Applied Thermodynamics for Marine Systems

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Lecture - 22

Psychometric Processes (Contd.), Air Conditioning

Good morning. We were discussing psychometric processes or processes involved in moist air. We have seen one important process in which two streams of moist airs are mixing together. Let us say this is one stream and this is another stream; they are mixing adiabatically.

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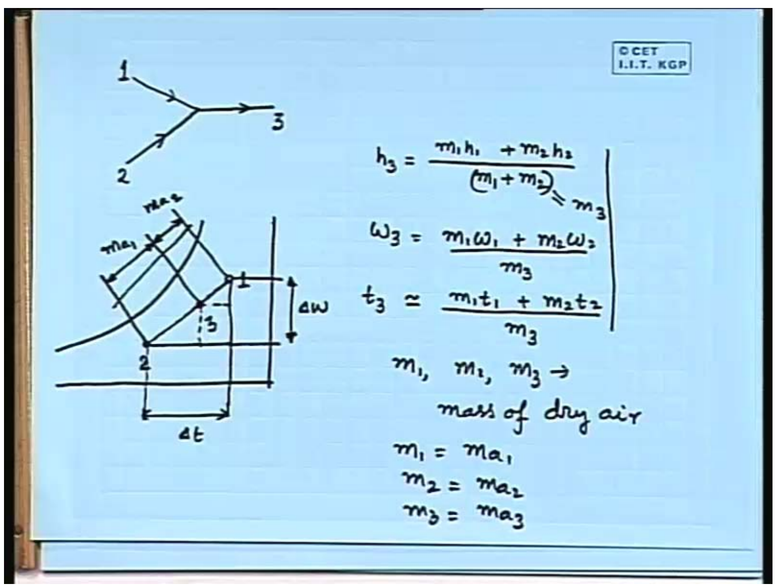

That means,there is no heat transfer with any external agency; whatever, energy exchange is there, that is only due to the mixing process and then the resultant stream is coming out. Basically, what we do here is we do mass balance; mass conservation has to be satisfied and we do energy balance. Energy balance means again we neglect the changes in kinetic energy and potential energy, but we take into account only the change in enthalpy because, that is the main contribution towards energy content of the flowing air stream. Also, we assume that during this process that there is no condensation. Doing all these things, we have got a few relationships.

One is the total mass will remain constant; the total mass of water vapour will remain constant and from there we have got or we can get h_3 if it is the enthalpy.

Let us put 1, 2 and 3 and these symbols have got their usual meanings. h_3 will be m_1 h_1 plus m_2 h_2 divided by m_1 plus m_2; m_1 plus m_2 is nothing but m_3; so this we will get. Then, we will get w_3 is equal to m_1 w_1 plus m_2 w_2 divided by m_3 and we will get t_3. t_3, is not exactly equal, but almost equal. This is m_1 t_1 plus m_2 t_2 divided by m_3. This is not exactly equal, but almost equal, so that for all our calculation purposes we can take t_3 is equal to m_1 t_1 plus m_2 t_2 divided by m_3. This I have derived in my last class. Actually in air conditioning calculation, the type of precision we need, there we can go for this type of approximation.

If I want to represent this on a psychometric plane, we are having two conditions (Refer Slide Time: 04:05 min). Let us say this is 1 and this is 2. That means we are having two samples of moist air and they are mixing together. The mixture condition, One can conclude from this mathematical relationship that mixture condition will lie somewhere on the line joining these two points. That is very important and that is quite useful. If you have got two points, then you can easily have the mixture point on the line joining them too, and then the point will be somewhere here, let us say. We can call this point as 3.

What is the relationship between 1, 2 and 3? The relationship between 1, 2 and 3 is like this. The ratio by which point 3 will divide the line 1 2 is like this. It is ma_2 and this is ma_1. This is how it will be divided. Here, please note down one thing; that is important and it is a ….. Let me write m_1, m_2, m_3, mass of dry air, because I said that I am doing the analysis based on the mass of the dry air. I can write m_1 is equal to nothing but m_{a1}, so m_2 is equal to m_{a2} and m_3 is equal to m_{a3}. Probably, I have used a different symbol earlier. Probably, I have used m_{a1}; so here m_1 is nothing but m_{a1}; please note that. This is nothing but the mass of the dry air. Number of times, I have told that the analysis is done based on the mass of dry air, not the total mass of the sample. This is how we will get. That means being a triangle, if we have these two straight lines, one line dropped vertically from 1 and another line extended horizontally from 2, then we will have a triangle. So this will indicate the change in the dry bulb temperature, delta t. This will indicate a change in moisture content or specific humidity. So this is delta w and this will indicate nothing but a change in enthalpy and here also we can have similar type of a relationship. This slant line is the change of enthalpy, because we have got enthalpy scale somewhere here. This indicates the change of enthalpy, this indicates the change of specific humidity and this indicates the change in dry bulb temperature. So that is how the process will be represented. Basically what we can do? We can use this formula or if we have a psychometric chart, geometrically also we can find out the condition of the mixed air stream.

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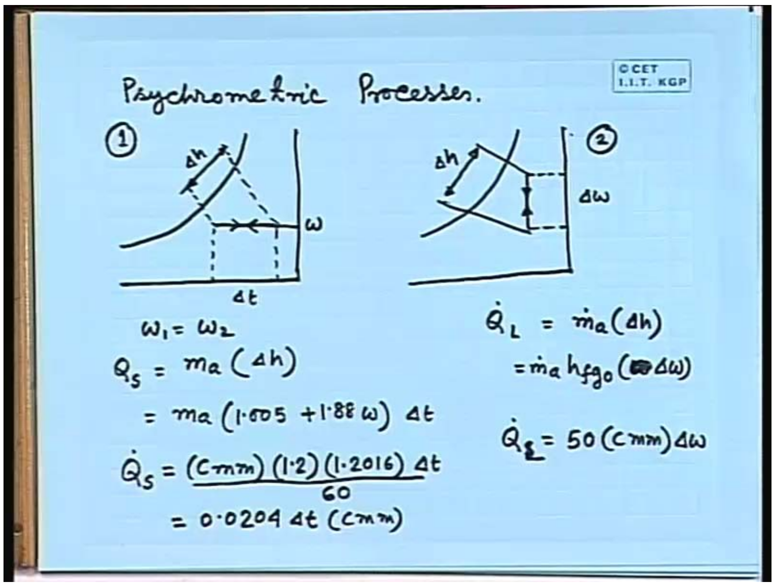

Now if we see the psychometric or psychrometric? processes, then apart from mixing there are two basic types of processes. One, there is a change in dry bulb temperature, delta t. This is delta h and another is there is a change in moisture content or specific humidity. This is delta w. In this case, also we will have some sort of a delta h. All the processes, they are combination of these two basic processes. Let us see these two processes and there are a few exceptions where condensation etc., are taking place because, part of the process is taking outside the saturation. But we are not going into those complicacies. In general, most of the air conditioning processes or psychometric processes, they are different combination of these two processes. If you consider there is only a change in the dry bulb temperature, but there is no change in the specific humidity, one can write it like this.

For this process, w_1 is equal to w_2 and in this case whatever is the energy transfer that is in the form of sensible heat. In the first case, let us say we call it process 1, in this case whatever is the energy transfer that is in the form of sensible heat. We can write Q sensible is equal to m_a. m_a I will write in terms of h, so I can write in terms of delta h. It may be cooling or it may be heating; that is why I have shown the arrow on both sides. We can write this one $Q_{sensible}$ as equal to m_a into 1.005 plus 1.88 w into delta t. This is what I can write, and then again, one can take this thing as an approximate specific heat for the moist air which I have introduced and then that will be 1.02016 into delta t. That means I am eliminating w. Please try to follow; what I am doing in that case is the sensible heat transfer I can calculate knowing only the temperature difference. I do not have to know the specific humidity of air, approximately I can calculate.

Then, there is another thing. Generally for air conditioning calculations, we do not specify the mass flow rate of air, we specify the volume flow rate of air and there is one advantage for air conditioning processes that the air pressure does not vary much; it is very near the atmospheric pressure. The density is almost constant. For all calculations, one can treat density to be almost a constant. Doing all these things, one can write Q dot S, the rate of sensible heat transfer is equal to Cmm. What is Cmm? It is cubic meter per minute; air flow rate in cubic meter per minute. Then, the density of air at atmospheric condition is 1.2 kg per meter cube. Then, 1.2016 is specific heat of moist air multiplied by delta t and divided by 60, because it is in cubic meter per minute. So you will get ultimately one number, which one can remember, 0.0204 delta t.

Whenever there is sensible heat transfer only, we need not bother to know the condition of air. We can do an approximate calculation knowing only the temperature difference and using this formula; I have missed something, so Cmm should be there. Actually, you cannot add up these two. What you have asked is like this: that 1.2016 whether it is coming by adding up these two terms. We cannot add up these two terms unless we know w, specific humidity and for different specific humidity, this value will be different. But, I have told that the contribution of the last term, 1.88w, is small and so that is why one can make some average, particularly which will be suitable for almost all air conditioning processes. That is why we have taken one average value 1.2016; this is little bit approximate. What is 1.2? 1.2 is the density of air at atmospheric condition - 1.2 kg per meter cube.

Should we go to the second process? In the second process which is another basic process, there is only transfer of heat due to latent heat transfer or there is transfer of energy due to latent heat transfer. Here also we can write that Q_{latent} is equal to m dot a into delta h. From enthalpy we can get that, but one can again do some sort of a calculation and one can write that this is nothing but m dot a h_{fg0} delta w. Again, I will do this same thing. I am not going to write it; that means I will bring Cmm, because in most of the air conditioning process the air flow rate is defined in terms of cubic meter per minute.

I can write ultimately Q dot L latent heat of transfer is equal to, doing all these mathematics, this is Cmm into delta w. These two formulae we can remember. Q dot S is equal to 0.0204 Cmm delta t and Q dot L is 50 Cmm delta w. The h_{fg0} is the latent heat of evaporation at 0 degree Celsius. Suppose we have water at 0 degree Celsius and we want to get saturated vapor at 0 degree Celsius we need h_{fg0}. Its value is 2501 kilo Joule per kg.

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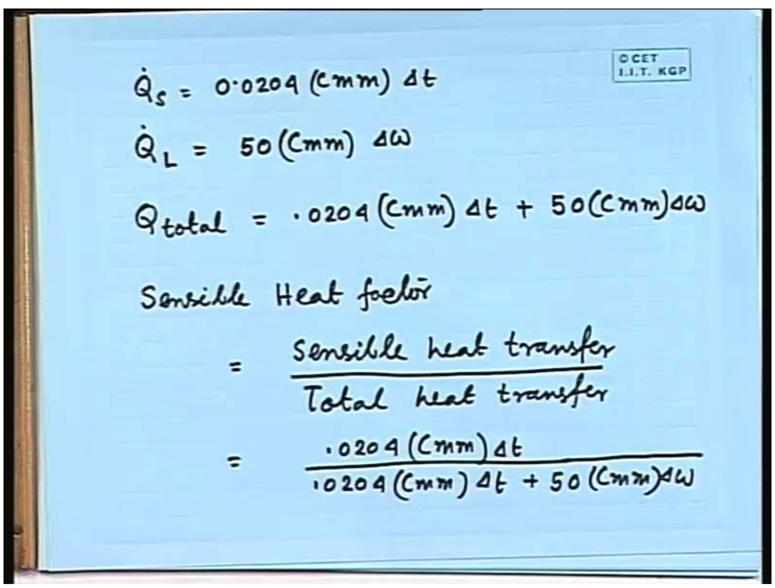

Let me write down these two. Q dot S is equal to 0.0204 Cmm delta t and Q dot L is equal to 50 Cmm delta w. Then we can have any process where both change in dry bulb temperature and change in specific humidity is there, where energy transfer is due to both latent heat transfer and sensible heat transfer. So we can write Q_{total} is equal to 0.0204 Cmm delta t plus 50 Cmm delta w. So this is what we can write.

Generally, we define one quantity here which is known as sensible heat factor. What is sensible heat factor? Sensible heat factor for any process is equal to sensible heat transfer divided by total heat transfer. Basically we will have 0.0204 Cmm delta t divided by 0.0204 Cmm delta t plus 50 Cmm delta w. This is your sensible, heat transfer divided by total heat transfer and, you can see Cmm can be canceled, dropped, from both numerator and denominator and one can divide it by 0.0204 and get some sort of a simplified number.

One can have a representation of this process also on the psychometric chart. You can do it easily.

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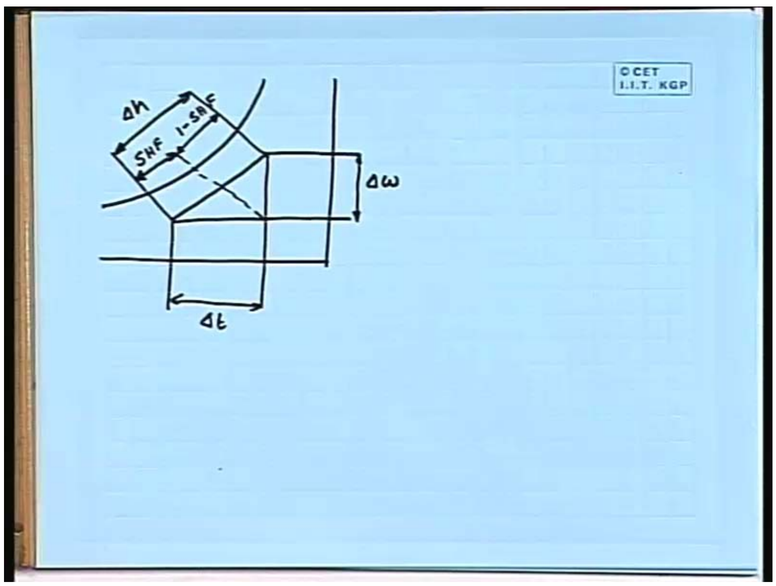

Let us say the total heat transfer process is something like this. This is the change in dry bulb temperature, this is the change in humidity ratio and this is the change in enthalpy. This is the change in enthalpy due to the change in dry bulb temperature. What one can write? This is nothing but sensible heat factor and this is nothing but 1 minus SHF. This will be the ratio by which this total enthalpy will be divided. This can be a representation of our sensible heat factor.

Let us slowly go into the air-conditioning process with this background.

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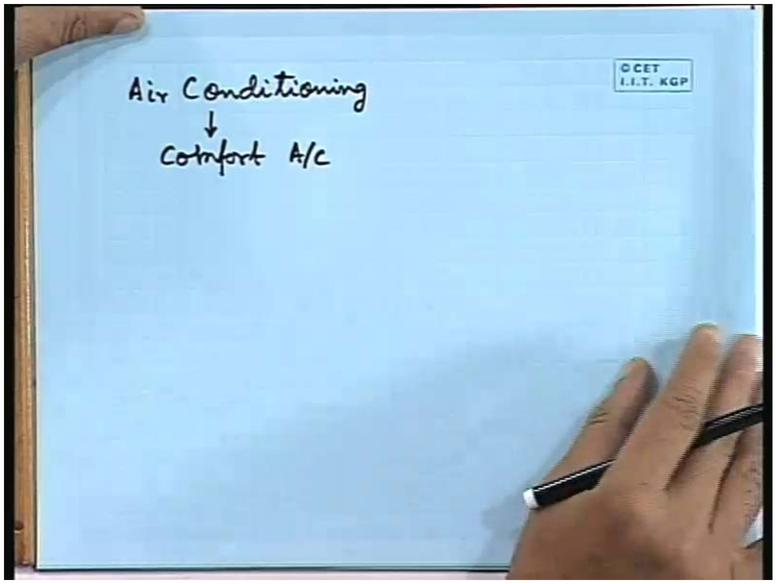

Before going into the psychometric process of air-conditioning, let me give a little bit of the principles or what we want to do in air conditioning. In air-conditioning, actually we are conditioning the air and there could be different purposes for it. There could be comfort air-conditioning and there could conditioning of air for preservation of foods, etc. Our concern is comfort air-conditioning. So, actually, we are going to consider comfort air-conditioning. In comfort air-conditioning, basically, what properties of air we want to monitor?

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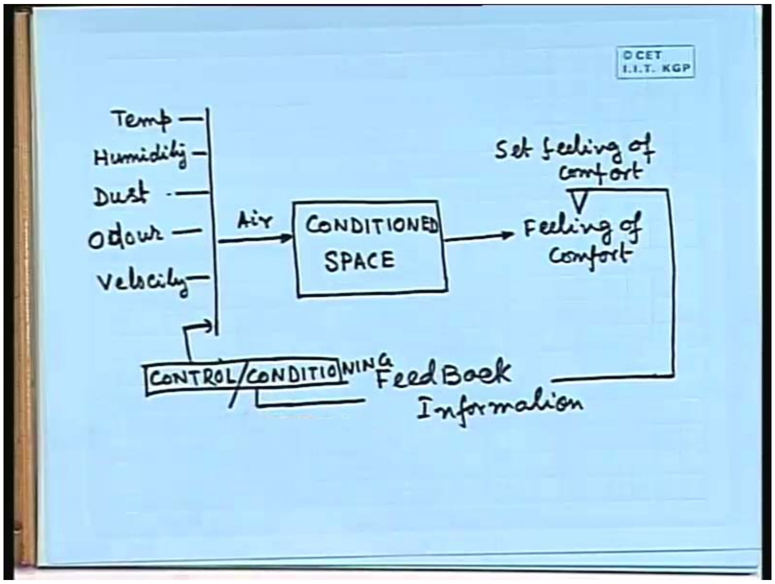

Actually, let me give it in a system representation. Let us say, this is the conditioned space. This is a conditioned space. Here as input, what I am sending? I am sending air as input and this air has got different attributes like temperature, humidity, dust, odour and it should have also some velocity. So there may be a few more attributes or qualities of air and as an output, what I am getting is the feeling of comfort. This feeling of comfort, generally it is compared with some set feeling of comfort. This is difficult because, the feeling of comfort generally cannot be defined in a very concrete manner. It will vary from person to person and even for the same person when he is well and when he is let us say, suffering from fever that will be different. But there are some set rules by which the feeling of comfort can be defined. So that is why there is some set feeling of comfort also and these two can be compared.

This comparison can be like this that one person is inside an air-conditioned room or conditioned space. He has got his system, he has some feeling of comfort and he is not feeling comfortable in the room and he can tell that it is not comfortable. That is a comparison between the feeling of comfort and the set feeling of comfort or it can be like this that it has been quantified, that we have assumed that in this room if we maintain 25 degrees Celsius temperature, then everybody should be satisfied. But I am seeing that the temperature is 23 degrees Celsius. Then, these two are not matching. So if these two are not matching then there will be feedback information. We will get the feedback information and that will do some controlling or conditioning. So this is control conditioning of air that will do the control or conditioning of air. That is how we can describe the function of an air-conditioning system.

Basically, we are supplying air to the conditioned space. The air should have some quality. These are like temperature, humidity, dust, odour, the velocity of air, etc. With this, it is entering the room. In the room there are occupants. They will feel a certain degree of comfort and that degree of comfort may not be equal to the set or desired degree of comfort. Then there will be some sort of feedback information, by which we will control the air. This is what is done in an air conditioning system. Basically, as far as thermodynamics or heat engineering is concerned, one should be interested in temperature and humidity. But as a system engineer one has to look into all these things like there should be filter for separating the dust particle, there should some method for cleaning the air from bad odours, there should be some technique for reducing the noise level; though it does not come directly in air, but people inside the room should feel comfortable; the noise level should be within particular limits. So the attenuation of noise should be there. For example, in this room, they have taken special care to have a particular quality of audio inside the room. Sometimes, this comes under the broader purview of air conditioning. But as this is a course on thermodynamics, we will mainly consider the temperature and humidity aspects.

Again, the temperature and humidity, these two we want to control and the air which we are taking and supplying to the room, conditioned space, that air we take from the ambient atmosphere. The comfort condition or comfort feeling, the demand for comfort for human being, that does not change throughout the year, whereas, the outside condition of air or condition of atmospheric air that changes over the year; seasonal changes are there and daily changes are there. So, methodology we will take for conditioning the air will be different at different times; which means, we cannot have a set process by which always we can have conditioned air which will give me the desired comfort condition.

Broadly, we can divide the air conditioning requirement into two categories: one is your summer air conditioning and another is your winter air conditioning.

Again, in summer air conditioning we can have different summer conditions. We can have hot and humid condition and we can have hot dry condition. Let us say desert condition which is hot and dry and our tropical country particularly like West Bengal, Northeastern region, etc., where you will have hot and humid climate. The techniques by which we will condition the air will be different in different cases. Before going into the details, we should have some idea regarding the comfort condition.

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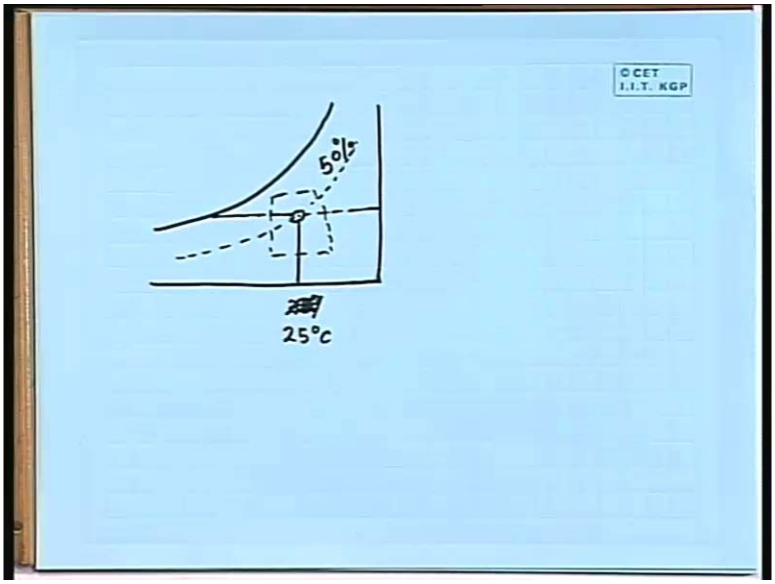

It means one can spend hours together on comfort condition. There are different recommended comfort zones. The air in the room should be within a certain range of the psychometric chart or its temperature and humidity should be within certain range, so that the average human being will feel comfortable. When nothing is given and this changes slightly from summer to winter. There are different norms given by Ashrae. What is Ashrae? That is a professional body which deals with refrigeration, air conditioning, ventilation, etc. It is an America-based professional body. It has got its activities throughout the globe. From different parts of the globe, one can become a member of it and can take part in different activities, but it is the global organization which is based in America for setting the norms etc., for air conditioning and ventilation. Ashrae has got different standards.

Without going into details, because, I do not have time; this is not a course of air conditioning. One can roughly take a few values like, Universally this is assumed to be the accepted comfort condition, though it can change from application to application. The dry bulb temperature is 25 degrees C; that is the dry bulb temperature and relative humidity is 50%. If we do not have access to the Ashrae comfort chart, we can take these values roughly, that it is 25 degrees Celsius dry bulb temperature and 50 % relative humidity. Actually, one can change these values; they are a little bit interdependent, which means one can change the value 25 degrees Celsius slightly. So, there will be some change in the relative humidity also and summer and winter there could be some changes. As I have shown, these two are not fixed values. Generally, one can get a range like this (Refer Slide Time: 36:27 min) within which people will feel comfortable.

Why have I told you all these things? These are important information and at the same time throughout the year I will try to keep my room at 25 degrees Celsius and 50% relative humidity. Through out the year I will try to do this. Let us see how can we do it in summer and how can we do it in winter. In summer, the outside ambient air temperature is more than 25 degrees Celsius and its relative humidity is also, because if we take a hot and humid climate, its relative humidity is also more than 50 degree Celsius or percent.

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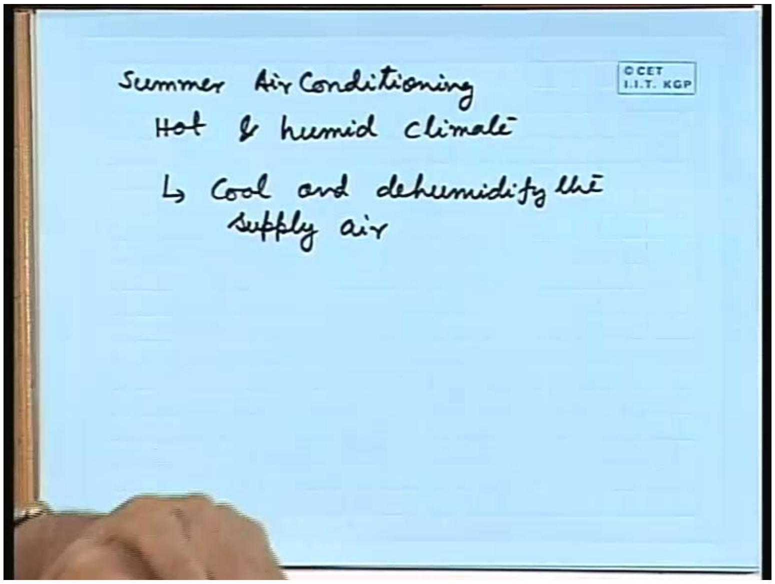

If we go for summer air conditioning and let us say hot and humid climate, we have to cool and dehumidify the supply air. In air conditioning, generally this is done by a single process. Mind it, we are achieving both cooling of air and the humidification of air, but conventionally in air-conditioning we achieve it by a single process.

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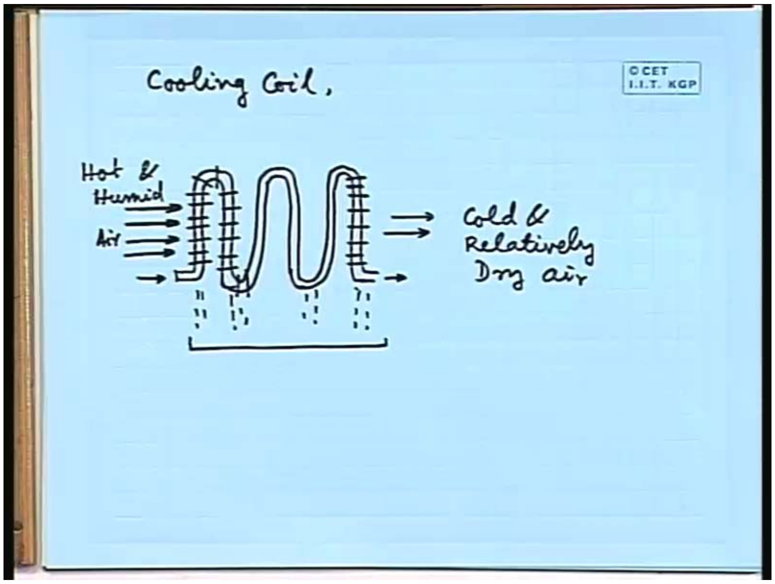

What is done? We have a cooling coil. Sometimes it is called dehumidifying coil also or cooling and dehumidifying coil also. The cooling coil, I am just showing it schematically. The actual representation is slightly different, but you can understand the cooling coil is a tube like this (Refer Slide Time: 39:39 min); schematic representation of this cooling coil is like this. Through this I am sending cold refrigerate. Basically, this is nothing but the evaporator of the refrigerant and with this coil for better heat transfer outside the coil, we are having fins. In most of the applications, it is a finned coil. Then refrigerant is passing through this. While refrigerant is passing through this, refrigerant is evaporating. So, it will absorb heat from the flowing air. This is air - hot and humid air.

Then when air will come out, it will be cold and relatively dry. Cold and relatively dry air will come out of it. Cold we can understand; it will become cold because, the refrigerant which is passing through it is having a much lower temperature. But relatively dry, how? For that, the temperature of the cooling coil should be so low that it should be lower than the dew point temperature of the incoming air. If it is lower than the dew point temperature of the incoming air, then condensation or partial condensation of the moisture content will take place. A certain amount of moisture will get separated and you will get moisture separated from here. If you see the practical construction of cooling coil, with all the cooling coil there will be some drip pan below it, where the moisture in the form of water, will be separated and collected and drained. This is the process by which we will achieve cooling and dehumidification.

What you have asked is, how exactly the humidity will be controlled? I will come to this issue afterwards, but one thing I will tell you. For general comfort air-conditioning, we can allow a certain range of humidity. It is not exactly at 50 %. It can be 55% or 50 to 60% like that. We can have a range of humidity, it is not exact. But there are certain applications like electronic industry where chip fabrication is taking place or some sort of photographic processing. There, the humidity has to be controlled at a very close level, low humidity. There are certain processes where we need high humidity also. In those cases special measures are taken, but for general comfort conditions, we need not go for a very precise control of humidity, there we should operate within a range.

Forget about the air passing over the tube. Through the cooling tube, cold refrigerant is passing. You will find that the tube surface temperature is also very low. It is so low that as soon as the air comes in contact with it, air becomes saturated and the separation of moisture takes place. As soon as it is exposed to air, you will find that water droplets are forming on it. The surface temperature of the cooling coil is known as apparatus dew point temperature – ADP; the temperature of the surface of the cooling coil.

With this definition, I will go to the psychometric chart.

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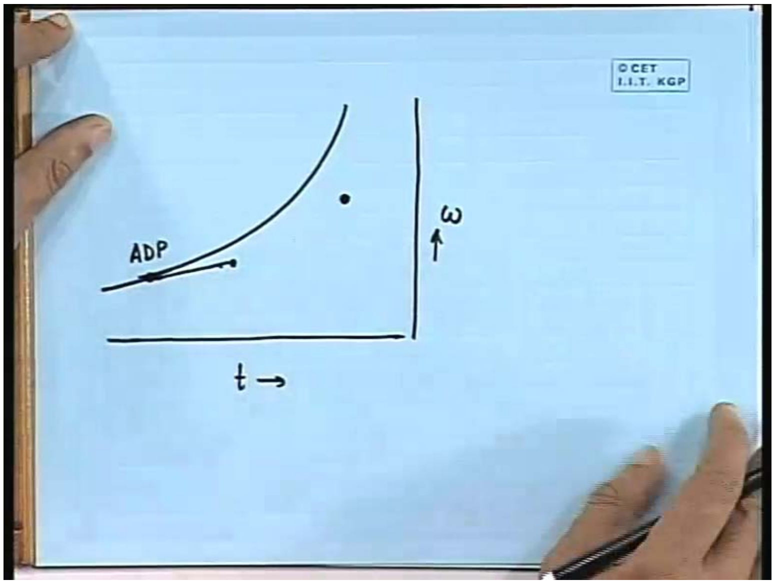

This is our psychometric chart. The apparatus dew point temperature is somewhere here. I call it ADP; I have explained what ADP is. I have explained apparatus dew point temperature. The ambient air is somewhere here and apparatus dew point temperature is somewhere here, because at this condition if the air comes, it will be saturated and its temperature will also be low enough. Again let us go back to this (Refer Slide Time: 46:33 min). Air when it is flowing through the coil we cannot expect that the entire mass of air will come to apparatus dew point temperature. If we want to have the entire amount of air to come to the apparatus dew point temperature, then it should have a very large time of contact with the coil. The coil length should be very large, almost infinity; that is not possible. So, when the air will go out its temperature will be lower than the supply air temperature, but its temperature will be higher than the apparatus dew point temperature. There will be some lowering of the humidity content, but it will not be as low as the humidity content corresponding to apparatus dew point temperature. What I mean to say is that we will have the condition somewhere here. (Refer Slide Time: 47:35 min)

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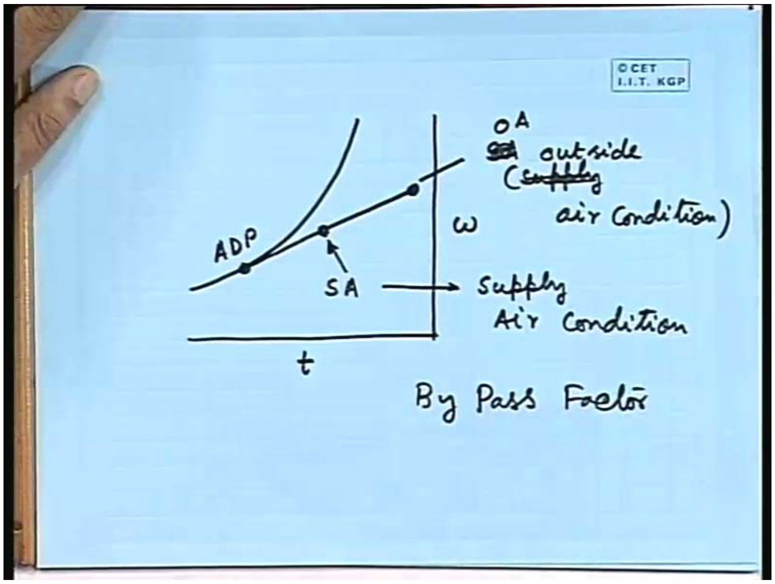

This is not a very good diagram that I have drawn. This is a bit exaggerated for understanding. This is your ADP, apparatus dew point temperature and this is the SA, supply air condition. We will have the air which is coming out of the coil and that will be somewhere here. (Refer Slide Time: 48:29 min). This particular aspect is described in a different manner in psychometry. It is understandable that if this is our apparatus dew point temperature, this will be the supply air condition. Actually, supply air condition, let us not write it supply air condition. Let me write OA, outside air condition and let us call this supply air condition because this is supplied to the room; SA, supply air condition. So this is actually supplied to the room. It will be somewhere on this straight line (Refer Slide Time: 49:44 min), joining the outside air condition and ADP - apparatus dew point temperature.

This phenomenon in terms of psychometry is explained in a different manner. It is like this; what we assume if you see the diagram here? We assume that the air which is passing over the coil, that is, only a part of it is contacting the coil or is in perfect contact with the coil and coming to the apparatus dew point temperature. The rest of it is not at all contacting the cooling coil; it is bypassing the cooling coil. The process which has been shown on the psychometric chart here is idealized like this, that the part of the air is in perfect contact with the cooling coil and part of the air is totally bypassing the cooling coil. The actual process is not like that. Certain air particles they are close to the cooling coil, so they will have a lower temperature. Then they will again have energy exchange with other air particles. It is like this; but we want to idealize the process and with that, we want to introduce one factor, which is known as bypass factor. Bypass factor I will explain in our next class.

Let us stop here.