Refrigeration and Airconditioning
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Lecture No. # 37
Psychrometry of Air Conditioning Systems

Welcome back in the last lecture we discussed the selection of inside design conditions based on the comfort criteria.

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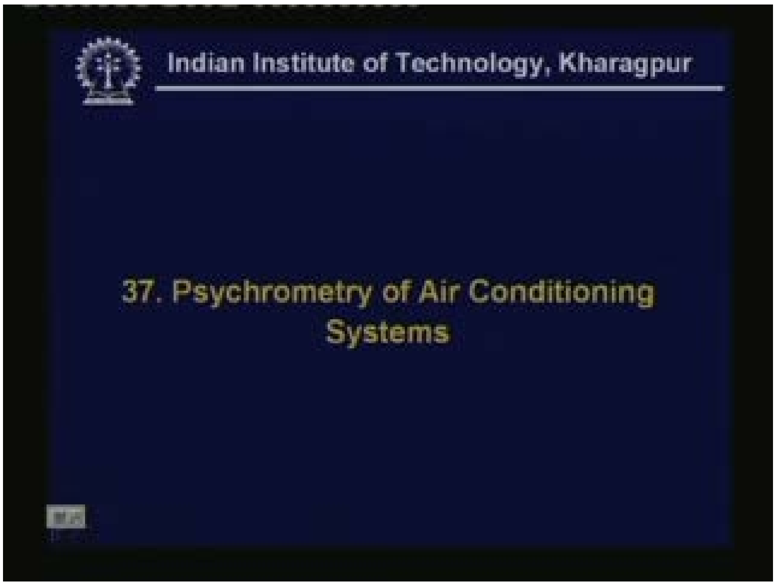

In this lecture I shall discuss the selection of outside design conditions and then selection of supply conditions based on the psychometric of air conditioning systems.

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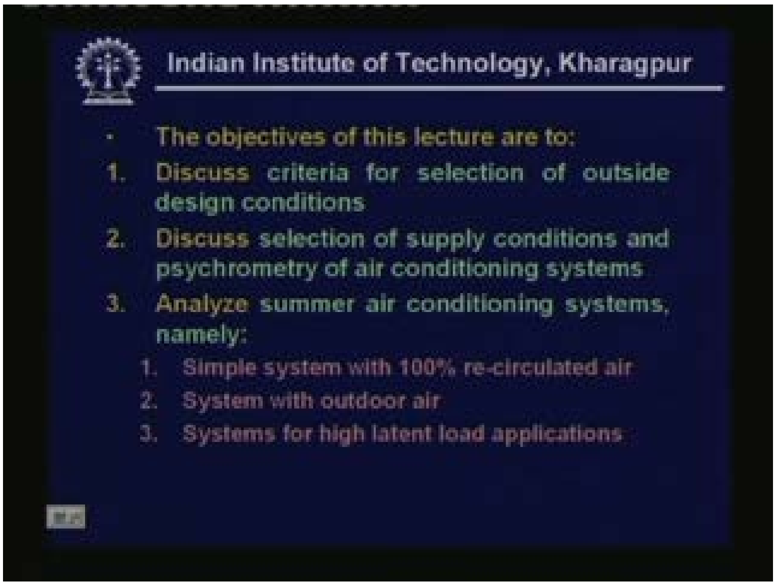

So specific objectives of this particular lecture are to discuss criteria for selection of outside design conditions, discuss selection of supply conditions and psychometric of air conditioning systems, analyze summer air conditioning systems namely simple system with hundred percent, re-circulated air system with outdoor air then system for high latent load applications.

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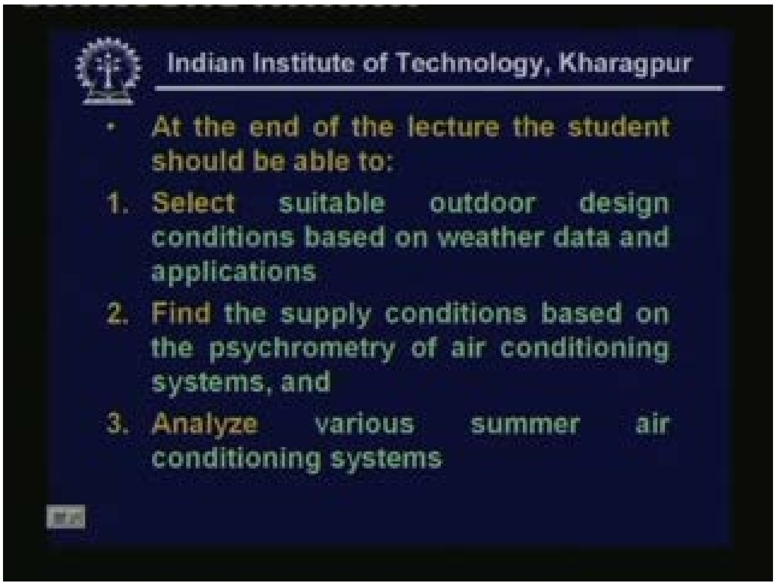

At the end of the lecture you should be able to select suitable outdoor design conditions based on weather data and applications find the supply conditions based on the psychometric of air conditioning systems and analyze various summer air conditioning systems.

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So first let us look at how to select outside design conditions. So the ambient term as you know very well the ambient temperature and moisture content vary from hour to hour and from day to day and from place to place. For most of the major locations of the world meteorological data are available in the form of mean daily or monthly maximum. And minimum temperatures and corresponding relative humidity or wet bulb temperature this data is recorded and it is available. Now selection of the worst possible conditions lead to excessive large cooling or heating equipment as worst conditions prevail only for a few hours in a year.

That means if you look at the meteorological data and if you select the worst possible condition. That means if you are designing a summer air conditioning system you take the maximum possible temperature dry bulb temperature in maximum possible wet bulb temperature and can do the cooling load calculations. And if you decide your capacity of the cooling system accordingly. Then you will find that the installed capacity is really excessive because the worst conditions generally prevail only for a few hours throughout a year okay. So it is not really economical so there must be some other criteria for fixing the outside design conditions. So let us look at these criteria.

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First let us look at outdoor design conditions for summer outdoor design conditions for summer or chosen based on the values of dry bulb and mean coincident wet bulb temperature. That is equal or exceeded one percent two point five percent or five percent of total hours from June to September. From June to September the total number of hours will be about twenty-nine twenty-eight. That means two thousand nine hundred twenty-eight hours. So what it basically means is you have to select let us say that, I am selecting one percent value okay. That means one percent of the time the outside design conditions will be higher than the selected condition. Okay. One percent of two thousand nine hundred twenty-eight is roughly about thirty hours okay. So only during thirty hours the outside conditions will be hotter in the humid air than the selected conditions okay. That means the system capacity may be inadequate only for thirty hours in one year okay.

If you are selecting let us say two point five percent of data then due for seventy-five hours the system capacity will be slightly lower than required similarly for five percent data. It will be about one fifty hours the outside conditions will be slightly more than selected conditions okay. This is the meaning of selecting the outside design condition based on one percent or two point five percent or five percent value of the dry bulb. And one more thing you have to notice here is you are taking the maximum wet bulb temperature you are taking the coincident wet bulb temperature. That means what is the wet bulb temperature when the dry bulb temperature is at one percent value or two point five percent value or five percent value okay. This is the criteria suggested for selecting the outside design conditions.

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These values are major locations in the world or available in data books. For example ASHRAE data book gives the one percent value or two five percent value or five percent value for major locations in the world and in the absence of any special requirements ASHRAE recommends the two point five percent value for summer outdoor design conditions. So a special requirements means there are some situations where the inside temperature is very critical. That means even for ten hours of the in throughout a year you do not want the temperature to exceed a particular comfort value okay. That means inside condition should not exceed a particular value under any circumstances then you have to go for one percent value instead of going for a two point five percent value. On the other hand there are some applications where the temperature is not so critical okay, too critical is variation is allowed then instead of going for two point five percent one can go for five percent value okay. So there by you will be saving the system cost okay. Both installed cost as well as the running cost but in the absence of any recommendation one can go for the two point five percent value okay.

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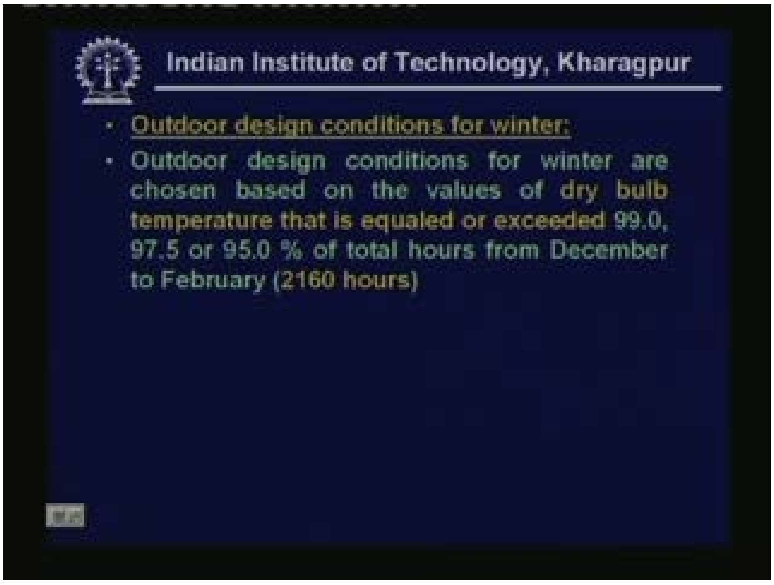

Next comes the selection of outdoor design conditions for winter just like summer outdoor design conditions for winter are chosen based on the values of dry bulb temperature. That is equal or exceeded ninety-nine percent ninety-seven point five percent or ninety-five percent of total hours from December to February December to February is the typical winter time. So if you count the number of hours you find that from December to February there will be about twenty-one sixty hours. So if I am selecting let us say ninety-nine percent value dry bulb temperature value.

That mean one percent of the time I mean, that mean, one percent of twenty-one sixty hours that is about twenty-one hours the outside temperature will be lower then what is required okay. That means your heating system will be inadequate for one percent of the total duration of two thousand one hundred sixty hours. Similarly if it ninety-seven point five percent means two point five percent of the time the outside conditions will be lower than the design condition. That means the system will be inadequate only for two point five percent of the time okay. So this is how the winter design conditions fixed similar to summer design condition winter design conditions are also available in data books such as ASHRAE data books okay.

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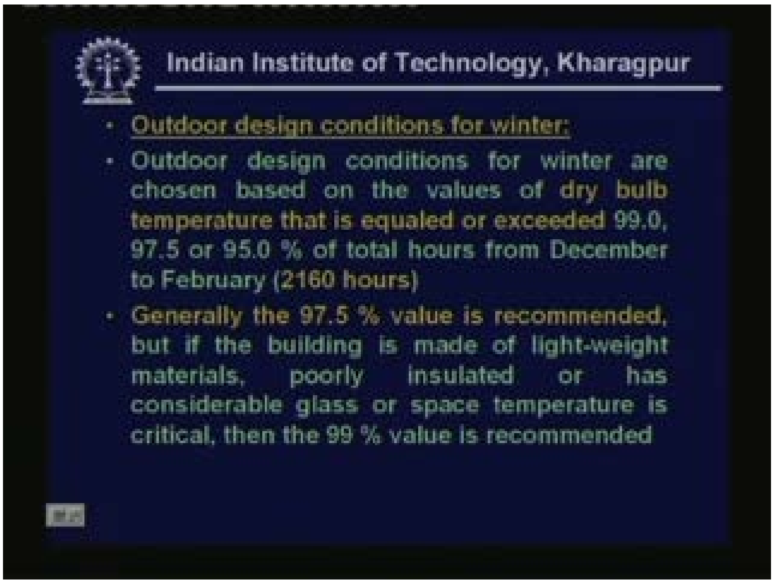

And generally the ninety-seven point five percent value is recommended if there is no special recommend special requirement exists. But if the building is made of light weight materials if the building is poorly insulated or if it has considerable glass are the space temperature is critical then the ninety-nine percent value is recommended okay. So when some special situations exist then we can go for ninety-nine percent value okay. Ninety-nine percent value means the installed capacity will be slightly higher than that of ninety-seven point five percent value okay.

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Now let us look at the psychometric of air conditioning systems from known cooling and heating loads on the building and design inside. And outside conditions psychometric calculations are performed to find supply air condition by supply air conditions we mean air flow rate. That mean mass flow rate of the supply air what is the supply dry air dry bulb temperature what is its humidity ratio and enthalpy. All these are known as supply air conditions second thing is we can also find out the coil specifications. That means what is the latent and sensible load from the coil what is the coil required coil ADP that is a due point and what is equal to the required coil bypass factor. Normally depending upon the ventilation requirements of the building the required outdoor or fresh air is specified okay. This something which is specified based on the ventilation requirements now let me show a typical summer air-conditioning system.

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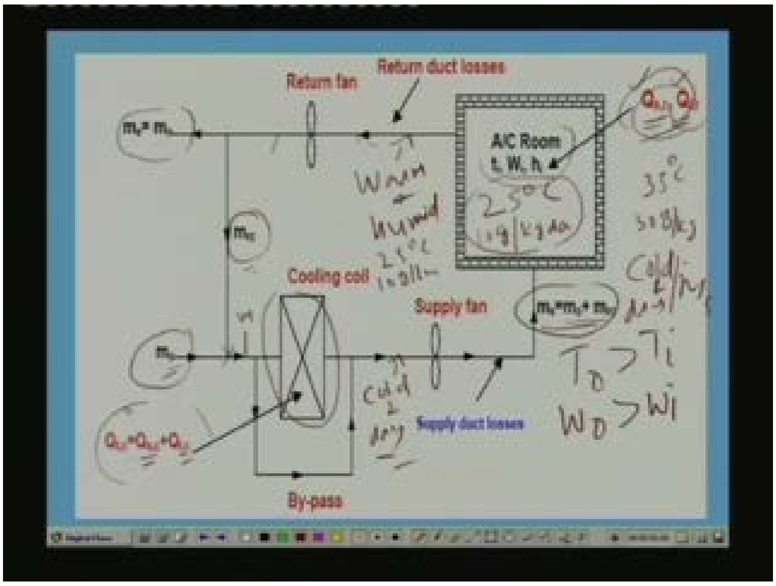

Okay, this can be any air conditioning system. But let me take the case of summer air conditioning in summer air conditioning, let us say that the required inside conditions are say at forty-five degree centigrade and required humidity ratio. Let say is ten grams per kg of dry air okay, and the enthalpy is the corresponding enthalpy. Let us say these are the required inside conditions which correspond to our comfort requirement. Since it is summer outdoor conditions will be hotter and humidor. That means let us say that the outside temperature is thirty-five degree centigrade and outside humidity is let us say thirty grams per kg of dry air since outdoor temperature is greater than inside temperature outside humidity is greater than inside humidity there will be and the building is not perfectly insulated. So there will be sensible heat transfer from outside to the inside of the building there will also be latent heat transfer from outside to the inside of the building okay. This could be single room or it could be huge building consisting of many rooms right.

So we want to maintain the inside conditions at these values and there is a continuous addition of sensible as well as latent heats to the building. So to maintain the room at these particular conditions we have to take out this heat at the rate at which it is entering into the condition space this is achieved by using an air conditioning system. In the air conditioning system what we do is we supply for this case. For example a supply air which is cold and dry okay. So cold and dry at the required mass flow rate is supplied to the building. This cold and dry air flows through the conditioned space and as it flows through it picks the sensible heat and it picks the latent heat. And we assume that when it comes out of the building or comes out of the conditions space its conditions will be almost same as the conditioned space conditions okay.

So what enters into the condition space is cold and dry air and what comes out is relatively warm and humid air okay. At the same conditions as that of the conditions with that means at twenty-five degree centigrade. And let us ay and the humidity of ten grams per kg okay. So at this condition the air comes out. Now the air goes out flows through the ducts these are all the ducts the lines okay. And some part of the air is thrown out that is exhaust air is thrown out and rest is re circulated this is the re circulated air. Now this air is thrown out because we continuously want to add some outdoor air to cater to the ventilation requirements okay. So we supply some outdoor air so at this point this re circulated air and outdoor air may get mixed and you have a mixed air here and this mixed air is quite warm and humid okay. So it has to be made again cold and dry. So it is made to flow through a cooling coil as it flows through the cooling coil it rejects sensible and latent heats to the cooling coil and in this in that process the air becomes cold and dry okay.

So this cold and dry air is again supplied to the building. This is cycle continuous okay. So ultimately you see that the building you have latent and sensible heat transfer to the conditions space and the air is picking up these heats. And it is rejecting that heat to the cooling coil this cooling coil could be the evaporator of a refrigerant system. So the refrigerant evaporates and ultimately this heat is rejected to the ambient at the condenser okay.

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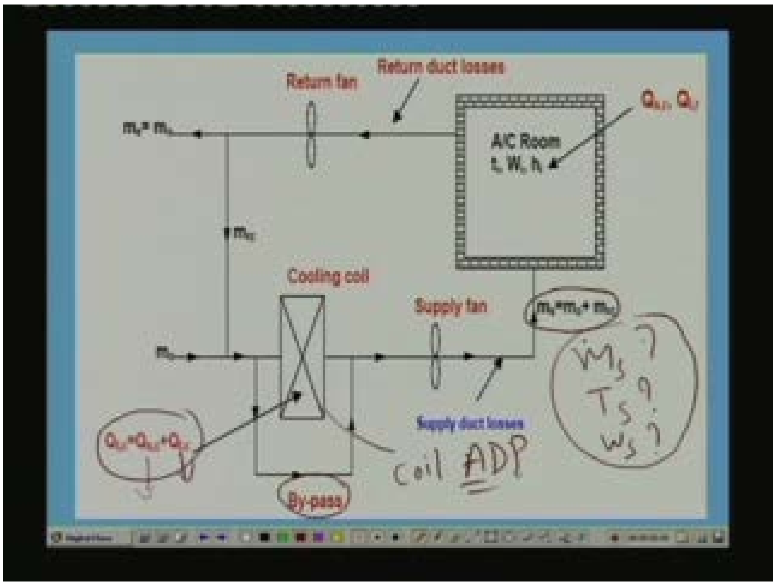

So this is the typical summer air conditioning system okay. And the psychometric we do the sub performance psychometric calculations first to find out what should be the required mass flow rate of supply air okay. What is the required mass flow rate and what should be its temperature and what should be its humidity ratio okay. So all these things we have to fix by performing psychometric calculations right and we also have to know what should be the required cooling capacity of the coil okay. How much sensible heat as to rejected at the coil how much latent heat as to be rejected at the coil what is the required bypass factor of the coil and what should be the a coil ADP okay. That is apparatus due point okay. So all these things will be will be obtained by performing the psychometric calculations okay.

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Now let us begin with summer air conditioning systems first let us take a simple system with hundred percent re-circulated air okay. Let me first describe the system.

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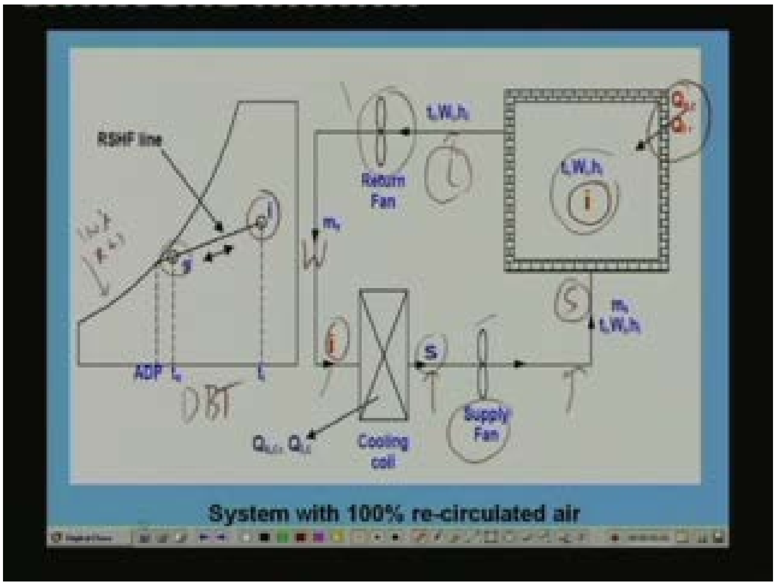

So as I said this simple system with hundred percent re-circulated air. That means we are throwing any air nor we are adding any outside air. So the flame air is flowing through the system again and again. So you can see that is a close system as far as air is concerned okay. Again you have the sensible and latent heat loads on the building. This is the i is the condition space state. And let us say this s is same as this is the state of the supply air and the state of the air at the exit of the condition space is same as the condition space i okay. And so if you are assuming that there is no heat transfer in the duct and if the fan power is negligible then you find that at this point. That means at the inlet to the cooling coil also the conditioned space conditions exist. That means you have the status i itself. So in the cooling coil light under goes cooling and humidification. So at point s you have cold and dry air okay so when the same cold and dry air so goes to the building.

So we have a supply fan here you have also have a return fan okay. Return fan is an option and as I said all these lines are the ducts through which the air flows okay. And the same process is shown on a psychometric chart here. So you have the dry bulb temperature here on psychometric chart as you know on the y axis we have the humidity ratio. And this as you know is the hundred percent relative humidity or saturation curve okay. And point i is the state of the conditioned air in the inside the building. And point s is state of the air at the exit of the cooling coil or at the inlet to the condition space okay.

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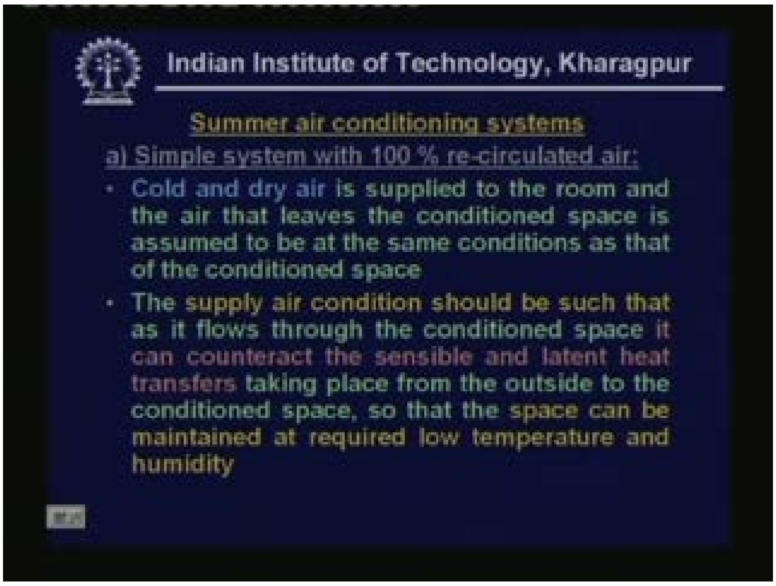

So as I said cold and dry air is supplied to the room and the air that leaves the conditioned space is assumed to be at the same conditions as that of the conditioned space. The supply air condition should be such that as it flows through the conditioned space it can counteract the sensible and latent heat transfers taking place from the outside to the conditioned space. So that the space can be maintained at required low temperature and humidity I have explained this already.

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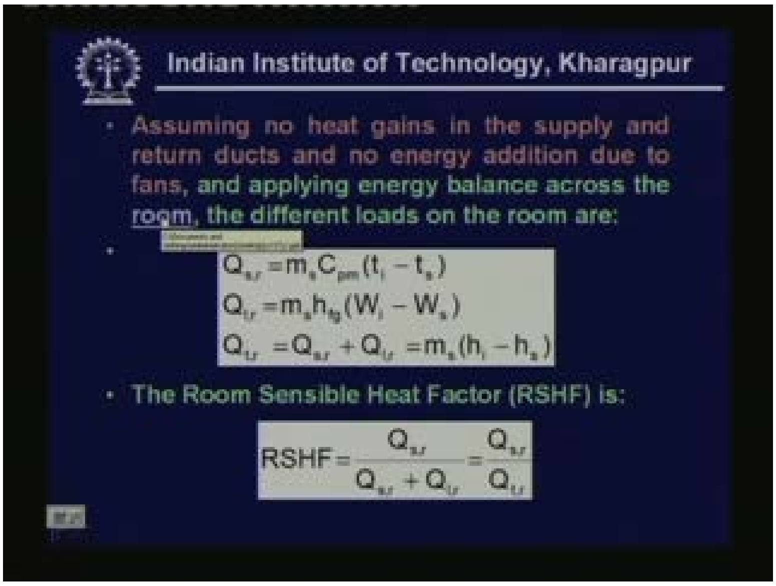

Now assuming no heat gains in the supply and return ducts and no energy addition to the fans energy addition due to the fans and applying energy balance across the room the different loads on the room are okay. So let us look at the room.

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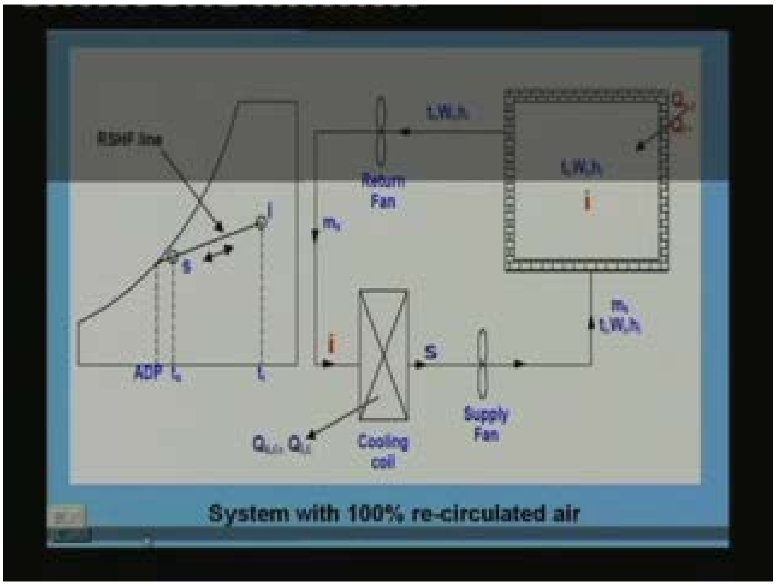

What we are doing is taking a control volume. Let us say I am taking a control volume okay. And if you are assuming a steady state and if you are applying energy balance across this control volume you find that the rate at which the sensible heat is entering into the building must be the rate at which it is leaving. Because the air flow that means Qsr should be equal to oh supply air flow rate into Cpm. That is the moist air, so humidity specific heat of the humid air into Ti minus Ts okay. This is the energy balance for the sensible heat similarly you can perform an energy balance for the latent part and you can also perform an energy balance for the total heat transfer rate okay. So that is what is done here.

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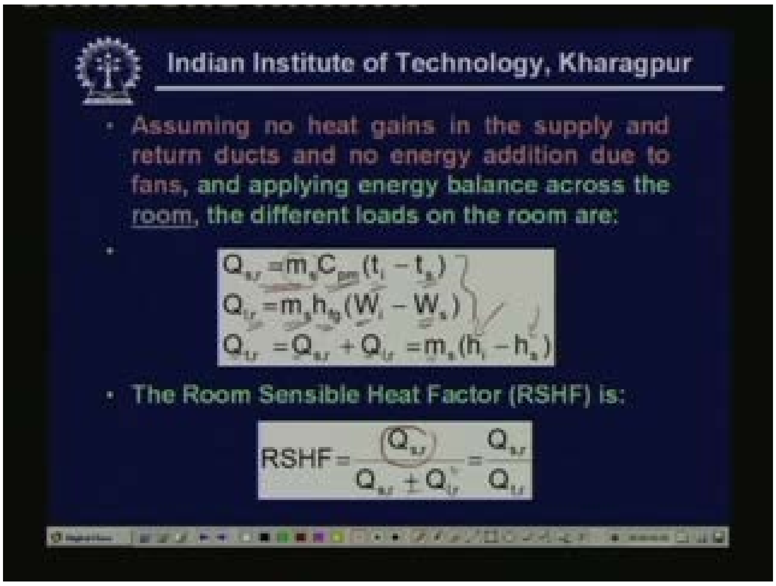

And you get this kind of equations of for the sensible heat transfer rate this is the equation Qsr is the sensible cooling load on the building okay. S stands for sensible r stands for the room or building that is equal to ms where ms is the supply air mass flow rate Cpm as I said is the specific heat of the moist air Ti is the condition space temperature Ts is the supply air temperature. Similarly the latent load on the building Qlr that is equal to mass flow rate of the supply air ms into hfg the latent heat of vaporisation multiplied by humidity ratio difference wi is the humidity ratio inside the conditioned space ws is the humidity ratio of the supply air okay.

So these two are for the sensible and latent heat loads or co sensible and latent heat transfers. Similarly you can draw a write an equation as I said for the total heat transfer rate Qtr is nothing but sensible heat transfer rate plus latent heat transfer rate. So that is nothing but mass flow rate of the supply air multiplied by the enthalpy raise of the air as it flows through the conditioned space here hi is the exit enthalpy of the air and hs is the inlet enthalpy of the air or supply air okay. And the room sensible heat factor as you have seen RSHF is simply defined as the ratio of the sensible heat transfer to the total heat transfer okay. Qsr divided by Qtr.

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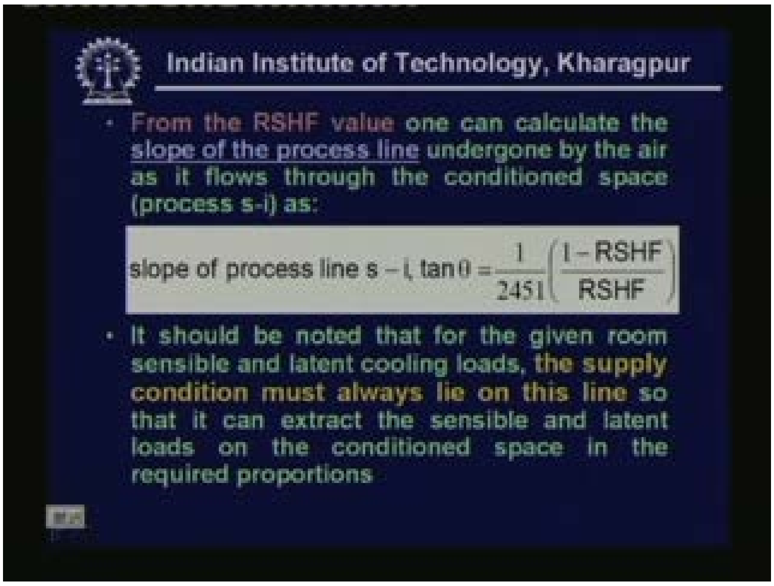

Now from the RSHF value one can calculate the slope of the process line undergone by the air as it flows through the conditioned space.

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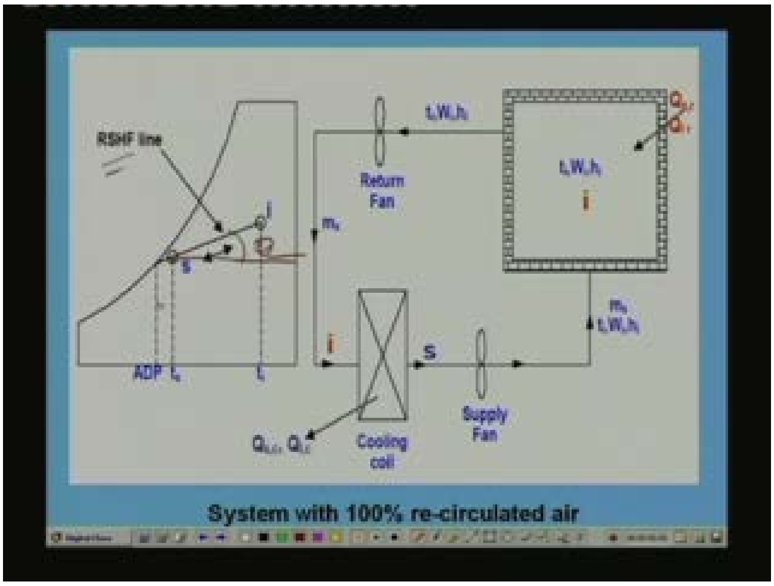

That means slope of this line okay. Let us say the, if this is theta okay, the tan theta is the slope of this line this we can obtain if you know the RSHF or the sensible heat factor this we have discussed in the last lecture okay.

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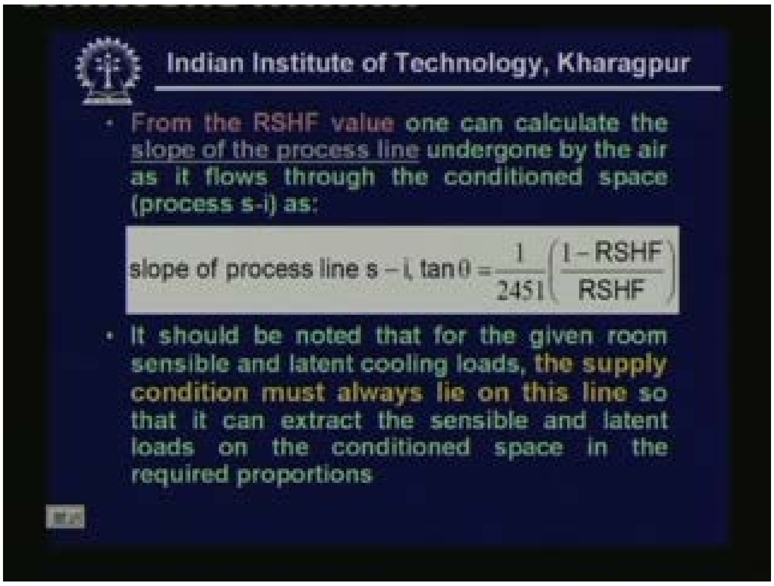

And we have seen in the last lecture that the expression for the slope is given by this value that is tan theta is one by two four five one multiplied by one minus RSHF divided by RSHF where RSHF is the room sensible heat factor which is known to us okay. And one very important thing to be noted here is that for the given room sensible and latent cooling loads. The supply condition must always lie a on this line. So that it can extract the sensible and latent loads on the conditioned space in the required proportions.

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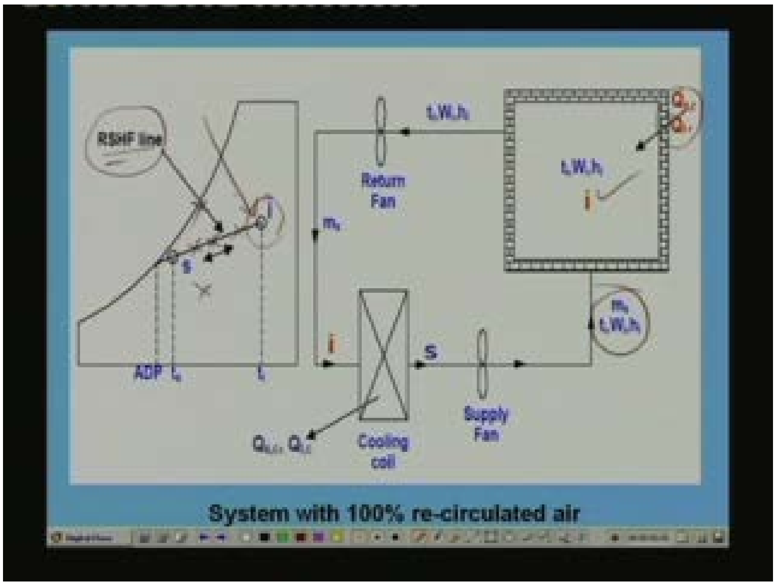

That means we know that as I said let me quickly repeat what I said. We know this conditioned space state i based on the comfort criteria this is known to us okay. So we can place this point on the psychometric chart and the slope of this line can be obtained. If you know the value of RSHF okay for the timing being let us say we know the latent and sensible heat loads on the building right. So we can calculate RSHF and from RSHF we can find out what is slope of the line once you know the slope of the line and this inlet state I then you can draw this line okay. This RSHF line and the supply air condition must lie somewhere on this line okay. It cannot lie anywhere else if it is lying anywhere else that, then it cannot take the sensible and latent heat loads in the required proportion okay. So if it has, if the air, this air has to take this sensible and latent heat loads in this required proportion then this must always lie on this RSHF line okay.

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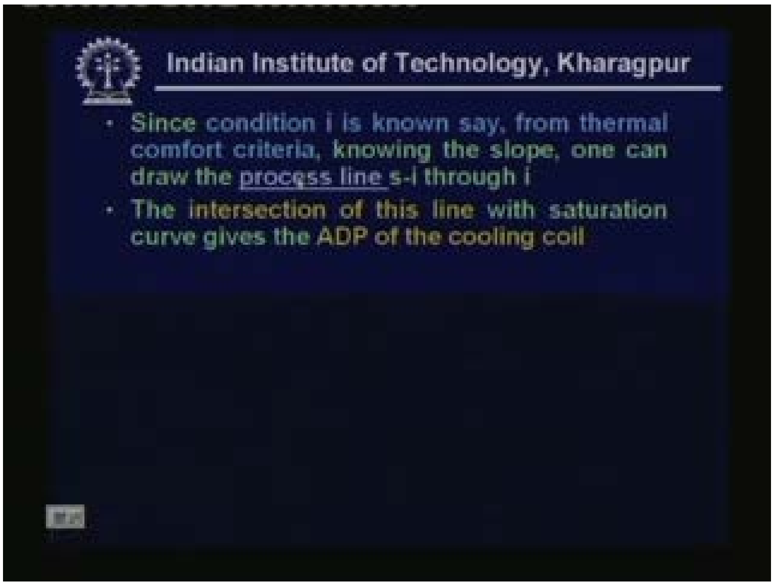

So that is okay. Now since condition I is known say some thermal comfort criteria knowing the slope one can draw the process line s-i through i we have already explained. This the intersection of this line with saturation curve gives the ADP of the cooling coil we also know this.

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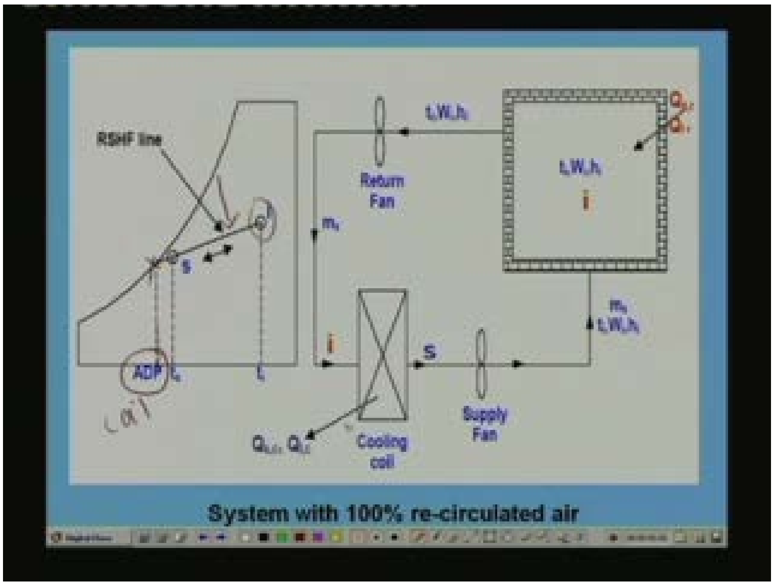

If i extend this line let us say that this line we are able to draw this line okay. We are able to draw this line because we know the slope of the line and we know one point. So if you draw this line and if you extend this line where this line extend this saturation curve that temperature will give you the coil ADp okay, ADp of the cooling coil.

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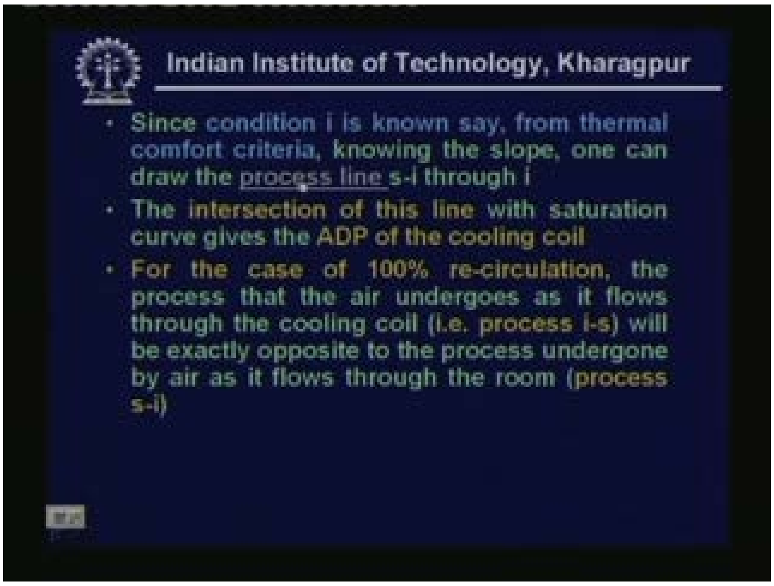

For case of hundred percent re-circulation the process that the air under goes as it flows through the cooling coil. That means process i-s will be exactly opposite to the process under gone by air as it flows through the room that is process s-i okay.

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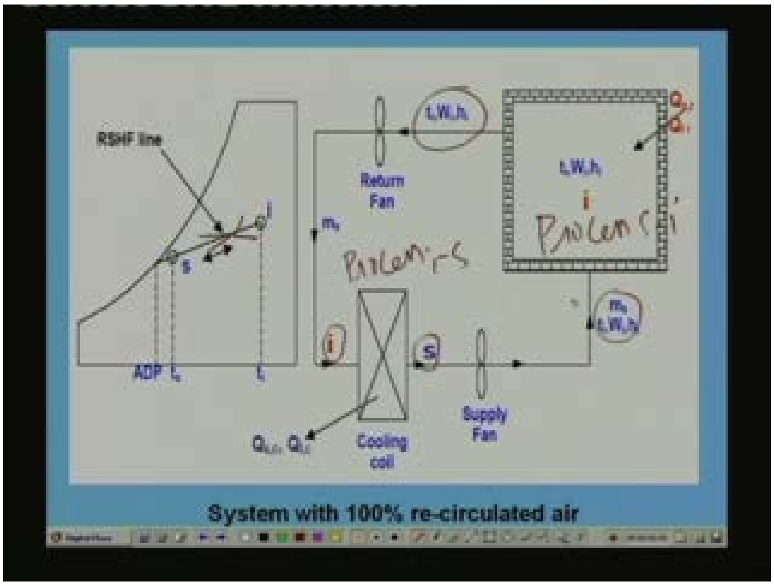

That means what is happening for the air as it flows to the conditioned space. That means as it moves from this point to this point will be exactly opposite to what is happening to the air as it flows through the cooling coil okay. That means process i-s will be exactly equal and opposite to process s-i. For this special condition of hundred percent re-circulated air that why you have a single line here okay. So as the air flows through the room the process will be like this and as air flows through the cooling coil the process will be like this. That means as the air flows through the condition space air picks up sensible heat and it also picks up latent heat that means its temperature increases and its moisture content increases okay. As it flows through the condition space and the same air as it flows through the cooling coil it its temperature reduces and its humidity ratio also reduces okay. Because that mean we have to go for a cooling and dehumidification process in the cooling coil okay. So as far as the condition space is concerned it is heating and humidification. And as far as the cooling coil is concerned it is cooling and dehumidification process and if you plot these two processes on the psychometric chart they exactly coincide only thing is that the direction will be opposite okay.

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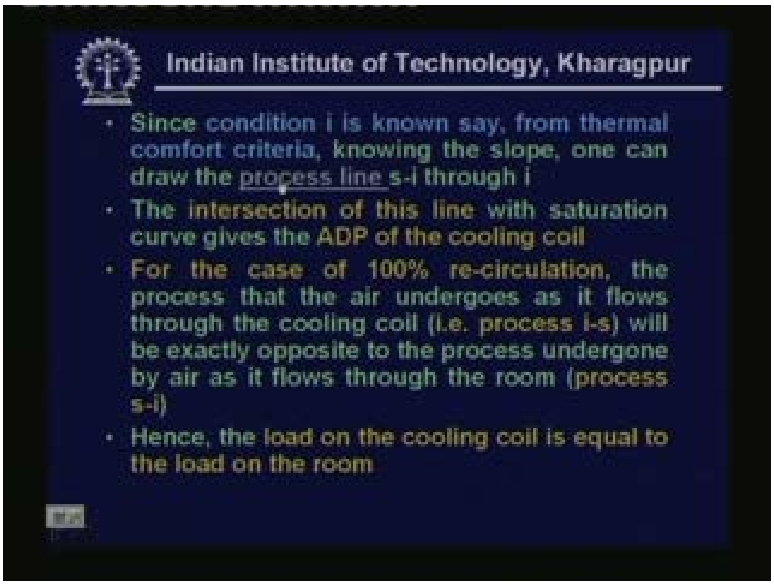

Hence the load on the cooling coil is exactly equal to the load on the room okay.

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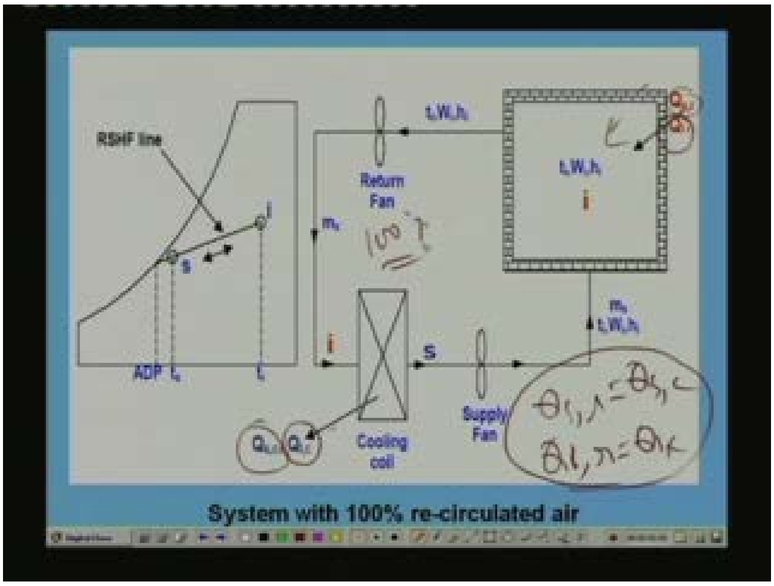

That means this Qsr is exactly equal to Qsc whatever sensible heat is being transferred to the room as to be rejected at the cooling coil similarly water latent heat is transferred to the room as to be rejected at the cooling coil okay. That means Qsr is equal to Qsc that is coil load and Qs Q sorry Qlr is equal to Qlc okay. This is not always valid this is valid only for this particular system with hundred percent re-circulated air.

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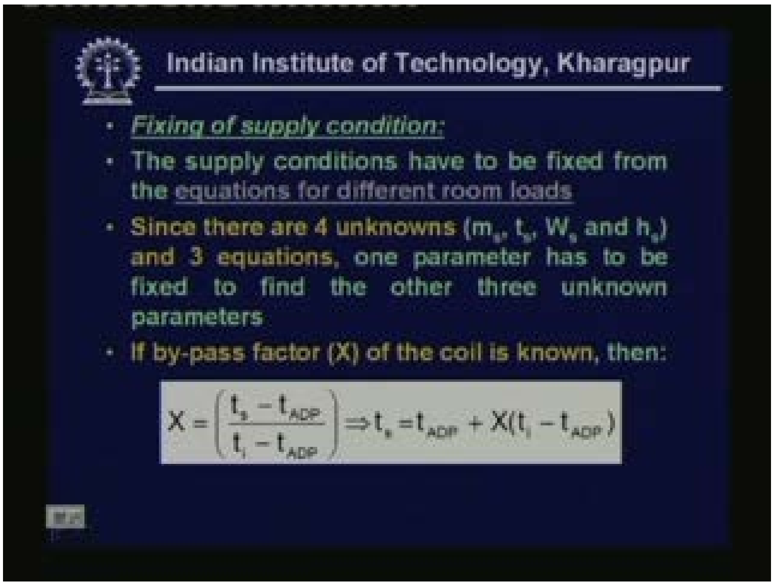

Now we have to fix the supply conditions how we fix the supply condition the supply conditions have to be fixed from the equation for different room loads what are those equations we have three equations.

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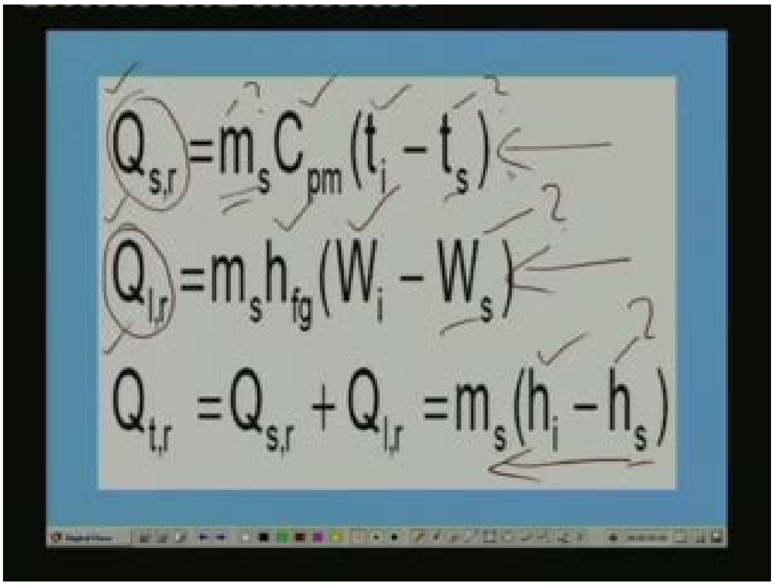

One equation for sensible heat transfer one for latent heat transfer one for total heat transfer. And if you look at these equations we know t i we know wi we know hi okay. Because these are fixed based on your inside conditioned space requirements. For example based on comfort criteria okay. So these are known and these will be estimated by performing cooling load calculations okay. This we will discuss a little later for the time being let us assume that we know these things also for cooling load calculations okay. So these things are known to us ti wi and hi are known.

And let us assume that Cpm is also known to us that is the specific heat is known latent heat of vapour is also known. So what are the unknowns are mass flow rate of the supply air temperature of the supply air humidity ratio of the supply air and enthalpy of the supply air. So there are four unknowns ms ts ws and hs and there are three equations okay.

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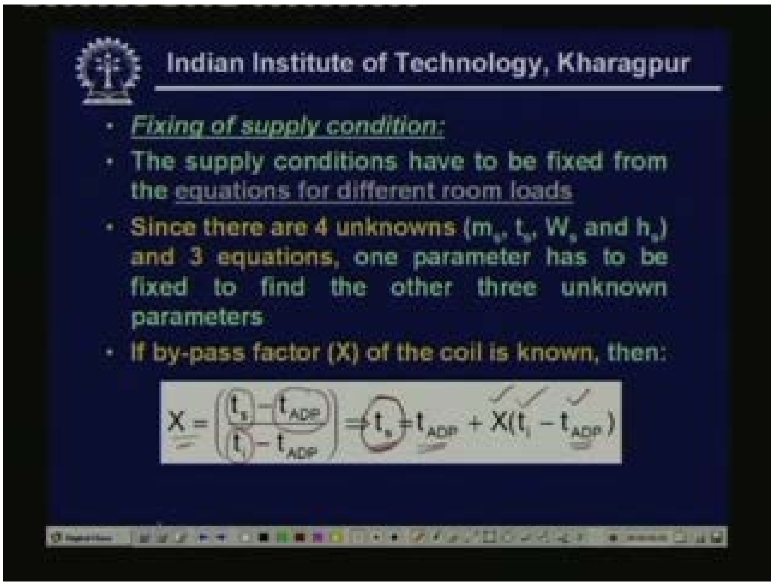

Since there are four unknowns and three equations one parameter as to fixed to fine the other three unknown parameters obviously. So if bye pass factor x of the cooling coil is known then from the definition of bye pass factor we know that for the cooling coil bye pass factor is given like this x is equal to ts minus tADP divided by ti minus t ADP where ts is a exit temperature of the cooling coil. That mean exit temperature air at the cooling coil tADP is the apparatus due point of the coil ti is the air temperature at the inlet to the cooling coil okay. So this is based on the definition of bye pass factor from this equation you can write ts is equal to tADP plus x into ti into tADP now x is known to us it is specified by the manufacturer. Let us say so this is known to us ti is known to us tADp we have obtained by extending the line and from intersection of that RAHF line with the saturation curves this is also known to us. So we can find out what is the required supply temperature okay.

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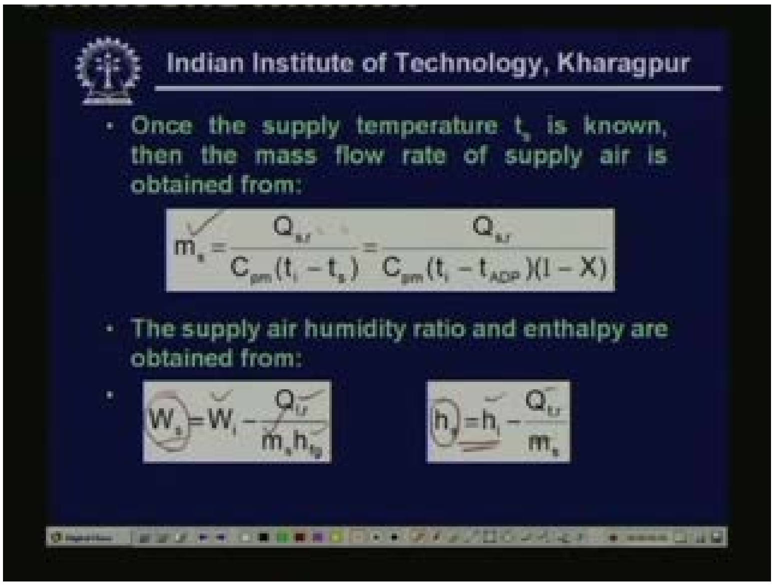

So once we know the supply temperature then the mass flow rate of supply air is simply obtained from this equation ms is equal to Qsr divided by Cpm into ti minus ts ti minus ti can be written in terms of coil ADP. And the bypass factor that is ti minus tADP into one minus x at and the supply air humidity ratio and enthalpy are obtained from the equations. For the latent load and the total load okay. So once we know this is known to us this is known to us everything is known on this side. So we can find out what should be the supply air enthalpy what should be the supply air humidity ratio okay. So once we know one parameter that is let us say to the supply air temperature all other things can be obtained.

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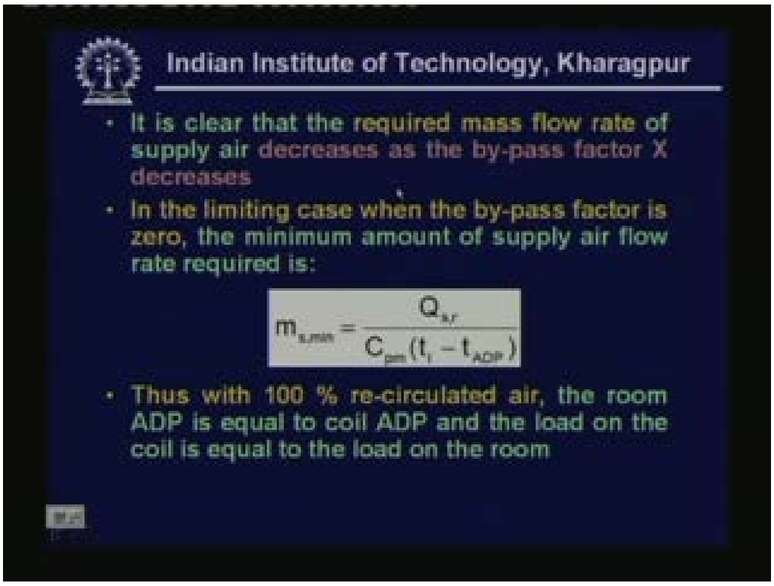

Now from the equation it is clear that the required mass flow rate of the supply air decreases as the bypass factor x increases.

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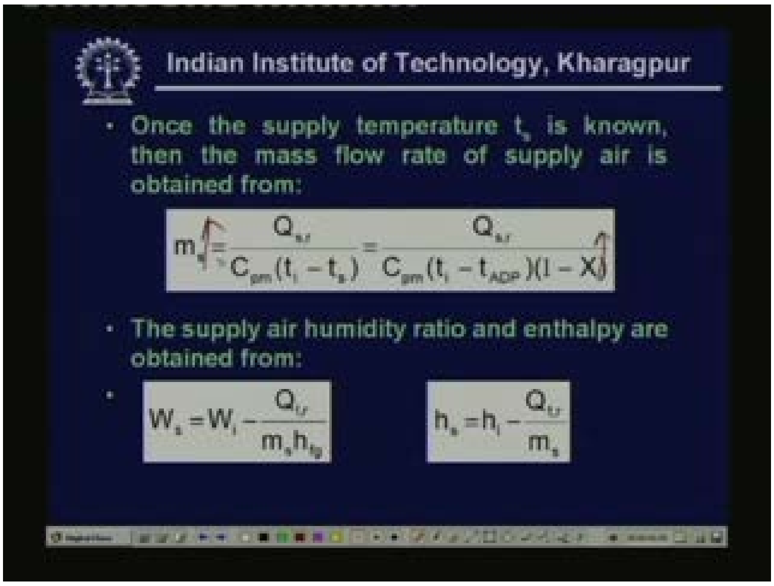

That means from this equation you can see that everything is fixed as the bypass factor x increases this also increases okay.

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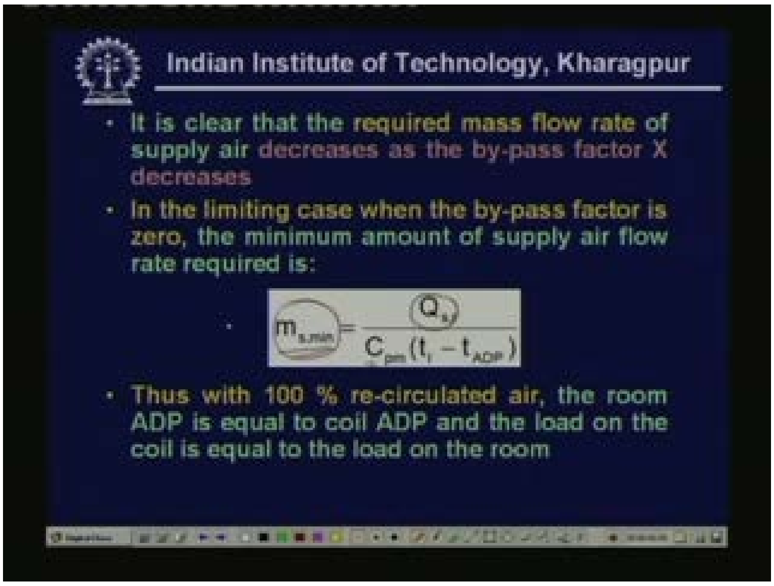

In the in the limiting case when the bye pass factor is zero okay. That means on the other side when the by-pass factor is zero the minimum amount of supply air flow rate required is given by this equation. This the minimum amount of supply air required that is equal to sensible heat load on the building divided by specific heat of the moisture multiplied by ti minus Tadp. So this is the minimum amount of supply air required okay. Thus with hundred percent re-circulated air the room ADP is equal to coil ADP and the load on the coil is equal to the load on the room okay. This is what we have to keep in mind okay. Normally this simple system with hundred percent re-circulated air is not practical means we always have to have some kind of some amount of outdoor air because ventilation is required okay. So but this is taken first because this is simple and rest of the systems can be developed from this system okay.

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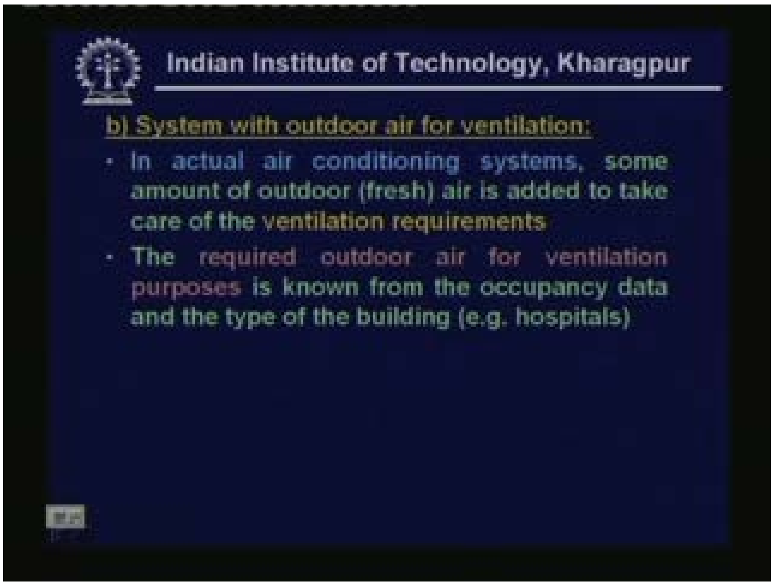

So now let us look at the system with outdoor air for ventilation. As I already as I have already explained in actual air condition system some amount of outdoor air or fresh air is required to take care of the ventilation requirements. The require outdoor air for ventilation purposes is known from the occupancy data and the type of the building. For example hospitals. First of all why do we require outdoor air as I have already told we require it for ventilation purpose. That means there are large numbers of people inside the condition space. So gradually the oxygen concentration digests because of the respiration process that because we breathe in oxygen and we breathe out carbon dioxide okay. So after sometime the oxygen level may drop okay. So this requires a continuous supply of fresh air to take care of the oxygen requirements more importantly it is found that the outdoor air is required to dilute the orders okay. Because a people continuously emit body orders so so that will affect the quality of the indoor air okay.

So you have to continuously add some fresh air which will dilute the orders okay. So in all actual systems fresh air is required right now some fresh air is required depend depends upon how many people are there of example in the conditioned space okay. Obviously more the number of the people in the conditioned space higher will be the amount of ventilation air required there are several standards which specify what should be the ventilation air required for person per second okay. So many meters per person per second again this also depends upon the application. For example in some applications the ventilation requirements may be high. For example in areas where there is heavy smoking okay. Then to dilute the orders of the smoke you have to supply more amount of fresh air. That means the required ventilation will be more also required ventilation will be more in areas like hospitals and all where the purity of air is very important okay. In hospitals and all in some cases all the air is throughout and you continuously take hundred percent fresh air okay. So what I am trying to say is the ventilation requirement depends upon all this data okay.

The occupancy data and type of the building etcetera okay. Generally this kind of data is available before we design the air condition system okay. Because we know what is the occupancy and we know what purpose the building is begin used okay. So we can estimate the ventilation requirement and at the beginning itself right.

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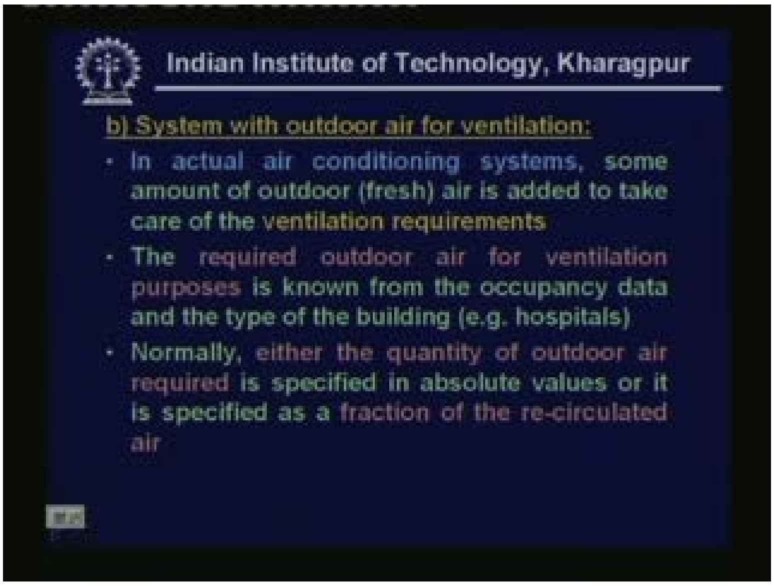

So as I said normally either the quantity of outdoor air required is specified in absolute values or it is specified as a action of re-circulated air okay, whatever be the this thing we know how much is required.

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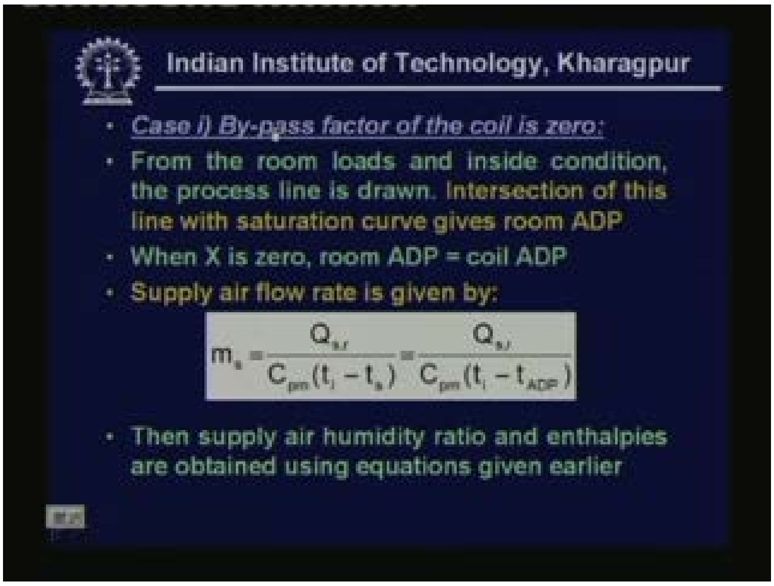

Okay, we let us take a simple case first the case one is where the bypass factor of the coil is zero. That means we are talking about a perfect coil so from the okay. First let me show the system and then explain the working principle.

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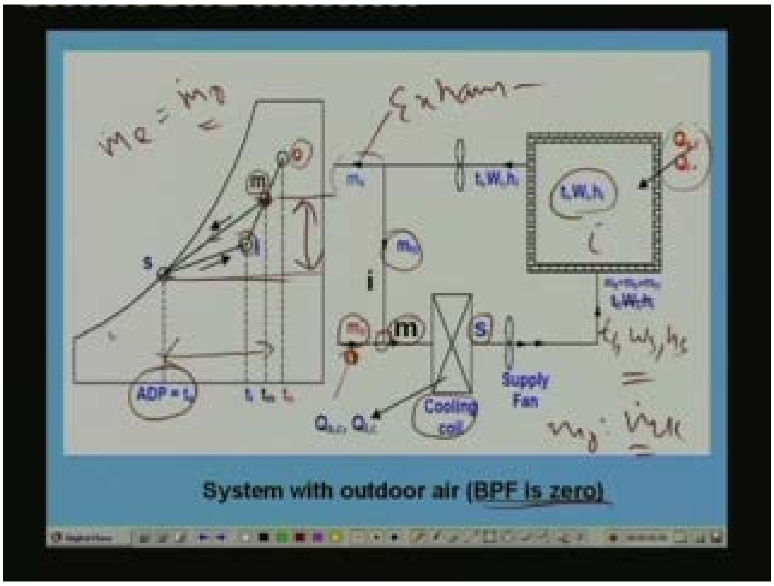

So if you compare this with earlier one we did not in the earlier system we did not have this arm okay. It was a hundred percent close system the same air is being be circulated but in this system you find that some amount of air is continuously thrown out and this is what is known as exhaust air and some amount of air is continuously added. This is if air is taken from outside so it as higher oxen level or it is purified and supplied okay. And if you look at the mass balance you find that the exhaust air mass flow rate is always equal to outdoor air mass flow rate okay. Because you have to ultimately balance the mass. So this outdoor air and the re-circulated air which is assumed to be at the same condition as that of the conditioned space or mixed at this point okay.

So what you have at this point is a mixed air this mixed air flows through the cooling coil it gets cooled and humidified and it comes out at the condition s and at this condition, I am sorry, should be ts ws and hs at this condition. It is supplied to the conditioned space. So that it can take care of the sensible and heat and latent heat loss on the building okay. Now if you draw this process on the psychometric chart this condition o is that of the outdoor air outdoor air is much hotter and humid air. So you have the, you can see that this is at this point and a point i is the conditioned required inside the building this is i this is o okay. And at this point this outdoor air and the inside air are mixed. And let us say that the resultant mixed condition m is here.

And we have discussed this earlier the resultant condition will be lying on this on a line joining these two points and the exact location of the point depends upon the ratio of mo to m re-circulated depending upon the at this point will be vary. Let us for time beginning assume that we have this point lies at this point. So at this point it enters the cooling coil and as the air flows through the cooling coil it under goes cooling and humidification. So its temperature drops and its humidity also drops okay. So this is the humidity drop and this the temperature drop okay. Since this is the case with of zero by pass factor you find that the exit condition s coincides with the apparatus dew point of the coil okay. So the exit condition is somewhere here okay. So the psychometric on the psychometric chart.

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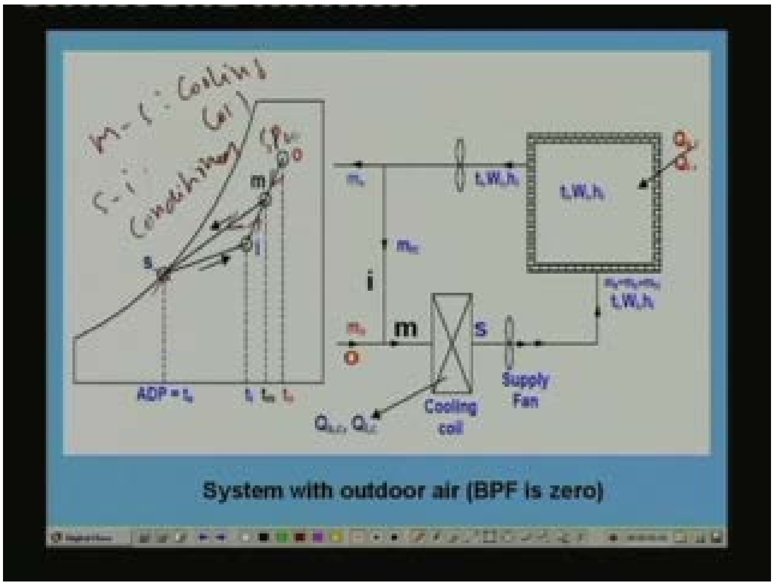

The process looks like this okay. So outdoor air is mixed outdoor and the indoor airs are mixed then this mixed air flows through the cooling coil. So process ms is what happens in the cooling coil okay. And at this point it enters into the condition space so process si is what happens in the conditioned space right.

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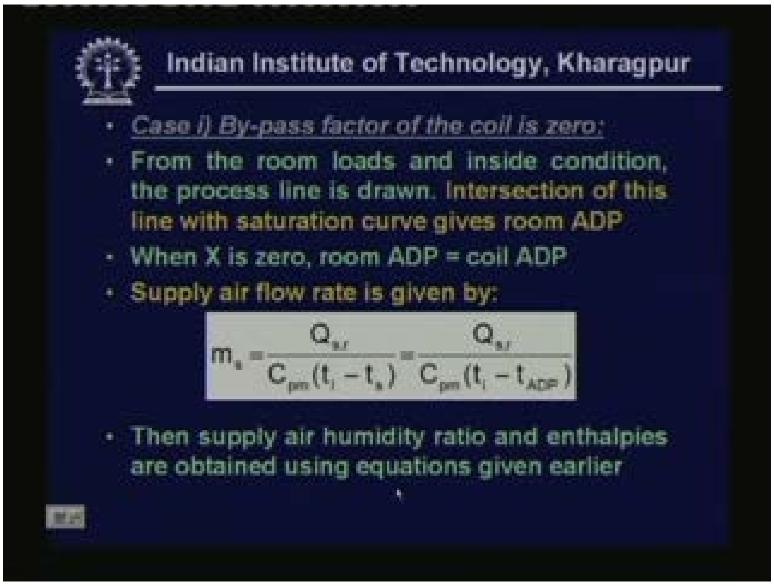

So again from the room loads and the inside condition the process line is drawn.

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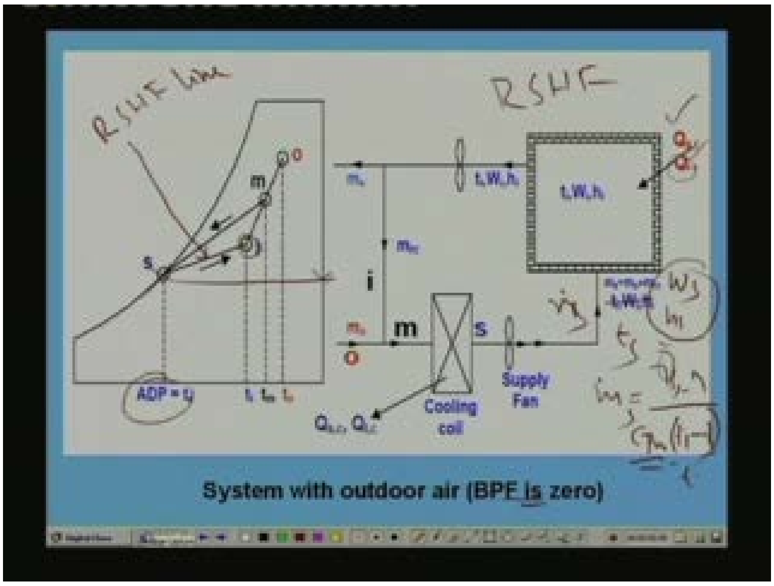

So we can drawn the fulfil assuming that we know these sensible and latent heat loads. Let say we know these line load so we can find out the RSHF once you find the RSHF you can draw this RSHF line. Because we know the point i okay. So you know the slope of this line and you know this point. So you can draw this line where this line intersects the saturation curve that is your coil ADP and for zero bypass factor that is also the supply air temperature. So that means we all also know this temperature from this point okay. And once you know this temperature then we can find out the mass flow rate of air okay, ms, how you find out the mass flow rate of air from energy balance for sensible heat portion. We have seen that mass flow rate of air is seen nothing but Cpm into ti minus ts Qsr divided by CPm into ti minus Ts everything is known to us Qsr is known, Cpm is known, ti is known, ts is known. So we can find out the mass flow rate of supply air once we know the mass flow rate of supply air then again performing latent cooling load balance and the total cooling load balance we can find out the supply air humidity ratio and supply air enthalpy okay. So we can fix the state of the air and that in fight for this simple case once you locate this point you can directly read this values from the psychometric chart okay.

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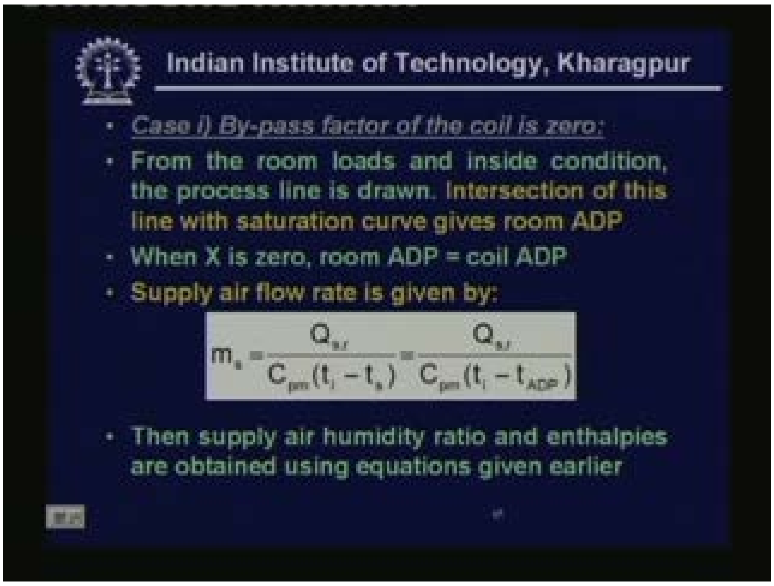

So okay, this is already is explained to you.

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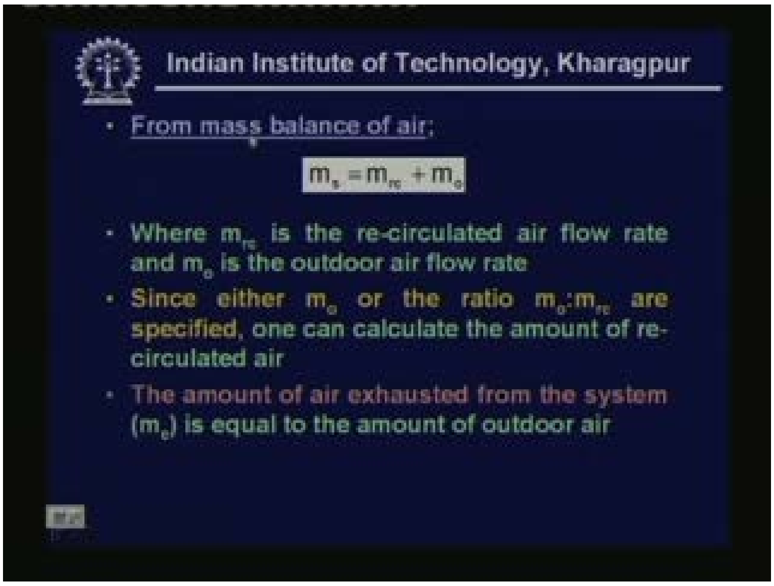

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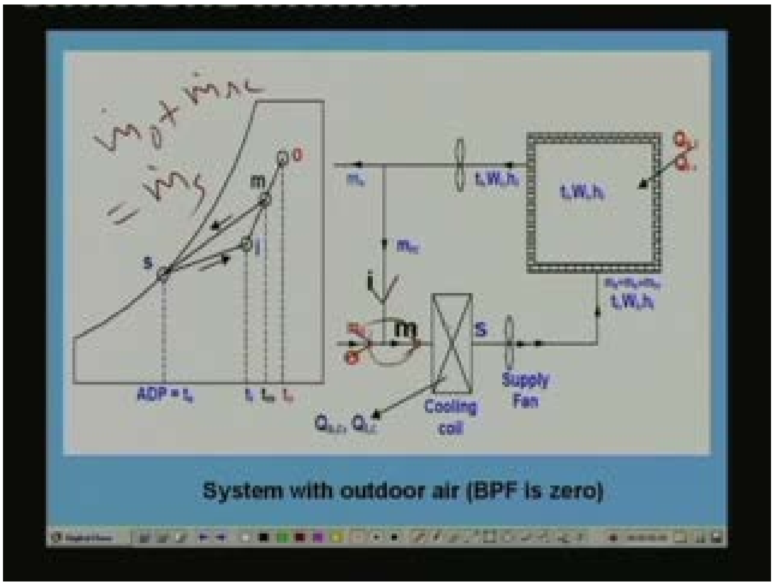

And from mass balance of air that means at this point if you do the mass balance at this point if you are doing the mass balance you find that m dot o plus m dot re-circulated is equal to m dot s okay. Because mass is entering like this mass is coming from this side and its getting mixed and the total mixed air is going in this direction.

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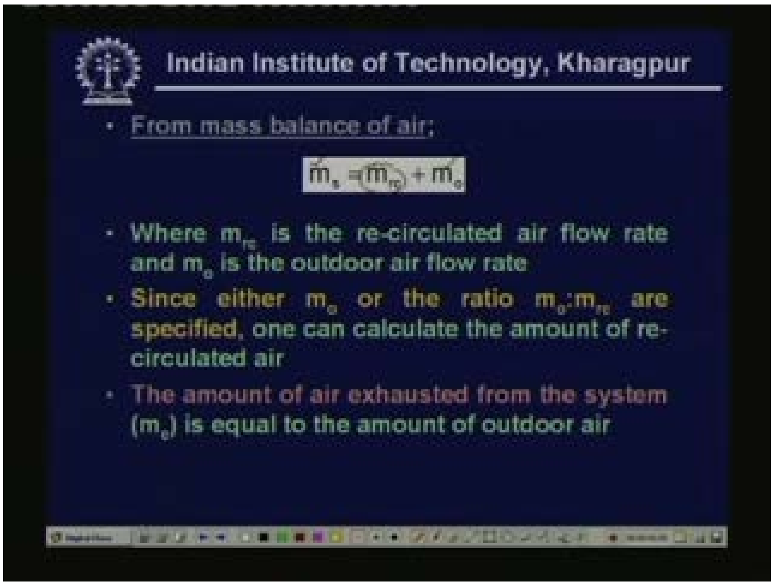

Where m subscript rc is the re-circulated air flow rate and m subscript o is the outdoor air flow rate okay. Since either m subscript o are the ratio of m mo by mrc are specified one can calculate the amount of re-circulated air. Because we have calculated this and from ventilation requirements we know this. So you can calculate what this, the re-circulated air and the amount of air exhausted from the system is equal to the amount of outdoor air as I have already explained.

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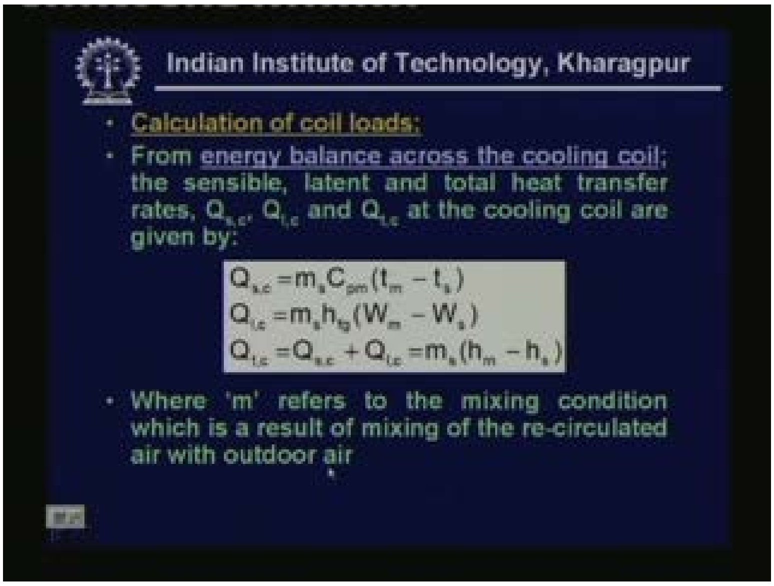

So now we have to find out the coil loads from energy balance across the cooling coil okay.

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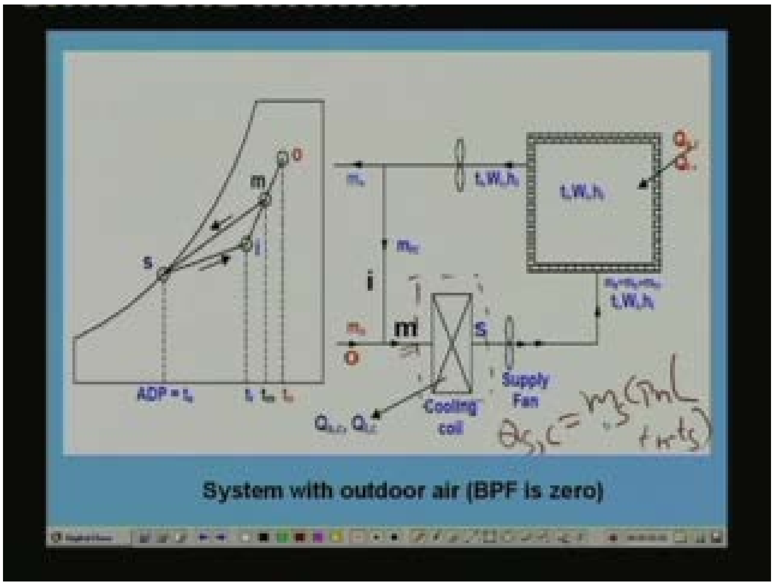

That means now you have to perform energy balance across the cooling coil. That means let us say take a control volume across the cooling coil and apply energy balance across the cooling coil energy balance means you can write down an energy balance equation for the sensible heat load only okay. That means Q sensible of the coil that is equal to mass flow rate of supply air into Cp of the supply air into the temperature difference temperature difference is nothing but inlet temperature minus outlet temperature inlet temperature is tm outlet temperature is ts. So this multiplied by tm minus ts okay. Similarly you can write an equation for the latent load and you can also write an equation for the total load.

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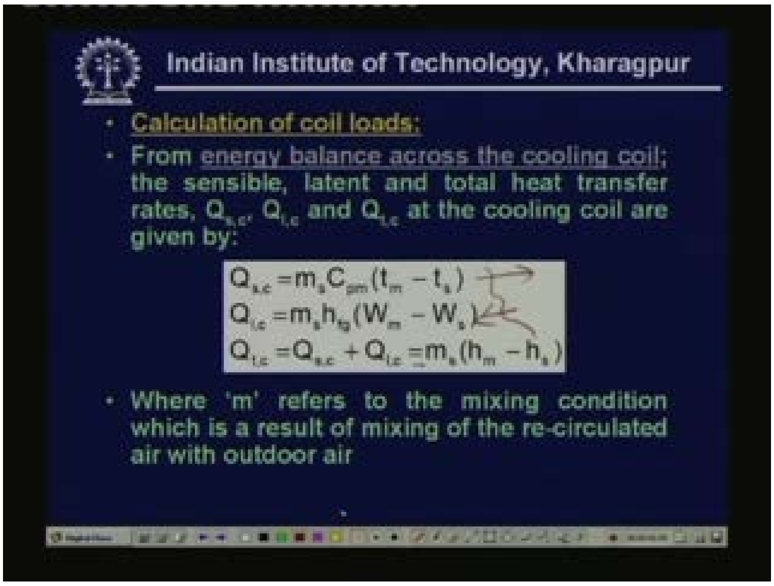

So if do that, then you will find that for the coil these are the different loads this is the sensible load this is the latent load. And this is the total load okay and here as I have already explained to you m refers to the mixing condition which is result of mixing of re-circulated air with outdoor air.

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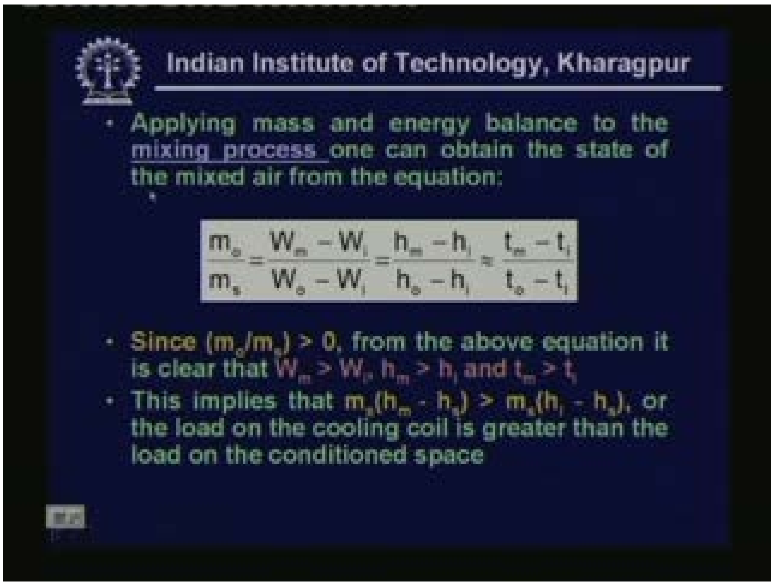

And applying mass and energy balance to the mixing process.

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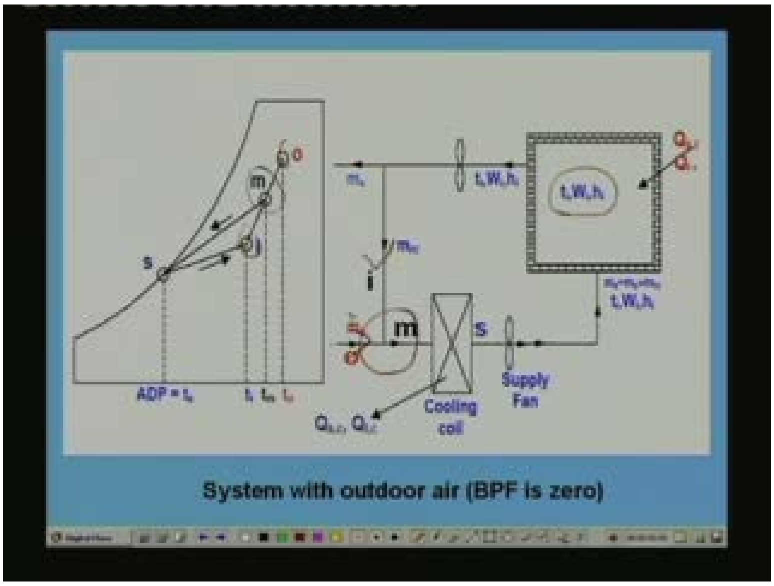

So this we seen in the earlier lectures how to apply the when two air streams are mixed how do we find the exit condition okay. So here we have mixing of two air streams okay. So this one air stream and if this second air stream these two air streams are getting mixed this air stream is coming from the conditioned space. At the condition same as that of the space and this air stream is coming from outdoor okay. That means this one and this one both are getting mixed and we would like to find out what do what should be this point okay. Where should be this point so that is obtained by again applying mass and energy balance across this point okay.

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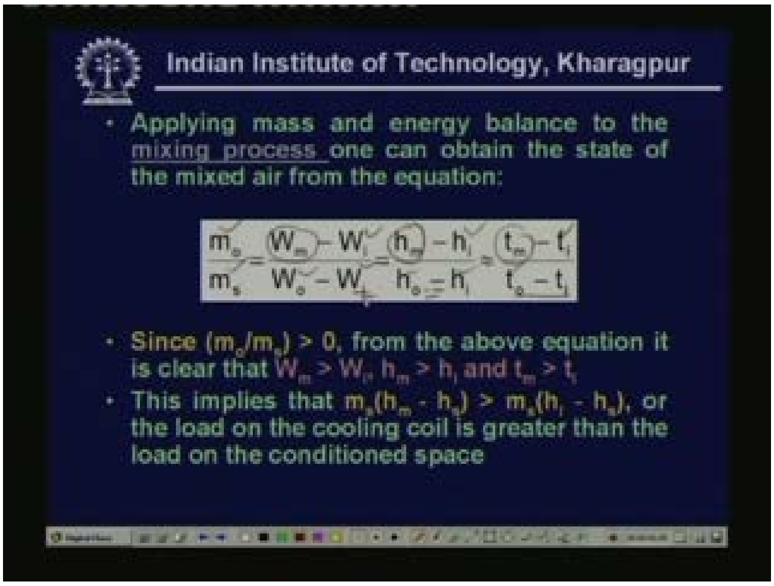

So from mass and energy balance across the point you can easily show that the ratio of outdoor air divided by supply air that is mo divided by ms is equal to wm minus wi by wo minus wi where wm is the humidity ratio of the mixed air and wi is the humidity ratio of the conditioned space wo is the humidity ratio of the outdoor air this also equal to the enthalpy ratios okay. And if you are assuming that the specific heat remains constant this is also approximately equal to the temperature ratios okay. And since we know this we also know this we know this. So you can find out wm similarly in this equation we know hi we know ho so we can find out hm similarly we can know we know ti to you can find out tm using this equation okay.

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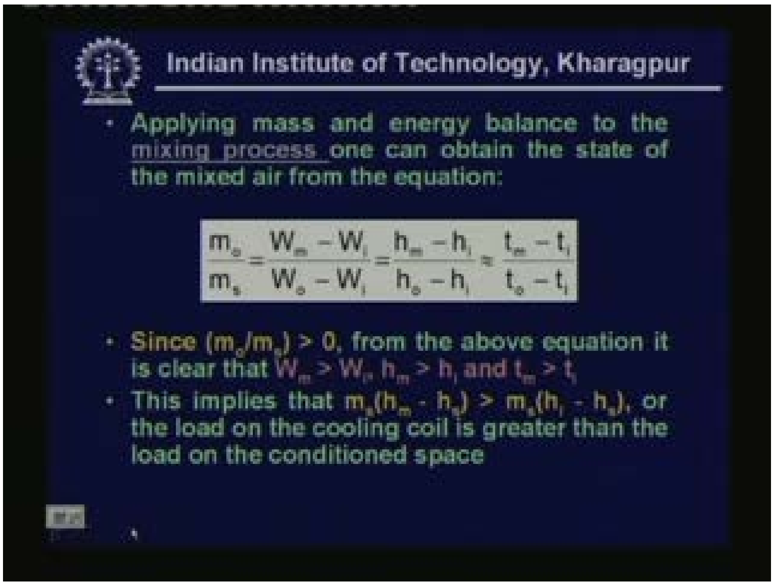

And since mo by ms is always zero. Because you are always supplying some amount of outdoor air from the above equation it is clear that wm will be greater then wi so hm will be greater than hi and tm will be greater then ti okay. This implies that ms into hm minus hs is always greater. Then ms into hi minus hs now what is ms into hm hm minus hs they are nothing but the load on the cooling coil and what is ms into hi minus hs that is load on the room. So you find t hat whenever you are using some amount of outdoor air the load on the cooling coil is always higher than the load on the room okay, load on the conditioned space this is obvious. Because what you are doing by adding outdoor air is you are adding some energy to the system.

And at the same time you are throwing out some air which is cold and dry I mean compared to the outdoor air okay. So if you throwing out some cold air and you are taking in some hot air so you have to pay some penalty for this. So this penalty is paid at the cooling coil by the difference between the loads on the coil and the building okay.

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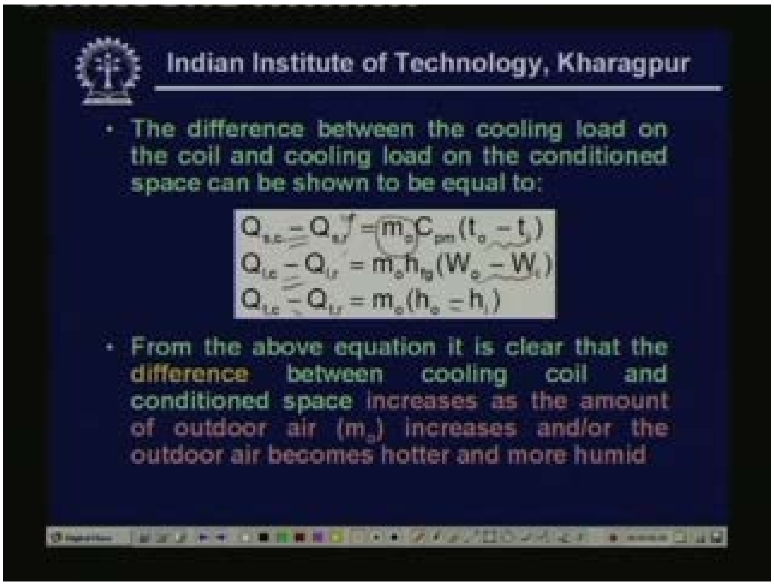

The difference between the cooling load and the coil and cooling load on the conditioned space can be shown to be equal to Qsc minus Qsr that is equal to mo into Cpm into to minus ti okay. This is the difference in the sensible cooling loads of the coil and the room and this is a latent heat loads of the coil and the room this is a total heat load. So this you find that is proportional to the amount of outdoor air added means also proportional to the temperature difference or humidity ratio difference or enthalpy difference okay. So from the above equation it is clear that the difference between cooling coil and conditioned space increases as the amount of outdoor air increases.

So you can see that as mo increases this difference also increases or as the outdoor air becomes hotter and more humid okay. This is the reason why in air conditioned buildings and all normally. For example air conditioned theatres and all they don’t allow you to smoke okay because once people smoke inside the conditioned space then the required outdoor air will be more okay you have to supply more amount of ventilated air or outdoor air to take care the odours because of the smoke okay. So a more amount of outdoor air means more amount load on the cooling coil more amount of load on the cooling coil means the cooling coil capacity as to be higher. So initial cost will be more and running cost also will be more okay. So smoking etcetera in the conditioned space is not good from this point of view okay.

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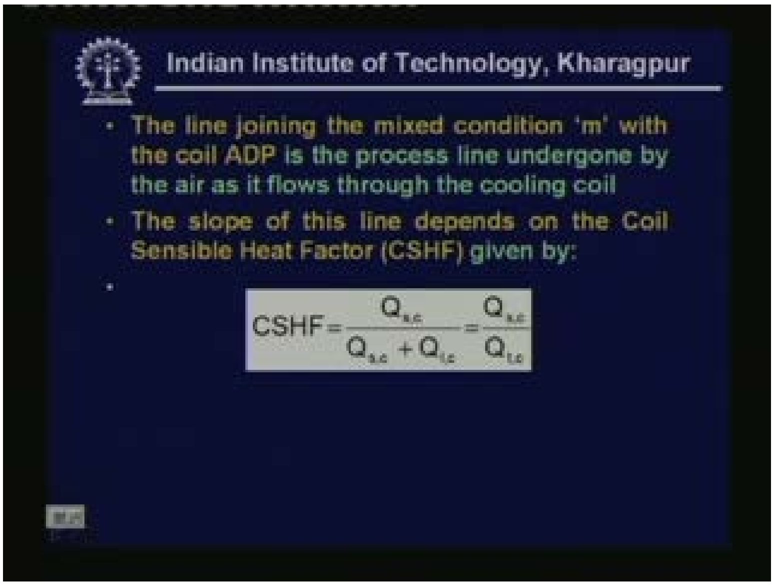

The line joining the mixer condition m with the coil ADP is the process line under gone by the air as it flows through the cooling coil the slope of this line depends on the cooling coil sensible heat factor okay. So let me just show the this thing.

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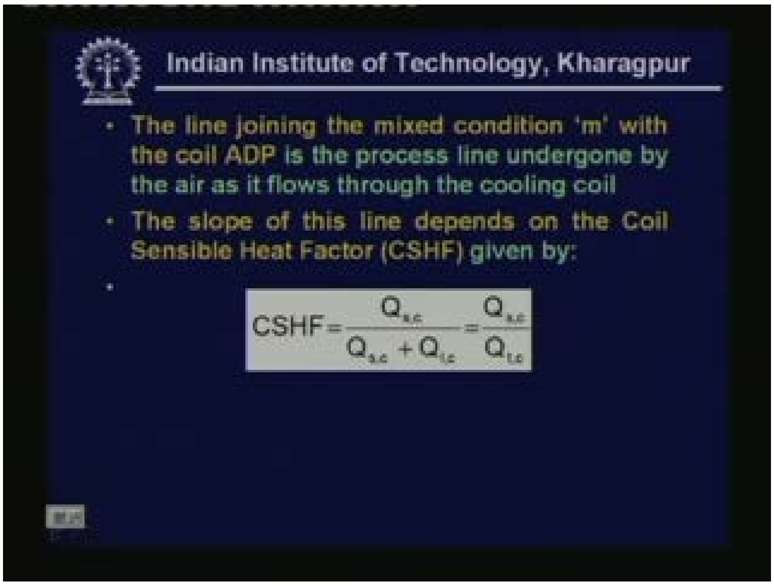

All I am talking about the, this line okay. This as we know this line is your RSHF line this line is nothing but the process line as the air flows through the cooling coil process ms okay. This depends upon what is the ratio of sensible and latent heat loads at the coil okay. So if you can define what is known as the coil sensible heat factor CSHF as the sensible heat load on the coil divided by total heat load on the coil okay. So that will give you the coil sensible heat factor and then you can find out the slope of this line. So slope of this coil line as let say that this is theta one. Let us say then tan theta one is equal to one by two four five one we can seen this one minus CSHF divided by CSHF okay. So this we can find out from the coil loads so you can find out the slope of this line.

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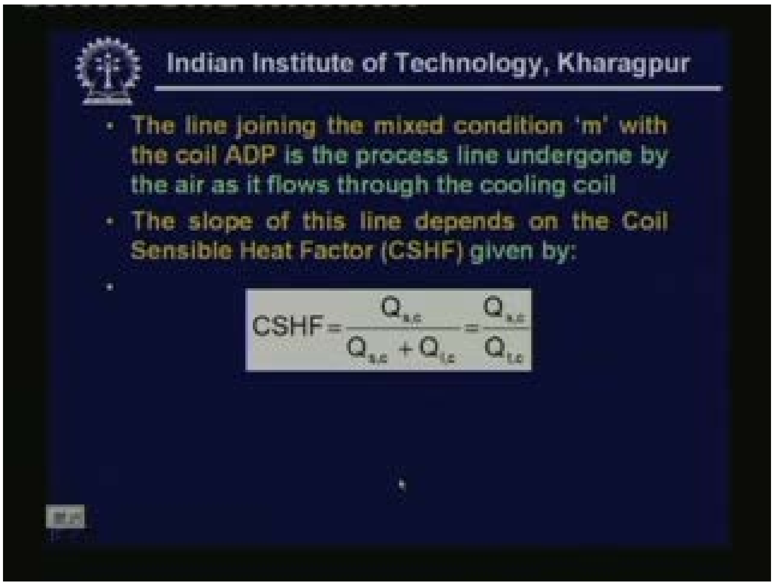

Okay so that is what is given here.

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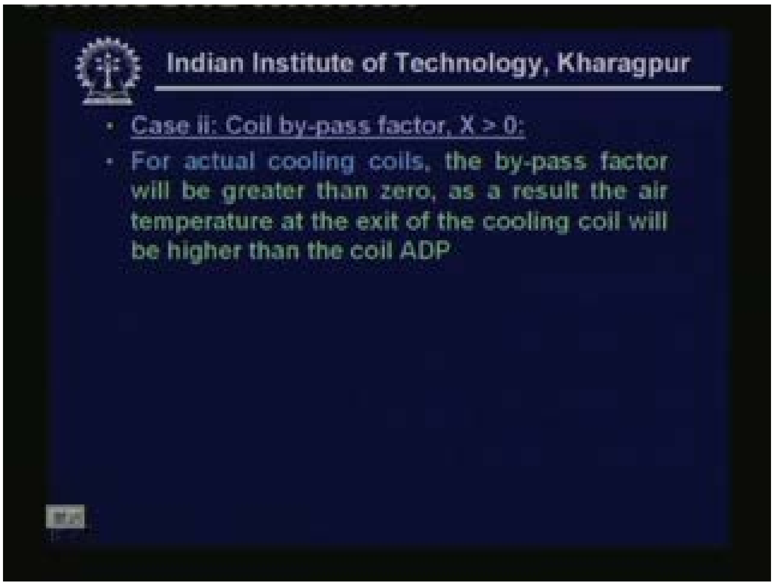

Mow let us look at another case two coil by pass factor x is greater the zero for actual cooling coils the bypass factor will be greater than zero as it okay. Because it is not possible to have a perfect coil. So you will always have some amount of bypass factor as result the air temperature of the exit of the cooling coil will be higher than the coil ADP and the process gets modified.

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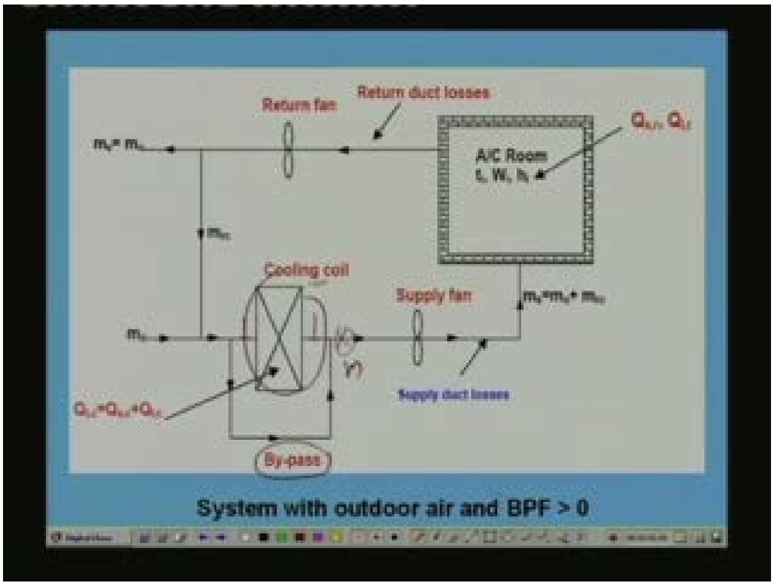

So when you have a bypass factor having a finite by pass factor of the cooling coil is equivalent to saying that some amount of air. That means this amount of air comes in perfect contact with the cooling coil. And this amount of air is completely by passing the cooling coil. So ultimately the mixer condition you get here is the result of the air which is completely by passing this and the amount of air that is completely in contact with the cooling coil okay. So again if you apply the mixing rule then you can find what is the mixed condition okay. This is a system with by pass factor greater than zero so what is the change in the psychometric chart.

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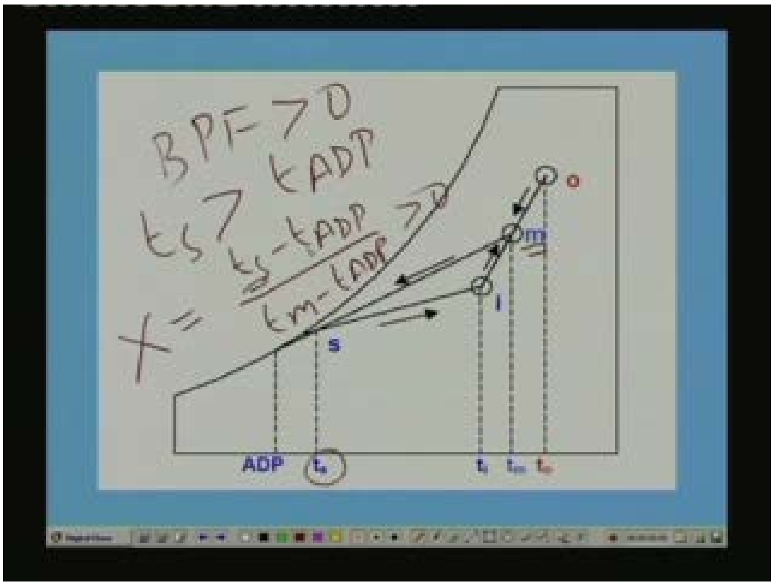

You find that on the psychometric chart there is a difference okay, since by pass factor is greater than zero you find that the exit condition of the air from the cooling coil ts is greater then Tadp. because form the definition of bypass factor we know that x is equal to ts minus tADP divided by tm minus tADP okay. m is the inlet condition to the cooling coil this is greater than zero and that means ts as to be greater than TADP okay.

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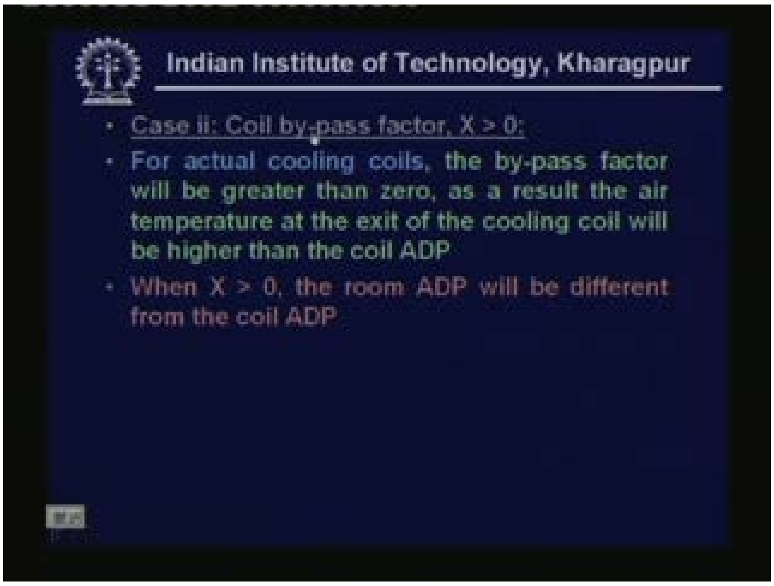

So when x is greater than zero the room ADP will be different from the coil ADP that is also clear form here.

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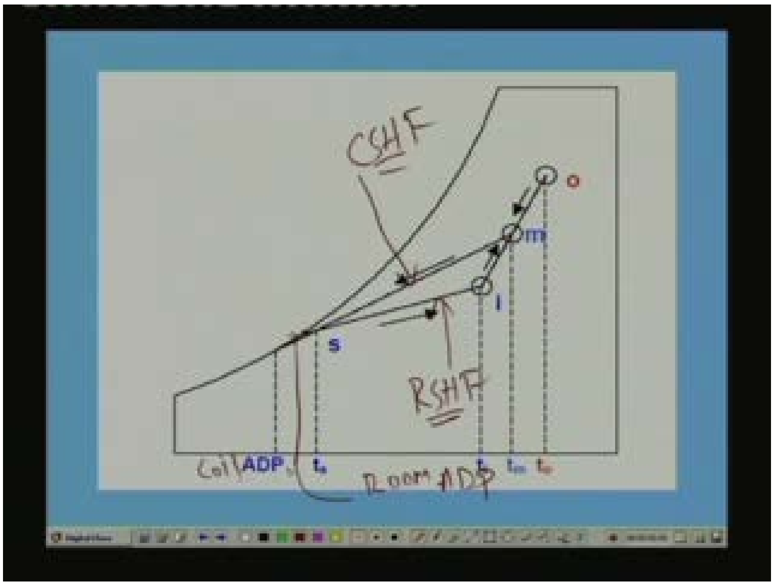

You can see that the coil ADP is this temperature room ADP is somewhere here where this is your room sensible heat factor line okay. This is you coil sensible heat factor line so the point where this line intercepts the saturation curve is your coil ADP and the point where the room sensible heat factor line intercepts the hundred percent saturation curve somewhere here let us say this is your room ADP okay. This is your room ADP and they are same here okay.

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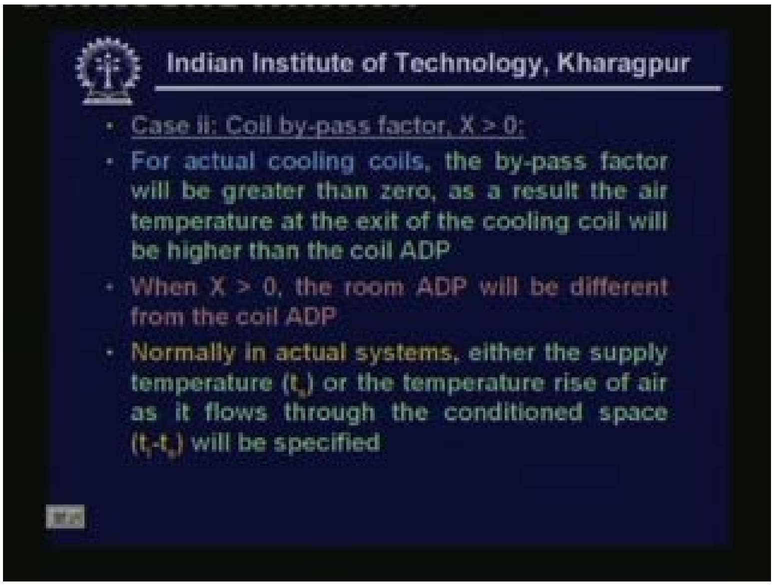

Normally in actual systems either the supply temperature ts or the temperature raise of air as it flows to the conditioned space ti minis t ts will be specified okay. Based on some other criteria which we will discuss little later generally in these values are specified either the supply temperature or what is the temperature raise of the air as it flows through conditioned space that is ti minus ts okay. These values are specified not the exact values will be specified. But the range is given okay for example it generally specified that ti minus ts should be between eight to fifteen degrees okay. So you can choose any equal between eight to fifteen okay.

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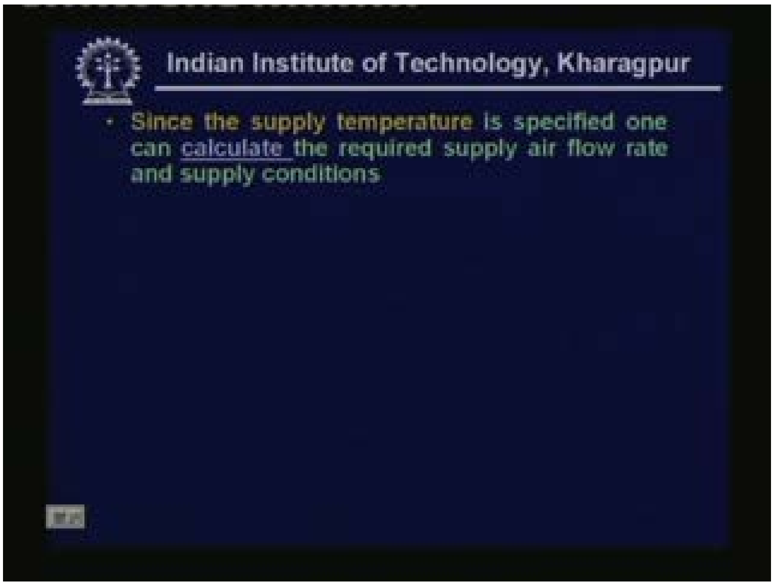

So since the supply temperature is specified one can calculate the required supply air flow rate and supply conditions okay.

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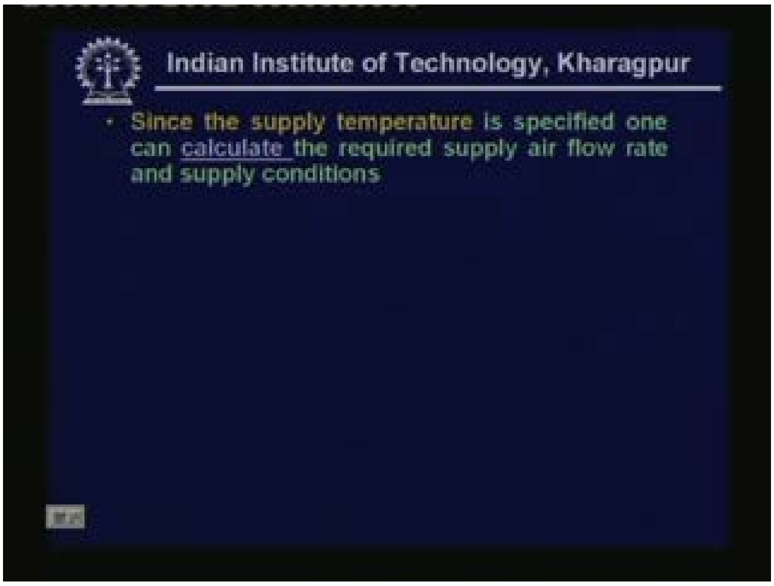

So what I am saying is we know this temperature this temperature is known to us this temperature is known to us we also know load on the sensible load on the building. So we have seen this equation before this is equal to ti minus ts so ts is specified ti is known to us Cpm is known to us this is knows. So you can find out what is ms similarly you we have seen the other equations sensible heat load of this thing is hfg into wi minus ws so ms is calculated hfg is known to us wi is known to us ws can be obtained. So you can fix this condition also okay.

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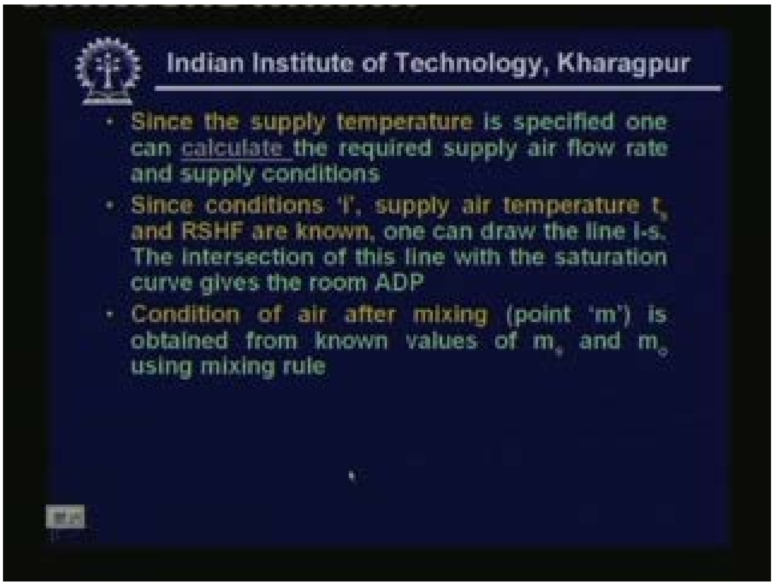

One can draw the line i-s from the known values of supply temperature and RSHF the intersection of this line. As I have already told you with the saturation curve gives the room ADP condition of air after mixing that is point m is obtained from known values of ms and m naught using mixing rule okay. So this again I have explained.

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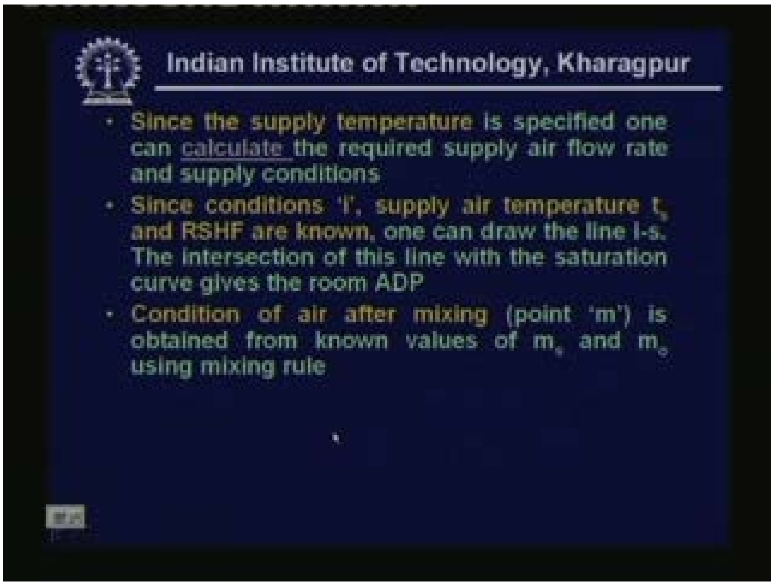

This condition okay, this in the mixing rule because we know the air flow rate and we also know this two conditions. So we can find out this point.

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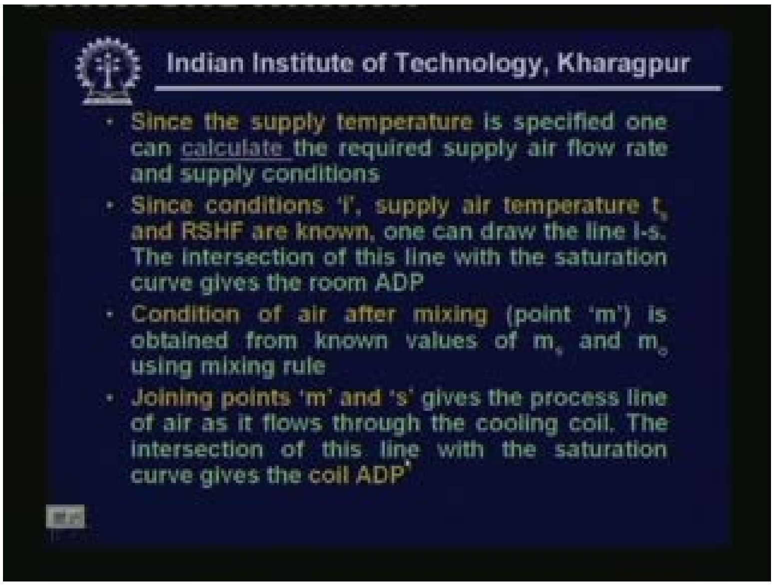

Joining points m and s gives the process line of air as it flows through the cooling coil the intersection of this line with the saturation curve gives the coil ADP.

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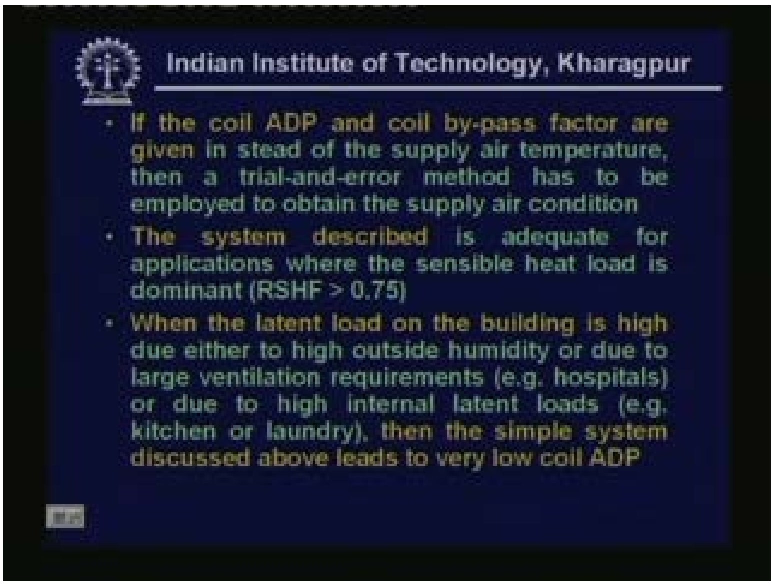

If the coil ADP and coil by pass factor are given instead of the supply air temperature then a trial and error method has to be employed to obtain the supply air condition okay. Instead of specifying the supply air temperature if the coil by pass factor is given then we have to go for a trial and error method okay. Because all that we can do is to find the room ADP and draw the room sensible heat factor line okay. We do not know what is the supply air temperature okay.

But the coil ADP is specified coil by pass factor is specified okay. So can put the draw the coil ADP or locate the coil ADP on the psychometric chart and using the bypass factor and using the trial and error method we can fix the supply condition okay. The system described. So for is required for applications where the sensible heat load is dominant. That means your room sensible heat factor is greater than about point seven five when the latent load on the building is high due either to high outside humidity or due to large ventilation requirements. For example in hospitals or due to high internal latent loads. For example your conditioned space consists of a kitchen or a laundry then the simple system discussed above leads to very low coil ADP okay. So what are the systems we have been discussing so for that is fine as long as your sensible load is more than three times that of the latent load on the building. That means your room sensible heat factor is greater than about point seven five which is normally the case.

But there are some special cases where the latent load on the building could be quiet high okay. So some of the examples are where the outside conditions are highly humid okay. For example in coastal areas or where there is lot of internal latent heat load. As I said, for example you have a laundry or kitchen inside the condition space a lot of moisture is continuously added okay. So under ofr these conditions you find that the room sensible heat factor will be low because the latent heat load is high okay. Low means it could be lower than point six or so okay, for these special circumstances if you are using the simple system you find at the required coil ADP. That means required surface temperature of the coil will be very low now the surface temperature of the coil is connected to the evaporated temperature of the system okay.

Since it is connected to the evaporated temperature of the system refrigerant system as to be operated at very low evaporated temperature okay. And as you know when you operate the refrigerant system at low evaporative temperature the COP of the system reduces okay. That means you are running cost of the system goes up okay. So normally of high latent heat load applications some modifications are done. So that you get reasonably high COP of the refrigerant system okay. So one of the modifications is what is known as the system with reheat coil.

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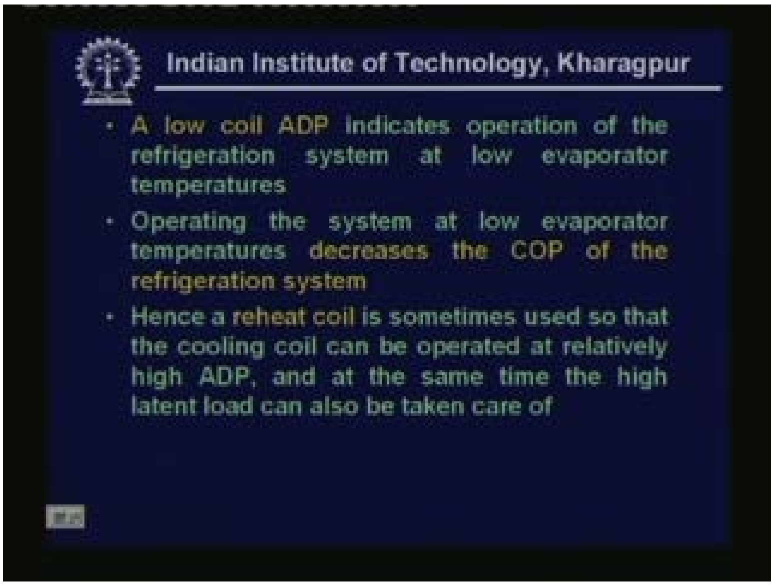

Okay, so low coil apparatus due point indicates operation at refrigerant system at low evaporator temperatures these all reputation of whatever I have said operating the system at low evaporative temperatures decreases the COP of the refrigerant system. Hence a reheat coil is sometimes used. So that the cooling coil can be operated at relative high ADP and at the same time. The high latent load can also be taken care of okay. I will explain this system shortly.

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When a system with reheat coil air is first cooled and dehumidified in the cooling coil and is then reheated sensibly to the required supply temperature ts using the reheat coil okay.

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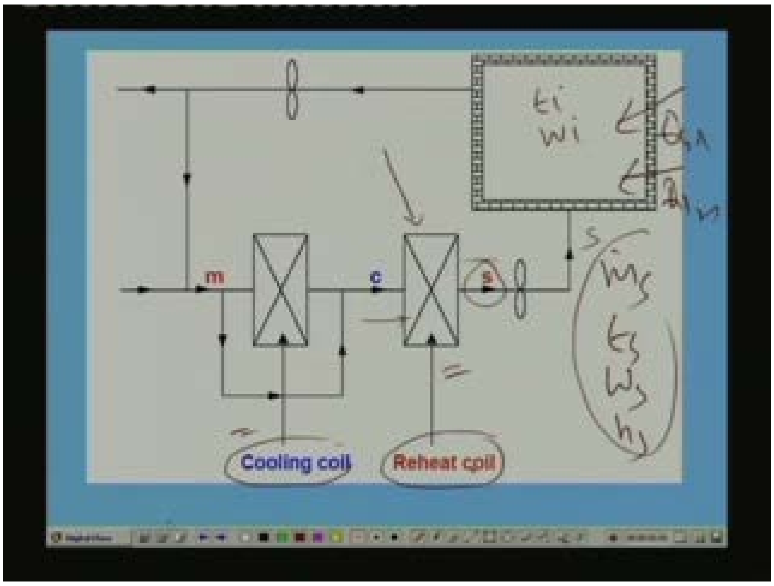

So that means a first let me explain the system hardware. So you again have the conditioned space here where we require ti and wi this is supply state here we require this much amount of air flow rate at this temperature and this humidity in this enthalpy. At this condition this is supplied to the conditioned space and f again we have the sensible heat load on the room latent heat load on the room okay. So we have the cooling coil here in addition to the cooling coil we have also a heating coil okay. So this is the heating coil okay. So first what is done here is the air is first cooled and humidified in the cooling coil. Then it is sensibly heated in the re heat coil okay. So first you cool the air and remove the moisture in this process that means it is a cooling and dehumidification process. And once you remove the moisture then what do you is you sensibly heat the air by passing it through the reheat coil so that you get the required supply air condition okay. So this is shown on the psychometric chart like this.

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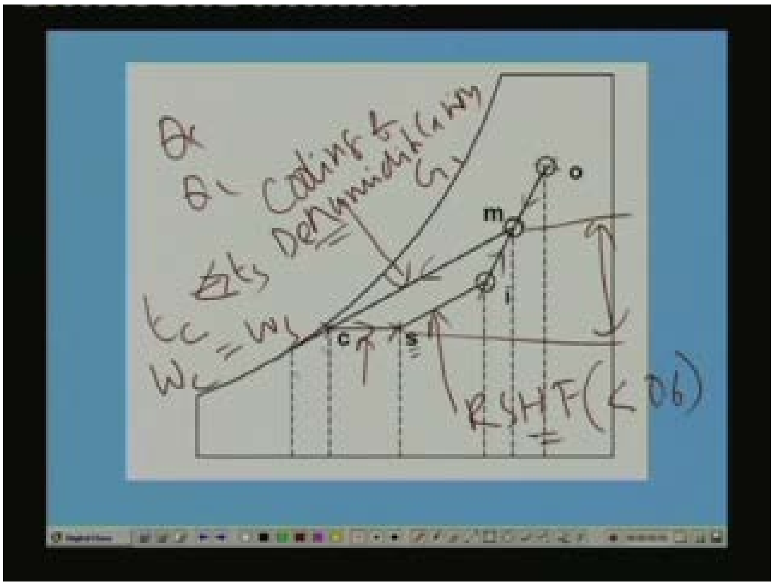

Okay, let us begin at this process we have the indoor air and outdoor air both are mixed and we get a mixed condition this mixed condition flows through the cooling coil cooling and dehumidification coil okay. This is cooling and dehumidification coil in this process you can see that the required amount of moisture is extracted okay. So this is the amount of moisture to be taken out. So that is achieved in this process but you find that this temperature or this point does not lie on the RSHF line okay. If this is this is your RSHF line and this RSHF will be quite low because the high latent load let us this less then point six okay. Since this point does not lie on this line if you leave air at this condition with conditioned space it cannot take the required amount of sensible and latent heat loads. So okay, somehow you have to bring this point on to the room sensible heat factor line okay.

So what for that purpose what is done is at this point air flows through the reheat coil and in the reheat coil it is sensibly heated okay. So in the reheat coil the temperature increases from tc to ts. So that the point s lies on the room sensible heat factor line so that it can take care of the latent and sensible and heat loads okay. Since it is sensible process tc will be lower then ts okay and wc will be equal to ws okay. So no change in the humidity ratio.

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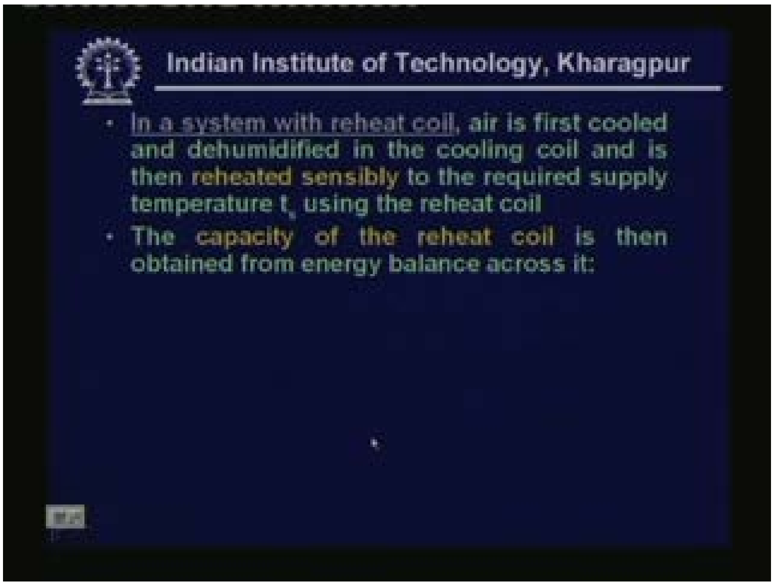

And we have to find out now the capacity of the reheat coil the capacity of the reheat coil is obtained from energy balance across the coil very simple.

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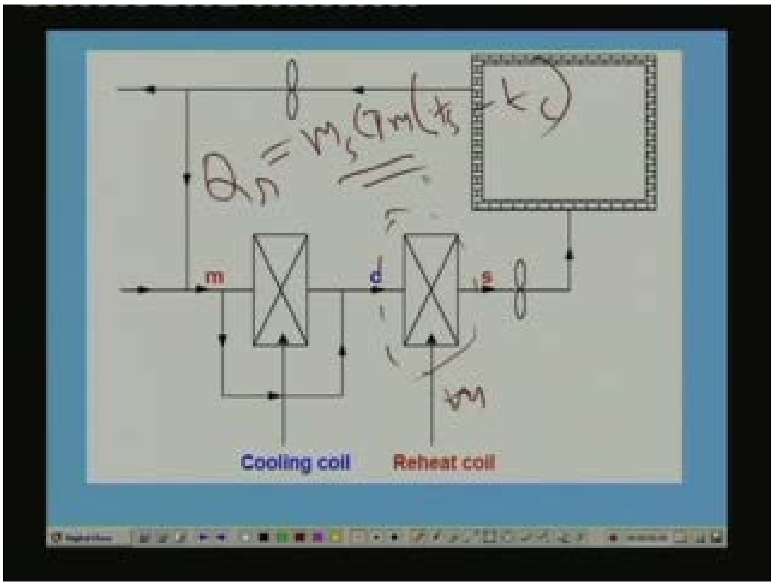

All that you have do is take this as a control volume and perform the energy balance. So okay, from that you find that only sensible heat transfer is taking place. So then reheat coil Qr is equal to mass flow rate of the supply air into specific heat of the air multiplied by the temperature difference ts minus tc okay.

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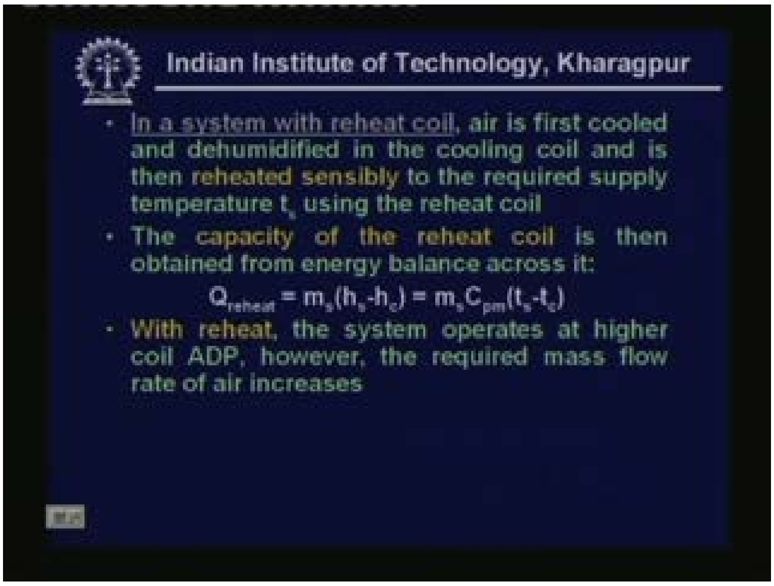

So Q reheat is given by ms into hs minus hc since this sh a pure sensible heat transfer process hs minus hc is written as Cpm into ts minus tc okay. So with reheat the system operates at higher coil ADP that means you can get expect high COP of the refrigerant system how do the required mass flow rate increases okay. So the benefit of the cool reheat coil is that you can operate your refrigerant system at a higher evaporated temperature. But there is also a disadvantage. Because first disadvantage we are unnecessarily cooling the air to a lower temperature and then you are heating it so energy is required first for cooling and energy is also required for heating okay. It is actually wasteful use of energy second thing is that because of this reheating process the temperature difference ti minus ts reduces okay. Once ti minus ts reduces the required amount of supply air increases. These are the two disadvantages of the reheat coil okay. And the benefit is higher COP so ultimately in an actual system one as to perform calculations and see whether reheat coil is justified or not okay.

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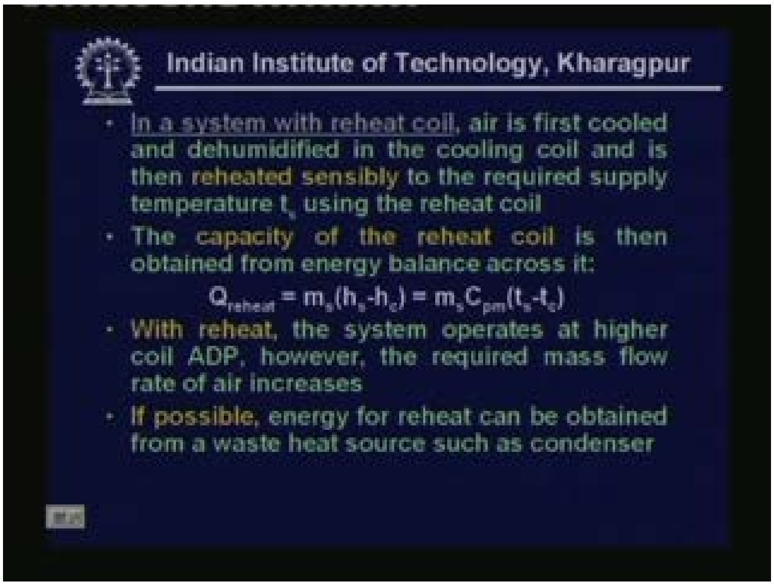

And if possible energy for reheat can be obtained from a waste heat source such as condenser okay. That means instead of using let us say an electrical heater for other reheat coil we can also use a waste heat source one of the waste heat sources is the heat rejected at the condenser okay. If it is possible you can use that heat for heating the air in the reheat coil okay. That is how you can reduce the, a energy consumption okay. So at this point is stop it and let us conclude.

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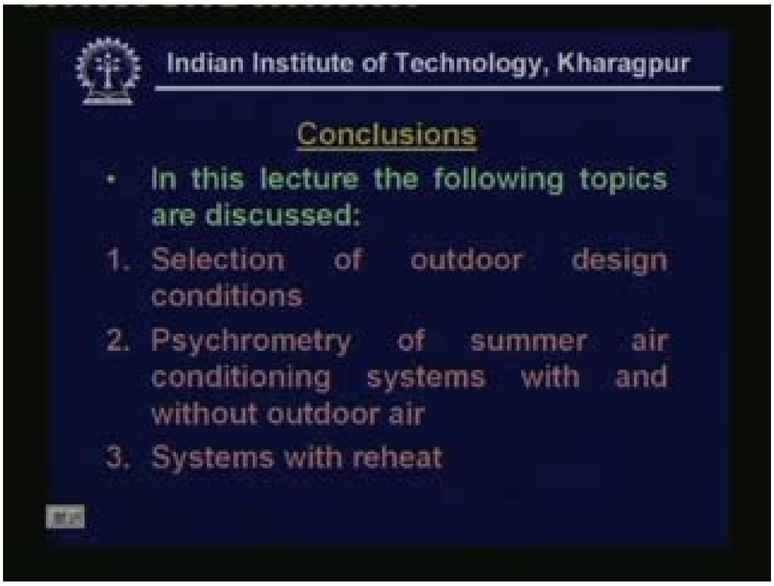

What we have learned in this lecture in this lecture the following topics are discussed selection of outdoor design conditions psychometric of summer air conditioning systems with and without outdoor air and systems with reheat okay. We will continue this lecture in the next class okay.

Thank you.