Solar Energy Technology
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Lecture - 28
Long Term Solar Energy System Performance
Simplified Design Methods

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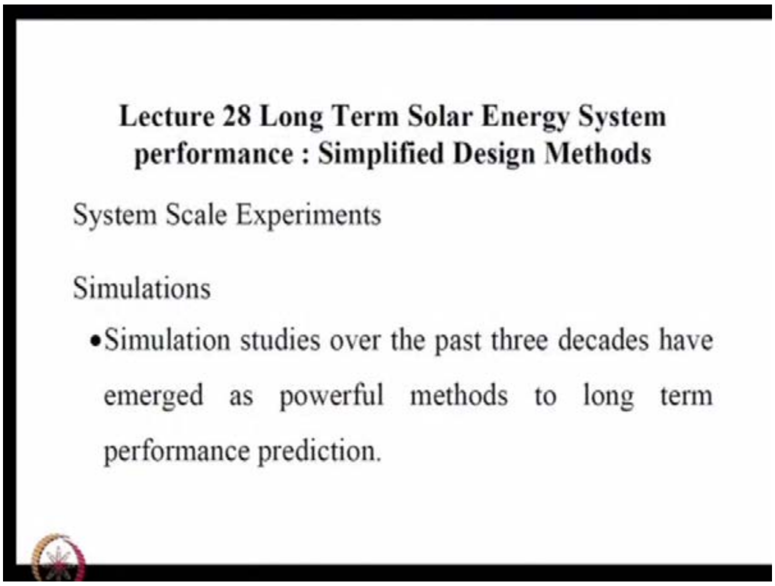

So, we had an idea of what is meant by long term performance prediction, or we said that the metallurgical cycle repeats itself over an year. Economic analysis is also is based upon the cost benefit analysis over a year, over the lifetime of any system in particular. We identified the difficulties with the solar energy systems, namely the you cannot get the performance output as simple efficiency multiplied by the solar radiation following over a long period of year; for the several reasons, which we have listed. And the methods that are available to absorb conducting system scale experiments, which could time taking. And of course, also expensive and the effect of parameters cannot be easily studied, because if you do an experiment for 1 year with 1 slope, and if you want to change it for another slope, you need another year or study to get that performance.

So, simulations turn out to be via media that means, you mimic the solar cycle and you model each component need together those models and give the output of the first module to the as input to the next module. Like for example, a solar collector dumping useful energy in to the solar tank, where the temperature increases which goes to meet the load. So, we can develop module for the number of types of components and the, these things have proved to be affective, which will take a fraction of time, it does not require an year.

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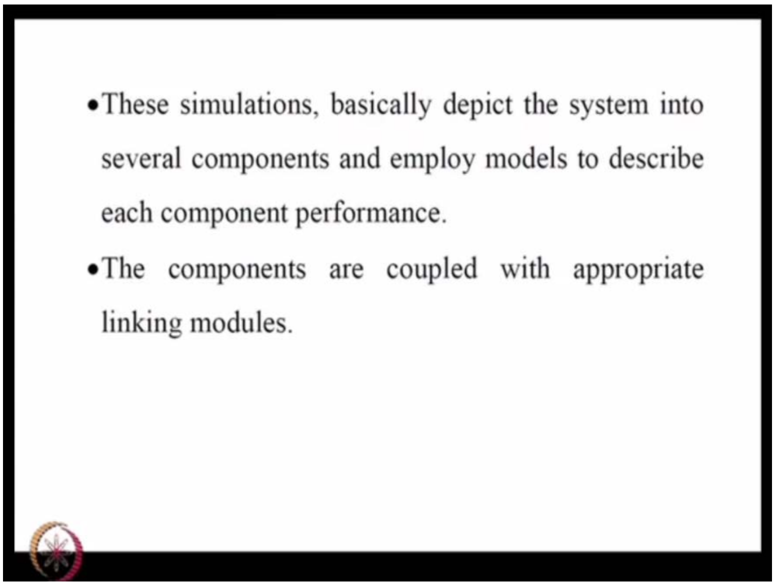

And these simulations basically depict the system into several components and employ models to describe each component performance. The components are coupled with the appropriate linking modules.

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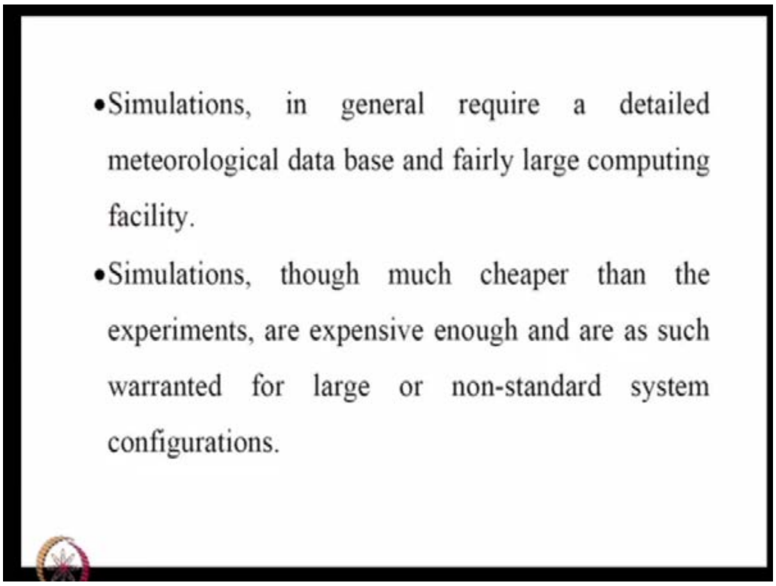

So, this requires a detailed metallurgical database; one is availability of the data and the ready available of the data. So, for example, if you consider the Indian Metallurgical Stations monthly averages are there available even on the net. But if you want hour by hour data, one has to acquire from the meteorological station or office in the Pune. And then these all these numbers say may have to be converted into a tape or putting the computer program to get that which is elaborate task. But however, if it is done once, it can be used. The other thing is most of these metallurgical stations are at the metros or the cities, it is very likely, because of the premium of the land solar energy systems are likely to installed at smaller places may be villages, where the actual data collection did not take place. So, in the long run, we , might say though simulations are cheaper.

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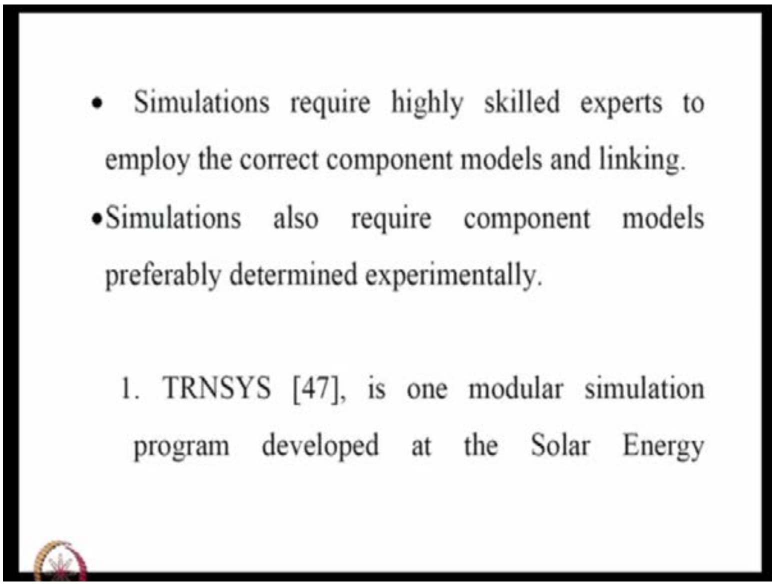

It requires the skill of experts or to stitch to that the components models and it requires of course, a detailed database.

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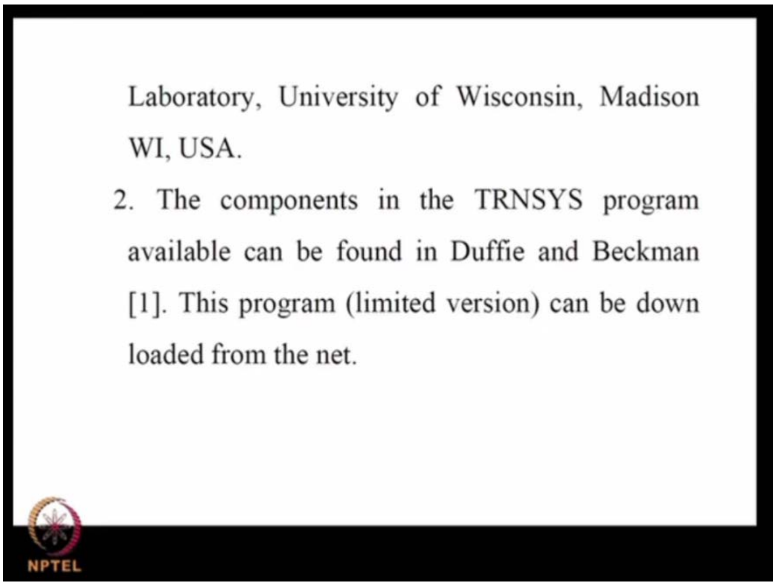

A TRNSYS is one such a program which was developed at the University of Wisconsin Madison.

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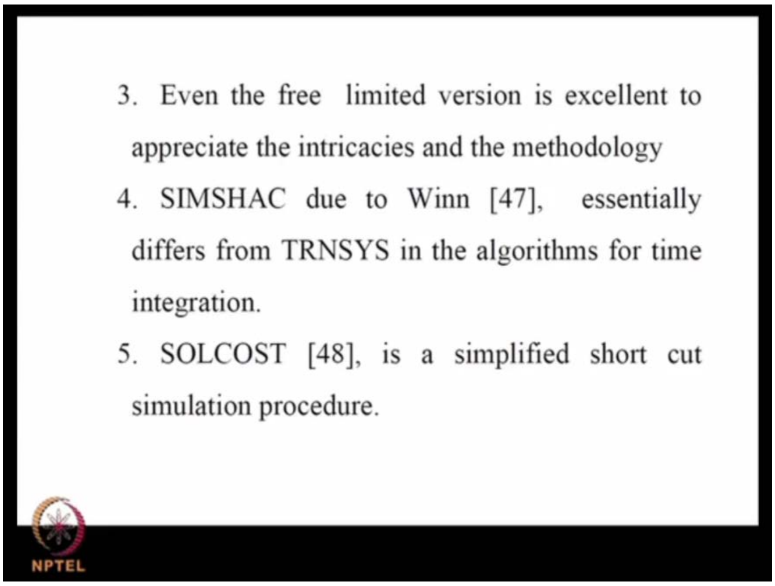

And then SIMSHAC is another. This is due to Winn, though it is not does not contain as many components or modules as TRANSYS.

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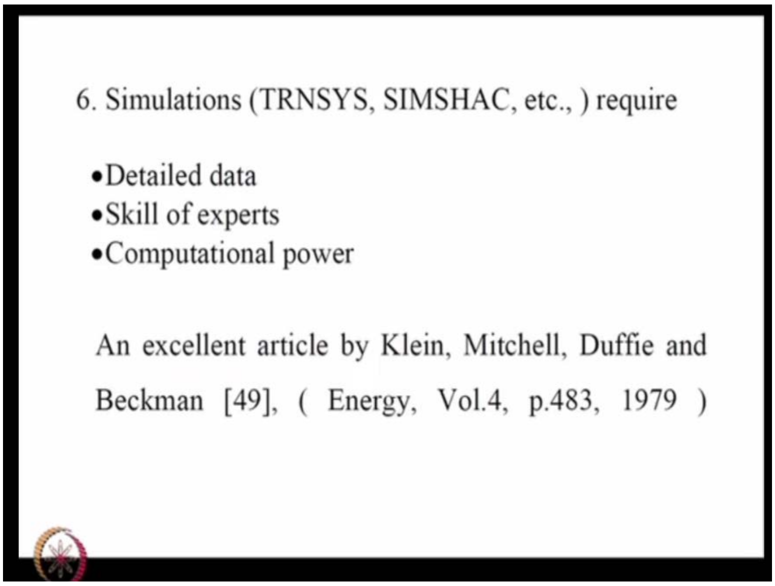

SOLCOST is the simplified method relatively it simulates a bright day and a cloud day, cloudy day and attaches certain weightages to get an overall performance. So, one can look at the text book by Duffie and Beckman and or this program can be downloaded a limited version free and 40 examples have been given. One can who is interested in going through those things, go through those things and obtain the performance of the certain standard systems. So that gives you a feel, how the data is metallurgical data is used and how the components are put together. So, in one sense you may see the somewhat desired values, are you need detail data skill of experts and computational power.

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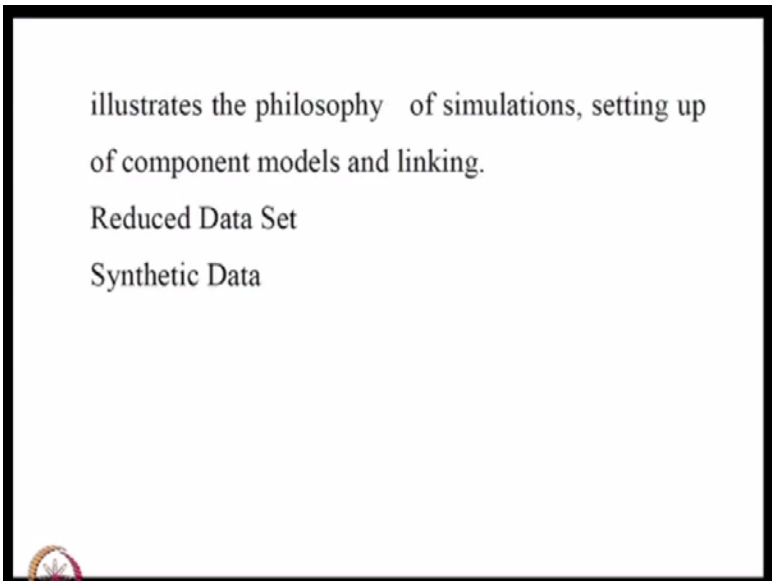

So, people have tried to lessen the computational requirement by using a reduced data set or even at times resulting or result resulting to synthetic data. Basically, synthetic data mimics the metallurgy of the particular location though it may not exactly satisfy hour to hour, day to day, but in general it will reproduce the averages, which are good enough to get a performance monthly wise or yearly wise.

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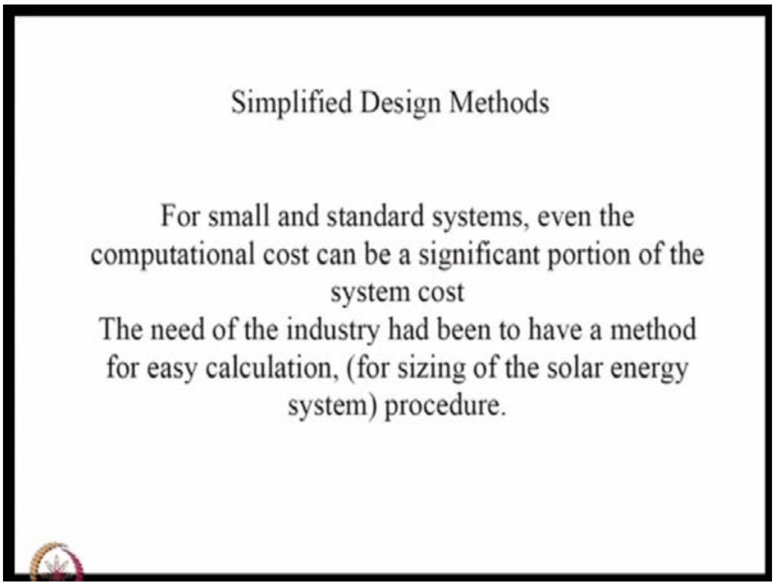

This advantage, this leads to an advantage almost, all the data can be generated through sort of equations though your components models could be analytical, which can be clubbed together along with this data. In other words, if I try to give an example.

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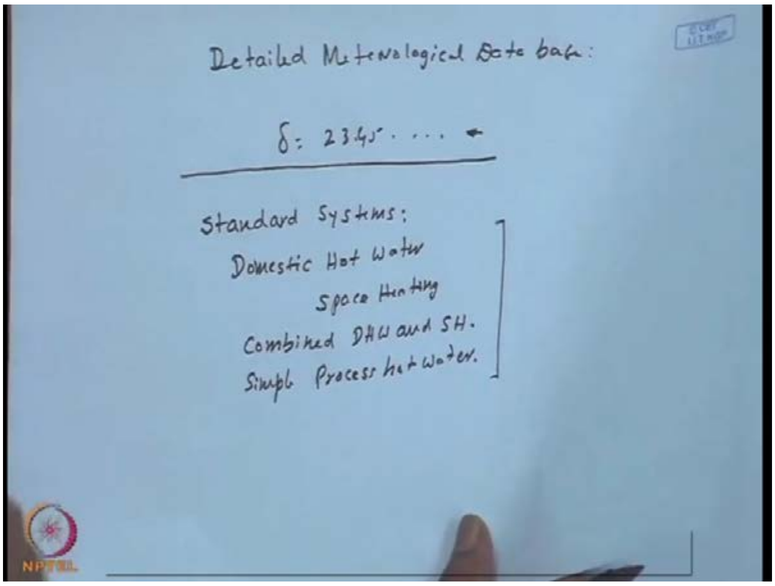

If delta equal to 23.45 something this equation is much more amenable for computer implementation than a set of 300 and 65 values of data delta for each day. Now, so if you consider you will also notice many of the systems are standard systems like say for example, most common used could be a domestic, hot water called space heating, or a combined domestic hot water and space heating, or a simple process hot water. For example, if you consider silk industry, the cocoons are put in a boiling water at a water of a temperature of about 80 degree, 85 degrees, degrees is done around 80, 85 degrees. So, there are number of applications, where hot water is required at a given temperature. So, these are the some terminologies which have become more common in the US, which when we translate to Indian conditions, which I shall point out slight differences one has to be little careful.

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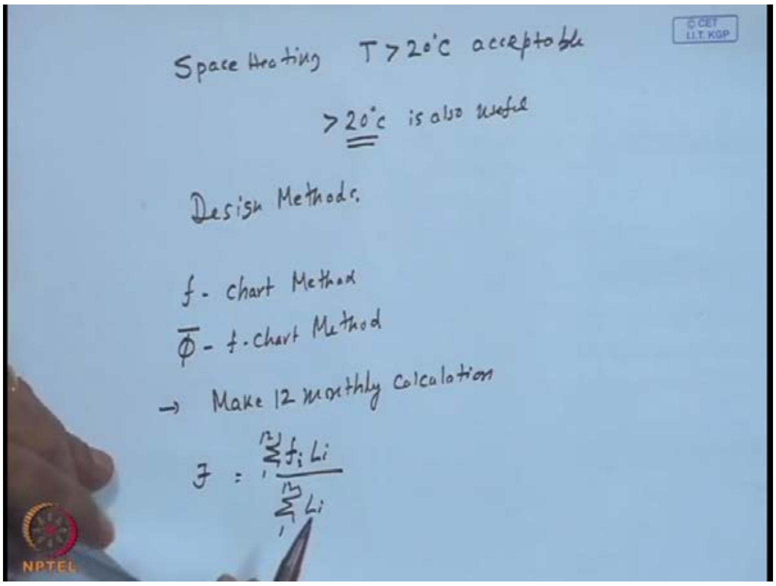

For example, space heating T above 20 degrees C centigrade is acceptable generally the comfort condition is approximately 20 degree centigrade in the room. So, any energy that is available to at or above 20 degree centigrade is useful and you can utilize for the purpose of space heating. Similarly, this domestic hot water or though you may be taking bath at a higher temperature and washing the dishes also may be at a higher temperature. Above 20 is also useful, for example, if your ambient temperature or the mains temperature is much lower than 20 like 10 degrees, 11 degrees even to wash your hands or whatever and you need 20 degrees is a comfortable condition.

So, particularly in cold countries there is a lot of application a lot of water needs to be heated from the main supply temperature, which is typically 11 degrees in the US to 20 degrees or above. Or the methods, whatever we are going to talk it does not mean the supply only at 20, they may be supplying at more than 20. But for the meeting the node it is not acceptable to have anything less than 20. Since, there are large number of applications of the standard systems, people have come out with what are called design methods, stimulations they do serve their role or whenever you want to design a large system and unconventional system and typically large systems like for example, you go for a power generation or solar furnace. Solar desalination, every specific detail of that particular location has be taken into account and the investments may be of the order few crores and stimulations cost is, but. But if you want 60 liters of water at 60 degrees, see it will demonstrate water heating system for bathing or possibly stimulation cost may remain the same.

But, the system cost will be only a fraction of the power generating system, so stimulations are not that much welcome and one goes for the standard or a designed method. This is also has been the need of the industry to have a simplified method without calling for the skill of experts. So, some of the resulting methods are popularly referred to as one is the f-chart method, again developed at the university of Wisconsin Madison and the other one is phi bar f-chart method. So, I have given the references, these methods make 12 monthly calculations, as we have discussed it length for the solar energy systems, or the solar load fraction is the performance indicator. And if f is the monthly solar load fraction, f i and load L i is the load fraction, load on the system per a month i 1 to 12, this is the yearly solar load fraction.

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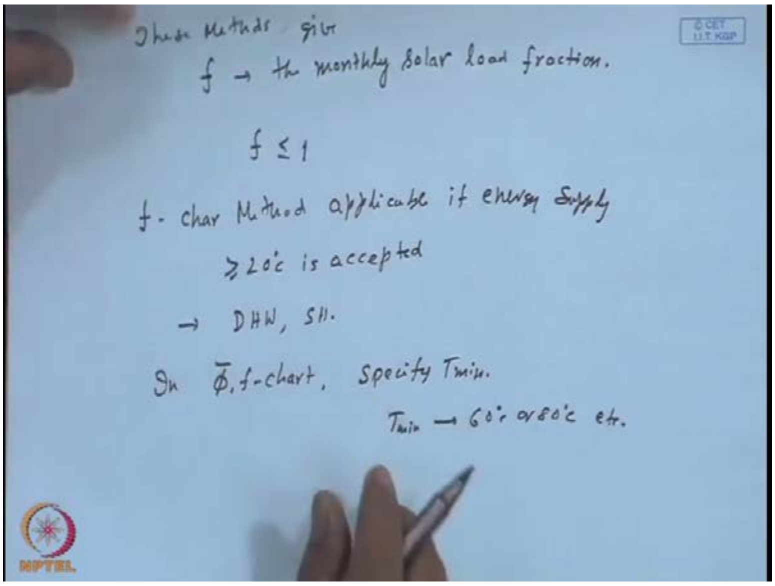

So, this is f-chart and phi bar f-chart methods will essentially, give you f, the monthly solar load fraction. We have also discussed earlier, that if the energy supplied by the solar energy system is in excess of the load that is not taken into account. So, f is always less than or equal to 1.

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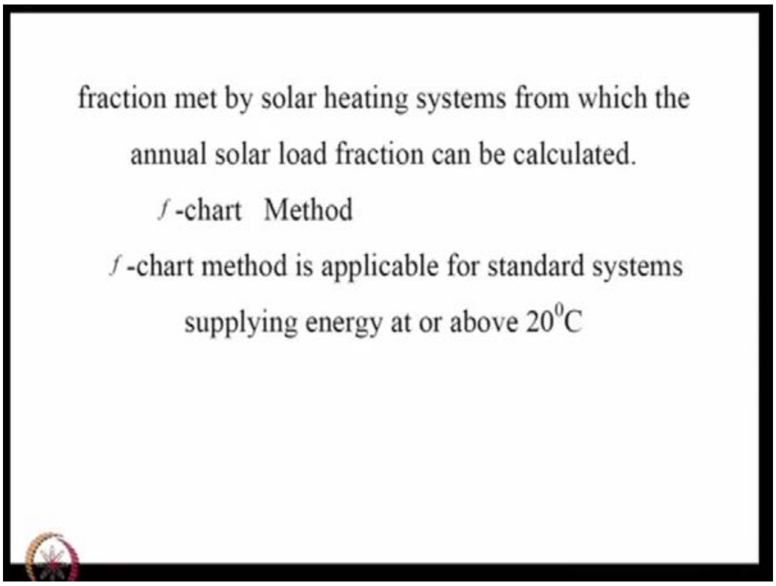

Now, what is the difference between these two methods? If you have f-chart method applicable, if energy supply greater than or equal to 20 degree centigrade is accepted. So, again contenders could be domestic hot water and space heating and a few other such applications, which require except 20 degree centigrade.

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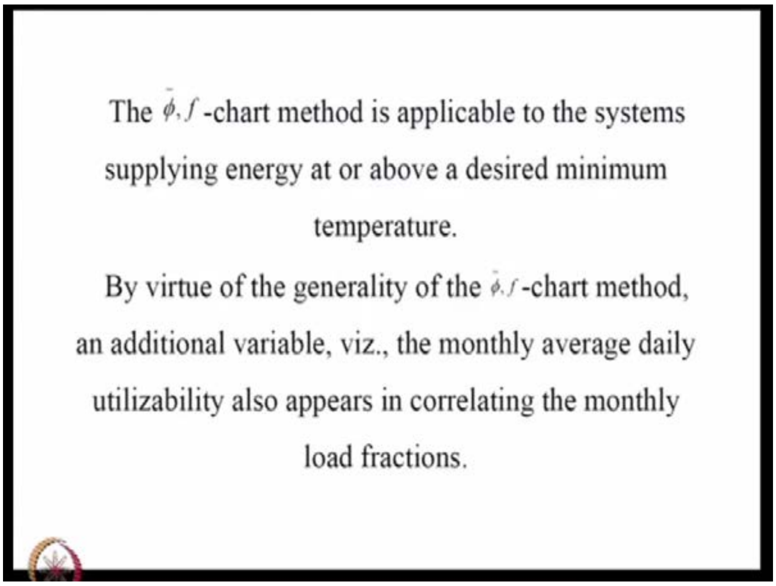

And then the in phi bar f chart, phi bar comma f-chart specify T minimum in other words, you can specify we want the immediate delivery at or above a particular temperature, 60 degrees, 50 degrees, 80 degrees. Whatever it is in other word, T minimum may be 60 or 80 etcetera. So, now since you are imposing that the energy delivery should be above a particular level.

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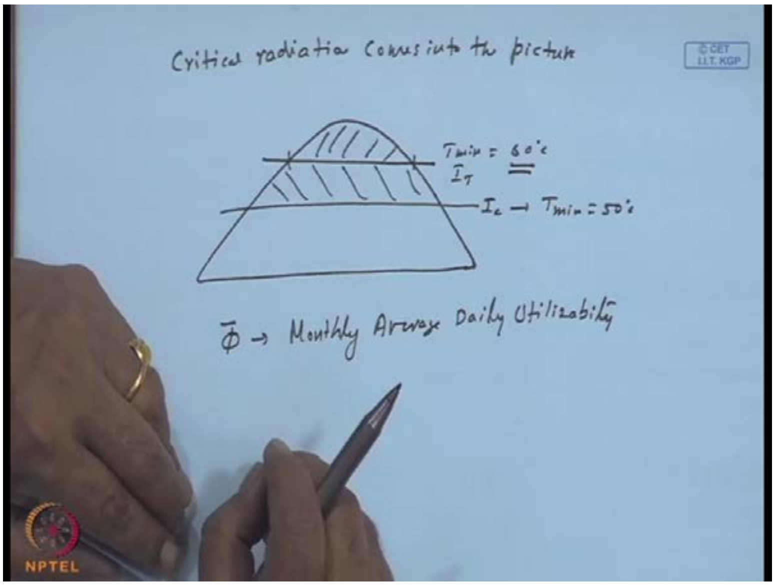

My critical radiation level comes to the picture for example, if this is typical solar radiation distribution I T or the solar collector. This is critical radiation level corresponding to a T minimum of 50; this will be corresponding to a T minimum of 60. So, if you want energy delivery at or above 60 degree centigrade, this part of the solar radiation is useful whereas, if it is at 50 hope this also is useful.

So, consequently we shall find out, what is a radiation available to you above the critical level over a month and that will be signified or indicated by the so called phi bar, which stands for the monthly average daily utilizabilty. We will spend some considerable time in how to calibrate this utilizability and what is the significance at this stage, I am pointing out the f-chart and phi bar, f chart method before. Because you specify a T minimum all the solar radiation available corresponding to a particular level is not useful. It will depend upon the T minimum that you wanted higher the T minimum lower will be the utilizability. And hence, my useful energy supplied at that temperature or above the temperature, which constitutes a lower or higher solar load fraction. So that is why f-chart methods is modified with phi bar and called phi bar f-chart method.

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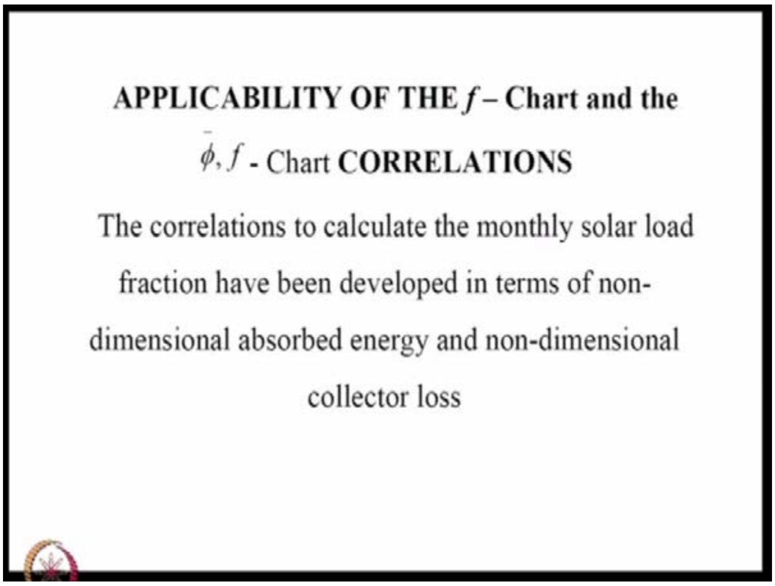

Now, if you look at it, what are the applicability?

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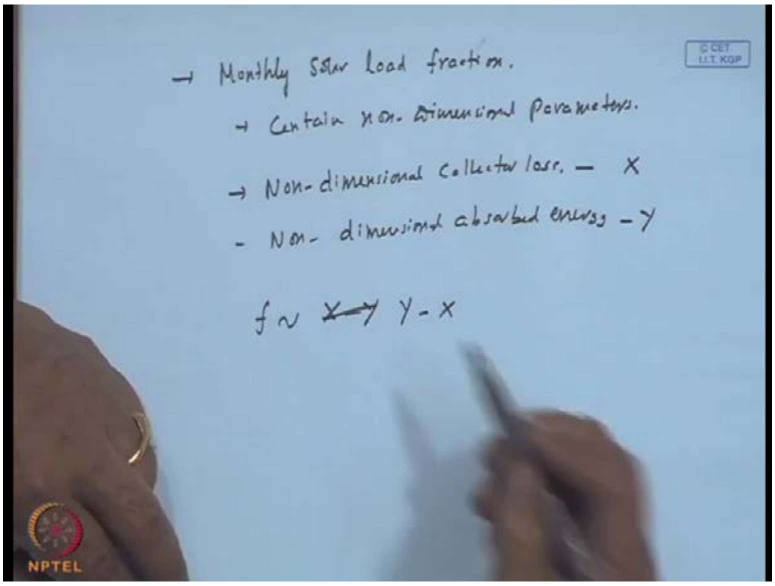

These correlations first of all they calibrate monthly solar load fraction. So, day to day may how much of load is met, it cannot view and they have been developed in terms of certain nondimensional parameters. There are minor variations between f chart and the phi bar f chart for some reasons ; one is the non-dimensional collector loss and the other is a nondimensional absorbed energy. If this is we call it X, let us say this we call it Y approximately, f should be proportional to X minus Y, if there are no nonlinearities or provided they are consistently unit wise, scale wise they are different.

So, you can expect a term like X minus Y plus so on and so forth. Sorry, it should be Y minus X, is the absorbed energy minus the losses. This is my simple useful energy equation looks like the absorbed energy minus the loss. But on a monthly scale because of excess energy, because of, other losses, because of pumping, because of, controls so on and so forth. It will not be a simple linear function of Y minus X, but it will be a non-linear function, which we will see.

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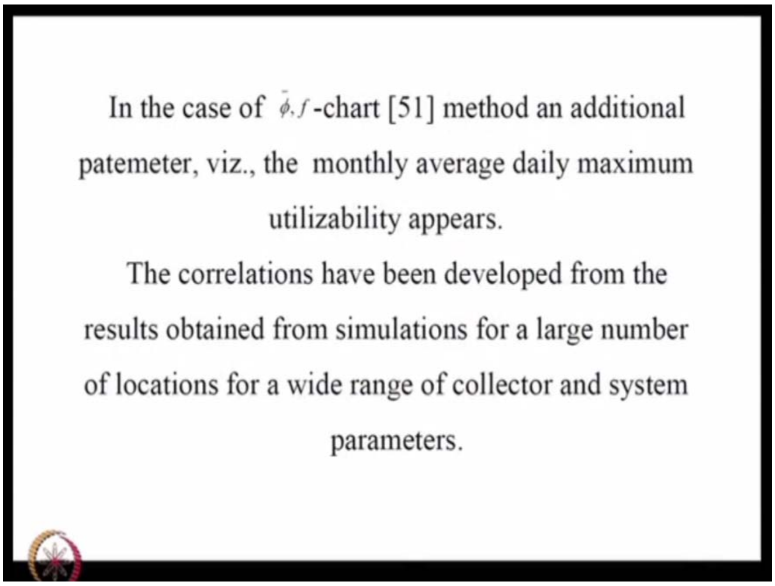

So that is why I already explained the additional parameter is the utilizability that appears in the phi bar of chart method, which in a way takes into account at what temperature, the energy is delivered. Now, how this methods or equations are developed?

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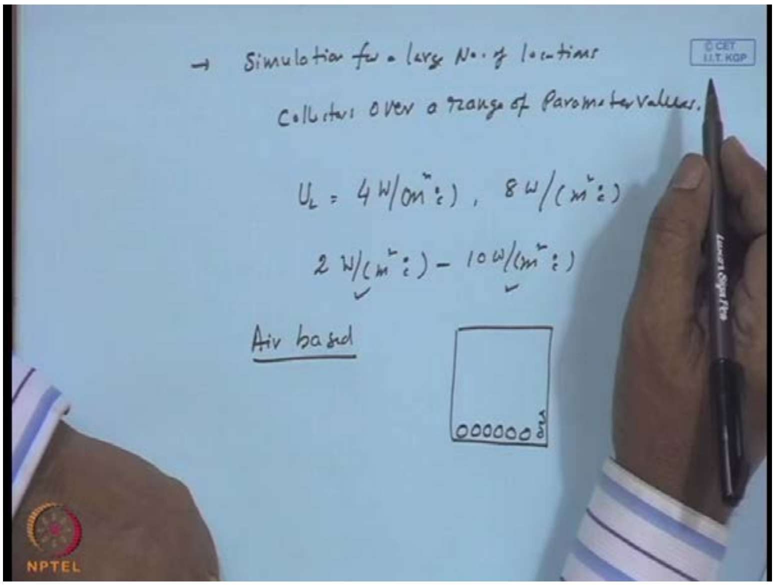

So, you do simulations for a large number of locations and for collectors over a range of parameter values. For example, if you consider the overall loss coefficient it typically U L may be 4 watts per meter square degree Celsius in for a 2 glass cover or 8 watts per meter square degree Celsius. So, if you some what do 2 watts meter square degree centigrade to may be 10 watts, it will include an extremely good collector and also fairly bad collector.

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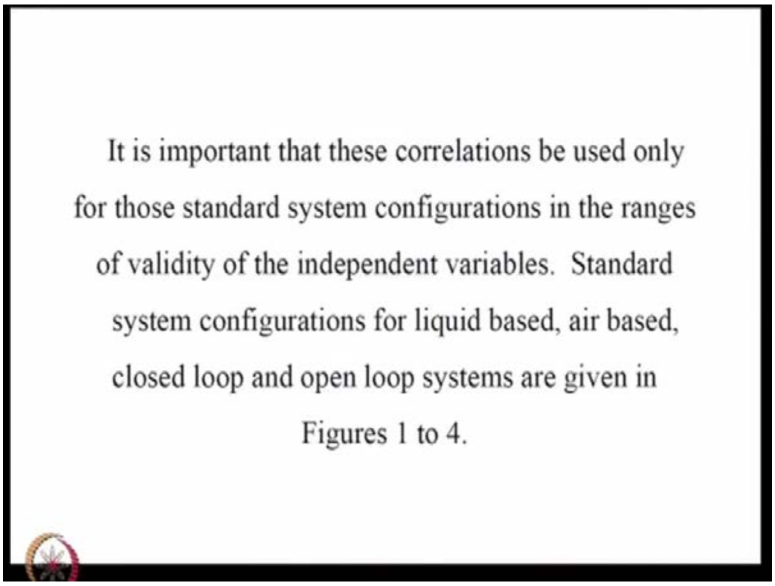

So, that is how these correlations have given. Now, what we mean by a standard systems?

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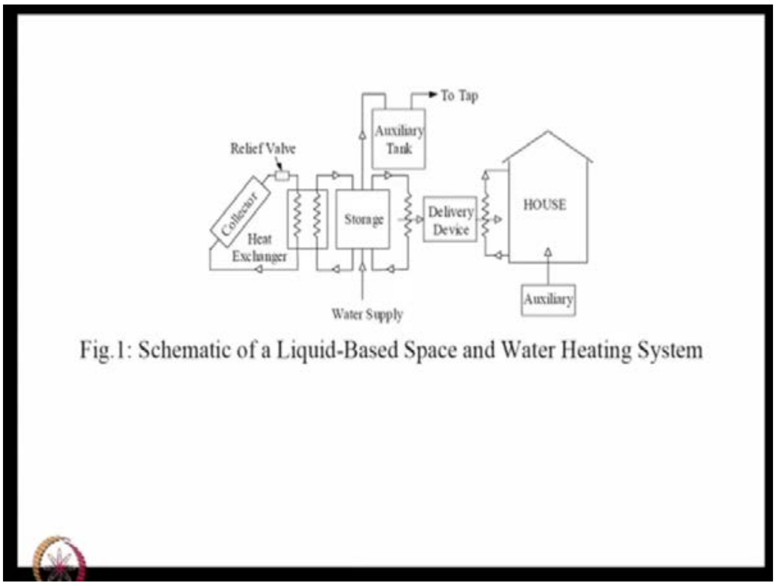

Fig.1: Schematic of a Liquid-Based Space and Water Heating System

Or figures are shown here. For example, you have a collector with a heat exchanger which dumps through another heat exchanger into the storage, from the storage it may go to an auxiliary tap, or tank from which it goes to the tap. So, that forms part of the combined liquid based space and water heating system and then through the delivery device and another heat exchanger it goes to the house, which will be meeting the space heating. The auxiliary will come in whenever, the solar is insufficient and either, for hot water or space heating. So, says of course, suppose I do not have a heat exchanger between, the collector and the storage room. I can put the effectiveness of the heat exchanger as unity then automatically it takes care of that collector is dumping or delivering energy directly to the storage. If auxiliary tank is not there, there will be no loss and of course, the delivery will depend upon the temperature that is available in the storage tank.

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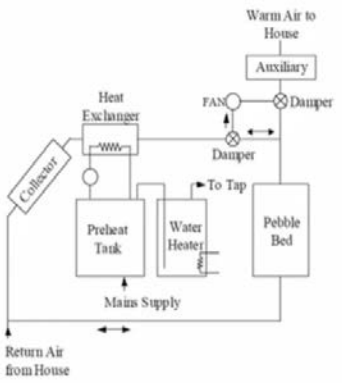

Fig.2: Schematic of an Air-based Space and Water Heating System

Next one is a, a typical and similar system, but it is air based the difficulties of this based system is you cannot store because, this specific heat and mass is smaller product. So, what you do is a rather it requires a huge volume, or with losses. So, you store the energy in their so called pebble bed over here and the pebble bed is nothing, but a pit you can put it underground with about 1 centimeter 1 inch, pebbles all packed. So, when there is excess energy the hot water goes through that heating the pebbles and then when, there is no solar energy, cold air goes through the pebble bed picking up the energy that is stored during the charging time.

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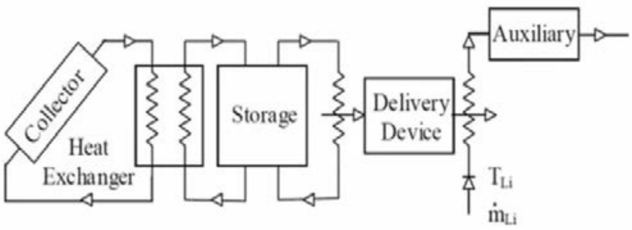

Fig.3: Schematic of a Closed-Loop Process Heating System

So, third one is a closed loop system similarly, auxiliary is put heater, auxiliary heater is put again in series. So, that it can make up the deficiency in the temperature or deficiency in the quantity.

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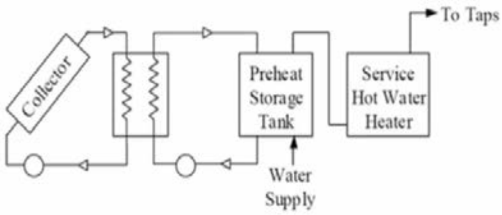

Fig.4: Schematic of an Open-Loop DHW System

Forth one is a service hot water, which again calls for a certain desired temperature. So, f-chart method can be modified to take care of a specified temperature that we will see in lend.

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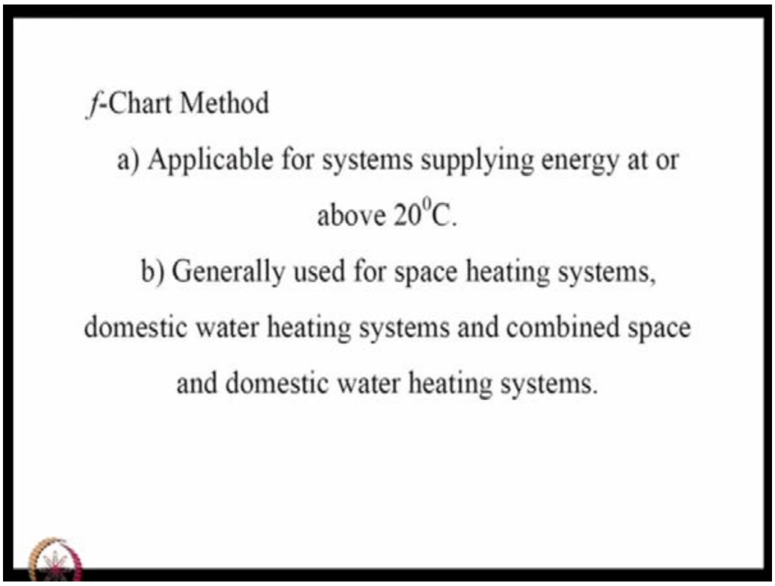

Now, if I tried to separate this f-chart and the phi bar of chart method.

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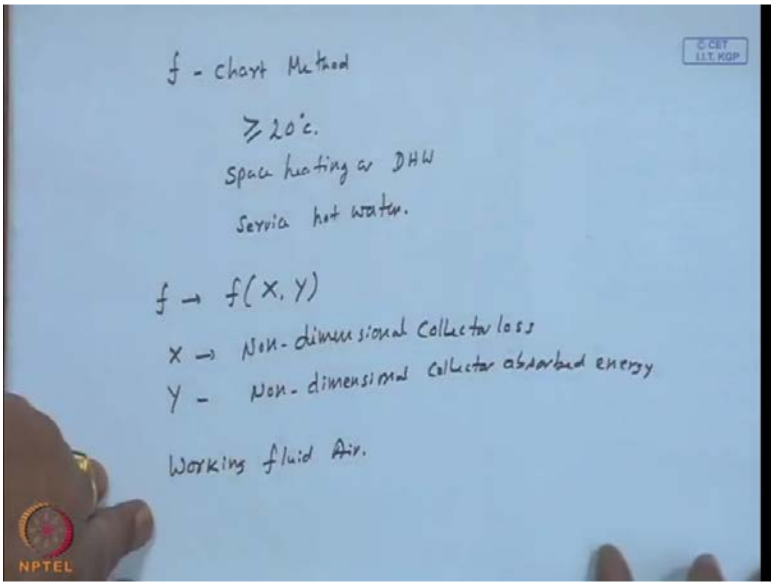

So, somebody can ask what are the limitations, or under what conditions f-chart method is applicable so at or above 20 degree centigrade. Of course, generally we said that space heating or domestic hot water, also used for service heating with a modification and it is correlated to 2 non-dimensional variables, which is a non-dimensional collector loss. So, f is a function of X and Y. Where, X is the non-dimensional collector loss and Y is the non-dimensional collector absorbed energy.

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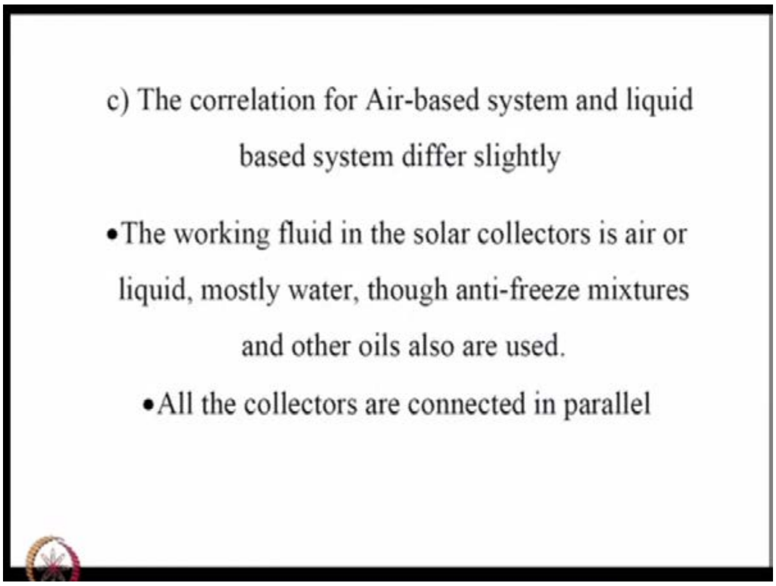

And the a special form, specific numbers rather form will be the same correlation for the Air base system and liquid based system differs slightly and, in general air based system means, the working fluid in the collector rather, it picks up the useful energy air. I have not checked really, I have not seen or held a gas being used instead of air except, some refrigeration applications people are trying carbon dioxide etcetera and, and liquid based system mostly it is water, though antifreeze glycol etcetera may be used or thermionic fluid also, can be used, where the thermal capacity characteristics will be better. So that your storage will be less volume wise, etcetera.

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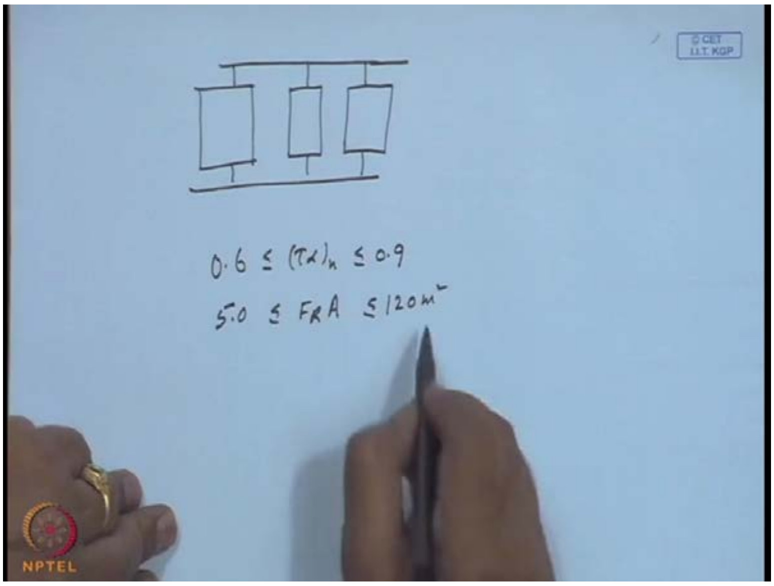

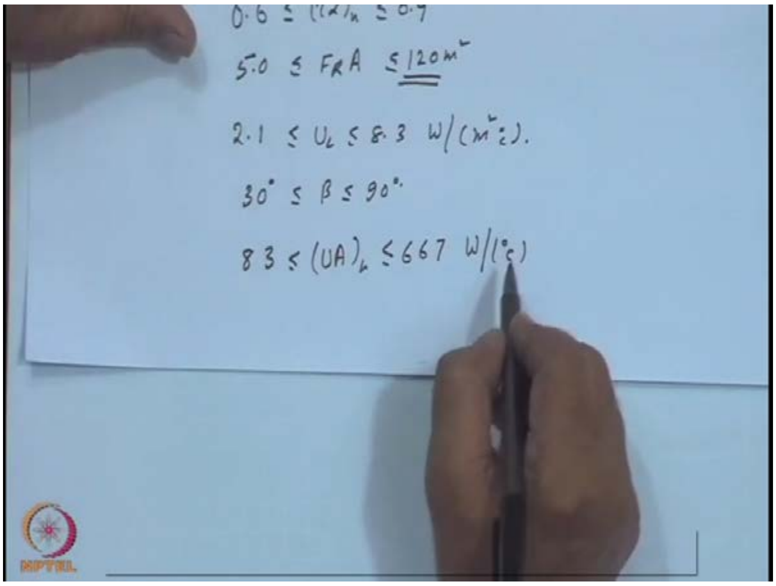

And in a f-chart and phi bar f chart, they assume all the collectors are connected in parallel. So, that each collector receives the same inlet temperature and if the size and everything is same delivers of the same temperature. Consequently, the performance will be a function of the number of collectors of the area directly proportional.

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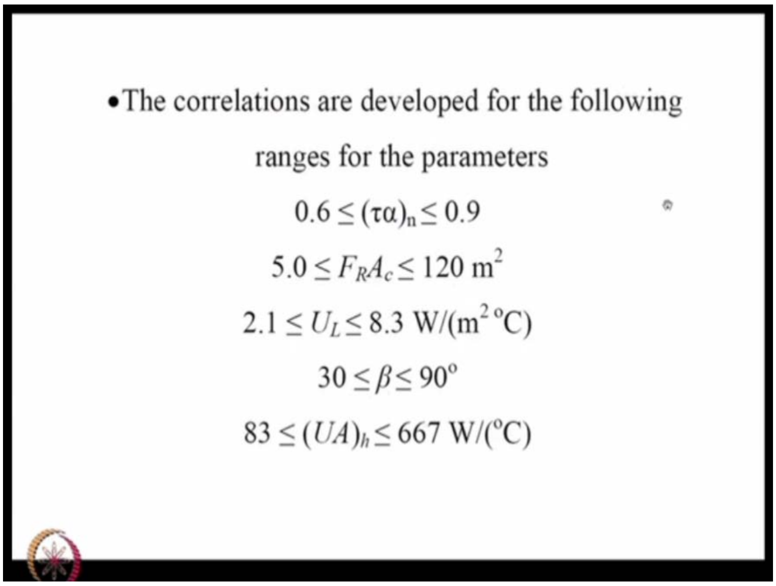

And this is the wide range for which the simulations have been developed based upon which the correlation have been formulated. First the material property I can say tau alpha normal 0.6 to 0.9 and this is product of heat removal factor, and the area of the collector 120 meter square. So, this equals to be somewhat a lower, but possibly assuming the linearity is, one can go for a higher range also, but strictly speaking they are expected to give acceptable results. When they are applied in the ranges that we are specifying and U L can vary from 2.1 to 8.3 watts per meter square degree centigrade and slope between 30 degrees less than or equal to beta less than or equal to 90 degrees.

So, this seems to be a little limitation, if you apply for a tropical climate and let us say something like Southern India and your, your latitudes will be lower than 30 in fact most of India is less than 30 degrees. So, this beta may be a limitation, and this will come again building heat loss coefficient, so many watts per meter c for degree c. U is the overall loss coefficient, if you consider and A is the surface area of the building then U into A will give you a product, which will multiplied by my temperature difference outside will give the loss, that is taken care from the house. So, from the loss that is taken care from the house I can calculate, what is this space heating load? If the house is going to be kept at a 20 degree c and the ambient is let us say 13 degree c.

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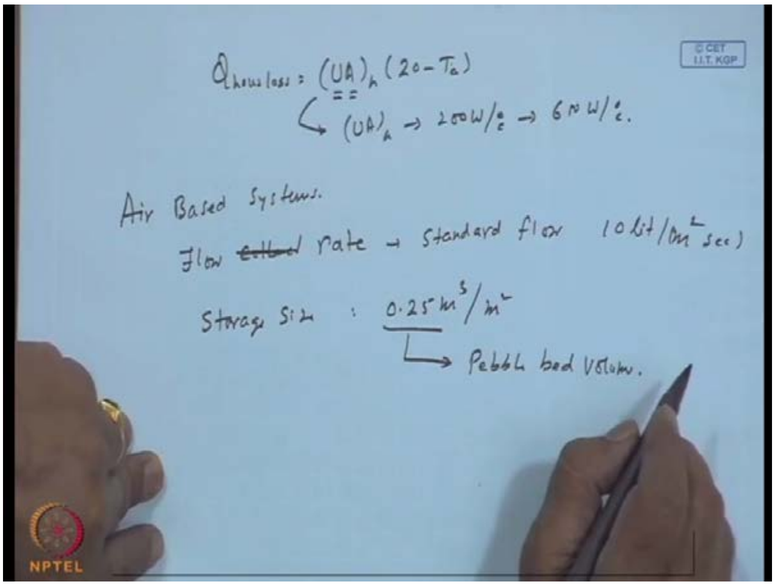

So, Q house loss equal to UA of the house times, let us say 20 minus T ambient in a simplistic manner, though it may have to be averaged or weighted averaged over a period of time. So, this is nothing, but an overall loss coefficient multiplied by the area participating multiplied by 20 minus T. So, this is a terminology which if you have got a standard construction of 1-bedroom or 2 bedrooms, you may have UA h or typically from 200 watts per degree c to 600 watts per degree c, depending upon how well it is insulated or how well it is not.

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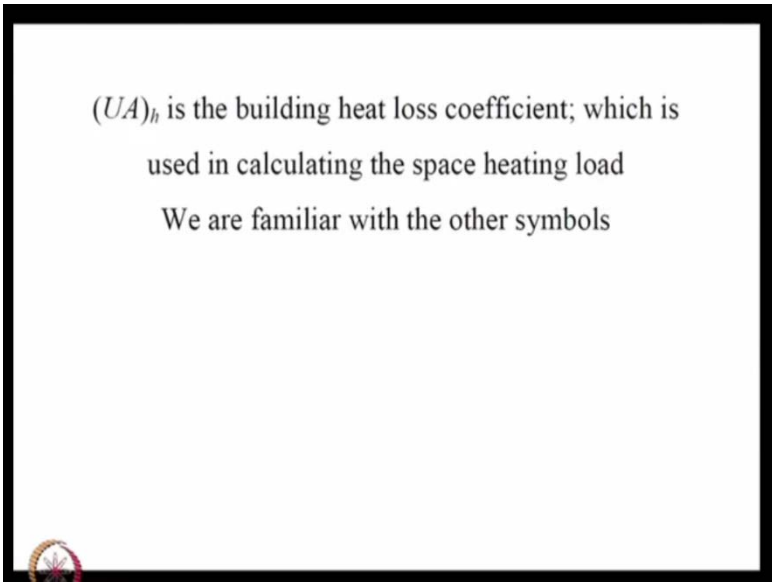

So, this is used for calculating the spacing heating load and other symbols like U L, F R tau alpha normal and beta we are already familiar with.

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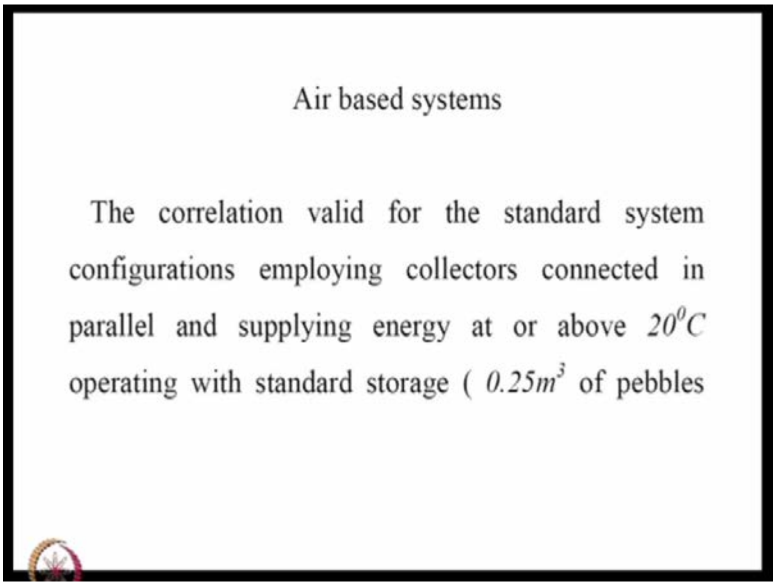

So, this air based systems, again there are other variables, other than tau alpha A, F R, U L and beta and UA H. What is the flow rate particularly, for air based collectors? In the case of air collectors, my heat transfer coefficient strongly depends upon the air flow rate number 1. And the stratification in the pebble bed may be seriously affected depending upon the flow rate. In other word, you expect a higher temperature A to B at the higher level, because of the lower density and if a gush of air or a blush of air, are the blast of it goes to the high velocity. This stratification may be disturbed consequently, the storage performance will be affected if the flow rate is too high. So, there is a standard flow rate for which the simulations have been made that is a 10 liters per meter squared or it per hour.

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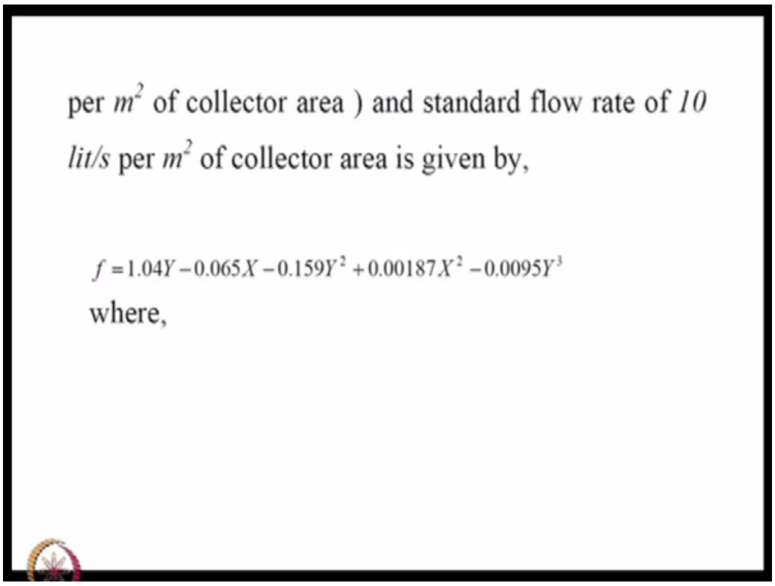

Yes, 10 liters per second per meter square of the area, so you except that the correlation to be valid. If your flow rate is around 10 liters per meter square 9.9 is fine and, and the storage size is 0.25 meter cube per meter square, this is the pebble bed volume. The pit we were showing earlier in the figure. So, you provide a 0.25 meter cube per square meter of area. Now, if you take into account the specific heat of the pebbles roughly, 1 inch size and the randomly packed and this may correspond to a heat capacity about 350 kilo joule which will have something relevant in the case of water heating systems. When, once you specify the mass, specific heat product of the storage tank, assuming the fluid to be water.

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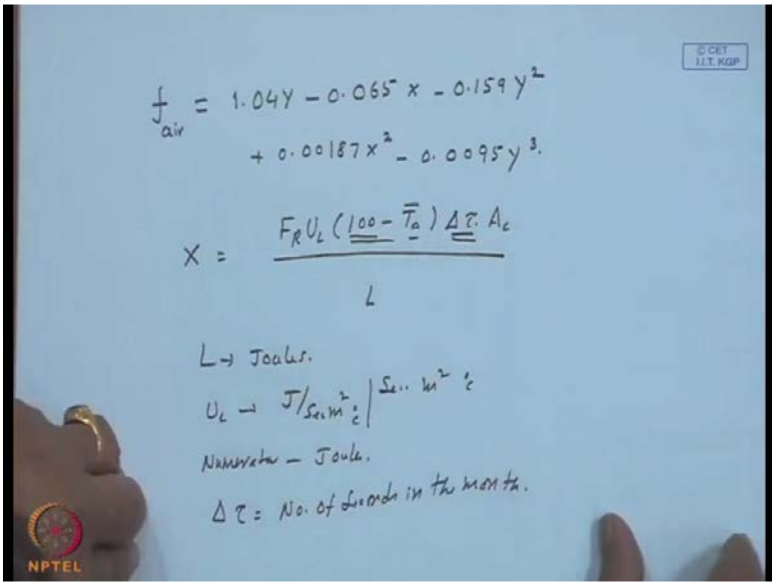

So, the solar load fraction of air based systems so for sake of clarity, I will write a subscript air, 1.04 Y minus point not 65 X minus 0.159 Y squared plus point naught, naught 187 X squared minus 0.0095 Y cube where X is the non-dimensional collector loss F R U L times 100 minus T a bar into delta tau times collector area A C by L.

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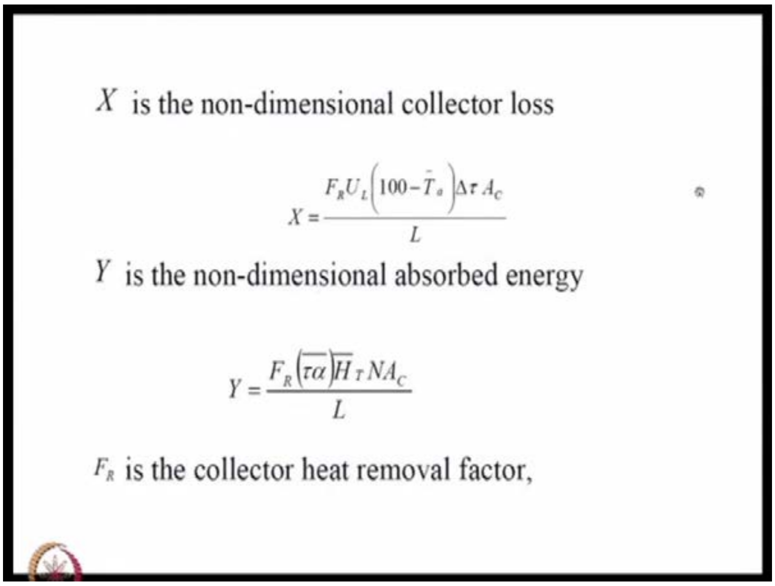

So, this will be a non-dimensional, if L is in joules, U L will be you can say joule per second meter square degree centigrade and delta T will be seconds area will be meter square and delta tau, sorry and this temperature difference is again degree c. So, this, this is U L is this much so numerator is joules and denominator also is in Joules.

Now, what you will find here is the number of seconds in the month is delta tau AC is area. It is not un-expected that the loss factor should be proportional to the overall loss coefficient. Of course, this is non-dimensional factor, the time area and 100 minus TA bar. This 100 has nothing to do with boiling point of water, that it give somehow it gives that impression.

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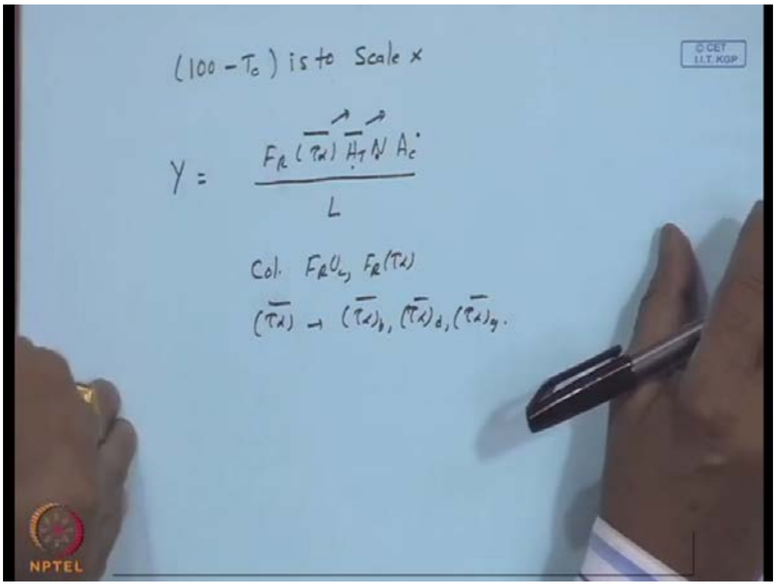

But just 100 minus TA is to scale X, if I put it as 20 minus TA or whatever is the collector operating temperature minus TA then we may get a 2 larger value or 2 smaller value for X. So, it is desirable whenever, you have any imperial correlation in general if the variables are of comparable order of magnitude, you are accuracy will be better. If X is something like 0 to 10 Y is 0 to 3 or 0 to 4 you will have a better correlation. Instead of Y changes from 10 to the power 6 to 10 to the power 9 and X changes from 10 to the power minus 3 to 10 to the power minus 1. The effect of X will be I mean Y will be completely lost because, this scales of those numbers are hugely different from each other.

So, that is the non-dimensional collector loss and I will again make a comment after defining this Y. The non-dimensional absorbed energy F R tau alpha bar into H T bar times N into A C upon L A C is a area N is the number of days in the month H T bar is the monthly average daily radiation on the collector surface multiplied by monthly average transformational sub product of course, multiplied by the collector property or heat removal factor upon the load. Now, you will understand all the processing we have done is get this H T bar at this tau alpha bar and of course, in the previous definition of X U L and F R. That means my collector parameters so F R U L and F R tau alpha and then my tau alpha bar comprising of tau alpha bar beam, tau alpha bar diffuse, tau alpha bar ground. So, all the trouble we have gone through is worth it, it is comes into the picture now in calculating my wife and the geometry is related ultimately through F R.

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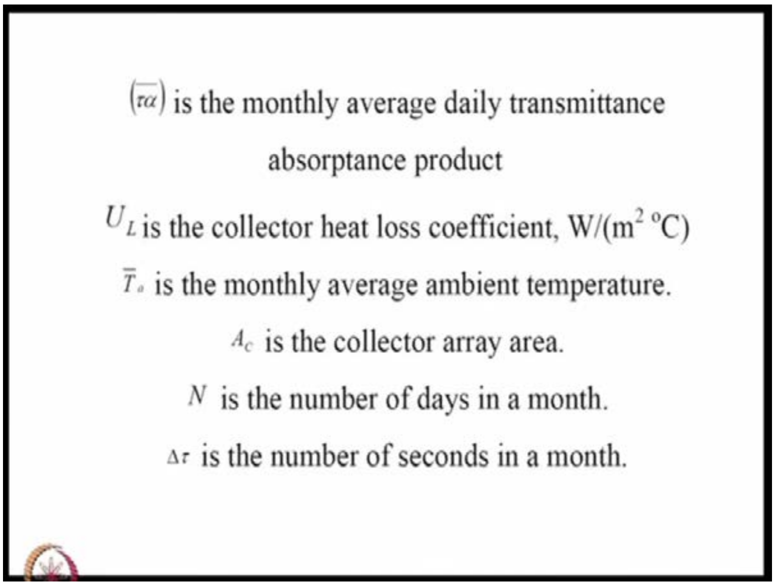

So, these are symbols are explained.

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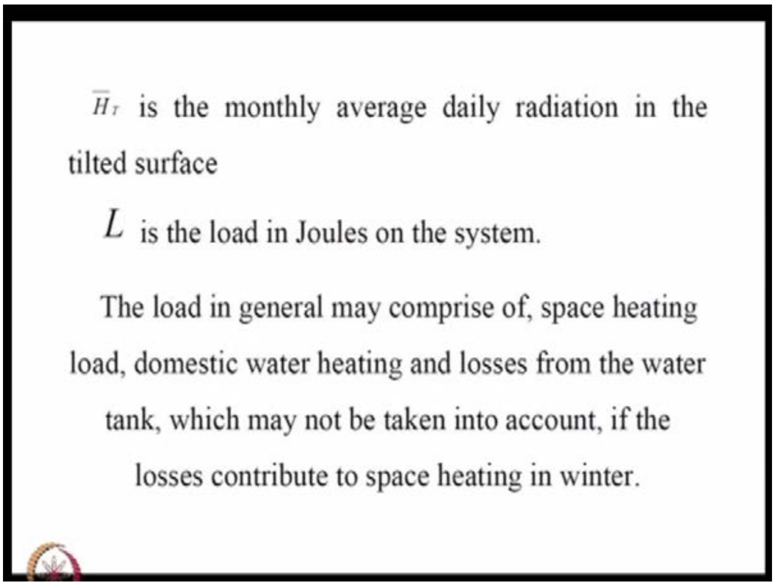

And L is the load on the system so given the collector parameters, I can calculate now the comment, I was trying to make was initially.

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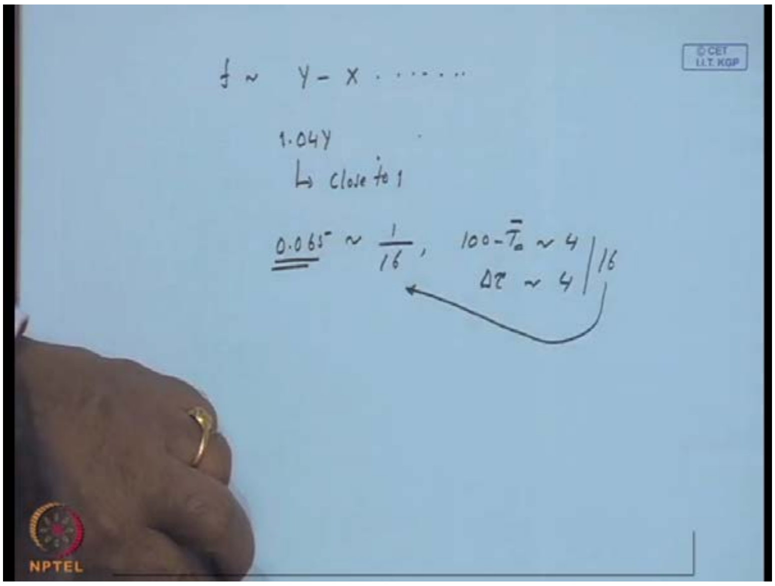

I just said that f should be because, non-dimensional Y minus X. Of course, there are non-linearities X square and Y square because, of the losses etcetera. So, the constant associated with Y is 1.04 Y pretty close to one whereas, this is 0.065 approximately, 1 by 16, which without the benefit of a computer. What I think is 100 minus T A is inflated by a factor 4 and delta tau is inflated by a factor of 4 because, typically if the collector operating period is 6 hours. The losses do not take place from the collector, all the 24 hours tank losses may be there pipe losses may be there, but the collector is shut off.

So, there is a sort of overestimate of the collector in terms of the delta tau being 24 hours and this 100 minus T A may be typically, 3 to 4 times. The actual whatever is the temperature difference responsible for the losses so I have got a factor of 16 that becomes a 1 upon 16, which is fortunately according to my imagination that almost coincides with the 0.065. So, the other things are the non-linearities so at times, why I specifically mentioned is it, is not just the imagination part of it you have a sensible correlation. If you can think of what could be the functional form and what type of a relation a particular independent variable, dependent variable may have with the independent variables.

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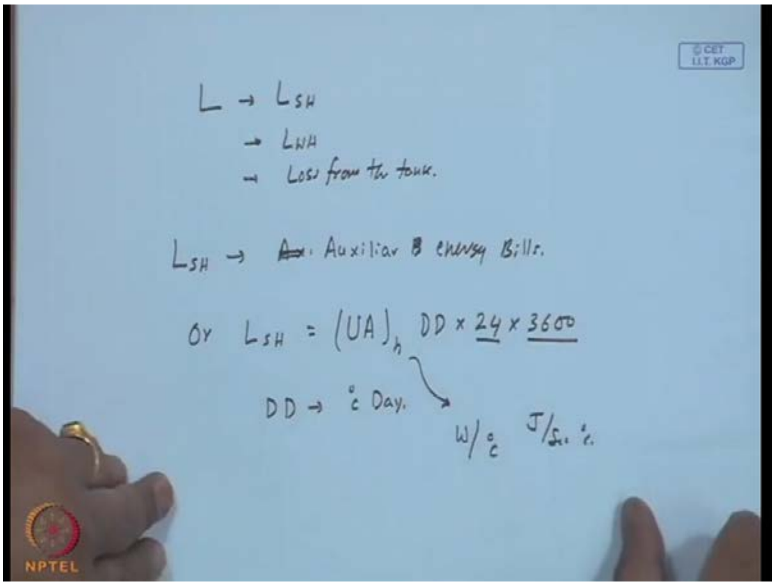

So, load in general may consist of space heating load and water heating load and loss from the tank water, tank there will be a certain loss taking place. So, that is also a part of the load to be made by the system of course, at times this loss may be contributing to heat your room. Then we will not take into account so we will go 1 by 1. How to calculate this X?

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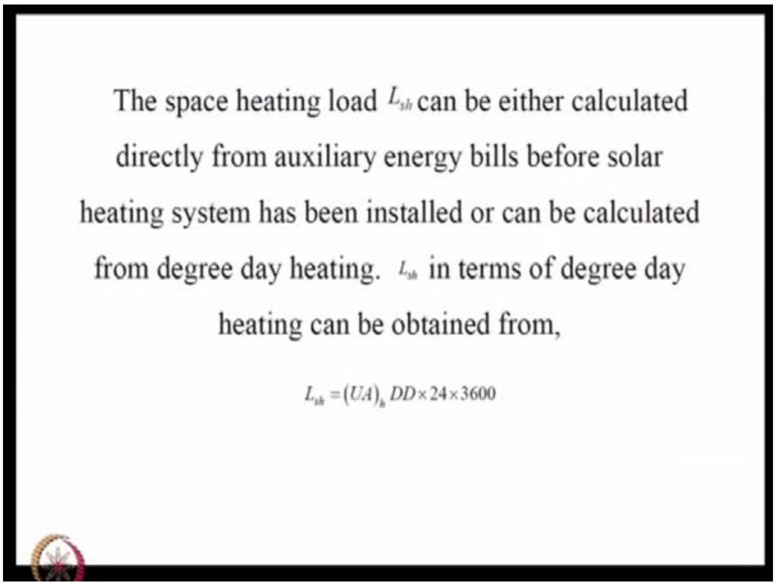

So, L s h the simplest way is from auxiliary bills, if it is an already occupied house and has a specific heating system be it gas heated or electric heated or steam heated. One can find out the utility bill and find out. So, much is the specific heat or you can estimate L s h as building loss coefficient, this is where my building loss coefficient is coming multiplied by DD, DD is degree days not an official designation. So, this is DD is degree c day, I will explain to you this is to make it hours, this is to make it seconds look at this UA h is watts per degree c. So, that is joule per second degree c multiplied by second that makes a Joules per degree c. So, this is the degree c day, day is converted into seconds.

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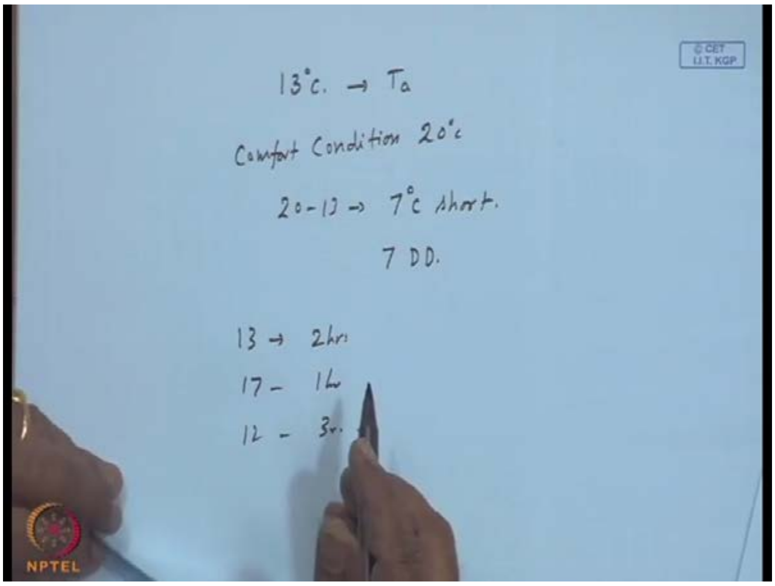

If you have an ambient temperature of 13 degrees, let us say and comfort condition. This is let us say T a, comfort condition is 20 degree c. So, this 13 is 20 minus 13 - 7 degree c short, if this lasts for one day suppose ideally my comfort, comfort condition does not change. It is 20 degree c throughout the day 13 degree c is maintained then this will be having 7 degree days. If the ambient temperature is 13 and the comfort condition is 20, it is deficit by 7 degrees. So, you have a degree days of 7 now of course, this 13 may be varying for 2 hours at 1317 for 1 hour 12 for 3 hours so and so on so forth. So, proportionately you can calculate, how many degree days each one if, it is 2 hours at 13 it will be 2 by 24 into 7; 1 hour for 17 is 3 into 1 by 24 so on and so forth and one can come out with the total number of degree days in the month. That is what we are calculating so degrees c day is for the month. So, you can calculate from the building loss coefficient and the degree day data and what is the space heating load.

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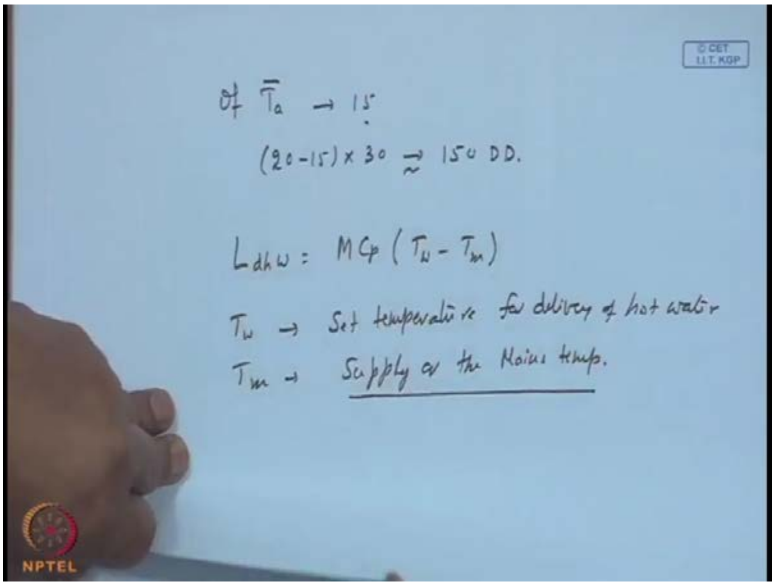

Another thumb rule approximately if T a bar, let us say monthly average daily ambient temperature which you can see from the metallurgical data in books like a money for Indian locations, Duffie and Beckman for US and Canadian locations or the ministry of nonconventional energy sources website. These days, if T a bar is let us say 15 then 20 minus 15 is 5 degrees multiplied by 30, that will become 1 50 DD. Approximately, if my ambient temperature is 15 degrees for the monthly average and if 20 degree is the comfort condition, then 20 minus 15 deficiency is there.

So, 150 degree days will be there of course, the biggest approximation is this 15 may be comprising of 10s, 20s, 27s, 22s consequently, it may not be always 5. But if T a bar is lower than 20 significantly may be 1512, this is a very good calculation, you can check yourself and with the data that is available in the sources. That I mentioned if as long as T a bar is less than 15. You can easily estimate the degree days within plus minus 5 degrees of course, if T a bar is 20, it does not mean; it does not require heating you may need both heating as well as cooling, day time cooling and night time heating.

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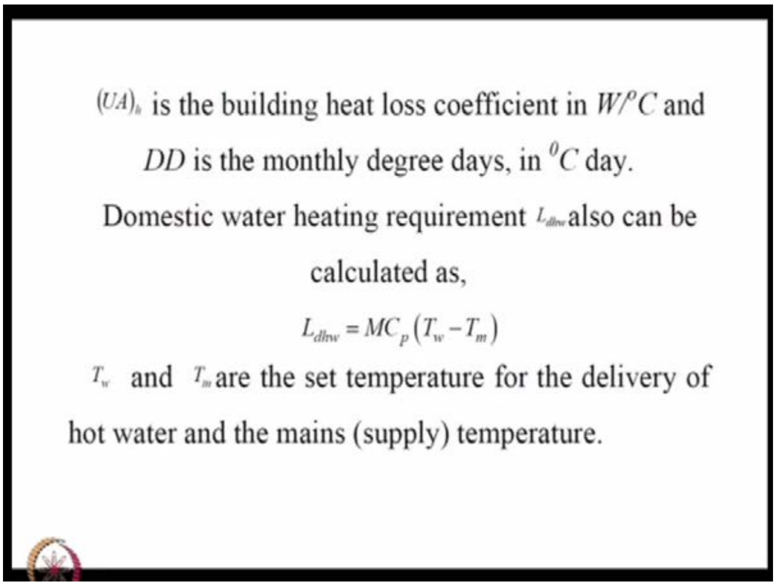

Then the domestic hot water requirement this L d h w mass of the water 500 liters, 200 liters or in kg is multiplied by specific heat multiplied by T w minus T m. This T w or the set temperature for delivery of hot water and the T m is the supply or the mains temperature. Now, we have to keep in mind the fact the best book or rather a excellent text book is by Duffie and Beckman and that is in the US. So, there is a supply or mains temperature unlike, what we have here is usually the ambient temperature only plus or minus few degrees and this certain temperature is something like If you imagine you have a gazer and inside there be a thermostat, it is set for 60 or 70 or 55. Whatever it is many times we may not know it, but it is set for a certain temperature.

So, it will cut off when the water inside the tank is heated, so this in no ways says that my solar energy system which is designed based upon the correlation of the f-chart delivers at 60. What all we are doing is, if I store 500 liters of water with the conventional system to deliver at 60 degree centigrade. When the mains are being at a particular temperature 11 degree c or 15 degree c. Whatever, then this is the quantity of joules, we have to supply so consequently this is the load on the system, but not a guarantee on the quality of the energy delivered nor is expected.

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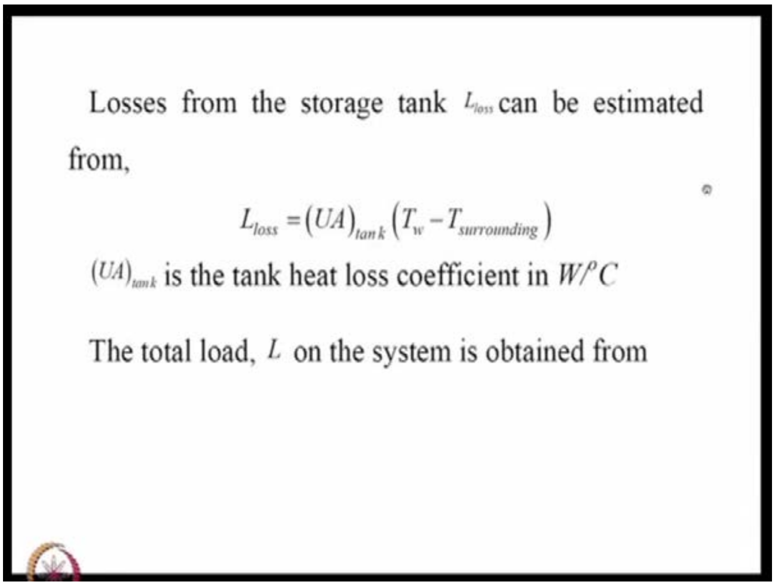

So, then L loss.

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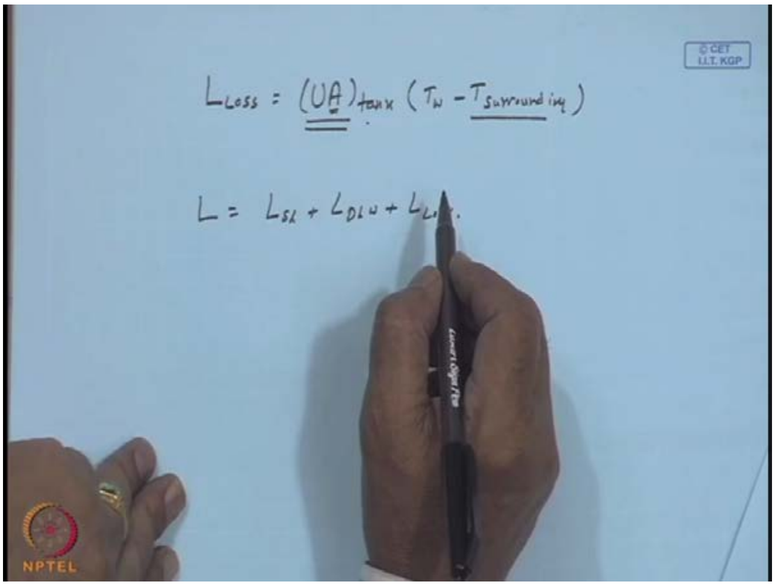

Lastly U A of the tank just like U A of the house, you can easily estimate for the U A of the tank so, this is a set temperature. So, the tank will be basically inside at T w losing heat to a temperature t surrounding T surrounding I have written it instead of the T a, or the whole tank maybe in a closed basement or inside your house. So, it may not be losing heat to the ambient so with this and this U A tank one can estimate based upon the how much of insulation is there. What is the diameter, what is the free conductivity of the heat coefficient conduction resistance and the area of the tank or used from the manufactured specification.

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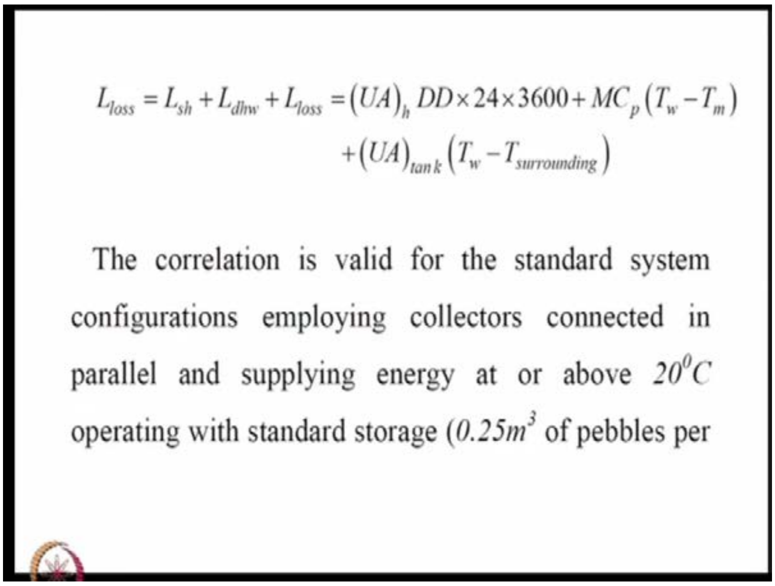

So, this total that should be only not L loss, it should be L equal to L s h plus L d h w plus L loss, where the components are written as UA h into DD into 24 into 3600 plus MC p into T w minus T m and UA tan k into T w minus T surrounding. Now, one will ask most important because the other ranges of the parameters are given.

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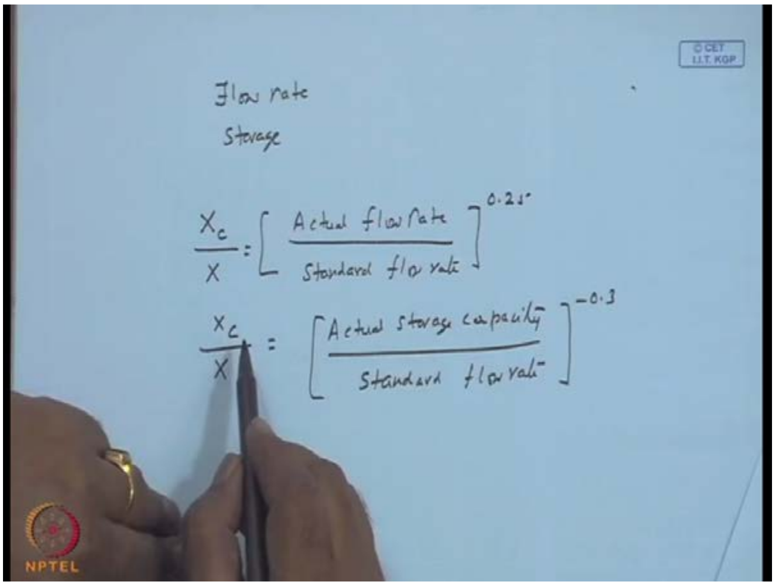

Flow rate and storage these are the two variables flow rate can be changed, if you want to improve the heat transfer characteristics. For example, or instead of 10 liters you may use 15 though, it may cost pressure dump may be more or it may go lower or storage instead of 0.25 meter cube. And if it is a tropical climate for the same energy or area of the collector you may provide 0.3, 0.35 or a larger storage.

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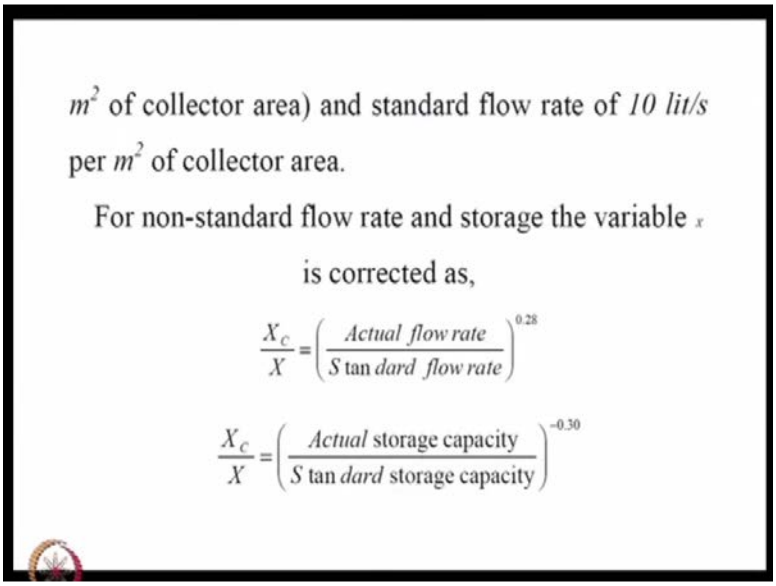

So, instead of another correlation for each flow rate each storage, what they have done is when the flow is non-standard correct the variable as X c by X as actual flow rate by the standard flow rate to the power 0.28, if actual flow rate is let us say 15 and standard flow rate is 10. This is 1.5 report 0.25 is more than 1. So, I will have a X c more than 1, it is little bit counterintuitive. But as I said, it is more to do with stratification this is actual storage capacity upon standard storage capacity. I do not know it almost looks like S n tan and R flow rate.

So, you can see that if actual storage capacity, to the power minus 0.3, if this is more this will be less than 1 making X c lower, if X is lower my f is higher. So, if the storage is more my solar load fraction should be higher, which is worn by this particular relation. So, these are the correlation for the air-based solar heating system, which can be expected to deliver energy at or above 20 degree c for an air based system. It will supply for a domestic hot water or space heating and combine a domestic hot water system including space heating.

So, we will go for the, and the corrections for non-standard flow rate and non-standard storage have been given simply the coordinate X c is the corrected value. If X is the one for the standard storage, this is how you modify now, you might wonder why X is changed and why not Y. So, the answer is these are correlations it is found that they actually correlate with the simulation results better and consequently X is corrected by this particular situation.

Thank you.