Energy Efficiency, Acoustics & Daylighting in building

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Lecture - 18
Admittance Method

So, far we took ventilation as constant C v was constant. Now, if C v is varying with time then you can not explicitly find out the temperature swing. So, far we found out explicitly, every time explicitly we found out the temperature swing above the mean inside temperature, but if where ventilation is varying then you cannot find out.

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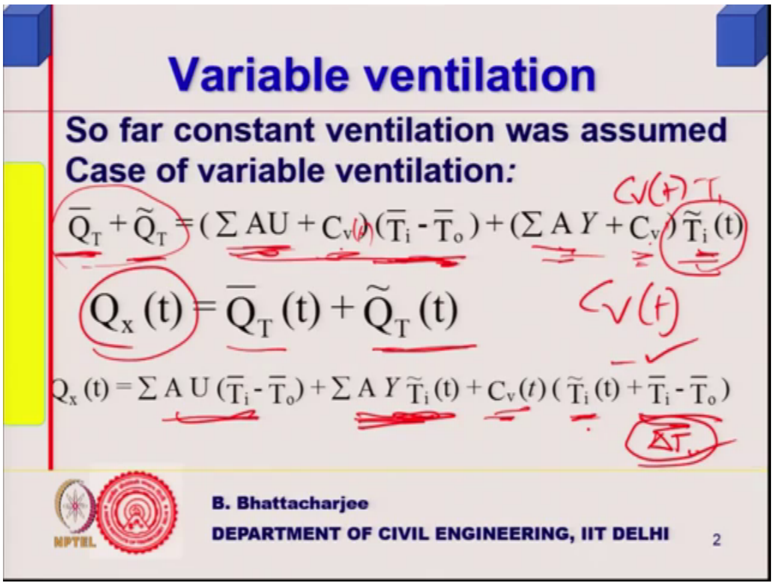

So, variable ventilation then we have a little bit of. So, what we can assume is we can write that there are 2 component of the heat flow, 1 is the mean steady part another is a fluctuating part and we could write it as AU C v into T i minus T o bar, that is how we wrote it and this we wrote as AY C v t i swing.

Now, see if C v is you know we C v is constant, I mean C v was constant here. So, will now vary C v as a function of time. Now, before I do that, supposing it is a function of time then I will have a product of C v T, C v that is a function of time and T i t as well. Now, you see this there is a product and you cannot find out T i t explicitly, coefficient of T i t will be a function of time, there will be 24 coefficients. Here, there was T i t this is constant, so you can explicitly find out, take everything on the left hand side divide it by this then you are finding out T i suing, this component you can find out, but supposing C v is also a function of time, then for each time you will get 1 equation, for each time supposing C v is a function of time you know C v t. So, this becomes C v t multiplied by T i t.

So, for each time I get 1 equation, I will get 24 equations and I got to solve those 24 equation to find out the swing, but there is another problem, even the mean delta T that I may have to find out together. So, basically I will have 25 equations to be solved to find out some matrix. So, solve inverse the matrix to get it, not very difficult because very much sparse matrix lot of zeros will be there. So, we will see that, so what we define is, we define Q x t, Q x t as sum of these 2. Q x t anyway this is not a function of time because this is mean constant this is a function of time.

So, Q x t is something like this. So, Q x t is this plus this A U T o right and C v is now a function of time. So, I am separating this out A Y T i t and C v is a function of time. So, I write it like T i t and from here this C v T T, I have taken out this side. So, you can see that it is A U T i T bar A Y T i t swing this is what I have written and C v part I have taken separately because C v is a function of time now. So, C v t and this is also taken into account because this is a function of time, this is also a function of time, so it is written like this. So, if I write like this what is this? This is nothing but I call it delta T bar, that is the temperature difference between inside and.

Student: Outside.

Outside mean. So, this is also an unknown for this 1 because unless I know earlier my C v was constant and therefore, I was able to find out an inside mean, but now C v is a function of time. So, I cannot find it out in straightforward manner, T i this will not be also known to me, this also will not be known to me it is also an unknown. So, the 25th unknown is this. So, I have got 25 unknowns now and I can write for each time an equation I will get 24 equation, I have to add 1 more equation and using 25th equation I will see that how we get it. I can solve those 25 equation to find out the difference in the mean and fluctuating component of inside temperature.

In other words, 24 temperature inside swing, temperature suing inside plus 1 difference in mean I can find out and use that to find out the 24 hourly temperature, let us see how do we do it.

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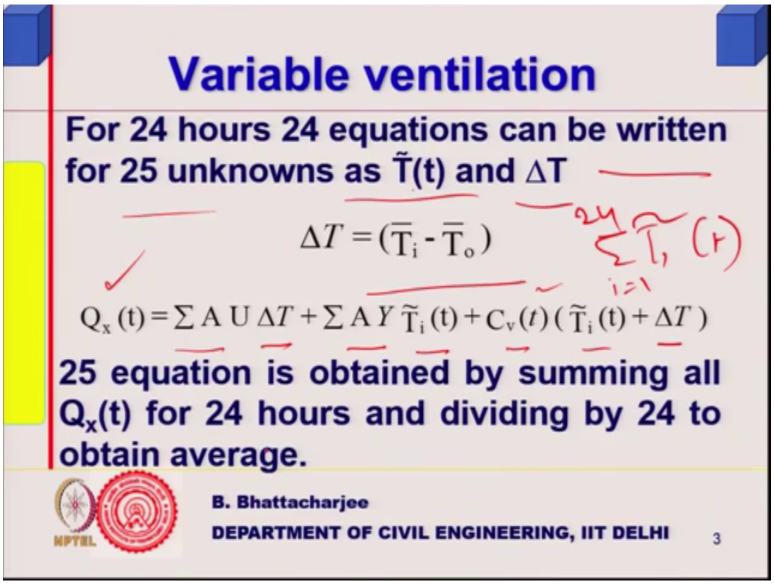

So, again we will solve an example also. So, if I 24 hours 24 equation can be written 25 unknowns as 24 of them plus delta T, delta T is this. So, Q x t is equals to A U delta T A U T i suing C v, this is how I can write, the same equation I am writing it in a slightly different manner and for each time because every hour I have got C v varying, number of air changes per hour is varying at every hour, hourly variations are there. So, therefore, I will get separate C v, 24 C v and I can write this equation. So, 25th equation is in the question, I sum up all those 24 hourly Q x t.

If I sum up all those 24 hourly Q x t, now what will happen, I will have sigma A Y plus sum of T i t you know this term will come, sum of T i t. What I going from 1 to 24, what will be this value? Sum of fluctuations for all 24 hours, it is equals to 0. So, if I put this equals to 0 that becomes a 25th equation, that is because if you the 25th independent equation. If I sum up 2 equations I get a third equation that is not an independent equation because that is what you, so this once we put this equals to 0, I get that 25th equation. So, I can solve all those 25 equation.

So, what we do is, we sum them up divide by 24 again. So, sum it up sum this up, divide by 24 and come to this sum of this 1 equals to 0, that is what I add because all swing will be equals to 0 plus minus all swings sum of all the plus you know this plus.

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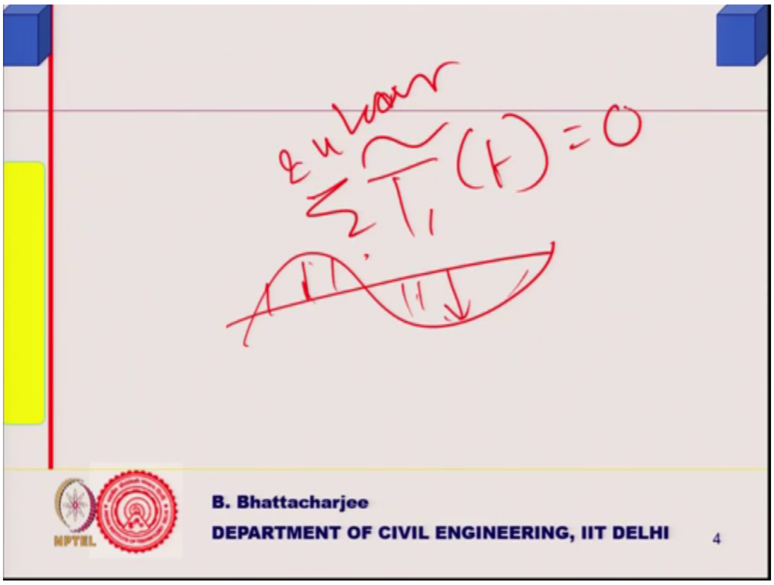

So, this area and this area is same. So, if I sum it up for all 24 hourly cases swing will be equals to 0, so T i t sum up for 24 hours that must be equal to 0.

So, if I put that into the equation I get the 25th equation. So, that is how what we do, let us see how we do it.

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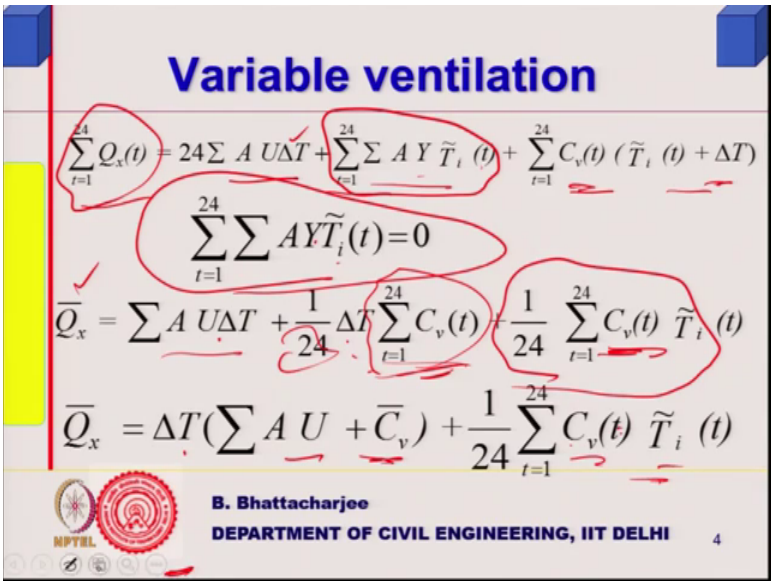

So, this is sum up for 24 hours, so this will be 24 constant because every this is delta T is constant all the time this I sum up and this also I sum up. Now, this is what I do for 25th T swing this will be close to 0 because a i a I can take outside and T i t swing is equals to

0. So, this term is equals to 0 and that gives me the 25th equation. So, therefore, that gives me the 24 equation A U delta T if I divide by 24 everything I get it Q x bar Q x sum for 24 hours Q x bar is equals to A U delta T 1 by 24 1 by 24 C v delta T into C v

So, delta T is constant, this C v t is sum up for 24 hours divided by 24, gives me the average C v, mean C v, this gives me the mean C v, this divided by 24 will give me mean C v. So, mean C v into delta T plus C v T into T i swing summed up for all 24 hours divided by 24. So, these 24 values you can calculate out. So, if you write it further Q x would be equals to delta T. So, total heat coming in is equals to delta T A U plus C v bar, because this is C v bar delta T, I am taking common. So, sigma U plus C v bar and this is 1 by 24 C v t T i.

So, this 24 every time this coefficient is different, I will have 24 different coefficients for each hour. So, I will have you know, this equation you make it for 24 hours, you get it for 24 hours because this you get it for 24 hours for the 25th equation you will get it, this is the 25th equation and 24 equations earlier I said. So, total 25 equations you will be getting and you can solve for all those 25 equations and you can find out the swing at every time plus the mean.

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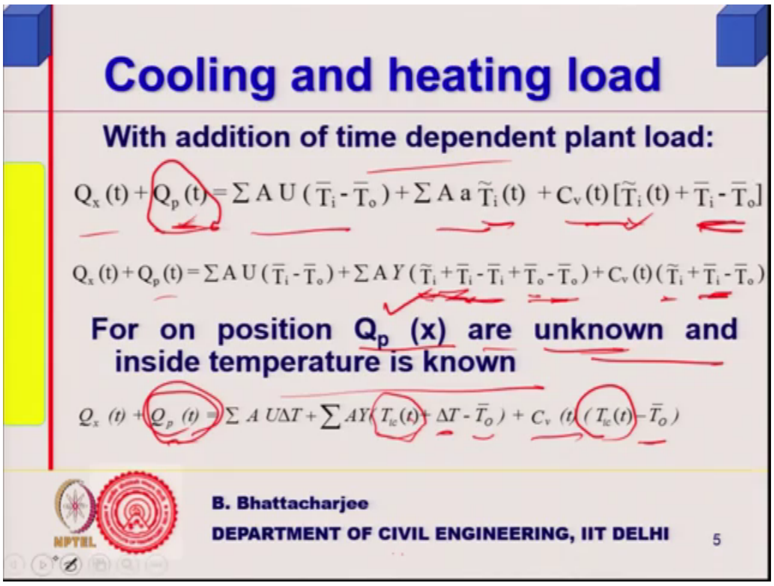

So, 25 equations, 24 equations because C v varies at every hour, so for each hour you will get 1 equation, additional equation you get by summing all of them up and dividing by 24 that is just simple algebraic manipulation and putting A Y sigma T i t equals to 0.

So, eliminating 1 of the terms that becomes a another independent equation. So, that is how we can calculate out.

One more thing, supposing my inside temperature is constant and I want to find out the amount of heat to be removed at every hour I can do the same thing. If it is, if the C v is constant explicitly for every hour I can find out because my T i t is now is equals to 0, if inside temperature is constant. Conditioned building for all time, every time T i t swing will be equals to 0. So, I do not have to you know, I just calculate out sum up all the heat coming in because inside mean is known to me, inside mean is a constant temperature that I am maintaining.

So, if you are trying to find out the energy load or energy that is to be removed, heat that is to be removed or to be supplied that you can simply find out if C v is constant explicitly for every hour you can find out using the same procedure. Here, we used the same procedure to find out the fluctuation mean and fluctuating temperature inside, but if my inside temperature is constant every hour you sum up all the heat gain taking time lag into account, no admittance is required anymore only the all heat gains you can sum up and that will be the energy load into the room at that particular time that is to be taken out.

How much is your AC capacity, that will be something more that is different we are not looking into that. It is only how much is the heat coming in that is what we are looking into right. So, that will be somewhat different, that would depend upon because how much is a capacity of the, how much is a air conditioner actually is consuming the energy, that would depend upon the process of air conditioning also, supply air temperature because it would supply the air that will absorb it, that is some because that is separate issue altogether. So, we are not looking into these, but what we said is you can calculate out explicitly every 24 hourly energy to be removed or supplied that you can calculate out using the same procedure.

But if it is part of the day it is conditioned and part unconditioned; then you calculate out for part of the day the energy required to be supplied and rest of the time it will attain some internal temperature naturally. In that case, this 25 equation comes out to be handy to us, we use the same 24, 25 equations in the same manner because now for certain period of time my T i is known, for certain other period of time T i is unknown. So, I got to solve for those hours you know, we are good to solve for those hours. So, I can do it. So, that is with the addition of time dependent plant load.

So, if I want to find out time dependent plant load. So, same thing, supposing I have a plant load same Q x that I talked about, I add Q p to it and that must be equals to same and C v is varying now, C v is varying. Even C v is constant does not matter, but then you can simply find out if C v is constant, then simply you can find out Q p, but if C v is varying then this becomes a equation and you can actually separate out this part as Ti Ti bar minus T i bar etcetera you can write like this.

This is the mean outside I have just added and subtracted each 1 of them because so somehow what the temperature would not be known to me for 1 position Q x p is are unknown and inside temperature is known because supposing my office starts at 9 AM, so I might put my air conditioner on there are various control system, but let us say it is a simple 2 on 2 point orphan control switch. So, what I do I come to my office or somebody comes to the office puts it on around 80, 830 because there will be an inertia of the system, it would require some time to reach the temperature. So, puts it on and puts it off around 5 PM right.

So, time of operation is known to me and during the time it is on operation Q x on position when it is on, this is my unknown. This is my unknown and when it is off position then these are my this one's these are my unknown and this is always my unknown because now part of the day temperature will be constant inside during the other period of time temperature is.

Student: (Refer Time: 15:31).

Changing; so, the mean temperature will be mean of both together, some time constant, some time varying. So, mean would be sum total of all the constant multiplied by the hour during which it is constant plus those time when it is not constant.

So, mean it will not be a fixed value you have to find it out, it would depend upon the inside temperature, so mean is also unknown. So, this part is also unknown, sometimes this is unknown, sometime this part is you know plant load is unknown. So, it would be again I setup same 25 equation Q P t etcetera, this becomes unknown for certain period of time and I can write that for some period of time inside constant temperature minus outside to bar, separate this out for certain period of time. So, this is the constant temperature inside delta T minus to bar, you know I am what I am doing is I am saying T i swing plus T bar is T C t, sometimes this is constant, sometime this is; sometimes it is varying.

So, for constant time I can write an equation of this kind, when plant load I have to calculate out.

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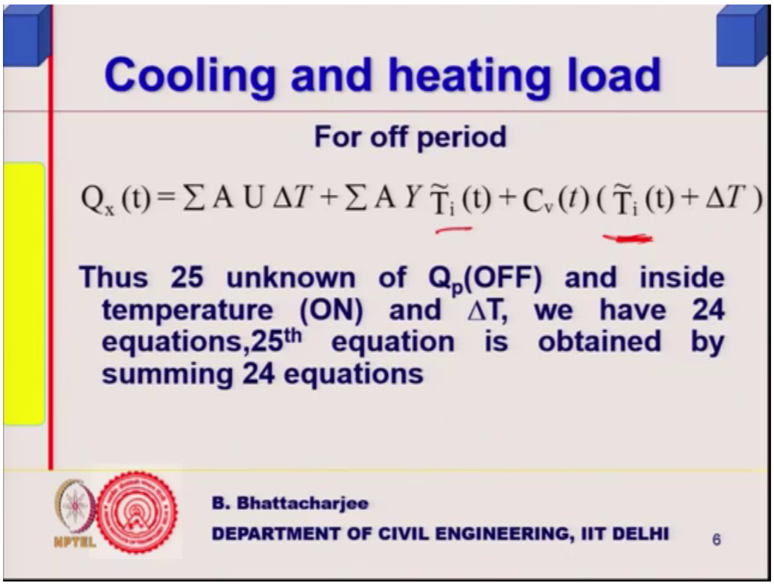

For varying point of time; for varying time what I do is for varying time for off period my equation would change, somewhat for off period my equation will change because then there is no Q P t plant load is 0, but this is unknown etcetera. So, that is 25 equations of the similar kind that we had and 25th equation we get the same manner as we have done earlier because the mean temperature sum swing or sum total of swing temperature would be again equals to 0 because sometime it is varying, sometime it is constant.

So, the mean would be above the constant like for example, 25 degree centigrade if I am maintaining during the conditioned time, but other time it will be 26, 27, 29, 30 whatever it may be or may be 19, 18 early in the morning. So, mean temperature is not 25, it is 25 into let us say 8 hours, so 12 hourly operation, say 10 hourly operation. So, 25 into 10 plus the 14, additional 14 hours I have 14 different temperature, sum of all those 24 divided, sum of all of them divided by 24 is a mean, which will be maybe higher than 25 or lower than 25 and swing is above that temperature.

So, you see the sum total of that swing again will be equals to 0. So, that is 25th equation I get in the same manner and I calculate out the plant load.

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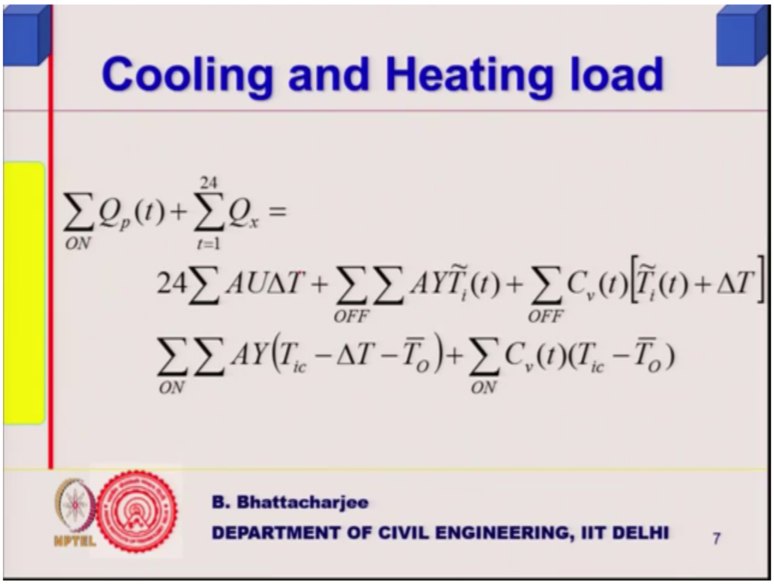

So, when you have you know when variable ventilation plant load you find out same again you are summing up everything and 25th equation you are getting and in the same manner as before applying following condition this is a condition I apply that sigma A Y.

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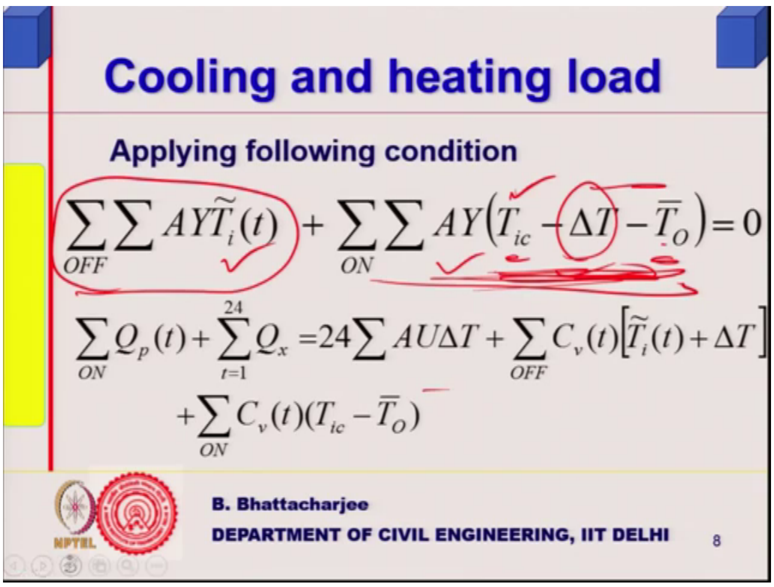

This should be equals to 0, during off period as well as on period the temperature swing inside because this is mean minus outside. So, this is nothing but T inside constant temperature right.

So, this is the inside temperature swing during the constant period, swing above the mean the difference between the mean to minus delta T is the inside mean minus T i c you know this is the swing in temperature during the 1 period, this is the swing in temperature during off period and total swing this and this multiplied by A Y they must be equals to 0 because swing will be positive I am calculating the mean in that manner.

So, some time my temperature will be higher than the mean, some other time it will be below the mean, some total will be equals to 0. So, my 25th equation comes in the same manner as before and just I remove that from the sum total and I find it out the 25th question in this manner and solve for this you know solve for the matrix that would generate 25 by 25 matrix, perhaps it is here somewhere and 25 unknowns can be solved from 25 equation, so that is what it is.

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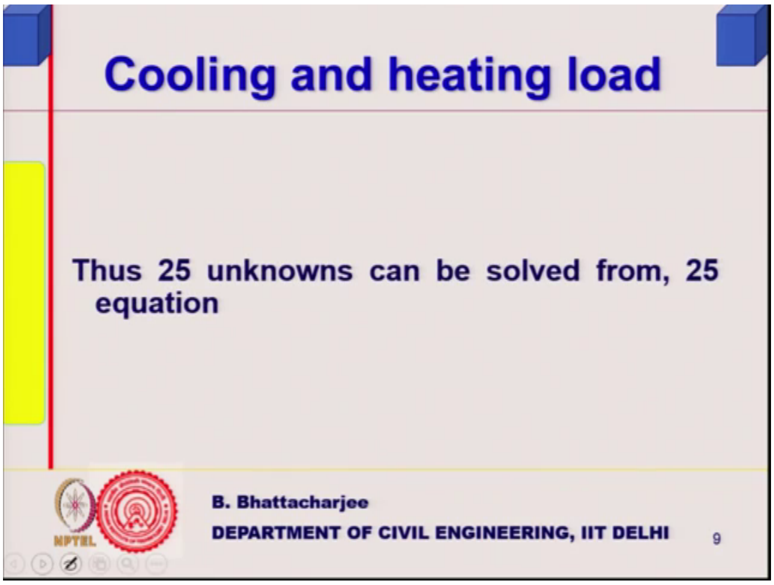

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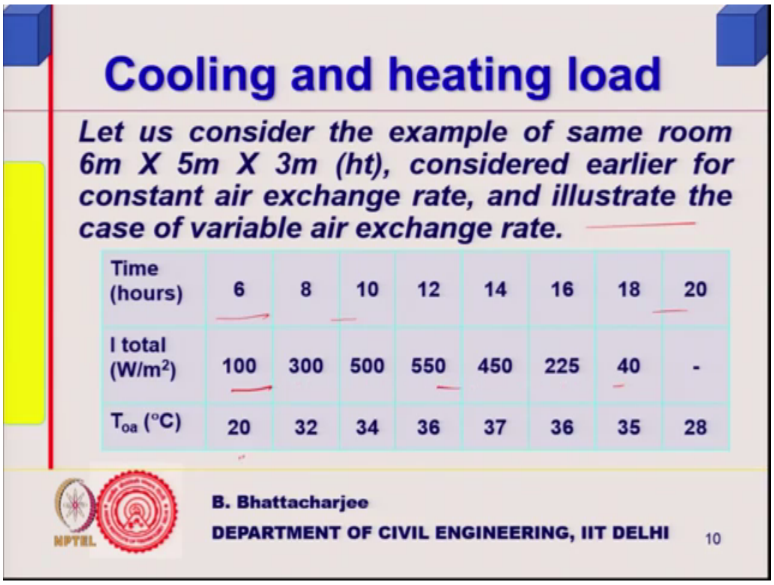

Now, you cannot do it by hand calculation; obviously, you cannot do it by hand calculation 25 by 25 matrix; however, sparse it is it is quite difficult to do that, if you remember there is you know it is the good old days, I mean it is there in again engineering mathematics Arwen k 6 book if you see the matrix chapter of the matrix, it will say 3 by 3 matrix because you have to go to 2 by 2 determinants 3 of them calculate out or inversion if you do by standard we have inversion, somewhere by 30 by 30 or 25 by or 30 by 30 matrix maybe even lesser than I do not remember takes 25 years by hand calculation.

So, inversion; obviously, there are other techniques Gaussian elimination and all that you can do inversion that takes much lesser time, that takes direct calculation from the matrix it will take very long time, but even doing a Gaussian elimination of 25 by 25 equation will take a long time or there are several advanced inversion techniques, it is very easy to do it in a mat lab or even in excel, excel gives you matrix inversion. So, consider this example same room, earlier for constant exchange in now I have time hours; time in hours and I is values are given outside temperature; air temperature is also given.

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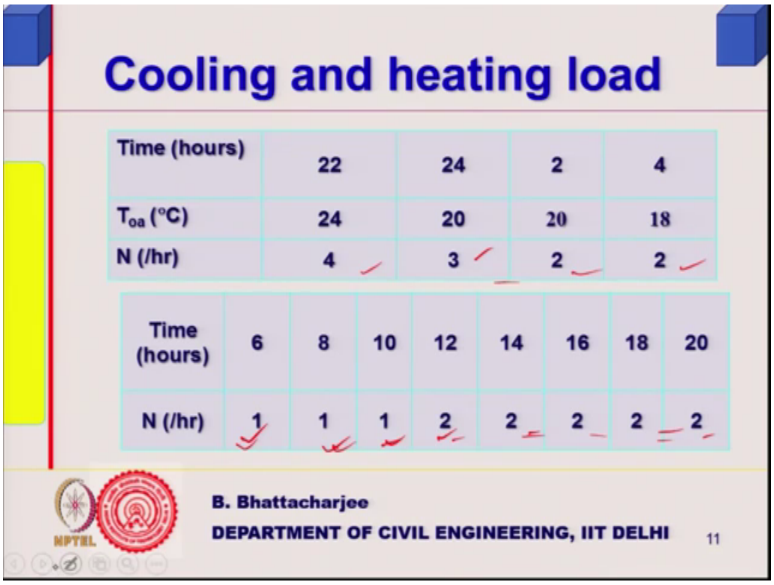

Now, the N values are given 6, 8, 10 this is the air changes. So, variable ventilation rate, variable ventilation the 6 AM 1 hour, 1, 1, 2, 2, 2, 2, 2 etcetera. So, variable ventilation rates are given here, in addition to the data that we had earlier.

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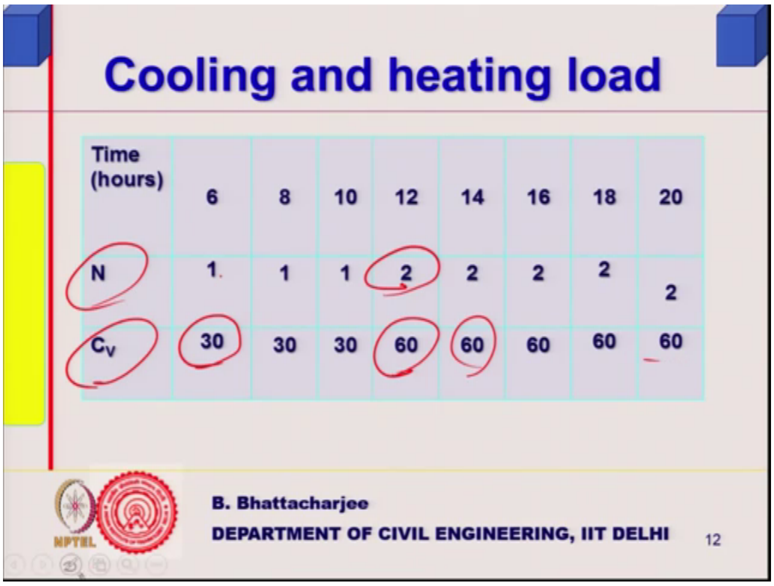

So, you actually got to calculate out N is known C v. So, N into room volume was 90 meter cube I think 6, 5 into 3, 6 into 5 into 3, 90 meter cube was the room volume. So, 90 by 3 into 1 is 30, 90 by 3 into 2 is 60. So, C v values are obtained accordingly for all the hours.

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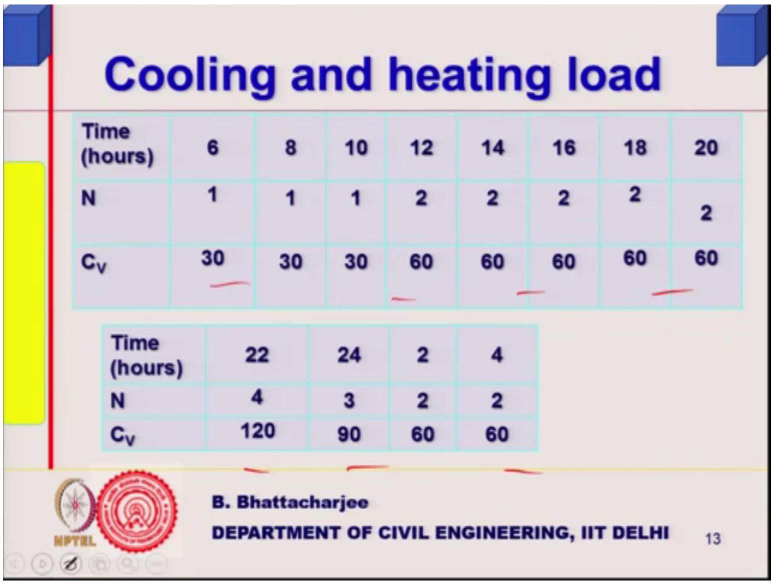

So, C v values are obtained accordingly as you can see C v values are obtained accordingly.

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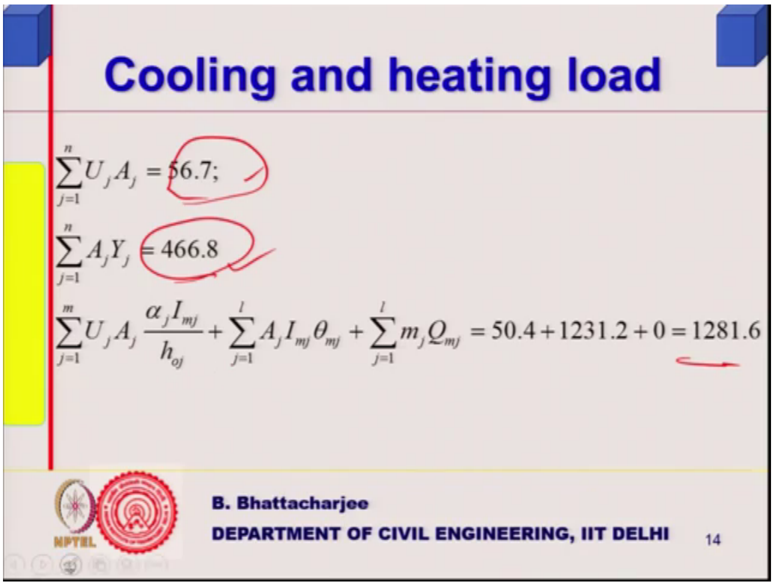

And then U A sum is this, sigma A Y sum this we calculated earlier for previous; remember, this we calculated for even mean calculation U A, this you did for calculating 6 PM temperature, we divided by 466.8 you know 1268 this is how we did and I am setting up the equations now. So, 1281 this was there right earlier even and now if you calculate out C v into T o a, C v s were known to us and outside temperature is 20, 32, 34 etcetera.

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Cooling and heating load

Time (hours)	22	24	2	4
C_V	120	90	60	60
T_{oa} (°C)	24	20	20	18
$C_V \times T_{oa}$	2880	1800	1200	1080

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C v into outside temperature that is what we are calculating, this will go into the heat gain you know, it to find out every 24 hourly temperature this will go into the heat gain side and T o a 24, so C v values are there.

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Cooling and heating load

Time (hours)	6	8	10	12	14	16	18	20
Q_{fc}	-8.2	-15.8	-15.7	-19.5	-15.8	6.9	10.71	14.4
Q_{fs}	-15.2	-15.2	-15.2	-15.2	-6.8	10.	26.8	31
Q_s	378	1134	1890	2079	1701	850.5	151.2	0
Q_{gc}	-126	55.4	85.7	115.9	131	115.9	100.8	-5.0

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Now, let us see what are those 24 equates, 25 equations are. So, if you time Q f c, Q f s, Q s at every time I am calculating because radiation is changing. So, Q f s would change, temperature is changing. So, this will also change you know temperature will change you know it is changing.

So, it will change accordingly, how is Q f c found out? Outside minus.

Student: (Refer Time: 24:13).

You know although all that time lag and all that taking into account. So, this is our results in from for those 25 by 25 matrix 25, but you have to do it yourself otherwise you would not get it.

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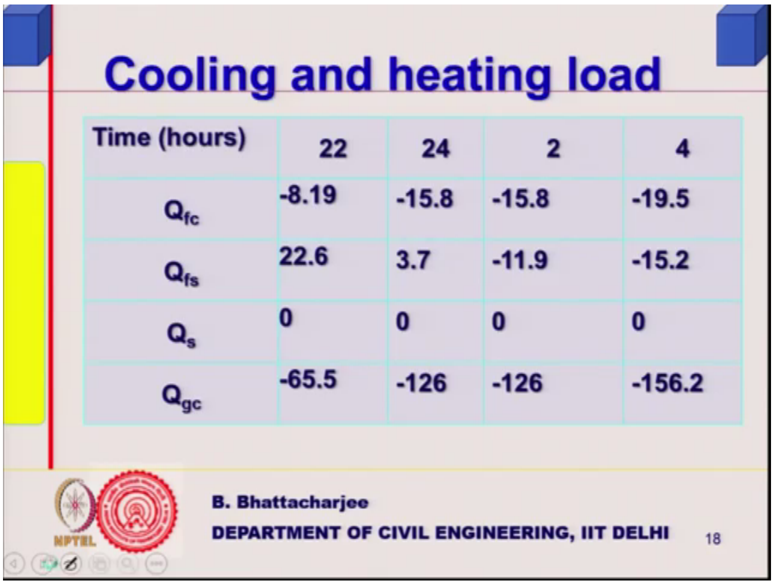

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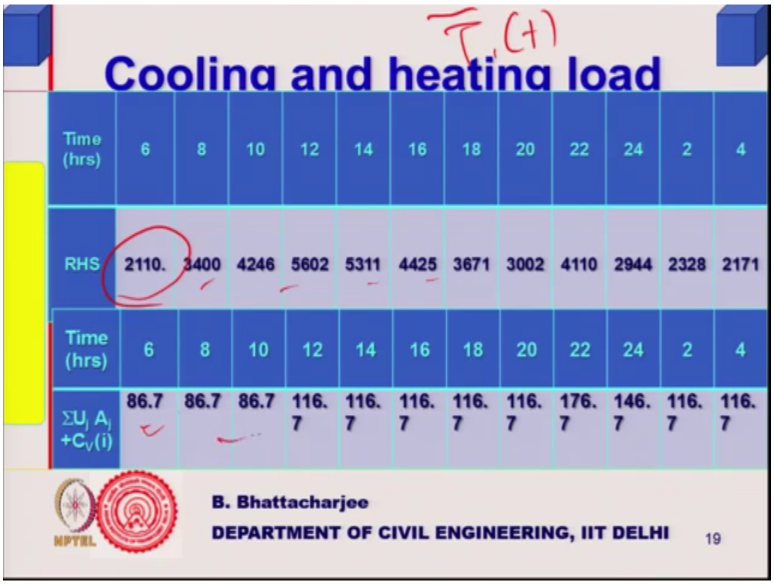

There may be some error in this and you know this is what finally results in, right hand side of the matrix in which T i a swing T you know these terms would not be there tai T terms would not be there, that is the right hand side of the matrix and this comes out to this and sigma's us C v etcetera comes out to be this and then 16.7 alright and the 25 equation that comes out would look like this, you have to do it yourself otherwise you would not get it because it is impossible to do the whole thing here in a class especially in a class of this level.

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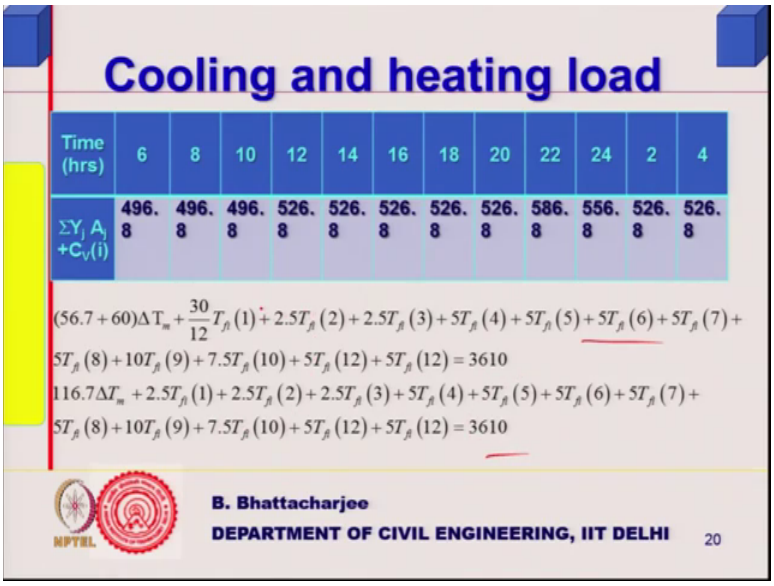

So, finally, 25 equation turns out to be something of this kind, some of those equations I am just showing and the matrix 25 by 25 matrix looks like this.

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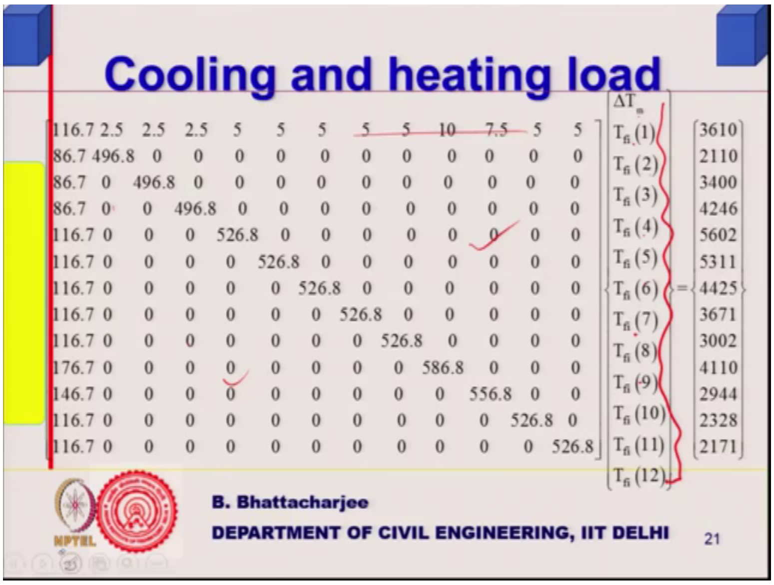

So, delta T m T a 1, 2, 3 etcetera 10 these are my unknowns 25 unknowns. Here, it was 12 because I have taken 2 hourly temperature, so I have 13 unknowns, 13 unknowns 13 equations and you can see lot of them are largely diagonal matrix, but there is 1 full column, this 1 full row.

So, it is largely diagonal matrix, if it was just diagonal matrix you could have implicitly solved them, I mean explicitly solve them, but then this would need doing a little bit.

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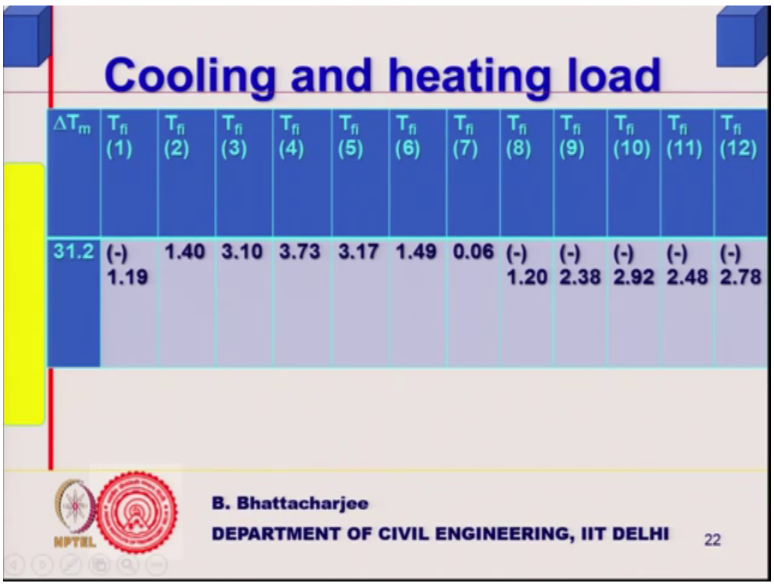

Of thing, but emulation of the matrix is pretty simple and if you do that you get delta T m is this and this is the swing in temperature 31 minus 1.19 will be the temperature first temperature that is I think must be 6 A m and so on, so forth. So, this is how we can find out the inside temperature, but you know this is how the matrix should look like and you have to obtain that matrix this example you can try it out and see if this is correct there will be some mistake, there may be some mistake do not take it for granted, you solve it out yourself and then (Refer Time: 26:29) get it.

So, that is how 1 can obtain the inside temperature and even cooling load for fluctuating ventilation condition. So, with this we can now look into thermal comfort, with this we can look into now look into thermal comfort actually. So, so far we talked of how to you know.

So, far we have said that how you calculate out the inside temperature, right we built it up from the beginning, first look we do a climatic features various types of climates and as I said thumb rule can be used there, but then if we I want to do a design I should be able to find out for a given outside condition, how much is the heat gain or what is the inside temperature? Supposing, in there my objective function or my objective could be to reduce minimize the inside temperature in a tropical summer situation during summer and that is what we were looking at and if it is cooling load or energy load I would like to minimize it.

So, for that I need to calculate out first and for various options and choose that option which will give the minimum. Now, this optimization procedure is separate that we will talk about later on, that I will talk about later on. So, that we can talk later on, but now we can look into thermal comfort. So, you can look into thermal comfort right.