Solar Energy Technology
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Lecture - 25
Device and System Performance

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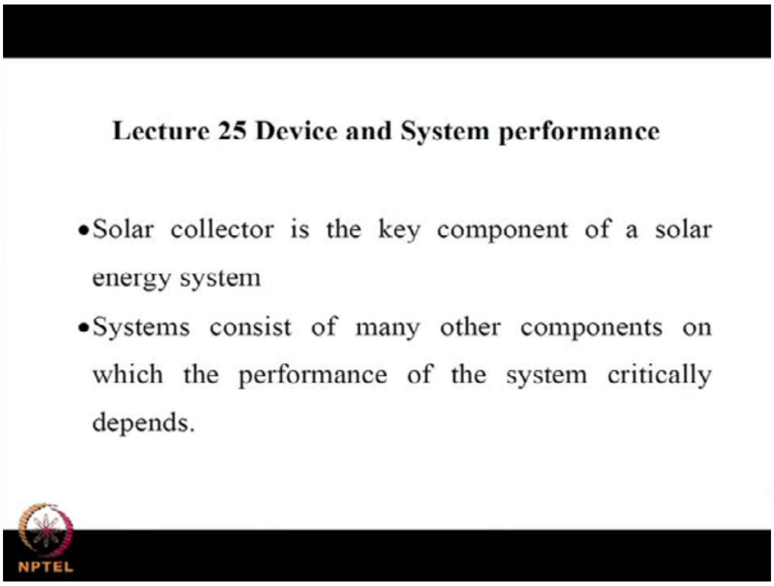

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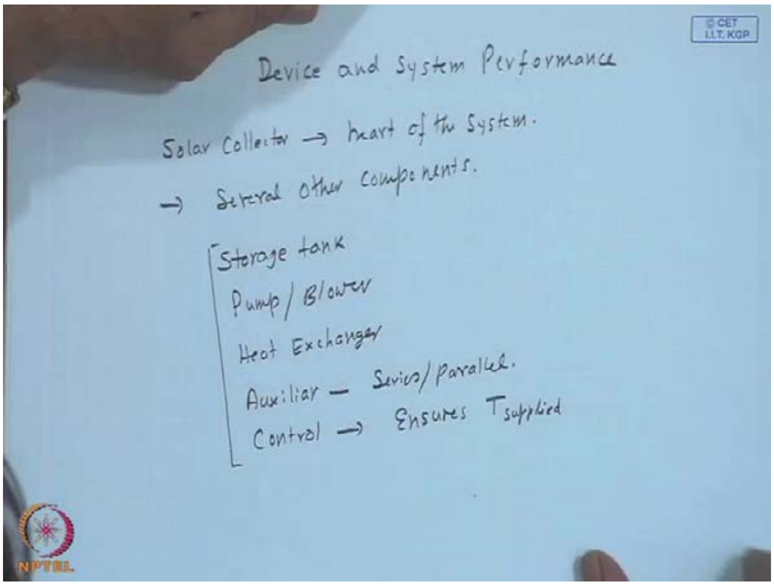

So, we have gone through certain exercise numerical problems, and we will go to the next topic now. Device and system performance; all the while, we were considering the solar flat rate collectors or constant rating collector, we were focusing or concentrating on the collector performance. So no doubt it gives you the useful energy, but then the complete system comprise or not only the solar collector, but several other components. No doubt solar collector, you may call it the heart of the system and it consist of several other components. For example storage tank a pump or a blower, you may have a heat exchanger more than one in fact, there may be auxiliary either in series or parallel, and you can most importantly control, we can choose T supplied is what you wanted in the design of the system.

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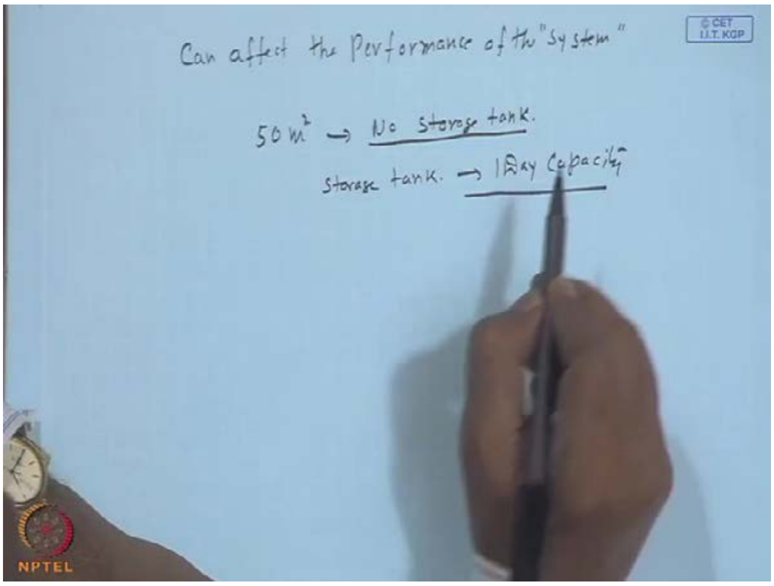

And all these things components can affect the performance of the system as a very extreme example to drive home the point somebody design and calculated require, let say 50 square meters of collector area for be ring in a hostel and then no storage tank. So, unless the demand matches, exactly with the solar radiation variation over the day, you will not have any water that is available to you let say, if you take a bath and early in the morning but, you provide is storage tank approximately of let say 1 day capacity in other words if 50 square meters are going to give you something like 50 into 60 liters of water at about 60 degree c, you have a tank capacity correspond to 50 into 60 liters and the that water will be available if collected today or tomorrow right from the, I mean whatever is the time that you need. So, the effectiveness of the same system is enormously increase, if you had no storage tank compare it to providing storage. So, this is an extreme example I gave to drive home the point, the system performance can critically depend upon the component performance though the collector is an essential and most important component in the system.

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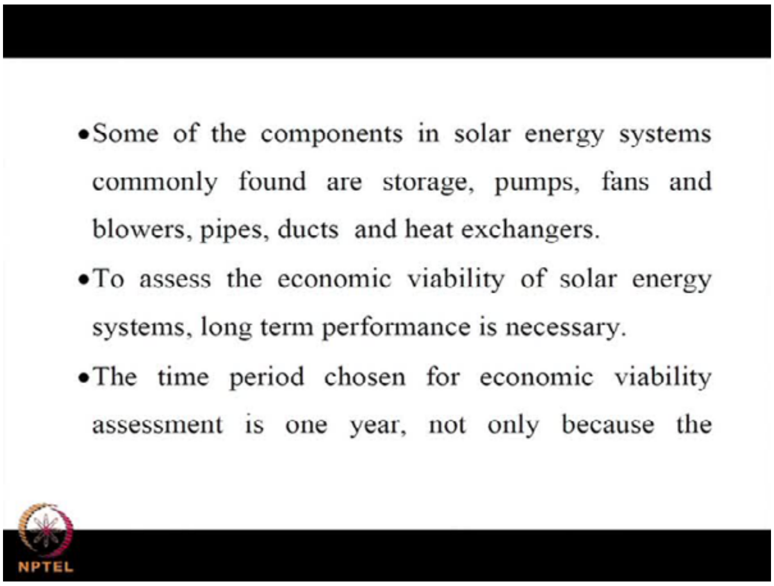

So, which we had already mention.

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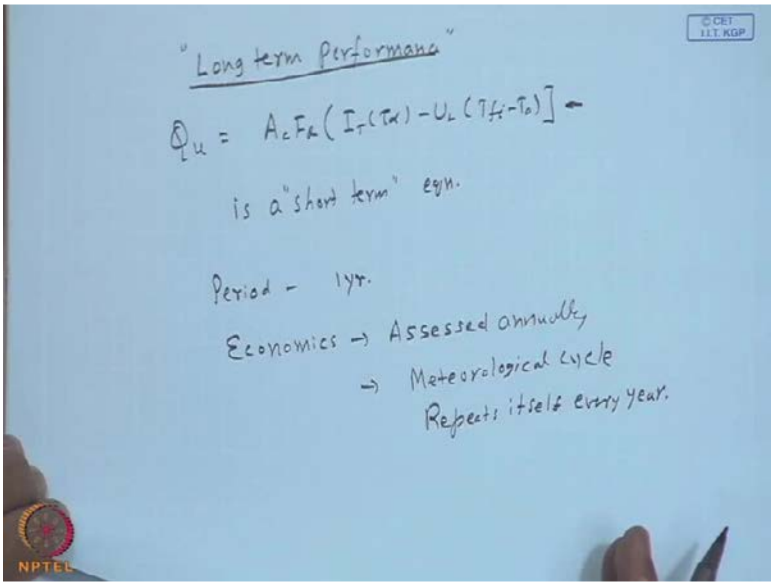

The other thing is, we talk about long term performance for example, your equation Q u is equal to A c F R times I t tau alpha minus U L T f i minus T a is a short term. So, you repeatedly apply this equation for different solar radiation different hours, different days and sum up over the year. And you will find out what is the useful energy delivered by the collector which we call the long term performance, which really means, it is a laborious calculation that is one part of it. But we will base our assessment of the system adequacy, based upon long term performance rather than the short term, the time period we choose is 1 year.

There are two good reason for it and one is economics is a usually assets annually; then second thing is metrological cycle repeats itself every year, I really do not meant to say that January 1 of 2012 will be identical to January 1 of 2013 or anything of that type of exact equivalence. But January average will be the same, if you look at it yearly average it will be then plus minus 5 percent of any previous 10 years or coming 10 years.

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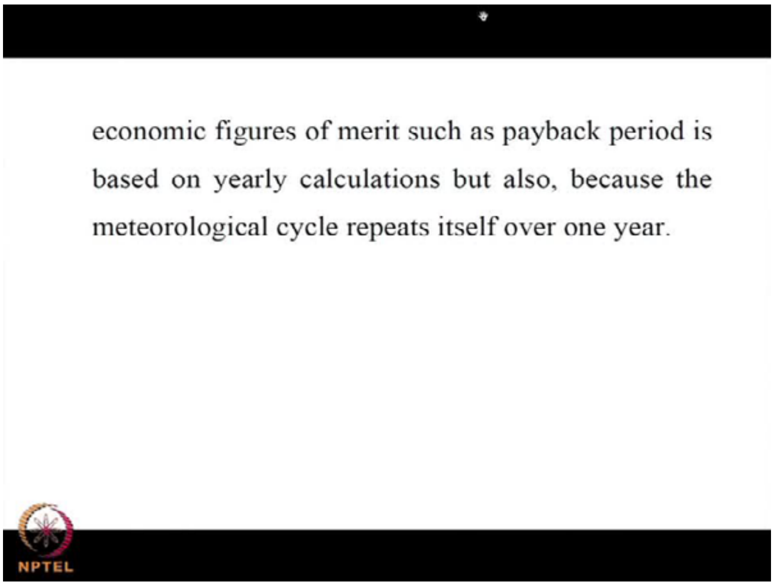

So, this is because of evaluating economic figures of merits what we called is based upon annual performance and also and if we find out the performances the system over a period of 1 year, it will be typical for that particular year and consequently you can aspect that this is the saving or this is the performance of the energy system that you output solar in this that you output over the year, because the season changes, the solar radiation changes, ambient temperature changes, consequently the performance of the collector and including in the losses from the tank heat exchanger etcetera etcetera could be time depended consequently, you will expect the typical output per year so much.

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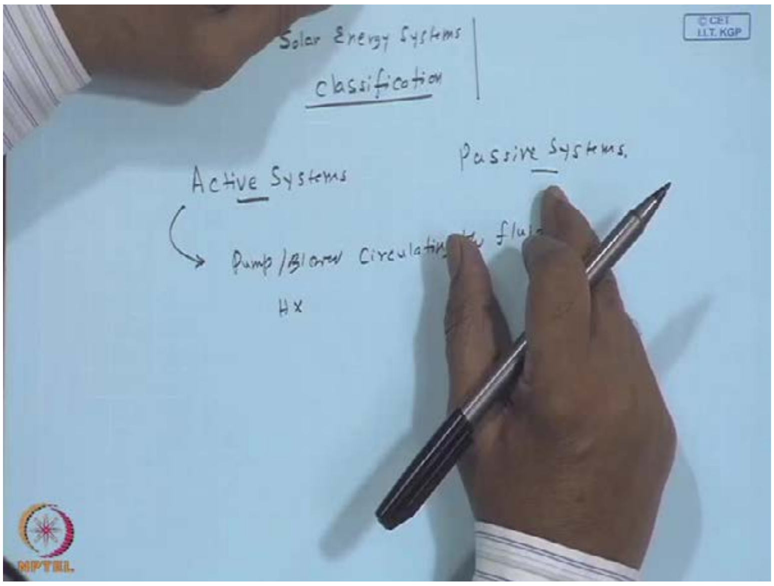

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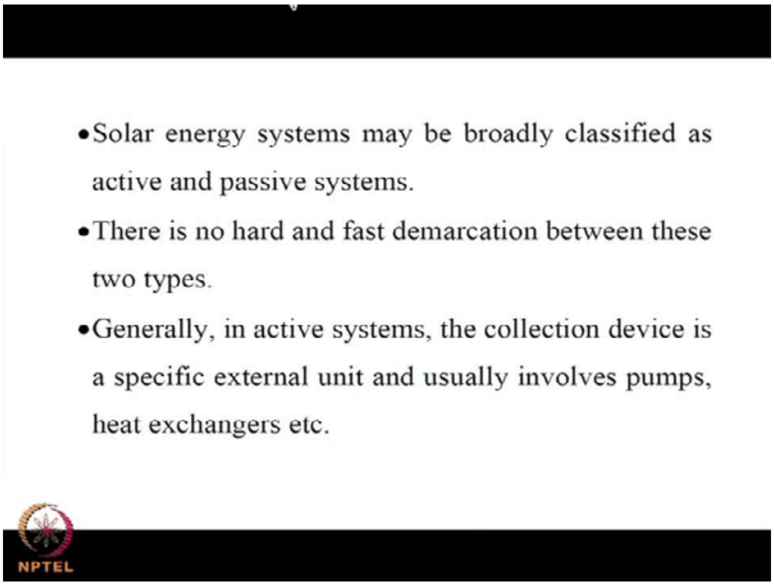

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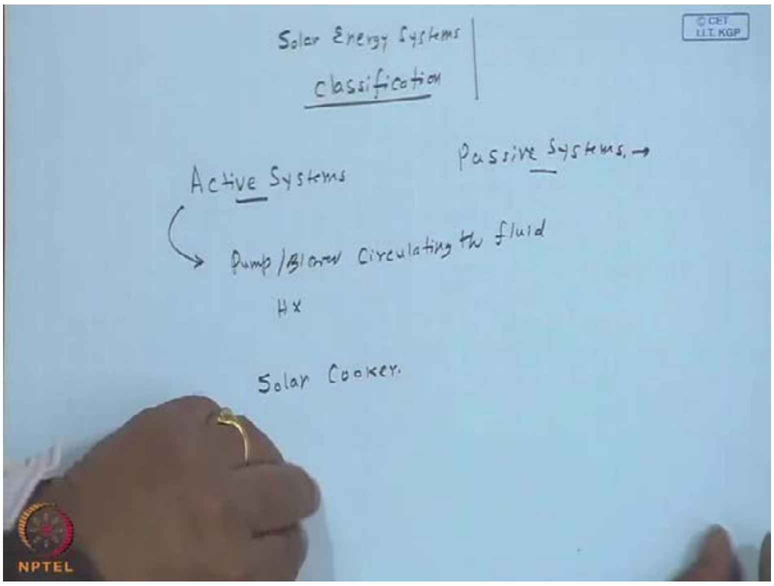

Now, how do you classify this solar energy system? So, earlier I did not want to classify first and then go for it, we have a lot of our radiation and optical properties processing a long term, short term, practically we are in a position to calculate the solar radiation on a any tilted surface or tracking surface, and then solar collector flat plate or concentrating we have collected enough detail. So, that we can have performance equation form which you can calculate the performance or the output from the solar collector for given input condition like solar radiation, flow rate etceteras etceteras; however, we have two major things which we call the active systems and then passive systems. It is not exactly like you can classify a blood group 1 or blood group 2, there could be overlap and it is general understanding that there is no hard and fast demarcation between these two terms.

Generally in active system, you have a pump or blower circulating the fluid and there may be heat exchanger but, this is not the same one can have a counterpart pass way system like a greenhouse which will deal little later, which may be have a small fan to exhaust the hot humid air. So, that is not a active system similarly, if there is no pump and if it is been circulated by thermo siphon action, still it may becomes a flat plate collector system and active system.

Then another way people try to clarify saying that passage system is a part of architecture, it may or may not be a part of the architecture, in the sense that in the building if you house flat plat collectors along with the roof or along with the tilted roof and then circulate the water, still it will be a consider as an active system compare it to whatever it is independently installed over roof top or even on the ground floor, and you can give also a counter example for a passive system which is a passive system though it could be external to the body, for example, a solar cooker so, you have a passive solar cooker though it is an external device and it is kept externally except it does not have a pump or a fan to circulate the fluid inside the device, we will deal with these some of these things little later but, I think a popular concept of a solar cooker, green house you must have heard.

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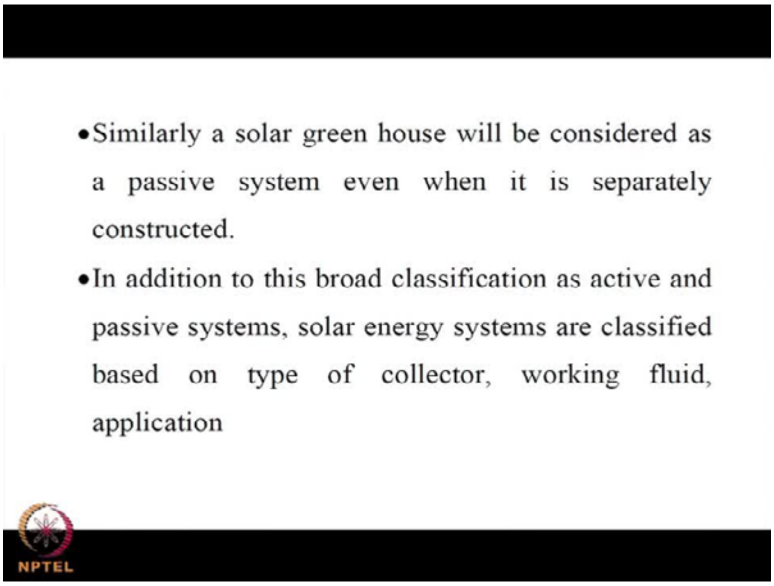

So, which I have already written that is solar green house will be considered as a passive system even when it is separately constructed. For example, in cold climate, to preserve the plants or to keep them live to make the seeds a solar green house are constructed and its very commercial proposition. In addition to this broad classification as an active and passive system, solar energy systems are classified based on type of collector, working fluid or application.

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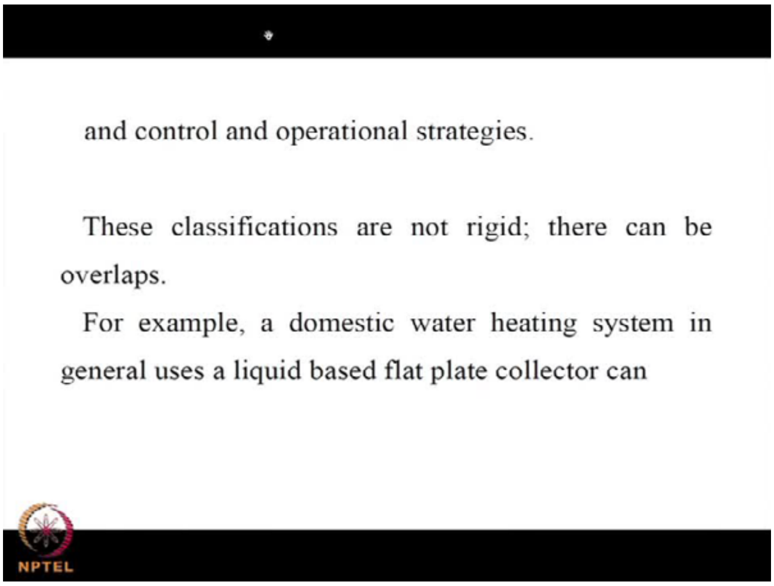

So, you may have and the when the control strategies. So, this classification are not that rigid; there can be overlaps and the one should not be upset, whether it is a passive system or an active system but, it should be understood in the spirit in which it is spoken.

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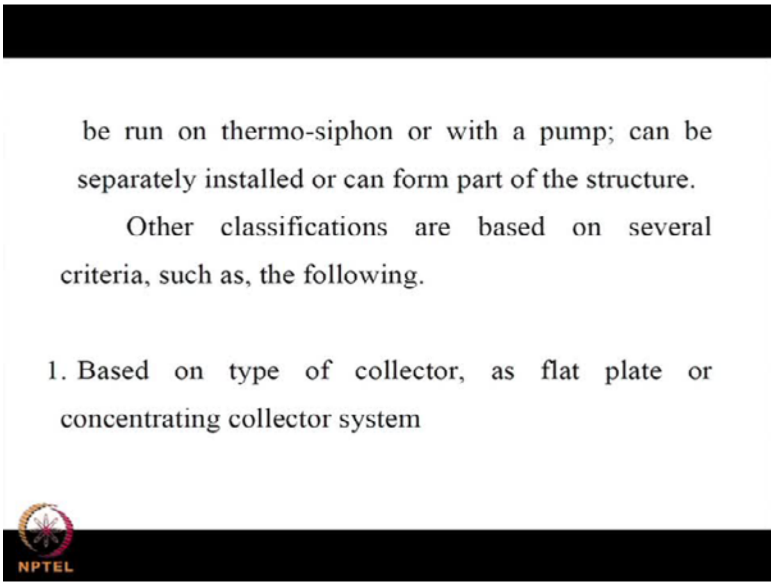

So, domestic water heating system general use a liquid based flat plated collector and can be run on thermo siphon or with a pump or without a pump separately installed and it is an active system.

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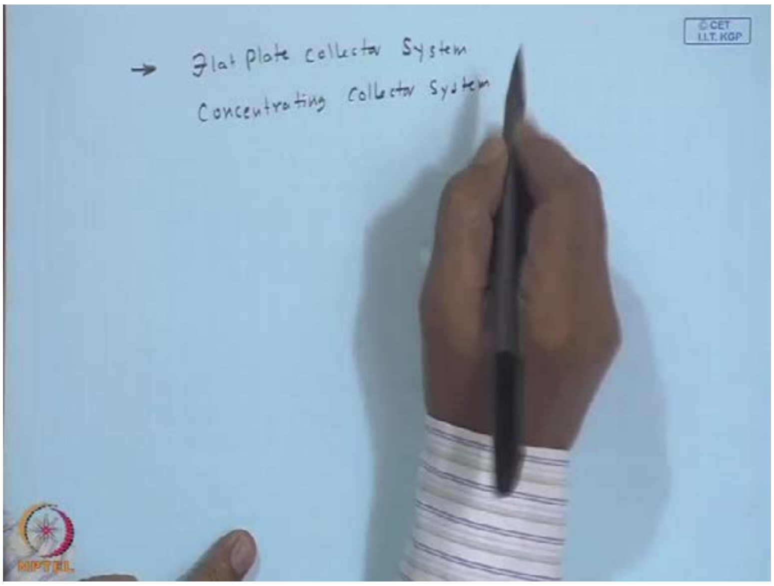

Now, you may have based on the collector system flat plate collector or concentrating. So, any this system uses the flat plate collectors what are gone be the application I may call it a system of a flat plate collector and system of concentrating collector, if concentrating collectors are used.

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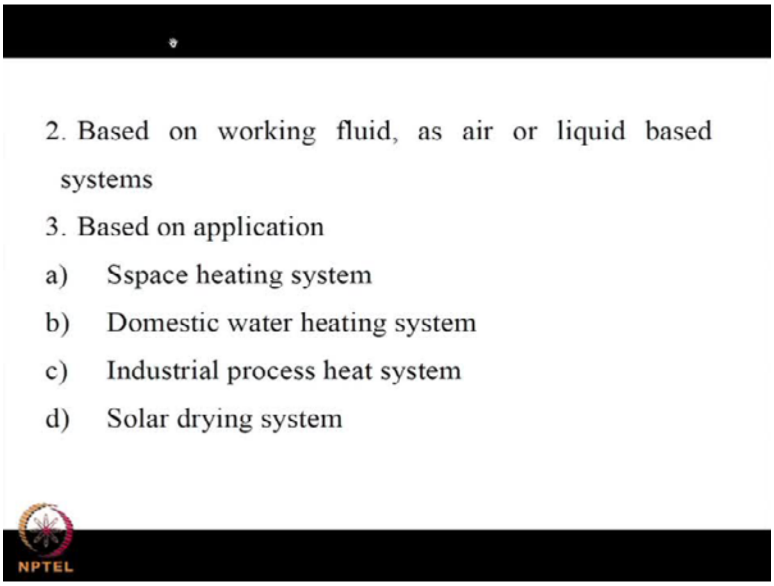

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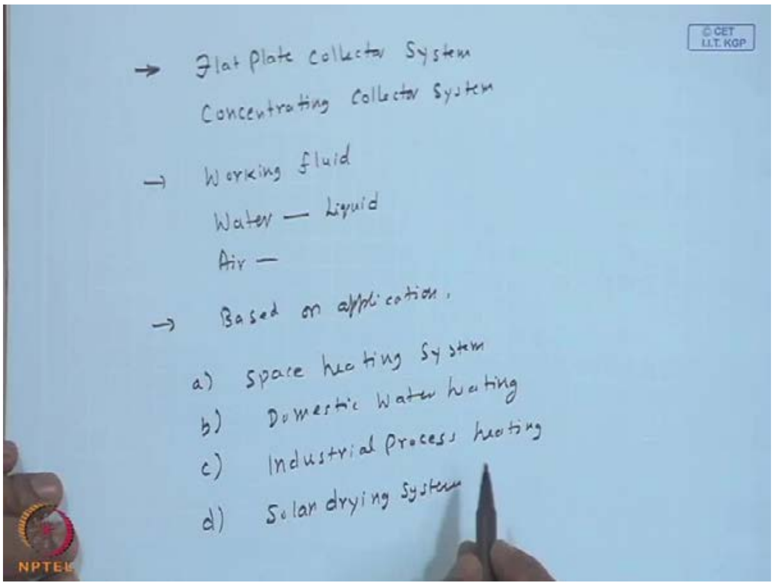

Then it could be based upon the working fluid, usually water or air instead of a water, it can be a liquid for certain advantages like antifreeze or even high thermal capacities fluids and generally gases are not heated most of the time only be air, and you may called it based on application third. So, another way is a functionality irrespective of what type of collector, you use whether you use a liquid or whether you use a air and flat plate or concentrating collector. It can be a separating system to provide comfort inside, if the temperature is bellow, the comfort condition of about approximately 28 degree c, you try to heat it up which has space heating system, and it may be domestic water heating, I shall make a comment about the terminology a bit later after finish this names, industrial process heat and then you may call it as solar drying system and tall the different from the above and depending your application.

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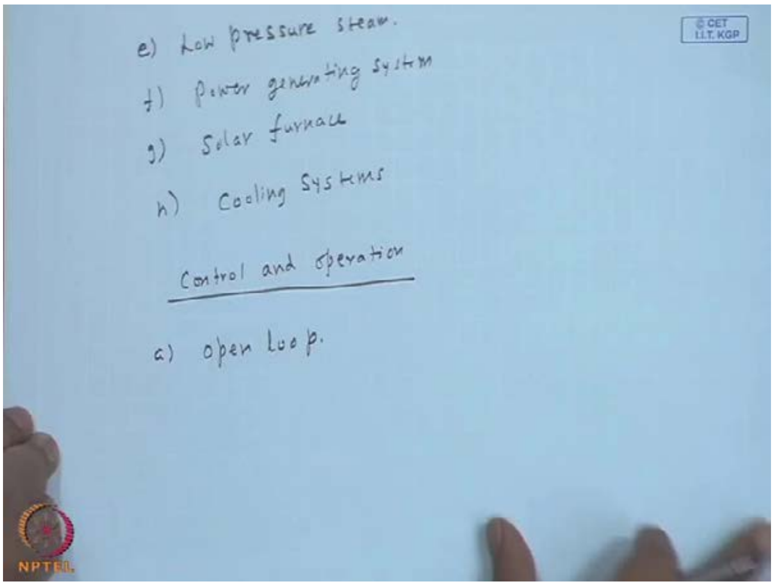

If it may be a low pressure steam system, so what we are trying to do from a industrial process heating is distinguish it, if it is steam or only a hot water or something else, then it could be a power generating system, if you restrict yourself to only thermal systems solar and the thermal system a power generation will be though a basically high pressure steam against the low pressure steam and at g it may be a solar furnish and the h could be cooling system including a siphon type or compression type or refrigerators and the cooling logy rule or cold storages, and then you may have based upon control and operation, this is an important aspect form the efficiency point of view or the effectiveness point of view though not necessarily form the classification point of view only you can have an open loop.

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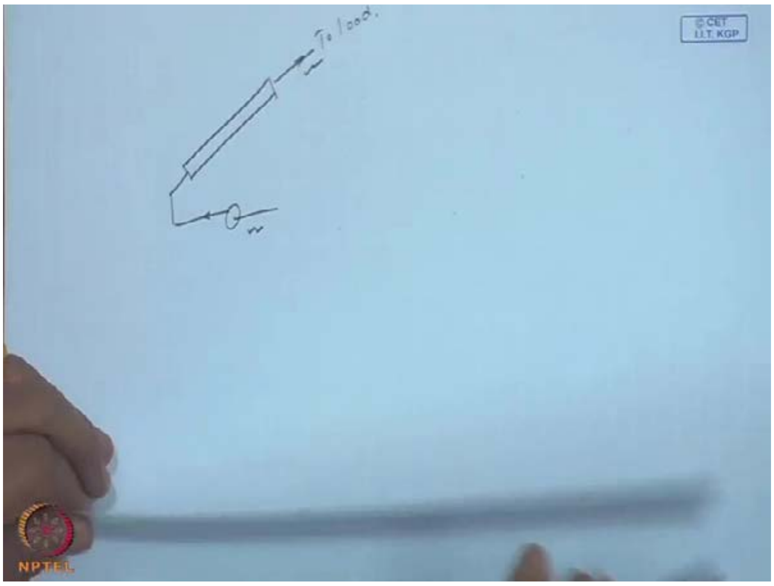

Say for example, you have got a collector this is the pump to load, simply it goes to collector once and output water or air whatever is collected and it goes to meet the load which is in open loop system, the influence of this output has nothing to do with this input.

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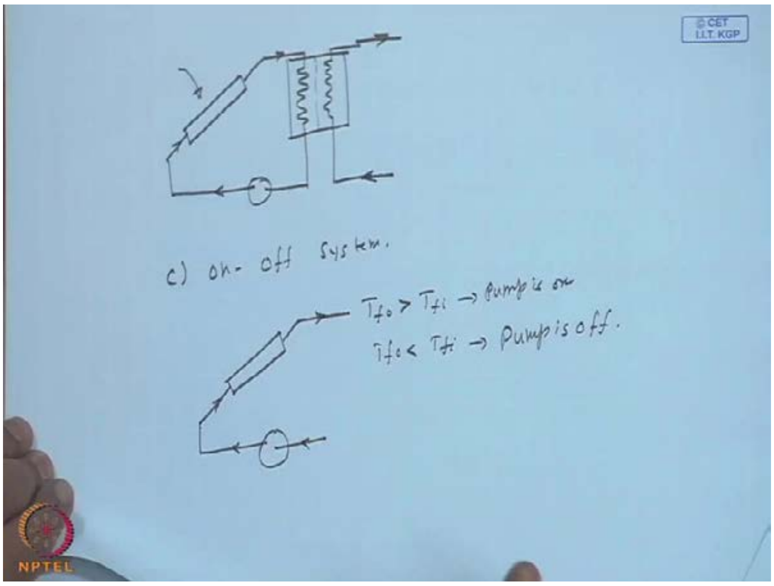

Then naturally you have a closer loop something like this. So, you keep on re-circulating the fluid though the collector and though it is not part of the definition, I may have an exchange here with a heat exchanger like this, in other words the energy collected by the collector after heating the fluid, dumps the energy in the storage tank, from that storage tank will pick up to meet the different loads, the load loop does not interact with the collector loop except though the storage or the heat exchanger and then you may have a on, off system, once again this also requires little bit of clarification. So, one can say that, if this the collector the output and entering cold fluid though a pump and you are having the direction like this, now if T f o is greater than T f i then the pump is on or it is off.

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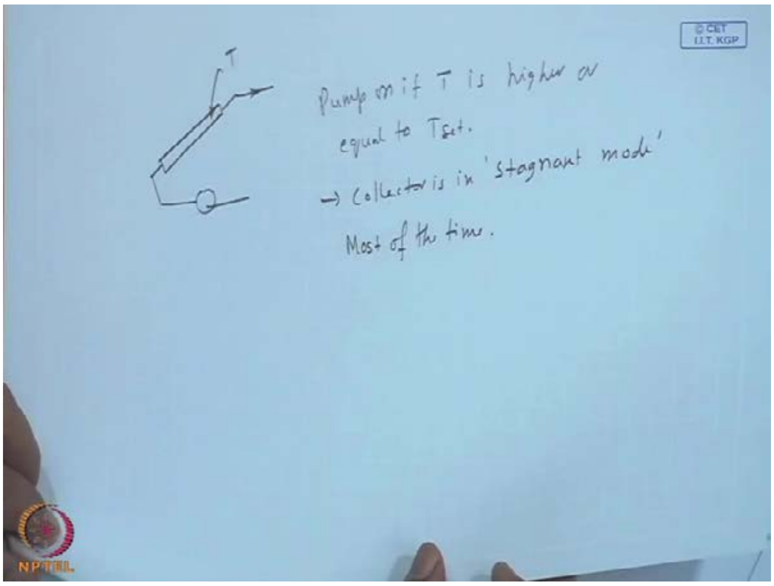

This is typical on off system or as practice out in the u s and of course, you may have it alternatively pump on if some where the T is higher or equal set temperature. So, this difference this is also on and off of the pump but, the difference is the collector is in stagnant mode most of the time. This is also on off as far as the pump is concern but, the operation is completely different between pump running as long as the outlet temperature is higher than the inlet temperature.

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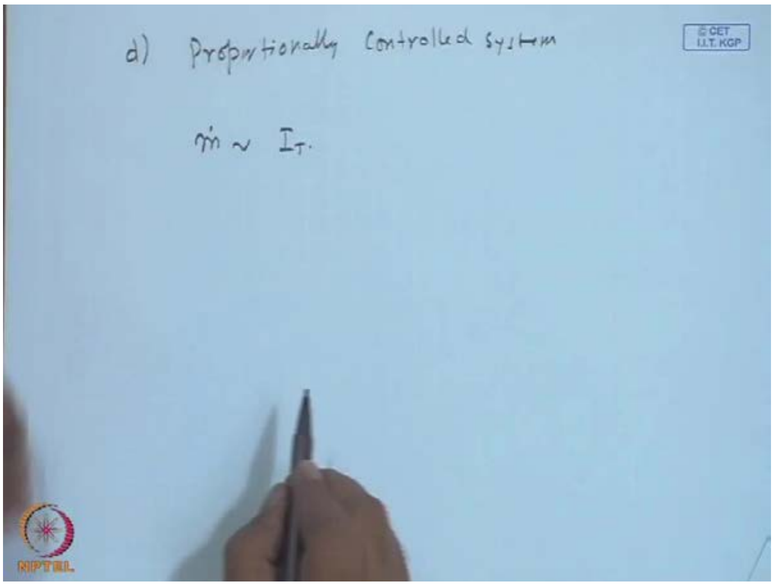

Compare it to the pump circulating the fluid only if the fluid reaches the desire temperature, then you have got a of course, a better one a proportionally controlled system, basically m dot is proportional to I t. So, you have a motorized mode which will sense, if the solar radiation is higher, it will sent a higher flow rater though the collector and if it is solar radiation is lower, a flow rate is sent though the collector. This insures more or less a uniform temperature output and the though put or the rather be water or the air being circulated to the collector being higher, if the solar radiation is higher and it is lower, if the solar radiation is lower. Of course, the designated energy temperature the whatever you desire is set depending upon as we discussed sometime back the critical level if it lower than the critical level no matter how small the flow rate is your temperature cannot be whatever the t minimums that you have set.

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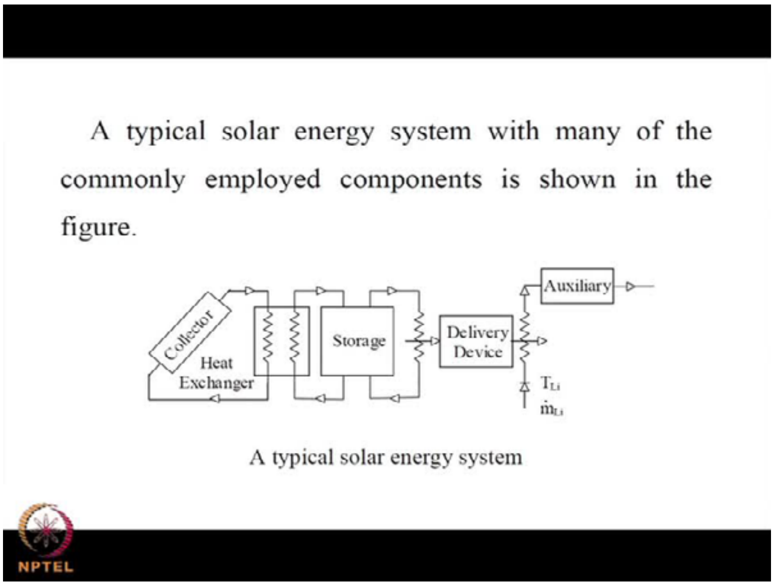

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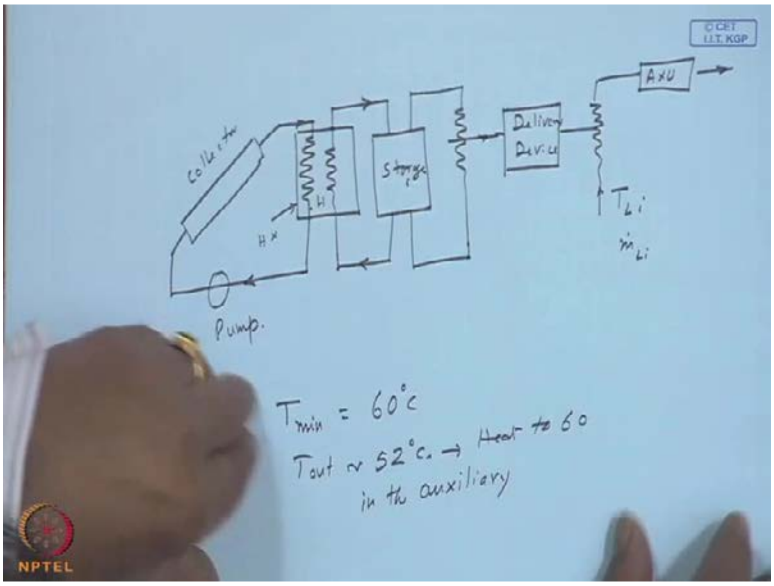

So, you can see this picture, which I will try to redraw, which consist of a typical components in a solar energy system, which I also tell you that some of them can be absent or present and you can equivalently model depending upon your need and depending upon the actual components that are present, then from here; I may have a auxiliary over here T load litter with the m dot litter, and this is auxiliary, this is sort of you can called it a delivery device, this is the storage, this the heat exchanger which separates the collector loop form the load group, and you have got here is a heat exchanger H x, collector and the pump, you may or may not have this heat exchanger, it may be directly be dumping the energy into the storage and they may or may not be a heat exchanger in between the delivery wise and the storage and another sort of heat exchanger before it meets the load, and before it meets the load, there will be an auxiliary. Auxiliary it could be an electrically heater or a boiler, which will make up either for the quantity that is desired, if my solar energy system is enable to supply or make up for the quality, suppose you want T minimum at 60 but, my T out is 52.

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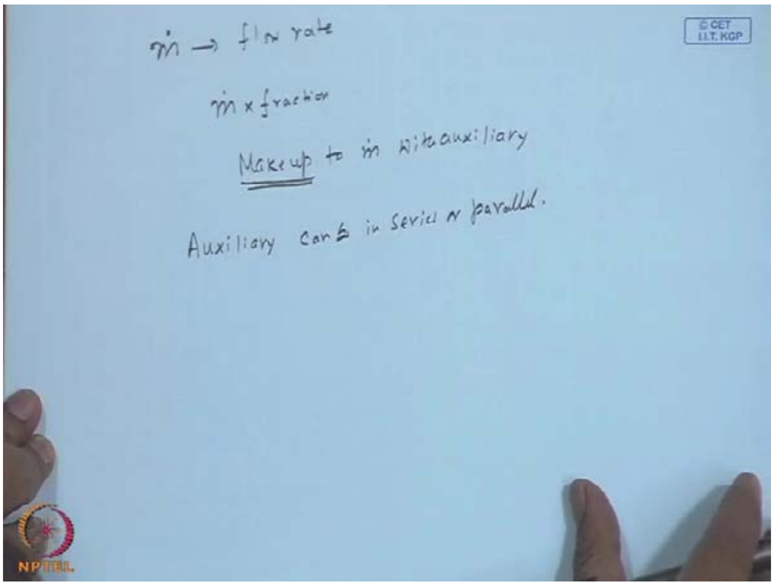

So, what I can do is take this 52 heat to 60 in the auxiliary or you need m dot flow rate meeting the energy temperature delivery or the solar energy system is able to cater to m do multiplied by some fraction ok. So, you can make up to match m dot with the auxiliary. So, I have shown here this, so called auxiliary in series, can be in series or parallel, so if it is parallel generally it is more convenient to do this make up business and if it is in series it is more easy to match the quality. Now we have got our challenge in the senses that compare it to most of the other conventional system, when you come to a solar energy system in general in particular or a environmentally given system in general.

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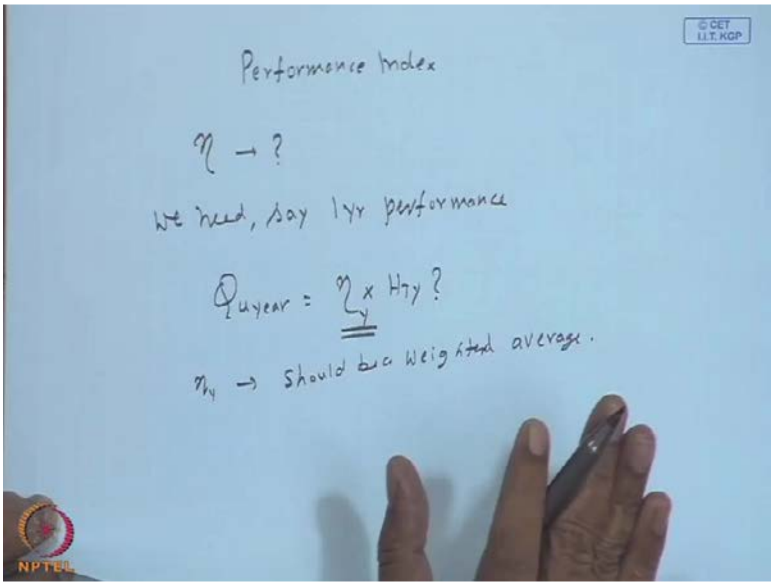

What is the performance in index? Is it the efficiency? If it is efficiency and we need say, 1 year performance, so useful energy gain for the year is it eta times H t y; obviously, this is not work and even if it does then this should be eta y should be a weighted average, because, we know that the efficiency depend upon the input solar radiation, ambient temperature, wind velocity so on and so forth. So, if I want to have a typical yearly efficiency average, I should earlier sum up all my inputs multiplied by the efficiency and divide which essentially means are calculation for entire year.

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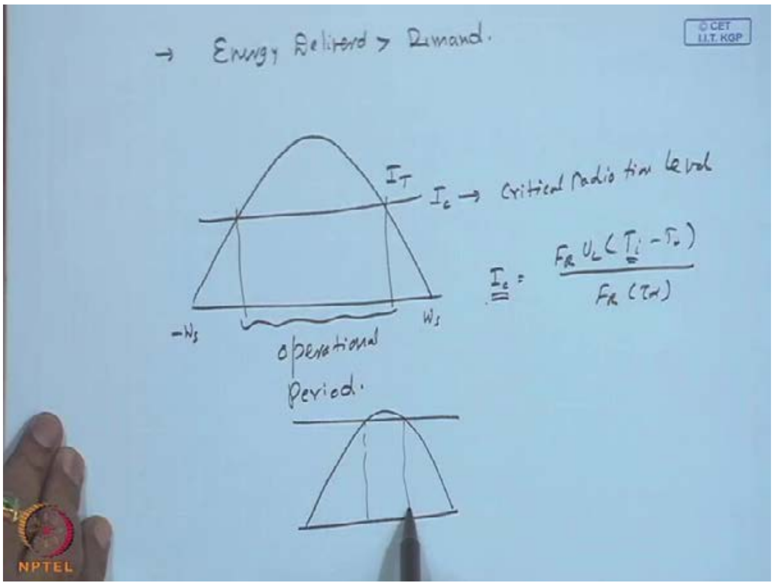

Then how do I account for that your energy delivery is more than the demand, you are not hungry; you are given a food, so will you pay for it. So, if the solar energy system delivers more energy than what is need, of course, it goes to the storage tank and over in that, it will go to the dump rather it has to be not accounted for in term of economic analysis. So, we have for a small period of time, we have the efficiency but, if you consider a long period of time, we have to consider the performance over short periods of time continuously for the period of 1 year or 1 month or whatever we want and the other thing which has mentioning, if you plot in an ideal day a solar radiation profile under collector surface from the sunrise to the sunset and this is my so called critical radiation level, this is critical level which is obtained as I c equal to F R U L into T i minus T a by F R tau alpha which is nothing but, the radiation should be above this critical level in other that there is heating up to d i. So, if you set the useful energy gain equal to 0, the minimum radiation required for the few water to be heated or the fluid to heat to T i meet ok.

So, now this is my time period of operation, this changes or because your T a may be changing, if your lost coefficient may be changing, solar radiation may be changing the and consequently the operational period will be different, when i said that solar radiation changes though this equation does not contain that if this curve is like this, and my critical level is here, it is a lower radiation then my operational period is much smaller, sometime there may be none.

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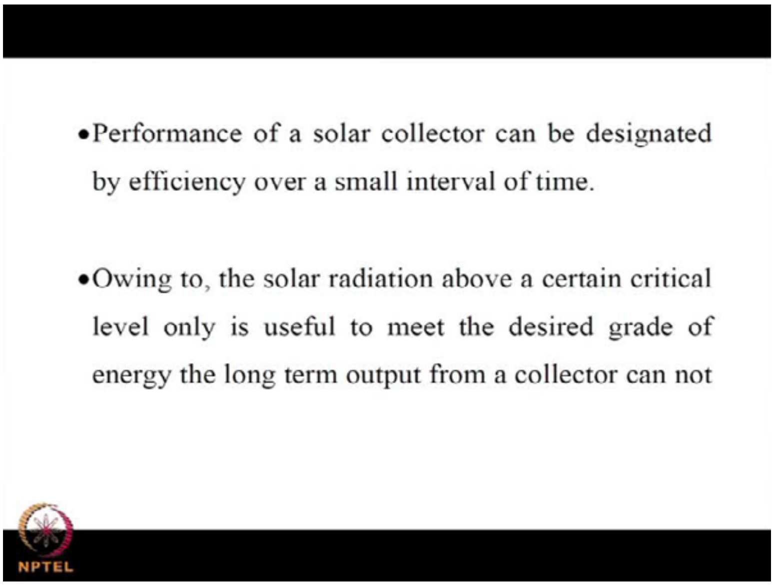

So, we need a long term output from the economic point of view and also to repeat to natural the metrological cycle being 1 year, you need a long term system performance.

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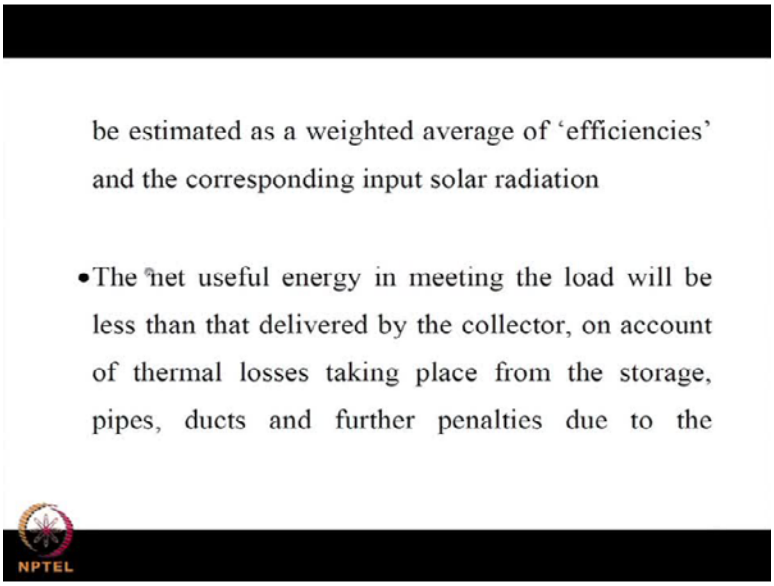

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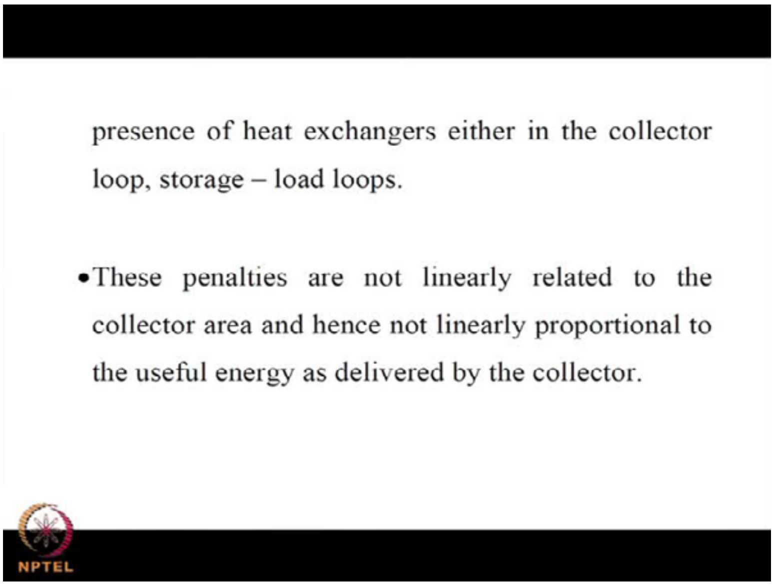

So, it has to be sort of weighted averages, the net useful energy in meeting the load will be less than that the delivered by the collector on account of thermal losses taking place from the storage pipes ducts and further penalties due to the presence of heat exchange either in the collector loop storage or load loops, and what are basically is try to say is my performance cannot be linearly proportional as delivered by the collector. So, if the energy delivered by the collector is q u over a short period of time if the solar radiation is double my useful energy is not doubled. Similarly, if you have got a particular type of control and there will be certain losses or heat exchanger, there will be certain losses but, again those losses are not proportional to the useful energy gain as developed delivered by the collector.

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So, collector is important in the sense that it does give the useful energy gain but, what we are interested is q u system, we would like to find out what is that part of the solar energy as delivered by the collector is going to meet the load. So, instead of a commonly thought of sort of efficiency we will go for something else here.

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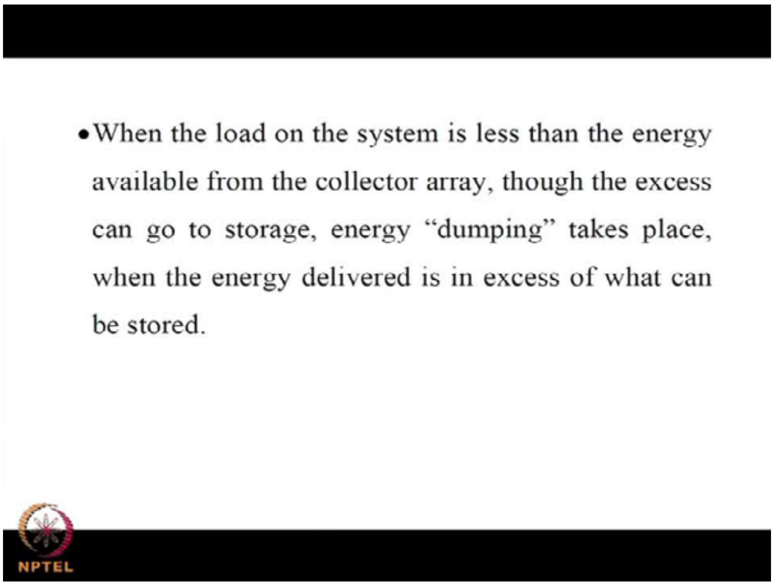

We have already said that excess storage will be dumped and consequently it cannot be taken into account your economic calculation or in your efficiency so called calculation.

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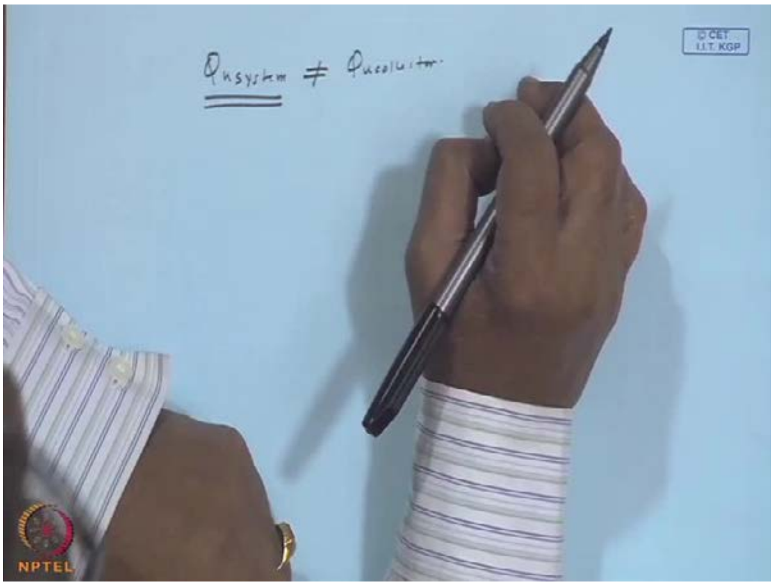

So, this q u system is not necessarily equal to q u collector, so to drive home the point or to emphasis this aspect if you say for example, have a ceiling fan and you use a voltage of 220 volts 50 cycles Indian supply and wherever you keep it. It performance exactly the same way whereas, a solar energy collector, solar thermal collector same design you keep it in Chennai, you will get 1 hour output and you keep it in New Delhi, you will get another output. So, consequently you cannot based or that efficiently of the system or the device multiplied by some input is equal to the output. So, this is what makes the solar technology now little bit challenging and interesting and it is not like a conventional device, where you take the overall input and multiplied by efficiency to get the output. So, this thing has to be done from location to location.

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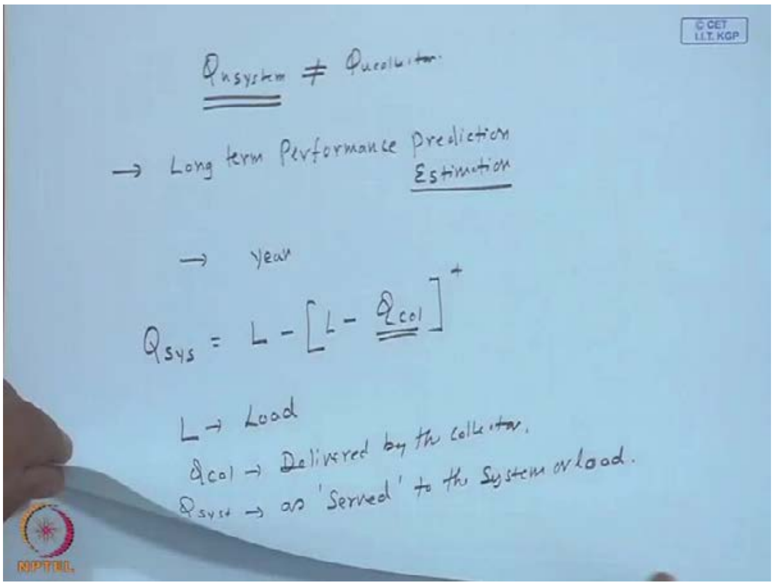

So, now we will call it long term performance prediction, it is not a hagioscopic prediction, it is you can may call it estimation, if you like it there are some people get allergic about prediction. So, it is a long term performance estimation for the solar energy system that period will choose a year normally, the reason as I explained because of the metrological cycle as well as he economical analysis. So, when we try to do this, we will not, I will write mathematically what I had explained earlier. So, let us say L is the load and Q col is an energy as delivered by the collector and Q system as served to the system or load in other words you have got 500 liters of requirement, you got 498 liters then the Q system is 498 and whatever is the Q collected should equal to Q system.

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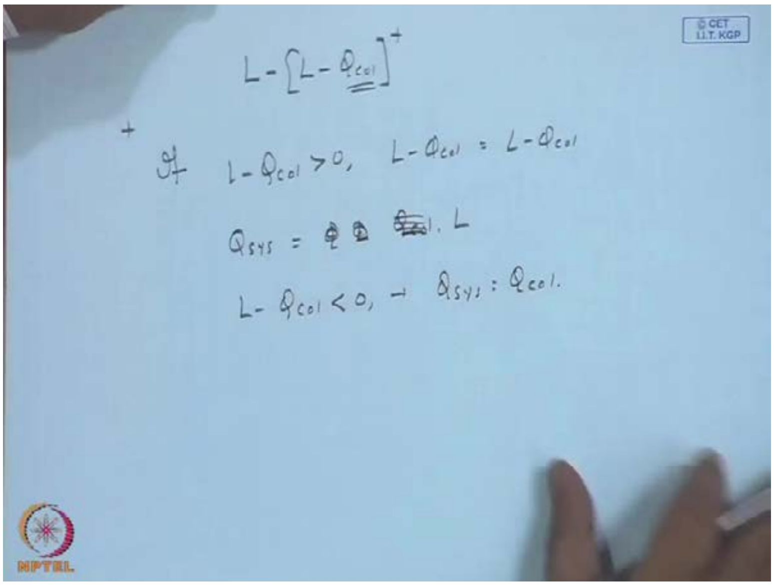

Now, this is written only for mathematical convenience, what all we are trying to say is l minus L minus Q col superscript plus which means if L minus Q col is positive, you take that, so L minus Q col equal to L minus Q col, so that Q system is equal to sorry, L l sorry, Q col. So, whatever is I am not talking about the losses, the principle is only that the system will not accept excess energy in the system, in the sense that you wouldn’t like to pay for what you do not want if the collector supplies more energy right after going to the storage still if there is an excess for that the economical benefit cannot be assigned. So, we will write it this in terms of this mathematical symbols and if L minus Q col is less than 0, we treat; that means, L is more and you have got Q system, if it positive it is and Q system equal to Q col right, right. So, this should be sorry L, in another word the system cannot have more than the load, in the case of when the supply is less than load then equal to the supply.

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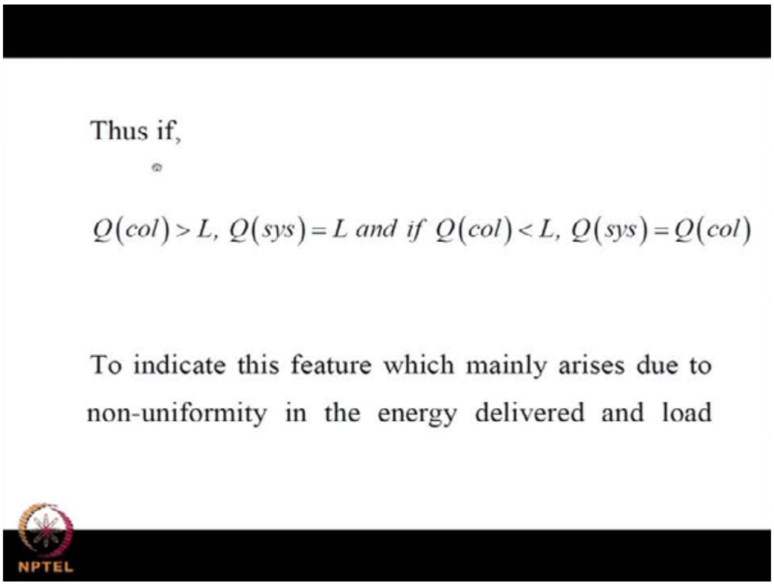

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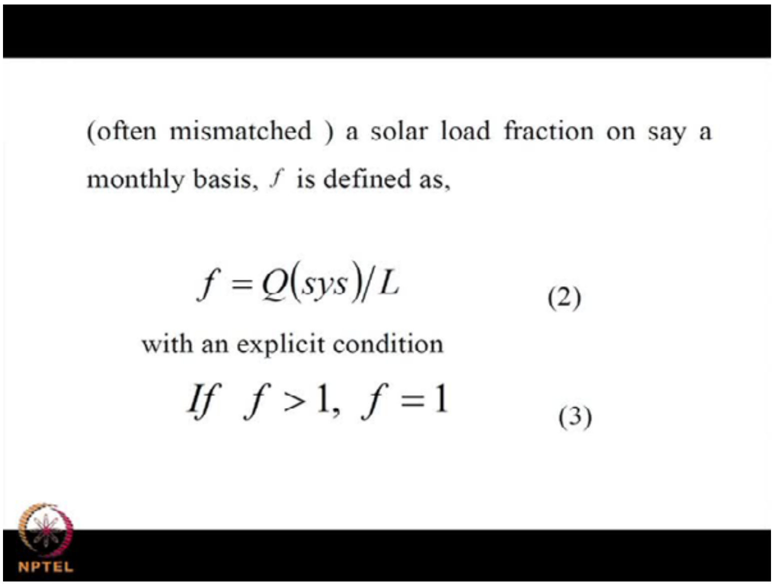

So this has been put I think more clearly and you can see this, this mainly arises due to non-uniformity in the energy deliver and the load is match. So, efficiency if you want to decide for a year, it involves a calculating of weighted averages then also it is also that of the collector then I am not able to combine it with the utility of this solar energy system in so far as meeting the load is concerned.

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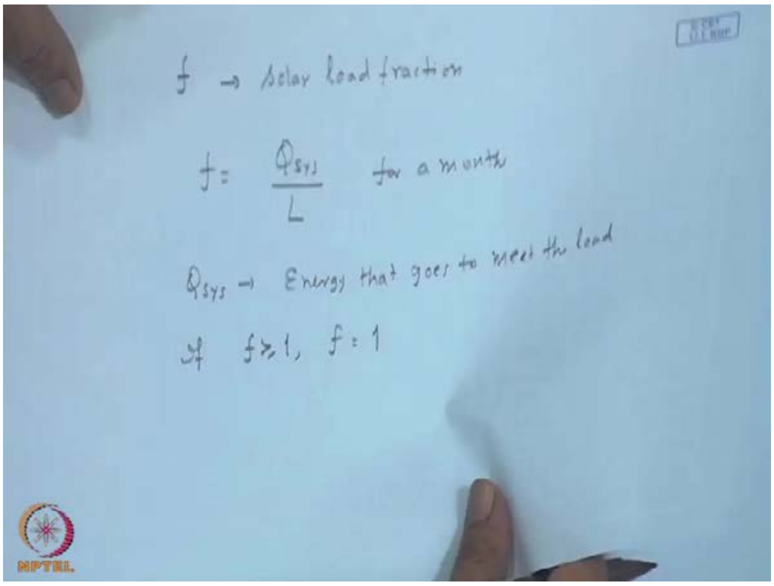

So, we will define a f the so called solar load fraction, this we will defined Q system upon L say for a month right. So, this is the so Q system is the energy that goes meet the load, I can even put a condition of course, earlier if you write Q system is equal to L minus L minus Q col superscript plus it takes care of or else if f is greater than equal to 1 set f is equal to right; that means, the solar load fraction cannot be more than 1 even if the collector is capable of supplying higher than the load required.

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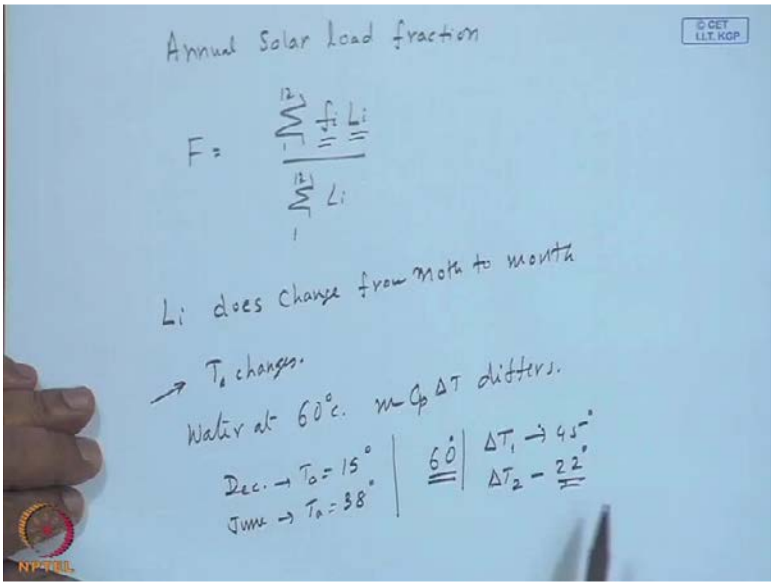

So, if that is for a month I can define the annual solar load fraction. So, it is a weighted average of the load fraction fi for a month I and corresponding load L i upon L i summed up overall. Please, recall recollect remember that L i does change from month to month at least, if it is day to day, it would even more difficult, I have to define for each day but, what we can say that month to month is my for example, if it is a simple water heating system T a changes. So, consequently if you want water at 60 my energy m c p delta t differs because, my t a is changing, because I am assuming for the time being that I am drawing the water from the atmosphere, open atmosphere which is effectively at a temperature T a. So, n a changes considerably for example, even in India, where the weather variation is not that much extreme say for example, typical December may be t a is 15 degrees and may be June t a is 38 degrees and I want at 60 degrees.

So, delta T for December will be 45 and for this it will be only 22 right. So, it is almost half of this in addition you combine the fact, December radiation may be two-thirds of the June radiation but, do not think of only for bearing any other application, if my desire temperature is 60, the load on the system in the winter is almost 4 times that is the load in the June right. So, if you design for December, it will be over design for June consequently the effectiveness will be only the L which may be so many mega joules, if I express it in term of energy unit and differently the excess energy has to put to some other use but, in evaluating this system viability it will not contemporize.

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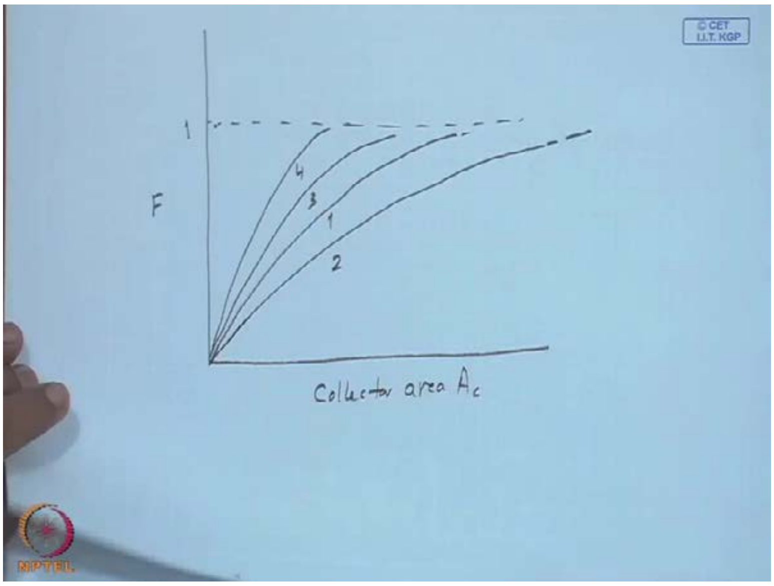

So, if I try to plot the solar load fraction f versus of course, the collector area, all other things will be parameter which I may have a curve ,1 this will be of course, one and this may be 2, this may be 3 and use the numbers this may be 4, so 1 2 3 4. So, this is a deliberately an output monotonically. So, this is my solar load fraction, if the total load in the year is completely meet by this solar energy system, it will be equal to unity and it shall approach to unity for pretty large areas, because at times it may be at least without infinite storage, you may not be able to meet all the load throughout the year. So, it will be 0.9995 and may not be 1 all the time, so this is the nature of the curve.

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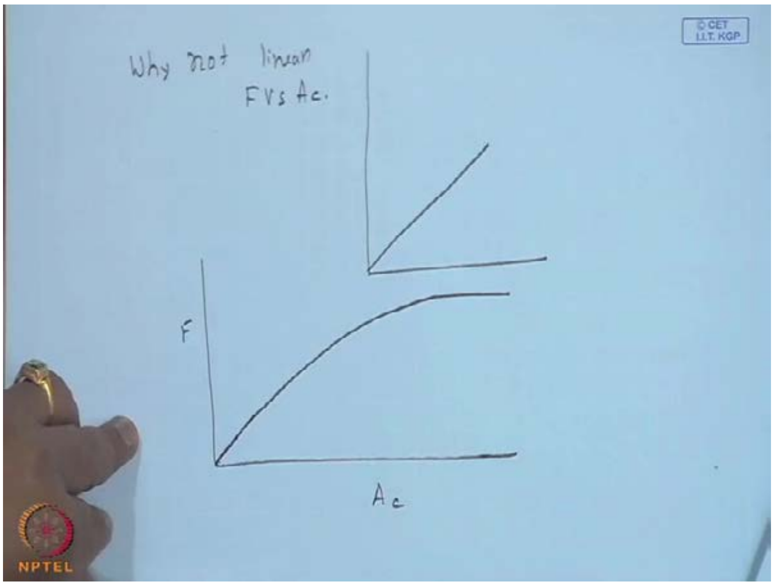

Now, the first question is whey not linear F versus A c? Why it cannot be you double the collector area, it does give double the useful energy. So, why not the load fraction, the reason is similar to what I have explained and the context of month of December and month of June. So, you have not been able to utilize the excess energy, when it delivers whereas when it does not deliver the excess energy the penalty remains. So, initial very small area there is no question of energy being excess of the load. So, it will increase as you double the area of collector, it will double the utilization consequently, it will initially line arise, now at the particular area something like this, it starts meeting the load fully let say in the month of October right then subsequently November subsequently, December if it is a winter application. So, my additional areas will be losing the extra energy delivered in the months of June, July where the demand is less. So, the additional benefit of F will be decreasing with the increasing area.

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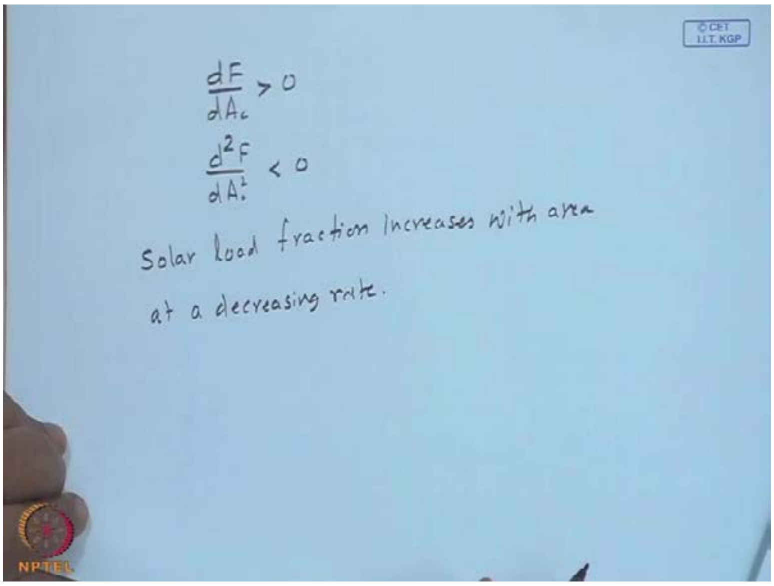

So, this is let us say in a mathematical sense, d F upon d A c no doubt is positive otherwise you would not put any additional area but, second derivative is negative, in other words solar load fraction increases with area at a decreasing rate; that is the mathematical that is the physical mean of a first derivative being positive and second derivative being negative.

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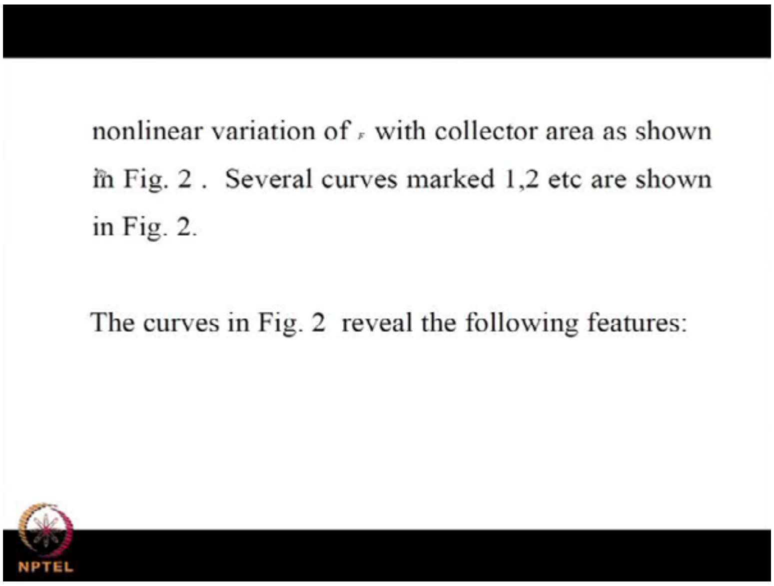

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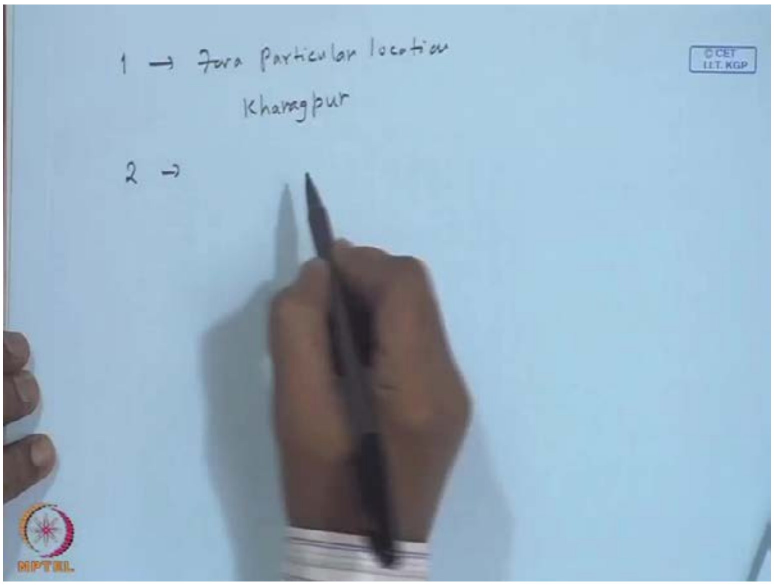

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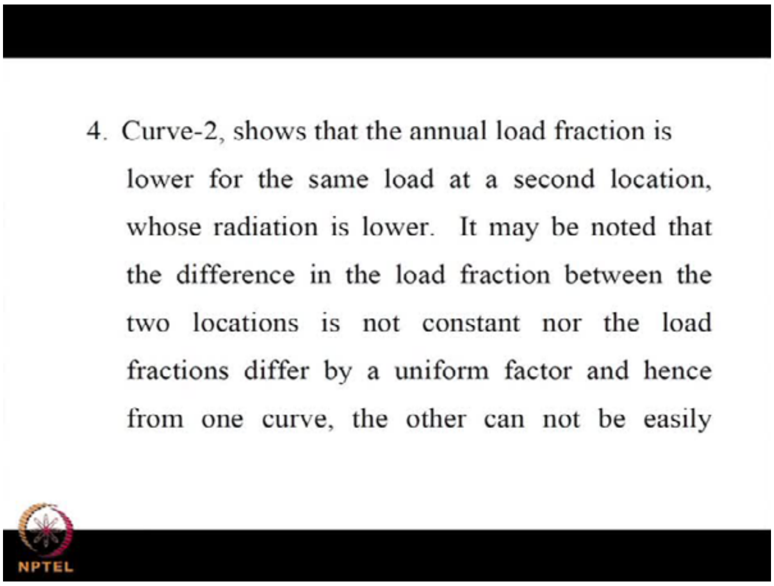

So, first of all this is non-linear, the reason for non-linearity is expressed, so we have marked the curve as a 1, 2, 3, 4 like that. So, curve 1 can be for a particular location, let us say Kharagpur and 2 is at a this features I have already commented on this 1 also, now this curve 2 is lower than the curve 1, let us just check it right.

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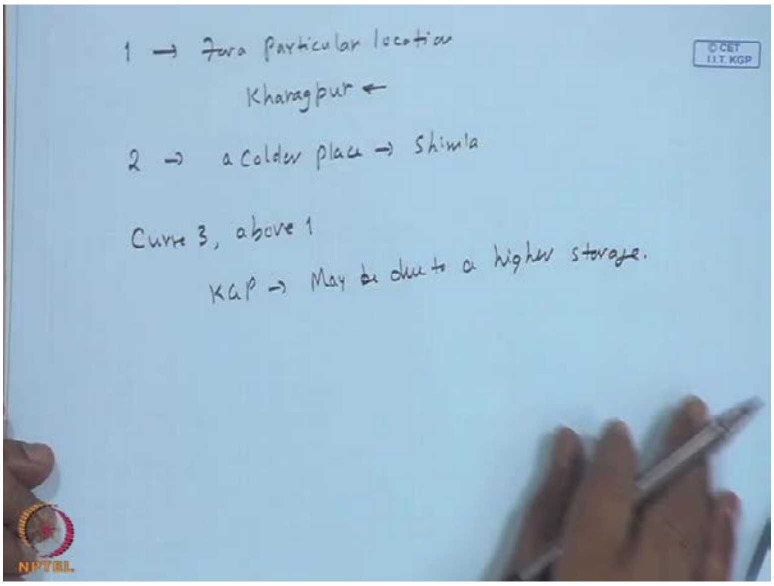

So, the solar load fraction at the same area is lower for curve 2; this may be a colder place may be Shimla. So the system if you put in the U S sorry, if you put it in the Shimla or a cold place, it will deliver energy may be same or less, because my solar radiation is less, but solar load fraction will be less on two counts, useful energy delivered by the collector is lower and then load also is higher, if it is a space heating system or even if it is a water heating system, simple your t m ambient or t minimum inlet temperature to the collector will be much lower, then what it could be Kharagpur or Chennai. So, curve 3 above one, even at the same place like say k g p Kharagpur may be due to highest storage, which means that dumping does not occur or dumping will be lesser.

So, you will have in a month like June, if there is extra energy delivered, there is a large in a storage for that energy to be stored and which can be utilized in a lean day when it rains or the subsequent month like October, November, December. In principle if you have a seasonal storage or the effectiveness will be very very much improved though one has to account for whether that larges seasonal storage is cost effective or not. So, we shall in the next class or try to find out, how we can find out this solar load fraction, one way is to make hour by hour calculation or or there any simpler methods.

Thank you.