Refrigeration & Airconditioning
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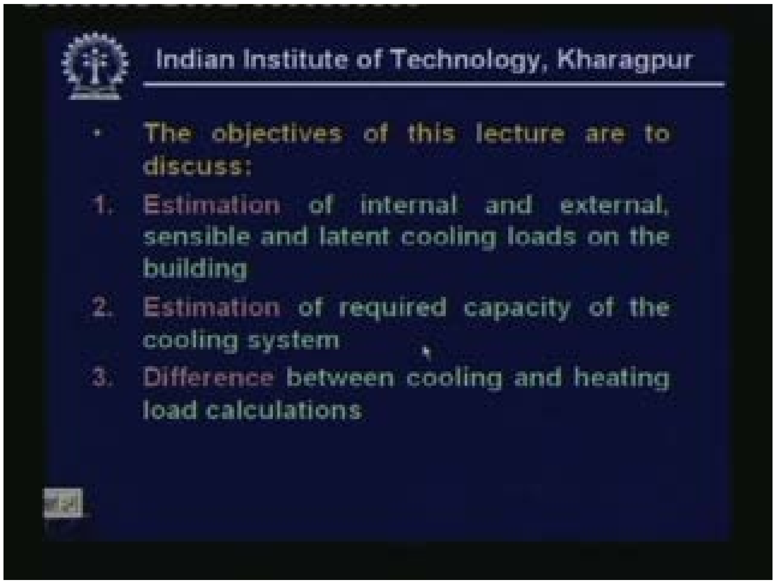
Lecture No. # 42
Cooling & Heating Load Calculations
(Contd.)

Welcome back in the last few lectures. I have discussed how to estimate heat transfer through buildings like through fake walls through fenestration and heat transfer due to infiltration ventilation etcetera. So in this lecture I shall discuss the methods of estimation of cooling and heating loads on a particular building and how to estimate the required cooling or heating capacities using the information provided in the last lectures okay. (Refer Slide Time: 00:01:09 min)



So the specific objectives of this particular lecture are to discuss estimation of internal and external sensible and latent cooling, loads on the building estimation of required capacity of the cooling system difference between cooling and heating load calculations.
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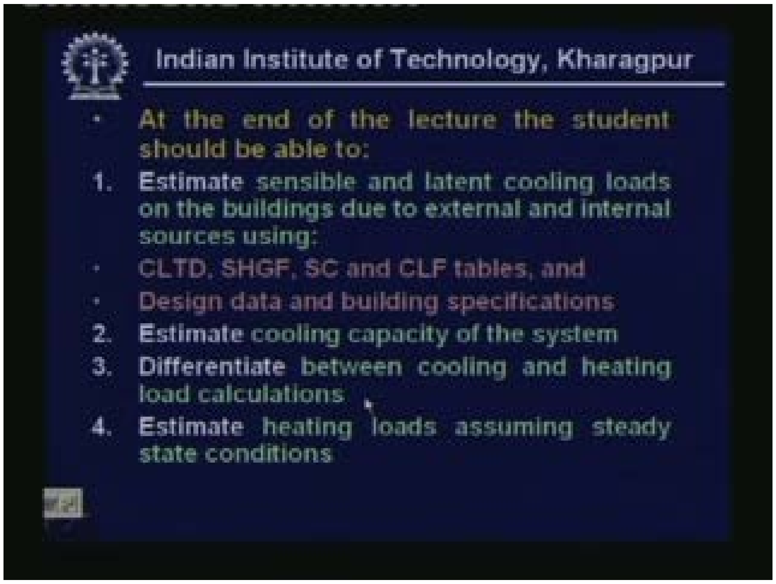

At the end of the lecture you should be able to estimate sensible and latent cooling loads on the buildings due to external and internal sources using CLTD SHGF SC and CLF tables and design data and building specifications and estimate cooling capacity of the system from the above information and differentiate between cooling and heating load calculations and finally estimate heating loads assuming steady state conditions.

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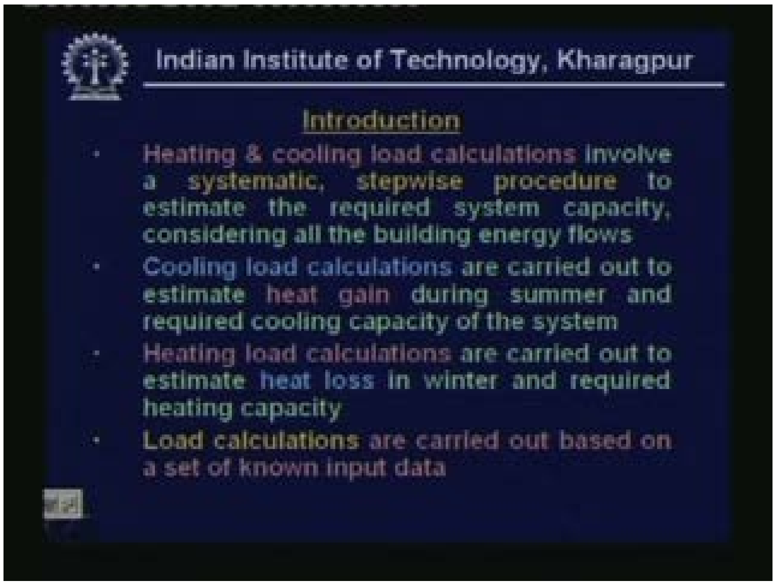

So let me give a brief introduction. Heating and cooling load calculations involve a systematic stepwise procedure to estimate the required system capacity considering all the building energy flows. As you know cooling load calculations are carried out to estimate heat gain during summer and to find out the required cooling capacity of the system. Whereas heating load calculations are carried out to estimate heat loss in winter and find out the required heating capacity and load calculations are carried out based on a set of known input data.

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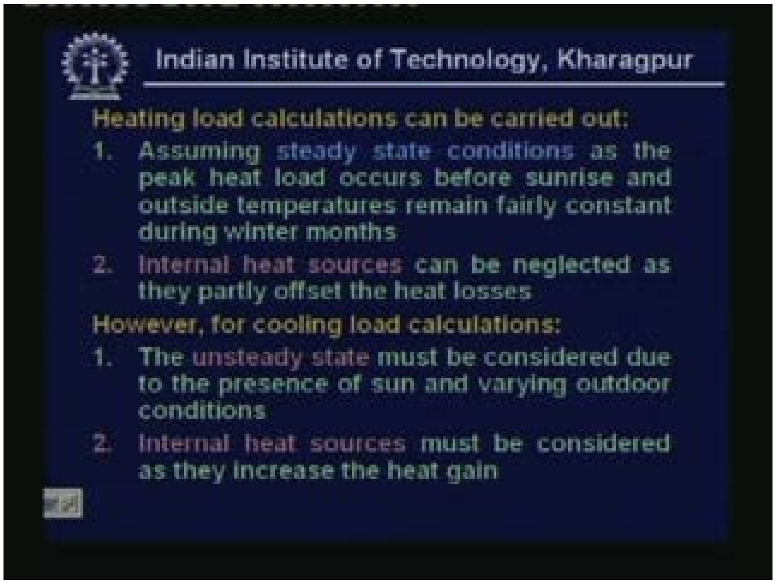

Heating load calculations can be carried out assuming steady state conditions as the peak heat load occurs before sunrise and outside temperatures remain fairly constant during winter months. And also you can neglect internal heat sources while estimating the heating loads. Because these internal heat sources partly offset the heat losses. However for cooling load calculations you must consider the unsteady state. Because of the presence of sun and varying outdoor conditions and we also have to consider the internal heat sources. As they increase the heat gain as a result you find that the cooling load calculations are invariably more complicated than heating load calculations. So in this lecture I shall first discuss in detail the cooling load calculations and the procedure for heating load calculations are almost similar and it is much simpler than this okay.

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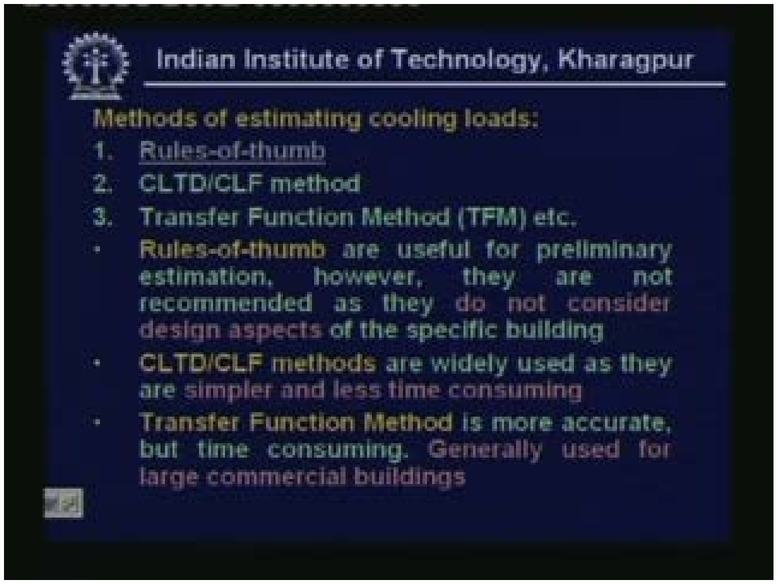

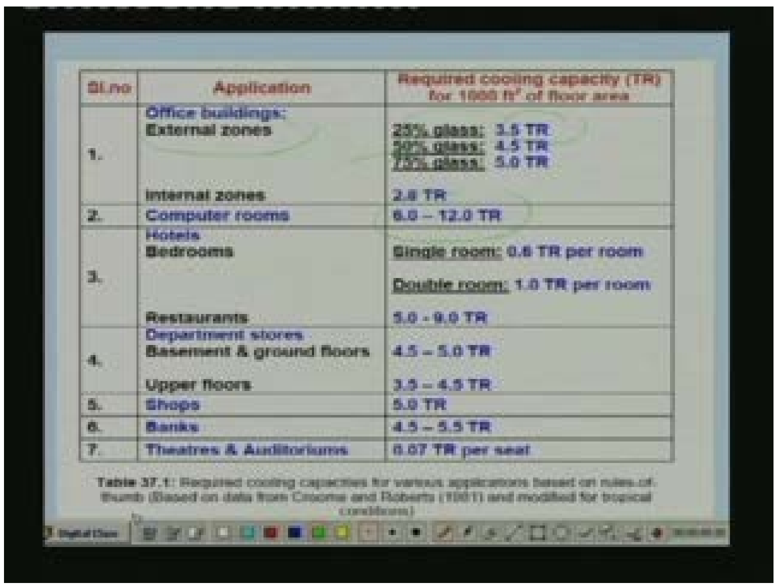

Sl.no	Application	Required cooling capacity (TR) for 1000 ft² of floor area
1.	Office buildings: External zones	25% glass: 3.5 TR 50% glass: 4.5 TR 70% glass: 5.0 TR
	Internal zones	2.0 TR
2.	Computer rooms	6.0 – 12.0 TR
3.	Hotels Bedrooms	Single room: 0.6 TR per room Double room: 1.0 TR per room
	Restaurants	5.0 - 9.0 TR
4.	Department stores Basement & ground floors	4.5 – 5.0 TR
	Upper floors	3.5 – 4.5 TR
5.	Shops	5.0 TR
6.	Banks	4.5 – 5.5 TR
7.	Theatres & Auditoriums	0.07 TR per seat

Table 37.1: Required cooling capacities for various applications based on rules-of-thumb (Based on data from Croome and Roberts (1981) and modified for tropical conditions)

Now let us look at the methods of estimating cooling loads. The easiest method is what is known as based on rules of thumb using CLTD and CLF method using transfer function method etcetera. First let us look at rule, rules of thumb. For example this particular table shows the required cooling capacity for various applications. For example you can see here that for an office building and if it is an external zone and if it has twenty-five percent glasses the required cooling capacity is about three point five TR okay. For thousand square of floor area okay, thousand feet square of floor area.

If the percentage of glass is fifty percent then the required cooling capacity is about four point five tonnes. And so on, similarly for other applications, for example, computer rooms the required cooling capacity lies in between six to twelve tonnes per thousand feet square of floor area. Similarly for other applications like hotels, bed rooms, departmental stores, shops, banks, theaters etcetera okay. So these are based on the long years of experience and these values are arrived at as I said a many years of experience okay.

So this at what is known as estimating the cooling capacity based on rules of thumb. You will notice that rules of thumb they are very useful for preliminary estimation however they are not recommended as they do not consider design aspects of the specific building okay. So rules of thumb are used only for preliminary estimation not for final calculations the CLTD CLF method which is basically suggested by ASHRAE it is widely used as, it is simple and it also consumes less time. The transfer function method is more accurate but it is more time consuming hence it is generally used for large commercial buildings. In this lecture I shall discuss mainly the CLTD CLS method.

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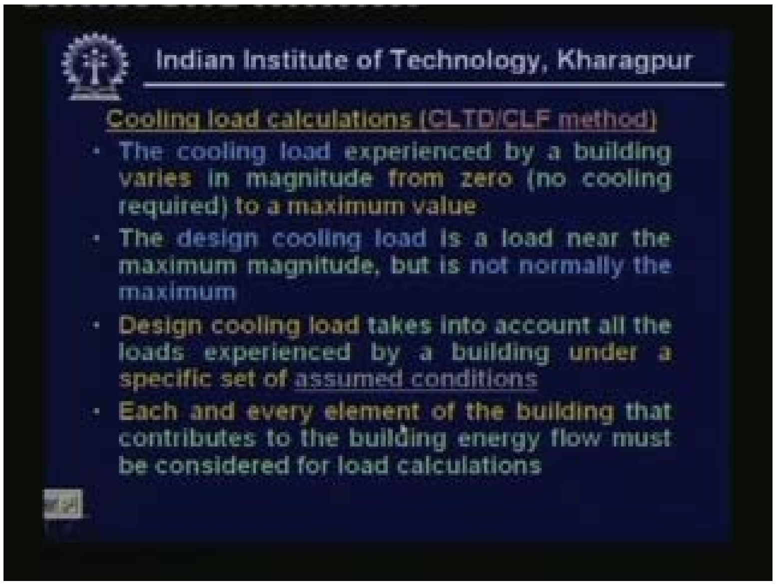

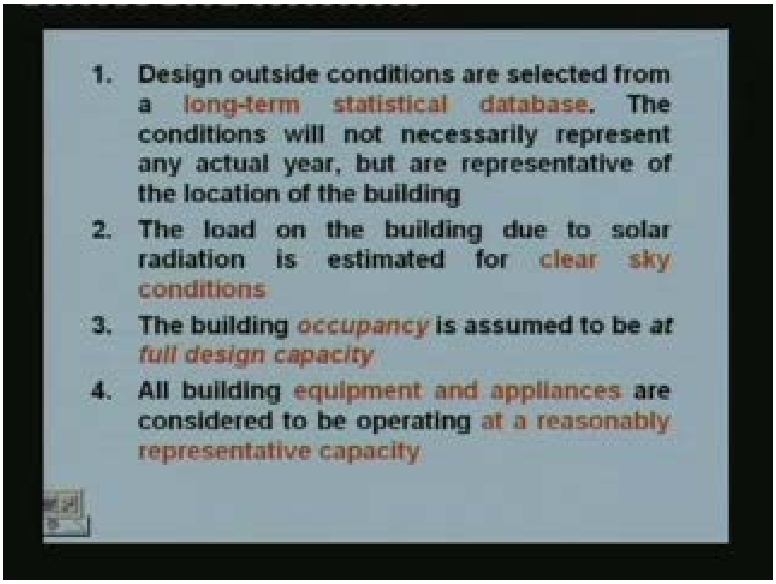

So cooling load calculations based on CLTD CLF method. The cooling load experienced by a building varies in magnitudes it does not remain constant. It varies in magnitude and the variation can be from zero. That means no cooling is required to a maximum value and the design cooling load is a load near the maximum magnitude but is not normally the maximum okay. It is near the maximum but not the maximum design cooling load takes into account all the loads experienced by a building under a specific set of assumed conditions okay. So what are the conditions based on which the cooling load calculations are carried out. First the designs outside conditions are selected from a long term statistical database.

The conditions will not necessarily represent any actual year but are representative of the location of the building next the load on the building due to solar radiation is estimated for clear sky conditions. That means we do not take into account clouds okay. The third point the building occupancy is assumed to be at full design capacity and finally we assume that all building equipment and appliances are considered to be operating at a reasonably representative capacity. So these are the conditions based on which we carry out the cooling load calculations and each and every element of the building that contributes to the building energy flow must be considered for load calculations. So we have to take into account all the elements of the building.

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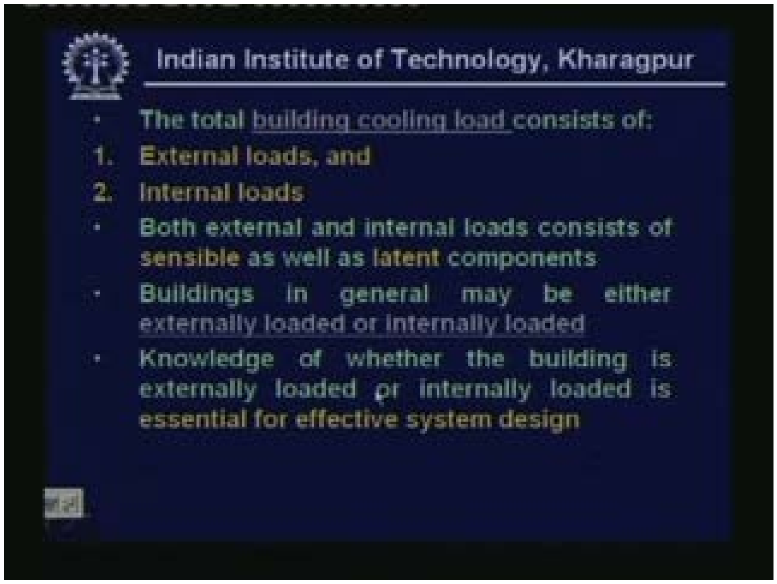

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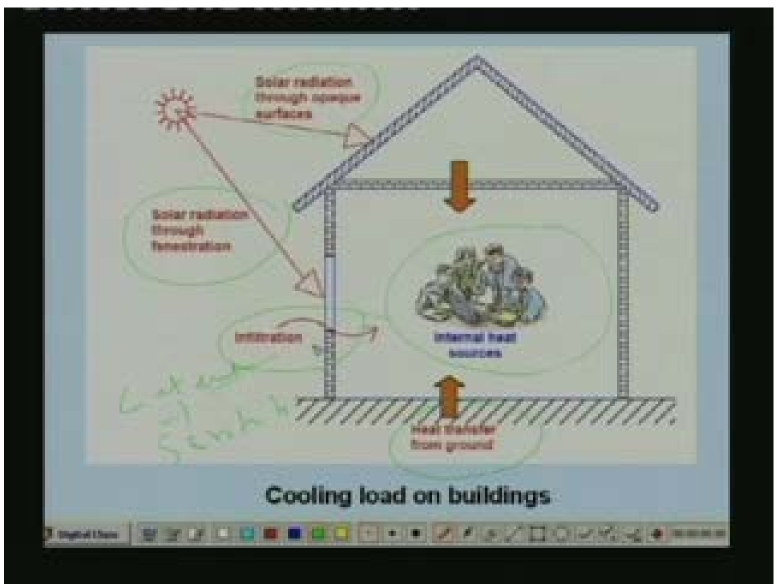
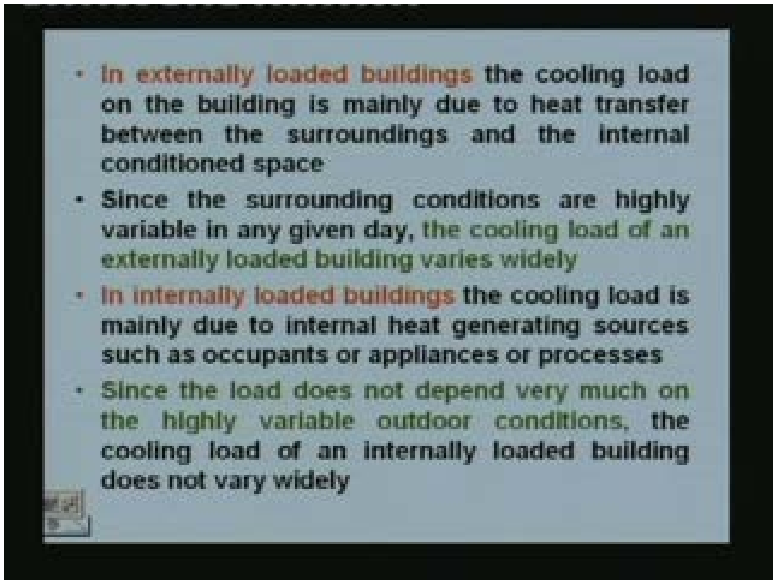
• The total building cooling load consists of:
1. External loads, and
2. Internal loads
• Both external and internal loads consists of sensible as well as latent components
• Buildings in general may be either externally loaded or internally loaded
• Knowledge of whether the building is externally loaded or internally loaded is essential for effective system design



Solar radiation through opaque surfaces
Solar radiation through fenestration
Infiltration
Internal heat sources
Heat transfer from ground
Cooling load on buildings



The total building cooling load consists of external loads and internal loads. Again both external and internal loads consist of sensible as well as latent components. Let me show this with the help of a schematic, for example, what is shown here is a typical building. So it is subjected to solar radiation. So heat transfer takes placed to the building because of solar radiation through opaque surfaces through fenestration okay. Similarly heat transfer also takes place from the ground. Heat transfer takes place due to infiltration. Infiltration heat transfer consist of both latent as well as sensible okay, latent plus sensible these are the external loads. In addition to this we also have internal heat sources for example the people inside the condition space they add load to the building. Okay.

So these are what is known as internal heat sources in addition to people we may also have several appliances equipment etcetera okay. So all these constitute internal heat sources. So you can see that a building is subjected to external loads as well as internal loads. Buildings in general may be either externally loaded or internally loaded. So what do we mean by externally loaded building or an internally loaded building. In externally loaded buildings the cooling load on the building is mainly due to heat transfer between the surroundings and the internal condition space since the surrounding conditions are highly variable. For example outside solar radiation outside temperature varies widely in a given day the cooling load of an externally loaded building varies widely okay.

So this is the typical characteristic of an externally loaded building in internally loaded buildings. The cooling load is mainly due to internal heat generating sources such as occupants or appliances or processes since the load does not depend very much on the highly variable outdoor conditions. The cooling load of an internally loaded building does not vary widely for example consider a theatre okay. A theatre can be treated as an internally loaded building because the heat generation due to the occupancy inside the building generally is much higher than the external loads. So you find that irrespective of the outside conditions the load on the building remains more or less constant okay, which depends upon the occupancy right. So the knowledge of whether the building is externally loaded or internally loaded is essential for effective system design it helps if you know before and whether it is externally loaded or internally loaded.

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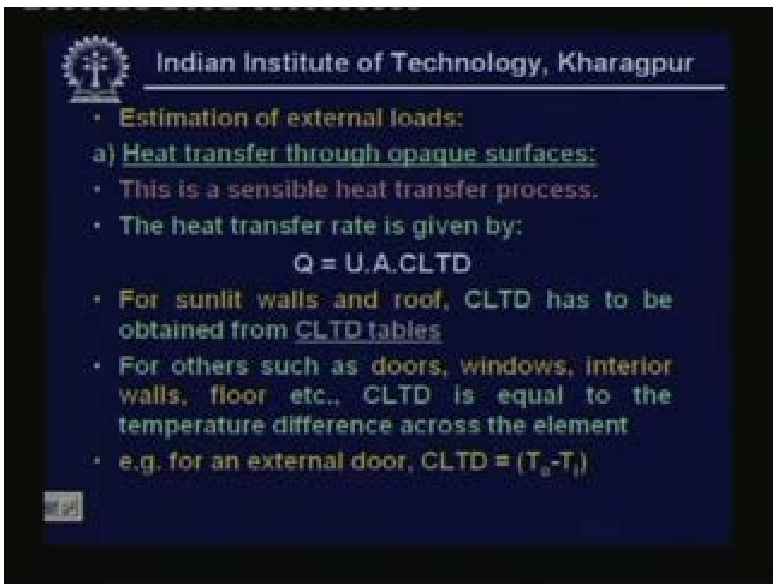

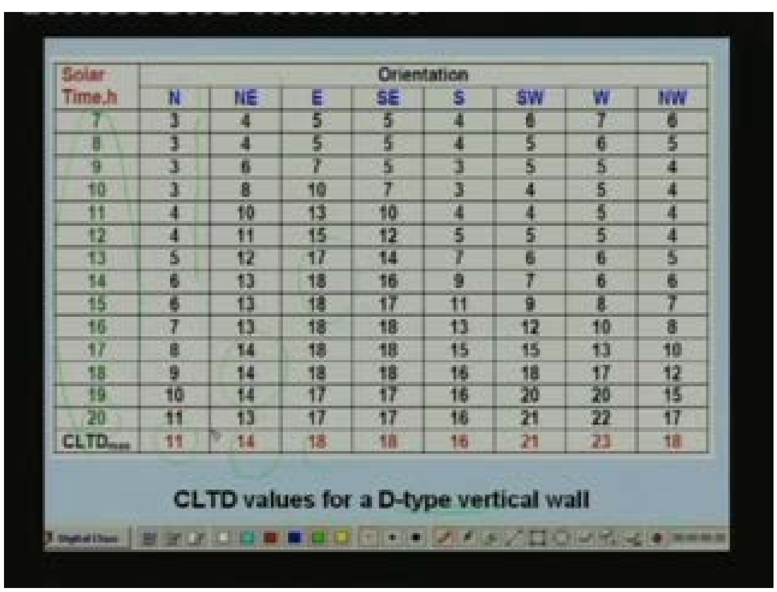

Solar Time,h	Orientation							
	N	NE	E	SE	S	SW	W	NW
7	3	4	5	5	4	6	7	6
8	3	4	5	5	4	5	6	5
9	3	6	7	5	3	5	5	4
10	3	8	10	7	3	4	5	4
11	4	10	13	10	4	4	5	4
12	4	11	15	12	5	5	5	4
13	5	12	17	14	7	6	6	5
14	6	13	18	16	9	7	6	6
15	6	13	18	17	11	9	8	7
16	7	13	18	18	13	12	10	8
17	8	14	18	18	15	15	13	10
18	9	14	18	18	16	18	17	12
19	10	14	17	17	16	20	20	15
20	11	13	17	17	16	21	22	17
$CLTD_{max}$	11	14	18	18	16	21	23	18

CLTD values for a D-type vertical wall

Now let us look at estimation of external loads. First we take, as I said we have to consider all the elements. First we take heat transfer through opaque surfaces. Opaque surfaces means all the walls roof floor doors etcetera okay. So the heat transfer rate through this opaque surfaces is sensible heat transfer only. You do not have any latent component and the heat transfer rate is given by Q is equal to U into A into CLTD where U is the overall heat transfer coefficient of that particular element. A is the area of that particular element and CLTD is the cooling load temperature difference as we have seen in the last lecture. And for sunlit walls and roofs CLTD has to be obtained from CLTD tables. This we have discussed in the last lecture how to estimate the cooling load temperature differences.

So using the tables let me show a typical, l here, for example this particular table shows the CLTD values in degrees centigrade or degrees Kelvin for a D type vertical wall. I have defined what is a D type vertical wall in the last lecture okay. So you can see here that here the cooling load temperature difference is given at different solar times okay. Starting with seven o clock in the morning to about eight o clock in the evening and for different orientations of the wall. For example if it is north facing, north east facing, east facing, south east facing etcetera okay. And you can see here that for a particular orientation the cooling load temperature difference varies with time. For example for a north facing wall it increases okay it reaches the maximum of eleven degrees at about eight pm okay.

Whereas for a north east face wall again the temperature difference varies and it reaches peak between five to seven right and for an east facing wall the peak is occurs around noon right. Similarly for other orientations and in this table what is given is CLTD maximum is also given okay. For a particular orientation what is the maximum value of a cooling load temperature difference? Now if you want to estimate the heat transfer rate through the building walls okay, a building may consist of four walls. Let us say and I would like to find out what is the, and let us say that all these four walls are external walls. That means they are all expose to outdoors that means there sunlit walls and they are also exposed to outdoor air. So if you, I would like to find out what is the total heat transfer through all these walls.

As you seen have from the table the CLTD values for a particular orientation varies with solar time and it reaches a maximum at a particular time for a particular orientation and the maximum CLTD value for all walls does not occur at the same time, obviously for east facing wall it occurs much earlier compared to a west facing wall. So it is generally advisable to calculate the heat transfer rate at different times. For example start the calculation at eight am let us say. So at eight am I find out what is the cooling load temperature difference for all the sunlit walls and multiply that into UA of the respective wall and find out the total heat transfer rate through all the walls.

Then I also do this calculations at nine am at ten am like that okay. Like that I continue the calculation may be till six or seven pm in the evening. Then I add up the total heat transfer rates. That means I find out what is the total heat transfer rate at eight o clock in the morning nine o clock in the morning three pm three pm four pm like that okay.

And obviously these values will be different for different times. So what I have to do is, I have to select the maximum value for a fixing the system capacity okay. The maximum value not necessarily occurs when all of them are maximum okay. Because all of them do not reach maximum value at the same time okay. So generally it is, you have to prepare some kind of a spread sheet okay. And calculate for east facing wall eight am nine am ten am, what is the heat transfer rate for west facing wall, what is the heat transfer rate at different times add up and see what is the maximum heat transfer rate and that is taken as the design cooling load on the building through the walls okay.

So this CLTD values and CLTD tables have to be used for all sunlit walls and roof and how about other elements. For example which are not sunlit for other elements which are not sunlit or which have very small thermal capacity for such as doors windows internal walls floor etcetera. The CLTD is simply equal to the temperature difference across the element. So here you do not have to consider the solar radiation aspects etcetera. Because either they are not sunlit or they have very small thermal capacity hence they do not store much energy okay. So for these elements the heat transfer rate is simply is equal to UA into temperature difference. For example for an external door Q is equal to U into A into T out minus Ti where T out is the design outdoor temperature and Ti is the design indoor temperature okay. That is how you have to find out heat transfer rate through all the opaque elements of the building.

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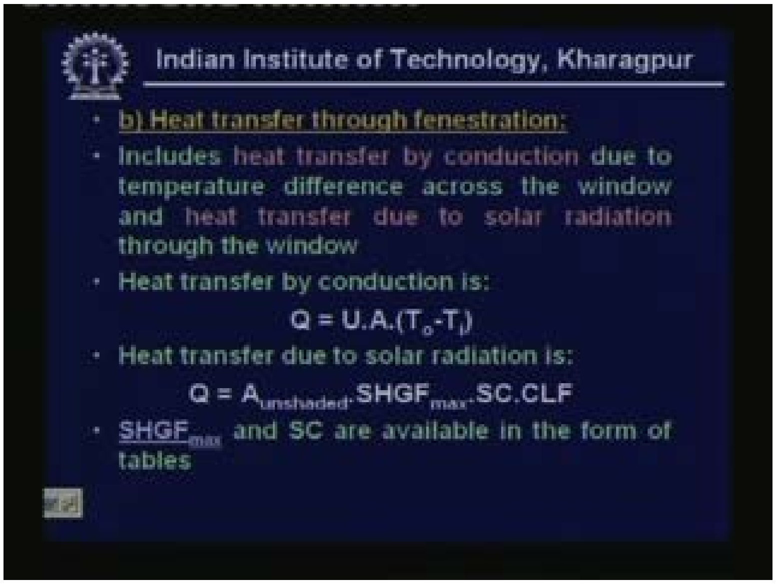

Next comes heat transfer rate through fenestration. As I said is a transparent surface such as windows etcetera for heat transfer through fenestration the, this includes heat transfer by conduction due to temperature difference across the window and also heat transfer due to solar radiation through the window. So it consists of two components again this is sensible in nature okay. So for heat transfer by conduction is simply given by Q is equal to U into A into T naught minus Ti where U is the overall heat transfer coefficient for that particular window and A is a surface area of the window and T naught and Ti are the design outdoor and indoor temperatures. This is only one part the second part is heat transfer due to solar radiation. This is given by Q is equal to A unshaded into SHGF max into SC into CLF this these aspects. We have discussed in the last lecture in this particular expression A subscript unshaded is the unshaded area of the window okay.

If it has any external shading devices such as overhang, so to find out the unshaded area and you have to use that area not the total area and SHGF max is the solar heat gain factor maximum. Solar heat gain factor SC is the shading coefficient which takes into account that different types of glass and also any internal shading devices such as curtains etcetera. And CLF is what is known as cooling load factor. And we have seen in our earlier lecture that the values of SHGF max and shading coefficient FC are available in the form of tables. Let me show typical tables which I have already shown.

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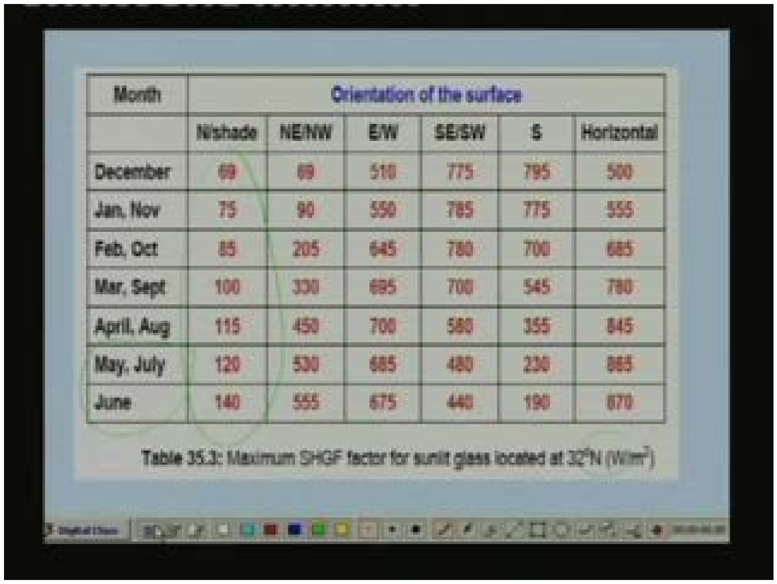

Month	Orientation of the surface					
	N/shade	NE/NW	E/W	SE/SW	S	Horizontal
December	69	69	510	775	795	500
Jan, Nov	75	90	550	785	775	555
Feb, Oct	85	205	645	780	700	685
Mar, Sept	100	330	695	700	545	780
April, Aug	115	450	700	580	355	845
May, July	120	530	685	480	230	865
June	140	555	675	440	190	870

Table 35.3: Maximum SHGF factor for sunlit glass located at 32°N (W/m^2)

Earlier, for example this particular table gives the maximum solar heat gain factor for sunlit glass located at thirty two degrees north latitude and the units are watt per meter square okay. Here the maximum value is given for different months for December from the starting from January to December for different orientations of the window okay. For example if the window is north facing or if it is in shade these are the values to be used okay. And for other orientation these are the typical values to be used if you are carrying out the calculations for summer typically we consider these months either from May to July okay. So you have to take either one of these two values depending upon where the design temperature is likely to be maximum okay. This is a table for SHGF max and such tables for different latitudes are available in ASHRAE hand books.

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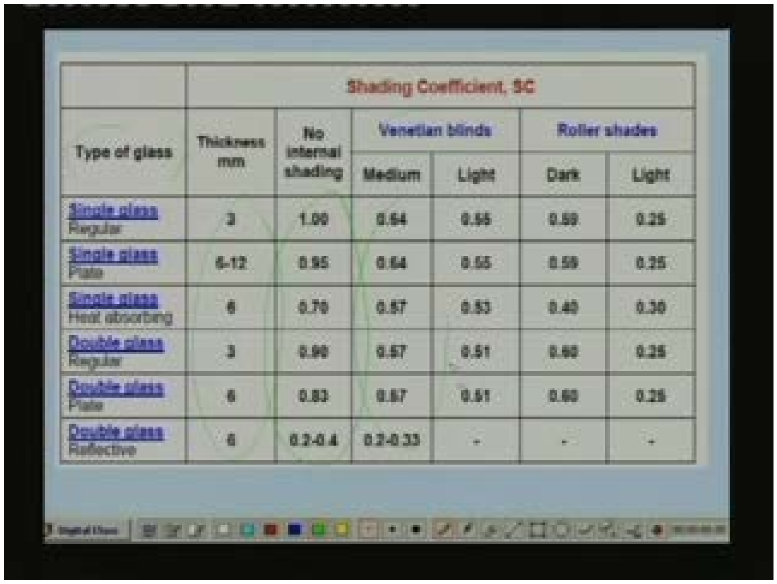

Type of glass	Thickness mm	Shading Coefficient, SC				
		No internal shading	Venetian blinds		Roller shades	
			Medium	Light	Dark	Light
Single glass Regular	3	1.00	0.64	0.55	0.59	0.25
Single glass Plate	6-12	0.95	0.64	0.55	0.59	0.25
Single glass Heat absorbing	6	0.70	0.57	0.53	0.40	0.30
Double glass Regular	3	0.90	0.57	0.51	0.60	0.25
Double glass Plate	6	0.83	0.57	0.51	0.60	0.25
Double glass Reflective	6	0.2-0.4	0.2-0.33	-	-	-

Next table shows the shading coefficient values. As I have already said the shading coefficient considers the type of the glass okay. Whether it is a single regular glass or whether it is heat absorbing glass or double glass right and for different thicknesses. And if they, if you do not have any internal shading this is the shading coefficient value and if you have any internal shading such as initial blinds or roller shades these are the shading coefficient values to be used okay. So this is as for as your shading coefficient and SHGF max is considered then what is cooling load factor.

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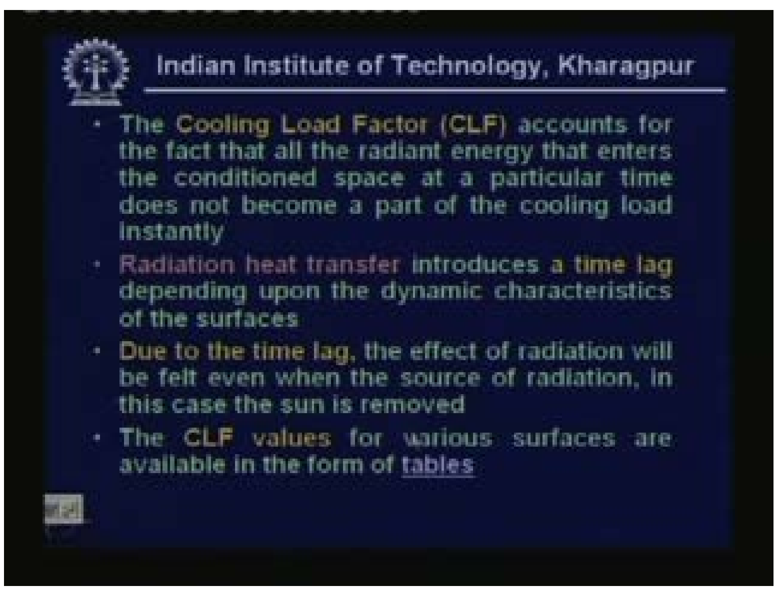

The cooling load factor CLF accounts for the fact that all the radiant energy. That enters the conditioned space at a particular time does not become a part of the cooling load instantly. Radiation heat transfer introduces a time lag depending upon the dynamic characteristics of the surface. So what happens when radiation enters into a conditioned space? Let us say that you a window expose to the outside and solar radiation enters into the conditioned space through the window okay. Since it is radiation the air inside the building does not absorb all these radiation okay. Only a small fraction of this is absorbed by the air most of it is absorbed by the surrounding surfaces. For example the walls floor roof if any furniture is there that also absorbs its radiation. So first the radiation is absorbed by the walls and the other surfaces and not by the air okay.

So as a result when radiation first enters into the conditioned space the conditioned air temperature does not increase immediately okay. So what happens is first all this surfaces absorb solar radiation as a result their temperature increases depending upon their thermal capacity okay. When the air temperature goes beyond the conditioned space temperature then there will be heat transfer by convection from the internal surfaces to the conditioned air only when this a heat is transferred to the conditioned air then only it becomes a part of the cooling load on the building not when it enters into the building okay. So that means you can see that there is a time lag that time at which the solar radiation enters into the building and the time at which it is transferred to the air okay.

So this time lag is coming because of the radiation factor okay. So this time lag is taken into account by introducing a factor called as cooling load factor okay. The radiation may also introduce a decrement for example if the surrounding surfaces are absorbing the radiation and a part of it may be transferred to the outside air not to the inside air okay. So all these aspects are clubbed into a single factor called as cooling load factor if you do not consider cooling load factor or if you take the cooling load factor as one that means you will be over estimating the heat transfer or over estimating the cooling load okay another peculiar aspect of this radiation heat transfer is that even when the source of radiation is removed still you feel the effect of the source. That means even when sunsets still inside the building it will be warm okay because of the time lag okay.

So this is the typical characteristics of radiation now due to the time lag the effect of radiation will be fell even when the source of radiation in this case the sun is removed okay. As I have already explained to you the CLF values for various surfaces are available in the form of tables okay. So these tables have been obtained from experimental measurements etcetera.

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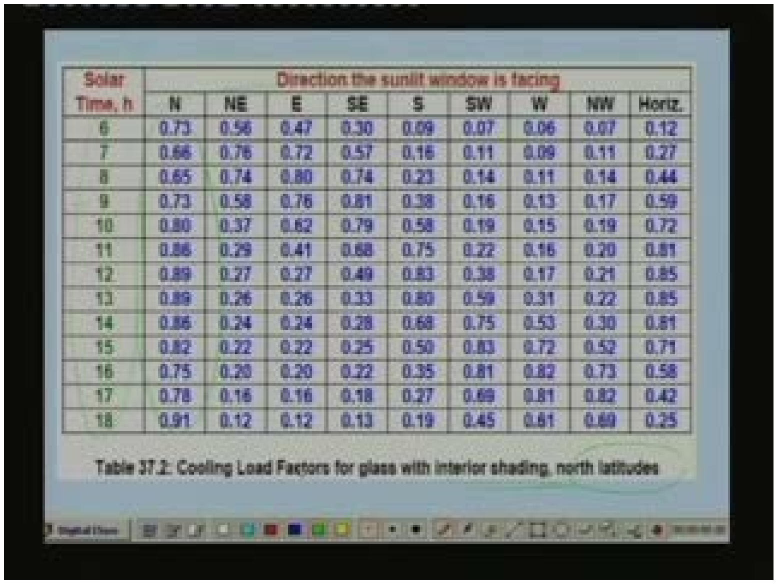

Solar Time, h	Direction the sunlit window is facing								
	N	NE	E	SE	S	SW	W	NW	Horiz.
6	0.73	0.56	0.47	0.30	0.09	0.07	0.06	0.07	0.12
7	0.66	0.76	0.72	0.57	0.16	0.11	0.09	0.11	0.27
8	0.65	0.74	0.80	0.74	0.23	0.14	0.11	0.14	0.44
9	0.73	0.58	0.76	0.81	0.38	0.16	0.13	0.17	0.59
10	0.80	0.37	0.62	0.79	0.58	0.19	0.15	0.19	0.72
11	0.86	0.29	0.41	0.68	0.75	0.22	0.16	0.20	0.81
12	0.89	0.27	0.27	0.49	0.83	0.38	0.17	0.21	0.85
13	0.89	0.26	0.26	0.33	0.80	0.59	0.31	0.22	0.85
14	0.86	0.24	0.24	0.28	0.68	0.75	0.53	0.30	0.81
15	0.82	0.22	0.22	0.25	0.50	0.83	0.72	0.52	0.71
16	0.75	0.20	0.20	0.22	0.35	0.81	0.82	0.73	0.58
17	0.78	0.16	0.16	0.18	0.27	0.69	0.81	0.82	0.42
18	0.91	0.12	0.12	0.13	0.19	0.45	0.61	0.69	0.25

Table 37.2: Cooling Load Factors for glass with interior shading, north latitudes

So for example this shows a typical table for cooling load factors for glass with interior shading and this is applicable to north latitudes okay. So you can see that for glass with interior shading and for north latitude okay. So here again you can see that the CLF these are all the CLF values okay, you can see that everywhere it is less than one right and this is the function of the solar time okay. So it varies with solar time and at also varies with the orientation of the window okay. If you are calculating radiation heat transfer just like CLTD what you have to do is you have to calculate heat transfer rate at different times. Let us say at nine am ten am eleven am etcetera okay. Then you have to calculate different times for all the windows that means windows in different orientations. And then you have to calculate what is the total heat transfer rate due to solar radiation at nine am ten am eleven am etcetera. And you have to select the maximum value okay for system capacity estimation.

Okay. As I said this kind of tables are available in several handbooks such as ASHRAE handbooks and all for different conditions okay. For example as I said this is with interior shading okay. Without interior shading you will have different values for cooling load factors for glass okay.

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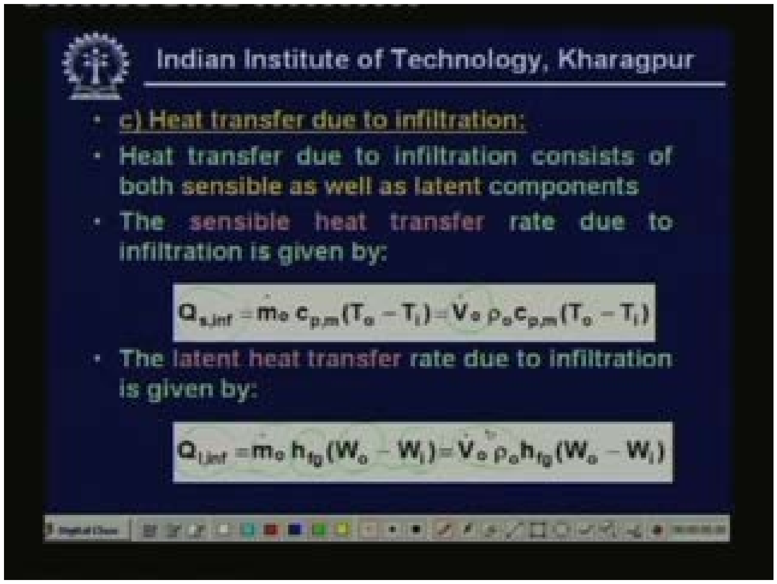

Next comes heat transfer due to infiltration. Heat transfer due to infiltration consists of both sensible as well as latent components. When outside air enters into the building it brings along with it both sensible heat as well as latent heat in the form of moisture okay. So due to due to ventilation as well as infiltration you have sensible and cooling loads being added to the building okay. So we have to find out what is the amount of sensible heat transfer to the building because of infiltration and we also have to find out what is the latent heat transfer to the building because of infiltration okay.

The sensible heat transfer rate due to infiltration is given by Q subscript s infiltration is equal to m m dot subscript o into Cpm into T naught minus Ti which is a, which is written in terms of volumetric flow rates. This is your volumetric flow rate. So many meter cube per second okay. Multiplied with density of the air Cpm is the specific heat of the moisture and T naught and Ti are the outdoor and indoor design temperatures okay.

So if you know the design outdoor and indoor temperatures and if you know what is the infiltration rate you can find out what is the heat transfer rate sensible heat transfer rate due to infiltration. Similarly the latent heat transfer rate due to infiltration is given by this expression. This is a latent heat transfer rate due to infiltration which is equal to infiltration mass flow rate of infiltrated air multiplied by the latent heat of vaporization for water multiplied by the humidity ratio difference where this is the outdoor humidity ratio, this is the indoor humidity ratio okay. Again this is written in terms of the volumetric flow rates right. So if you know the infiltration rate then you can easily calculate what is the heat transfer rate due to infiltration. Of course the main problem is how to estimate the infiltration rate.

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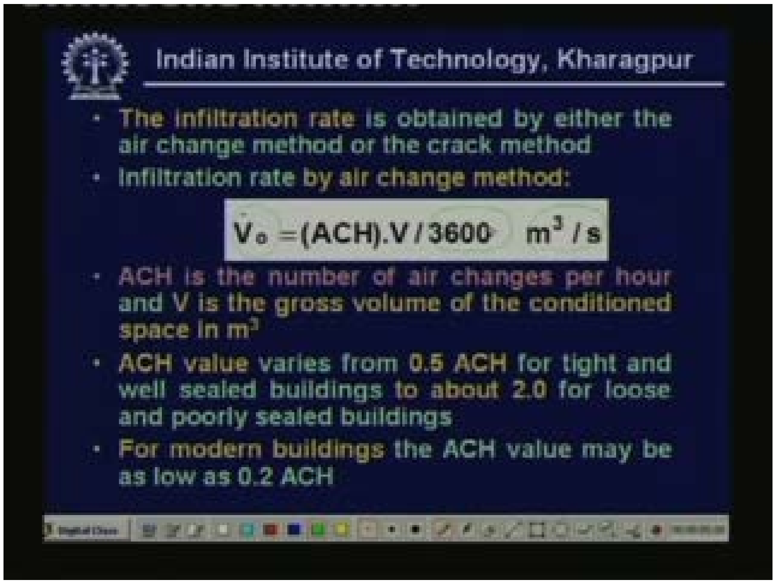

The infiltration rate is obtained by either the air change method or the crack method okay. This also I have discussed in the last lecture in one of the lectures infiltration by air change method is given by this formula infiltration rate okay, in meter cube per second right is given by ACH multiplied by V divided by three thousand six hundred where ACH is the number of air changes per hour and V is the gross volume of the conditioned space in meter cube okay. Since air changes are per hour where we have to divide by three thousand six hundred to get meter cube per second okay.

And these ACH values it is observed that the air change values vary from point five ACH for tight and well sealed buildings to about two for loose and poorly sealed buildings okay. And it can be as low as point two for modern buildings which are very tight okay. The modern buildings are generally designed not to allow any outdoor air that means they have very small infiltration rates okay. So knowing the infiltration rate from air change method from air changes you can calculate what is the heat transfer rate due to infiltration of course how do you decide whether the building is well built tightly sealed or what should be the value of ACH to be used okay. Generally the value of ACH depends upon the condition of the building the building is old okay.

And if it not poorly if it is not properly sealed that means windows and all there will be lot of air gaps then obviously the ACH value will be higher okay. So you have to use some experience in choosing a proper value for ACH okay the next method.

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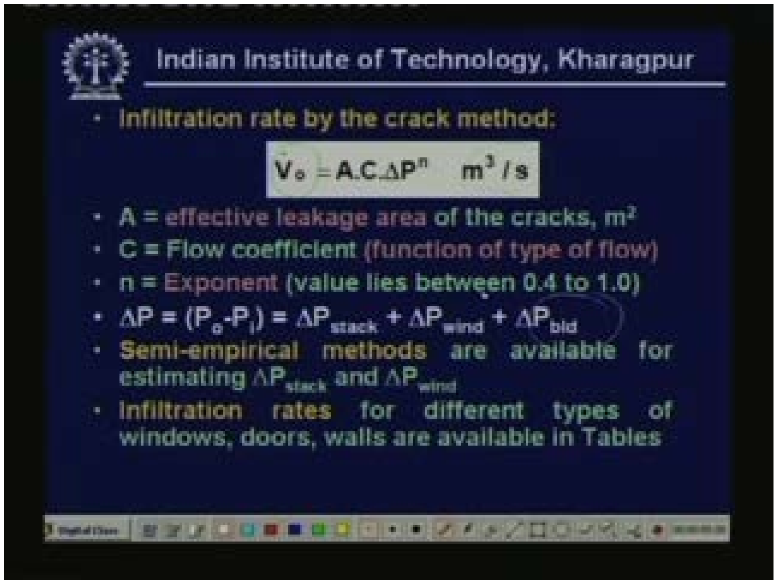

As I said is what is known as infiltration rate by the crack method okay. So this is given by again the infiltration rate here this is the infiltration rate in meter cube per second this is equal to A into C into delta P to the power of n okay. And it is in meter cube per second what is A? A is what is known as effective leakage area of the cracks okay. The units are meter square and C is the flow coefficient which depends upon the type of flow that means type of the air flow through the cracks okay. So depending upon the type of flow the value of C varies and n is an exponent which again depends upon the type of the flow okay.

And its values lie between point four to one okay. And what is delta P delta P is nothing but that pressure different between outdoor and indoors. So delta P is equal to P naught minus Pi where P naught is the outside pressure and Pi is the inside pressure and it is seen that delta P is equal to summation of pressure difference due to stack effect pressure difference due to wind effect and pressure difference due to building pressurization okay. Delta P this is particular this is that pressure difference build due to building pressurized. That means if the building is pressurized there will be a pressure difference okay.

And I have explained what do you mean by stack effect and wind effect and last in one of the lectures okay, stack effect occurs due to temperature difference between the indoors and outdoors. So these also known as chimney effect okay. Because the temperature difference there will be some buoyancy effect and because the buoyancy there will be a mass transfer between the outdoors and indoors okay. Air enters or leaves because of this and the wind effect when wind is blowing over the building. That means outside this also introduces a pressure difference okay.

So this is a pressure difference due to wind right so the total pressure difference between the conditioned space and the outdoors is a summation of pressure difference due to stack effect pressure difference due to wind effect plus building pressurization okay. And semi empirical methods are available for estimating delta P stack and delta P wind actually the estimation of delta P due to stack effect and delta P due to wind effect analytically can be very complicated okay because this depends up on the construction of the building okay. And direction of the wind also may vary and wind is highly variable okay. So analytical estimation of delta P because of these two factors can be quite complicated okay. However semi empirical methods are available using which one can estimate the pressure difference because of these two effects right once you know the pressure difference and once you know what is the type of flow then you can calculate what is the infiltration rate of course you also have to know what is the area of the crack which is again difficult okay.

So what is done in practice is for different types of windows doors buildings etcetera. The infiltration rates have been measured okay, as a function of temperature difference as a function of the wind velocity etcetera and they are available in the form of tables okay. So knowing the outdoor and indoor temperatures and knowing the wind velocity one can estimate the infiltration rate depending upon the type of the window okay. That is what is generally done while estimating infiltration rates.

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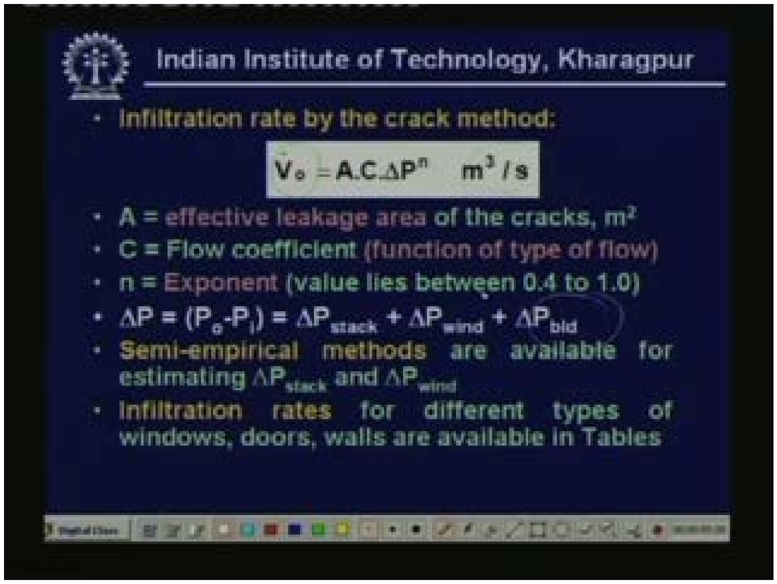

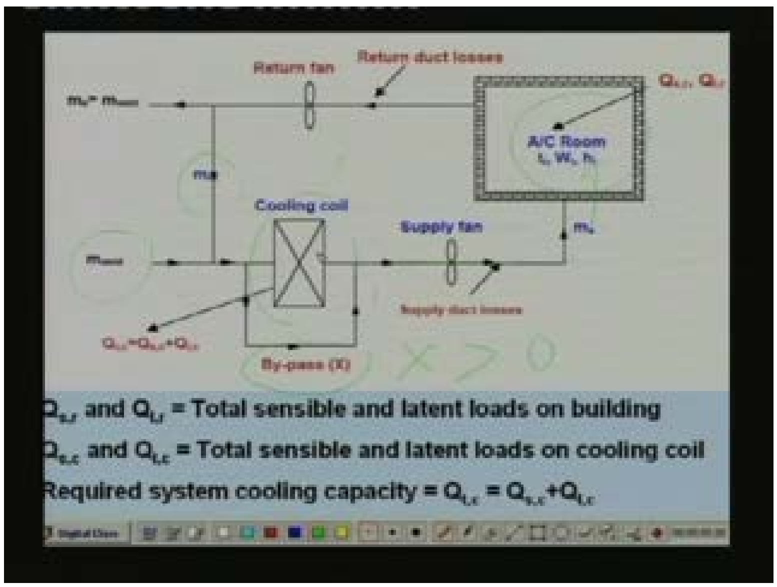

Next in addition to all these factors if the cooling coil has a positive by-pass factor then some amount of ventilation air directly enters the condition space in which case it becomes a part of the building cooling load. Let me explain this, what is shown here is a, an air conditioning system right. So you have the conditioned space here and we are right now we are finding out what is the total heat transfer rate to the conditioned space okay. Sensible as well as latent and ventilation if you if you remember I have discussed this earlier you some amount of ventilated air is required for indoor air quality. So generally what is done is this outdoor air is mixed with some amount of re-circulated air then it is processed in the cooling coil and the processed air is supplied to the conditioned space okay.

But normally all cooling coils will have some by-pass factor okay. This by-pass factor means in general greater than zero and it will be less than one okay. So because the by-pass factor what happens is some amount of outdoor air does not flow through the cooling coil but it by-passes the cooling coil and directly enters into the building okay. So it is not rejecting, its heat to the cooling coil but it is rejecting its heat to the conditioned space in which case it becomes a part of the cooling load of the building not a cooling load on the coil okay. I will show the different between the load cooling load on the coil and cooling load on the building in the later slide right but you have to keep in mind that if you have a non zero by-pass factor you must consider that while estimating the load on the building okay.

So how do we estimate the latent and sensible heat transfer rates because of this bypassed ventilated air. So it is very simple the sensible and latent loads due to the by-pass ventilation air are obtained using the values of ventilation rate by-pass factor and using expressions similar to that of infiltration. All that you have to do is you have to replace the infiltration rate with this quantity okay. You have to replace it with this quantity and this quantity is nothing but the, a flow rate of air bypassed ventilated air okay, that is what you have to do.

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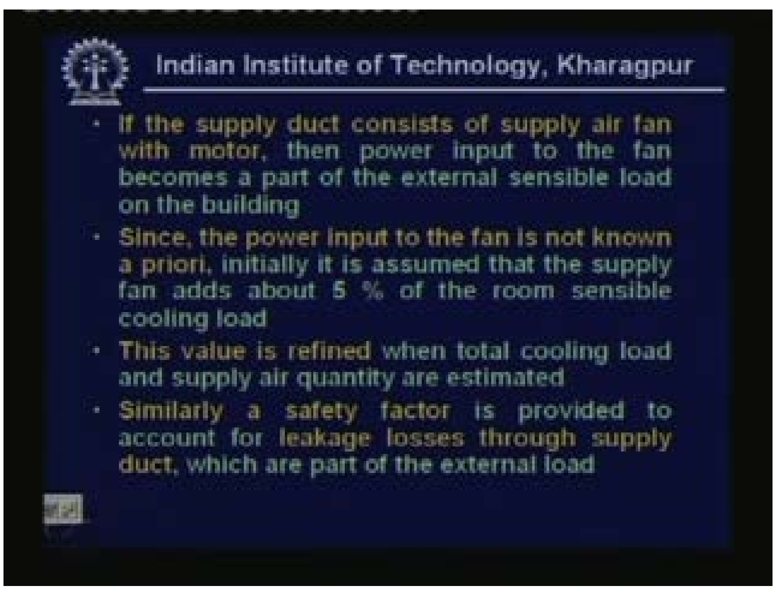

In addition to this if the supply duct consists of supply air fan with motor then power input to the fan becomes a part of the external sensible load on the building okay. You have seen that normally a supply duct consists of a fan and supply duct even though it is insulated it is not possible to perfectly insulate the supplied duct. So the inside temperature, that means the temperature of air inside the supply duct will be much less than the temperature outside okay. So as a result there will be some heat transfer from the outside to the inside air through the insulation okay. This is sensible heat transfer in addition to that if the supplied air duct has some leakages through which air is escaping okay. This also a loss right and this becomes a part of the external load on the building.

So these factors also have got to be considered while calculating the external load on the buildings okay. How do we consider this the problem here is that since the power input to the fan is not known before hand what we normally do is we assume that the supply fan adds about five percent of the room sensible cooling load. Because initially we do not know what is the power input of the fan right. Because we have not yet selected the fan how do we select the fan we select the fan depending upon the flow rate. So at this moment we do not know what is the required air flow rate. Because we have not yet estimated the total load on the building right but the fan power is the part of the building load okay.

So what is normally done is we initially we assume that the fan adds about five percent of the total cooling load on the building okay. So you take multiply the building cooling load by one point zero five okay, where point zero five takes into account the heat added due to the fan right and you do the regular load calculations and at the end when you know what is the supply air flow rate then you can select a fan and then again you can refrain this value by taking the actual fan power conjunction to account this is what is generally done okay. Similarly this is what I have mentioned similarly a safety factor is provided to account for leakage losses through supply duct which are part of the external load okay. Again external leakage losses through supplied duct this also difficult to estimate at this point because we do not know what is the size of the duct.

So we will see in a later lecture that the size of the duct has to be decided at depending upon what is the required flow rate okay. Since we do not know the flow rate at this point we can at find out what is the loss though the supply duct. So what we do is we add or we take a safety factor which will account for heat losses through the supply duct and which can be again defined in the end when you have all the other values okay.

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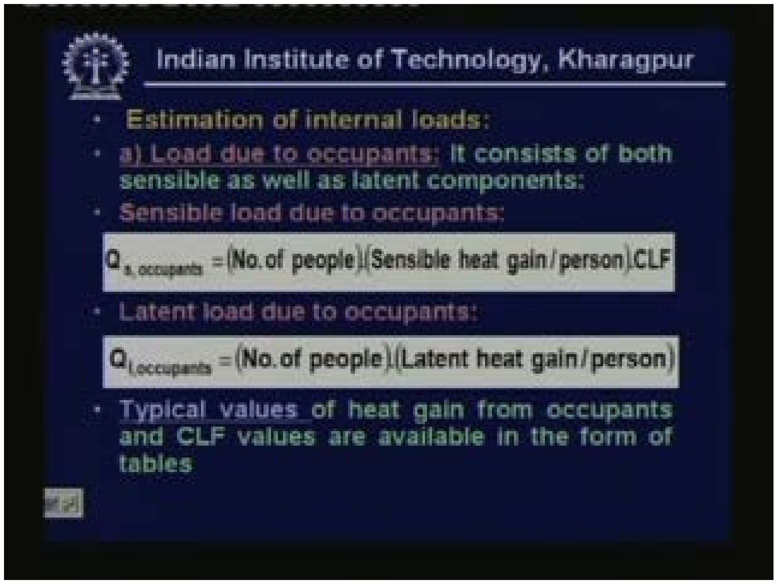

Now we have seen all the external loads. Now let us look at internal loads how do you estimate cooling load due to internal heat generating sources what are the internal heat generating sources first internal heat generation source is the occupant himself okay. So what is the load due to occupants as we know the load due to occupants consist of both sensible as well as latent components okay. Because sensible heat transfer because of heat transfer between the human body and the surrounding air latent heat transfer because of evaporation and respiration from the body okay.

So sensible load due to occupants is given by number of people multiplied by sensible heat gain per person multiplied by CLF okay. Where CLF is the cooling load factor why are we using cooling load factor here we are you we have to use strictly speaking we have to use cooling load factor because the heat transfer rate sensible heat transfer rate from a human body to the conditioned air takes place by convection as well as radiation okay. You also have a radiation here the moment you have a radiation again it does not become an instantaneous load on the building okay. Again there is a time lag so strictly speaking if you want to find out what is the sensible heat transfer rate from the occupants you have to consider the CLF for the occupants cooling load factor just like radiation through fenestration okay.

Next comes latent load due to occupants latent load due to occupants is given by number of people in the occupied space multiplied by latent heat gain per person okay. Here you do not use any cooling load factor because the latent load is an instantaneous load because the moisture is instantaneously added to the surrounding air and it becomes an instantaneous load. So you do not have to use any CLF value okay. And typical values of heat gain from occupants and CLF values are available in the form of tables okay. Let me show a simple table.

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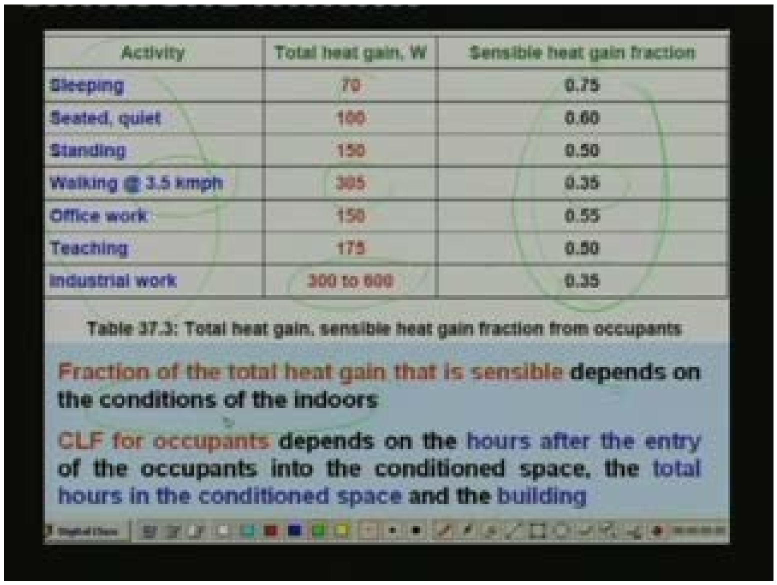

Activity	Total heat gain, W	Sensible heat gain fraction
Sleeping	70	0.75
Seated, quiet	100	0.60
Standing	150	0.50
Walking @ 3.5 kmph	305	0.35
Office work	150	0.55
Teaching	175	0.50
Industrial work	300 to 600	0.35

This table here shows what is the total heat gain per person okay. As a function of activity right for different activities okay. So this is the activity this is the total heat gain per person right seventy watts per person hundred watts per person like that and out of this what fraction of it is in the form of sensible heat and what fraction is in latent heat okay. For example if the person is sleeping that means if the occupied space consist of people who are sleeping then heat gain per person is given by seventy watts and out of this seventy watts seventy-five percent is in the form of sensible heat and twenty-five percent is in the form of latent heat and if the occupants are seated okay.

Then they release about hundred watts of heat per person and out of these sixty percent is in the form sensible heat and forty percent in the form of latent heat. Similarly for different activities for example the conditioned space has people who are walking at a rate of three point five kilometer per hour then they release much larger amount of heat because of higher activities. So you find that bout three naught five watts per person is released and out of these only thirty-five percent is sensible and sixty-five percent is latent okay. Similarly for other activities for example industrial work lot of heat is released about three hundred to six hundred watts per person and out of it only thirty five percent is sensible and sixty five percent is latent okay.

This kind of information for a wide variety of activities are again available in air conditioning data hand books okay. And month in year you must keep in mind is that the fraction of the total heat gain that is sensible that means this factor okay. This depends very much on the conditions of the indoors okay. If the indoor temperature increases then the sensible heat gain fraction decreases and latent heat gain fraction increases okay and vice versa. And again these kinds of information's available what is the sensible heat gain fraction as a function of the indoor conditions okay. That information also available in hand books right next comes the CLF value for occupants CLF value for occupants are also available in the form of tables and this depends on the hours after the entry of the occupants into the conditioned space the total hours in conditioned space and the type of the building okay.

So depending upon all these factors the CLF values have been obtained you will appreciate the use of CLF factor we know from common experience that let us say that you have a theatre okay. And lot of people is there in the theatre and surrounding air becomes warm okay. So even when all the people leave the theatre still the temperature inside the occupied space continues to increase. Because of the time lag right this is because the fact that the human beings release heat sensible heat in the form of radiation as well as convection okay. So all that radiation portion is absorbed by the building surrounding building and it is slowly released okay. So as a result you feel the effect even when there are no occupants okay.

So this factor is taken into account by the CLF factor okay. In some of the air conditioning load estimation methods the CLF is simply taken as one. That means they do not consider the radiation effect. So if you do not consider the radiation effect and take CLF as one normally you will be slightly over estimating the required cooling capacity okay. Of course if you do not have any information it is always better to take a CLF value of one. So this is a heat load due to occupants.

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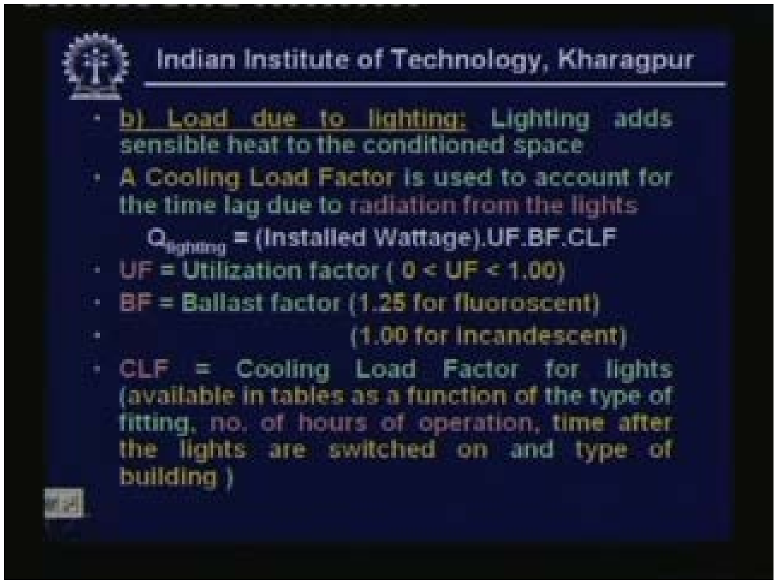

Next comes load due to lighting adds sensible heat to the conditioned space and we know very well that the heat added by lighting is mainly if it is a incandescent lamp it is in the form of radiation. So again you have to use a cooling load factor okay. So a cooling load factor is used account for the time lag due to radiation from the lights and the total heat transfer rate due to lighting is given by this expression Q lighting is equal to installed wattage multiplied by UF multiplied by BF multiplied by CLF where installed wattage is the total amount of lighting. That means so many watts of lights inside the conditioned space and what is UF? UF is known as a utilization factor and the value of UF lies between zero to one what is utilization factor utilization factor is that at the time of load calculations all the lights in the building may not be on okay, only few lights may be on.

So if you take the installed wattage then you will be over estimating the required cooling capacity. For example if we are doing the load calculation for day time okay. And if it has considerable natural light then most of the lights may be off right then there is no point in considering the wattage of all this lights because they are not on. So they are not load on the building okay. So if you want to be more accurate you must consider the utilization factor okay. Which as I said is lies between zero to one then comes the ballast factor BF, BF is known as ballast factor and the ballast factor is one point two five for fluorescent lamps and it is one for incandescent lamps.

That means lamps with choke you have to take twenty-five percent higher than the rated wattage where as for incandescent lamps which do not have any choke the ballast factor value is one and CLF. As I said is a cooling load factor and cooling load factor for lights. That is again available in tables as a function of a type of fitting I mean what kind of light fitting it is and the number of hours of operation. That means how many hours lights are on and time after the lights are switched on and type of the building okay. So depending upon all these factors the CLF values have been obtained and they are available in the form of tables okay. So using the table and using suitable values we can find out what is the load due to lighting of course load due to lighting is purely sensible you do not have any latent component okay, load due to lighting can be considerable especially in modern buildings which do not have any external windows okay. So one should not neglect this one must consider load due to lighting okay.

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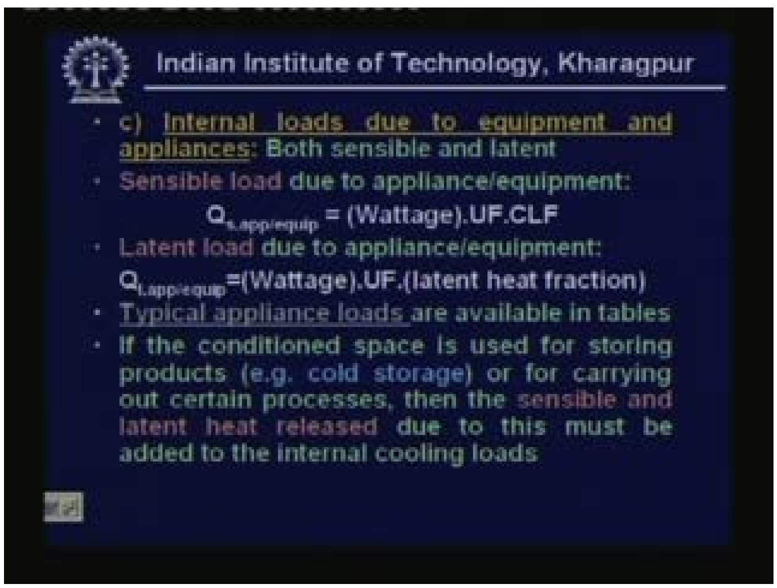

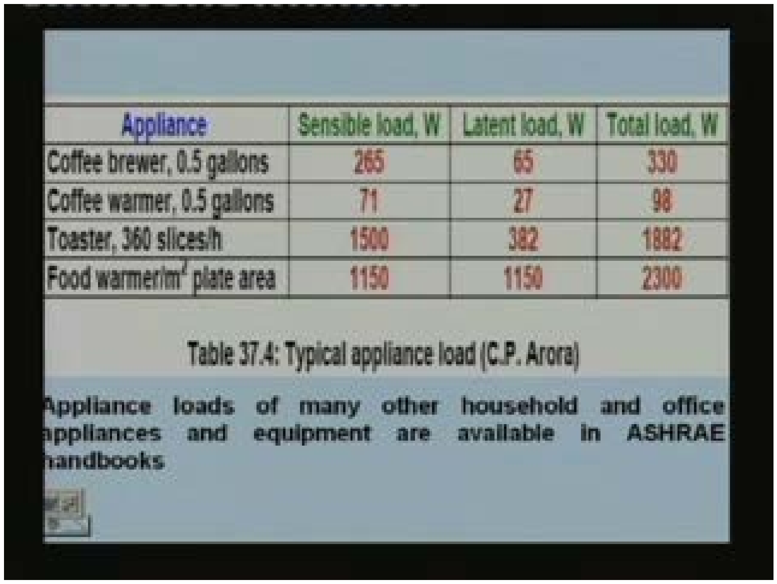

Appliance	Sensible load, W	Latent load, W	Total load, W
Coffee brewer, 0.5 gallons	265	65	330
Coffee warmer, 0.5 gallons	71	27	98
Toaster, 360 slices/h	1500	382	1882
Food warmer/m^2 plate area	1150	1150	2300

Next comes internal load due to equipment and appliances and when in a conditioned space may consist of many home appliances or several equipments such as computers printers etcetera. All these generate heat and this heat is added to the air inside the conditioned space and it has to be ultimately taken out from the building okay. And this load can be sensible and latent depending upon the type of the equipment and how do we estimate the sensible load due to appliance or equipment it is simple it is given by Q sensible load due to appliance or equipment is equal to rated wattage multiplied by the utilization factor UF multiplied by the cooling load factor. Here again you can have a cooling load factor because some of the sensible heat from the equipment or appliance may be in the form of radiation.

For example if you have an oven or if you have an electrical heater inside the conditioned space then most of the heat may be in the form of radiation in which case you have to consider the cooling load factor okay. Again as I said UF is the utilization factor and then what is the latent load due to appliance or equipment latent load due to appliance or equipment is given by the rated wattage multiplied by the utilization factor multiplied by the latent heat fraction. That means how much heat how much of the total heat is in the form of latent heat okay. For example if you have a pressure cooker okay then there may be a lot of moisture addition to the conditioned air okay. In which case the appliance the adding load of latent heat to the conditioned air. So you have to treat that separately okay.

So one must have information about this even though the equations for estimating internal loads. For example for occupants for lighting and for appliances appear to be quite similar quite simple okay. They are simply multiplication of wattage and you have utilization factor etcetera. In actual case it could be quite complicated because of the fact that the utilization fact has been vary widely okay.

So precise knowledge about the utilization factor is generally not available okay. Most of the time you have to make an intelligent guess and use in proper utilization factor. If you are taking a utilization factor of one and taking a cooling load factor of one. As I said you will be over estimating the capacity right on the other hand if you taking two lesses two smaller value then it will be under estimating the capacity and the system may not be adequate okay. So this is what brings in the difficulty and typical appliance loads are available in the form of tables. Let me show a typical table so this table is taken from professor Arora's book. And here it I have just shown the four appliances a coffee brewer of point five gallon capacity it rejects about two sixty-five watts of sensible load and about sixty-five watts of latent load and the total load of this particular appliance is three thirty watts okay. And a coffee warmer of point five gallon capacity it rejects about seventy-one watts in the form of sensible heat and twenty-seven watt in the form of latent heat if you have a toaster of three sixty slices per hour then the sensible load is about fifteen hundred watts and the latent heat load is three eighty-two watts.

And for example a food warmer it is eleven fifty watts of sensible load per meter square of the plate area and eleven fifty watts of latent heat load per meter square of plate area. So total heat radiation is two thousand three hundred watts okay. And appliance of loads of many other house hold and office appliances and equipment are available in ASHRAE hand books. In fact if you look at ASHRAE handbooks it covers a wide variety of all kinds of home appliances and office equipment okay in addition to that if the conditioned space is used for storing products for example if you are doing the load calculation for a cold storage then you will be using the conditioned space for storing food products.

For example I am designing a cold storage for storing potatoes okay. So potatoes are live products so they will be adding continuously heat to the conditioned space. So I should be able to estimate what is the heat generation rate because of the products stored inside the conditioned space in this case potatoes it could be potatoes or it could be anything right. So I should be able to know uh what is the amount of sensible heat generated because of this and what is the latent heat generated okay. Because of the product stored in the conditioned space again lot of informations available on the amount of heat released in sensible as well as in latent form by a wide variety of products which are normally stored in cold storages okay. So you can look at any uh air conditioning design or refrigeration design data book.

So you find that this information is available okay so this is very important for estimating the loads of cold storages and other industrial or commercial air conditioned buildings okay. In addition to this if some process is taking place inside the conditioned place okay. Let us say that we are talking about air conditioning of a chip manufacturing factory okay. So the lot of processes will be taking place inside the conditioned space which will be adding heat okay, either sensible or latent or both. So again we must have information we must have knowledge about how much heat is being added by all these internal processes for estimating the loads okay. So you can see that for load calculations a large amount of input data is required okay, a liable accurate input data is required only then you can have accurate estimations of the loads okay.

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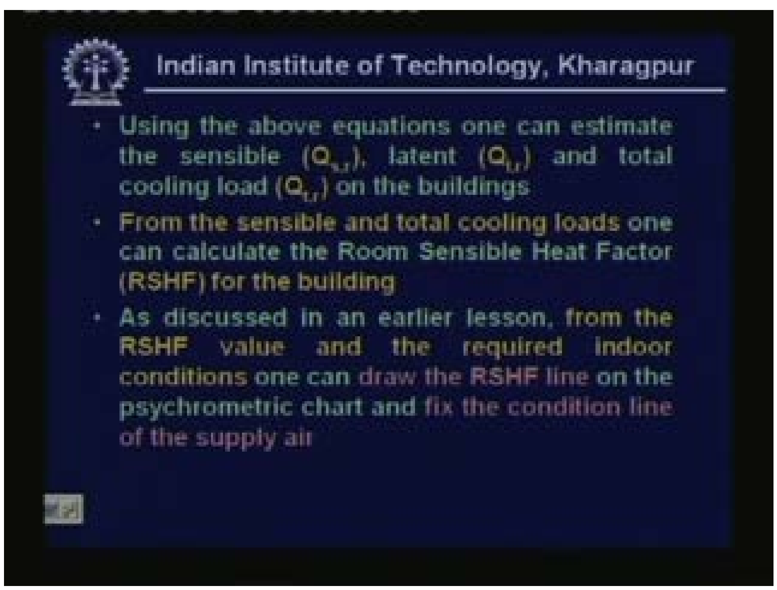

Using the above equations one can estimate the sensible total sensible load on the building total latent load on the building and total cooling load on the building total cooling load on the building is nothing but some of sensible loads and latent loads okay.

So what you mean by total sensible load on the building sensible load due to external sources sensible load due to internal sources. We have to add up all these so that will give you the total sensible cooling load on the building.

Similarly we have to add up all the latent cooling loads on the building both internal as well as external okay. We have seen individual loads we have to add up now and that will give you the total loads and when you add up everything you get the total cooling load on the building okay.

And from the sensible and total cooling loads one can calculate the room sensible heat factor RSHF for the building okay. These aspects we have discussed in our earlier lectures the room sensible heat factor as you know is nothing but the ratio of the total sensible load on the building divided by the total load on the building okay.

So since you have got all this information from the load calculations you can calculate now what is the RSHF of the building okay. And as discussed from the RSHF value and the required indoor conditions one can draw the RSHF line on the psychrometric chart and fix a condition line of the supply air okay. At this point since we know the RSHF and we also know the inside conditions you can draw the RSHF line and as you know the supply conditions must lie on this RSHF line. So that it can meet the sensible and latent loads in the required proportion okay. So at this point you can draw the process RSHF line okay from this information.

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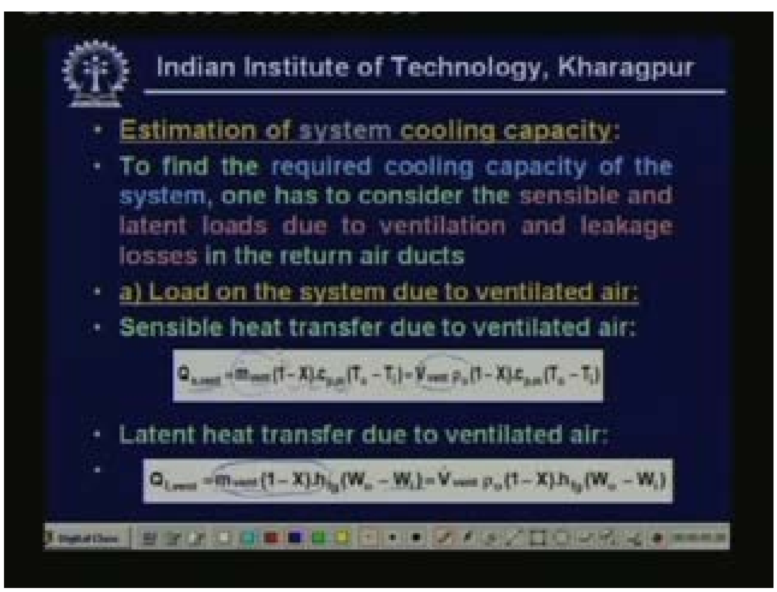

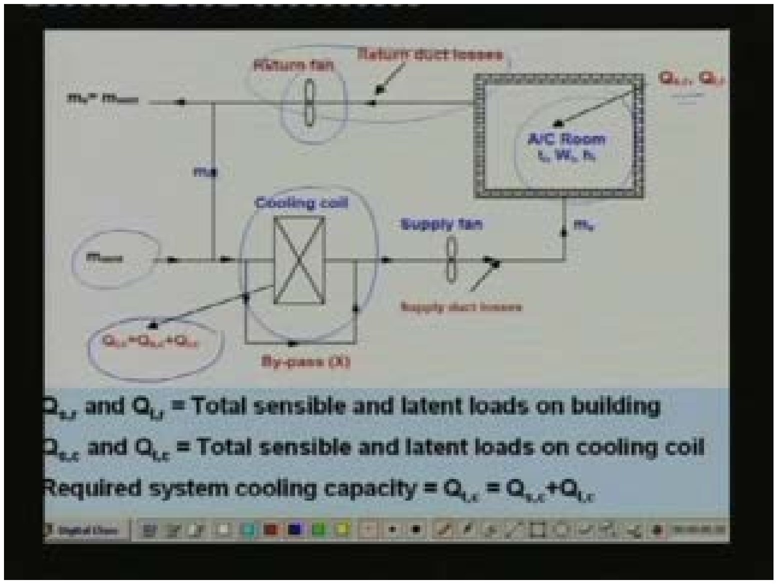

Now let us look at estimation of the system cooling capacity because ultimately we are interested in finding out what is the required cooling capacity of the system okay. To find the required cooling capacity of the system one has to consider the sensible and latent loads due to ventilation and leakage losses in return air ducts okay. So let me show a picture it will be clear again this is the picture we would have discussed earlier you can see that this is the building and this building is subjected to some amount of sensible heat load and some amount of latent heat load. And I am interested in finding out what is the required capacity of the cooling systems. That means what is the amount of heat that has to be rejected in the cooling coil. That means this okay, what is this will see a later that this is nothing but the load on the building plus load due to ventilated air that is flowing through the cooling coil plus load due to losses in the return duct okay.

So you may have return duct losses leakage losses you may also have heat addition in the return duct because of the presence of return air fan okay. So this plus this has got to be added to the building load to arrive at the total system capacity okay. So load on the system due to ventilated air is simply given by this expression is almost similar to the load due to infiltration this is equal to this a sensible load on the coil due to ventilated air which has flown through the cooling coil that is equal to ventilation rate multiplied by this factor okay, where x is the by-pass factor so one minus x is the fraction of this air that has flown through the cooling coil multiplied by specific heat of the air multiplied by temperature difference outdoor minus indoor temperature. And this can be written again in terms of flow rate okay V of ventilation air. That means in terms of meter cube per second so this is the amount of sensible heat added to the coil because of the ventilation. Similarly the latent heat added to the coil because of ventilation is given by this expression again this factor considers the amount of air that has flown through the coil and this the latent heat of vaporization and this is the uh different between the humidity ratio between the outdoors and indoors okay. So if you know the by-pass factor and if you know the amount of ventilation to be provided we can easily calculate what is the load due to ventilation right.

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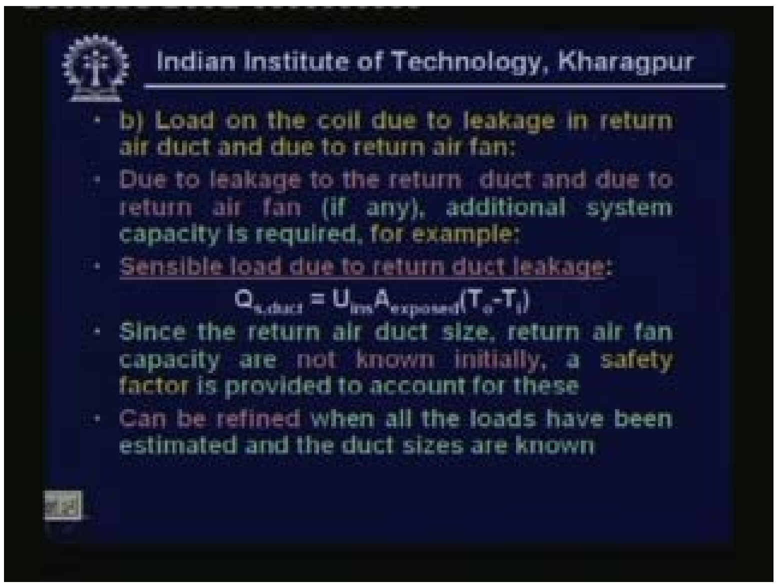

Next comes load on the coil due to leakage in return air duct and due to return air fan due to leakage to the return duct and due to return air fan if there is any fan it is not necessary that return air duct should have a fan but in some cases you may have a fan. So if you have a fan the fan and the leakage adds to the load on the system. So we must consider this okay, for example sensible load due to return duct leakage is given by Q sensible due to duct is equal to U subscript ins into A exposed into T naught minus Ti where U uh subscript ins is the overall heat transfer coefficient of the return air duct and A subscript exposed is the exposed area of the return duct.

If the return duct is in the inside the conditioned space then that need not be considered. Because that will not form a load so since the return air duct size return air fan capacity are not known initially a safety fact is provided to account for these. So just like supply air duct we do not know about a supply air duct dimensions etcetera at this moment we have taken a safety factor similarly for return air duct and return air fan we can take a safety factor and these can be refined when all the loads have been estimated and the duct sizes are known okay.

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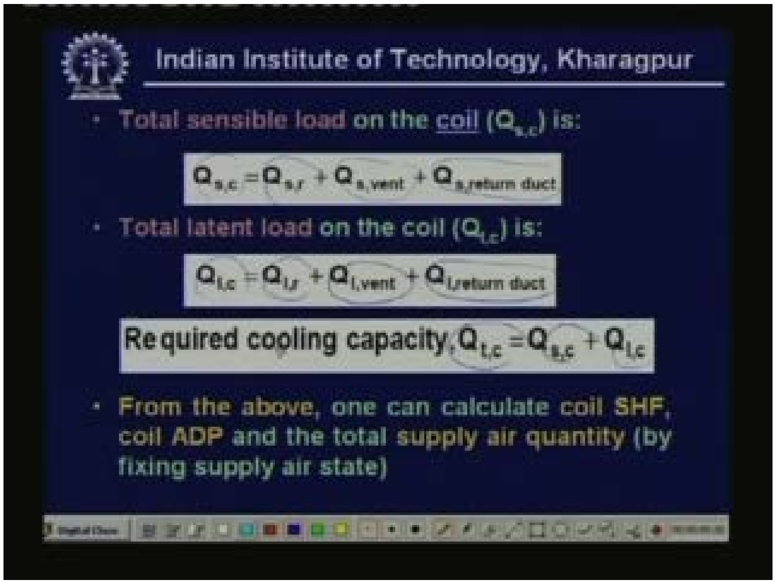

So finally the total sensible load on the coil is simply given by this is the total sensible load on the coil this is the, this is equal to sensible load on the building plus sensible load on the coil due to ventilation plus sensible load on the coil due to return air duct. Similarly total latent load on the coil is equal to total latent load on the building plus latent load due to ventilation plus latent load due to return air duct okay. So finally the required cooling capacity is nothing but total sensible load on the coil plus total latent load on the coil.

So at this point if you add up everything we can find out what is the required cooling capacity. So many kilo watts or so many tonnes and from the above one can calculate coils sensible factor coil apparatus due point and that is coil ADP and total supply air quantity okay. So all these things can be calculated at this point and these aspects we have discussed in an earlier lecture okay. So this is in brief is a method based on CLTD and CLF.

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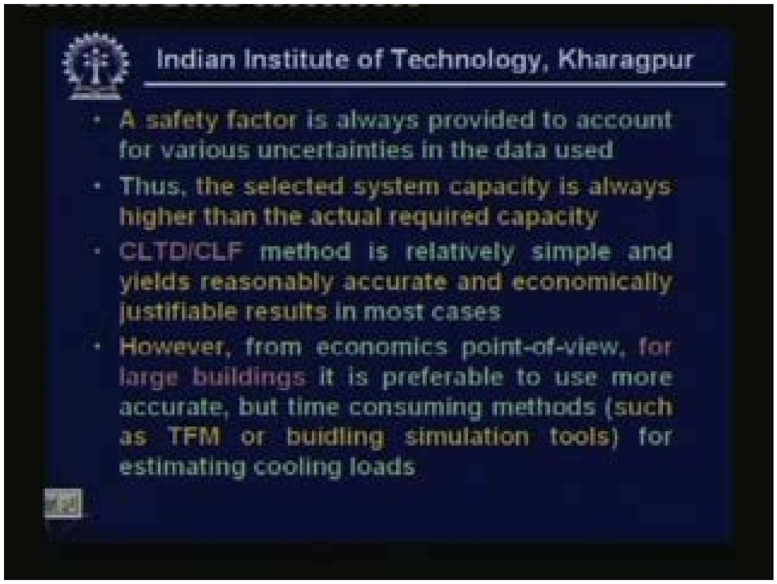

So normally all cooling load calculations, for example based on CLTD and CLF method a safety fact is always provided to account for various uncertainties in the data used okay. So for you finally multiply this by a safety factor okay, to take care of the uncertainties thus the selected system capacity is always higher than the actual required capacity CLTD CLF method is relatively simple and yields reasonably accurate and economically justifiable results in most of the cases. So this is this method is very widely used because of these reasons. However from economics points of view for large buildings it is preferable to use more accurate. But time consuming methods such as transfer function method or building simulation tools okay. If you want to find out the exact cooling load or very accurately you have to use either transfer function method or you have to actually simulate the building okay. For estimating the cooling loads, so there by you can calculate the required system capacity more accurately okay.

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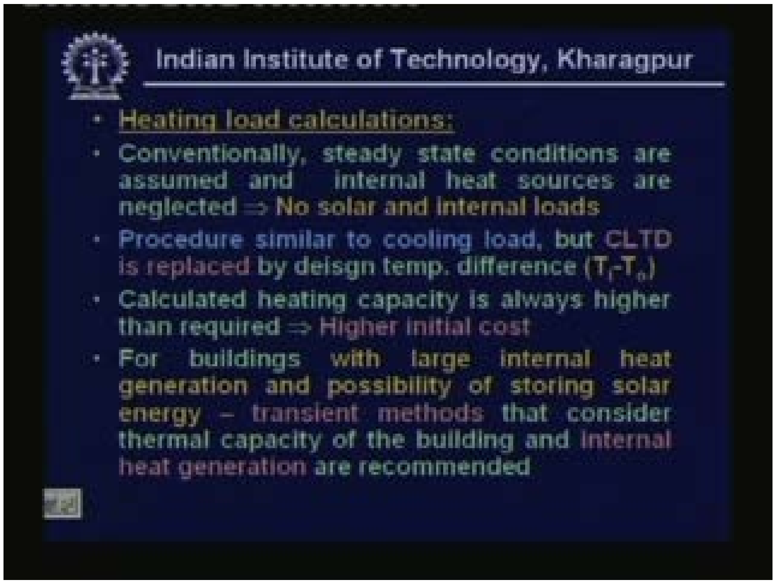

Next let us look at heating load calculations as I said heating load calculations are fairly simple and conventionally steady state conditions are assumed and internal heat sources are neglected. That means you do not have to bother about solar loads or internal loads okay. So you have to consider only external loads due to heat transfer and due to ventilation and procedure is similar to cooling load the only difference is that the CLTD value everywhere is replaced by design temperature difference that is, that means the temperature difference between the indoor and the outdoor that is T subscript i minus T subscript o. Otherwise the procedure exactly similar and you find that if you are following this method the calculated heating capacity is always higher than the required okay. As a result you will be actually spending more because the uh initial cost will be more because of the installed higher installed capacity than required.

But this is safer and that is why this is conservative okay. However for buildings with large internal heat generation and possibility of storing solar energy it is always recommended to use transient methods that consider thermal capacity of the buildings and internal heat generations.

So if you are considering the transient characteristics of the building and if you also consider the internal heat generation you find that the required heating capacity will be much less than what you get by using the steady state methods and what you get by neglecting internal loads. So thereby you can arrive at an economically justified results okay. So this in brief is the heating load calculation so let me summarize what we have learned in this lesson.

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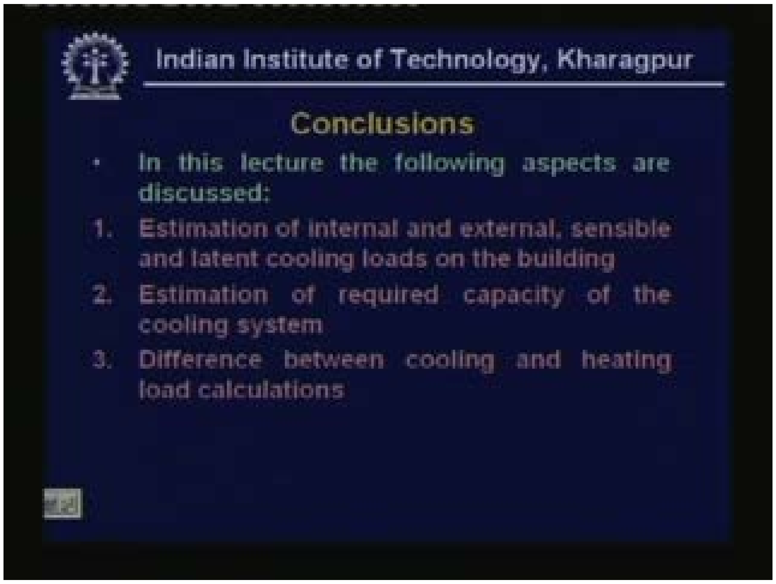

In this lecture the following aspects are discussed estimation of internal and external sensible and latent cooling loads on the building estimation of required capacity of the cooling system and difference between cooling and heating load calculations okay. So at this point I stop this lecture and in the next lecture we shall see how to select a suitable air conditioning system.

Thank you.