BUILDING ENERGY SYSTEMS AND AUDITING

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Week - 01

Lecture - 04

Lecture 05: Psychometric Operations

Welcome to the NPTEL course on building energy systems and auditing. Today is the last lecture on module number one. This lecture will be on psychrometric operations. In this lecture, we will start with the air and its properties, which have already been discussed in the previous lecture on ventilation. We will discuss the concept of enthalpy and alSo, the psychrometric chart and its operation, of course. So, we have discussed two major things. One is the DBT and the WBT in the previous lecture. Next is the humidity ratio.

The humidity ratio is defined as, in a particular mass of air at a certain volume, what is the total ratio of the mass of humidity, that is, the mass of moisture, to the mass of the sample of that particular dry air. As we have already discussed, there is a three-phase diagram where we have empty spaces and two substances: one is the air molecules, and the other is the molecules of moisture. The ratio of these is the humidity ratio, which is alSo, going to play a very vital role. Absolute humidity is a kind of density. We can alSo, say that it is water vapor density, which is how many kilograms of water or moisture are there in how many m^3 of the dryer. That is the absolute humidity. Suppose we have a temperature of 15° C.

We have some 20 air molecules and some 12 spaces for the moisture to be retained in a particular state of, say, 1 cubic meter or whatever a particular 1 cubic meter of air. Now, let us suppose, just for our understanding, that one of those molecules of air has 1 gram of weight, and one molecule of moisture, if there is any, will have 2 grams of weight. So, at that particular point, suppose I have, out of the moisture space which is 12, 3 spaces filled with water. So, there are 3 molecules of water and 20 molecules of air. If you count the number of Green dots, they are 20. If you count the number of yellow dots, they are 3. So, that means if the humidity ratio I have to find out, I can say how much is the total weight of the water molecule. There are 3 into 2, So, 6 grams. There are 3 molecules, each of 2 grams.

And how much is the total dry air? So, there are 20 such molecules and 1 gram, So, 20 grams. So, 6/20, So, 0.3 gram per gram of dry air will be the humidity ratio. Whereas, absolute humidity will be 6 grams of water per m^3 of the air because I have I thought that this is, I have assumed that this is 1 m^3 of the air.

So, 1 m^3 of the air, dry air is having 6 grams of the water. Similarly, if the number of molecules increases, now there are 9 molecules, there are 3 empty spaces, your humidity ratio will be 18, which is 9 to the 18 and 20 grams of air will remain the same because I have not increased the number of air molecules that remain as 20, So, 0.9 gram per gram dry air, So, that is the humidity ratio. So, definitely, the humidity ratio increases, and absolute humidity alSo, increases because 18 grams is now the water weight divided by one m^3 of the air. So, next is the specific volume of the air, which is a very straightforward definition, that is, how much m^3 of air is actually going to be in 1 kg of the dry air or so.

So, it is, you can say, the reverse of the density, kind of specific volume, the reverse of the density. Density, we sometimes say, is kg/m^3; it is just the opposite, m^3/kg. So, how many m^3 of the air are actually occupying a space, how many m^3 of that volume, if the air weighs 1 kg or so. The next is the relative humidity.

We started discussing that in the last lecture also. If you remember the DBT, WBT drop, and all. The relative humidity, by definition, refers to the water vapor pressure or water content or vapor content in the air, expressed as the percentage amount of moisture it can retain in the atmosphere at a given pressure and temperature. So, that means, at a given temperature and pressure, air has some quantity of empty spaces; how much percentage is filled with the with this vapor or the moisture? So, that is, if it is fully filled, you can say it is 100% relative humidity; if it is very less, 10% or so. So, here you see, I have the same, uh, the three-phase diagram where 20 molecules and three of them are filled with the water.

20 molecules of air, of course, there are 9 spaces of the moisture and 3. So, that means relative humidity is 3/12 because 3/12 because there were 12 spaces of the molecules, out of which 3 are filled. If it increases, So, now it is 9/12, So, it is almost 75% RH. If you remember, there are 12 such spaces. Out of that, 3 are filled and 9 are empty. So, 9 are empty and 3 are filled. So, the total amount of spaces will be 12.

So, for every case, the next case also, it is always going to be the amount of capacity is 12. And now, how much are you filled? Only 3. So, 3/12 is 25%. This is your how much? 9/12.

This is your 75% and this is the whole field. So, 12/ 12, 100%. So, after this, there is no space available. So, 100% relative humidity is moist water, moist air. The air is fully filled with moisture, whatever the retaining capacities are.

So, now, the enthalpy. The enthalpy is a concept. And it is kind of defined as the internal energy of any such product, particularly we will say here for the air. So, air has a sensible heat component because it has some kind of heat. It may be 15° or 20°, whatever. So, that actually contains some kind of sensible energy in it, and also, it has some amount of moisture in it, and the moisture has some kind of latent heat component. So, if I want to, it has some kind of energy state, suppose maybe it is E1. So, that is its enthalpy, and now if I want to increase the temperature from 15° to 20° C or so.

So, definitely there is a sensible heat change. I have discussed in the earlier lecture that the temperature change will definitely be governed by the sensible heat. Input or output. So, if there is a 15 to 20, there is some input of the sensible heat, and suppose there is a moisture change also. So, there is either some latent heat in or latent heat out. So, depending upon your relative humidity changes or whatever.

So, that will give you some kind of a total state of energy to E2. So, the difference between this E1 and E2 is the enthalpy difference between these two coordinates of the air. So, as I have discussed these two, we can find out the enthalpy h a plus x times h w. h a is the specific enthalpy of the dry air from a sensible heat point of view. x is the humidity ratio, and h w is the specific enthalpy for the water vapor. So, broadly, it is classified in this way. If I know this, this is another equation we can actually use to find out the enthalpy. How much is the enthalpy in KJ per kg or whatever in that particular unit? So, it is an energy unit.

So, it is in KJ per kg of air. So, if I know the DBT, if I know the HR, which is the humidity ratio. So, I can use this equation to find out the enthalpy. So, I have calculated. If you can check it with the 25° and some humidity ratio, the enthalpy is coming out to be 57. So, you change it. If you change the DBT, that means you are changing the sensible heat, plus or minus, whatever. If you change the HR, plus or minus, the latent heat, So, you will get a new amount of h, which is the enthalpy. So, you can use this particular psychrometric property calculator.

So, if I go to that particular, this is that particular psychometric calculator. Suppose I give some 30° dry bulb temperature and if I give wet bulb temperature, of course, it will be a little less than that. So, if I give, suppose, 28°, the relative humidity is very, very high, almost 86%. And if I say, suppose, wet bulb temperature if I give 30°, So, definitely the relative humidity will be 100% because that is saturated. So, suppose if I go to some 20 or if I just suppose.

And suppose if I give this is 35° and we usually give relative humidity, suppose 70%. 35° DBT, the temperature of the air, and 75% is the relative humidity. If I go for calculation, I can get the enthalpy as 99.78 KJ. Per kg, we can find out the humidity ratio as 0.0252 kg per kg, and also, you can find out the specific volume as 0.009 m^3/kg. So, this is something you can do; otherwise, you can do it from the psychometric chart. We will discuss that one. Let us go again to the PPT. So, you can use this; you can actually use this one. I have shown you now; otherwise, you can go to the psychometric chart. In the psychometric chart, it has broadly two axes. The x-axis stands for the DBT. So, if I have some DBT or some DBT if I want to place, I have to see or check the x-axis.

And the y-axis stands for the, sorry, WBT will be in that curved line, and it will be inclined kind of thing. These blue lines are for the WBT, representing the WBT. So, any cross-section is the WBT-DBT, your particular WBT-DBT or particular combinations. And the y-axis is your humidity ratio. Right, the y-axis is your humidity. The x-axis is your DBT, y is your humidity ratio (HR), and this curve axis and these inclined lines are the wet bulb temperature. In this, there are So, many other lines also; there are this way, there are some curved lines that will follow the final curve line.

Those are the RH lines, So, humidity ratio lines. So, lower will be less, suppose this is 20%. So, let me take. So, this is you suppose 20%, this is maybe 60% RH or something like that. And enthalpy lines are almost parallel to the WBT line.

So, that line will actually give you the enthalpy. And there are other lines in another direction which are giving you the specific heat. So, in a nutshell, what I am going to see in a particular, suppose if I just go a little bit forward to a particular psychrometric chart. See, in the x-axis, I am getting WBT. In the y-axis, I am getting humidity ratio.

These are my wet bulb temperatures. This is the enthalpy scale. These are the enthalpy scales. These three or two scales are there. And these are the specific volumes.

Okay. And these curved lines represent your relative humidity. This is 10%, 20%, 30%, and so, on. And finally, the last one is your 100%. Okay.

So, now, if I go back to the next slide. So, If I know, if I have some data about air, such as how much is the dVT and how much is the RH, I can plot one point. So, for any one point I want to plot, I need two data points. It is a 2D graph, So, I need two.

Either I need the humidity ratio and the DBT. Or I need the WBT-DBT, or I need RH and humidity ratio. So, what we actually get from the hygrometer is the DBT and the RH. So, let us plot one point. So, after you get a point, you are going to know a lot of things about that particular state of the air.

You can actually go like this and to the WBT scale, you can find out the WBT. You can go to the enthalpy, how much is the state of that particular air, having how many KJs per kg. You can go to the right-hand side to get the humidity ratio. You can find out how much is the specific volume. So, once you get a point,

you can get all the data, and once you get another point, suppose from this point I have to go to some other point or so, I again I'll get a lot of data, and I can find out what is the difference of the enthalpy, what is the difference of the humidity ratio, So, like that I can find the difference of the DBT, find the difference of whatever, and then I can actually get to know a lot of things. So, I can also, find out the dew point temperature by going straight, striking to the 100% RH line, and dropping back to the DBT line. So, the dew point temperature can also, be measured. So, here and now, suppose we discuss a little bit on this relative humidity and the temperature. Suppose at 15° temperature, which I have started since the last class, last lecture.

We have 20 air molecules and we have 12 spaces available. If I increase the temperature, what is going to happen? The intermolecular distance of the air is going to increase. So, whatever may be there, maybe 1 inch or something, now it will be 2 inches or something. So, in between now, more air molecules can fit in.

So, if there is dry air, no molecules of water are there, it has 12 spaces. At a time when there is a 15° temperature. If I increase the temperature to 25°, The number of air molecules remains the same because the volume remains the same. I am not adding any more air molecules.

So, there are 20, but the space for moisture increases from 12 to 16 because the intermolecular distances are greater. Now, 1 cubic meter will be maybe 1.2 m^3. The volume has increased because the temperature has increased. Charles's law. Now, next is

At a 15-° temperature, I have 12 molecules and suppose 6 molecules of air. Then I have 50% RH, right? Now if I change the temperature, what happens? This... The same amount of water molecules are there, 6.

But now the total space becomes 16. So, the RH becomes 37.5°. So, what we understand is that if the humidity ratio remains the same, no new air molecules are getting into the air space. Because of the temperature increment, as the volume is higher, the volume is increased. So, the intermolecular distances are increased.

There are new spaces available for the air moisture. The RH or the relative humidity is decreasing. But we have the same humidity ratio because we have 20 grams of dry air versus 12 grams of moisture here also, at 15°, and on the other side also, at 15°, but as the RH decreases because you now have more space to fit in, right? That is one of the very important things. So, if the DBT changes, that means sensible heat changes from one place to another, you see, at this particular point, you have 60% RH.

You do not have any change in the y-axis. That means your moisture content or the humidity ratio remains the same. But your RH decreases. It is something like 30%. So, what we have discussed, at a higher temperature,

Volume increases, Charles' law, the number of air molecules remains the same, moisture-holding space increases, humidity ratio remains the same, same axis in the Y, same axis, Y axis, it is not going to change from here to here, absolute humidity ratio decreases because volume increases. And relative humidity decreases because of these two lines. So, from here to here, it is a below line. So, it is 60°. It may be 40° also.

So, it decreases. So, that we need to understand. Next is if we are not going to change that. Suppose you take this blue line. We are not going to change the DBT.

You are changing the humidity ratio. As and when by increasing the humidity ratio, your humidity ratio increases and more humidity fills more spaces and it is leading from 0 to maybe 100% of the relative humidity. So, that is obvious. But the amount of 15°, the amount of space is less. So, it will be very quickly it will be of.

It will go to 100%, which may be around 0.01 or something, but in the case of 25°, you may require 0.02 or something like that. So, you require more moisture to make it 100% RH if the DBT is higher. So, that also, qualifies whatever we have discussed earlier. So, suppose I have taken an example. So, the DBT is 40%, and the RH is 50%.

So, what to do? I have to plot a point. So, that point is DBT 40, and this line, this line, this black line is for 50%. See, I have marked it in the red circle. So, this point is ready, and as and when this point is ready,

I can know a lot of things from here. I can see, I can find out the WBT is 30° because this is, I told you, this is the WBT scale, this 20, 15, or whatever. I can also, find out the dew point temperature, which is almost about 27° or so. I go straight to strike this 100% saturation line and drop back, drop to the x-axis to almost about 27° or so. I can find out the humidity ratio, which is 23.5 grams of moisture per kilogram of dry air.

And I can also, find out the enthalpy, which is always going to be almost parallel to the WBT line. So, which is striking to almost about 100 KJs per kg per dry air. So, I can also, find out what the S-V ratio is. This is the specific volume, which is 0.92 m^3/kg of dry air. So, by virtue of two given data points, I first find out one point on the psychrometric chart.

I will provide a psychrometric chart in our forum. So, you can use that one. You can take a print and you can use that one. Or you can use that particular website, which can directly give you those kinds of pair properties based on two given data points. So, any two given data points are required to get the first point, and that point now gives you other data.

And why we always go with DBT and RH is because a hygrometer will give you these two data points. It gives you the air temperature, and it will give you the relative humidity. So, it is always better to plot the data or get the data point, plot the point, the particular point of the air state, by virtue of the DBT and the RH. Of course, in some of our questions, some of our assignments, we may give some other WBT and RH also, or WBT or DBT also. That is immaterial, but at least you require two data points to plot a point, and other data can be found out from that point onwards.

And you have to please try to maintain the axis. Which axis belongs to whom, that you need to know. So, the inclined axis is both the WBT and the enthalpy. The other inclined axis is your specific volume.

The y-axis on this side is going to be your humidity ratio and dew point temperature, also, you can get those current lines you have to actually see for your RH. Now you see I have actually plotted that one, I just in that particular psychometric, this particular website I can go, my data was dbt 40 and RHS 50, So, I plotted that one here, dbt 40 and relative humidity 50, these two are my input data and I calculated there and see I got this 100.81 as a KJ per kg as enthalpy which was 100 measured in the psychometric chart very close. Humidity ratios measured are exactly the same. It is given you see it is given as kg per kg, but in the psychometric chart which I have used there it is given 23.5 gram moisture.

So, it is exactly the same. Specific volume Here it is given 0.92. I also, got 0.92. So, it is almost the same.

Wet bulb temperature is 30.31°. I think I also, got 30°. Let me check. Yeah, 30°. So, it is almost the same.

So, either of these two ways, we can find out the properties. But try to do with this thing, the psychrometric chart. Get some printout; it is also, available in online sources. You just give the psychrometric chart, printable psychrometric chart, but you see the SI unit. There are other charts also, psychrometric charts based on the other, the foot-pound unit also, So, better or Fahrenheit° or whatever, So, better to take the SI unit one. So, next one, what I see is, if I know, suppose the outdoor temperature of a volume V and The RH is this much, RH A. So, I can plot with the temperature dbt TA and RH A, a point A, right?

Similarly, I can plot another point B. If I give you another set of data that the dbt of the particular air has to be a little bit cooler, TB, and relative humidity also, may be a little less. So, that is RH B. So, imagine, suppose it is very humid and very high-temperature air outside, which is maybe 38° and 40, sorry, 80% humidity, which is maybe this one. Maybe I can say this is 38° and 80%. So, you represent that; represent this particular point A.

And I want to cool it down to maybe 20° centigrade with, suppose, 30% RH. So, that will be a little less amount of the DBT, which is this, and that will be represented by V. Now, these two points have their own values, right? It has its own enthalpy value. It has its own HR value. It has its own SV values also.

So, if I see, I want to go from A to B. That means that much 38° of V volume to 20° of the same air I have to convert. So, I have to actually use some kind of energy, which is actually required in a chiller plant or some air conditioning plant. So, how much is the delta E? So, it has some kind of enthalpy value for A,

Suppose I may say this is Ea, and this is my Eb. So, this delta E is my Ea minus Eb, which I can find out. So, I know that this is my change, and this is KJs per kg. So, if I can multiply with some V or rho, that is, suppose, m^3/kg is my rho. If I multiply with this KJ per kg, which is my enthalpy delta enthalpy, and if I, what is V? V is a volumetric rate in m^3.

Second, So, if I can make it like that, I can easily find out Rho is kg per meter. Sorry, this is Rho is kg. Or m^3, So, this is the density. This is the volumetric air exchange rate also, and this is enthalpy. So, kg cancels kg, and m^3 cancels m^3, So, this gives me KJ per second, which is your kilowatt, right? Kilowatt. So, I can find out this Q as kilowatt. So, if I know that, I can actually find out how much energy is required to cool down some amount of air from one state to another state by virtue of the psychrometric operation. So, that ends the lecture of this module today.

And this is the module. The first module is over then. Then, we will go to the next module with some other chapter. The chapter will be your building energy systems. In that, we will start with the HVAC systems, and again, we will continue with the psychrometric operation for that. So, what we conclude today in this particular lecture is that the state of air is always described by the moisture content and DBT, particularly DBT and the RH.

We can consider the sensible and latent heat for any such changes because those changes are actually reflected by the enthalpy. And the state of energy of particular air at a particular time with some DBT and some kind of volumetric moisture content gives the enthalpy. Psychrometrics provide the interrelationship of the DBT, WBT, RH, moisture content, enthalpy, and by virtue of that, we can actually find out how much energy is required from one state to another state of the air. Thank you very much.