Solar Energy Technology

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Lecture - 33
Exercise – 2

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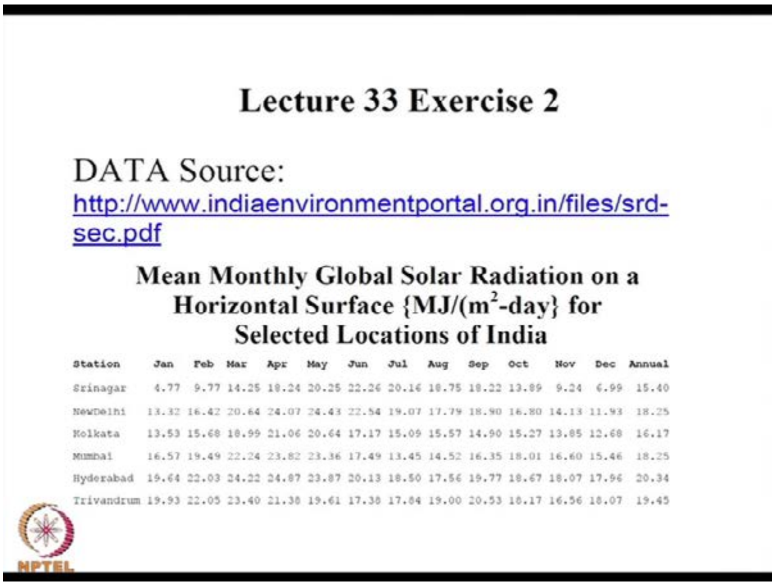

Lecture 33 Exercise 2

DATA Source:
http://www.indiaenvironmentportal.org.in/files/srd-sec.pdf

Mean Monthly Global Solar Radiation on a Horizontal Surface {MJ/(m^2-day} for Selected Locations of India

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Srinagar	4.77	9.77	14.25	18.24	20.25	22.26	20.16	18.75	18.22	13.89	9.24	6.99	15.40
NewDelhi	13.32	16.42	20.64	24.07	24.43	22.54	19.07	17.79	18.90	16.80	14.13	11.93	18.25
Kolkata	13.53	15.68	18.99	21.06	20.64	17.17	15.09	15.57	14.90	15.27	13.85	12.68	16.17
Mumbai	16.57	19.49	22.24	23.82	23.36	17.49	13.45	14.52	16.35	18.01	16.60	15.46	18.25
Hyderabad	19.64	22.03	24.22	24.87	23.87	20.13	18.50	17.56	19.77	18.67	18.07	17.96	20.34
Trivandrum	19.93	22.05	23.40	21.38	19.61	17.38	17.84	19.00	20.53	18.17	16.56	18.07	19.45

We shall continue with the example that we have been discussing last time; meanwhile, I could get useful information, which is a data source for Indian locations - that is a http addresses given over here.

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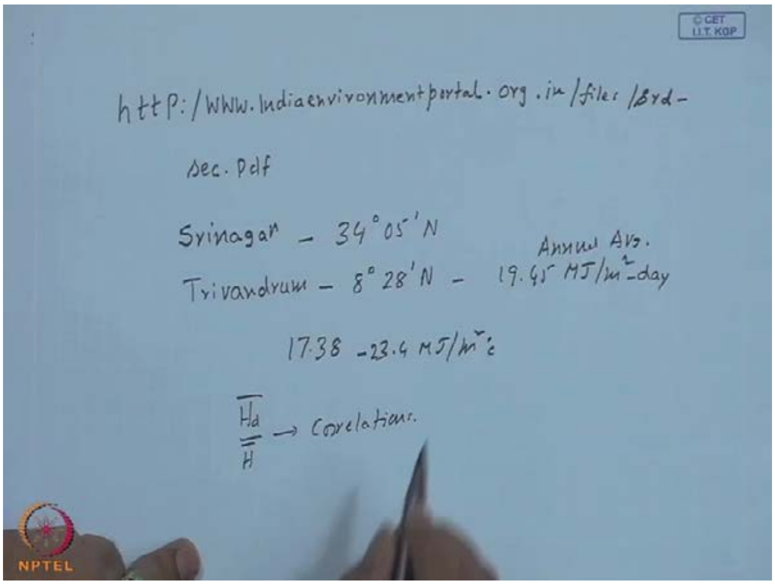

I shall write it down, in case you cannot go to this original document… Hyphen s e c dot p d f. So, this has got one of the examples that you can see clearly on the screen; mean monthly global solar radiation on a horizontal surface in mega joules per meter square a day, for selected locations of India, I have shown here with something to bring in. This numbers you cannot read, but you can always go to the original source, and have a look at the data that is compiled by solar energy center MNRE Indian metallurgical department. So, this has got lots of contents which you can have a can you focus on the screen.

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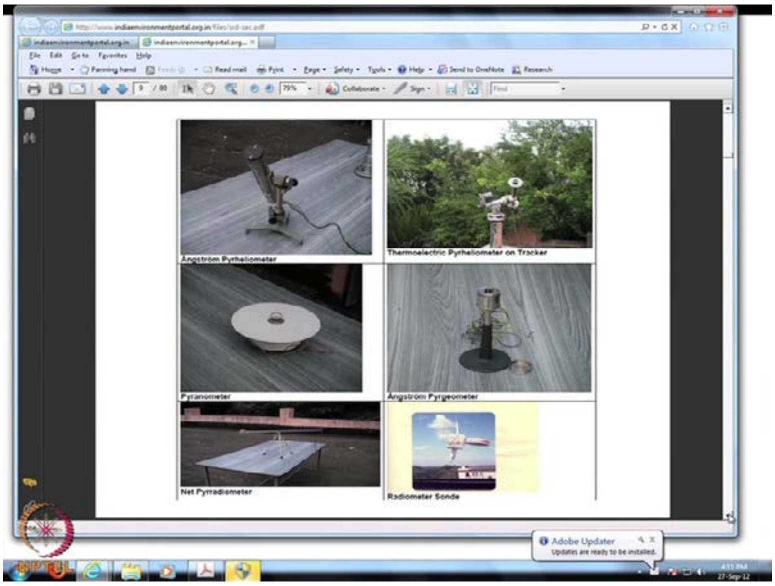

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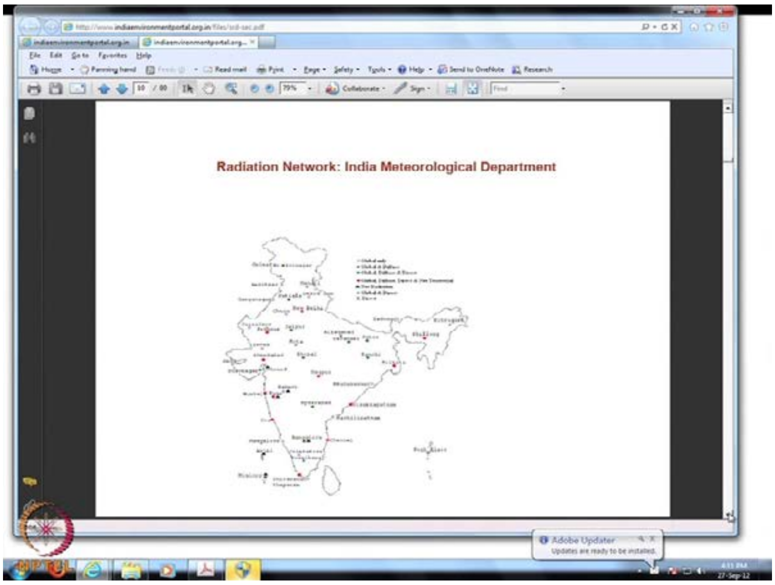

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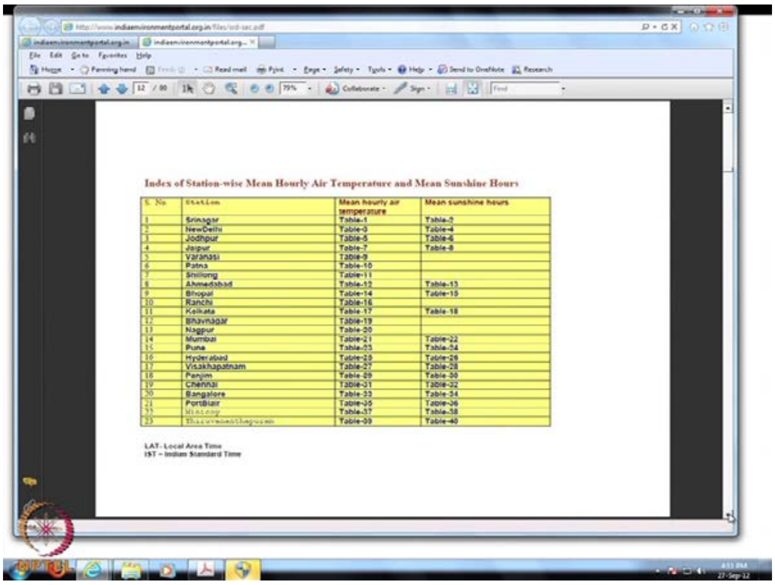

Index of Station-wise Mean Hourly Air Temperature and Mean Sunshine Hours

S. No.	Station	Mean hourly air temperature	Mean sunshine hours
1	Srinagar	Table-1	Table-2
2	NewDelhi	Table-3	Table-4
3	Jodhpur	Table-5	Table-6
4	Jaipur	Table-7	Table-8
5	Varanasi	Table-9	
6	Patna	Table-10	
7	Shillong	Table-11	
8	Ahmedabad	Table-12	Table-13
9	Bhopal	Table-14	Table-15
10	Ranchi	Table-16	
11	Kolkata	Table-17	Table-18
12	Bhavnagar	Table-19	
13	Nagpur	Table-20	
14	Mumbai	Table-21	Table-22
15	Pune	Table-23	Table-24
16	Hyderabad	Table-25	Table-26
17	Visakhapatnam	Table-27	Table-28
18	Panjim	Table-29	Table-30
19	Chennai	Table-31	Table-32
20	Bangalore	Table-33	Table-34
21	PortBlair	Table-35	Table-36
22	Minicoy	Table-37	Table-38
23	Thiruvananthapuram	Table-39	Table-40

LAT- Local Area Time
IST – Indian Standard Time

The sun solar radiation spectrum, and the various measuring instruments, and the locations where the measurements have been made and the terminology and this is about twenty three locations that we have got, which basically has got mean hourly ambient temperature and for each month, then the monthly global solar radiation and the monthly diffuse radiation, and given I have given here selected from Srinagar which is more or less a high latitude location in India, upto Trivandrum which is in down south Kerala which is almost low latitude, which I have shown the latitudes here.

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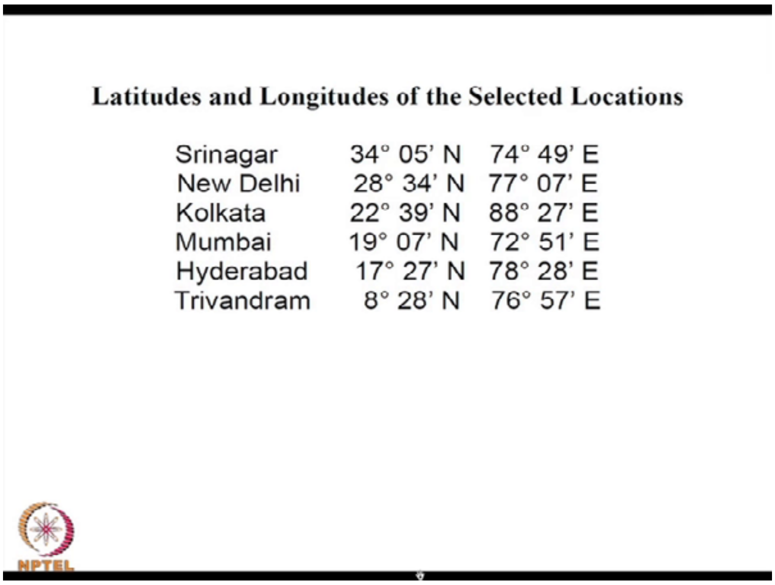

Srinagar has a latitude of 34 degrees 05 minutes north and of course, the corresponding longitudes also are given over here. And whereas, Trivandrum has 8 degrees 28 minutes n. One of the ideas is not just I have taken or south, north, east, west and something middle, so that you will have a feel for the variation in the solar radiation. If you look at Trivandrum, this is the diffused radiation, this is the global radiation, the average is 19.45 mega joules per meter square day which is annual average, and it varies only between 17.38 which is a minimum I could see and goes up to 23.4 mega joules per meter square a day; that is if you statistically say that the standard deviation is very low, and as you are going very near the equator the variation between January to December or their summer June to December is very small. Like that you can make an interesting observation for the remaining locations, and that is my idea of showing it here.

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Mean Monthly diffuse Solar Radiation on a Horizontal Surface {MJ/(m^2-day} for Selected Locations of India

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Srinagar	3.79	5.51	6.20	5.95	6.14	6.35	6.54	7.22	4.88	3.49	4.38	4.10	5.40
NewDelhi	5.21	6.22	7.56	8.83	10.68	11.66	11.83	10.27	8.27	6.37	4.92	4.87	7.82
Kolkata	5.92	6.77	7.72	9.27	10.67	10.67	10.28	9.76	8.68	7.37	5.94	5.37	8.19
Mumbai	6.09	6.79	7.17	8.25	9.82	10.85	10.45	11.41	10.61	8.73	6.63	6.16	8.52
Hyderabad	4.67	4.85	6.22	6.42	7.03	8.64	10.04	9.32	8.20	6.69	5.17	4.32	6.76
Trivandrum	6.75	7.01	7.84	9.22	9.69	10.16	10.69	10.70	9.38	8.73	8.10	6.90	8.72

The corresponding diffuse solar radiation on horizontal surface is given; one of the idea says giving this data particularly to you, is that you might verify the h d bar by h bar corelations for the Indian locations, because this co relations were developed with mostly North American data. So, their applicability has been tested, but now you have got a lot more data for the Indian locations. So, you might as well re establish or validate those corelations. So, these numbers may be useful to us when we solve some examples for the Indian locations.

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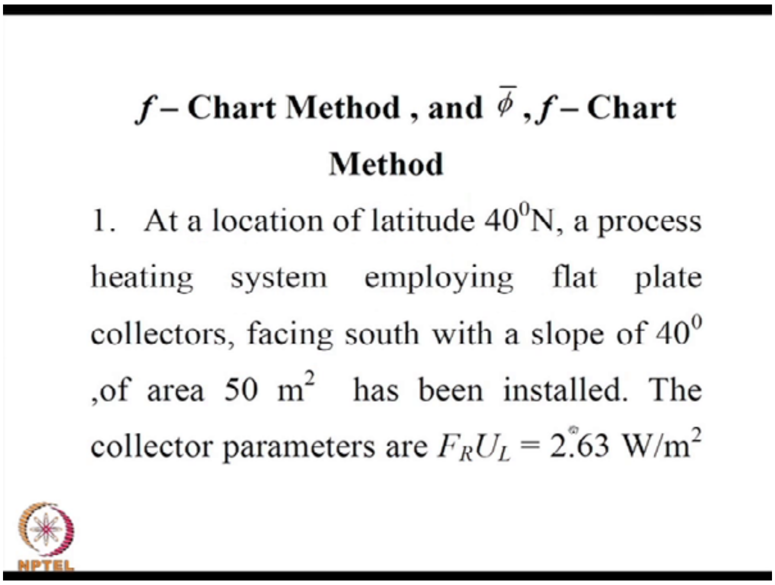

This was the example based upon f chart method and a phi bar f chart method, we have been discussing. It is at a location of latitude 40 degrees n, a process heating system employing flat plate collectors facing south with a slope of 40 degrees, area 50 meter square has been installed.

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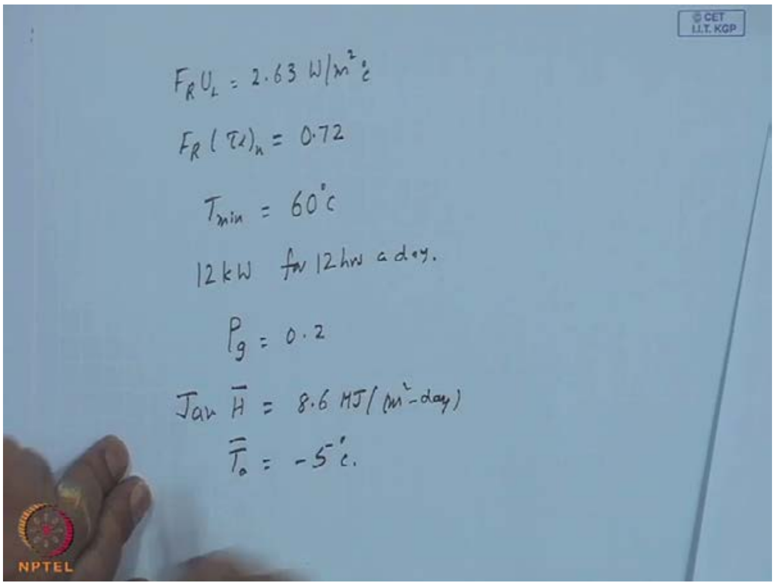

The collector parameters are F R U L is 2.63 watts per meter square degree c, and F R tau alpha for normal; this we have done, but this is for the sake of your continuity 0.72; and it is suppose to T minimum is 60 degree c and 12 kilo watt for 12 hours a day. Of course, the other data ground reflectance is 0.2 for the month of January H bar is 8.6 mega joules per meter square a day, and ambient temperature is minus 5 degree c. So, this is the given data which we wanted to calculate.

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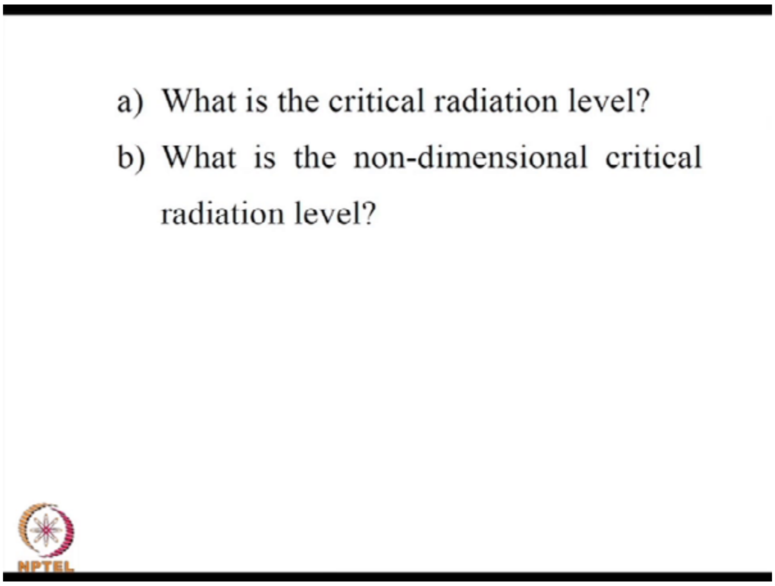

What is the critical radiation level?

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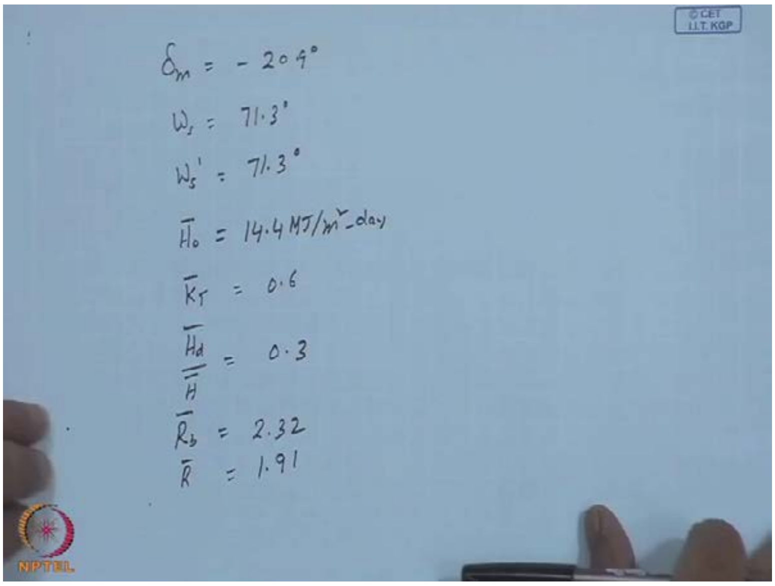

This after a lot of preliminary calculations we have calculated for, for example, mean declination for the month of January is minus 20.9 degrees, at the end the sunset hour angle is 71.3degrees, in this case omega s dash also will be 71.3 degrees, and we got the extra terrestrial horizontal monthly average daily radiation to be 14.4 mega joules per meter square day. And then the clearness index K t bar is 0.6 - that is 8.6 upon 14.4; and the diffuse fraction H d bar by H bar we got as 0.3 using co relation; then we got R b bar 2.32, I remember and R bar 1.91 right, all these calculations we have done in detail.

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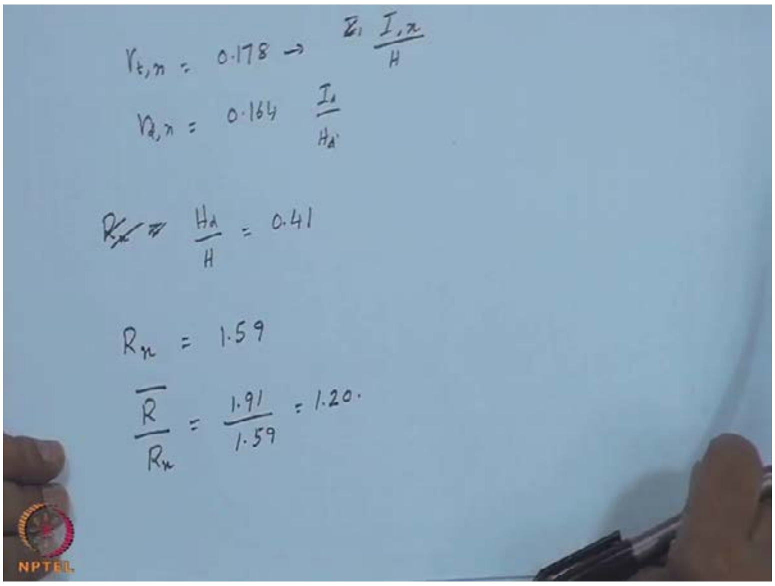

And from this we proceeded to calculate r t, n, which is 0.178, once again this is a co relation due to (( )), and r d n is 0.164 this is a relation due to Liu and Jordan; and remember that this is I t sorry I at the noon time by H for the day or the monthly average day; this is I d by H d, in other words if you know H d or H we can calculate I r I d. Then in calculating R n we need H d by H that turned out to be 0.41, and similarly ultimately we got R n equal to 1.59. So, R bar upon R n is 1.91 by 1.59, which is about 1.20 R bar by R n is equal to 1.91 by 1.59.

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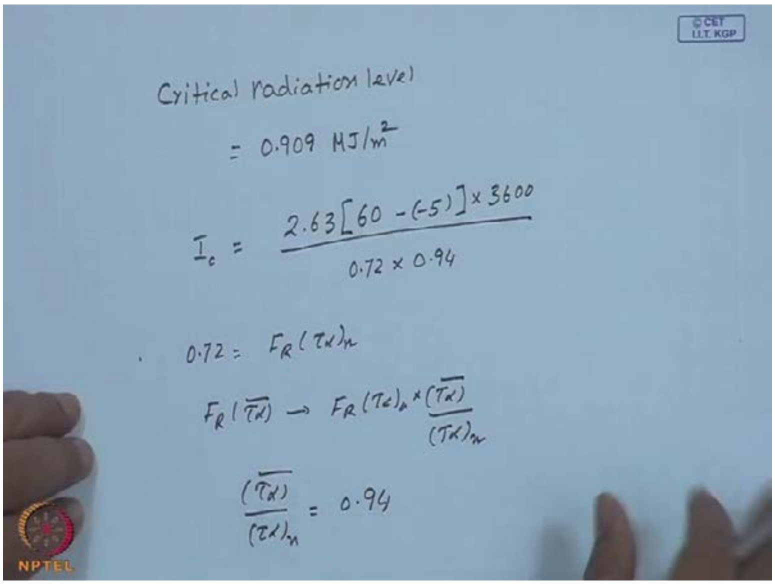

So, subsequently we estimated the critical radiation level, which turned out to be 0.909 mega joules per meter square; this is for a hour. This is where I wanted to continue from here. So, this I c equal to 2.63 times 60 minus minus 5 times 3600 upon 0.72 into 0.94 this 0.72 is F r tau alpha normal, but my I c formula I need is F r tau alpha bar, which is F r tau alpha n multiplied by tau alpha bar by tau alpha n. So, this is equal this tau alpha bar by tau alpha normal is equal to 0.94.

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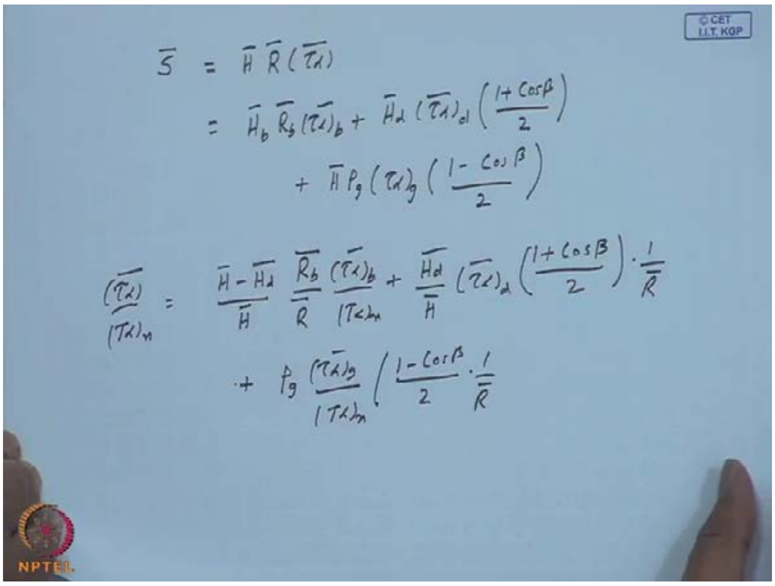

I shall show the calculations for this, so that we will have an exercise in calculating tau alpha bar also. So, if you look at it this way the absorbed variation S bar… Can you come here?

(( )) fine fine (( )). So, the absorbed radiation S bar is given by H bar R bar times tau alpha bar. So, this should be equal to the beam component H b bar R b bar tau alpha bar b plus the diffused component… d times 1 plus cos beta by 2 plus H bar into ground reflectivity into tau alpha for the ground reflected radiation times 1 minus cost beta by 2.

So, what we want is, tau alpha bar by tau alpha n. So, I can divide throughout with this that should be equal to if I write H b bar as H bar minus H d bar by H bar times R b bar upon R bar times tau alpha bar b by tau alpha n plus H d bar upon H bar times tau alpha bar d 1 plus cos beta by 2 plus rho g tau alpha bar g by tau alpha n into 1 minus cos beta by 2 times 1 upon r bar, here also 1 upon r bar. This we have done, but then I wanted to say that the number 0.94 simply written you should not wonder, how you got it how we got it.

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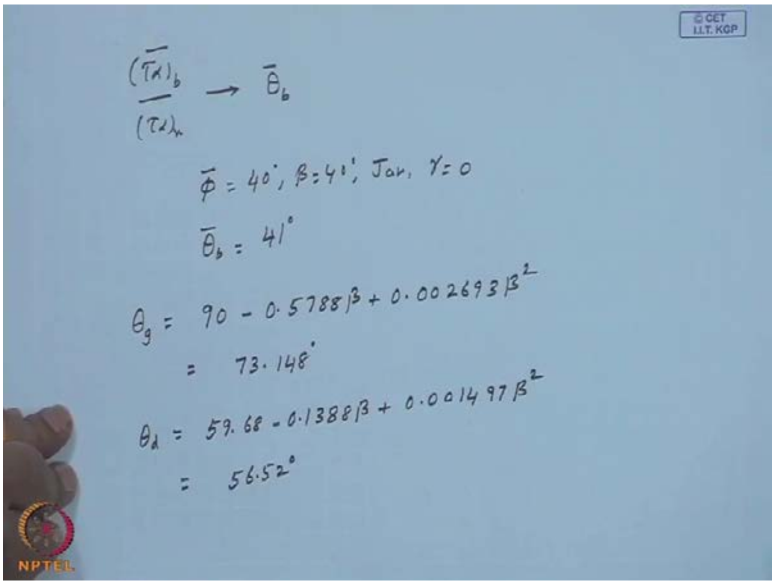

So, this is and how do we calculate tau alpha bar b upon tau alpha n is the effective transmittance of product for the direct variation for which we need theta B bar that is the effective angle of incidence for the direct radiation, for which we have already demonstrated that there are charts. So, from the charts I have picked up for phi is equal to 40 degrees beta is equal to 40 degrees month of January, and gamma is equal to 0, theta

B bar is equal to 41 degrees, this is approximate, because I added from the charts. And the effective angle of incidence for the ground reflected radiation theta g is from the brand mule and bakeman co relation 90 minus 0.5788, all these relations are there in your, in your lectures. So, you should not be looking surprised, where from these things have come. So, this will turn out to be 73.148.

Now you see we got a theta g greater than 60 degrees calling for some relation for theta to be valid other than the ashtre relation, which is valid for less than 60 degrees. Similarly theta d for the diffused radiation is 59.68 minus 0.1388 beta plus 0.001497 beta square this will turn out to be 56.52 degrees. So, this is within that asthre limit of 60 degrees.

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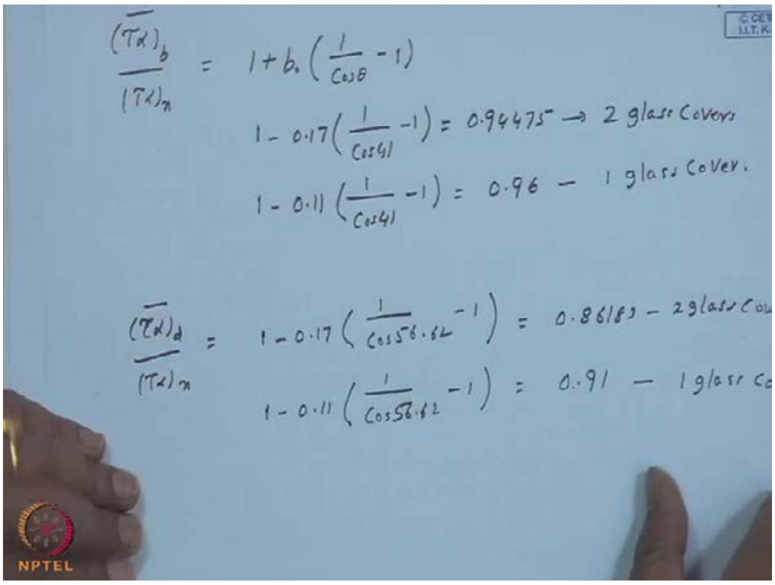

So, what we get now is each one of them, so tau alpha bar b by tau alpha n, which will turn out to be in the relation 1 plus b 0 into 1 by cos theta minus 1. So, I made the calculations, the data is not given whether it is a one glass cover or a two glass cover - collector, we will see what difference also it makes. If it is two glass covers, 1 minus 0.17 by 1 by cos 41 minus 1 which is 0.9445 for two glass covers. And if it is a single glass cover, I use the constant incidence angle modifier co efficient b zero as 0.11 minus upon one upon cos 41 minus 1 this turn out to be 0.96 this is for one glass cover. If you recall the tau alpha variation with theta, one glass cover will be a cover up above the two glass covers curve. Then similarly tau alpha bar diffuse by tau alpha normal also in the less than 60 degrees zone. So, I will have 1 minus 0.17 into one upon cos 56.62 minus 1 which is 0.86183 for two glass covers, and this will be 1 minus 0.11 into 1 upon cos 56.62 minus 1 which is about 0.91 again for one glass cover.

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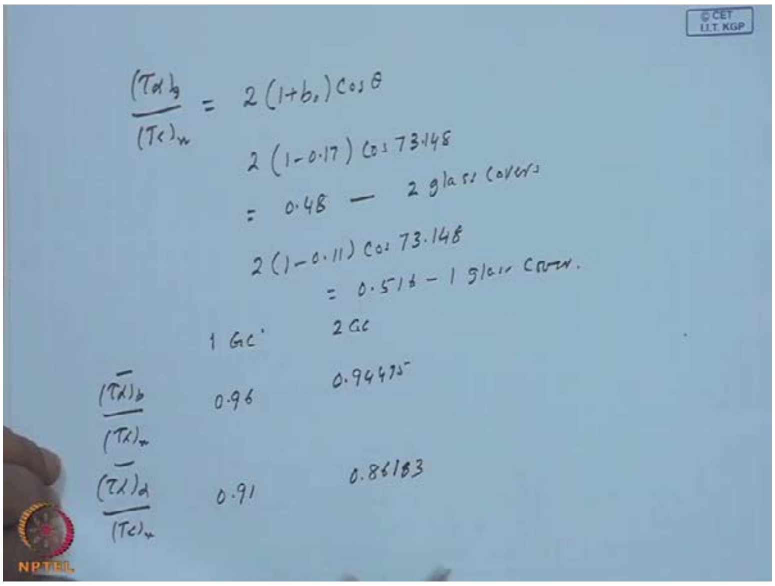

So, for the ground reflected portion, so tau alpha g tau alpha n, I will use the relation proposed at IIT Kharagpur two times 1 plus b 0 into cos theta; this is nothing but at theta is equal to pi by 2, this will be 0, and at theta is equal to 60, it coincides with the previous relationship. So, if you do this and you have point this is 2 into 1 minus 0.17 into cos 73.148. So, much of accuracy is not needed, because there are many approximations we have been doing, this comes out to be 0.48; and if it is that is for two glass covers; and if it is one glass cover you have got 2 into 1 minus 0.11 into cos 73.148 which is0.516 for one glass cover. So, just lets write it down tau alpha bar b upon tau alpha n this is one glass cover, this is two glass covers, which will be 0.96 and 0.9445 tau alpha bar d by tau alpha n for 1 glass cover 0.91 and for two glass covers 0.86183, I think.

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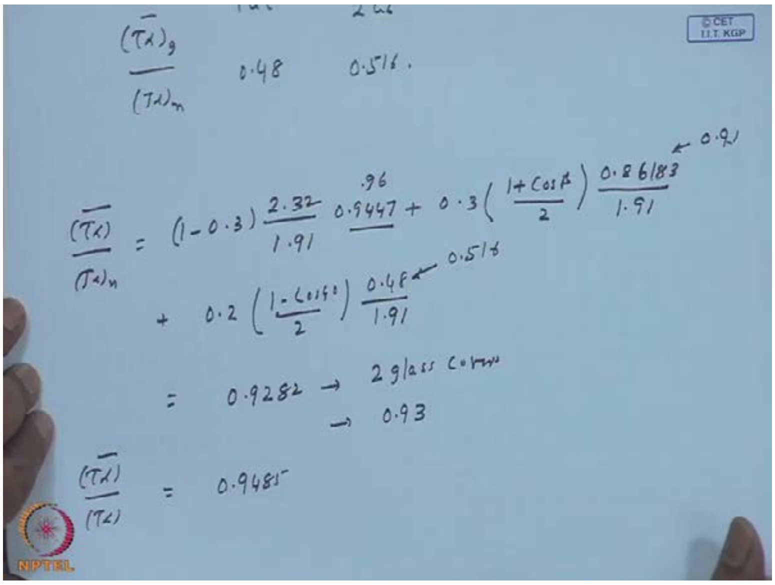

And the last one of course, is tau alpha next one - tau alpha bar g by tau alpha n for one glass cover it is 0.48, for two glass covers it is 0.516. So, if I plug it in the relation that we have written tau alpha bar by tau alpha n is equal to 1 minus H d bar by H bar into R b by R bar R b bar by R bar 1.91 times 0.94475 for do two glass covers plus 0.3 that is H d bar by H bar into 1 plus cos beta by 2 times 0.86183 by R bar 1.91. The third component will be rho g times 1 minus cos 40 by 2 into tau alpha bar ground reflect is 0.48 by 1.91. If you do this, you will get 0.9282. And if you replace this numbers, this is for two glass covers. So, this is about 0.93, which is given as 0.94, but small difference may be due to the theta b bar. But if I do with one glass cover tau alpha bar by tau alpha n is 0.9485; what I have done is, I have replaced this 9447 with 96; and this when with 0.91 and this one with 0.516. So, it will be enhanced soon. The truth may be between 95 and 93, the average is 0.

So, since we do not have that data, but remember, we now got the detail of calculating the transmittance of (( )) product or the absorbed radiation for a day. So, as I was mentioning or emphasizing this 1 plus be 0 into 1 by cos theta minus 1, the incidence angle modifier co efficient relation for tau alpha by alpha n in general, depending upon the theta that you use for the direct radiation or the diffused radiation or the ground reflect radiation, it will give you the appropriate tau alpha by tau alpha normal.

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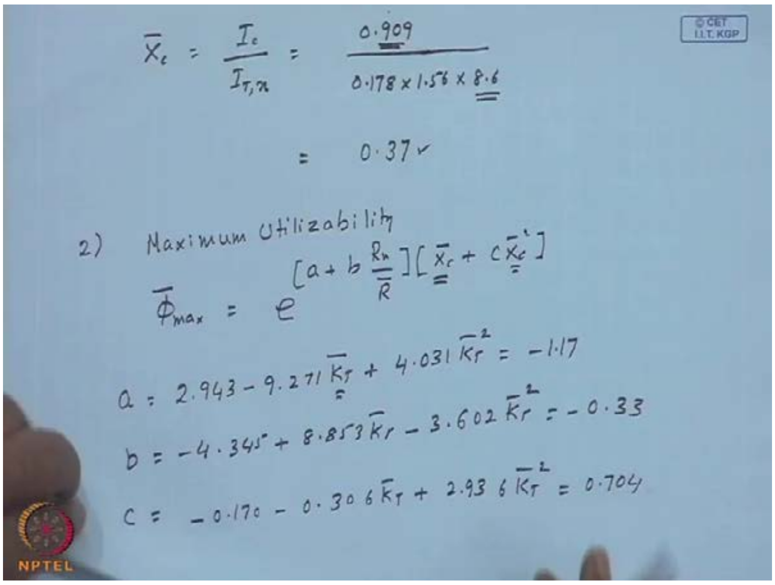

So, we got this now the other thing was what is the non dimensional critical level? That is x c bar is I c by your I t noon equal to which we have already calculated as 0.909 by R t n 0.178 times r n into 8.6. So, this is also in mega joules, and now this is also in mega joules, so there is no problem this non-dimensional critical level will be 0.37. We got the non dimensional critical level, we got the critical level. Then second problem I am separating it out, what is the maximum utilizability? That is we want phi bar max; that is from cleans correlation exponential to the power a plus b R n by R bar times x c bar plus C x c bar square and the constants a 2.943 minus 9.271 k t bar plus 4.031 k t bar square which will come out to be minus 1.17. b will be 4.345 plus 8.853 k t bar minus 3.602 k t bar squared equal to minus 0.33.

Of course, it is time taking and but yet I am preferring to write this relations as many times as possible, because when you solve in the examination or when you want to solve the problems, the relations will be at different places in the text book or if you compile all of them, there are certain differences like I d by I H d by H H d bar by H bar H 0 H 0 bar. So, there are minor differences, but then a repetition of these things may give you an idea that if you are calculating the monthly average delay utilizability, the constants a b c are there, which are different from the constants a and b in the correlation.

And you should also have some sort of an idea that these things are related and correlated to clearness index for some reason, whereas a and b in co relation for r t are just geometric factors. So, if you remember the little bit of physical basis behind these correlations, you will not pick up the wrong relation. So, this is 306, I will have a little if I do not continuously talk this is 0.704.

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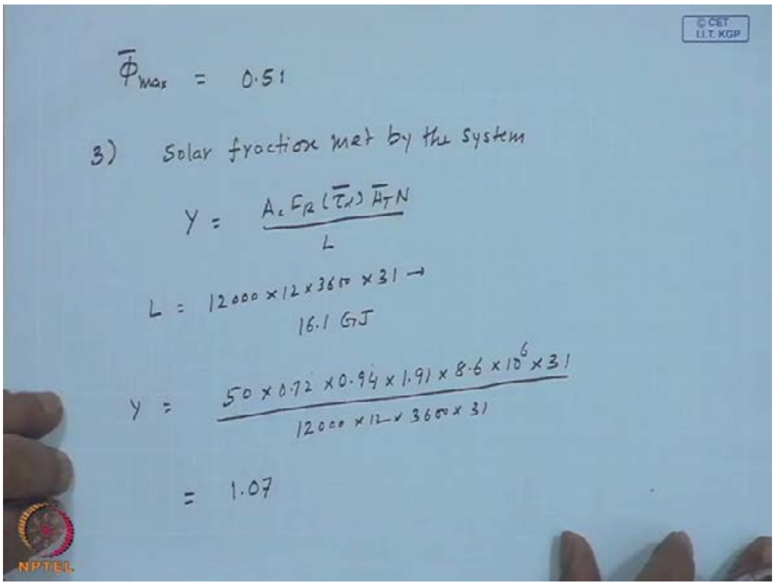

So, phi bar max we got it of course, you can plug in these numbers as 0.51. So, once again first thing is all preliminary R R bar R n H 0 bar K t bar H d bar by H bar I c and I t noon, then from that, the critical radiation level, we have calculated, then the non dimensional critical level, then the maximum utilizability corresponding to t minimum, based on which we have calculated I c. So, that is the sequence. Third part solar load fraction met by the system. So, we need the variables y, which is A c F r tau alpha bar H t bar and number of days in the month by the load. The load in this case will be 12 kilo watts; that means, 12000 watts for 12 hours multiplied by seconds multiplied by 31 actually this comes out to be 16.1 giga joules, if you divide this by 10 to the power 9, you will have 16.1giga joules. So, y will be area is 50, F r tau alpha normal is 0.72 multiplied by tau alpha bar by tau alpha normal 0.94, just now we have calculated times R bar 1.91 times 8.6 into 10 to the power 6 joules multiplied by 31 by this chunk 12000 into 2 into 3600 into 31, which will come to 1.07. Remember y is of the order of 1 2 3, whereas x dash will be little larger.

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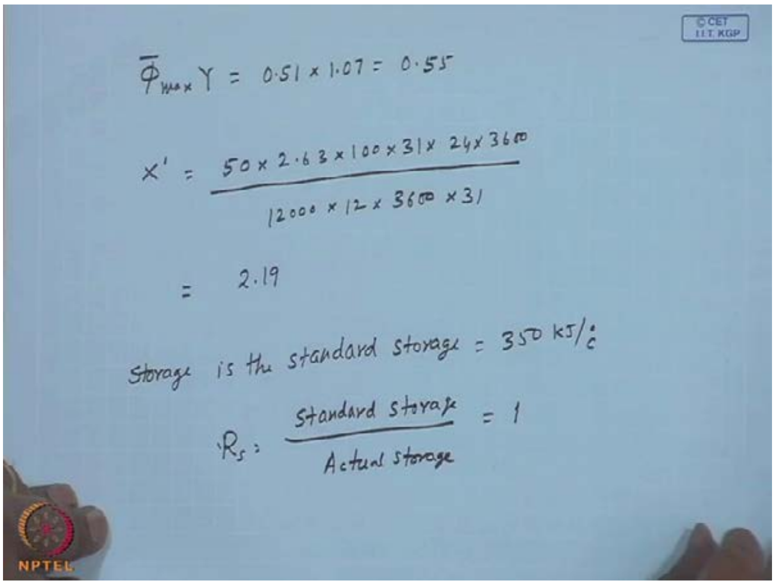

So phi bar max y, which in a way represents the maximum possible solar load fraction that the system can meet will be 0.51 times 1.0 equal to 0.55; in other words if anybody calculates and comes out with a number larger than this obviously, there is a calculation mistake. And the second variable x dashed is area multiplied by F r U l times just a scaling factor 100 multiplied by the number of days or number seconds in the month by the chunk 12000 12 3600 times 31. Please remember when the load is given in joules or mega joules make the consistent units, if it is kilo watts for certain time, you have to convert it to joules; that is power is drawn over a period of time, which makes it the energy; this will come out to be 2.19. Storage is the standard storage which is 350 kilo joules per degrees; this directly does not come in the calculation except in the R s which is the ratio of standard storage; this is a actual storage, and in this case, it is equal to unity.

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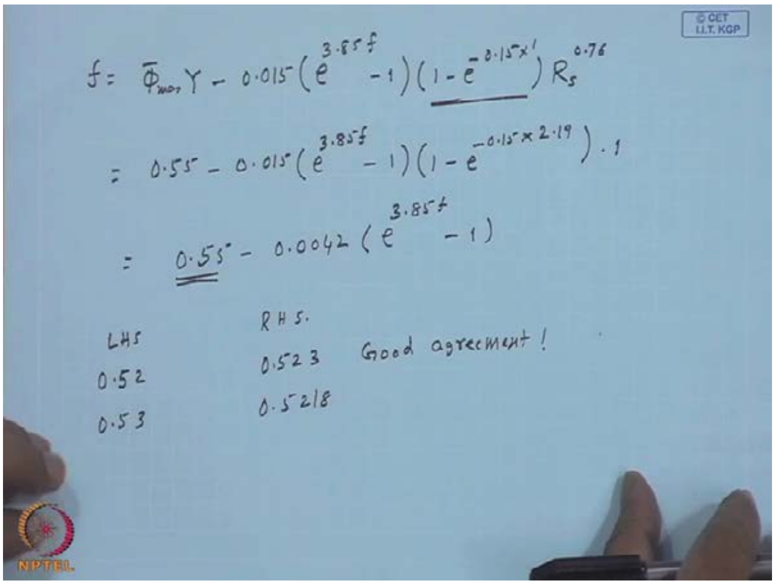

So, now, solar load fraction f by the phi bar f chart correlation is phi bar max y minus 0.015 times e to the power 3.85 f minus 1 times 1 minus e to the power minus 0.15 x dash times R s to the power 0.76. So, this I will try to put all the number that we know, so that it will be easy to iterate later on, because this is an implicit relation 0.55 minus 0.015 times this is not known, because f is not known, 3.85 f remains as these times 1 minus e to the power minus 0.15 into x dashed, which is 2.19 into 1. So, this is 0.55 minus 0.0042 e to the power 3.85 f minus 1.

So, what I have done is, I have set myself up a table calculate LHS and then the RHS. So, I know phi bar max y is about the maximum solar load fraction, if you forget all these losses part; this is basically a loss and this implicit relation indirectly expresses f again in terms of f. So, this f I know should be less than 0.55 I S u need to be 0.52 RHS will come out to be 0.523 oh good good agreement. I tried with 0.53 I got 0.5218. So, it may be 52 or 53. And if you want to see the efficacy, you may start with 0.4, then this will be too large, then you have to bring it down. So, it is not as difficult as it looks like, when you have this long equation, it is only just if you have the calculator particularly, if you have a programmable calculator, even if you have no idea, except that it will be nice if you have the idea that f will be less than this phi bar max y, and particularly f should be less than 1, then the iteration is not a difficult thing, it does not take more than five minutes.

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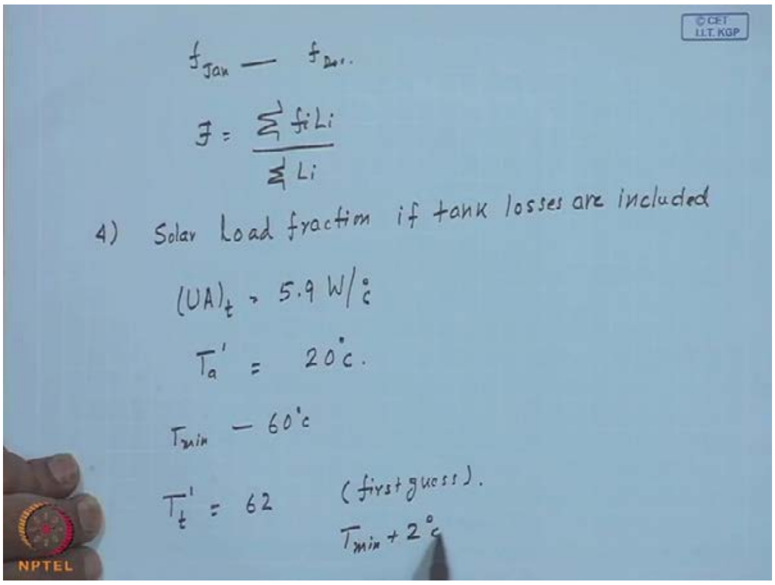

Now, this is a the solar load fraction we have calculated, as per the specifications of the system meets 12 kilo watts 12 hours a day for the month, and the collector parameters are given for one month January. Then you can calculate that f January to f December and then capital F will be sigma f i L i upon sigma L I; I do not have the number I will let you know tomorrow if you want, but the whole thing is repetitive; and it is certainly not very easy for hand calculation for all the 12 months. So, a small program can be written for this and you can make 12 calculations with the power of the computers available now, practically quite fast. Four solar load fraction will try to calculate if tank losses are included right and given the area overall loss co efficient product of the tank is 5.9 watts for degree c, and environment or the surrounding temperature we would call T a dashed is at 20 degrees c. So, T minimum we know is 60 degree c. So, I will assume as a first years for the tank temperature to be 62, so first guess. So, roughly that is t minimum plus 2 degrees.

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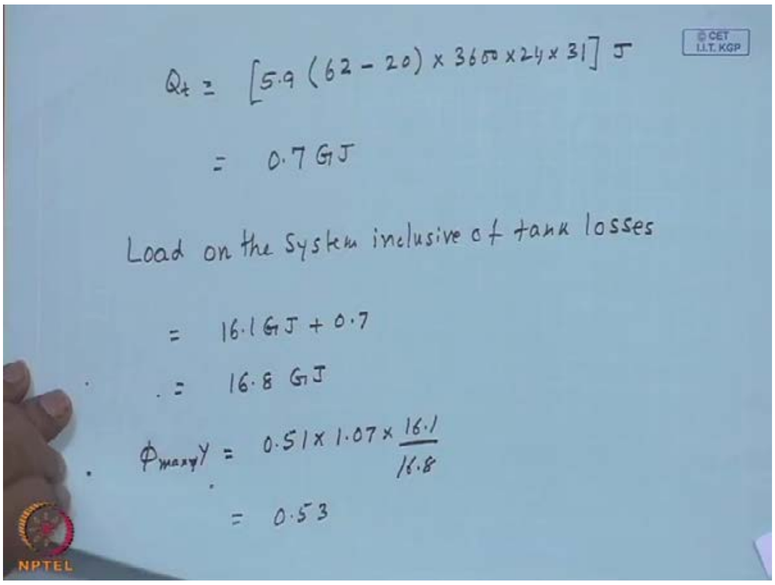

So, with this assumed temperature of the tank losses from the tank Q t will be equal to 5.9 that is u a product times 62 minus 20 times 3600 joules 24 times 31 number of days, so many joules, this comes to 0.7 giga joules. So, it is not too small. So, now, the system is supposed to meet the load inclusive of the tank loss. So, load on the system inclusive of tank losses, which will be 16.1 giga joules plus 0.7 that comes to 16.8 giga joules. Now, my phi bar max y is proportional to this original 5.1 times original y 1.07 into 16.1 by 16.8 which is 0.53 phi bar max y in naught subscript.

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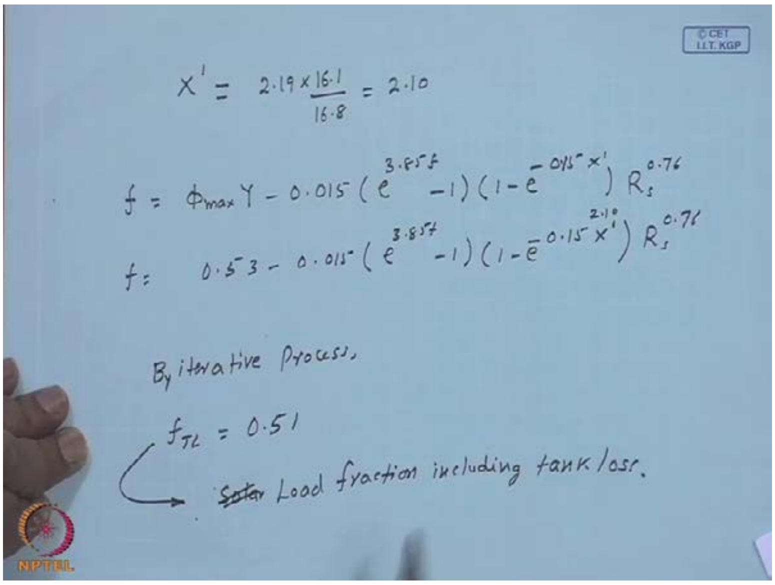

Similarly x dashed should be enhanced equal to 2.19 into 16.1 by 16.8 this is equal to 2.10. So, again f is phi bar max y minus 0.015 times e to the power 3.85 f minus 1 times 1 minus e to the power minus 1 5 x dashed into R s to the power 0.76. So, you write it f is now 0.53 minus 0.015 e to the power 3.85 f minus 1 into 1 minus e to the power minus 1.15 sorry it should be minus 0.15 times x dashed is 2.10 times R s to the power 0.76. So, I set up myself the same table, now I will come out by iterative process f t l equal to 0.51. Now, you remember this is the solar load fraction, where there I will just call it the load fraction including tank loss; that is our notation.

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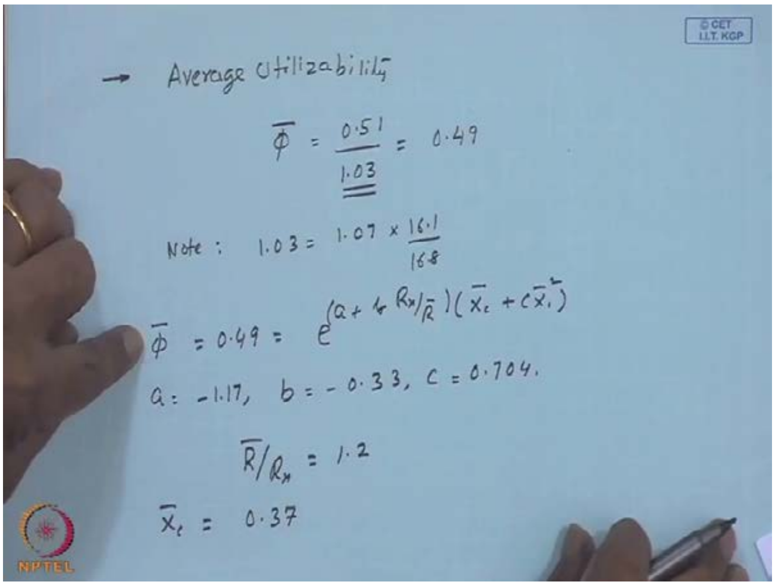

So, this we said there is an iterative process to set up the iterative process average utilizability not the maximum, because this is sort of a overall load fraction met by the solar energy system, which does not distinguish between the load on the system as needed by the consumer as well as the load, because of the additional tank losses to be met by the system. So, utilizability corresponding to this average utilizability, which we would just call it phi bar is that point phi 1 by 1.03 of T l by y; that is right; y is 1.03. So, this will be equal to 0.49. So, again I just wanted to make sure note how we got this number 1.03. 1.03 is the original 1.07 into 16.1 by 16.8 original y multiplied by enhancement or depreciation factor, because of the tank loss.

Now this phi bar will turn out to be again we have got the you use a same constants equal to minus 1.17 and this is 0.49 already known to us equal to e to the power a plus b r n by r bar, just be cautious, because everywhere else it is R bar by R n written; I do not know in the text books and including I picked up same habit, but the relation is in terms of R n by R bar x c bar plus c x c bar square, where a is minus 1.17 and b is minus 0.3 and c is 0.704. So, R bar by R n again you see R bar by r n 1.2. So, if I plug it in everything is known to me. So, X c bar I back calculate it should turn out to be 0.37. So, this is an equation set up to calculate X c bar. So, this is caused by a certain temperature difference.

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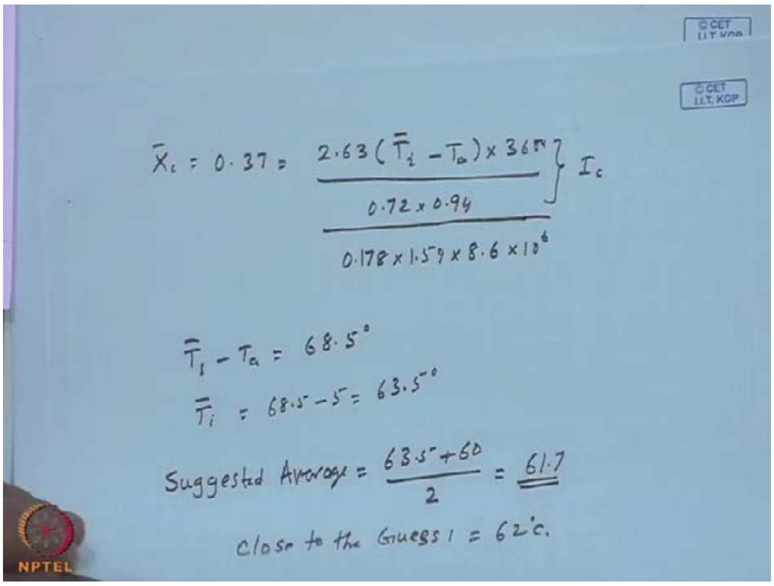

So, I will not go about the roundabout way x c bar straight forward equal to 0.37 equal to 2.63 into that suggested average inlet temperature minus T a times time unit tau alpha normal into point tau alpha bar by tau alpha n; this is whole thing is I c by I t noon R t n R n times 8.6 into 10 to the power 6 to make it joules. So, my T i bar minus T a equal to 68.5degrees. So, T i bar is 68.5 remember T as a minus 5. So, it becomes plus 5 over here minus 5 is 63.5 degrees. So, suggested so average 63,.5 plus 60 this is the minimum; this is the possible value comes to 61.7 close to the guess 1 equal to 62. If you are not satisfied, you could start with 61.7 and you do the calculation you may come out with 61.8.

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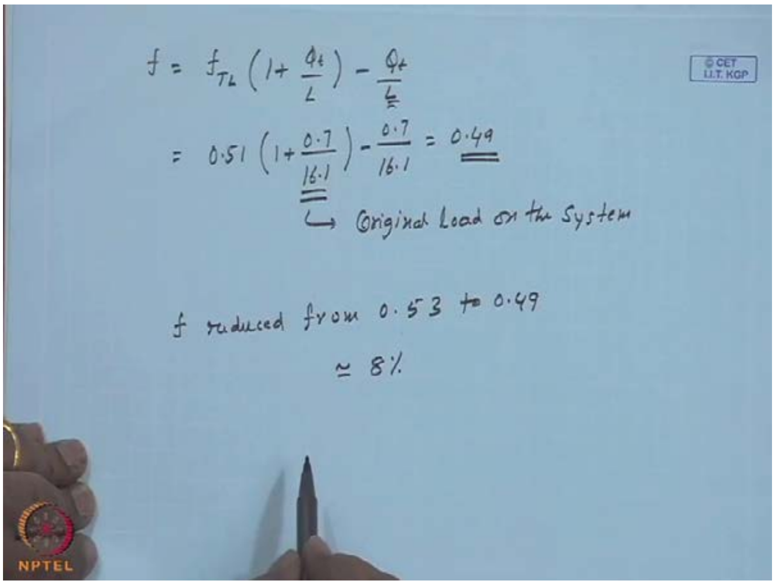

So, that is the f t n we got and f the solar load fraction will be f T l times 1 plus Q t by L minus Q t by L that formula we have got which will be equal to 0.51 into 1 plus 0.7 by 16.1 minus 0.7 by 16.1, which will be equal to 0.49. Remember here this is the original load on the system. This is the original load on the system, because we defined f T l as Q s plus Q tank by L plus Q tank. So, that we divided throughout with l the load on the system. So, in this formula it is important to remember this is 16.1 not the 16.8 which included the tank losses. So, f again is we got 0.49, which essentially means f reduced from 0.53 to 0.49 about 0.04 in 0.5 that is approximately 8 percent reduction. So, tank losses will reduce the solar load fraction by about 8 percent, but that can significantly depend upon the minimum temperature at which energy delivery is needed. In the case of f chart it is a single unit, so the correlation takes care of the losses etcetera in the case phi bar f chart instead of 60, if you have got 80, it would have been much higher number than 8 percent.

So, this as we have said right from the beginning the once again to repeat and to make you understand the logic behind it we estimate the tank loss assuming a tank temperature, we treat the tank process as a part of the load recalculate the coordinates, I mean variables x dashed and y; and use it to the phi bar f chart method to find out the load fraction. That load fraction is the, so called load fraction inclusive of the tank losses; whether the guess temperature is correct or not, is found out by obtaining what we call the average utilizability, which corresponds to some sort of an average x c bar, which should have been corresponding to a average inlet temperature to the collector.

So, we suggested possibilities being T minimum equal to 60 or whatever, and this T i bar we take the average; and if this average is close to the guess that we made in the beginning, then we will stop the iteration, otherwise you take the new value that is obtained and go through the procedure again. So, this how the tank losses can be taken care of; next time we shall find out the effect of the heat exchanger, and then the effect of the heat exchanger plus tank losses; until then bye.