BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 02

Lecture - 07

Lecture 07: Lighting System

Welcome to the NPTEL course on Building Energy Systems and Auditing. So, we are in module number 2. Today, it is the second lecture of module number 2, lecture number 7. We will discuss the lighting systems. In the previous lecture, we discussed the HVAC systems.

So, here we will start with the types of lighting. Mostly, we will discuss artificial lighting, and we will see some illumination level calculations. Basically, our idea is to find out how much energy is required. So, as we all know, there are typically two types of lighting systems: one is natural lighting or daylighting. The source is mostly the sun, or sometimes it is moonlight if it is allowable in some conditions. One very important point about natural lighting is that it cannot be controlled; it is actually nature-given.

The second one is artificial lighting, and as you know, we have full control over it. We can change the brightness, adjust it according to the mood of the people, or adapt it to some thematic concept of the particular space. However, artificial lighting mostly deals with energy, which is electrical energy or maybe some other type of energy. Whereas, daylighting and natural lighting are fully natural. So, no energy is being used there. We will discuss daylighting perhaps when we discuss the ECBC code, maybe in the fourth module. Today, we will discuss artificial lighting and try to see it from the energy consumption point of view.

How artificial lighting can be designed or maybe it is already designed. I am not going to tell you about the design methodology of artificial lighting, but that is not in the scope of this particular course. So, we will actually focus on the energy pile. So, some of the design principles, if I see it, the purpose of artificial lighting is actually to maintain a particular illumination level of a particular space, and that space actually has to consider how much the illumination level has to be discussed or thought about. According to the activity of that particular space.

The second is that we have to see the background, we have to check the background level, you have to see the task level lighting also, and also you have to see that there should not be any kind of excessive light that creates glare. We have to actually see from the architectural point of view that it should be very pleasant and aesthetically very much soothing, and the last two points are almost vital. It should be economical, it should not actually provide a huge amount of running cost, or the installation cost should not be that much, and it should be energy efficient. So, first of all, let us go through some of the very basic definitions of illumination. The first is candela.

The candela, if you see it, is the amount of light that is emitted in a particular steradian, one steradian, the solid angle from a source. And it is defined that the source is actually a radio, the radio electromagnetic spectrum of 540×10^{12} Hz. So, that particular spectrum is emitting light in a particular steradian angle, one steradian angle, the amount of light, the amount of brightness of the light is called the candela, but that intensity has to be 1 upon 683W. So, that is a typical definition.

But the next definition talks about the luminous flux, which means now in a particular body, in a particular emitting body or source of light, the amount of candela emitted per steradian. So, it is actually mentioned as per the definition of the luminous flux that the total amount of visible light that comes out from the body. It is not talking about how much steradian or so. It is the total amount of visible light that comes out from the body. Of course, if the body is spherical, it has a different amount of the luminous flux.

If it is cylindrical, then it is some other type of the luminous, other type in the sense not type, other magnitude of the luminous flux will be emitted. The third important definition is the illuminance, that is how much lumen and the luminous flux is actually the unit of that is lumen. So, how much that luminous flux that radiation, the radiation of the light, artificial light, that much lux, the lumen is incident over a particular area. So, the lumen per area, how much lumen is actually incident on that particular area is called the lux.

And this lux level is specified for any kind of task because when I do something, suppose I am reading something, So, I need a typical type of intensity of the light. If the intensity of the light is low, that means the amount of flux, that light flux is lumen, that falls upon a surface is not that much adequate. So, I have to increase the brightness of that lamp or whatever. So, to increase the amount of luminous flux in such a way that the lux level per meter square, the amount of striking light is more.

What I have written over here is this particular candela, lux, and lumen. These three are the main fundamental units of illumination study, but sometimes it is a bit confusing. So, what I have drawn over here is that from a source, in a one steradian angle, the luminous intensity is the candela. But overall, if you see, first what I have written over here is that the visual intensity of a light source is quantified in terms of candela. The visual intensity of any light source. The second one is the lumen. Lumen is the flux, how much.

So, from a body, an emitting body, or the source of light, how much total amount of light is coming out, maybe in all three directions or so, or maybe in a spherical way or maybe in a cylindrical way. The amount of light emitted from any source is measured in lumens. So, there is a slight difference between these two. Finally, if it is emitted from any body, it will fall on any particular surface, and in that particular surface, if it falls, then it will be measured per square meter or per unit area, and that will give you the intensity or the luminance. A surface's luminous flux is measured in lux, and this is the actual brightness of a particular surface. So, I hope it is understood.

So, lumen per square meter will be the lux level, and that particular quantification, lux level quantification, is definitely going to be important for any kind of lighting design. So, lumen per meter square is lux, and if you want to have some foot-candela unit, so if one square foot, so how much lumen falls upon that is foot-candela, and one foot-candle is almost approximately 10 lux. So, these are some of the recommended values for different sources, different light levels, illumination levels for different room types. So, mostly it lies between 200 to 500, mostly it lies between 200 to 500. And, for reading activity, suppose it is the classroom, the general minimum is recommended as 300 to 500 or so.

And, suppose in any kind of corridor, if you see a corridor, if you see it is 50 to 100, this is important for our classrooms or so, and maybe some area where it is a little bit higher, maybe it is a laboratory, a professional laboratory or so, where you require some kind of very precise and high level of working. So, it may go up to 750, a minimum of 750 or so. Laboratory, classroom laboratories are also 500 to 750 because we need to see a lot of small work, detailed work or so. So, then the level of illumination will definitely be going to be high.

These are the lux levels mentioned as per the details, and it was given in this particular book. The Introduction to Architectural Science, which is a very nice book, and from the casual viewing from that point of view, rough task with a large detail with some kind of ordinary task which is 400 lux mentioned. So, what we understand from here is that the lux level or the illumination level depends upon two things mostly. One is the work and what activity I am going to do in a particular space, it is a very minute critical activity.

It is a very detailed activity. Suppose I am going to draw an architectural drawing or something, I require more amount of illumination, more amount of lux, whereas, if I want to just read, then I may require a little less. So, those are the typical scenarios where different types of lux levels are required. Next, we should also understand two more units or parameters, I must say, which are very much essential to us from the point of view of the energy efficiency of any lighting systems. One is called efficacy.

Efficacy is, you can say, the efficiency of a lighting source. So, there are typical types of lights: we can have an incandescent lamp, we can have a fluorescent lamp. There are so many types, so many different types of physics behind them, and based on that particular physics or that particular mechanism, it emits light. So, when it emits light, it emits lumens, but in the background, some electrical energy actually comes into it, and that electrical energy triggers some component inside the electronics or electrical component, and due to that, the body or that particular object will emit some lumens. So, on one side, it is electrical energy, which I can measure in watt because when I go to some shop to purchase some lights or bulbs or whatever, I say that I want a 60-watt bulb or a 100-watt bulb.

We do not say that we want a 1000-lumen bulb or a 2000-lumen bulb. We always call upon that, give me the 60-watt bulb. So, 60W is the electrical energy consumption of a bulb, whereas the output is the lumens. So, we want to see a particular efficiency in terms of how many lumens it can deliver per watt. If it can deliver more lumens per watt, definitely that is a more efficient bulb or electrical system or lighting system, and it is called efficacy over here.

So, light output by the energy input, that is the lumens per watt. And this is another parameter that is very important nowadays to see how much energy you are going to use for a particular area. So, that is considered as LPD, which is lighting power density. So, what is lighting power density? Suppose a particular space has some area, suppose this is a classroom where I am sitting.

So, this requires a 300-lux illumination level to teach. So, I provide some amount of lighting, and all the lights are actually consuming some amount of electrical energy. So, if I calculate how much is the total amount of electrical energy required to illuminate that particular surface to a required lux level of 300. That is the LPD, the lighting power density. So, the total lighting electrical load on the area is only the lighting load, nothing else—no fan, no air conditioner, no equipment, nothing—only the total load.

The electrical load on a particular room, which can be measured in watt and divided by the total area. So, that is W/m^2, which is the unit of that, called the lighting power density or LPD. So, this particular chart has been taken from the NBC 2016, which recommends some standard values of watt ranges. So, suppose an incandescent lamp—of course, incandescent lamps nowadays are not used because their efficacy is very poor. It is 12 to 20 lumens per watt.

So, if your expenditure is 1 watt, you will only get a lighting output of 12 to 20 lumens, whereas, if you see some compact fluorescent lamps, it is 60 to 70. So, 60 to 70 lumens will be the output if you actually use per watt of electrical energy. If you go to LED, LED is much better, 60 to 100. So, the first row gives the watt range.

So, maybe from 50 to 15 to 200-watt bulbs are available. The compact fluorescent, that is CFL, is 5 to 40, and LED comes about 0.5 to 2W in range, and those are the standard. Whereas, this is the third column, which gives me the life, how much is the working life mostly. So, that is also required sometimes. We will see in the future that this life of any bulb system is required to understand how much will be my payback period or all those. So, that also is very important data.

So, we can actually use this NBC data for our future purposes. The next is the ECBC data. ECBC 2017 also talks about the LPD. See what is the maximum LPD range of each and every area, mostly the areas. So, that means what is this?

Suppose if I say, it is a stairway. If you see this is a stairway, it is 5.5 W/m^2. So, you have to select that type of light, and that light should provide the minimum amount of illumination required in a stairway. In terms of LASK, and then you have to check that the stairway should not have more than the 5.5 W per/m^2 of the energy footprint. You can also say this is the lighting energy footprint also.

So, those are there. So, if there are some high numbers, if you see low numbers, they are definitely corridors and High numbers may be, if I say it is 21, see the operating room for a hospital, it is 21.8. Suppose any gymnasium play areas, gymnasium it is 18.8 or so, for a lobby of a performing arts theatre it is 21.5, sitting area of the performance art theatre it is 22.5. So, these are the

some of the areas where we probably require a little bit more energy because of some typical lighting systems also. So, it has been given some more amount. So, that is the standard particular LPD chart we must follow from our ECBC. It is provided in the ECBC code, ECBC 2017. So, next let us calculate some of the illumination levels for our design purpose and from there we see how much is the energy consumption of that.

So, as you understand now, I require quite a few things as my input. to know about how many bulbs and how many lux levels and all those. So, we should know the lumen output of the lamp or otherwise we should know the efficacy of the lamp and also the power rating of the lamp. Type of luminaire is also required because sometimes you have to see the polar diagram and we have to see how much will be the lumen output also because there are some kind of direct lighting, indirect lighting, semi-direct, semi-indirect like that. We also should know about the proportion of the room where the room index will be coming from.

But this type of luminaire room index is required for the calculation, but for the purpose of this course, I am not going to take that one. We will take the bare minimum formula for our equations, but from the illumination engineering point of view, we definitely require that room index and all to go for the very minute level of calculations or so. The reflectance of the internal objects is also going to help. I mean, what is the color of the walls, what is the color of the ceiling, and how much is the reflectance of that. Depreciation of the lumen because it is burning out. So, we have to take some kind of depreciation factor, which is sometimes called a utilization factor.

Depreciation due to dirt and some other things will actually be deposited in the luminaries in the room. So, we have a formula, and this method is called the area method because I am the concept of this area method is that the total illumination is assumed to be constant over a particular area. So, how much lumen is actually the total lumen output of a particular room by n number of lamps? Suppose if I say this is the n, the number of lamps. Which is this, and I is the lumen output of each lamp.

So, N multiplied by I is nothing but the total amount of lumen that we are going to provide in a particular room, divided by the area. So, that actually gives this N I by A, which is actually the LOX level, right? But it is multiplied by two factors: the utilization factor and the maintenance factor, which are always going to be less than 1. They are always going to be less than 1, and so the overall effect will be a little less because it will be multiplied by two numbers less than 1, and then we should actually get the value of E, and E is nothing but the average illumination on the working top. It is, of course, average. If I consider some room index, if I consider some point load method, then probably I can get the exact.

But, my first assumption is that I am assuming that all the lamps and all the lamps provided are providing the lumen all together, which is equally distributed over the working. So, let us discuss the utilization factor, the utilization factor. A factor which is always going to be less than 1, it depends upon the type of lamp and what type of reflective surfaces are there near to the lamp. Sometimes we may see that the lamp is a kind of conical enclosure. So, the enclosure will actually provide some reflections.

The room shape is also going to depend upon the room index and how much is the mounting height; those are a lot of the parameters that are there to express to get the exact value of the utilization factor. But it is going to be always less than 1. So, whatever comes, I have to reduce it by some percentage. So, that is one of the factors we should consider mostly in the examination, and in those cases, we sometimes provide you the utilization factor in different cases, but in practice, when you want to find out this utilization factor, those points have to be considered. Next is the maintenance factor; the maintenance factor, as you know, when we actually design anything, we install it on the very first day, and the illumination level will definitely be the brightest, but it actually accumulates a lot of dust. Sometimes you have to see that that particular dust will actually cover a partial or some portion of the luminaries or the light, and then

We sometimes may not clean it; it may be in a very remote area. So, that will definitely decrease the illumination level. So, that maintenance factor should also be considered, and the maintenance factor will definitely be very low if, suppose, in a kitchen or maybe in industrial buildings. Where there is more oily smoke and all that, definitely the most amount of dust or dirt collected on a particular surface or the light surface will be more. So, the maintenance factor will definitely be less.

So, again, this maintenance factor is also going to be less than 1. So, let us solve a very simple problem which has been asked in the 2015 GATE examination. So, a classroom measuring 10m x 8m x 2.7m is required to be illuminated with 500 lux at the desk level using 40-watt fluorescent lamps. And the number of lamps I have to find out if the utilization factor is 0.5 and the maintenance factor is 0.8, and it is also mentioned that the 40-watt fluorescent lamp has a rated output of 5000. So, it is very simple. What I will do, let us discuss.

I know the area of the room. I do not need the height, and I know the total lumen output because the total lumen output is N multiplied by 5000. Even this 40-watt is also not going to be useful for me because that is not there in my formula. What I read is that the number of lamps is nothing but the illumination. I just changed this particular part. If I go back, so, N is actually from here. You see, N is actually E multiplied by the area divided by I multiplied by UF multiplied by MF. So, I just rearranged the formula and used this formula

here itself. See, N equals this. So, E is my 500. Let us write over here: 500. The lumen output is 5000 per lamp. UF and MF are mentioned as 0.5 and 0.8, and the area of the room is 10 meters by 8 meters, so it is 80 square meters. So, just putting all those, I found out that the number of lamps required is 20. Twenty lamps will be required. So, go to the next problem. This problem states that an office space of 15 meters by 22 meters needs to be illuminated, and the required level is 300 lux. The utilization factor and maintenance factor are given.

Estimate these two things for the two cases. The first one, suppose I want to go for the number of lamps required in case of the number of lamps required in case of it is an LPD required for these cases. Case 1 is if I go for the fluorescent lamp of 60W having an efficacy of 40 lumens per watt and a cost of Rs. 125/- per piece.

And the second case is if I go for the LED lamp of 28W, with an efficacy of 90 lumens per watt and a cost of a little more, 600 rupees per piece. And I have to find out the number of lamps required in both cases. The lighting power density in both cases and also the energy required for 8 hours to run this operation, suppose it is 8 hours per day or the office hours are 8 hours per day, and the cost of installation. So, let us do it very quickly. Again, I will take the same formula. I know everything; I just have to see the two different cases, two different outputs because both are having different wattages and both are having different efficacies.

In case number 1, I know the lumen output will be 60 multiplied by 40. Why 60 multiplied by 40? Because it is a 60-watt lamp and 40 lumens per watt is the efficacy. So, the total lumen output is 2400. Now, I have my formula ready.

This 300 is the lux level required, and 330 is the area. If you go back, you will see that 330 is the area. 300 is the lux level which will be E and A, and this I am going to change. I am going to change it for different cases. We have 2 cases. So, I just put it over like this, and I required 74 tube lights or fluorescent lamps. And then I required this much watt because each lamp is of 60W.

So, this much of 4440W, and I know the area is 330. So, 13.45 is the LPD. The total amount of wattage is for 674 fluorescent lamps because 74 are required for having a 300 lux illumination level. And I also found out that if it runs for 8 hours, so it is for 1 hour, so almost about 35.58 kWh is the energy requirement if I run 74 such lamps for 8 hours, and the cost of insulation is 125 rupees into 74, so almost Rs. 9250/-. Similarly, I did it for the LED, so the LED's efficacy is much higher.

So, your lumen output is 25200, and then here I found out that it is 2500, not 10, which is extra. So, I required 71 such lamps, and it has a total power requirement of 1988W. And my LPD is very low now. You see, the LPD is very low, which was 13 over there, and now it is 6. So, because the LED is a much better energy-efficient lamp, its efficacy is high. So, high efficacy means that it will definitely drop down your LPD values, and similarly, I found out how much energy is required, which is 15, almost 16 kilowatt-hours per day.

And, the cost of installation, of course, was more than 42,600, which was almost 9,000 something over there that we can compare. So, what is the LPD for the first case? It is 13. Second case, 6, a much more efficient system, LED. The installation cost, definitely, for the LED will be more, almost 4 times, like 4 to some more than 4 times, 9,000 to 42,000. The daily energy requirement, of course, is much less, almost 50 percent less for the LED. So, this is all about lighting design.

So, these are the references. So, what we discussed is the individual lumen output, lumen level, and the level of illumination. Also, we discussed that lighting power density and efficacy actually give the energy footprint of a space because of lighting. Thank you very much.