BUILDING ENERGY SYSTEMS AND AUDITING

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Lecture 38

Lecture 38: BIPV and Solar Thermal

Welcome to the NPTEL course on Building Energy Systems and Auditing. Today, in the last module, Module 8, which is based on Green Energy and Sustainability. In Lecture 38, we will discuss BIPV and Solar Thermal. So, in this particular lecture, we will cover Building Integrated Photovoltaic. And the solar thermal energy systems and their applications, particularly the application of solar collectors.

So, first of all, let us discuss something about photovoltaic materials. So, there are three types of materials that can be implemented in PV cells, and they have their own positive and negative factors. The first one is called monocrystalline silicon, and we can also call it single-crystal silicon. And the next one is polycrystalline silicon, which is also called multi-crystal silicon, which is based on how it is prepared from the silicon base. In the case of monocrystalline silicon or single-crystal silicon.

We will have to cut it from a wafer of a particular object, and in the case of polycrystalline silicon, we have to cut it from a block. The third one is called thin-film sections, which is a bit costly and has a variety of applications. And that particular thing is based on a kind of 3D printing were. So, the crystals and the PV cells are actually printed over a particular thin film. And if you see the conversion ratio, we have already discussed that the conversion ratio of the photovoltaic cell ranges from 10% to 20% mostly.

We are thinking of or the things are going to be better in the future days. probably and the presently the crystalline photovoltaic which is the poly and the mono centric are those kinds of the silicon PV shells are actually captured the market almost 90% of the market is captured by them it is very popular. The life expectancy of the photovoltaic cell is about 30 years it is depend upon lot of other issues also. But definitely the efficiency will degrade as and when it is going to be older. The energy payback is range from 2 to 8 years that means, after 2 to 8 years you will actually get back the amount of the investment you have made in the very first day.

So, I have written down the three types of monocrystalline and polycrystalline and the thin film kind of the PV types and there are some other parameters how it is look like. The first one monocrystalline is look like blue and sometimes it is grey in color. The polycrystalline is bright bluish and sparkled tone color, thin one is the reddish black color and it is also very flexible in nature. It can become in a sheet kind of a form thin sheet kind of a form. And the third column gives the module efficiency.

If you see the module efficiency is decreased from top to bottom that means the thin film is having much more efficiency. So, in that much more efficiency in that sense that it is having the 6 to 8% efficiency, but probably for the kind of the harvesting kind of the situation where per square foot of area it shows the higher, I mean it is opposite because the watt peak is higher for the surface area. So, if you have if there is a slight difference between this module efficiency and the surface area of 1 kW peak per m^2. Per m^2 the watt peak is higher in the thin where is lower in the monocentric one, but the efficiency module efficiency is much more in the monocentric that means, per square feet it may generate less. But overall efficiency losses and all will be less in the monocentric with respect to the thin.

So, we will go along with this modular efficiency, which is better to choose because, finally, that will be counted when we consider any kind of energy generation from a practical point of view. So, visually, if you want to differentiate, it will look like this monocrystalline silicon. The polycrystalline silicones are a bit darker in color, and there are very close lines over there. The thin films are similar-looking to the monocrystalline, but they are very flexible in nature. So, now let us see what the parameters are that energy generation through solar panels depends upon. So, there are 7 to 8 factors.

So, based on that, let us discuss the first one, which is definitely solar radiation, as you know, it initiates with solar radiation. Today, if the sky is overcast, it would not generate that much solar energy. So, radiation is one of the issues. The next one is the location and orientation of the solar panels, which we discussed in the last class. The tilt angle towards the south and the west, and the location is the latitude, and also based on all those criteria.

The radiation also depends upon the duration of the day, and all these things are there. Different charts are available for how much kilowatt-hour is available for different locations, at least in India and some countries abroad. The third one is the degradation of the solar panel due to age. This is one of the things that we were just discussing in the earlier slide. The efficiency may be the current efficiency or the very new material efficiency or panel efficiency, but it has another peak. Initially, the thin film may give you 17 17 kW peak per m² or so, but its overall efficiency is 6 to 7% or so.

So, that is the degradation due to solar panel due to the edges or so that is depend upon the what material you are going to employ. how you are handling that one. Sometimes it may be broken because of some mishandled or something like that in the rooftop or so, maybe some kind of the cyclone or something like that. It may have some kind of a degradation that is the external degradation, but during the due to the old edges of this particular panel because of the material over there.

So, it has a kind of a degradation. So, based on that it is better to calculate the areas based on the modular efficiency not from the watt peak per m² or so. Next is the wind velocity, wind velocity is also the different the velocities in the different time will definitely going to fluctuate the amount of the electricity generation. The temperature of the panel is another issue, temperature of the panel if it is increased the electrons that the movement of the electrons is going to decrease. What we know from our the literatures and all of when I am not very much knowledgeable in particular in that one because it is all comes down to the semiconductor physics.

So, temperature of the panel is the issue. So, sometimes people are thinking of using some solar heater back side of the back side of the panels. So, that the temperature can be reduced down and also you can generate some kind of a heat that is another issue. And this is one of the most important issues because when the solar radiation is very high, it has a high potential to generate electricity and that time the temperature is also very high of the solar panel temperature is also very high. So, it may reversely affect the harvesting capacities also.

The next one is the shading upon the solar panel because of some parapet wall or may be some trees nearby or may be some building nearby there may be some shade and for that definitely it will be the it will be restricted the generation will be restricted. The dust accumulation over the solar panel this is another issue we have to clean it properly and regularly in periodical interval. So, that dust is not accumulated over the panel which will again decrease the efficiency of the panel and that will reduce the electricity generation. So, now if you go to the building integrated photovoltaic, it is another type of photovoltaic which is be applicable to the whole facet of the building. So, I have written down the output energy over here is electricity.

The application is offset building electricity consumption and export to the grid. So, it is mostly for the generation or regeneration. It is applicable in the high rise building and specifically it is in the vertical facet to sun without obstruction is the specific requirement. Now, one thing is very clear to us that if I want to generate electricity and if I want to have more and more electricity. I have to increase the amount of panel area of the panel.

So, if I go in case of the high rise building as you know the rooftop area is remain same ok. Suppose it is a G plus 3. So, whatever may be the rooftop area for G plus 5 or G plus 7 the rooftop area will be the same. So, if I only bang on the rooftop area then I can have a limited amount of the generation of the electricity and based on the increment of the high rise building I cannot cope up my electricity generation through the solar through solar panels will not be high if I go high rise. So, only thing I can do that.

As we go high, we can the building will increase its surface area. So, if I can put the in the solar panels in the surfaces all the 3 or 4 surfaces potential surfaces of the building then the amount of the generation will be also going to be high. So, for 3 storied building it is may be of may be 9, 10 meters for 5 storied building it is the 15, 17 meters. So, as and when the building will be going higher, I will get more surface area potential surface area and I can have more generation which is needed for the to take care of the zero energy or something like that to take care of the balance. But if I only bang on the rooftop solar AC I cannot increase the surface area even if I increase the high rise the number of floors.

So, that is why this building integrated photovoltaic is very much important to apply in this the high rise building to generate more and more electricity as in when it is go higher and higher to increase the surface area. The earlier one the rooftop AC what is there the it is also generating electricity it is also the application from point of it is the offset building electricity is also it is suitable for all type of building applications actually and is also required the shadow free area. So, now in the building integrated photovoltaic application where we can put even the rooftop installation are one of the type of the BIPB. BIPB is building integrated. So, even if it is a rooftop, it is one type of BIPB.

So, what are the other type of BIPB? It can be in facet. So, BIPB system can be installed in the facet as a cladding or curtain wall or as a window. So, if I can use that as a cladding, I have two benefits. One is I can actually go to give a shade to my wall.

So, that will actually be cooler, and the total energy or heat energy which will actually penetrate through conduction will be less. Of course, there is a catch point over here: in between the wall and the PV cell, there should be a gap, and that gap should be thoroughly ventilated; otherwise, it will trap heat because it is blackish in color. It will trap heat, and that may increase the conduction of heat. So, that is one of the issues. So, you may have some kind of ventilation, like a forced ventilation system in between, but in general, theoretically, we can say that I can increase the potential amount of surface area to generate electricity if I apply the BIPV system in the facade. We can also

go with externally integrated systems, maybe installed in the balcony railing or any kind of porch, any kind of area—only suppose if I go for some portion of the areas of the parapet wall, balcony, or some kind of porch wall, chhajas, and all. So, that can also be beneficial because as you go higher, your parapet wall may remain the same in area, but the amount of balconies, the amount of roof chhajjas, the amount of some portion of the grilled work, or maybe some kind of portion of the shaft that takes care of your water supply or the sanitary pipes—all those shafts, the length of the shaft or the height of the shaft is going to increase. So, only if I choose those areas—not the actual longer or wider facade area—that can also be incremental as I increase the height of the building, and that can fetch some kind of electricity.

Why can we go for these externally integrated building systems or so? Sometimes, architects may not like to wrap the whole building with the blackish color of the building-integrated photovoltaic. It may not be good also; sometimes, it may look like it doesn't fit that particular area aesthetically or culturally. That particular building may not take that; it may not be viable for that. So, in those cases, we can go for those small areas and actually generate some kind of electricity.

So, the BIPV can be used in the car ports. So, the car parking area surface car parking area for some institutional building maybe some kind of a mall where that can be available. So, over the car porch we can provide the shading and with the shading can be provided with the BIPV and this also be the same the parking shades for all. And there are some few buildings in India also the abroad also I have one building from the India. data center in the Mumbai which is about to be I mean they told to be I have visited their site and I have collected one photograph from the site the website itself and it is given as it has installed the solar PV of 863 kW peak which is very good and very high.

And it has a capacity of it has actually installed 2466 numbers of panels almost which is wrapped the whole facet. You see there are some mechanisms which has been placed over there some kind of the vertical girder kind of a thing which is movable and that can be actually provided because to clean those surfaces also. It has 9 intervals, it has those and it has a almost like very huge 1208200 the kilowatt hour per year generation capacity, which is quite a significant amount of electricity can be is generated in this building. So, next one is the Johan Cruiff Arena of Amsterdam. It is a football stadium where it has been you can see again, I have visited their website and then I have taken this photograph from that.

It is a international football arena where there are the big football matches are going on. It is a very popular stadium and this stadium is the It is kind of a indoor football stadium kind of a thing and it has a panel, it has a solar panel in the stadium top which is told to be given as almost 930000 kWh electricity per year of course, which is 10% of the total demand of the because it is an indoor. So, it required artificial lighting to play football. So, 10% of the yearly it has been given and I heard that this particular stadium is also sometimes when it is required when it is off time.

So, it generates electricity, and that electricity is actually sent to the charging station car park, to the car charging stations. This is going to prevent the emission of carbon dioxide entering the atmosphere, equivalent to almost 180 cars in a year or so. So, that is a considerable amount of reduction, and these small interventions can be made because we also have a lot of this kind of roof structure in our country. We have a lot of maybe open stadiums, maybe we have— How many? Maybe 15 to 20 very good cricket stadiums, around 10 football stadiums. So, those are open stadiums, but they have some kind of covering or something radially.

So, in those cases, we can also think of some kind of intervention like this kind of BIPV, which can generate a lot of electricity. We have some other areas as well—a lot of bus stands, railway stations, and airports. Everywhere, this large number of roofs is available, and we can generally think of implementing this kind of intervention. There are different types of solar panel facets, and this is still going on—this kind of intervention. We can have solar cladding, which we have just now discussed.

Photovoltaic cells directly integrated with the building cladding systems can also be considered. We can think of transparent solar facets; we can actually replace the— You can have kinetic solar facades, which can actually change the orientation at different angles at different times of the day. We can have solar shading systems, adjustable shading systems that align with the sun's angles, which will provide shade inside and also harvest some electricity. We can have ventilated photovoltaics, which have a kind of gap in between and can be ventilated through that.

So, next let us go to solar heating, which is another application of the direct use of solar power or solar electricity. The output energy is heat, not electricity. It is heat. So, hot water—I am going to generate, I can generate low-pressure water or, sorry, low-pressure steam—and then we can apply it to domestic hot water supply, use it for laundries, some cleaning operations, hospitals, hotels, and all. And then again, we require a shadow-free rooftop. So, this is the circuit diagram or maybe the system diagram of this kind of solar heater tank.

So, there would be a hot water tank. I may say it is not only hot; initially, it may be a cold water tank, and then gradually the water temperature can be heated by some circular loop. So, it admits some kind of cold water to advance to the solar collector. Solar collectors are some kinds of PV panel. which does not look like a PV panel, but it has two types we will discuss later.

So, the solar collector will absorb solar energy from solar radiation, and the circulation of the water—which is cold water now—can be a little bit higher in temperature, and it returns to the system. And again and again, it will be circulated based on your speed or whatever your pump efficiency may be. And after a certain time, when the temperature reaches a kind of the design temperature level, you can take that hot water to supply to different parts of the building—your hotels, your hospitals, or maybe your housings. So, in the solar collector, there are two types of solar collectors.

So, you see, it is a drum attached to the solar panel. So, that means this is a kind of solar collector. The first one is called the flat plate collector (FPC), which is a kind of dark, thin box with a transparent cover. Below the cover, there are small pipes, and water moves through them. The second one is called the evacuated tube collector. It does not have a flat kind of sheet.

It has a series of tubes, and these tubes have an inner and outer shell. The technology is such that it transfers the photons' radiation energy to heat energy directly to the water or any fluid inside it. Any fluid inside it. So, it is called ETC. Now, evacuated tube collectors are considered to be more efficient compared to flat plate collectors. So, how do we design the system?

So, as I know, there is a supply side where the solar radiation supplies the energy. So, what I have to do is know the solar radiation intensity. So, for a particular day, I need to know the kilowatt-hour per square meter per day—how much solar radiation there is. Of course, that is available. We have seen in the last lecture that it is available for some typical cities in India. So, I can collect that data, and I can also find out that this much area of the collector I can allocate in square meters. So, this is the supply side.

So, in that again I need to know the what is the collector efficiency collector cannot give you the 100% efficiency. So, SPC has little less efficient. So, the flat plate collectors are having 35 to 60% efficiency, whereas the evacuated tube collectors are bit more efficient in nature. So, it has a 55 to 75% of efficiency. So, this initial sorry the solar radiation I the collector's area A and the efficiency if I multiply then I will have to have the supply side equation ready.

In the demands and radiation what I demand? I demand to increase the temperature of water. So, I need to know how much the amount of kg of water I have to handle per day. So, that I need to know. I need to know the what is the ambient temperature of the water.

So, normal temperature of the water that particular day or that particular month average temperature of the water in that particular month. Because, winter month it will be little low the summer it will be little high. So, that I need to know I need to know the what should be the hot water temperature T h how much temperature I require to the increase the temperature. Maybe I can get 20° temperature I need 60° temperature water. So, this what is this 60 and what is this there is 20.

So, the ambient and hot water temperature I need to know, and also, I need to know the specific heat capacity of the water. It is 4182 joules per kg per° C. So, these are the three parameters: the mass, the specific heat capacity of the water, and the delta T, the temperature difference on the demand side. I can multiply them and equate them. So, I can equate them and multiply them, then let us see what the unit balance between these two will be. So, if I take the first one, the unit of I, which is the solar radiation, is kWh/m^2. For a day, I am going to calculate it by multiplying with m^2, which gives the unit as kilowatt-hour on the supply side.

Please remember that eta, the efficiency, does not have any unit because it is unitless. On the supply side, it is this, and the demand side has three again. The mass is in kg, the Cp, which is the specific heat, is in J/kg/°C, and delta T, the change in temperature, is in° C. So, finally, it is in joules. So, on the demand side, it is in joules, and on the supply side, it is in kilowatt-hour, which is also joules, but you have to relate them by the transformation factor. Because 1 kilowatt-hour is 3.6 mJ, which is 3.6 into 10 to the power 6 J. So, by virtue of that, I can equate the supply side and the demand side, and anything unknown between them I can easily find out.

So, let us go to problem-solving. So, I have an institute guest house located in Pune. It has 25 double-bedded rooms, okay? 25 double-bedded rooms, and I have to install a solar rooftop heating arrangement to get a daily water supply for all my guests. So, for all my guests, it is estimated that each person will require almost 5 liters of hot water at 80°s centigrade. So, I am going to supply per person 5 liters of water for this guest house, which has 25 double-bedded rooms, at a temperature of 80°s, right?

The design the design of hot water heat. solar heater should be incorporated the monsoon and the winter season the data are given below. So, data for the monsoon time and the winter time in the August and January in Pune is given below. So, what are the data? The solar radiation in kWh/m²/day is given as monsoon is 3.49 and winter is 5.04.

Whereas, the ambient temperature of the water mostly run mostly in an about in monsoon time is 25° and the winter time it is 20°. So, I have to actually see or do a comparative study or as an assessment based on the which type of technology, I am going to do this SPC or ATC and based on that and we have to definitely assume some further suitable data. So, let us go with the demand side. What is the demand? Demand is I have 25 rooms, 2 beds.

So, almost in a full house condition I have almost 50% in my guest house 5050. and 5 liter per day that gives me 250 liter I am assuming that 10% extra consumption may be that is good to do and so that means I have to have prepare for 275 liter per day which is equivalent to 275 kg of water because 1 liter is equal to 1 kg. I have Cp with me 4182 joule per kg per° C and also the required the hot water temperature is 80° C for both the season I required 80° C, but the ambient temperature different. Now, the ambient temperature in monsoon and the winter are different for this two month 25 and 20. So, I found out for the monsoon month how much is the demand.

So, what I did is that the delta T is 55 for the monsoon season, 80 minus 25, whereas in the winter season it is 60°s—sorry, 80 minus 20. So, M into Cp remains the same for both seasons; only delta T changes—once it is 55 and once it is 60. So, this joule I have calculated, and definitely in the winter season, it is a much higher amount of energy required. Next, let us go to the supply-side condition. On the supply side, who is going to supply me?

The solar radiation is supplied, and this solar radiation is again having a fluctuation. So, monsoon is 3.49 and winter is 5.04 kWh/m²/day. So, in the case of the flat plate collector, now let us come back to the two types of collectors, taking the things differently on the supply side because the efficiency is different. I am assuming an FPC flat plate collector efficiency as 50%. So, my supply-side equation is I into A into this efficiency eta, where A is unknown to me—that is my design. How much area I require for this particular collector, I have to find out. So, in monsoon,

I have multiplied 3.49. Into this area is unknown to me; 0.5 is efficiency, and this is the conversion factor—3.6 into 10 to the power 6 is the conversion factor. Similarly, in winter, the change is this only—this is the change. Instead of the 3.49, I have used 5.04 kWh/m²/day for winter. So, these two are the two different numbers for the demand side, and now I can equate them. Force—sorry, I—let us go to the evacuated also.

The evacuated base collector I am assuming a efficiency of 70%. So, I have done the similar calculation with monsoon and the winter only change will be the efficiency 70% over here and 70% over here and rest all the data as per the monsoon and the winter will remain same. So, I get again get two different figures in joule. So, now my supply side and the demand side both the part of the equations are ready only unknown is the A. So, I can find out the A. So, first what I did I first estimate the collector area from the

FPC point of view. So, supply side and the demand side equation I have equated. So, this is the demand side equation side that we have generated in the very first slide. This is the second slide generated that the supply side energy equation is generated. I have equated to them this is the equation and then I got the areas.

I got the monsoon areas, monsoon time if you want to harvest you require almost like 10 m² of the area. Whereas, in the winter time it is little less areas required 7.6. Please remember in the winter time solar radiation is higher it was 5.04 and monsoon it is lower 3.09 that is actually playing the role. Of course, you may say that in the monsoon time temperature is higher the ambient temperature of the water is higher. Whereas, the winter it is low, but still here what you see is that winter you require less amount of the area, monsoon you require more amount of the area.

So, we may go with whatever maybe you can go with some kind of averaging, or if my initial investment is applicable to that, I mean I can go for a 10 square meter. I will be really. I do not have to bother about anything. I can run things in a normal way. Otherwise, during monsoon time, if I go with 7.6, a little bit extra energy I have to put in through electricity to get that much amount of temperature. So, next, let us calculate the collector areas for the evacuated tube collector. Similarly, I did it and I found the areas like this. Now the thing is that for evacuated tube collector, you have to find out not only the area but also the number of tubes. So, the length of the tube varies from 5 feet to 8 feet, which is 1500 millimeters to 2400 millimeters.

The diameter of this tube varies from 1 inch to 3 inches, which is 25 to 75. I have assumed for this particular problem as a 6 feet long tube with 2-inch diameter, which is 1800 mm and 50 mm, which is the area. So, I have found out the area, and in the areas, because it is the area of the cylinder, not the surface of the cylinder, but the projection area of the cylinder.

So, the diameter and the length will multiply. So, that gives me 0.09 m^2, and I can find out the number of tubes required for the monsoon and the winter season by dividing that area by the area of the evacuated tube. So, the only thing is that there is again a small typographical error; it has to be ETC area, not FPC. FPC was the earlier one. So, that is all for today's lecture, and that ends the lecture on solar one.

So, what we have understood from here is that solar energy can be generated through the building surface and other types of applications on the solar PV. Solar energy can also be directly used for heating applications in the building. And we will move on to the next two types of energy, RE energy, renewable energy, in the next slides. Thank you very much.