we take up lesson 18 of the series on lighting calculations. So far we have been looking at the need for illumination engineering or the artificial illumination. We had a look at the various types of artificial light sources, the physical principles that are involved needless to mention that quantification becomes very important in any branch of engineering and science. So, we had a look at the way to measure these standardize and measure the light outputs. Having done that we had a look at the spectrum of lamps that are possible and then the lamps alone cannot take care of a complete lighting scheme that is it works as a lighting system which comprises of the accessories and the support structure which we call luminaires.

So having done that we had a look at the recommended levels, it must be mentioned here that the recommendations are standardized and they follow internationally the what we call as CIE recommendations and based on these each country has its own standards likewise we have Indian standards. So having had a look at the recommended levels for both interior lighting that is the lighting of any building interior. The exterior lighting that is predominantly the source lighting and the road lighting, it's necessary for us to probably look at how one could do these lighting calculations and achieve those recommended levels so that’s the objectives of this lesson.

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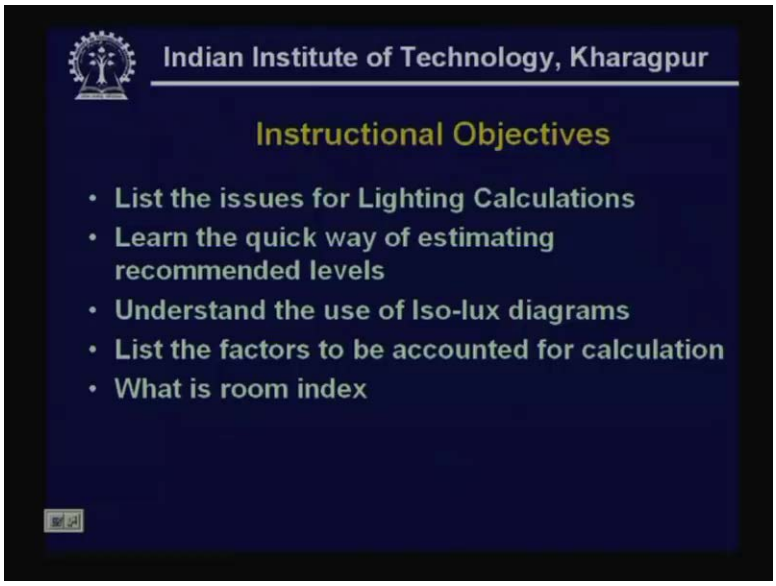

And if we try listing the instructional objectives, it would be list the issues for lighting calculations, learn the quick way of estimated recommended levels, understand the use of what we call as iso-lux diagrams. Incidentally the recommendations often times talk in terms of the illuminance is the light intensity on the work plane which is specified in terms of lux. And therefore it's the diagrams which are specified as iso-lux diagrams they are used. List the factors that need to be accounted for calculation. In some sense, some of these aspects have been covered as all along, when it is an effort to have all put together in one lesson that is the aim of today's lesson. What is room index? If you consider an interior lighting, we talk in terms of what we call room index so that in fact we have said in no application a single lamp or single light system does the required function and therefore there could be array of lamps which the most convenient in fact if you see most of our interiors are cuboidal and the most convenient arrangement is in the form of a matrix. That is you have certain number of lamps located in certain along a road and there could be number of columns, so that's the way I mean the room index is a way of specifying these things according to CIE.

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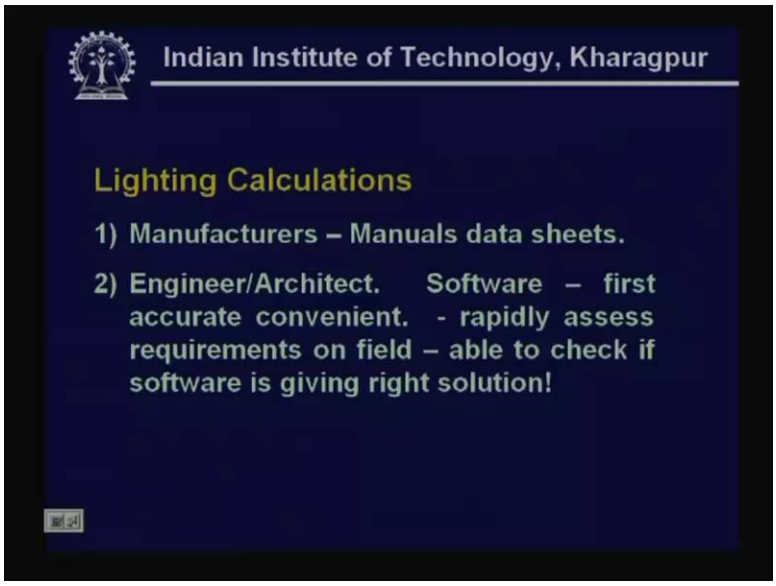

So what are the issues that we look in for lighting calculations? Here recall the various types of artificial light sources we have seen were dependent on the phenomena of incandescence or the incandescent lamps which for all practical purposes could be viewed as a point source of light. Next we had the fluorescent lamps which are quite often used for the interior lighting and which are more like line source and then we had the discharge lamps based on the mercury vapor and the sodium vapor, in fact we also mentioned the halide lamps or metal halide lamps which are nothing but the high pressure mercury vapor lamps with certain metal halides to improve their what we call colour rendering ability.

Colour rendering ability we said was the ability of reproducing the object colour as close to as it is felt due to the natural light. Remember in all the effort which we are putting into designing a lighting system is to recreate the natural light conditions and possibly extend the hour ability to function round the clock otherwise in prehistoric days, our activities were limited from sunrise to sunset. So we said there are point sources of light, line source of light and depending on a choice of a luminaire and the placing of lamps we could in fact have a sheet source of light. Now based on this in the earlier lecture on the photometry, we observed that at any point below the lamp on a point source it is directly or inversely proportional to the square of the distance illuminance whereas when for a line source of light it was inversely proportional to the distance whereas if you are able to create a large sheet of source, imagine a large surface, large area with large number of lamps placed with a diffuser, it could act as a sheet of source light. So these aspects have to be kept in mind.

So the lighting calculations, the way to do is one has to see first thing one does is takes the manufacturer’s manuals and data sheets because there are several manufacturers available, we know the recommended levels as per the CIE. So the user first picks up the manuals, data sheets to know the kind of light output that is the photometric data based on the measurements available in the form of tables, graphs and the cost price etc.

So the engineer together with the architect, engineer here is the illumination engineer who is conversant with both electrical because remember the illumination is done by the use of electric energy. Now these days in order to almost most manufacturers do provide even the software which can do the same calculations which we have done rapidly for all kinds of geometry. And in fact one may wonder why at all we are looking at these lighting calculations the way it's being done in this lesson when these software's are available. Well, software's are there and they invariably involve a three step process. Step one is to the way you define your geometry, step two the choice of the required illuminance levels that what does it depend on? It depends on the application whether it is indoor, outdoor.

If it is indoor is it for precision task or is it for prayer, is it for relaxation I mean depending on the service for which it is being used but how do we know that the output obtained in the form of a calculated drizzles are all right. There should be some physical understanding of the way to assess these calculations. So from a learner's point of view it's felt that these calculations, the way it was done conventionally needs to be done for a quick assessment of the solution obtained from software. Yes, the complex problem, see it is essentially trying to do these simple calculations over and above for large number of locations, large number of planes, at various angles so that becomes probably boring if one has to do with long hand and that's where computer helps but unless we know how these calculations done we will not be in a position to rely on those software's. That is the thing.

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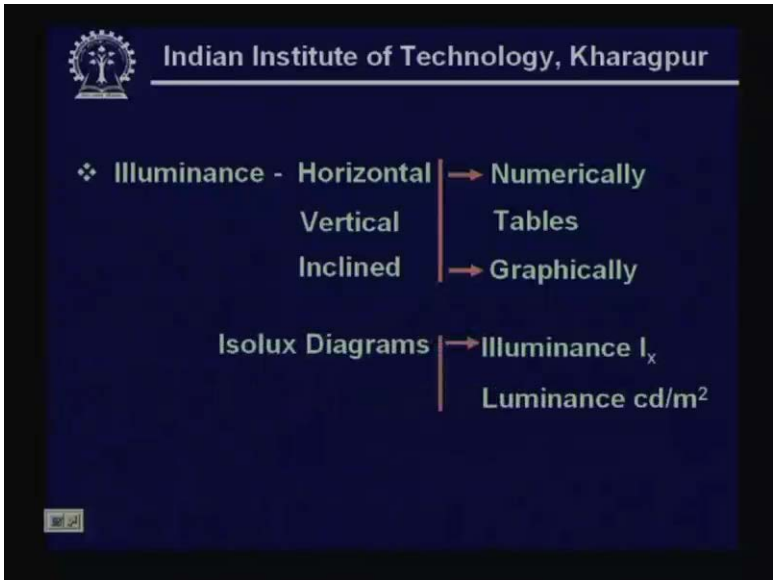

So what are the things that are to be assessed? The things that need to be assessed is in fact we are always talking in terms of the recommended levels like I say that most theaters and class rooms should have an average illuminance of 300 lux. Where is it? It's on the working plane that is in a class room the desk where the students sits I mean students sits at the desk, he reads, writes or solves problems or does his design on the work plane so that is the thing. So we talk in terms of a horizontal illuminance there.

In the same class room let us look at the screen or the black board which perhaps I should in today's terminology call it as a chalk board where instructor uses a chalk to write. It is in the vertical plane so one has to look at the illuminance levels required for the vertical plane and there are situations when you need to have on the inclined plane. So this is where our fundamental understandings of the light output and illuminance levels obtained based on the source need to be taken which normally based on these relationships, the manufacturers provide in their catalog in the form of numerical values in the form of tables, graphically in the form of what we call as diagrams. So there are these diagrams in fact are called iso-lux diagrams. All of us are aware like the whether man talks about isotherms that is the equal temperature curves.

In similar way the lighting engineer works with equal illuminance diagrams which are iso-lux diagrams. The other important issue which comes for a lighting system is the luminance which loosely termed or conventionally termed as brightness is expressed in candela per meter square that is the per units surface watt in that direction where you are interested. So what do we have? We have the illuminance which is a very important thing, depending on the nature of the work plane horizontal plane, vertical plane and times inclined plane, this data is available in the form of numerical values which are tabulated or graphically in the form of iso-lux diagrams which in fact illuminance in fact here it's been abbreviated as l_x. We find that illuminance which is the nothing but the light flux intensity at any point has is abbreviated as e and as also I, these two one has to keep in mind.

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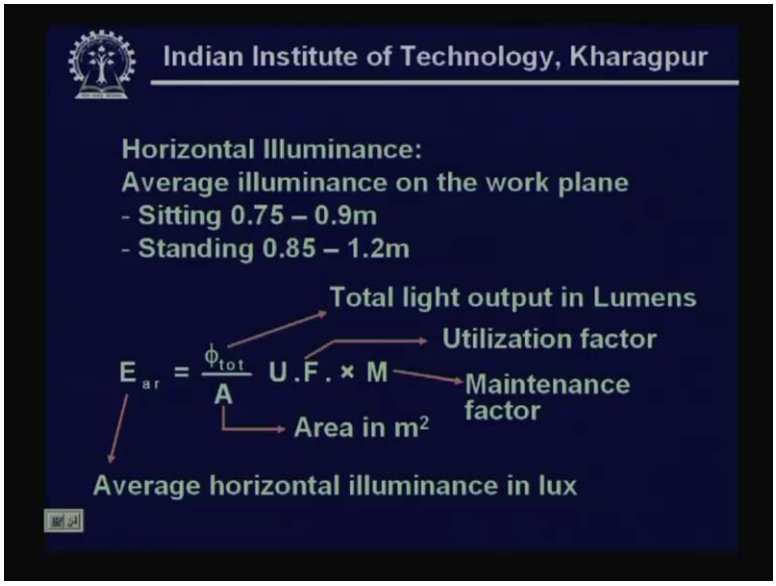

Most of the times we are concerned with horizontal illuminance because we work at a table which is horizontal, typically if we sit and work it may be at height of about 0.75 to 0.8 meters from the floor. On the other hand there could be certain operations where the operator stands and works then the height could be close to 1-1.2 meters. These are the kept in mind but there are applications where we do have vertical plane as I mentioned a chalk board in a class room. The other area where you are concerned with vertical illumination is outdoor applications. If you take the street lighting you need to know the objects in the vertical plane coming in the abstracting the

user of the road. If you take sport arena you need to know depending on the type of sport, you need to have in all directions in fact, so we try to have the average illuminance in the work plane. We have already seen, we talk about the uniformity ratios, we talk about the average illuminance required so as I was telling you, you talk about the work plane if you are working at a table sitting, the distance could be from the ground could be 0.75 to 0.9 meters.

On the other hand depending on the height of the person, it could be when you are working standing it could be 0.85 to 1.2 meters. So how do we do? We have a defined average horizontal illuminance, there is the relationship that's given is based the total light output in lumens that is available to the total area in the meter square. We find that there are two factors which are there. Remember all the light output that is radiated is not available on the work plane, some is lost. This we have already discussed when we were discussing the illumination system where luminaires depending on the way they are located all of it does not result in the useful flux and therefore depending on the way we locate there is a utilization factor which is specified.

The second thing is we have seen for different types of lamps there are what are called as a mortality curves or with the age, there is a depreciation in the light output and further it is accentuated by the maintenance procedures which we in fact we mentioned the periodic cleaning and dusting becomes very important otherwise dust accumulation is one aspect which reduces the thing. Therefore E average which is given by phi total by the A is multiplied by two factors utilization factor and the maintenance factor. The area in question here depends on the work plane okay, which could be around 1.2 meters from the floor, if you are looking about an operator working in a standing mode and could be anywhere from 0.75 to 0.8 for a sitting at a table.

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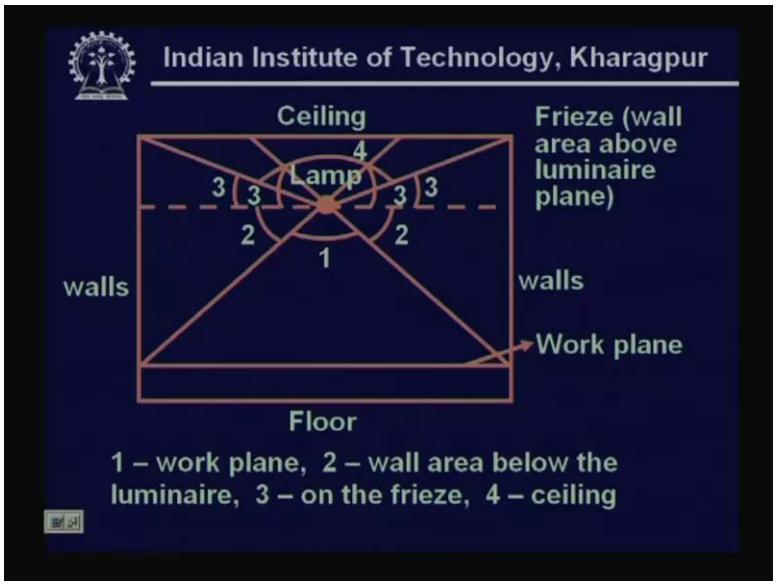

Now look at this apart from this, this maintenance factor and utilization factor come from what we call for an interior lighting based on the reflectance's which are involved.

Here is a picture which shows a lamp is located at a certain height from the ceiling. And if this was imagine a simple incandescent lamp, you will find incandescent lamp can be thought of as a point source which is spherical in nature. Then we have the light radiated in all directions depending on the nature of the walls, nature of the ceiling there can be various deflection factors involved and there by the amount of light that may be radiated to the amount of light available on the work plane could be different. Look at this, the plane or the volume has been divided into four areas, one is the direct work plane which is marked one. Two is the walls below the luminaire you have a horizontal plane passing through the luminaire, the wall area that's coming below the luminaire and three is what we call frieze, four is the direct ceiling. Frieze is the wall area above the luminaire.

In fact the way to reduce this frieze the light lost in that process is one of the techniques as we have discussed earlier also and is often practiced is to have a false ceiling in line along with the horizontal plane passing through the lamp. Two is instead of suspending the lamps from the ceiling, you have them resistant the ceiling. If you look back the older buildings pre independence they would have very high ceiling, so there it was necessary to suspend the lamps whereas the modern buildings where the ceiling heights are lower these days, especially for interior work where the controlled environment is what is necessary, keeping in mind the load it may force on the air conditioning plant they are always provided with false ceiling and the lamps are placed recessed the ceiling.

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Now the utilization factor is one factor we said that needs to be taken into account in order to work out the average illuminance. This depends on the light distribution of luminaire which comes in the form of polar curves in the horizontal plane and the vertical plane, we showed that in the lecture on photometry and in fact in early days to arrive at mean spherical luminance intensity one would go through closer curve which is not necessary these days. Keeping this in mind and keeping the reflectance's, remember there is some light on the wall area above the plane through the luminaire which we called frieze goes waste. And the depending on the

dimensions the CIE recommendations talk in terms of what call an index. Once you arrive at that index considering that reflectance's, one can suggest the number of rows and columns. I told you the simplest way is to arrange in the form of a matrix like you have certain number of rows and certain number of columns, most often we find we try to place them in such a way as they are placed width wise in rows and number of them in columns.

Now consider the room surface reflectance and referred to the manufacturer's catalogue, obviously one has to look at the manufacturer's catalogue to look at the kind of output one may arrive.

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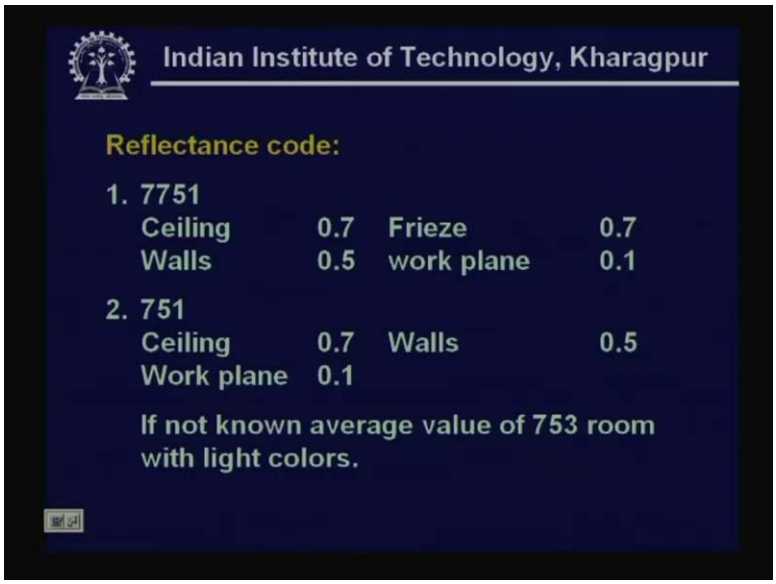

The reflectance's are categorized or standardized specified by a certain way like you see the example one, we say the reflectance code is 7751 is a four letter code, four number code, four digit code which corresponds to consider that there is a frieze. That means the lamp is suspended from the ceiling and ceiling and frieze are having the reflectance of 0.7. That's very good most of the light is reflected back. We know often times the ceilings are painted white and in fact whiter as near white as possible in fact false ceiling is also taken to be that way, walls have around 0.5 and work plane will have 0.1.

You don't want any reflectance, reflection from the work plane, you want the light to be available for the operator to effectively work. In case the lamp is mounted or recessed in the ceiling, one cannot have a four digit reflectance; it is a three digit one. For instance here we have 751 meaning ceiling has reflectance of 0.7, walls have 0.5 and the work around 0.1. Observe work plane should not reflect to the extend in fact ideally it should be 0. So this is how the catalog talks about the codes. Now these code, this is how it is specified but these have to be considered considering the type of interiors one has. So the lighting engineer has to sit with the architect and the interior designer to look at these factors and then choose accordingly. But if these are not known the general design principles for the interiors tell us that in an average value of 753 can be taken if light colours are used.

We do find that often times the roof is painted white and the walls unless for a personal choice or light creamish, light greenish these are the type of colour that are employed, so one may take 75 and possibly work plane may not be as good as we expect it to be towards the ideal, so if a factor of three for reflectance 0.3 can be taken. This is the guideline.

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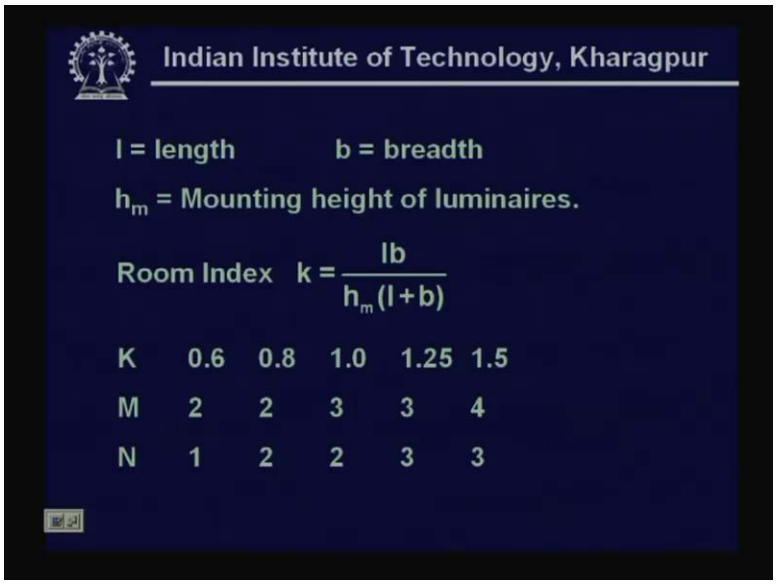

Now how do we arrive at the index, room index because I said room index is the one which tells based on which the CIE guidelines give us the number of luminaires that may be located. So first thing we will see is mounting height. As I told you these days for most of the interior lighting, a mounting height would be same as the ceiling height or the height of the false ceiling because they are not so high building, ceiling height is quite small these days. So the room index as can be seen is the product of area l length into breadth and depending on the mounting height one.

Now how do one choose the mounting height? You look at this, recall the average I mean the illuminance right below a point source of lamp is proportional to one over the height square. Keep that in mind that tells us the suggested or possible mounting height. Once we have this, we can see in a rectangular arrangement where one could have a certain number of rows and certain number of columns, it is here we have said M and N that is length wise and breadth wise, we are going to place the luminaires.

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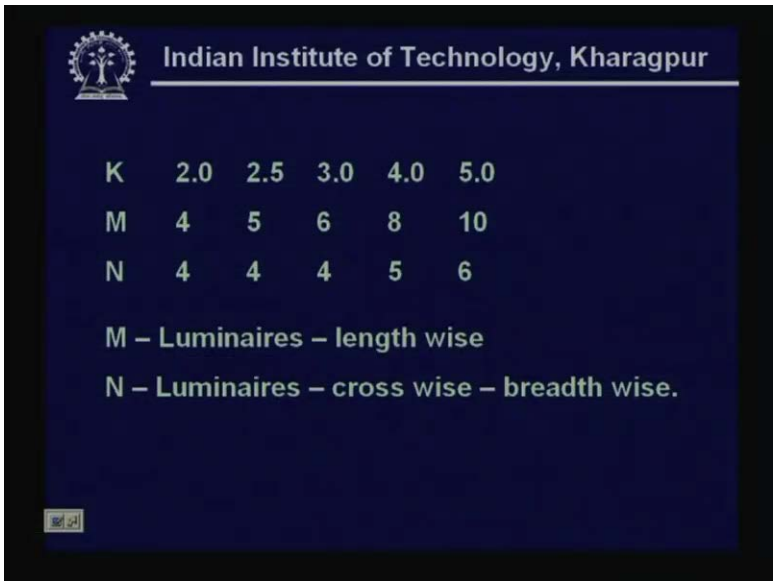

So go back to the first table. Look at this for various values of room index it specifies, okay. So as you can see the room index increases as the area increases okay and as the mounting height reduces you can see the number of lamps that are required. For a room index of 0.6 we find two lamps are adequate, two length wise probably only one width wise that is you have to buy one, one column and two rows we could say.

Similarly as the k goes increasing, you do find so this k corresponding to 5 would pertain to a very large hall may be a drawing hall where you have 10 lamps 10 luminaires. I have not said lamps because again depending on the service, depending on the luminaire, illumination required in a single luminaire I may have a single lamp or may have a matrix of lamps if they are incandescent lamps or a matrix of lamps if they are compact fluorescent lamps or a set of fluorescent lamps minimum being two and these days we do have 3 and 4 provided, okay. So this is a one thing.

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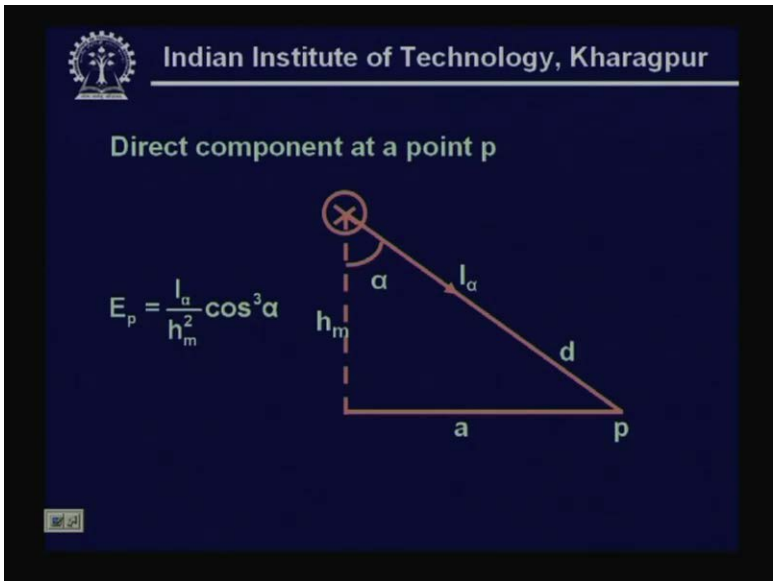

Now all this is based on our understanding of how light flux provides the illuminance at a point. So we recall in fact we had had a look at this in the lecture on photometry. Direct component at a point p due to a lamp located at a height h_m from the work plane at any point p which is the distance d is given by this. Recall if I were to calculate the lux level right below the lamp, it would be I by d square and that at p, I by d square by d is equal to h_m that is I by h_m square whereas at the point p it would be… (Refer Slide Time: 00:33:41). What is this I? It is the candela power or luminance of the lamp.

Now if I had to look at the thing at point p, I would say I by d squared into cos alpha, alpha is the angles suspended by the straight line from the source of lamp to this point with the vertical and this when expressed in terms of mounting height works out to be I_{alpha} by h_m square cos cubed alpha where alpha is the angle which is very clear from the picture. This was due to a point source.

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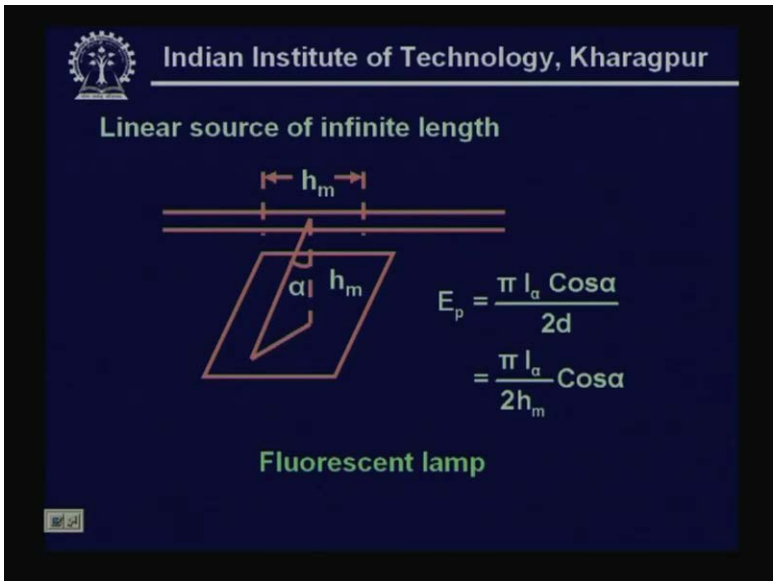

As opposed to this I told you there are two distinct kinds of sources, one is the point source other is a line source. An array of line sources or a matrix of point sources together form a sheet source and that. Similarly like a linear source of infinite length, again we see mounted at a height h from the work plane concedes mark, at any point p the straight line to this point from the line source is at an angle alpha to the vertical then we deep, we can arrive at this as pi I_{alpha} cos alpha by 2 h_m. This is as I told earlier for a point source, the illuminance is proportional to 1 over d square where d is the distance to the point whereas where line sources it is 1 over d and that's what it is.

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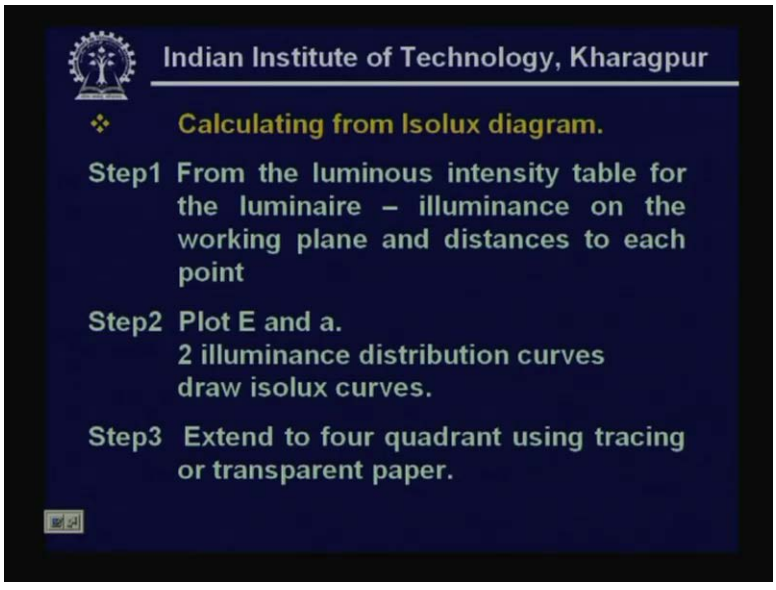

In case if you are able to create a large sheet of light source that is by having number of fluorescent lamps together or alternatively a matrix of incandescent lamps as point sources, put in a single luminaire with a diffuser, so that you really do not what you get is a, then it would be independent of the mounting height or the distance and you get a uniform light on the work plane. This is one way. The other thing I said apart from the tables you are also given iso-lux diagrams in the where, manufacturer's catalogue. We are said that yes, powerful programs are available today but it is not enough to use powerful programs without basic understanding. So the lesson tries to look at how one could with the help of the manufacturer's catalogues quickly assess.

So one other approach was to use the iso-lux diagrams, it consists okay, after having chosen the luminaire the luminaires intensity table one works out illuminance on the working plane and distance to each point. It will become clear because we will take one example where layout of lamps are there and at a particular point we see the… Then we plot E and a that is with the distance from that point, we plot the illuminance curves which could be circular or iso-lux curves. Then draw the distribution curves, we could perhaps draw in one quadrant and extend it to four quadrants. See this method is not necessary if you are able to assess from the numerical tables given.

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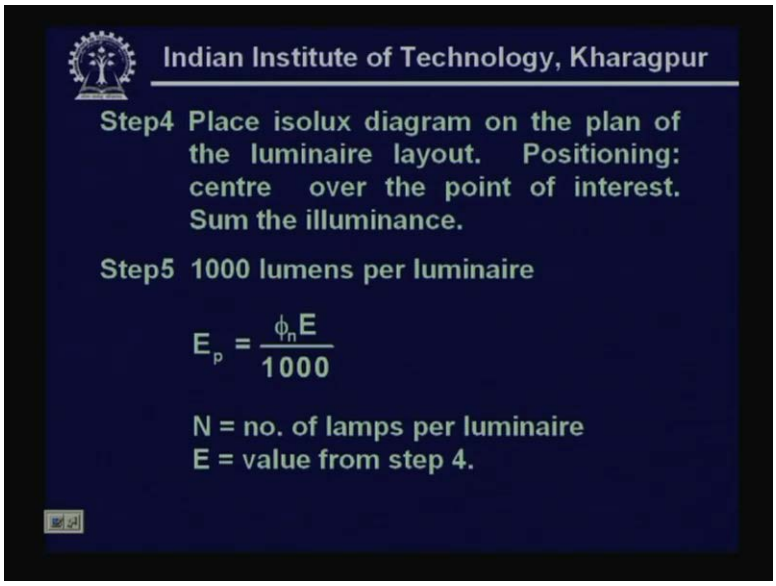

Then place the iso-lux diagram on the plane of the luminaire layout. Where do you place the center? Place the center at the point of interest that is wherever you are interested in arriving at the illuminance. So, take the iso-lux diagrams for the lamp in question, place it at the center of that iso-lux diagram at the point where you are interested and thereby and often times these are given in terms of 1000 lumens per luminaire that is the kind of a thing. Then one works out by summing the total illuminance and then knowing the number of them and the light flux output, lumen output which is given in the tables you get the… So here n stands for number of lamps which we get in each luminaire.

I said there need not be one, it could be a matrix of incandescent lamps, it could be a matrix of CFL lamps or it could be in fact if you recall early days the fluorescent lamps which were used in the offices would always be twin fluorescent lamps and these days we have larger luminaires with 3 and 4 units placed together. E, the illuminance that obtained from the step four, that is how.

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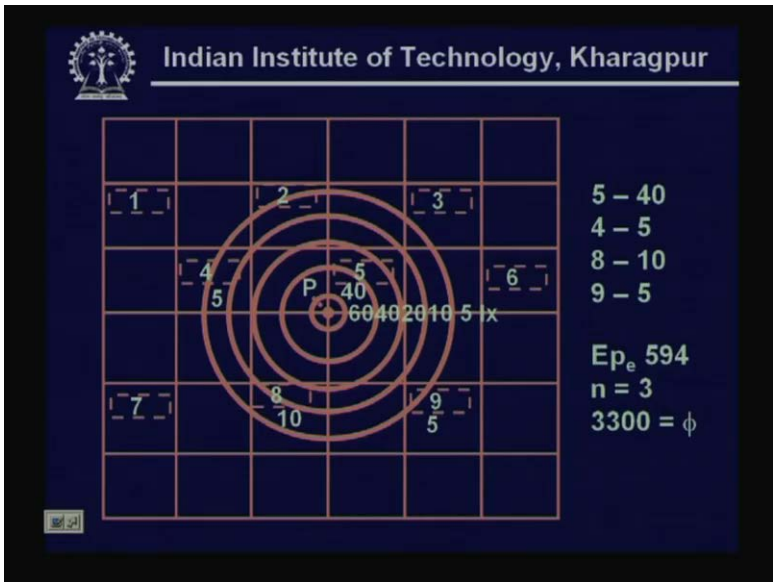

Look at this picture, this shows that there are is a rectangular space which is divided in terms of number of grids and in this particular example, each luminaire you can see they are marked with hatch 1 2 3 4 5 6 7 8 9 and each of them is having a total flux out, 3 lamps with each lamp having a flux output of about 3300 lumens. Remember that this is pertaining to a rectangular room which could be an interior surface and each luminaire could be a fluorescent lamp set three of them placed and or it could incandescent lamps each having about 1100 lumens.

Now from the manufacturer's iso-lux diagram we place it, we are interested, incidentally the picture shows the calculations being done at the center of these diagrams that is at p, I place the iso-lux diagram p and I get the illuminance levels for various lamps. If you see carefully, the lamps that are contributing appear to be 5 4 8 9 and some extend 2. So, we get the 5 is passing through the 40 lux curve whereas 8 is passing through 10 lux curve, 9 is passing through 5 lux curve.

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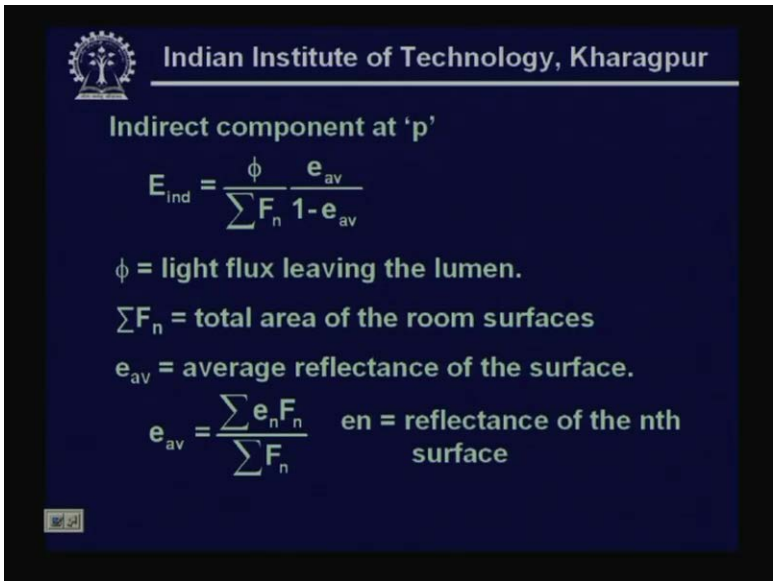

So knowing this one can get the total flux using the relationship which we have seen, phi is 3300 and n is 3, there are 3 lamps per luminaire and E we have got by summing up that and there by one arrives at that. Similarly you need to find indirect component at every point that was the direct component, knowing total area of the room surfaces and light flux leaving the lamp in lumens and considering the reflectance of the surface, one can get the total distance. The average reflectance is considered by taking reflectance of each surface which is given as row n E n here. That's about the horizontal illuminance.

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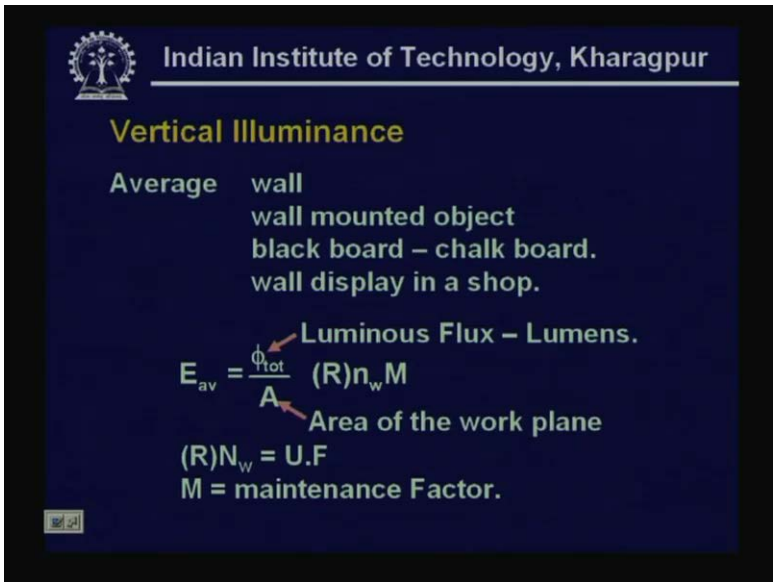

Now the next thing that needs to be considered is the vertical illuminance. We said there are applications where especially the outdoor applications, indoor when you are looking at a black board you need to have. So this could be to look at objects in a wall, black board or a display in a shop that's where it becomes. This is again specified in terms of the luminous flux, 5 total that's available and the n_w which is specified here is essentially the utilization factor, m is a maintenance factor, R n_w which is given as, this is so specified to distinguish it from horizontal illuminance which we considered earlier. This is as per the CIE norms.

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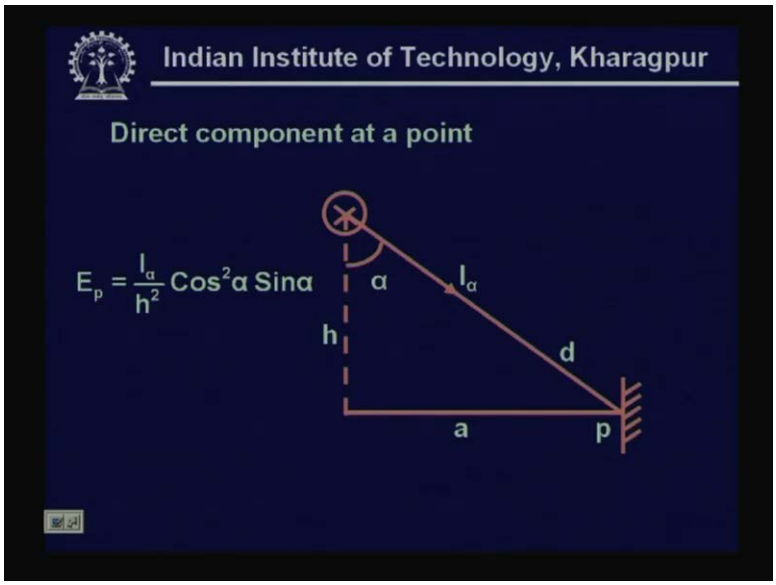

So again we go back to the photometric class then the direct component on a vertical plane at a point p, okay. When the line joining the point source at the p is making an angle alpha with the vertical to the ground we get E_p in terms of I over h squared cos squared alpha sin alpha. This was from the cosine law of illumination which we saw in photometry.

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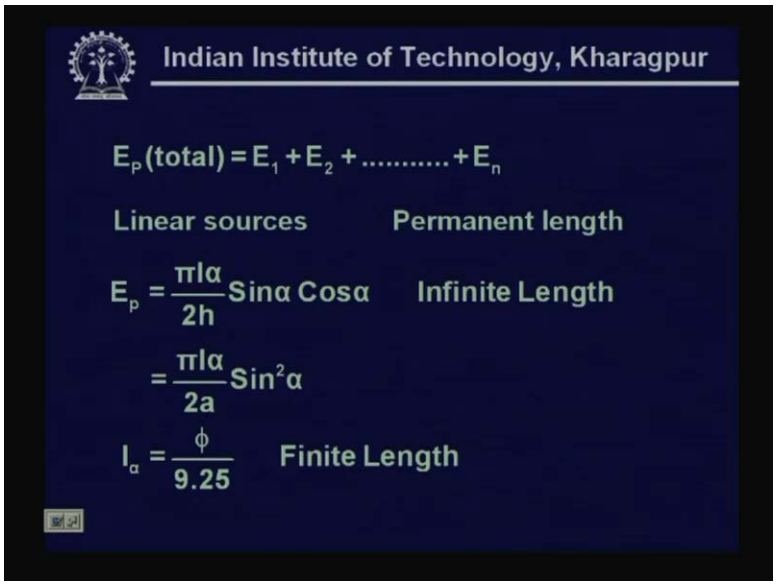

So having done that one gets the total from various sources, linear sources in fact if you have infinitive length relationship was seen to be this but for finite length, this is approximated in terms of the flux by 9.25 length. This gives the I alpha value, using this one can use the relationship phi alpha over 2 a where a is the distance to the point under consideration from the lamp. So what we have seen? We have seen, we got the horizontal illuminance earlier, now where necessary especially for wall mounted objects, walls and display surfaces we need to find the vertical illuminance. This is what we…

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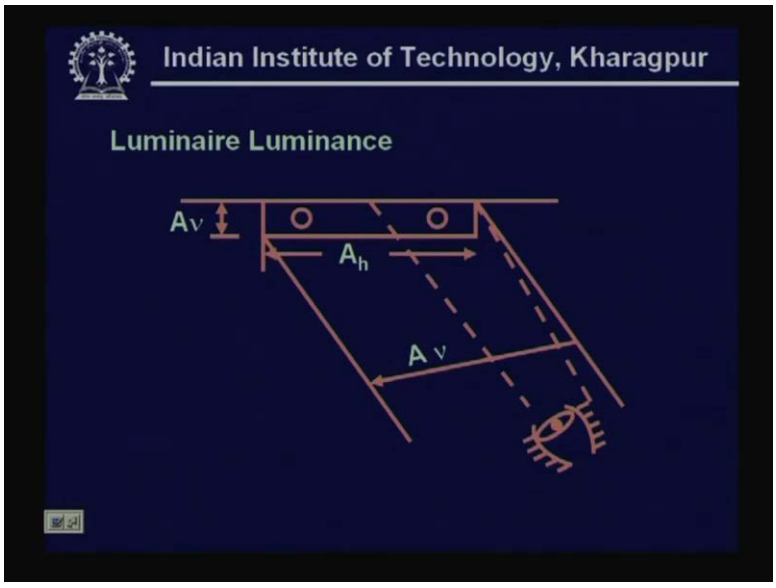

Now sometimes luminaire has a whole has to be seen based on the area of the luminaire. Here this picture shows that this particular luminaire has a horizontal area of A_h and vertical area of A_v at an angle inclined from the observation angle gamma. How does one take care of luminance, because we said the three steps that are involved in accessing are one use of the tables which have the numerical values, two is the graphical diagrams in terms of iso-lux diagrams. Thirdly, it is the luminance which is the, for the luminaire candela per meter square.

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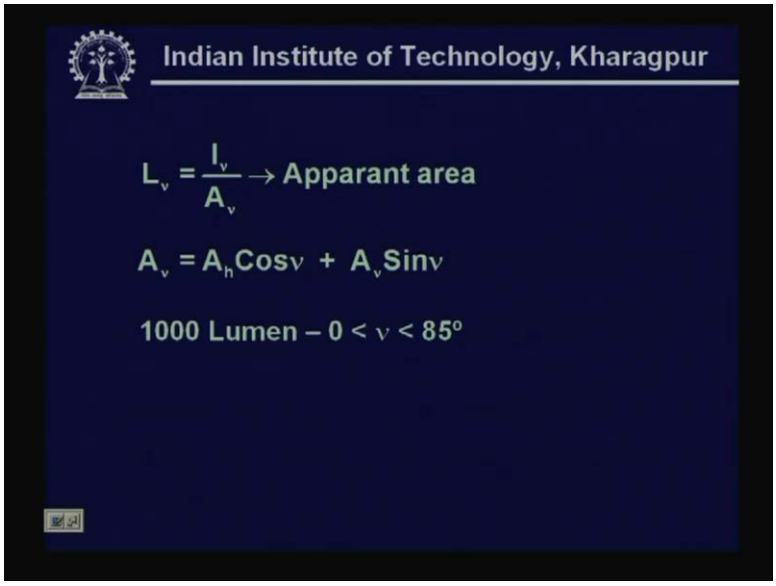

So this is got in terms of the I gamma over a gamma is the apparent area. Now this apparent area is nothing but A_h cos gamma plus A gamma sin gamma. Now where is this gamma? Gamma is the angle which subtends at the observer's eye with reference to the vertical to the luminaire, okay. This is how one takes care of. Now most of the times these tables give the data for gamma varying from 0 to 85 degrees that's what has been specified even in fact when we are talking about the illumination systems and even for glare specifications we said this is the angle which needs to be considered, for every 100 lumen it is given so depending on the lamp one could again work out.

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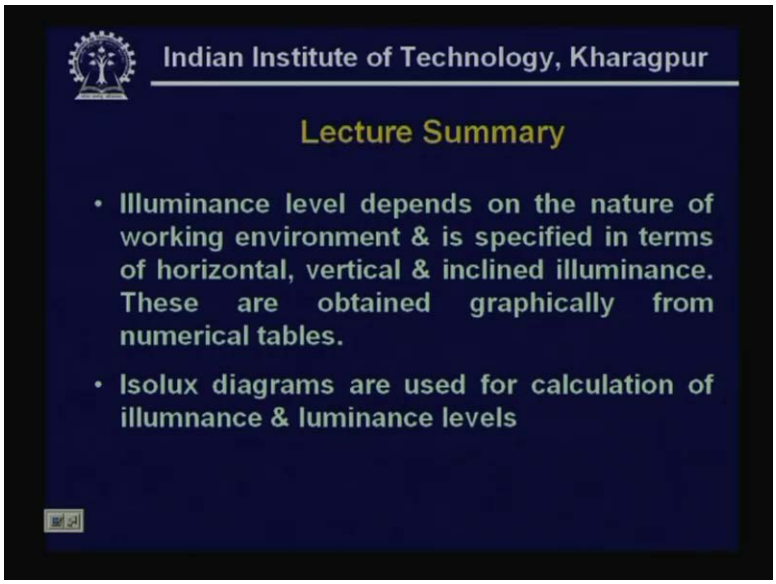

So in total the lecture could be summarized that the illumination level depends on nature of the environment which is in terms of the horizontal, vertical and inclined illuminance. These no doubt can be calculated using powerful software but are more easily accessible using the numerical tables and graphical diagrams available from the manufacturer's catalog. Understanding that most of the sources could be either point sources or a line sources or a sheet sources, remember a point source has the illuminance varying as 1 over d square where d is the distance to the point. A line source has variation as 1 over d and sheet source does not depend on the distance.

This is the reason why good large conference rooms on the conference tables to the extent possible the luminaire arrangement is made as close to a sheet as possible which may be by way of a matrix of incandescent or the CFLs or large number of fluorescent lamps that is single diffuser. The iso-lux diagrams together with polar diagrams for the luminaires, for assessing luminance level are used for calculation both depending on the nature of the service one has to work out on the horizontal as well as the vertical plane.

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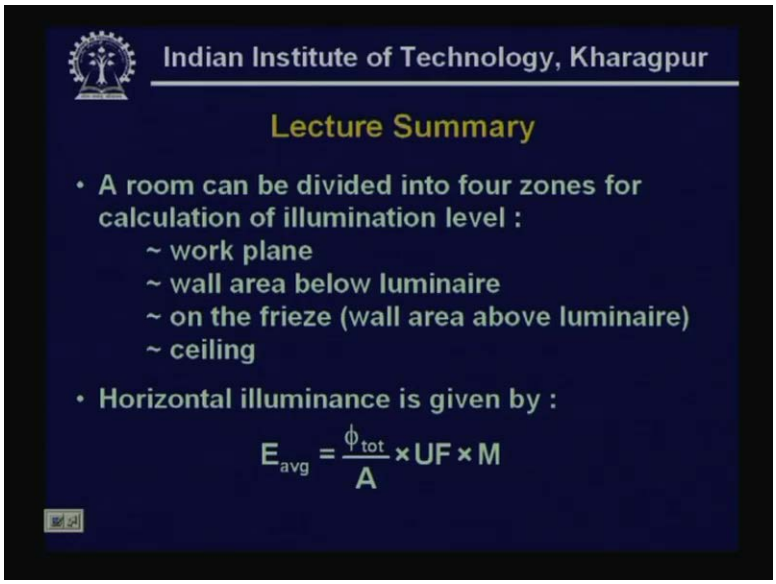

The room perceived from the point of view of calculation has four zones, one is the work area or work plane, this is for the interior, wall area which is below the luminaire on the frieze and ceiling. However it may be mentioned that most of the modern designs do not have a frieze, the lamps are located recessed in the ceiling or in the false ceiling. Keeping in mind that we do not have such large ceiling oriented buildings these days, because one has to keep even the air conditioning load into mind. The horizontal illuminance in total is given in terms of the total lumen output by the total area involved which is reduced because of the utilization factor which depends on the luminaire usage one can get from the luminaires and the maintenance factor which depends on the maintenance obtained which is followed, okay.

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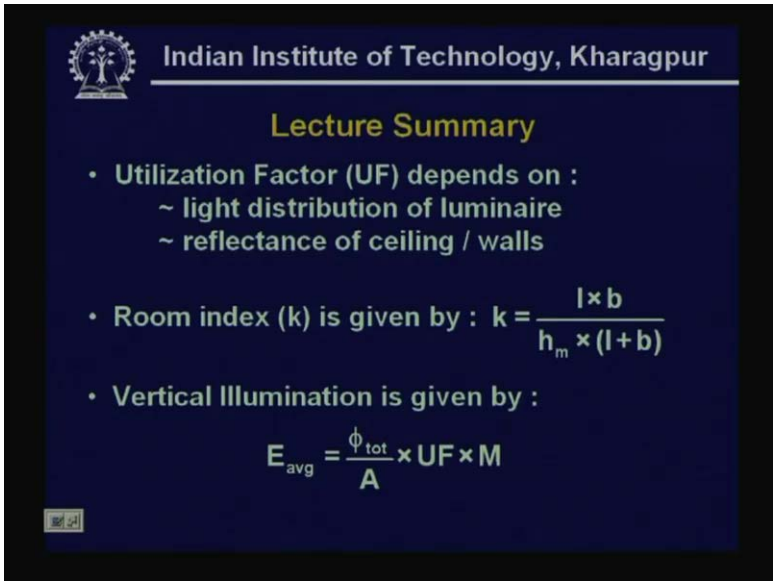

The utilization factor depends on the light distribution of the luminaires, reflectance of the ceiling walls and in using the arrangement of lamps which is usually in the form of a matrix as length wise and breadth wise, room index is given which is given in terms of the length, breadth and the mounting height. As I said when suspended mounting height becomes different from the height to the ceiling, if it mounted at the recessed in this thing it is same as the ceiling height. Similarly one can get the vertical illumination.

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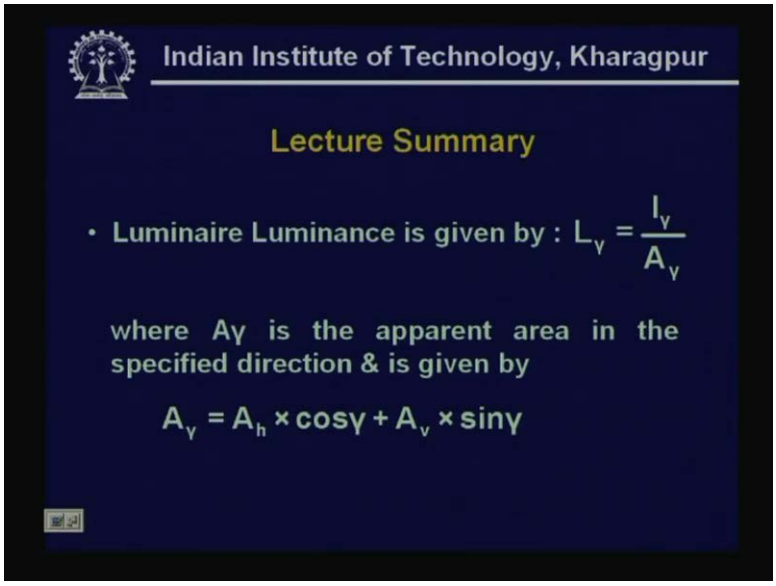

So luminaire luminance is of course given by the angle subtended at the observer from the luminaire and in doing this, the inclined area is obtained in terms of the which is called the apparent area given by A gamma considering the horizontal area of the luminaire plus the vertical area that is one going length wise another going breadth wise A_h cos gamma plus A_v sin gamma.

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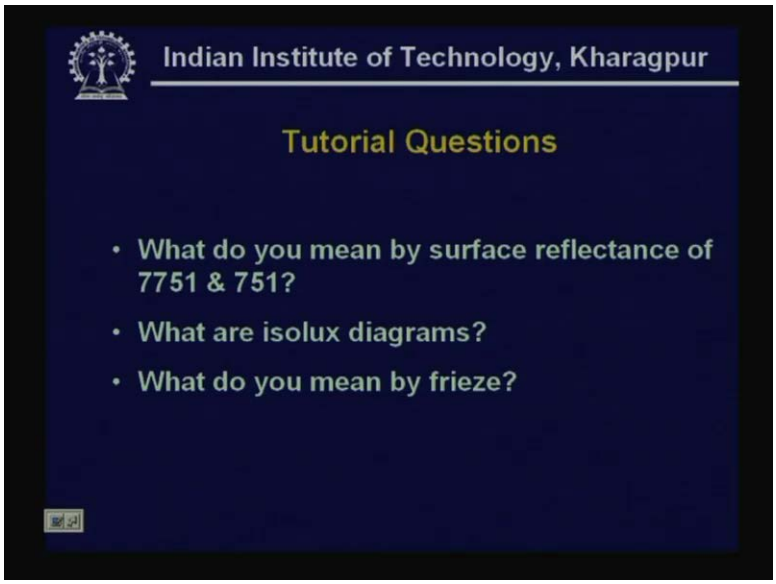

Coming to the tutorial question that may be addressed. The surface reflectances are specified by a four digit or a three digit. So the first question is what do you mean by surface reflectance of 7751 and 751. What are iso-lux diagrams? What do you mean by frieze?

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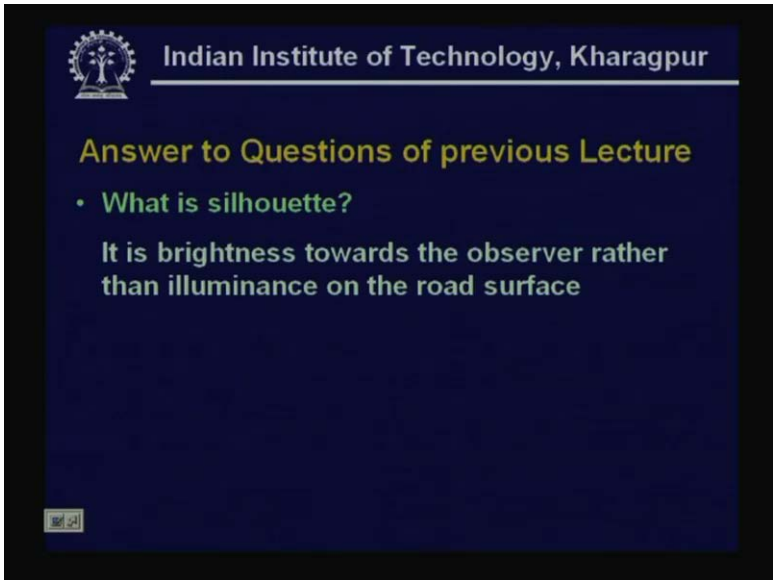

The answers to some of the questions which are addressed in the last lecture. What is silhouette? It’s a brightness towards the observer rather than illuminance on the road surface and it's not a complete detailed image but it's outline kind of a thing.

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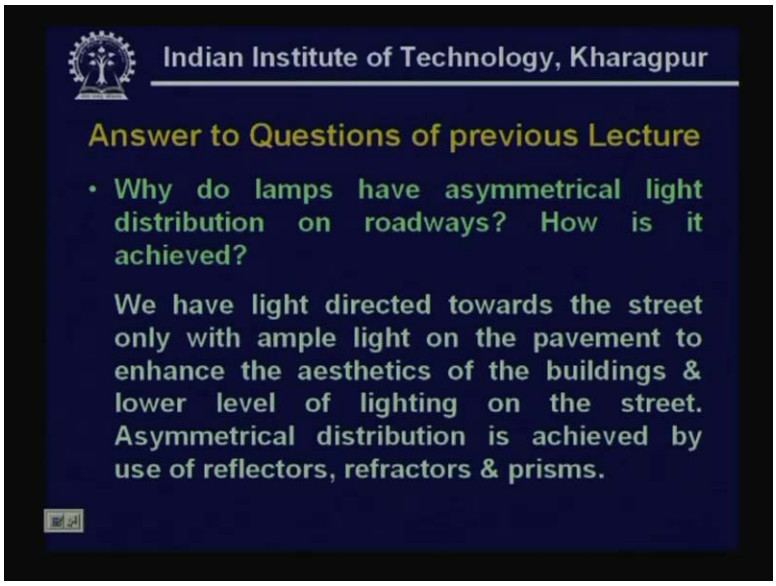

Why do lamps have asymmetrical light distribution on roadways, how is it achieved? We have light directed towards the street only with ample light on the pavement, this applies to the lighting within the city where enhancement of the aesthetics of the buildings is required. The symmetrical distribution is of course taken care by suitable design of the reflectors, refractors and prisms that are employed within the luminaire.

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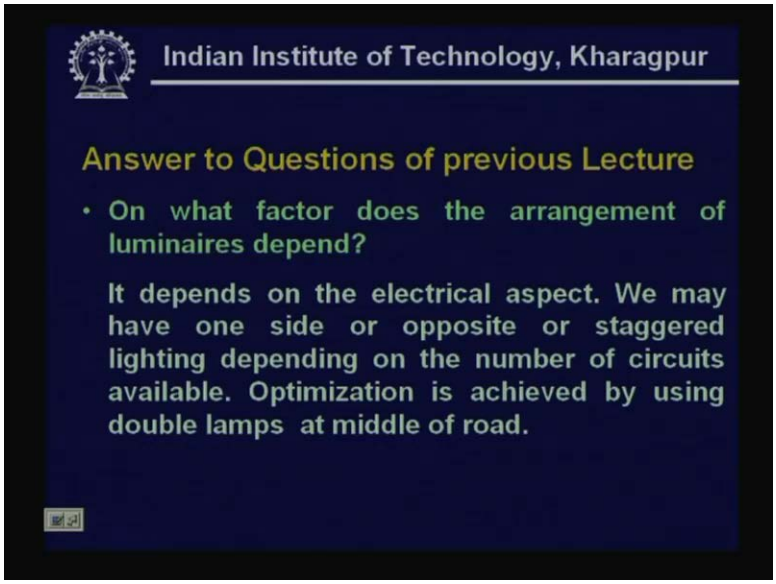

On what factor does the arrangement of luminaires depends? See among the various factors, first and foremost of course they required illuminance levels as per the CIE guidelines which depends on the road traffic density, nature of the road and depending on the ease of providing circuits, it

depends on the more on the ease of the circuits. If you have on one side or opposite side or staggered side, the number of circuits become complicated, one has in fact wherever possible if the road has more than one lane with a separator it's preferable to provide the lamps on the separator circuits becomes employed.

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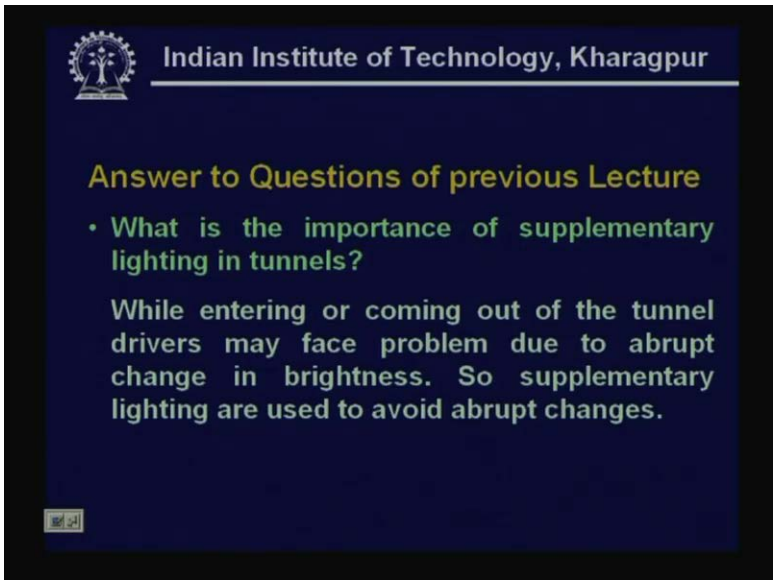

What is the importance of supplementary lighting in tunnels? See some tunnels depending on the length as we said there are number of zones, so one has to be careful that gradually the user is adapted to the light levels outside and inside. Therefore supplementary lighting is necessary to avoid abrupt changes, in fact some supplemental lighting at the increased level is necessary during the day time than more than the night time. This applies even to the close corridors for interior lighting. Thank you.