Solar Energy Technology

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Lecture - 26

Long Term Solar Energy System Performance

Last time, I have introduced the distinguished between a device, a solar energy device and the system; and we also found that the performance of the system will depend critically on the component combination, in spite of the fact that a collector may be efficient unless you have sufficient storage, it will not be able to meet the requirement. Further, we distinguish between the performance which is indicated, let say by efficiency over a short period of time versus a long term performance, the time period being a year, because a metrological cycle repeat itself over a year and also, the economic analysis or based on yearly return.

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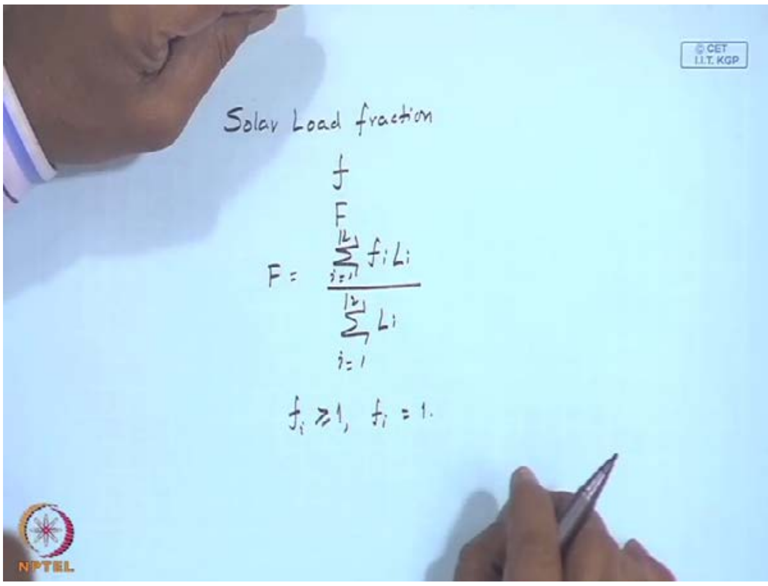

Last, I was discussing about a performance index, which we call the solar load fraction; on a monthly scale indicated by small f, on yearly scale indicated by capital F, where this capital F will be a summation of weighted averages of the monthly solar fractions with the load on the system every month upon L i, i may be equal to 1 to 12 for the 12 months.

So, with a explicit condition f i, if it is greater than and equal to 1, it should be treated as equal to 1 which is translated in simple term a solar energy system supplying energy. More than the requirement or more than the load on the system shall not be taken into account, and it shall be equated as if it is supplying only the energy need. Of course, the role of the storage is taken into account. The excess energy will go into the storage, but nevertheless, it cannot meet any more thing, more than whatever is loaded in the system.

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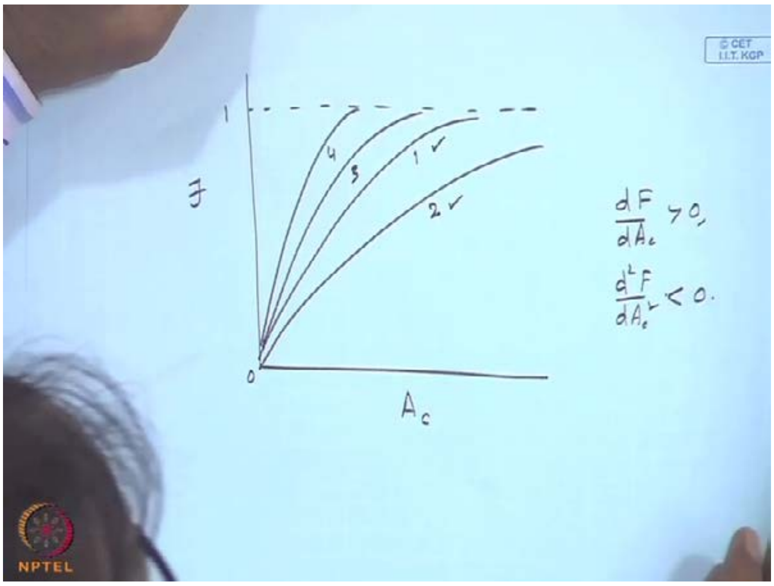

So, I have shown curve of solar load fraction yearly versus the main parameter being the collector area, and this is 1. It can be more than 1 and you have got several curves like this, asymptotically starting from 0 and going to 1. As area increases, this may be 1, 2, 3, and 4. We try to describe the differences. This may be a typical location. This may be a location where the solar radiation is lesser, consequently my load fraction meet is lower and we also said that d F upon d A c is positive. The load fraction increases with area, no doubt, but d square F upon d A c square with a convex upward curve is less than 0. What it means is the load fraction increase at a decreasing rate as the area increases.

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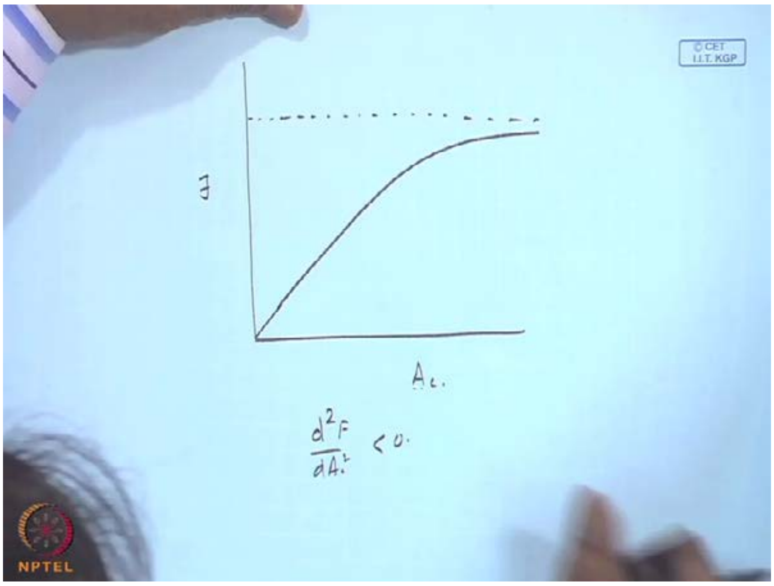

Initially for small areas, it is almost linearly proportional as you double, let say a 0.25 square meters and doubled to 0.5 square meters. There is no question of energy being in excess of the demand. Consequently, continuously the load fraction on a day basis or a monthly basis increases and hence, it will be directly proportional to the area. Subsequently, either may be because of non-uniform in the load or the non-uniformity in the solar radiation. Equal incremental areas will not result in equal incremental f. It will be less which makes it convex upwards curves making d square F upon d A c square negative. That means f increases at a decreasing rate with area.

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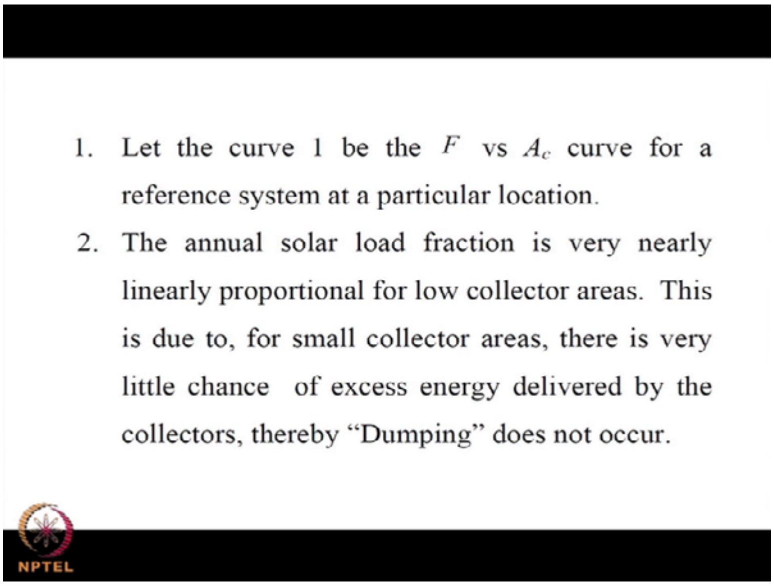

So, each curve has been described as due to either a lower radiation or a higher load fraction or a higher load, and the features we have already described last time and curve 3 shows the variation of F with the system when it is provided with a larger storages.

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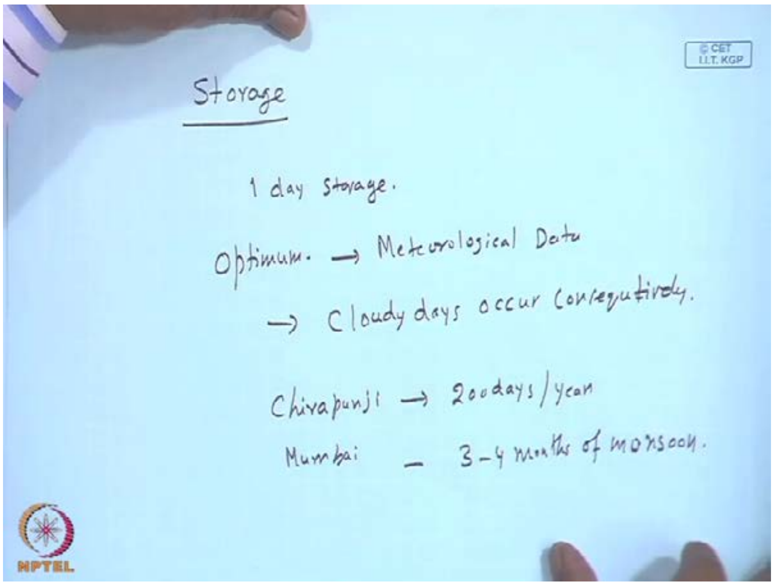

So, we need what is a storage size. My performance is going to be fairly critically depended upon the storages, say for example, you can have one day storage. Of course, the energy delivered will depend upon what is that one day, a bit December, bit June. Obviously, depending upon the solar radiation that is available, the energy deliver will depend upon the season and you may typically provide one day storage, so that the energy collected over today shall be available for use irrespective of the timing the next day. So, one day storage is typical and in optimum method, one has to go through this. This requires metrological data which essentially shows how many cloudy days occur consequently. So, for example, if you consider location like Cherrapunji in the eastern part of India or even Mumbai, this almost rains 200 days. Any year this will be 3 to 4 months of monsoon. So, you may consider how many days of continuous uninterrupted rain fall could be there.

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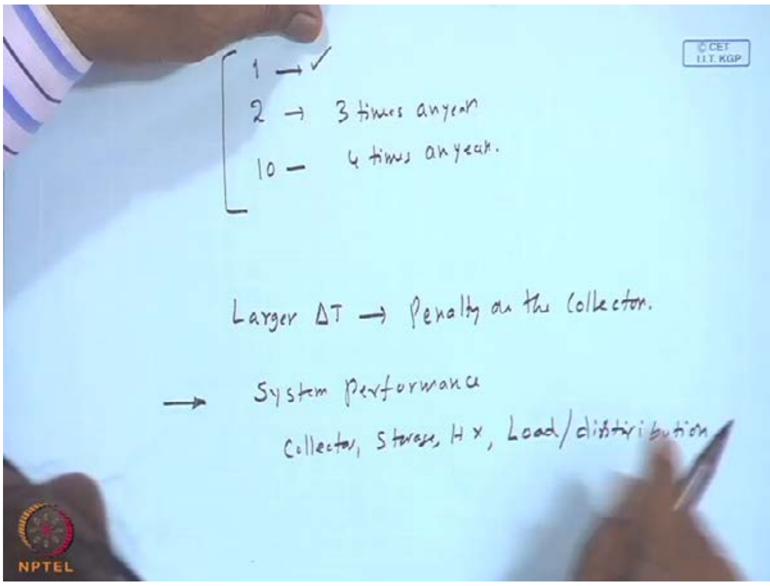

It can be only a day for many locations or two days 3 times a year and in a place like Cherrapunji, it may have 10 times or 10 days consequentially or 4 times a year. Now, you have to find out an optimum, whether you will provide simple one day storage or two days because it is likely to take care of 3 time in a year when there is no sunshine and when it is rainy. So, that is an optimization which will depend upon the specific metrological detail of the location.

So, our curve four is better heat exchanger or a worst heat exchanger. If the heat exchanger has low effectiveness, it requires a large delta T. Consequently, it is a penalty on the collector, right. So, you are asking the solar collector to deliver energy at a higher temperature, much higher if the load heat exchanger is put and hence, the collector will be operated at a lower efficiency and hence, you have a higher curve or a lower load fraction meet by a particular system. Now, if you really want to summarize, we want a system performance which includes all the components like collector storage, heat exchanger and interestingly, load and its distribution. This does not come explicitly in the curves I have described, but actually illustrate these facts.

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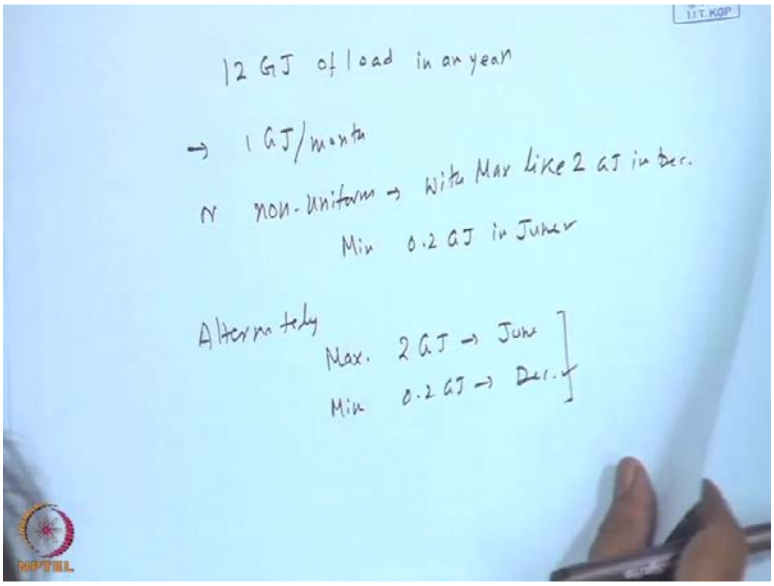

Suppose, you have got 12 gigajoules of load in a year, this can be 1 gigajoule every month or non-uniform with max like 2 gigajoules in December and a minimum like 0.2 gigajoules in June. Ultimately, you may also have max 2 gigajoules in June that mean 0.2 gigajoules in December. So, you need not take them latterly. Why? By choosing June and December, I essentially mean the highest radiation and the lowest radiation matching with the high demand, not matching with the highest demand. So, consequently your load fraction shall not be able to save the energy or load that meet with the energy delivered when the excess radiation is there, when there is no demand, but in the case of when it is unable to demand, you have a penalty.

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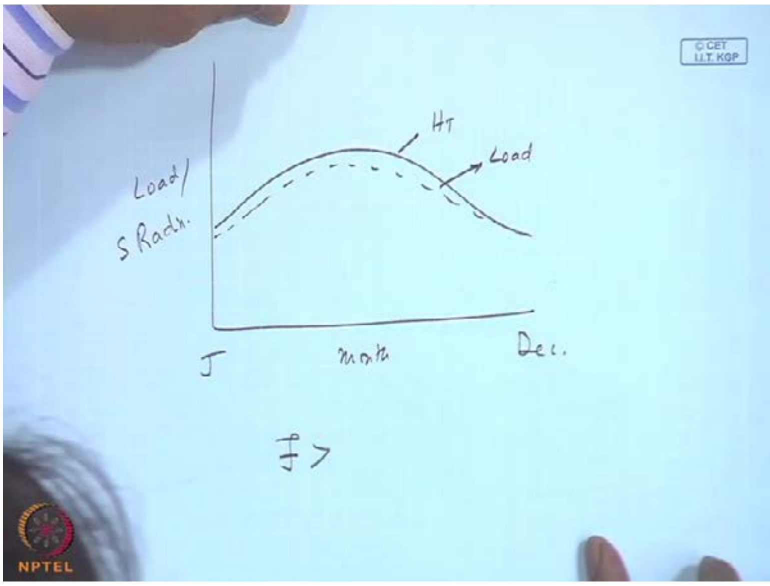

So, if my solar radiation, if this month is typically like this January to December and my load is following the solar radiation. Then I can expect this load or solar radiation, my f will be higher compared to this situation like this, where you have of course the same variation of the load solar radiation, sorry and with the months and my load can be like this. No load, when the radiation is maximum; and the higher load, when the radiation is lower.

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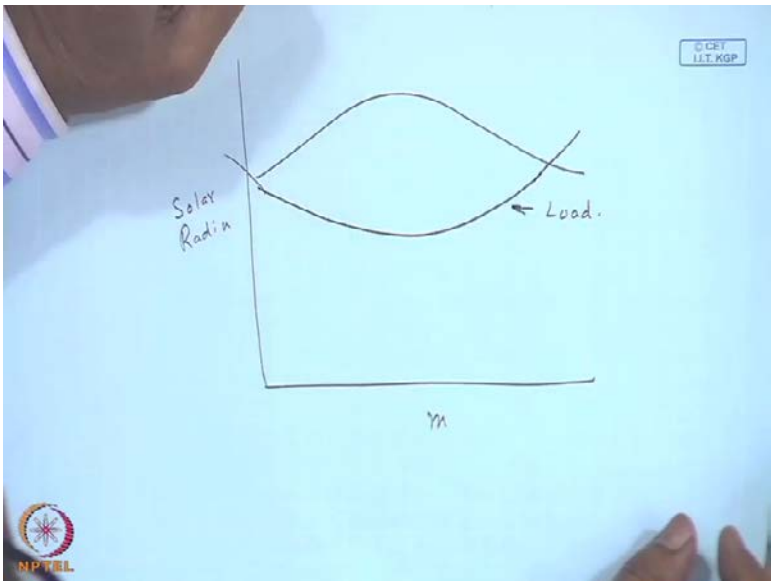

So, this will be adverse compared to the pervious curve I have shown. So, the total load on the system in one year may be the same, but if the distribution is different, my effective performance is going to be different. This is one thing we have to keep in mind in designing the solar energy system.

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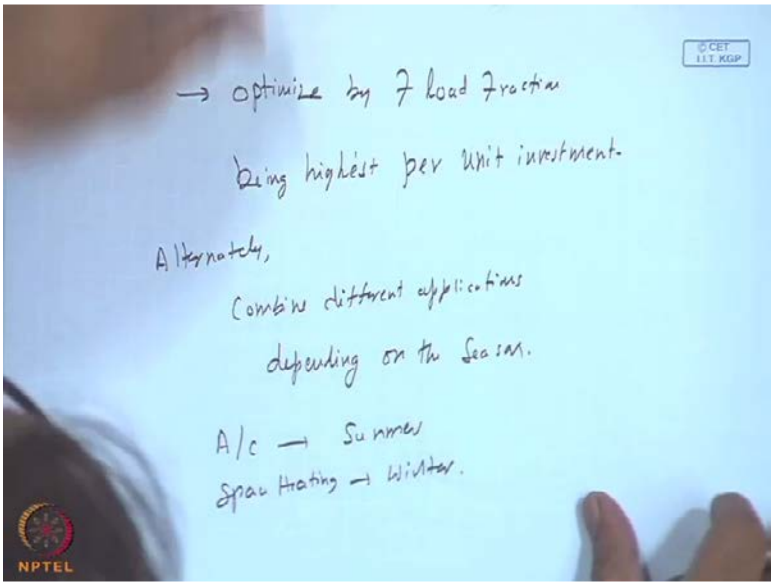

A solution could be optimized by f, the solar load fraction being highest per unit investment or alternately combined different applications depending on the season. Typically, if I have an air conditioning in summer and space heating in winter, my total load fraction will improve enormously if I can do both with the same system whatever we are talking about, the system and the components.

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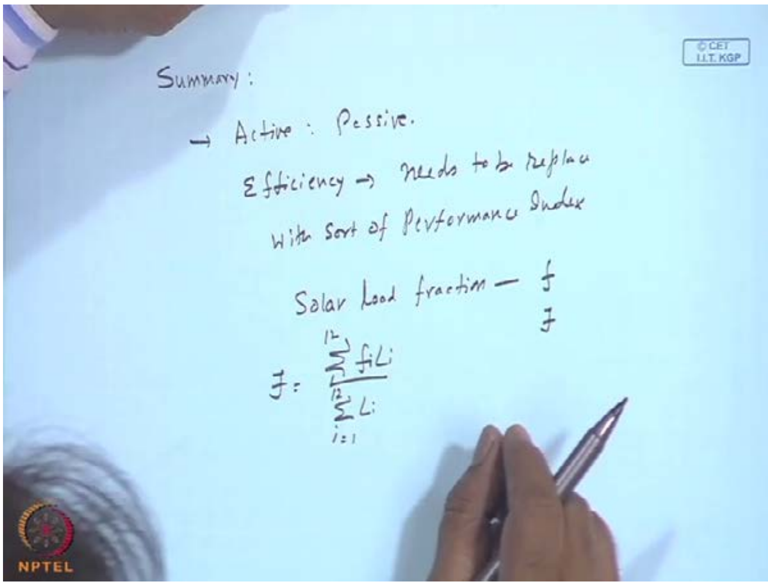

If we try to make a small summary, then they are broadly classified as active and passive systems, though there is no hard and fast demarcation and a single efficiency needs to be replaced with sort of performance index, which we call the solar load fraction, which may be defined on a monthly basis or on yearly basis, where yearly values will be weighted average of f i L i upon L i, where i is equal to 1 to 12, where L i or the load for each one and f i are the corresponding load fraction.

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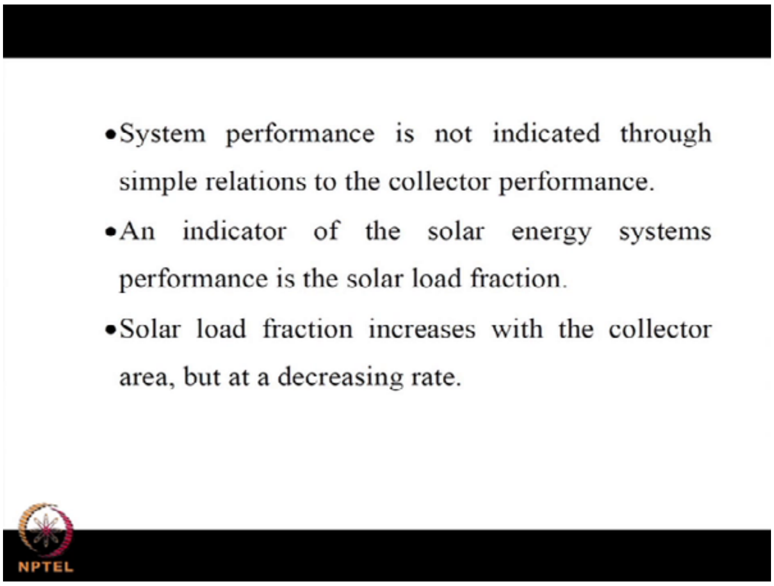

So, that is we are getting is a load fraction and this solar load fraction increases with the collector, but at a decreasing rate.

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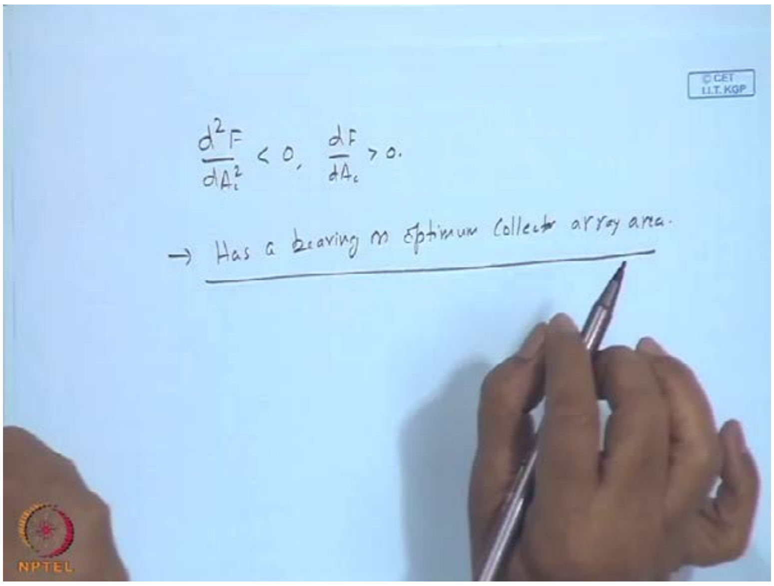

So, this features d square F upon d A c squarer less than 0, d F by d A c is positive and has a bearing on optimum collector array area. So, this non-linearly tells us rather gives us a clue that we should not, we need not rather try to replace an existing conventional system with the solar energy system, but use the solar energy system, such that you will have the maximum energy delivered per unit or in a investment, if you spend one rupee and you should be able to get so many joules which will be the highest for that particular combination. The issue is not whether you are meeting all the loads or not, but a fraction of that load been met and the highest or rather lowest investment.

Now, all these things points to something else. If you put a solar energy system in Chennai, south India or Delhi, north India, for the same application, the performance is not going to be same. The energy deliver may be comparable or can be proportional to the solar radiation. Nevertheless, considering the fact that the ambient temperatures are different and if you consider heating load or a cooling load, there will be entire different consequently effective solar load fraction for the same area, for the same collectors will be different at different places.

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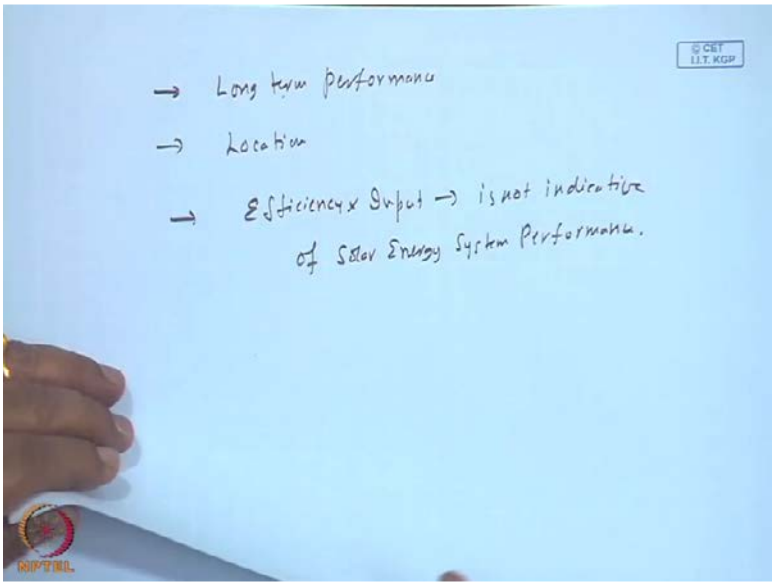

So, what we notice is you need long term performance and this depends upon the location because my load is distributed according to the particular location under consequences. This makes it interesting as well as challenging. So, a simple efficiency multiplied by some sort of input is not indication. So, unlike a conventional fan or a generator or any other machine, it is not efficiency multiplied by input. Your overall effectiveness depends upon the load, the climate and of course, your collector performance along with the other components, like storage, heat exchangers and controls. So, a given collector shall not be equally effective at every place, but it will depend upon so many points.

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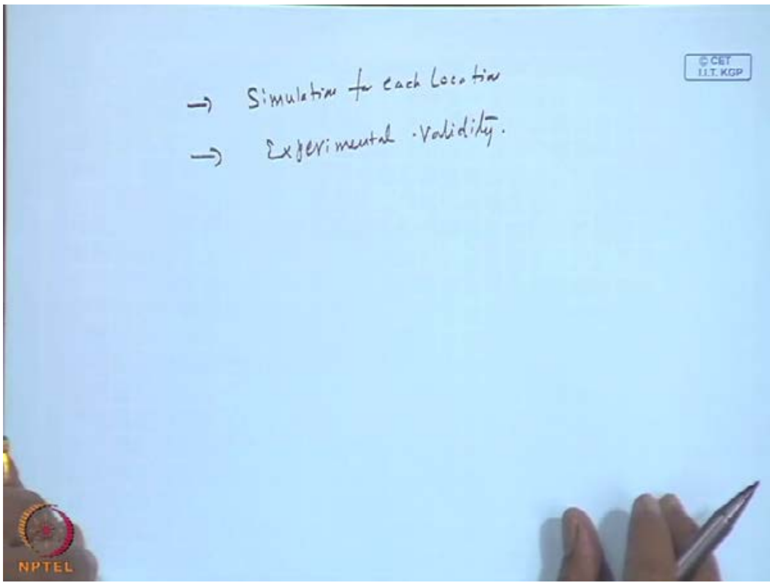

So, we need to have a design procedure or optimization procedure depending upon the load, depending upon the location which cause for either a simulation for each location or may be experimental validity. We shall come to the advantages and disadvantages and the information. These things that trivial if you do an experimental studies or a simulation, we also realize that we need long term system performance.

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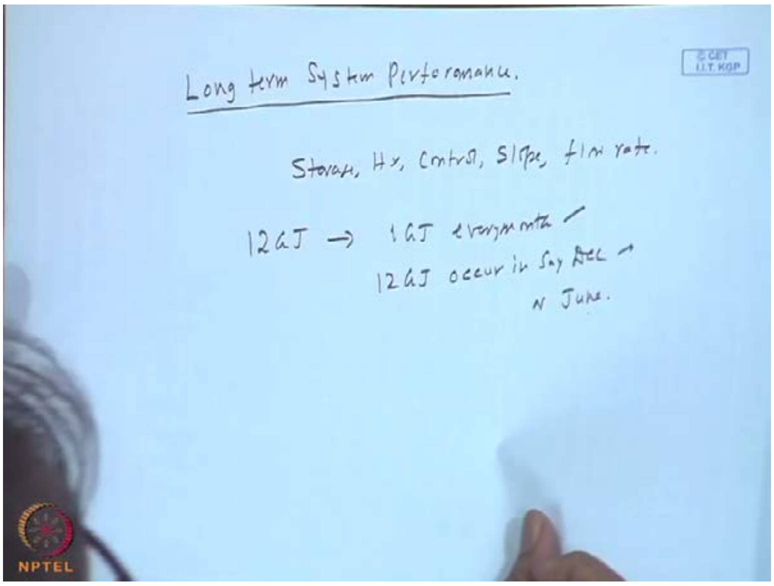

I am deliberately avoiding the word prediction of the long term system performance because some people get confused and say what is going to happen tomorrow or day after. It is not that type of a prediction we do, but this is an estimate of a typical system that is likely to deliver so much of energy for a typical climate of that particular location under consideration. When we do according to certain modeling, you can arrive at whether a collector with a certain orientation is better than a collector with another orientation or another collector and the storage. So, you can optimize, for example, storage heat exchanger control and so on and so forth depending upon the component, it may be even the slope flow rate etceteras, right.

So, there are so many variables based upon which your effective system performance is going to depend, and we said that single efficiency determine isn't indicative of the performance of the solar collector, but its effectiveness in meeting the load will depend upon not only the climatologically data, but also in the load itself. To illustrate the point, I may have 12 gigajoules distributed equally, 1 gigajoule every month, but the other one is all the 12 gigajoule occur in, say December or may be June, anyone. So, this is likely to have a higher effectiveness for a given area than this particular distribution and this is likely to be better than what it would be in December. So, not only the quantum of the load, but its distribution also plays an important role. Sometime, the system may be, it may be fortunate for us in the sense that if the demand meets the solar radiation in general flows, the solar radiation in other words have a higher demand in summer and lower demand in winter, then you will have a better performance index rather than the other around.

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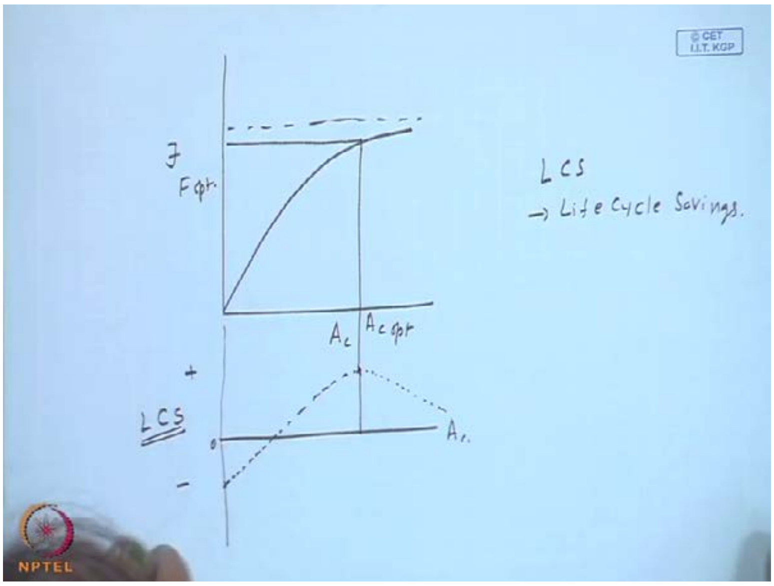

So, what we try to do is, we play on this non-linearity. So, this is f and this is area, I would like to pick up the best area, though we will come to economic shift. If time permits a little later, I will call this ordinate as LCS, which is life cycle savings. In simple terms, this is the amount of money that the solar energy is going to save in its life time. It may be 10 years, it may be 15 years, it may be 20 years, whatever the life is and this is area A c. So, it starts with negative and this is positive. In other words, when area is 0, I think he may be (( )) he bought the heat exchange, the storage tank site preparation, everything, but did not put any collector. Consequently, all that cost will give rest the negative life cycle savings.

Life cycle saving in simple terms can be defined as in the life time of the solar energy system how much is the amount of money that it is going to save. So, you have to take into account the investment, interest term in the investment and these are expenses plus the maintenance, but what is your credit side is the saving of the fuel and if this is high, then compare it to the expenses. Then, you have a positive life cycle savings over a period of 20 years one can take depending upon the reality of the situation, the influence of the oil price or the conventional fuel price and the depreciation of the system. The interest that you pay for the amount invested initially installing the system. So, this is a complete economic exercise which will ultimately give you if the collector system is going to operate for a period of 10 years, you are going to have net profit or net savings of so much.

So, when the area is 0, you have spent money on the other components. You will not have any life cycle saving, a negative life cycles savings only. So, as this area increases, this life cycle savings increase. Now, as the slope d square F by d A c square is negative, in other words, incremental areas are not resulting and proportional increase in the solar load fraction, my life cycle saving start taking. So, this may be the point where I have maximum savings. So, this is my Ac optimum and this may be F opt. So, you combine this solar load fraction curve versus Ac with the life cycle savings or any other academic curve, and you pick up where you are going to have the maximum savings. In other words, the idea is not to replace an existing system, but use a solar energy system such that my returns are the maximum. So, this is how it is done, though the combination of life cycle savings versus the solar load fraction why I had to get into this economics a little bit.

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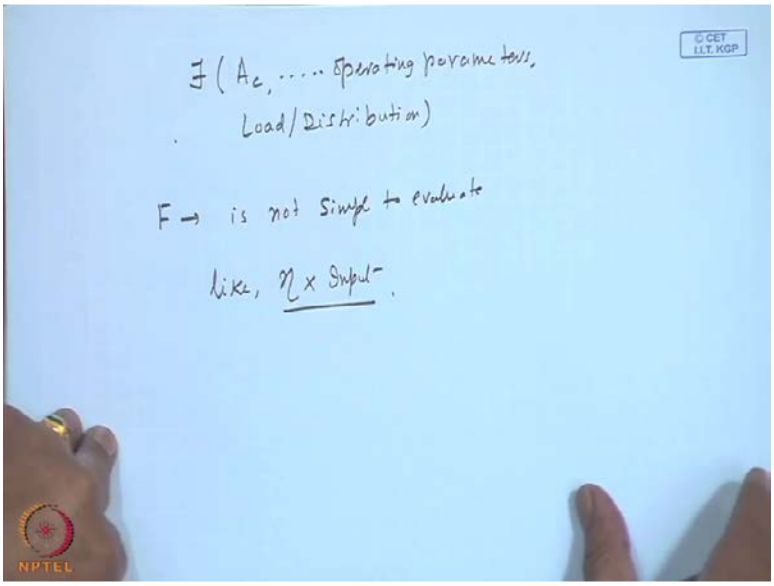

Here, we need this f which will be a function of the area mainly and other parameters like operating parameters plus your load and the distribution, the important features of solar energy system in particular and in general of environmentally division systems. So, what we try to say is I have already demonstrated 12 gigajoule uniformly distributed is not the same thing when 12 gigajoule occurs over a month or even in a day, though the total yearly appears to be same. So, we somehow try to optimize making use of the non-linearity versus Ac curve, so that my investment made yields the maximum return per unit times. So, it should be based upon the long term performance and then, that performance is depended upon the location, the load and load distribution. Consequently, F is not simple to evaluate like efficiency multiplied by input. So, this is not on. So, how do we get this step? The subject matter now is the long term performance. By long term performance, we intend that the performance of the solar energy system over a period of one year, you may make a monthly calculation, you make a hour by hour calculation or conduct an experiment putting up a system and the actual site or way is possible and then, monitor for a year or so.

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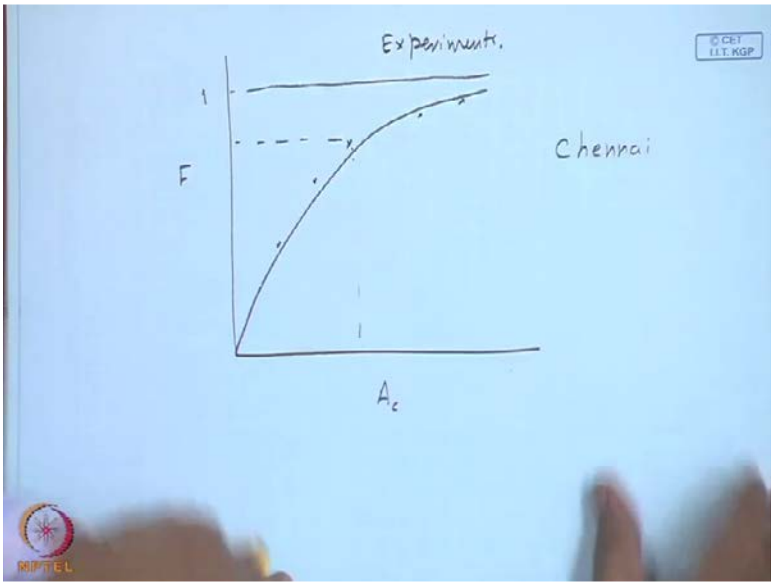

So, if you do that, if you conduct the experiment for one particular area, you will get one point and the time needed is experiments. Let say, first for in the system scales, not only there expensive one's single area will give me one single point. Then, in order to save time, you may do the experiments with the area Ac 1, Ac 2, Ac 3 like that and I may be able to get a few points. So, I can join and get this F versus Ac curve for, let us say one location Chennai, right.

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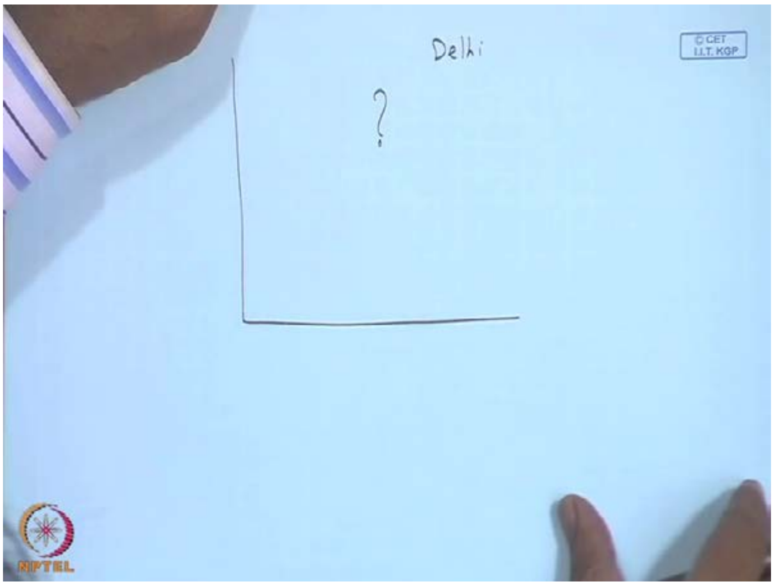

Now, if you wanted for Delhi. So, you have to redo the experiment in Delhi, which is prohibitively expensive and I will need to take also the time even if you are concentrating only on a certain location and somehow, save time by putting up 10 systems of different areas and found out that the solar load fraction versus the area curve was whatever I have depicted earlier for Chennai.

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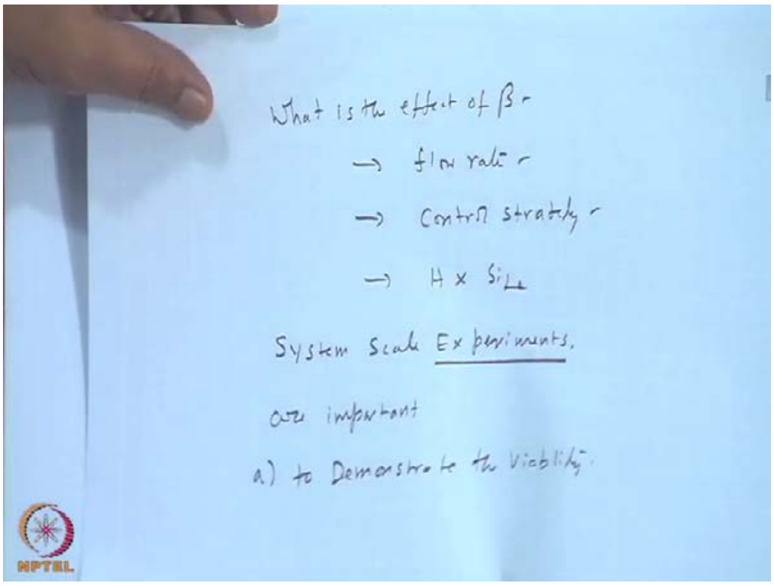

Somebody smart can say what the effect of beta is. I will change the slope. What is the optimum slope? Then similarly, the flow rate and control strategy which we should come to it a little later, for each one of these variables, anything or heat exchanger size. So, you have to keep on doing the experiment to experiment which is not only expensive, but also time taking to do system scales experiments. Now, it is not that we are pediatrician and trying to run down the experimental procedure. Experiments are important to demonstrate the viability. Yes, before you have marked an academic viability, you should say, you should prove that the system works, so that the experimenter can establish the viability of the system.

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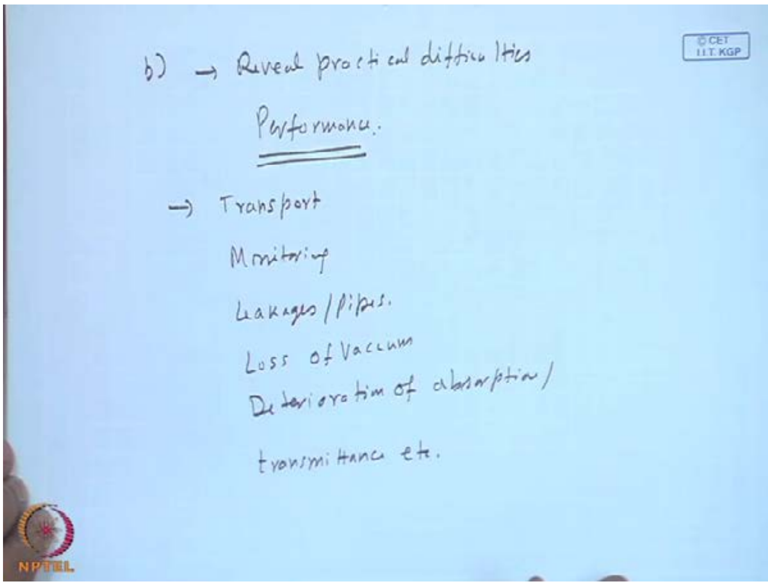

Technologically, it will reveal the practical difficulties and performance. For example, the practical difficulty could be even transport or monitoring of the system and the performance, though your solar load fraction as you can calculate, find out what is energy delivered compared to, what is the energy that is met by the load on the load. So, this performance what I mean is or their leakages in the collector or the pipes or if it is evacuated loss of vacuum and deterioration of absorption or transmittance etceteras.

For example, if you have got a black painted surface (()) type of wave surface which you have discussed in detail, it may so happen over a period of 6 months or 8 months. The black paint may piled off or may not have the same absorption that we have had at the beginning. Similarly, the transmittance though not of the glass covers, if particular if plastics are used, they are not UV stable. Consequently, your transmittance suffers or deteriorates as time passes or proceeds. So, we would in turn say that system scale experiments are not always feasible on account of the time involved in the expenses. Also, they are not valid for another location. Further, influence of changes in design conditions cannot be easily accessed, but this is not to say that it is not necessary. It is only the system scale experiments that can reveal the practical difficulties or that in a system may encounter.

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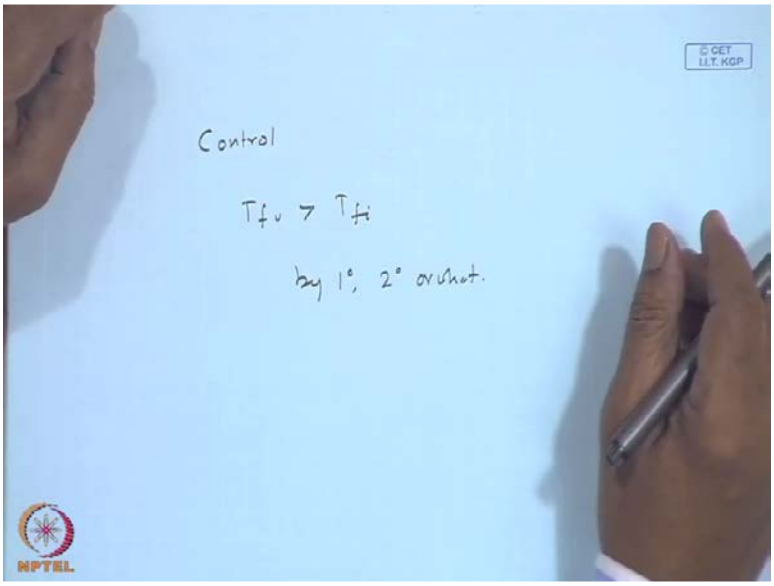

If you consider the control, so that T fo is greater than T fi outlet temperature from the collector is higher than the inlet temperature. How much? It is by 1 degree, 2 degrees or so. If you put the thermostat in the control, actually you will find that it is turning off or turning on the pump with 5 minutes or 5 degrees are band width compared to another control which may have a band width of only 1 degree, ok.

So, which one is better will depend upon again your utilization and the predictability. If the plus minus 5 is valid, it means that pump will not be turned on may be, unless the outlet temperature is more than 5 degrees of the desired temperature and it will not be shut off even when it is less by 5 degrees. So, you may not be pumping at the right temperature, waiting for still higher temperature and pumping at times at a lower temperature than what is desired. The first one leads to a loss of efficiency and the second one leads to loss of quality or the energy delivered.

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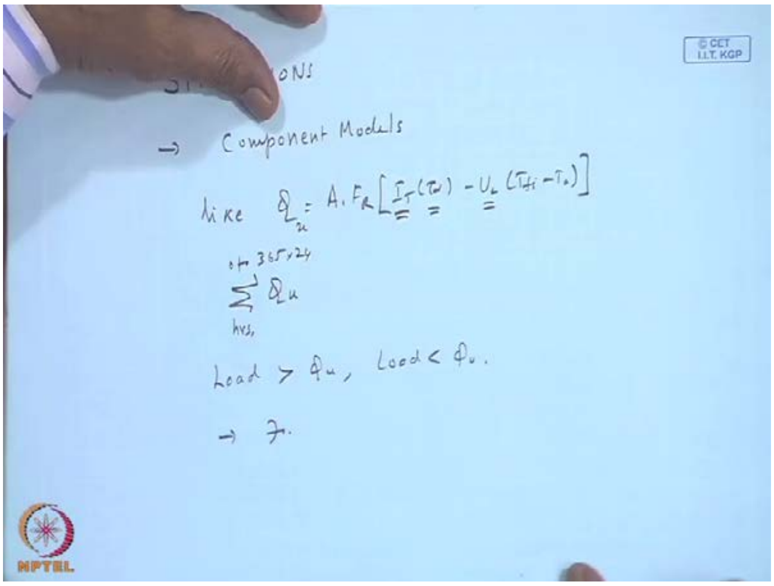

So, how do we solve this problem of time expenses? At the same time, we would like to have a answer for a system that is optimum for given applications and locations simulations seemed to be unanswered, that is you developed component models like for example, for the collector. So, useful energy gain from the collector is A c F r into I T tau alpha minus U l times T fi minus T a. I have the weather date of file and process it to calculate I T tau alpha and estimate by the methods we have described for the conditions of operation and then, multiply by of course, T f i minus T f o and the T a. I keep on adding this Q u or the E r, sum it up Q u or hours, all hours from 0 to may be 365 into 24. Then, I will also take care of the fact whether the load is higher than Q u or load is less than Q u at every instant or a day or a month. Then finally, compute this f.

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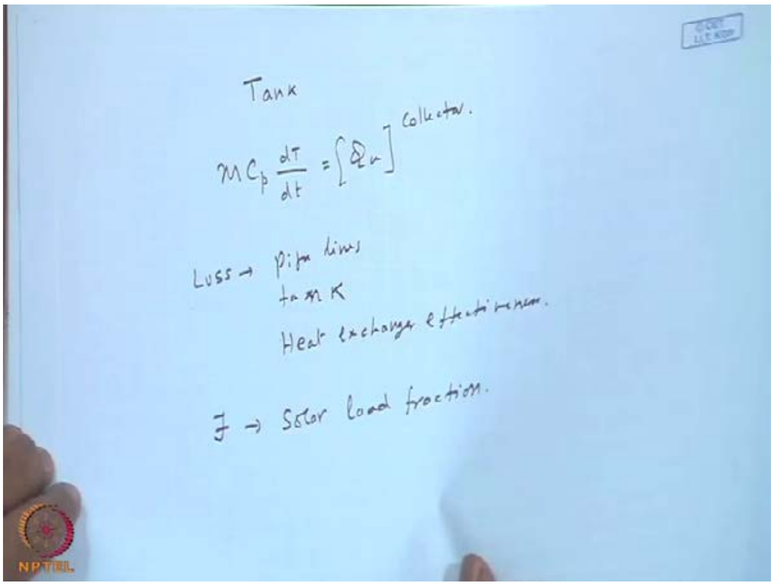

So, then I may have to add other component models like for example, a tank, storage tank. If m is mass of the water in the storage tank or the mass flow rates, it is a mass. This should be equal to Q u. So, the rate of increase of energy inside the tank should be equal to whatever is given by the collector. Likewise, I can model loss in the pipe lines tank and the heat exchanger effectiveness etceteras and ultimately, come out with my solar load fraction for the year.

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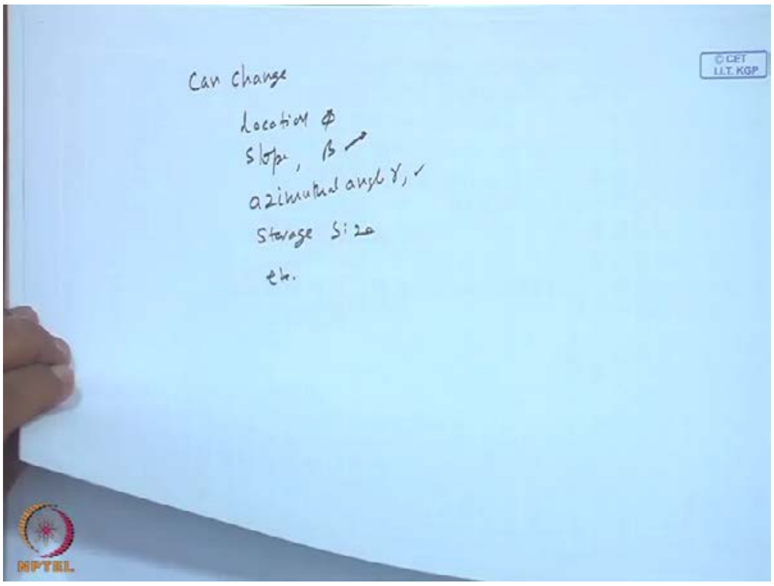

So, when once you have the component models and couple them as for the need, it is a simple job. It can change locations, slope, even if you want the azimutual angle, storage size etceteras. So, all the variables that are involved, I can just once complete linking or the simulation of the system model is complete, we can change. We make a simulation for Chennai, we can make a simulation for Delhi, Srinagar, Shimla, and Darjeeling, whatever locations you want and then, find out the best for that particular location. Either, you independently optimize or maximize the solar radiation falling or we will be ultimately going for the solar energy system performance because the excess radiation at time may not result in higher load fraction improvement. If F is already equal to 1, so we might just go for by F optimization.

Then, similarly, azimutual angle if you are talking about in general, a solar collector, azimutual angle may be equal to 0 is the best solution; that is south facing in the northern hemisphere or if it is a window, where you do not have a control, you might change gamma and either gain maximum energy or not to gain lot of energy like in tropical climates in storage. Of course, I have already emphasized the importance of the size of the storage.

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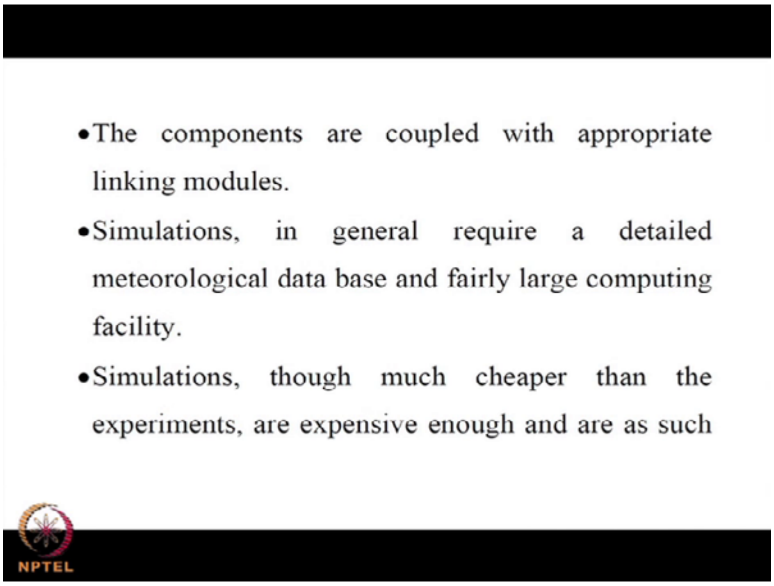

So, this we have already gone through, though the components are coupled with appropriate linking modules. Simulations, in general require a detailed metrological data base and fairly large computing facility. Of course, they are much cheaper than the experiments and you can use simulations for large and in general, non standard systems. This looks like a swiping statement.

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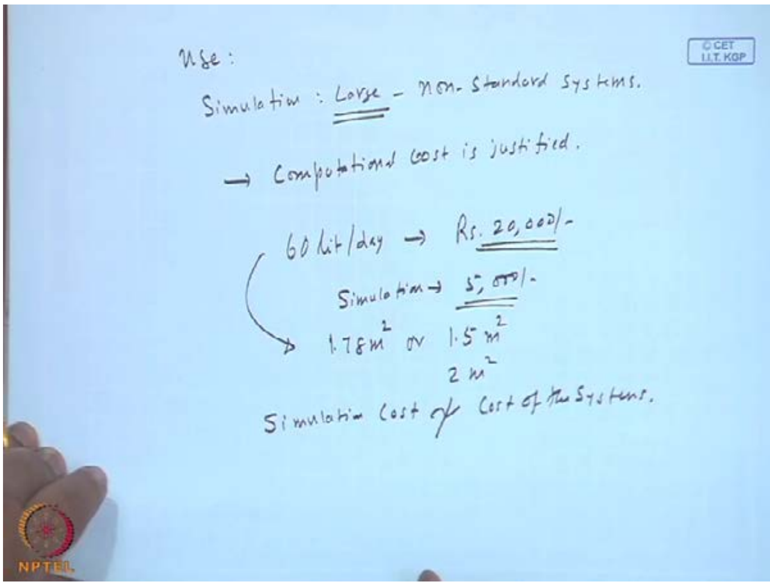

Let me elaborate it little bit by large system. What I mean is the expense involved is very high, like for example, a power generating system and non-standard system. It is not just run of the machine or run of the mill, where you need 60 liters of water for bedding or domestic applications, something like this, but then when industrial application which will be requiring larger quantities which do not have the standard components. So, if you do assimilation for a large non-standard system computation system, then computational cost is justified. So, we should also understand even though the cost of simulation.

So, a fraction of the experimental cost, cost of simulation can be significant if you are talking about a small scale system. For example, a domestic water heating system supplying about 60 liters a day may be approximately or Rs. 20000. Now, if you want to simulate including the computed time and the time money that you paid to the expert or the skilled person or it may be simulation, may be 5000, right. This way very modest figure, right and this 5000 compared to 20,000 is 25 percent. If this 20,000 is economically viable, 25,000 may not be economically viable. Consequently, if you have a standard system, you would like to have a simple method instead of going to the simulation which ultimately may come out with an area requirement of 1.78 meter square or you may have a module of 1.5 meter square standard or 2 meter square. Well, you put 2 meter square at the rate of this 20,000 in addition 5,000 get (()) and you do not need to go through this. 1.5 of course will be cheaper. Consequently, again if it is a small system, you may not want to go through simulation. Particularly, they are standard system.

The other thing that we need to mention in the same context is unfortunately or fortunately, simulation cost is not proportional to cost of the system. If instead of 60 liters, you want 600 liters, it may be multiplied by 10 with some scale economy. It may be less than that, but simulation cost and the time of the computer is going to be exactly the same almost or whether the area is 60 square meters or 60 liters system or a 600 system. So, this is one thing we have to keep in mind.

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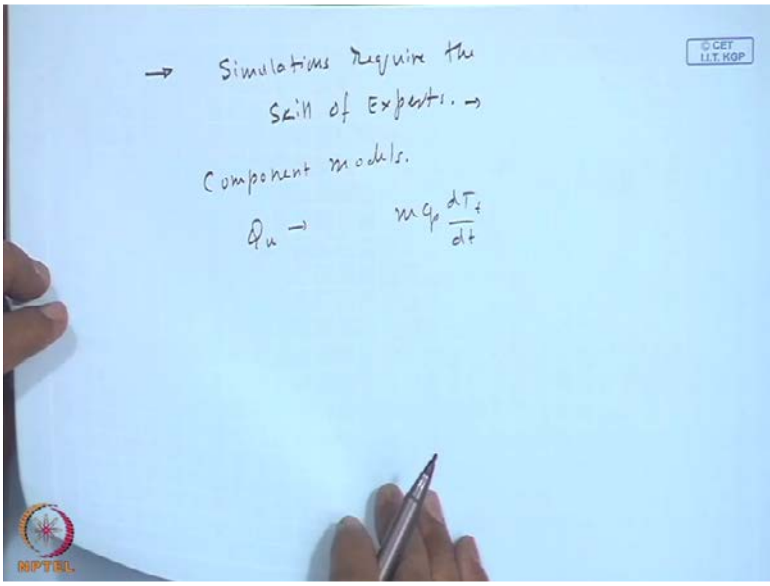

So, once again we may have to say that simulation require skill of experts. So, the person should be knowledgeable in the area of solar energy and of course, know how to run the computer simulation. So, this is going to be a little expensive if a system is to be simulated and you hire a consultant, you have to pay for him; and if that is going to be significant portion system caused, then one has to think about simulations and it cannot be done routinely by the industry.

So, these things of course require component models, though it is a term or technical sounding. It is nothing but whatever we have written for Q u for the collector or the energy stored in the tank, these are the component models. And if you take for example a pipe and you estimate the loss as the surface are multiplied by effective heat transfer coefficient and delta T, that will be the model for the pipe, and the length of the pipe is going to determine how much losses are going to take place. So, we need the component models and sometime, it is complicated. You have to develop the component models depending upon the component; that is being applied. So we shall have to go through the different methods of long term performance prediction by either experiments or the simulations, and there is a simpler method in the next lecture.

Thank you.