Refrigeration and Air Conditioning
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Lecture No. # 38
Air Conditioning Systems

Welcome back in the last lecture I discussed summer air conditioning system and the psychrometry of summer air conditioning systems.

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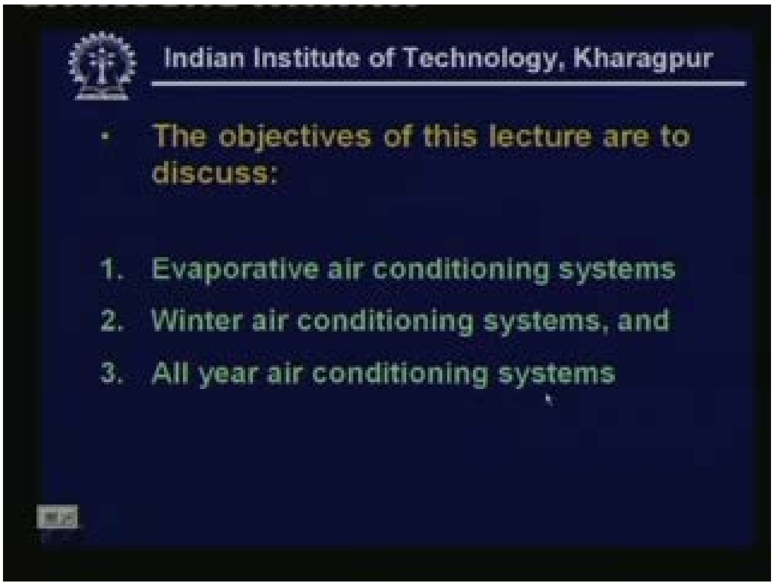

In this lecture I shall discuss evaporative air conditioning systems air conditioning systems for the winter and an all year air conditioning system. So the specific objectives of this particular lecture are to discuss evaporative air conditioning systems winter air conditioning systems and finally all year air conditioning systems.

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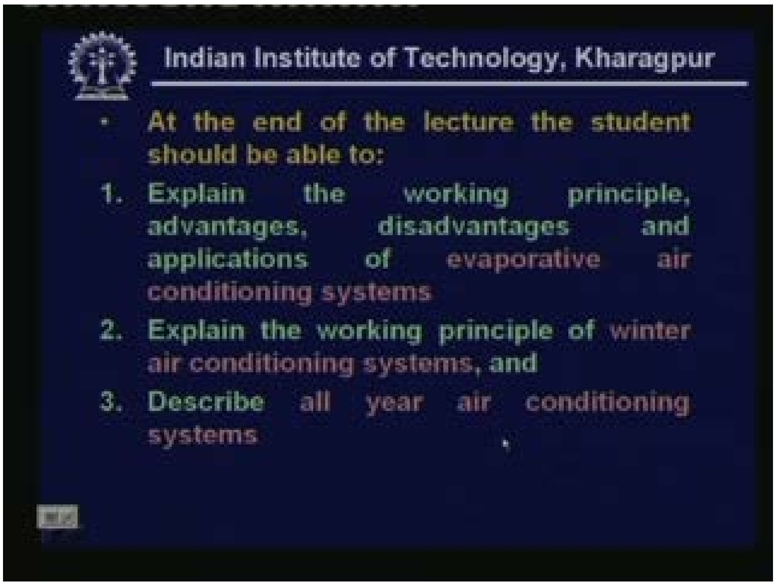

At the end of the lecture you should be able to explain the working principle advantages disadvantages and applications of evaporative air conditioning systems explain the working principle of winter air conditioning systems and describe all year air conditioning systems.

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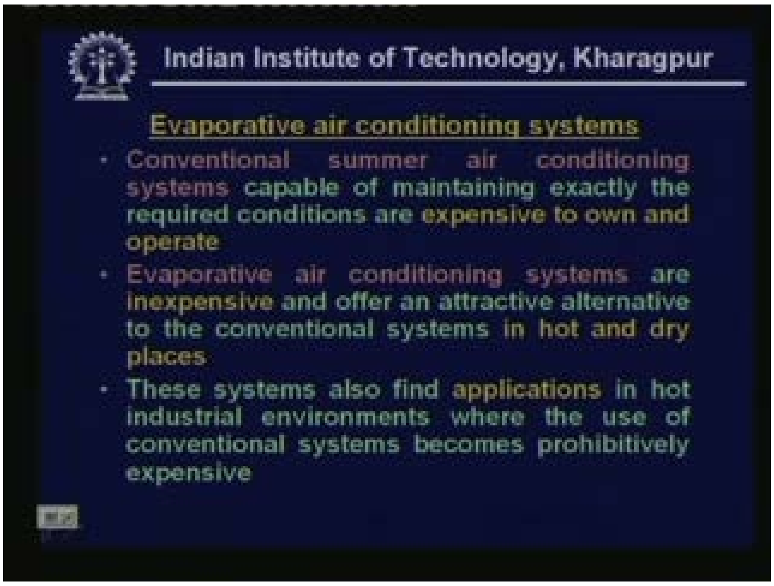

So let me give a brief introduction to evaporative air conditioning systems conventional summer air conditioning systems. Which we have discussed in the last class which are capable of maintaining exactly the required conditions or expensive to own and operate by conventional air conditioning systems for summer, what I mean is the air conditioning systems. Which are based on refrigeration cycles, which in turn are based on either vapour compression systems or vapour absorption systems? These systems can be used in any location and they are they can be used for precise control of the condition space conditions okay. However they are very expensive and they are expensive not only the initial cost is high but the running cost is also high. So you will find that in certain applications the cost may be prohibitive in such cases one has to look for alternative systems oaky. So evaporative air conditioning system is an alternative to summer air conditioning systems which can be used in hot and dry climates. So evaporative air conditioning systems are inexpensive and they offer an attractive alternative to the conventional systems in hot and dry places. And evaporative systems also find applications in hot industrial environments where the use of conventional systems becomes prohibitively expensive. Because of the large loads involved.

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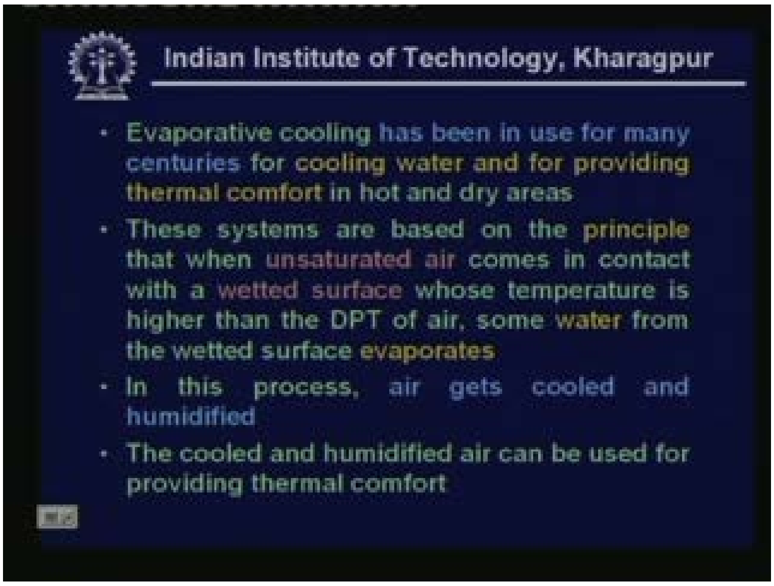

So the evaporative cooling by the principle is very well known and it has been in use for many centuries for cooling water and for providing thermal comfort in hot and dry areas all of us know that in hot and dry places you can cool water by storing it in earthen pots and here the principle is that water evaporates from the pores surface of the pot and as a result water stored in the a pot gets cooled. So we all know this and we have we are also familiar in hot and dry places that we use dry herbal mats called as khoose which provide us when you wet them and you expose it to an air stream they provide us with cool and nice smelling air okay. So these principles are very well known and they have been in use for many centuries in many centuries in many countries including India okay. So what is the principle behind this these systems are based on the principle that when unsaturated air comes in contact with a wetted surface whose temperature is higher than the dew point temperature of air some water from the wetted surface evaporates.

So there is a basically evaporation of water from the wetted surface as a result of this the air which is in contact with the wetted surface becomes cool and humidified and this cooled and humidified air can be used for providing thermal comfort. So this the principle simple principle behind the evaporative cooling systems.

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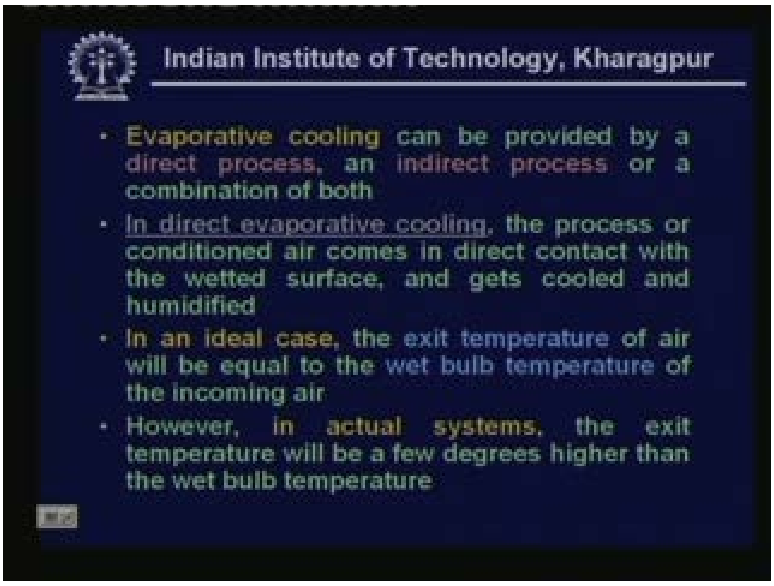

Now evaporative cooling can be provided either by a direct process or using an indirect process or using a combination of both. First let us look at a direct evaporative process in direct evaporative cooling systems the process or conditioned air comes in direct contact with the wetted surface and gets cooled and humidified. That is why you call it as direct evaporative system by because there is a direct contact between the wetted surface and the process air and in an ideal case the exit temperature of air will be equal to the wet bulb temperature of the incoming air. I will explain what an ideal case is. However in actual system we find that the exit temperatures will a few degrees higher than the wet bulb temperature of incoming air. So let be show the schematic of a direct evaporative cooling system.

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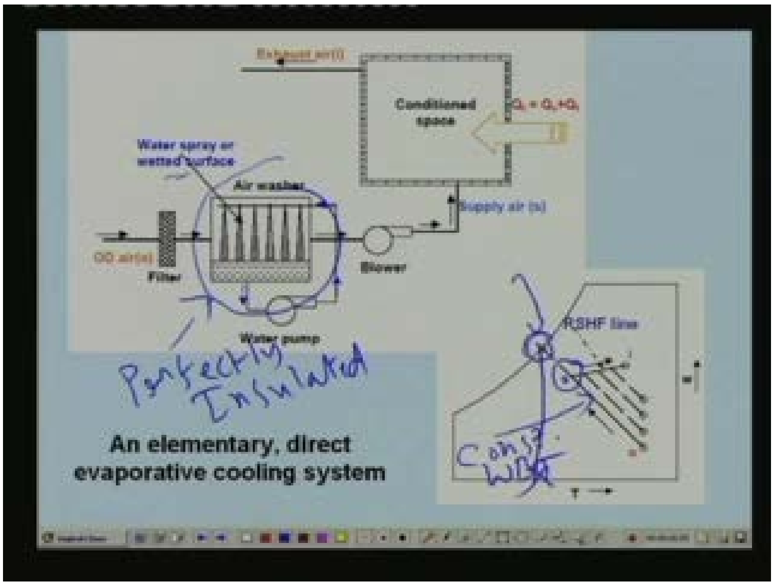

Because here you can see a simple an elementary direct evaporative cooling system this is called as a single stage system you can see from the schematic that outdoor air okay, outdoor air which is hot and dry. Dry means which has very less moisture content first flows through a filter this filter filters the air and it removes any dust particles etcetera. And the filtered air flows through an evaporative cooler or an air washer in the evaporative cooler or air washer this dry and hot air comes in contact with a wetted surface or a water spray if you are using a an air washer.

Since this air is unsaturated there will be evaporation of water from the wetted surface to the air since evaporation is an endothermic process the latent heat of evaporation has to be supplied. And this latent heat of evaporation is supplied by air or water or both. So in this process what happens the air which comes out of the evaporative cooler becomes cooled okay. It may waits they loses its temperature because the sensible heat is used for converting water liquid into vapour okay. For the exit of the evaporative cooler you have cool and moist air or cool and humidified air okay, cool and humidified air. So this cooled and humidified air is blown into the conditioned space where you want to maintain the comfort conditions using a blower okay.

So that air you call it as supply air so this supply air which is at a lower temperature. But at a higher humidity flows through the condition space and as it flows through the condition space it extracts the sensible and latent heat form the building. And it maintains the conditioned space at the required condition and finally the air is exhausted or wented out of the building okay. So this is the principle of an elementary direct evaporative cooling system the same thing is shown on the psychrometric chart here we have the dry bulb temperature on the X axis and humidity ratio on the Y axis so point O is the condition of the air at the inlet to the system okay. As you can see here the temperature is high and humidity is low. That means the air is hot and unsaturated. So as it flows through the evaporative cooler or air washer it gets cooled and a humidified. So its temperature reduces and their humidity increase that means it follows the process OS okay. So it moves in this direction. And point S is a exit condition of the air at the evaporative cooler and this air which is cooled and humidified is sent to the condition space.

So as it flows through the conditioned space it extracts the sensible and latent heat and finally leaves the condition space at this state high okay. And this line SI is nothing but room sensible heat factor line which we have discussed in the last lecture okay. So this is the basic principle of direct evaporative cooling system. As I have mentioned in an ideal case the exit temperature of air will be equal to the wet bulb temperature of the incoming air but in an actual case the exit temperature will be higher. So what do you mean by an ideal case ideal case means, oh, this evaporative cooler or the air washer is perfectly insulated okay. Then you call it as this is perfectly insulated from the surroundings okay. That means the process is adiabatic right and there is an infinite area of contact between the air and the wetted surface okay. In such cases what happens is the process line follows the constant wet bulb temperature line.

So if it is perfectly insulated this is your constant wet bulb temperature line okay. And at the exit condition will be same as the wet bulb temperature that means the exit will lie somewhere here okay. So this will be our exit temperature right in an ideal case but you will find that in an actual case there will be some heat leaks into the system as a result the process line lies slightly above the wet bulb temperature line and the exit temperature will be higher than the wet bulb temperature. That means instead of being here the exit condition will be at point S which is few degree higher than the wet bulb temperature line okay.

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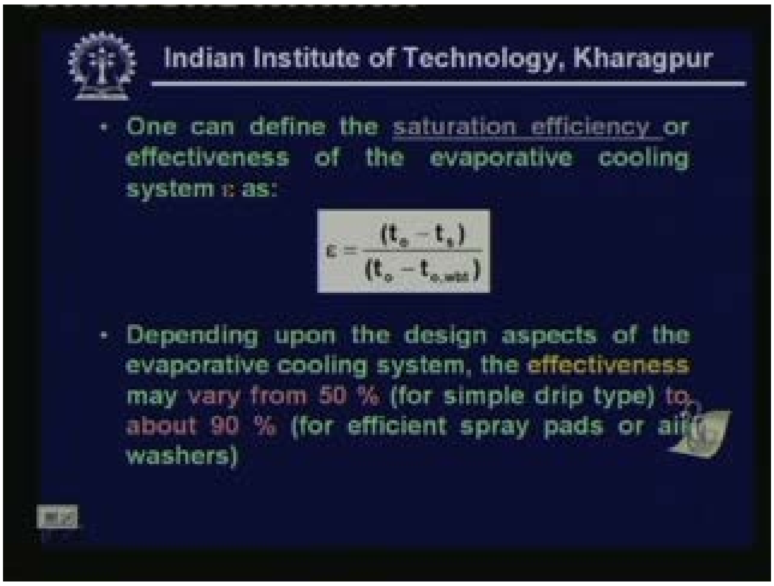

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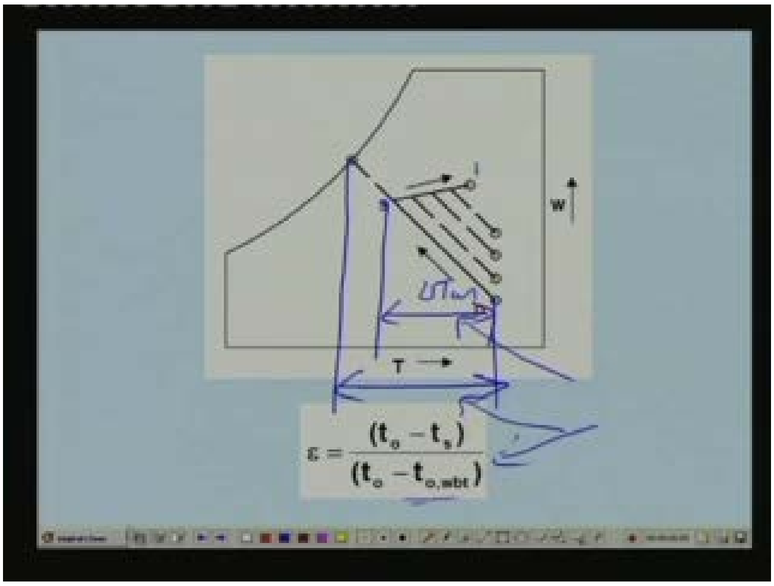

Since the exit temperature is higher than the wet bulb temperature line we can define what is known as saturation efficiency or effectiveness of the evaporative cooling system epsilon this is defined. As you can see here t naught minus ts divided by t naught minus t naught subscript wbt where t naught is the inlet dry bulb temperature ts is the exit dry bulb temperature of the air and t subscript o wbt is the wet bulb temperature at the inlet condition. So this is very clear from your psychrometric chart. If you look at the psychometric chart this is a expression for effectiveness or efficiency as you can see t naught minus ts is nothing but this temperature drop okay. Or you can call this as actual temperature drop and t naught minus twbt is nothing but this okay. So in an ideal case you get this but in an actual case the actual temperature drop will be lower.

So the efficiency or effectiveness is nothing but this divided by this okay. But depending upon the design aspects of the evaporative cooling system the effectiveness may vary from fifty percent for simple drip type evaporative coolers. And it can be as high as ninety percent for efficient spray pads or air washer based systems. So the efficiency will vary from fifty to ninety percent depending upon the design.

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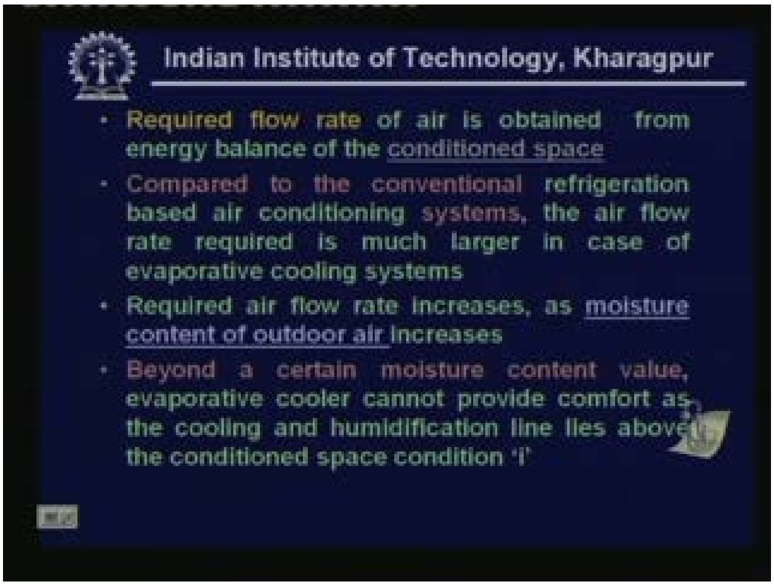

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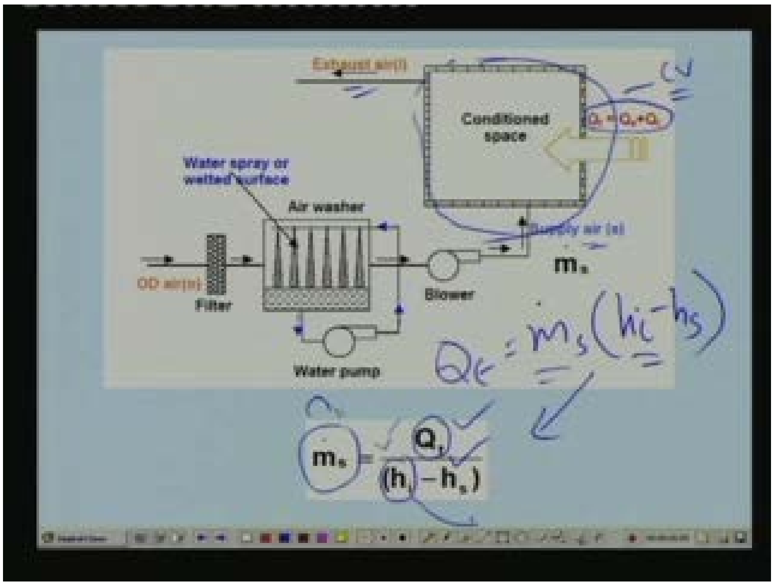

Now the required flow rate of the air is obtained from energy balance of the conditioned space we have to find out what is the required air flow rate. So that is that can be easily obtained. If you take a control volume across the conditioned space and if you assume that steady state conditions prevail. So you take a control volume across this and apply energy balance okay. And neglect kinetic and potential energy changes. So the rate at which heat is being added to the conditioned space that is nothing but Qt should be equal to the rate at which heat is being extracted by this air stream okay. So energy balance becomes Qt is simply equal to m dot s into hi minus hs where hi is the exit enthalpy hs is the inlet enthalpy oaky.

So this is the energy balance assuming of course negligible kinetic and potential energy changes for the supply air. So from this expression you can find out what is the required air flow rate m dot s which is nothing but Qt divided by hi minus hs. So if you know what is the rate of heat transferred to the conditioned space Qt if this is known and hi is nothing but the enthalpy of the conditioned space air. So which is normally known from our requirements. So hi is known to us and if you can fix the supply condition hs. Then you can find out the required mass flow rate of supply air okay. Compared to the conventional refrigeration based air conditioning systems. The air flow rate required is much larger in case of evaporative cooling systems.

This is, this can be viewed as an advantage or it can also be viewed as a disadvantage normally it is observed that for the same cooling capacity. And for same inlet and outdoor conditions the required air flow rate in case of evaporative air cooling systems will be about eight to ten times it can be as high as eight to ten times that of a normal air conditioning system which is based on vapour compression or vapour absorption system. So the air flow rate required is very high okay. And the required air flow rate increases as moisture content of outdoor air increases this, I will explain with the help of a psychrometric chart. And we also find that beyond certain moisture content value evaporative cooler cannot provide comfort as the cooling and humidification line lies above the conditioned space condition okay. So one thing you must observe is the required mass flow rate increases as the outdoor air humidity increases and beyond a certain point these coolers will simply. They cannot simply work okay. You cannot use the coolers when the outdoor air humidity exceeds certain value okay. So let me show that by using a psychrometric chart.

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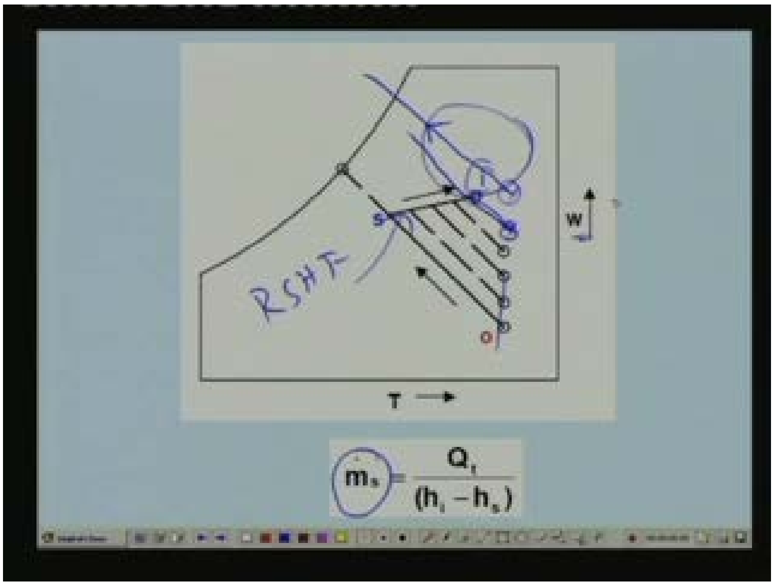

Okay, so this is again what I have shown earlier this is the psychrometric chart you have the dry bulb temperature and humidity ratio and this is your cooling and humidification process that take place in a evaporative cooler okay. So O is the inlet condition and S is the supply condition and we have seen that from energy balance the required air flow rate m dot s is Qt divided by hi minus hs okay. Let us say that this is your humidity. That means this is your inlet condition okay, the, which is nothing but the condition of the outdoor air then hi minus hs is nothing but if you draw enthalpy constant enthalpy line. This is your hi minus hs. So you can see that the required mass flow rate is inversely proportional to this enthalpy difference. Now if the temperature remains same. Let us say and the humidity ratio increases to this point oaky.

When the humidity ratio increases to this point hi minus hs decreases, because, now the, hi minus hs is this okay. Since hi minus hs decreases mass flow rate of air increases if the humidity increases further to this point let us say then there is further reduction in enthalpy raise across the condition space. So there is further increase in the mass flow rate of conditioned mass flow rate of the supply air and you find that beyond a certain point. For example if you are, let us say that humidity ratio is at this point temperature is same but humidity ratio is here then when you use an evaporative cooler you find that the process line proceeds like this okay. That means it does not intersect this room sensible heat factor line at all okay. That means you cannot use evaporative cooler beyond a certain point in fact when the humidity ratio lies at this point and if the process line pass passes through the conditions point i. Then you will find that the required amount of supply air is infinite oaky so beyond a certain humidity ratio this system does not work okay. So this is a very important thing one must keep in mind.

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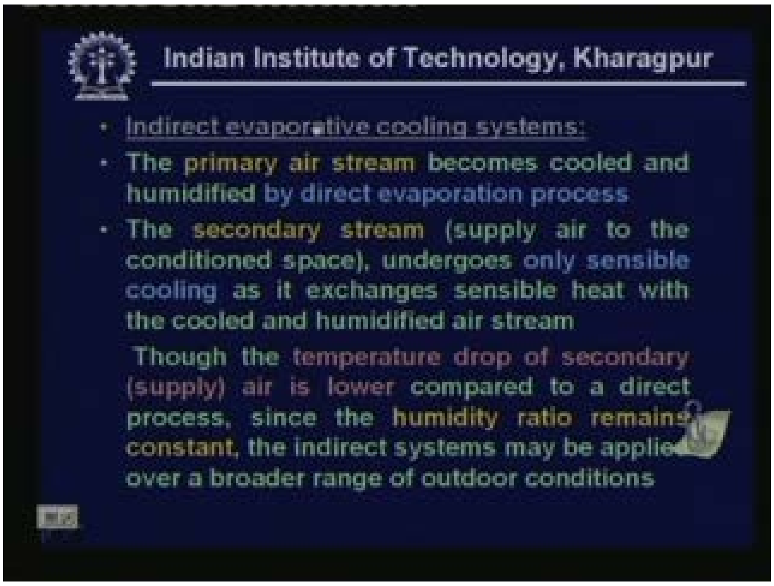

Now let us look at indirect evaporative cooling system. So far we have discussed direct evaporative cooling system. Now let us look at indirect systems in an indirect system we use a primary air stream and a secondary air stream. That means two air streams are used the primary air stream becomes cooled and humidified by direct evaporation process whereas the secondary air stream which is nothing but the supply air to the conditioned space under goes only sensible cooling as it exchanges sensible heat with the cooled and humidified air stream. Though the temperature drop of secondary air is lower compared to a direct process since the humidity ratio remains constant the indirect systems may be applied over a broader range of outdoor conditions okay. So this is the advantage of indirect evaporative cooling systems over direct evaporative cooling system. Now let me show a schematic of indirect system.

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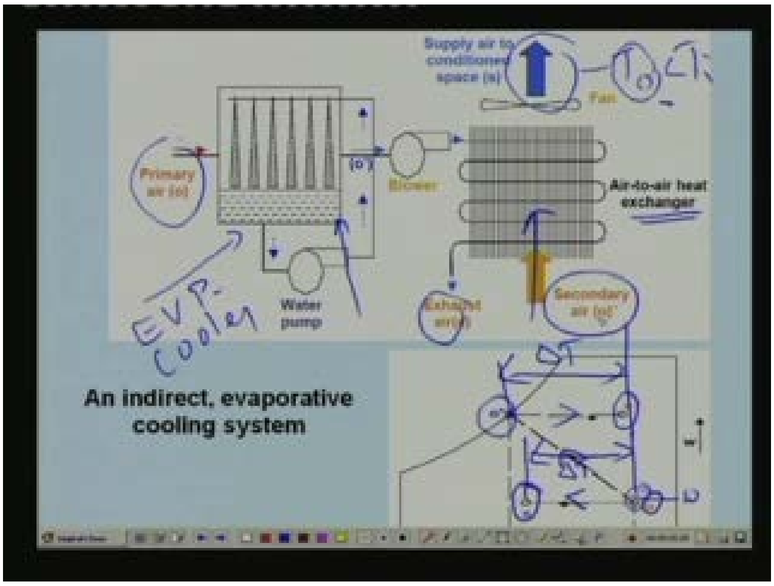

Okay, so as I said here you have two air streams one is primary air the other one is secondary air okay. The first primary air is cooled and humidified in this evaporative cooler. So this is your evaporative cooler okay. So as the primary air flows through this evaporative cooler it gets cooled and humidified. Now this cooled and humidified air is blown through an air to air heat exchanger okay. So this is an air to air heat exchanger let us for the sake of simplicity. Let us assume that it is a fin and tube type of heat exchanger and this cooled and humidified air flows through the tubes. Let us say and the secondary air which is nothing but the supply air to the conditioned space flows over the tubes and over the fins okay. So there is no direct contact between the primary and secondary air okay. So secondary air is flowing in this direction and primary air is flowing through the tubes since the temperature of the primary air is lower than the secondary air there will be sensible heat exchange between the secondary air and primary air as a result you find that the secondary air gets cooled sensibly okay. So at this point the temperature lets us say t outlet will be lower than the t inlet for the secondary stream.

So this cold air is supplied to the conditioned space for providing thermal comfort okay. So this is the, this is an elementary indirect evaporative cooling system and the same thing is shown here on a psychrometric chart. You can see here that process O to O dash is what happens to be primary air as it flows through the evaporative cooler. As you know it gets cooled and humidified in an ideal case it leaves the evaporative cooler at the wet bulb temperature oh is okay. So this is the process undergone by primary air. So at this point this air enters into the air to air heat exchanger okay. So in the air to air heat exchanger this exchanges heat with a secondary air which is again at this temperature okay. So there is heat exchange between hot air which is at this temperature and cold air which is at this temperature okay. So since there is no direct contact the secondary air undergoes only sensible cooling. So its temperature reduces in this direction and the primary air temperature increases in this direction okay.

So finally the primary air is exhausted at this point at condition e and the secondary air which is at the temperature s is supplied to the conditioned space you can see here that the secondary air which is nothing but our conditioned air gets cooled but its humidity ratio remains constant okay. That means inlet and outlet humidity ratios remain constant. So this is an advantage of indirect cooler because we are increasing the humidity of the air whereas you can see that the temperature drop of the secondary air is only this much okay. Whereas the temperature drop of the primary air is higher okay. So this is one disadvantage of indirect evaporative cooler because the required available temperature drop is reduced.

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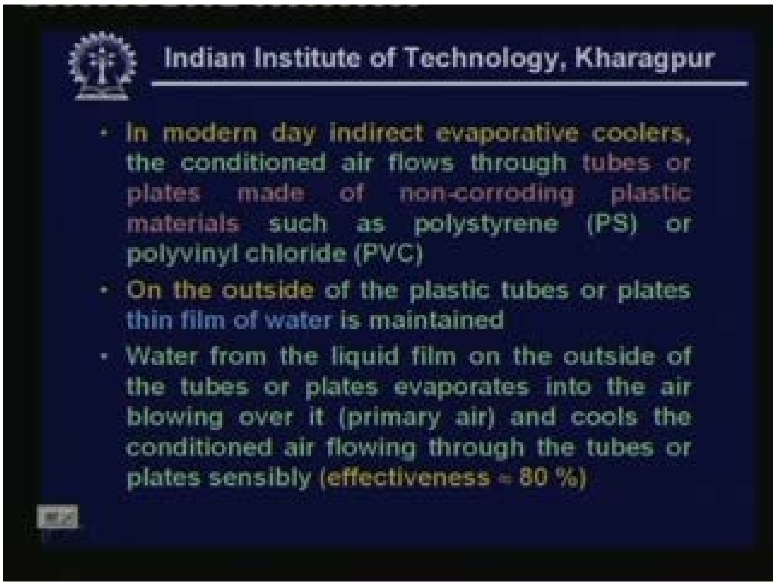

In modern day what I have shown is only a schematic and in modern day indirect evaporative coolers what is done is the conditioned air flows through tubes or plates made of non corroding plastic materials such as polystyrene PS or polyvinyl chloride okay. That means what happens in an modern indirect coolers are you have a tube, let us say okay, you have a tube like this okay. This is just a schematic so through this your secondary air flows okay secondary air okay. This is a wall of the tube and you maintain a thin layer of water on the outside of this tube. So this is a layer of water okay, say is a water layer and over this the primary air will be blowing okay. So as the primary air blows over the tubes wetted tube water evaporates from the thin layer okay.

So as a result there is a sensible heat transfer here. So this layer becomes cold and there will be heat exchange from the thin layer to the secondary air which is flowing through the tube okay. So as I said on the outside of the plastic tubes or plates thin film of water is maintained water from the liquid film on the outside of the tubes or plates evaporates into the air blowing over it and cools the conditioned air flowing through the tubes or plates sensibly okay. And using these kinds on an arrangement you can get an effectiveness as high as eighty percent even though you may be surprised that we use plastic materials plastic tubes or plastic plates in a heat exchanger. Because as you know plastic has low thermal conductivity still you manage to get high effectiveness. Because you get very high heat transfer coefficients outside the tube because outside the tube you have latent heat transfer okay. So a since latent heat transfer provides high heat transfer coefficient you get very large convective heat transfer coefficient on the outside at this more than makes up for the low thermal conductivity of the tube material or plate material okay. As a result you get very good effectiveness for with this kind of evaporative coolers okay. And plastic is also cheaper and it’s also easier to manufacture.

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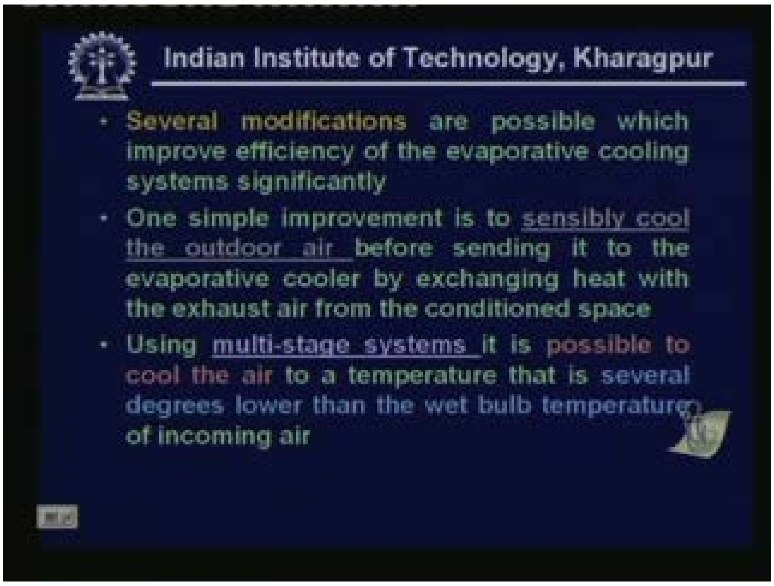

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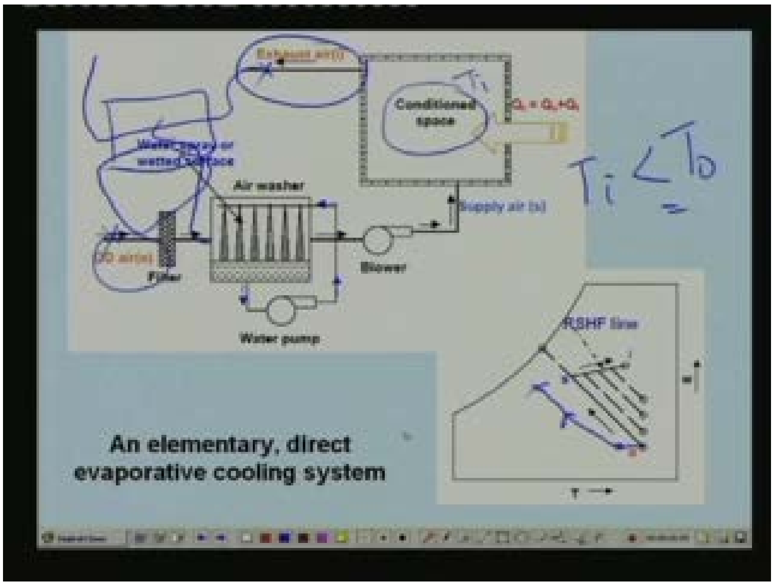

Now several modifications are possible which improve efficiency of the evaporative cooling systems significantly okay. So let us look at what are these modifications I will just discuss one or two modifications one simple modification is that you can sensibly cool the outdoor air before sending it to the evaporative cooler by exchanging heat with a exhaust air from the conditioned space. So this is one of the simple improvements. So let me explain this remember that this is a air in a normal simple system you are throwing this exhaust air into the atmosphere and this exhaust air is at temperature equal to that of the conditioned space okay. Conditioned space temperature is Ti let us say and we know that the conditioned space temperature Ti is less then To okay. That means the temperature of the air at this point will be less than the outdoor air okay.

So what you can do is you can exchange heat between these two. For example if I put a heat exchanger here okay. So this air flows through this like this and this primary air before sending it to the air washer flows through this let us say it flows like this. So as a result what happens the temperature of the outdoor air gets reduced as it exchanges heat with a exhaust air. So what enters evaporative cooler is a cooled air that means instead of entering at this point this will be sensibly cooled by exchanging heat and at this point cooling and dehumidification takes place. So you can see that you can achieve lower temperatures by using this simple modification of course achieving good heat exchanger effectiveness using air to air kind of heat exchanger is very difficult. Because you to have large surface area etcetera that means you have use compact heat exchanger if you want to have good effectiveness okay.

So you have to see the benefit verses the cost involved okay but in principle this is a simple modification which can give a certain improvement. One can also use multistage systems and using multistage systems it is possible to cool the air to a temperature that is several degrees lower than the wet bulb temperature of incoming air. So this is an advantage of multistage systems. So let me explain a very simple multistage system.

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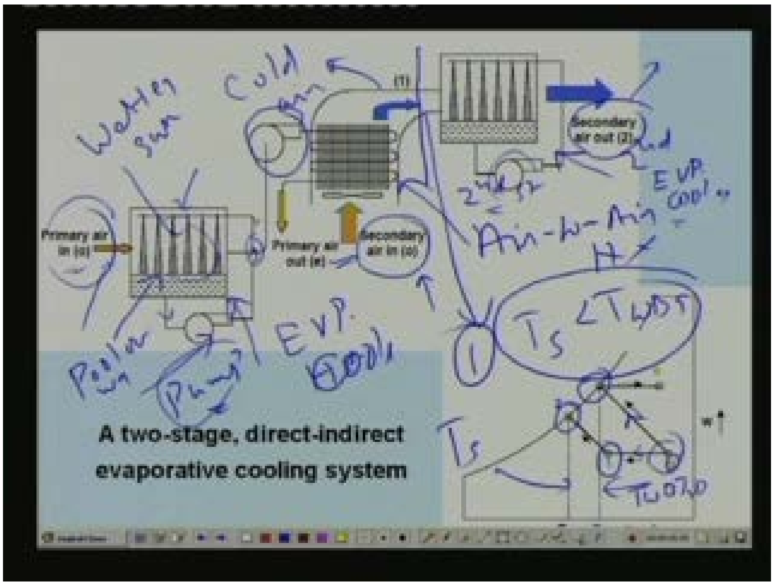

Okay, so this shows a simple a two stage direct indirect evaporative cooling system again we have a primary air stream here and a secondary air stream here. So in the first stage what happens is the primary air stream is cooled and humidified in the evaporative cooler okay, like we have discussed earlier evaporative cooler. So it gets cooled and humidified then this cooled and humidified air flows through an air to air heat exchanger okay. Air to air heat exchanger where it exchanges sensible heat with a secondary air okay. So up to this point it is exactly similar to an indirect evaporative cooler. So what you get out of this first stage is cold air okay whose humidity is same as the outdoor air humidity right. So its temperature reduces but humidity remains constant.

Now in the second stage this point onwards this is the second stage in the second stage what happens is this secondary air under goes direct cooling and humidification in a second evaporative cooler this is your second evaporative cooler okay. So in the first stage only primary air gets cooled and humidified and secondary air exchanges sensible heat whereas in the second stage the secondary air undergoes cooling and humidification. So as a result what you get out of this that means at the final exit of the system you get air which is much cooler than the incoming wet bulb temperature in a okay, wet bulb temperature the incoming air the same thing is shown here on the psychrometric chart. For example this is a condition of the secondary air here and the primary air here okay. So the primary air under goes cooling and humidification. So O dash is a exit of the first evaporative cooler and at this point this flows through the air to air heat exchanger. So its temperature increases and the temperature of the secondary air reduces in this direction okay.

So at the end of this okay, point one is here. So at this point it enters into the second evaporative cooler okay where it under goes cooling and humidification. So finally what leaves this complete unit is air in an ideal case which is at a temperature t two okay. So this is a final temperature of air from this system. Now you can see that this temperature t two is much lower than the wet bulb temperature corresponding to the inlet air that is nothing but this okay. Let this is the wet bulb temperature corresponding to outdoor condition and this is your exit temperature Ts. So you can see that Ts is lower than T wet bulb temperature oaky. So this is a simple two stage system one can also think of other schemes okay. One can also go for three stage right. Three stage direct indirect direct indirect like that several schemes are possible.

So using these multi stage schemes you can achieve temperatures which are much lower than the wet bulb temperature of the incoming air. But of course disadvantage of these kind of systems are the cost increases because your adding more and more components okay. So the initial cost of the system increases and the running cost also increases. Because you have several pumps and blowers etcetera, all these components require some power okay. So both running as well as initial cost increase and the benefit you get is you get a t air which is at much lower temperature. So you have to again see which is beneficial right. One thing I forgot to mention is the use of this pump okay. So we use a, we have to use a water pump in an evaporative cooler. Because in a typically evaporative cooler you have to maintain these wetted surfaces continuously wet okay.

These are the wetted surfaces which have to remain wet continuously. So what you have here is a pool of water okay, a pool of water this pool of water the pump is connected to this pool of water. So it continuously draws water from this pool and it pumps it to the top of the evaporative air cooler and it throws it onto the wetted pads or if it is an air washer then it sprays the water droplets into the air washer okay. So the pump is required for the continuous circulation of the water whereas the blower is required for I am sorry a blower is required here for circulation of air okay. So these this these are some improvements using which you can extend the application of evaporative coolers.

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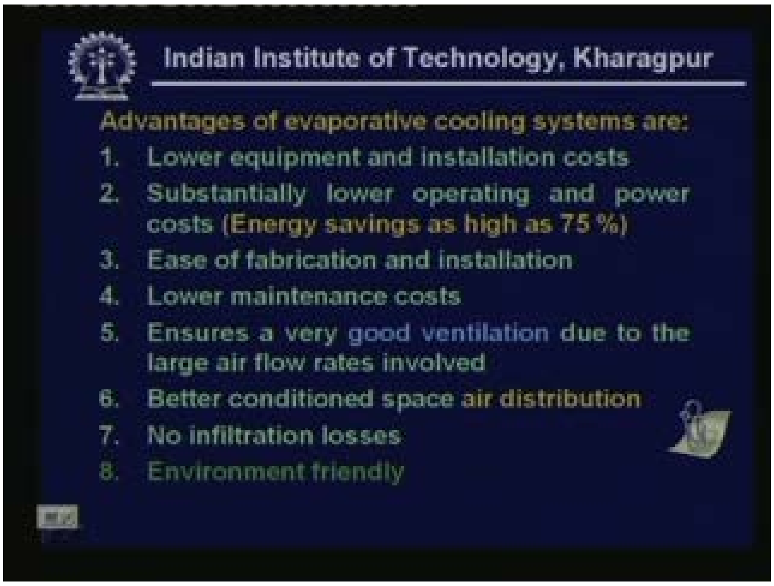

Now let us look at the advantages and disadvantages of evaporative coolers, what are the advantages? First advantage of course is that they have lower equipment cost and installation cost compared to the conventional refrigeration system based air conditioning systems okay. The equipment and installation cost can be several times lower than the conventional systems and they also have substantially lower operating and power cost. Because all that you require is power for running the blower and for pump you do not have a compressor there. So the power consumption is reduced substantially and the energy savings can be as high as seventy five percent compared to a conventional air conditioning system these are major advantage of evaporative cooling systems.

And of course the third advantage is that it is very easy to fabricate these systems. And it is also easy to install the fabrication is so easy that it is like a cottage industry or like a small scale industry and in several places in India very small industries manufacture these evaporative coolers. So as a result they are available at a much lower rate okay. Whereas the conventional systems not everybody can manufacture. Then because the manufacture of a compressor and all is a very expensive business. So a fabrication is also difficult there where a evaporative coolers can be fabricated very easily and the installation is also very easy. For example if you are using it for cooling a room you do not require any installation at all that you have to do is buy it bring it and plug it in okay. So it is as simple as that but if you want to use a conventional air conditioning system then you have to install the system you have to create air ducts etcetera okay.

And lower maintenance cost since you do not have any compressor the maintenance cost is considerably reduced. So this is another advantage and these systems ensure very good ventilation where this is because as I have already mentioned the required air flow rates are very large in these systems and typically in these systems you don’t re-circulate the air. So where as in a conventional system you re-circulate the air but whereas in an evaporative system you exhaust the air okay. So you continuously draw a fresh air cool and humidified and supplied to the conditioned space okay. So not much of recirculation is used recirculation is not very effective also. So as a result a continuous supply of large amount of fresh air is ensured whenever you are using evaporative coolers. So this will take care of ventilation okay.

So this, another major advantage. So because of the large flow rates involved the conditioned space air distribution is also ensured. That means you get better condition space air distribution. Because of the large amount of air flow rates involved and there are no infiltration losses because the air flow rate is very high. So normally you find that whenever you are conditioning a building using evaporative cooling system the pressure inside the building will be positive. That means the pressure inside will be higher than the outside pressure. So as a result if there is any leakage it will be leakage of air from the inside to the outside not the other way okay. That means there won't any infiltration of outdoor air into the system into the conditioned space. So there are no infiltration losses right and last but not least these systems are environment friendly these systems are environment friendly. Because we do not use any chlorofluorocarbons or any harmful chemicals etcetera in these systems. So all that we use is air and water okay. So they are very environment friendly systems okay. See in over and above that since the consume less power obviously they also lead to lower global warming potential okay.

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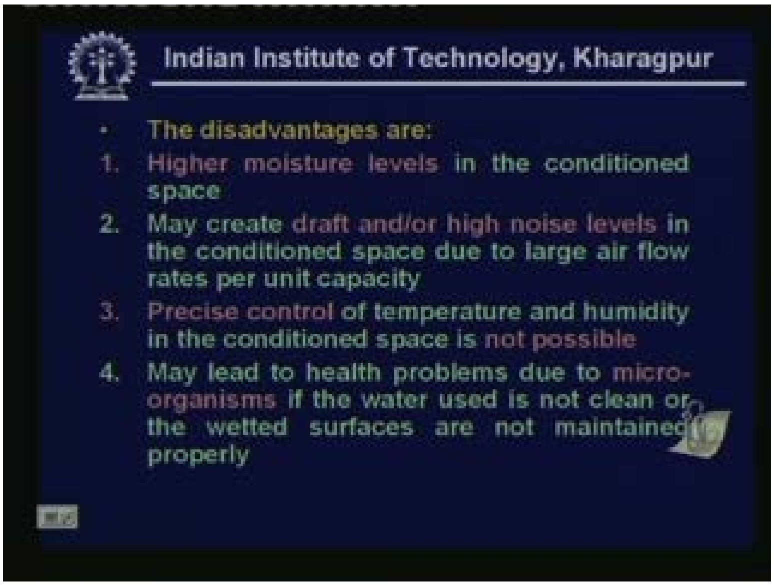

However these systems obviously have some disadvantages what are the disadvantage of these systems first disadvantage is that higher moisture levels in the conditioned space. Because you the air that you supply to the room is at a much higher humidity ratio. So the moisture levels in the conditioned space will be higher and these systems may create draft or high noise levels in the conditioned space due to large air flow rates involved okay. Since you have you have to deal large air flow rate inside the fan may create large noise okay. In the flow rate is also high you will also have you may also have the feeling of draft this could be a disadvantage from the comfort point of view. And another disadvantage with these systems is that precise control of temperature and humidity in the conditioned space is not possible whereas using a conventional system you can precisely control the temperature and humidity inside the conditioned space.

And fourth disadvantage is that these systems may lead to health problems due to micro organisms if the water used is not clean or the wetted surface or not maintained properly okay. So if the if we use a dirty water or if you do not clean the evaporative cooler from time to time then fungus or algae or something may form inside the evaporative cooler or on the wetted surfaces which give raise to growth of micro organisms. And since air blows over it and you inhale that air this air may give raise to health hazards okay. So you have to maintain it properly. So that no fungus formation or no micro organism formation takes place okay.

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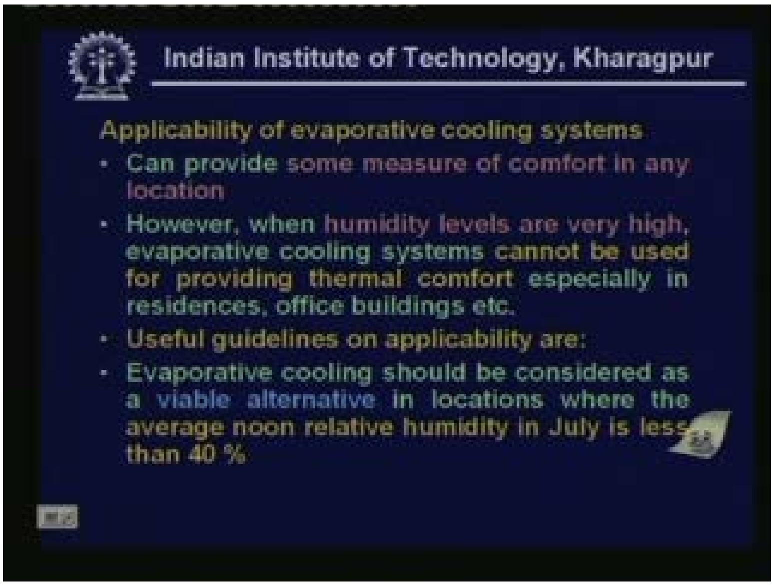

Now let us look at the applicability of evaporative cooling systems I have mentioned that one of the disadvantages or one of the limitations of evaporative air cooling system is that as the outdoor air humidity increases the required mass flow rate of air increases and beyond a certain humidity ratio you cannot use evaporative cooling systems okay. That means you can use them beneficially in certain locations and you cannot use them in certain location. So how do we decide where these systems can be used or where these systems cannot be used what are the guidelines okay so let us look at these guidelines. It is observed that these systems can provide some measure of comfort in any location okay.

However when humidity levels are very high evaporative cooling systems cannot be used for providing thermal comfort especially in residences office buildings etcetera. In residences and office buildings etcetera, providing thermal comfort at the required level. That means maintaining the conditioned space at the required level is very important okay that is the primary job of any air conditioning system oaky. If the outside humidity ratio is very high or the outside air is very moist then we have seen that these systems. That means the evaporative air cooling systems cannot provide the required levels of comfort. That means you cannot use them for comfort applications where the outs outdoor air is very moist or very humid okay.

So what are the useful guidelines the, these guidelines are not very stringent but they just give some idea on where you can use or where you cannot use okay. One older guideline is that evaporative cooling should be considered as a viable alternative in locations where the average noon relative humidity in July is less than forty percent okay. That means if the noon relative humidity at noon during the month of July average relative humidity during the month of July at noon if it is less than forty percent then you can definitely use evaporative coolers. And you must consider evaporative coolers as a viable alternative to the more expensive conventional air conditioning systems okay. However it is seen that you can also use evaporative coolers in areas where the noon relative humidity's higher than slightly higher than forty percent okay. So that means this is a very stringent guideline so there is another broader guideline which says that.

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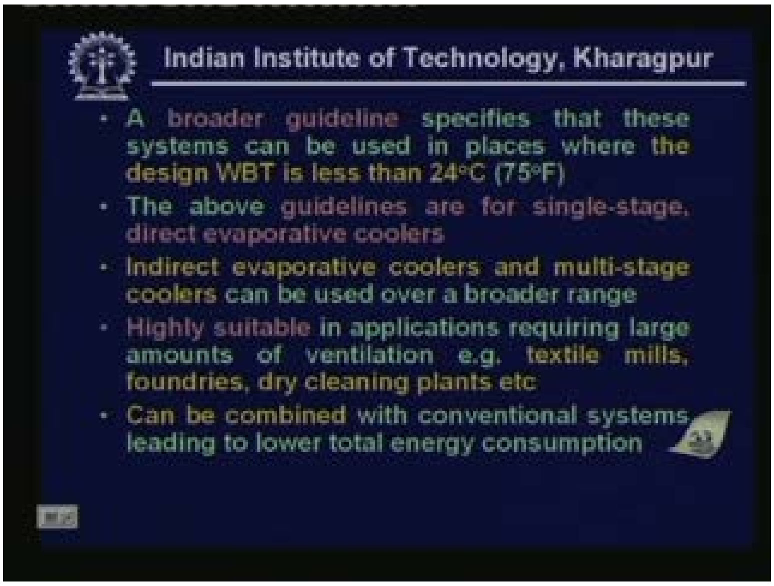

Evaporative coolers can be used in places where the design wet bulb temperature in summer is less than about twenty four degree centigrade or above seventy five degree Fahrenheit okay. That means if you know the design wet bulb temperature during summer and if you know that it is less than about twenty four degree centigrade then again you can consider the use of evaporative coolers okay. These guidelines are obtained mainly for single stage direct evaporative coolers and indirect evaporative coolers and multi stage coolers can be used over a broader range okay. That means you cannot simply say that evaporative coolers cannot be used in particular location okay.

You cannot use simple direct evaporative cooler in certain location. But if you make modifications if you use a multistage system you can extend the range of application of these systems oaky, to even humid areas and these systems are highly suitable in applications requiring large amounts of ventilation okay. There are many application such as textile mills foundries dry cleaning plants etcetera which require large amount of ventilation and here you cannot provide full comfort. But even if you can provide a partial comfort that is more than welcome.

So in such situations you can think of using evaporative coolers which will give you a very cost effective solution okay. And evaporative coolers can be combined with conventional systems leading to lower total energy consumption. That means you can also think of hybrid systems which use a combination of evaporative cooling systems and a conventional air conditioning systems okay. Using a combination of these two you can arrive at lower energy consumption okay. So one simple scheme is that the outdoor air is first cooled in an evaporative cooler then you send that cooled air which is not cool to the required extend. But which it is cool to certain extent that cold air is sent to the conventional air conditioning system so that the load on the conventional air conditioning system reduces okay. So which will give raise to savings in energy right. So there are lot of possibilities where you can have think of hybrid cycles okay.

So as far as possible looking at the geographic locations and looking at the climatic conditions one must see first of all whether one can use evaporative coolers or not if we can use evaporative coolers. Then you should definitely use it. Because it is it is having many advantages and it gives raise to many benefits both as in terms of initial cost as well as in terms of running cost okay. And however there are certain applications as i have already mentioned where you cannot use the okay. In certain in such cases you have to go for the conventional systems okay.

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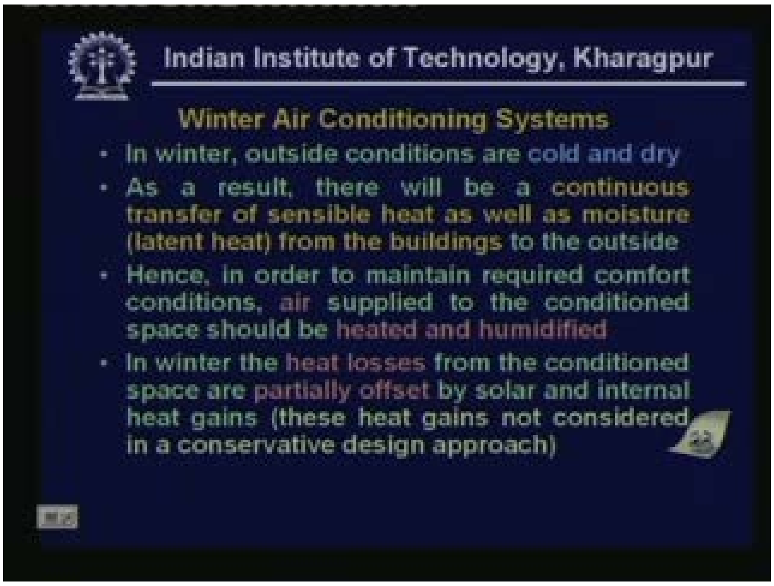

Now let us look at winter air conditioning systems in winter outside conditions are cold and dry. So that means outside temperature will be very low and outside humidity will be very low. That means outside moisture content will be low as a result there will be continuous transfer of sensible heat as well as moisture from the buildings to the outside. That means the buildings continuously loose sensible and latent heat to the outside environment. So in order to maintain required comfort conditions air supplied to the conditioned space should be heated and humidified in summer outside conditions are hot and humid. So what you have to do is you have to supply air that is cold and dry okay. That means you have to generally supply cold and dehumidified air in a conventional system whereas in winter, it is exactly opposite you have outside condition which are cold and dry okay. So there will be heat losses from the building.

So to overcome the heat losses you have to supply air which is hot and humid okay. That means basically you are looking for a heating and humidification process okay. And another difference between summer and winter is that in winter the heat losses from the conditioned space are partially offset by solar and internal heat gains okay. The solar energy actually adds heat to the building and internal heat gains are also add heat to the building. So that it partially offsets the heat losses from the building. So in a conservative approach what is done is these heat gains are not at all considered in the design okay. And you assume that there is no internal heat gain and there are no solar heat gains and you arrive at the required system capacity. So this is a conservative design approach as far as winter air conditioning systems are concerned.

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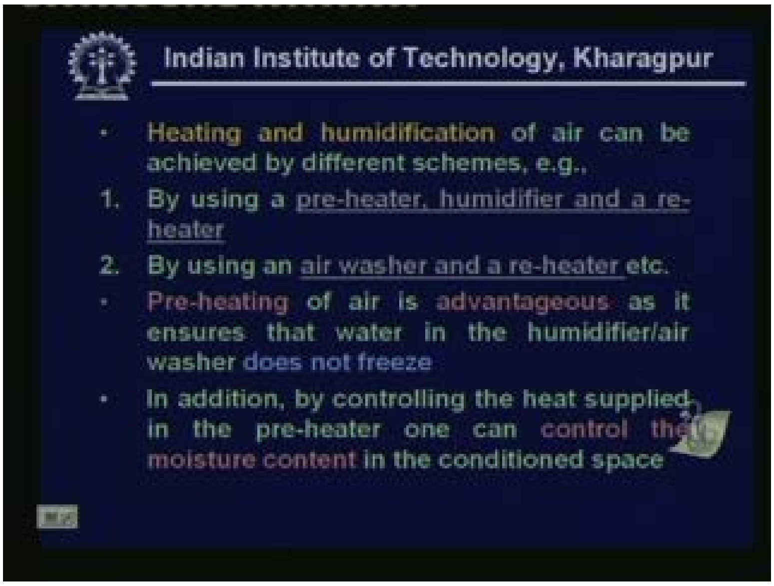

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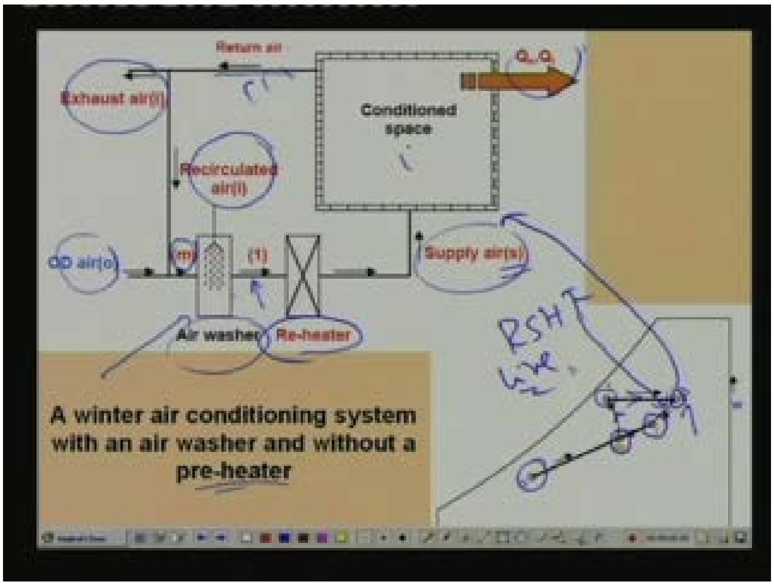

Now heating and humidification of air can be achieved by different schemes. For example you can use a pre-heater a humidifier and a re-heater so let me explain this system. This is a winter air conditioning system which uses a pre-heater okay. So we let us let me begin at this point here you have outdoor air which is cold and dry this certain amount of outdoor air is mixed with the re-circulated air which is coming from the conditioned space okay. So the re-circulated air from the conditioned space and the outdoor air are mixed and the mixed air which is at condition m first flows through a pre-heater okay. This is a pre-heater in the pre-heater air undergoes sensible heating process. That means its moisture content remains same but its temperature increases from tm to t one okay. So only sensible heating takes place in the pre-heater. Now this heated air flows through a humidifier in the humidifier as the name implies water vapour is added to the air okay. That means the moisture content of the air increases okay. So the humid air now flows through a re-heater okay. So it enters the re-heater at state two which has high moisture content and this humid air flows through re-heater where it is heated to the required supply air temperature S. So this hot and humid air okay hot and humid air flows through the conditioned space where it takes care of the sensible and heat losses from the building okay. So finally this hot and humid air leaves the conditioned space at state I which is same as the state of the conditioned space okay, right. And this return air some amount of return air is thrown out this amount is equal to the outdoor air which is required for ventilation purposes and remaining amount is re-circulated again the re-circulated air comes here it mixes with the outdoor air and again the mixed air flows through pre-heater humidifier re-heater etcetera, the cycle continues okay.

So this is one typical winter air conditioning system which uses a pre-heater the same process is shown here on the psychrometric chart O is the condition of the outdoor air as you can see the temperature is very low. So you here the dry bulb temperature on this axis you have dry bulb temperature and here you have the humidity. So the outdoor air is very cold and very dry this is mixed with the re-circulated air which is at the condition I okay. Certain amount of air at this state and certain amount of air at this state they are mixed. So the resulting air is at this condition m okay. So at this condition it enters into the pre-heater and it is sensibly heated from tm to t one okay.

So m two one is what happens in the pre-heater. So at this point it enters into the humidifier, in the humidifier. As I have already mentioned the humidity of the air is increased. So it follows the process line one to two and this process path depends upon how humidifier is constructed or how you are adding the moisture okay, whatever it is humidity increases in the humidifier from point one to two and this humid air now flows through the re-heater again the process is sensible heating. So its temperature increases from t two to Ts okay. So this is the state at the inlet to the conditioned space okay. So this hot and humid air flows through the conditioned space and as it flows through the conditioned space it takes care of the sensible and latent heat losses. And this line S two O is again your RSHF line for the winter okay so this is your psychrometric cycle right for a winter air conditioning system using a pre-heater.

So this is one way by which you can heat and humidity the air you can also use an air washer and a re-heater and you can again have same heating and humidification. Let us look at this scheme. So in this scheme you can see that it is exactly is almost similar to the earlier scheme except one difference that difference is that you do not use any pre-heater here instead of a pre-heater use an air washer okay. This air washer directly humidifies the air right. So outdoor air again outdoor air and re-circulated air are mixed. So the mixed air at condition m flows through the air washer and in the air washer its humidity increases to the required level and this humid air now flows through the heater where it is sensibly heated to the required supply temperature S and this hot and humid flows through the conditioned space takes care of the load and comes out at the conditioned space condition i okay. And some part of it is exhausted and the remaining part is re-circulated okay.

So this is another system which does not have a pre-heater and this process is shown again on the psychrometric chart here you have the outdoor air and re-circulated air both are mixed. So this is the condition of the mixed air. So this process m to one is what happens in the air washer. So the humidity increases to the required level okay and at this point it enters into the heater where it is sensibly heated to the required temperature S okay. And at this state it enters into the building right and as it flows to the building it takes care of the load and again this is your RSHF line okay so this is another system. Now preheating of course as certain advantages what are the advantages of preheating of air is advantage is as it ensures that water in the humidifier or air washer does not freeze. And in addition by controlling the heat supplied in the pre-heater one can control the moisture content in the condition space okay, when you are using a pre-heater.

If this air is, let us say very cold okay. Let us say that, this air is at minus twenty-five degree centigrade which is possible in cold countries if this air is very cold there is a possibility that the mixed air is at a temperature lower than zero degree centigrade. If it is at a temperature lower than zero degree centigrade and if you do not use a pre-heater in the humidifier water droplets or wetted surface comes in contact with air whose temperature is lower than the freezing point. So there is a possibility that the water may freeze in the humidifier okay. So this can be prevented by using a pre-heater so in the pre-heater since you are using. Since you are heating the air first its temperature increases beyond the freezing point. So there won't be any freezing in the humidifier okay that is the advantage of using a pre-heater in addition to that you can control the heat supplied to the pre-heater okay, by controlling this you can control the humidity level in the conditioned space okay. So this is the advantage of using this system.

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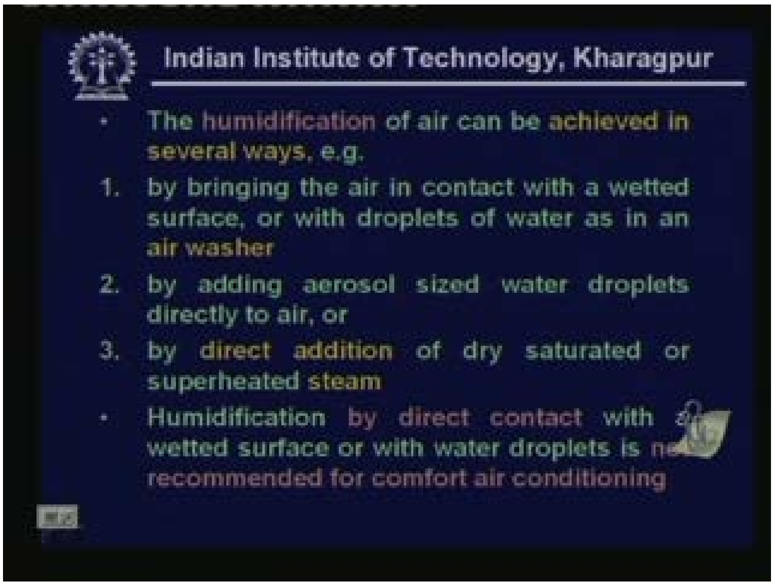

Now the humidification of air can be achieved in several ways. For example you can humidify air by bringing it in contact with wetted surface or with droplets of water as in an air washer or by adding aerosol sized water droplets directly to air or by direct addition of dry saturated or superheated steam okay. So these are the ways by which you can add water vapour to the air humidification by direct contact with wetted surface or with water droplets is not recommended for comfort conditions. This is for the same reason which I have explained earlier because whenever you are singing a wetted surface there is a possibility of micro organisms growing on the wetted surface which may give raise to health problems okay.

So in comfort air conditioning systems for winter normally wetted surfaces or air washers are not used okay. Air washers are wetted surface can be used for industrial air conditioning system where human beings are not present okay, because of the health problems right.

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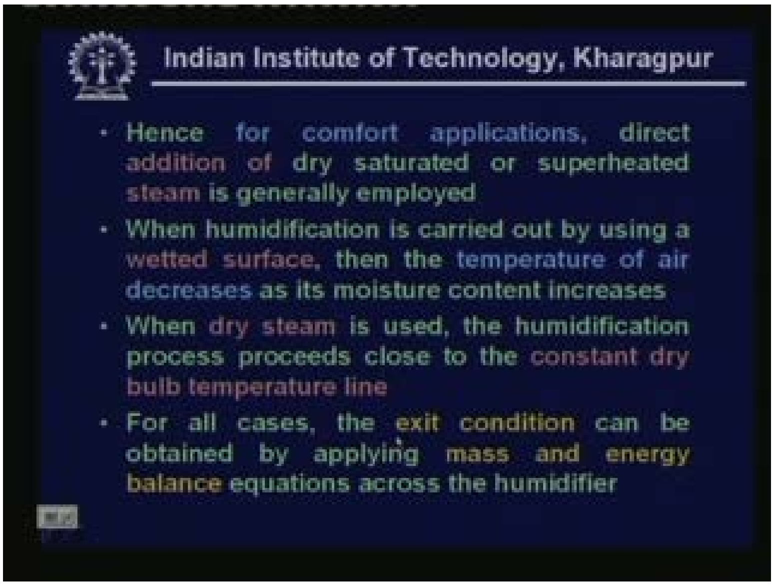

So for comfort applications direct addition of dry saturated or super heated steam is generally employed. So that means in winter air conditioning systems for comfort you always add steam directly to the air steam oaky. When humidification is carried out by using a wetted surface then the temperature of air decreases as its moisture content increases okay. Now there is a difference between the process line when you are using a wetted surface or when you are adding a dry steam okay. For example when you are using a wetted surface okay, such as an air washer or a something like an evaporative cooler where the air comes in contact with a wetted surface what happens is, water evaporates okay. And the latent j heat of vaporization is drawn from water and air. As a result the temperature of air reduces. That means the process moves along the or close to the wet bulb temperature line okay. So whenever you are using a wetted surface. However you are using a dry stream then you find that the humidification process proceeds close to the constant dry bulb temperature line okay. So I can explain this using a psychrometric chart. For example let us say that this is a psychrometric chart okay.

Let say that this is the inlet condition of air to the humidifier and if you are using a wetted surface okay. That means this then you find that if this is your wet bulb temperature line the process line may proceed along this or slightly close to this okay. So the outlet temperature will be lower than the inlet temperature okay, whereas if you are using steam okay. And if you are using steam you find that the humidification process follows a close to the constant dry bulb temperature. And you know that the, this is a dry bulb temperature line okay. And if the steam is super heated the exit temperature will be slightly higher than the inlet temperature right. So these are the difference between the humidification processes which depends upon the way how you are humidifying the air. And for all cases the exit condition can be obtained by applying mass and energy balance equations across the humidifier okay. So whatever be the process if you want to find out the exit condition all that you have to do is you have to take a control volume across the humidifier and apply mass balance and energy balance mass balance. Means you have to account for the mass flow rate of water vapour and mass flow rate of dry air. And similarly you have to account for the energy okay. The rate at which energy is being added is equal to the rate at which energy is being removed in a steady state. So if you apply the mass and energy balance equation you can get the value of the outlet temperature and outlet humidity okay and the amount of supply air required.

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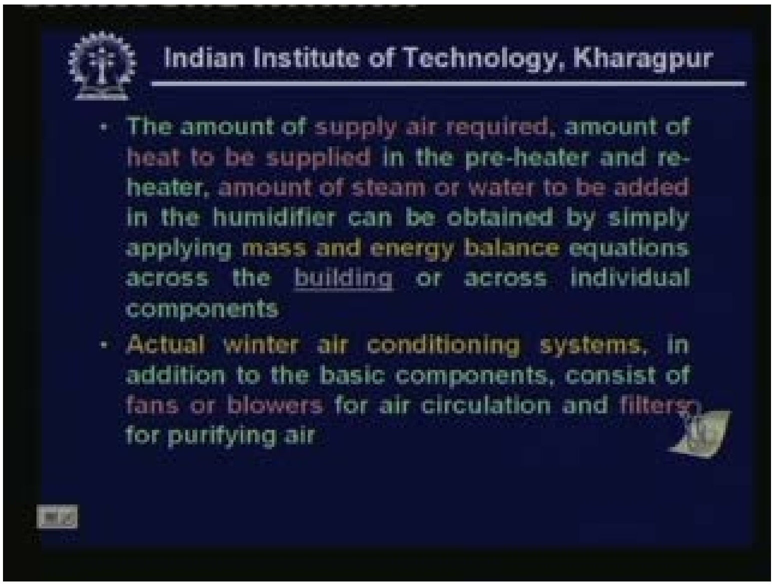

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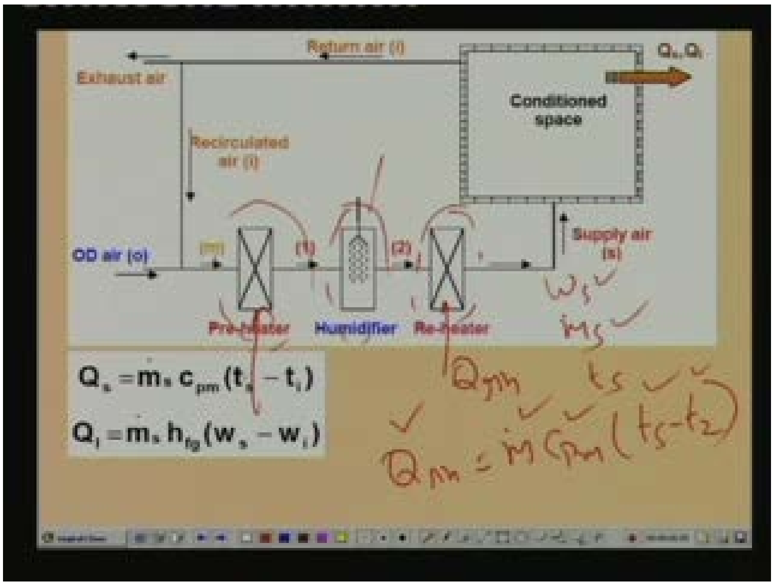

Amount of heat to be supplied in the pre-heater and re-heater amount of steam or water to be added in the humidifier all these things can be obtained by simply applying mass and energy balance equations across the building or across individual components. Let me explain this. This is very easy. You can for example I want to find out what should be the supply air flow rate okay i want to find out this okay. What should be the supply air flow rate m dot s. Then what I do is, I take a control volume across conditioned space and suppose from load calculations. I know what is the rate at which sensible heat is being lost from the building and what is the rate at which latent heat is being lost from the building. I know Qs and Ql. Then if I apply energy balance for this control volume I can write Qs like this Qs is equal to m dot s into Cpm into ts minus ti where ts is the inlet temperature and ti is the outlet air temperature and m dot s is the air flow rate and Cpm is the specific heat of the moist air right. And similarly you can write for the latent heat you can write the energy balance like this. Latent heat transfer rate Ql is equal to m dot s into hfg which is nothing but the latent heat of vaporisation of water multiplied by Ws minus Wi where Ws is the humidity ratio of the supply air and Wi is the humidity ratio of the outlet air okay.

Suppose I know ti from our comfort criteria ti is known to me okay. And Qs and Ql are known from load calculations. Then using this equation I can find out and I am also fixing ts. Let us say ts is fixed based on certain criteria then in this equation this is known to me. So I can find out what is the required mass flow rate. Then what I do is I substitute this in this equation and again in this equation. I know what is the latent heat transfer rate. I also know what is the conditioned space humidity Wi. So I can find out what should be the required humidity ratio at the inlet to the conditioned space. So I can find out this okay. And once you know what is the required humidity ratio at this point. And if you also know what is the these things are known to you then you can easily find out what is the rate at which heat is to be added in the re-heater.

For example take a control volume across the re-heater then heat to be added in the re-heater Qrh is nothing but m dot into Cpm into ts minus t two right m dot is known to me. This is known to me and this and ts is known to me and if you know t two then you can find out what is the rate of heat addition in the re-heater. Similarly you can apply energy balance for the pre-heater and find out what is the amount of heat added in the pre-heater apply mass balance across the humidifier. And find out how much vapour as to be added in the humidifier like that okay. In actual winter air conditioning systems in addition to the basic components you also have fans or blowers for air circulation and filters for purifying the air okay. I have not shown these components in the schematic. But in a actual system consist of these components also in addition to the basic components.

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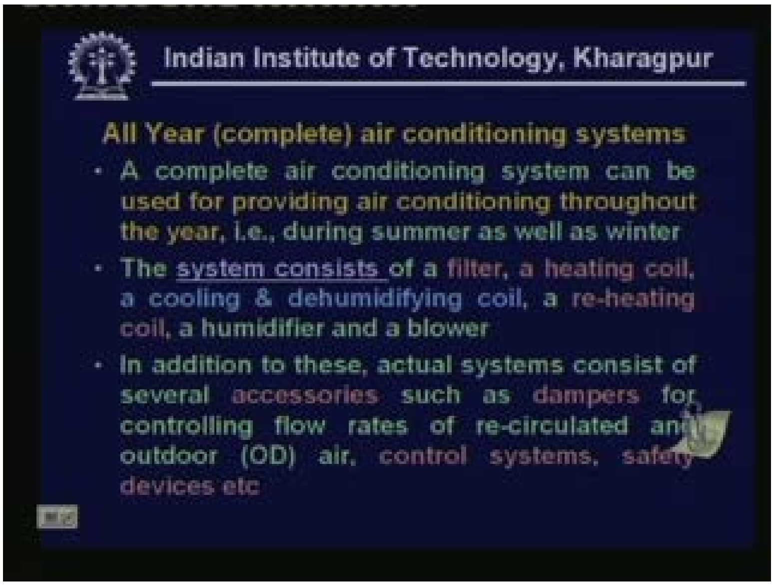

Now let us look in a at an all year or complete air conditioning system a complete air conditioning system can be used for providing air conditioning throughout the year. That means during summer as well as winter the system consist of a filter a heating coil a cooling and dehumidifying coil a reheating coil a humidifier and a blower in addition to these actual systems consist of several accessories. Such as dampers for controlling flow rates of re-circulated and outdoor air control systems safety devices etcetera. So let me quickly show a schematic of a complete or all year air conditioning system.

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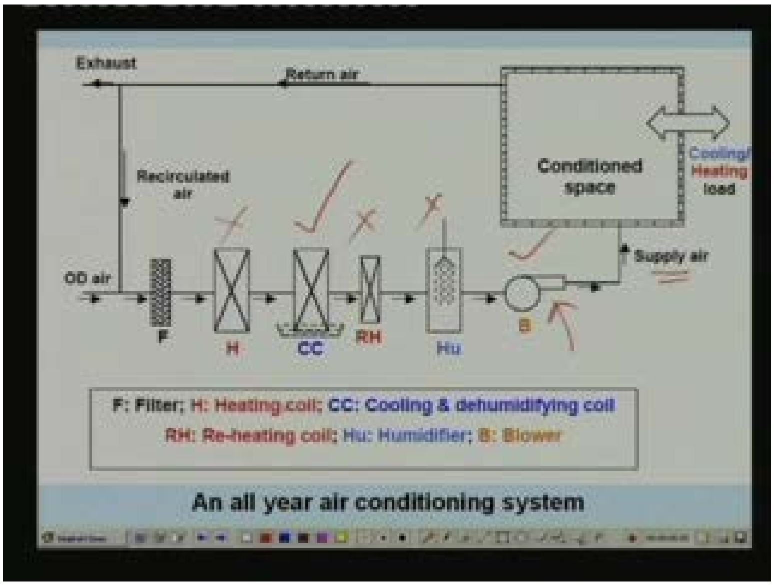

So this is a typical all air year air condition system this is your conditioned space and you have a filter for purifying the air you have a heating coil you have a cooling. And dehumidification coil you have a re-heater of course re-heater can be here or it can be here and you have a humidifier and you have a blower for circulating the air right. So in winter we require heating and humidification. So in winter you do not have to run this cooling and dehumidification coil. So this is not operational okay. So heating oil is on reheating coil is on humidification coil is on. So you can achieve heating and humidification and you can get hot and humid air here during winter right. Whereas during summer we require cold and dry air. So during summer what you can do is you can switch off this you can switch off this you can switch off this and you run only a cooling and humidification coil. So that you can get cold and dry air at the inlet to the conditioned space okay. Of course the blower is always required because you have to maintain the air circulation either in winter or in summer okay. So this is always on right. So depending upon on the season the some of the components will be on some of the components will be off right.

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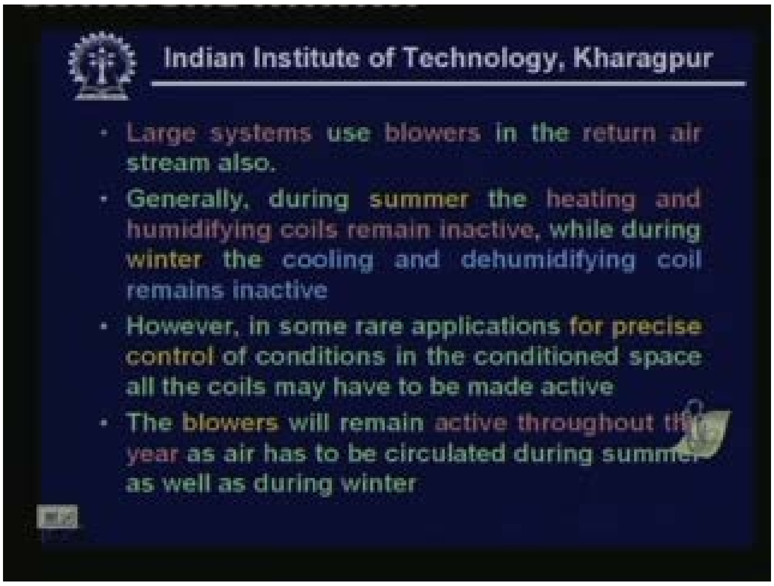

So large systems use blowers in the return air stream also I have shown blower only in the supply air stream. But you can also use a return air blower in large systems and generally during summer the heating and humidifying coils remain in active. As I have already explained while during winter the cooling and humidifying coil remains inactive. However in some rare applications for precise control of conditions in the conditioned space all the coils may have to made active okay. So rarely you keep all of them active but it is possible in some applications and the blowers will remain active throughout the year air as the air has to be circulated during summer as well as during winter.

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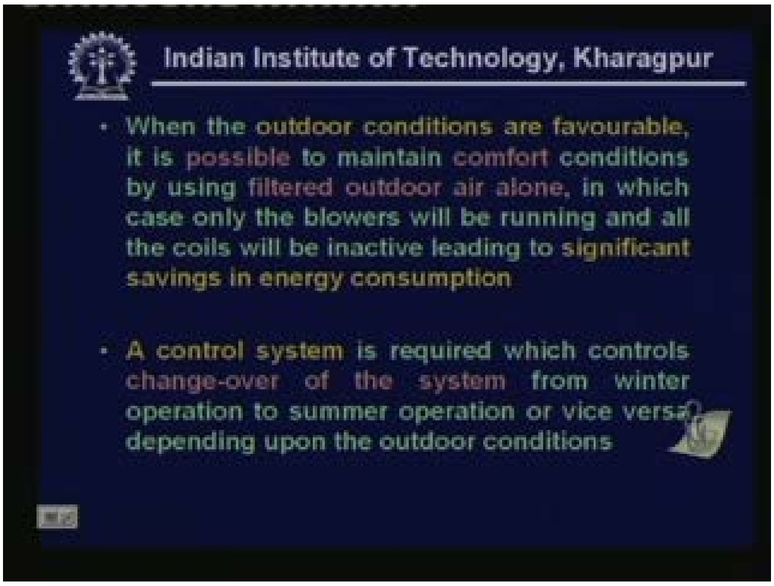

And when the outdoor conditions are favourable it is possible to maintain comfort conditions by using filtered outdoor air alone. That means you can switch off everything and just run the blower okay in which case only the blowers will be running okay. And all the coils will be inactive leading significant savings in energy consumption. So when outdoor air is cool. Let us say then you do not have to use any cooling or dehumidifying coils or anything just run the blower.

And use full outdoor air and provide comfort and normally a control system is used in an all Airconditioning system to control the change over change over. Means you have to change over the system from winter operation to summer operation or vice versa depending upon the outdoor conditions okay. So a control system will be sensing the outdoor conditions and depending upon the outdoor conditions it keeps either the summer air conditioning system on or winter air conditioning system on okay. So this is all about an all an air conditioning systems. So let me quickly summarise what we have learned in this lesson.

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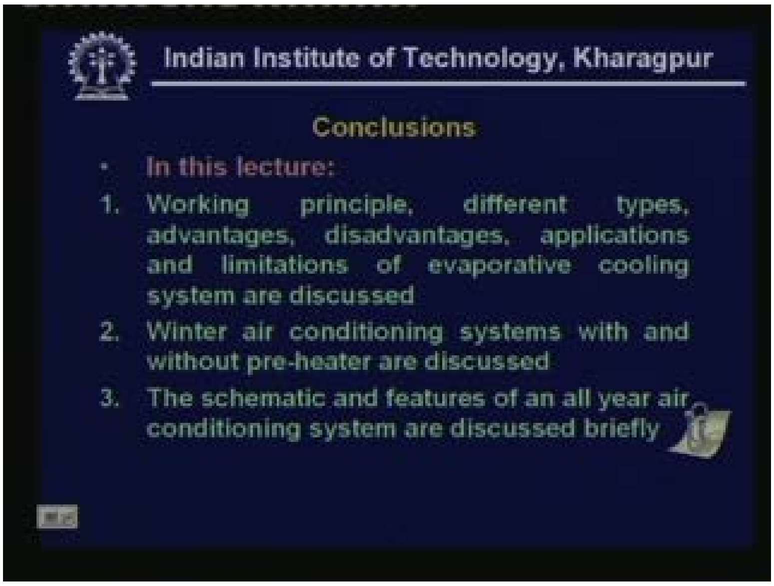

In this lecture we have discussed evaporative air cooling systems. And we have looked at the working principles different types advantages disadvantages applications etcetera. And we have also discussed winter air conditioning systems with and without pre-heaters. And we have also discussed briefly the schematic and features of an all year air conditioning system or a complete air conditioning system okay. So in the next lecture I shall discuss the cooling and heating load calculations okay. So with this I stop this lecture we'll continue this in the next lecture.

Thank you.