BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture 36

Lecture 36 : Solar Energy-I

Welcome to the course on Building Energy Systems and Auditing. We are in the last module, Module 8. In Module 8, we will again go through 5 lectures. The topic of Module 8 is Green Energy and Sustainability. So, in the 36th and 37th lectures, we will discuss solar energy.

So, in Lecture 36, we will discuss Part 1 of it. In this module and in this particular lecture, we will discuss renewable energy applications in buildings, and we will also see how solar PV components and energy calculations are done through some steps. So, if you see, renewable energy is integrated into the building systems, and one of the components of present building systems is the renewable energy systems. If you remember, in the very second module, we discussed a lot of systems, starting with HVAC, then lighting, then other types of systems like lifts and escalators, and also the low-energy building systems. But there, I think I mentioned that another system in green energy systems or RE systems would be discussed later.

So, in Module 8, we are going to discuss that. So, as you know, almost about 40% of worldwide energy is consumed by buildings annually. As per the report of the International Energy Information Agency, each year, the energy expenditure and expectation from people, which will be going to consume some kind of building energy, is increasing by 1.4% per annum. And it will continue till 2035 or so. So, each year, there is a huge potential for demand.

So, there are two approaches that we can take to make two kinds of compromises or two ways—I may say two ways—of balancing energy with each other. The first one—I have written down the two points. The first one is to reduce the need for energy. As we have discussed so far, we can use some kind of passive systems, think of envelope redesign, or even consider retrofitting buildings. Based on that implementation, we will try to reduce the energy pressure or energy demand. The second approach is to offset the remaining building energy needs from renewable energy sources—offsetting the other part which is the additional part, a subset of the total energy. We can think of harvesting from the building itself or around the building through renewable energy sources.

So, in renewable energy sources, what are the sources—there may be plenty—but what are the sources we can actually use for building integration? First of all, the one that comes to mind is solar energy. Then, there is wind. Many buildings these days employ wind turbines and generate energy from the wind. Then, geothermal energy—we have discussed that in low-energy systems, like heat pump systems, where we can use some kind of energy. Then, we can go for biomass.

We will discuss wind and biomass in the fourth lecture of this module. We can also think of fuel cells, which won't be discussed in this module, but we will define what a fuel cell is in subsequent lectures. In solar energy, there are many types of solar energy potential that can be integrated into buildings. One is straightforward: photovoltaic cells, solar PVs. Then, we can go for building-integrated PV systems (BIPV).

So, on the surface of the building, we can integrate the PV systems. We can think of some buildings where hot water is required for solar thermal systems, and also, you can use some kind of hybrid solar PV systems—that is, solar photovoltaic and thermal—both can be integrated with each other. In the case of wind, we can also have two different levels of energy generation from the wind. One is the community-level wind turbine, and another one may be the building-integrated wind turbines or so. Further, when we think about the potential—the potential—when I can think that this renewable energy can be integrated into the building, there are some factors, and we have to check each and every factor before deciding whether we can actually integrate the RE or renewable energy system.

And which type of system we can integrate also depends upon those factors. The first one, if I just go through one after another and discuss a little bit, then let us say that available renewable energy resources at or near the building site—that is one of the most important things. What sources are available? If your building is a very low-height building and it is surrounded by high-rise buildings, I think we cannot go for solar because there will always be high-rise buildings around casting a shadow on the rooftop or the building wall. You cannot go for BIPV or rooftop solar PV. rooftop solar PV.

Similarly, we have to see what sources are available near the building and consider the nature of the building—what sources we can think of.

Available area for siting those technologies. Next is the cost of energy purchase from the electrical and thermal energy providers of the building. So that is also one of the issues. If the cost is low, we probably do not go for those kinds of RE systems. But if the purchase cost of electricity is very high, then people may think of going for renewable sources because that will be cheaper. Available incentives for offsetting the installation process for renewable energy systems—sometimes people may think of getting subsidies or some kind of relaxation in their taxation or something if they go for renewable energy sources from the government. So that is also one of the very important issues or important factors that

People might go for or might opt for those renewable energy systems or so. Local rules and regulations affecting renewable energy systems are also very important because sometimes the building bylaws, local building bylaws, the height of the building, and sometimes certain tenant-related issues and other concerns are present. There may also be issues like the amount of floor area, and based on that, the services required may have some restrictions. From that point of view, it may sometimes not be possible to adopt renewable energy sources. But those local rules are gradually changing in favor of using RE systems.

Desire to preserve or not alter existing architectural features. Building architecture and facade architecture play an important role in the building itself. It is likely one of the important factors that the client can consider. They may not want to change those architectural features, which may sometimes hinder the adoption of RE generation. Characteristics of the energy profile to be offset by the renewable energy installation mean the total annual generation amount and potential fluctuations. These renewable energies depend on natural resources, climate, and other factors. If these are not favorable, for the energy generation profile through RE, then there may be some issues.

Now, let's move to solar panel systems, which are very common nowadays. We will see what panels are and what kind of assembly they have. First of all, there is a solar cell, which is a very small PV cell, like an electronic chip. It measures 156 by 156 millimeters, a very small dimension. These cells harvest energy and are placed in an array. They create a module, which may be 2 feet x 4 feet or 2 feet x 8 feet in size. This is formed by multiple arrays and has a rating like 100 V or 200 V.

Now, those arrays are one single array that will be put on a particular rooftop or maybe in some area where there are a series of or an array of solar panels, and all of them will harvest energy as per their rating, provided they do not get hampered by shades or other issues. And these solar arrays are typically a design factor, but how much empty area or siting area I have, how much area I have in the south-facing or west-facing direction—those are the typical requirements. And finally, those array systems will have some kind of supporting systems; we have to have some kind of mounting systems, and based on that, the PV system will be fixed in a particular area. Next is how this particular system actually works. If you see this, it is a very schematic kind of diagram. These solar arrays or the solar PV modules have some kind of differential layers.

It mostly has two or three layers, and in between these particular layers, there is an n-type semiconductor and a p-type semiconductor. Actually, it is an electronic device. The motion of the electrons is based on the principle of semiconductor devices, n-type and p-type. And in between the n-type and p-type, there is a junction which we call a p-n junction.

And there are Above the n-type, there are some solar glasses for protection. The solar rays, the radiation, when they penetrate through this glass, they excite the n-type semiconductor. There are some cathodes and anodes arranged in the topmost and bottommost portions, and in between the n-type and p-type junctions, there is an ion exchange. The n-type will have a higher accumulation of electrons or negative atoms, whereas the p-type will have a higher accumulation of positive atoms or positive charges.

So, there will be a flow between two electrodes, and through that flow of electrons, we can actually harvest some kind of electricity. This is a very basic way of understanding solar PV systems also. Now, this particular solar PV system has various components. We have a tracking system which can track the solar path or the sun path. We have mounting systems.

Yes, sometimes tracking systems may not be provided because it is a costly affair or may involve other electronic devices. So, we can have only mounting systems and fix the inclination. There must be some kind of cables, a DC isolator, and of course batteries because we need them for using this electricity at night or other times. We need an inverter, AC isolator, charge controller, and an electric meter. So, if I see now how this particular circuit is going to be arranged and what is the work of each and every component, then first of all, we have to have some kind of solar PV that we have discussed. As many solar PVs as we can actually put, as per my demand and also the area or space available. So, from the solar PV, it has to go to some kind of electronic device called a charge controller.

It will control the amount of charge that is generated in the solar PV systems because of the solar radiation. So, it should not overcharge the battery, and it should not cause any damage to the battery. So, it will control that particular charge and will be connected to the battery systems. So, the battery will now be charged—it will be fully charged after some hours of operation by this charge controller and from the PV. From the battery, it will go to the inverter. Now, this is one of the important things: why I need an inverter because, in our country, almost all the

Loads are electrical loads, which are the alternating current (AC) kind of load. But you cannot store the current in an AC battery. You have to actually store the direct current (DC), which does not have any kind of amplitude or variation. So, whatever current comes from the battery is DC, so you have to invert it to AC. That is why you need an inverter to use it for alternating current applications. After the inverter, it goes to the electric meter, and then from the electric meter, it goes to different types of loads like lights, ceiling fans, or other equipment. But if any electrical equipment can run on DC, then the inverter may not be required, and we can directly connect the battery to the DC load. Nowadays, there are some products that can run on DC.

This bypasses the inverter effect. So, if some portion of the building or some equipment uses AC and DC, we can directly connect the AC components to the inverter, while the rest goes directly. Now, let us see how to estimate solar power and other factors. There are two methods. In this lecture, we will discuss the first method.

In the next lecture, Lecture 37, we will discuss the second method. In the first step, we will determine the photovoltaic array area and its efficiency. We need to assess how much area we can provide based on the available rooftop space or dimensions. We also need to consider the efficiency of the PV modules we plan to install. Unfortunately, until today, module efficiency has not been very high.

It is 10-20% is the efficiency of the module. people are actually doing lot of research in this area to improve the efficiency from 20 above or so and this efficiency is called as a conversion efficiency please remember that this efficiency what i am talking about is the efficiency of the of the solar power panel pv panel it is not the efficiency of the whole system now when i say about the whole system it does not have only the pv panels it have the charge controller it has a lot of other things like battery it has a the inverter so each and every component has its own efficiency and it is a complex efficiency can be calculated or determined by this virtue of the some calculations or some kind of the approximate assumption so this 20 to 10 - 20% is the efficiency of the power system the solar panel system so now the second step will be to determine the tilt angle of the solar array so what should be my angle of tilt that such a way that in the maximum time i will get the perpendicular radiation and perpendicular radiation from the sun will definitely better than some inclined radiation because that will the reduce down the the amount of the harvesting or the energy generations also the tilt angle is depend upon the solar lot of things that is that your latitude and the location and latitude it also depend upon the date when I am going to calculate the tilt angle and also time.

That means this tilt angle is actually depend upon the solar altitude angle. So, suppose this is your solar altitude angle this is the solar altitude angle and then the tilt angle can be calculated by 90° minus the solar altitude angle. So, this is your tilt angle this is the Ta If I say TA and this is the solar altitude angle, so definitely the relation between them is 90 minus solar altitude angle. So, and you see it is every time it is changing even in a particular day in different time the solar altitude angle is changing.

So, your tilt angle should change, but that is not possible. So, what we can do is that otherwise we can go for some kind of a tracking system, the electronic tracking system which I can set some of the standard or some kind of the parameters. So, it automatically it will track and then your tilt angle will change. or otherwise we can actually fix two typical tilt angle one for the summer and one for the winter season ah in ah and that may help me a bit because i do not require another type of system in ah or in another investment in the the solar array such a way that it can be the that that your tracking system may not require so there is a thumb rule that thumb rule is that The optimum tilt angle, see it is optimum tilt angle and this is a thumb rule.

Rule of thumb is that adding 15° to your latitude during winter. So, suppose your latitude is 30° north, then you add 15° that means 45°. So, I told 45° in time of winter. And in case of the summer, you subtract 15°. So, it will be 15°.

30 - 15 is your 15°. So, it is plus and minus 15° in time of winter and summer respectively. So, in winter, I will actually... tilt it at about 45° and in the summer, I will tilt it about 15°. So, as in case of the summer the solar altitude angle is very high with compared to the winter.

So, you require a lower amount of tilt angle because the relation between the tilt angle and the solar altitude angle is 90 minus solar altitude angle. So as in when the solar angle is high you require a low amount of tilt angle and in case of the winter you know that the solar altitude angle is not so high. I mean I am talking about the approximate the solar altitude angle is not so high. It is a low sun movement. You require high amount of tilt angle to make perfectly perpendicular to it.

So, this can be used and for the thumb rule and you need to take the third step is that determine the monthly average solar radiation data you need to generate or you need to get it from some website or some kind of a data book. So, this is one of the one of the data books gives us some the yearly the or monthly the radiation and all the some of the cities of in India and this is given in kilowatt sorry kilowatt hour per square meter per day. So, per square meter per day how much kilowatt hour the solar radiation is actually implied that is given over here and if you see Ahmedabad suppose the first row it is 6.41 in January that much kilowatt hour per meter square. February it is again little high, March again high and then gradually maybe in July, August it is very low, very low 4.26 and 4.56 because those days are cloudy days because it is monsoon time those days are cloudy days.

So, in India in monsoon, you will get the lowest amount of solar radiation. So that data is required in the third step and then we can find out the calculate the energy output from the monthly databases or so. So, we will do a small problem over here. Suppose this is a rooftop the plan of a building which I am going to have some kind of a PV installation. All dimensions there are two parts of the rooftop.

It is the L kind of a shape of a building. There is a corner of that two wings. There is a service area. And I have 13 meter by 5 meter of the one side full rooftop area is for available for my solar installation and another side is 12 meter by 8 meter is the area which is available for the installation. So, I will be going to install the solar panel of conversion efficiency of 15%.

That data can be how that data is actually calculated and all this we will discuss in the next lecture. Let us suppose it can give 15% of conversion and the solar panel size are 2 meter height and 0.6 meter 2 feet width. So, 8 feet by 2 feet. It is recommended that south facing solar panels will be mostly effective to produce electricity and it is in Mumbai so the latitude is 19° north. So, first of all, what I have to do?

I have to find out the tilt angle both in the summer and winter and take the highest one and then I have to see how I can actually fix it and how much panels I can fix it in my rooftop. So, I know that with the thumb rule winter I require 34° as a tilt angle and the summer I require 4° 19 + 15 and 19 - 15. So, now by the simple arithmetic sorry the trigonometric calculation I found that this is the blue color the slanting line is the solar panel height that is your 2 meter height which I have mentioned over here. So, let us suppose it is h. So, the ground projection is your base.

So, that particular portion is your base portion and that base portion is your h cos theta where this angle or the tilt angle is your theta. So, either it will be 34° or 4° depending upon your winter or summer. Now, the next one will be provided somewhere here. So, this will be this particular portion Dimension will be your row spacing and the row spacing will be about h sin theta into tan theta ok.

If I just reduce it then what suppose if I start it from here. If I start it from here, so this portion will be always under shade, right? This portion will be always under shade because the sun will come, rays will always give me a shade of the earlier one, the earlier in the row, the solar panel. So, it is mostly effective if I just see the tilt angle and then I decide that where will be the foot of this particular next row and then I decide about the row spacing. So, row spacing I have calculated because if this is your theta this is also going to be your theta and this is your h sin theta and then this will be your h sin theta tan theta okay this this this portion.

So this will be so I have calculated the base as the 1.66 meter for winter and your the row spacing at 0.75 meter so adding this to it is 2.41 meter but in case of the winter sorry in case of the summer it is 4° so this way this is 34° I have used for the winter and this 4° I am using for the summer right for summer and I got the row spacing as 2 meter is required for the summer row spacing Sorry not row spacing the row spacing and the base both. So, this two whole spacing whole the spacing of the row spacing plus the base is your 2 meter and 2.41 meter. So, I will have to take the 2.41 meter because the highest one I have to keep.

for my design calculations or so. So, 2.41 meter will be my spacing. So now I have this dimension and I am going to put the array such a way that it is going to face the lower side, the southern face. And in that what I did is that I have kept a particular 2 feet, the 0.6 meter in and around this hatched portion, the red color hatched portion as a circulation area. So, as the circulation area is 0.6 meter, now the left area is going to be calculated for the module size.

So, in this particular 13-meter by 15-meter space, it is now reduced to 5 minus 0.6 and 13 minus 0.6. So, 13 minus 0.6 divided by 2.41, 5 is almost equal to 5. Why 2.41? Because it is the rows. The base and the row spacing altogether I am using 2.41 meters, which we have calculated. So, 5 will be in a row, and the number of PV panels in each row will be 5 minus 0.6. So, 5 meters is the total, and 0.6 is

deducted because of the circulation, and 0.6 is the width of one module. So, about seven in each panel in each array will be accommodated. So, seven fives are thirty-five modules or panels will be accommodated. So here also, I did the same way: 8 minus 0.6 divided by 2.4 is 3 in a row, and the panels in a row are 35. So, almost about 105 module panels will be in a row. So, I have calculated two dimensions of the I have two dimensions.

I have deducted 0.6, 0.6 from each dimension, and one I divided by 2.41 and another I have divided by 0.6 to calculate the number of rows and number of PV panels in a row and multiply that. So that gives me the number of rows. So, in total, I now have 140 panels that can be accommodated in that particular rooftop facing south. Each module size is 2 meters x 0.6 meters, so 1.2 m^2. So, the total panel area is almost like 168 square meters. I'm in Mumbai, so I will use this data. So, this data I used now. Let us see how I have calculated this data. So, this monthly average solar radiation in kilowatt per square meter per day I have tabulated from the table.

So, it is you see it is January it is 6.51, February 7.06. So, similarly 6.51, 7.06 that I have tabulated January to December. Now, daily average output in watt. So, so daily average output in watt will be the total monthly average intensity multiply the total exposed area into the conversion efficiency so in case of the first row how i am going to get this one is 6.51 is the january data per day in the january per day you see the per day January 6.51 kWh/m^2 can be generated. So, next I multiply with the meter square this is the meter square and this is the efficiency efficiency. So, that means, 164.05 kilowatt per day can be generated in the month of January. 164.05 kW/day. So, if your total amount of load per day is something like 160, 162, it is good.

So, it can be actually taking care of that. Number of days in month, that month 31, January is in 31. So, monthly output megawatt per month will be 5.09. So, monthly output I have found out the daily average output which is this 164. multiplied by 31 number of days whatever comes i again divide that by 1000 so that gives me the megawatt this is given sorry that gives me in the megawatt okay like that i have

calculated for all the months so i see that the highest peak will be almost let me go to the next slide so that gives me the the total data so it will be almost march will be the march april is the almost peak and the the july august will be the June, July, August will be the little low. So, we need to see that even November is also very good, December is also well or October. So, that way we can see that the monthly average and the daily average or so and then we can take some decision that yes what should be my total load I can think of to go with the solar PVs or so. So, that is all for this lecture these types of renewable energy application in the building.

We have discussed in a brief and we have started with this lecture the solar energy integration with the building within the building. So, thank you very much.