Water Management
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Lecture 09
Crop Water Requirements (Continued)

In the last class just at the end Dikshit had asked a question which is a very relevant question. He wanted to know what is the relationship between humidity and temperature? To answer this question I think we have to go to a basic relationship because humidity is basically a function of vapour pressure. So we must have a proper understanding what is the vapour pressure? How it changes with the temperature? And that is the relationship which is influencing the effect of temperature or humidity as well.

There is a relationship between the vapour pressure and temperature and the relationship is named as psychometric curve which looks something like this. If I express this vapour pressure and millibars and on this side we have temperature, this curve is the envelope curve which gives us the saturation vapour pressure.

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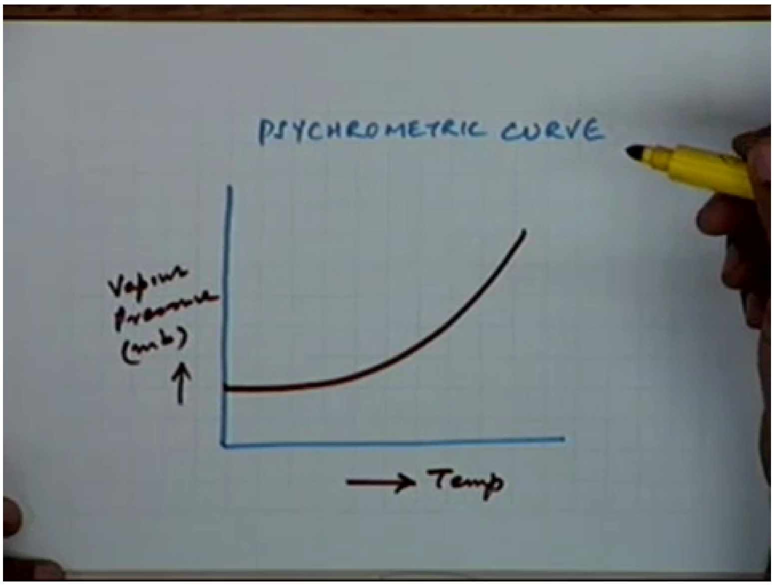

First of all we have to know what is the difference between saturation vapour pressure and vapour pressure? Vapour pressure as is defined is the partial pressure exerted by the vapours at a particular location and that partial pressure is called the vapour pressure. Now to give you an example if we have an air mass at this location and let me say that we are having an air mass which is in a controlled environment. This is a vessel which is a closed vessel.

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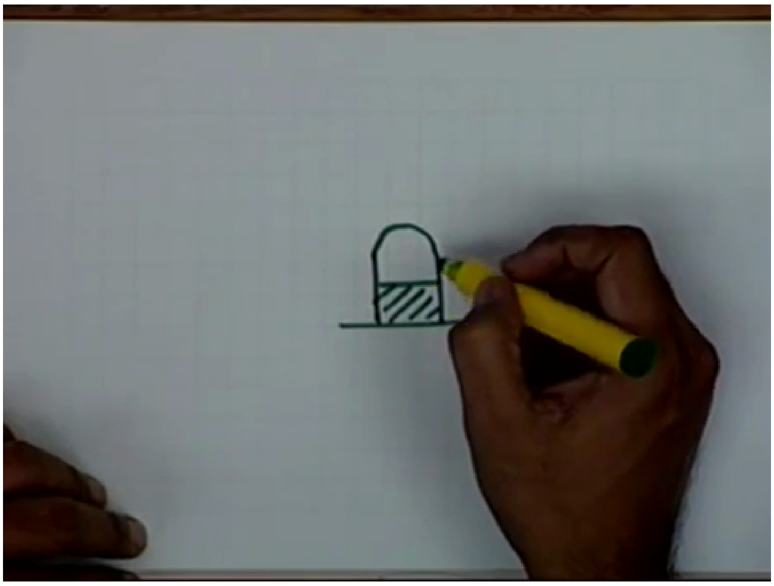

The air mass is in a closed environment and this air mass is at some temperature. The temperature at which the air mass is temperature t here.

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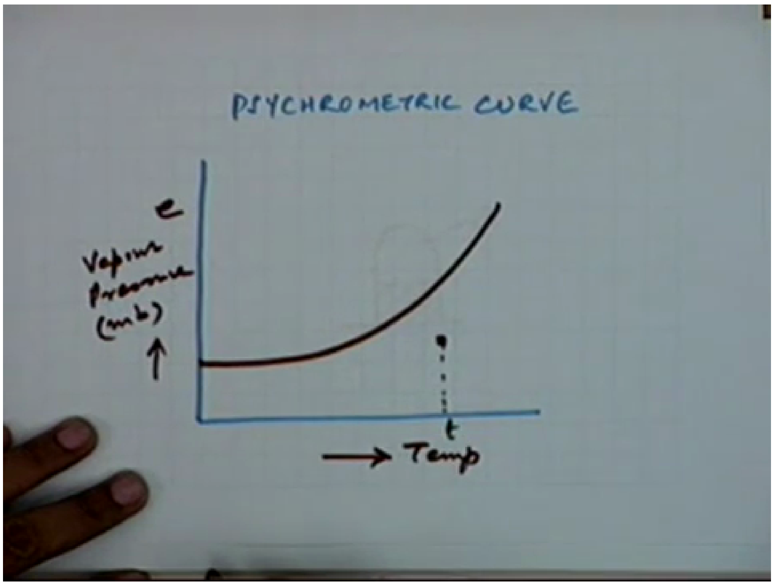

Now if you supply more energy, if you increase the temperature of this air mass by heating it up, the temperature of the air mass will go up and with the temperature the absorption capacity of the air mass will also go up. The air mass and can absorb more moisture from this water or you can say that this water, since you are supplying energy, it will be in a position to evaporate some of the moisture from this water and that moisture will be going into the air mass. That will be increasing the vapour pressure of the air mass.

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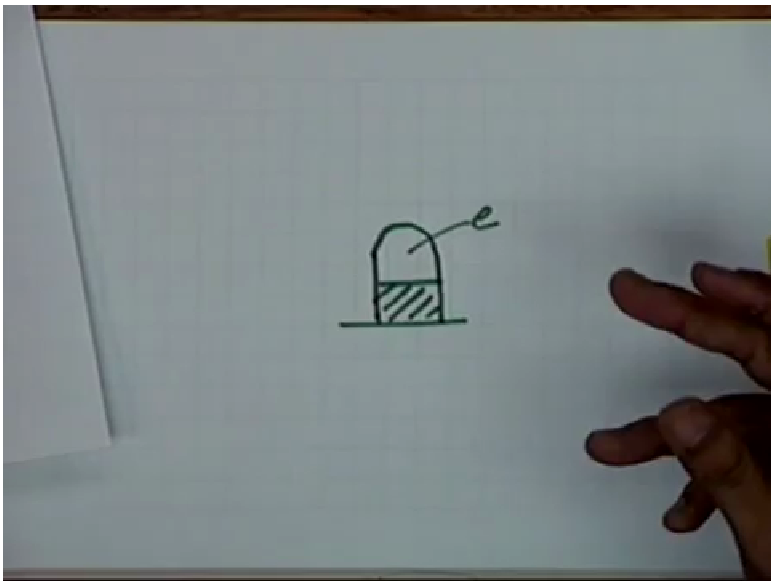

To which extent this air mass can keep on absorbing more moisture is defined by this psychometric curve. This is the maximum level up to which it can absorb moisture.

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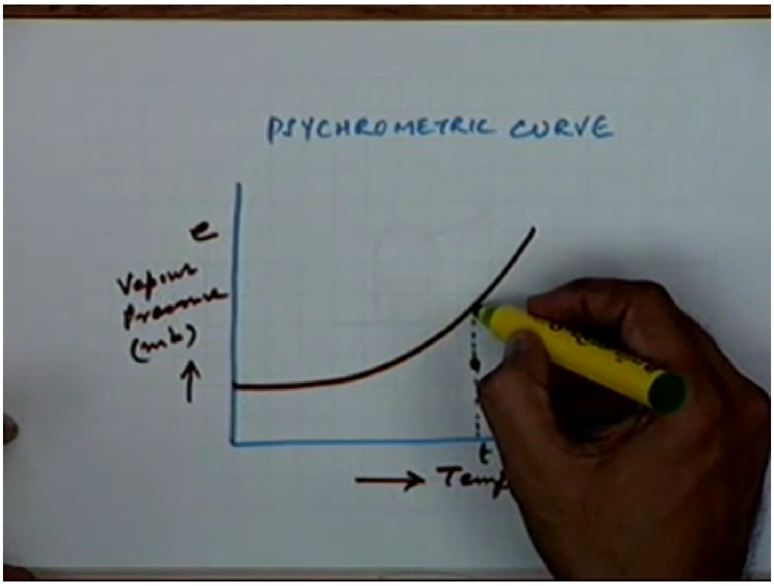

So as you keep on increasing the temperature, at a particular temperature there is a corresponding vapour pressure which is known as the saturation vapour pressure. So this vapour pressure is the saturation vapour pressure which is the vapour pressure corresponding to a particular temperature up to which the moisture can be absorbed. Beyond that if you will try to heat it up further there is a chance that since in this particular case we are saying that the temperature is being controlled, we are looking at the same temperature.

If the temperature is (con) controlled, you are increasing the vapour pressure of the same air mass at the same temperature up to a level which is corresponding to a saturation vapour pressure.

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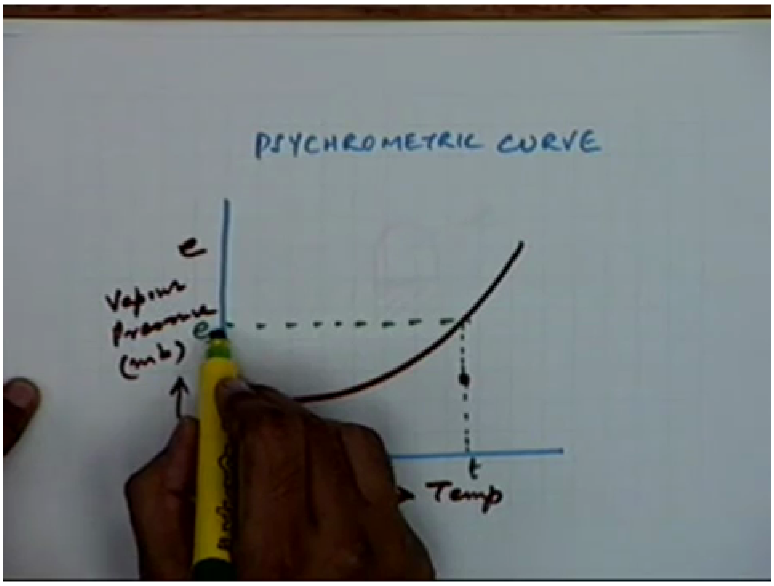

But if you change the temperature and then at a different temperature the saturation vapour pressure will be different. So air mass can absorb more moisture if the temperature increases. But at a particular temperature there is a capacity of the air mass to absorb moisture and that capacity is known as the saturation vapour pressure.

So from that angle it is important parameter which needs to be observed. Let us look at another aspect of the same thing that now if I am trying to reduce the temperature of the same air mass, I reduce the temperature from this level to this level.

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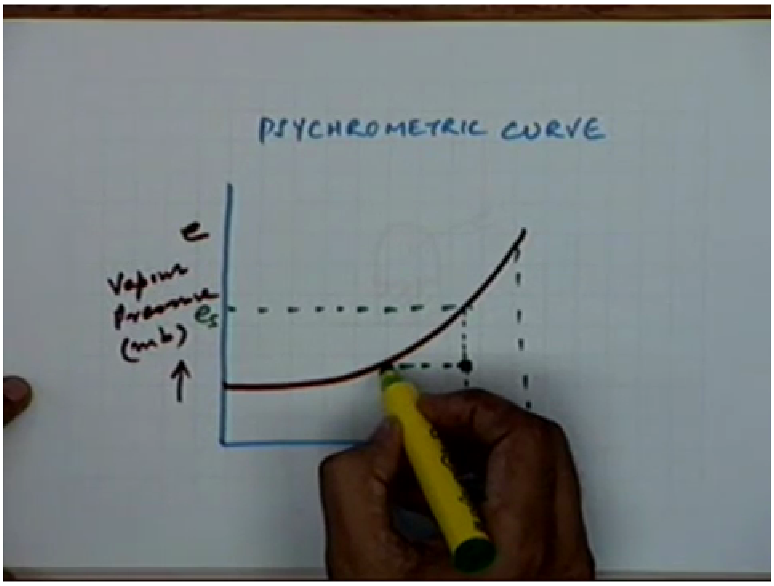

Now the air mass is having some moisture availability at this particular temperature. When I reduce the temperature what will happen? The temperature will reduce to an extent that it will reach this level which is the corresponding level at a temperature t 2. If this is t 1 at a temperature t 2, corresponding to that temperature there is a corresponding saturation vapour pressure.

So if I try to reduce the temperature beyond this temperature, the condensation will take place and that is what is known as dew point temperature. This is the dew point temperature and at this temperature the condensation will take place.

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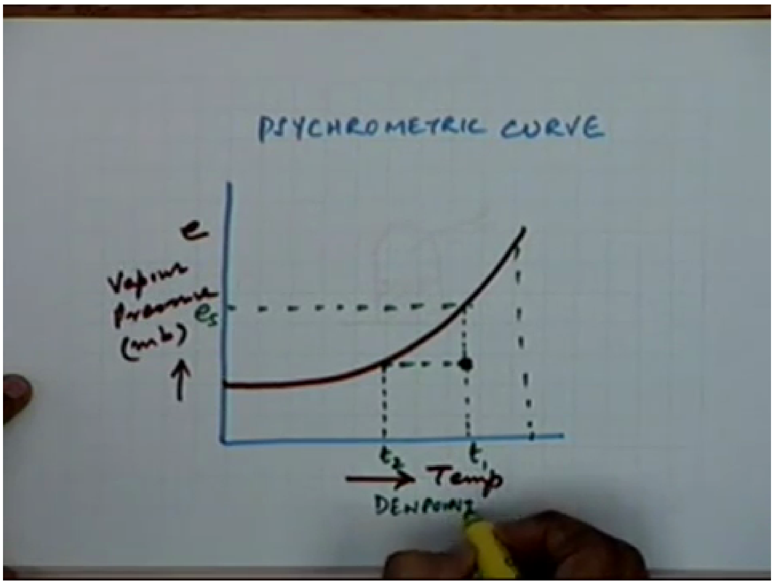

Now this deficit between e s and e a, this is called the saturation deficit. The difference between e s and e a this is known as the saturation deficit. This is the important factor which influences the evaporation activity or in other words the evapotranspiration activity as well because evaporation and evapotranspiration they are all related. Is that clear?

So if you now look at the relative humidity in this context, what is relative humidity? The relative humidity is the ratio of e a to e s or the way I think we were given the nomenclature we were calling the saturation vapour pressure as e a and e d was known as the actual vapour pressure of the air.

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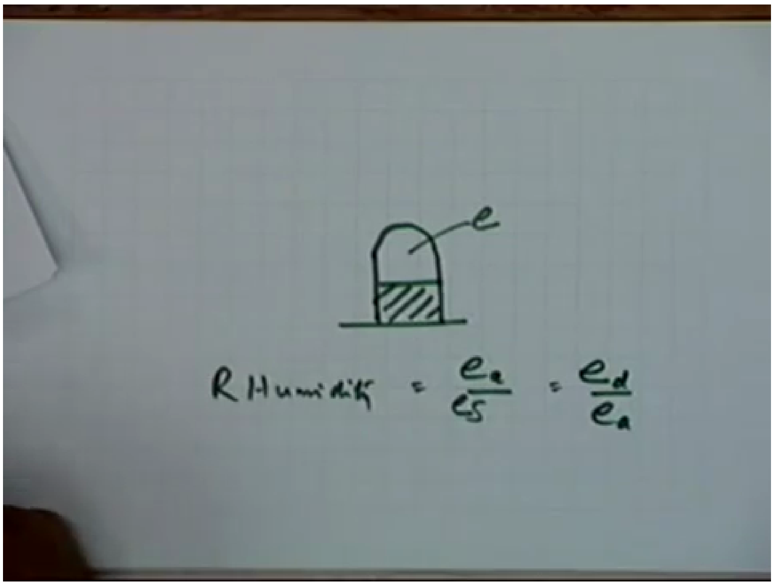

The nomenclature has changed. I am sorry for that. For all practical purposes you can resort to the same nomenclature. This is e a and this is e d, this is e a as per our previous nomenclature which we have been using.

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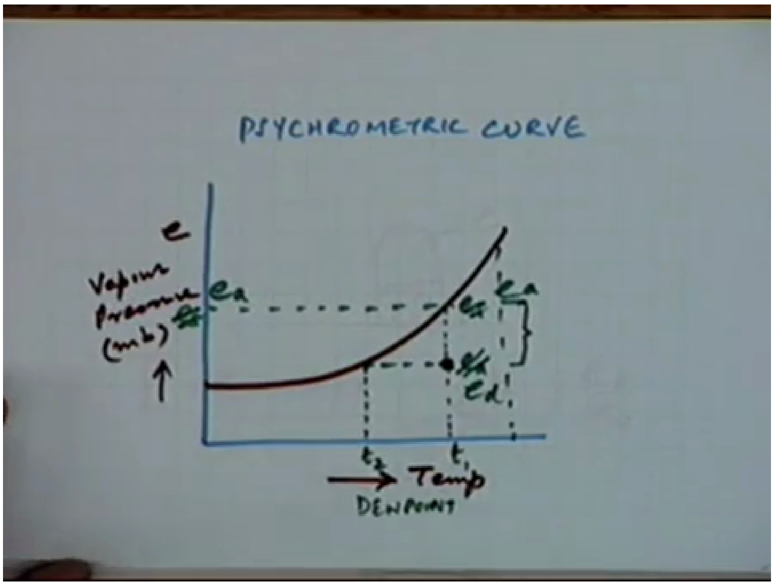

So it is the ratio between the actual vapour pressure and the saturation vapour pressure expressed in percentage. That is what is the relative humidity. Is that clear? Okay. Now another thing which somebody had mentioned and we were trying to have a saying that there are other ways of expressing the function or the graphical representation which have been given in the last lecture.

For example in the case of Blaney Criddle equation for the correction factor we had used ultimately one graphical representation but there are ways and means by which you can avoid using those graphical relationships. You can instead, there are relationships available which can be directly used if you have all the parameters.

They are absorbed, they are known, then you can avoid using. So in this particular case there is another form of the Blaney Criddle equation which is similar. Earlier I think in this place this was the correction factor.

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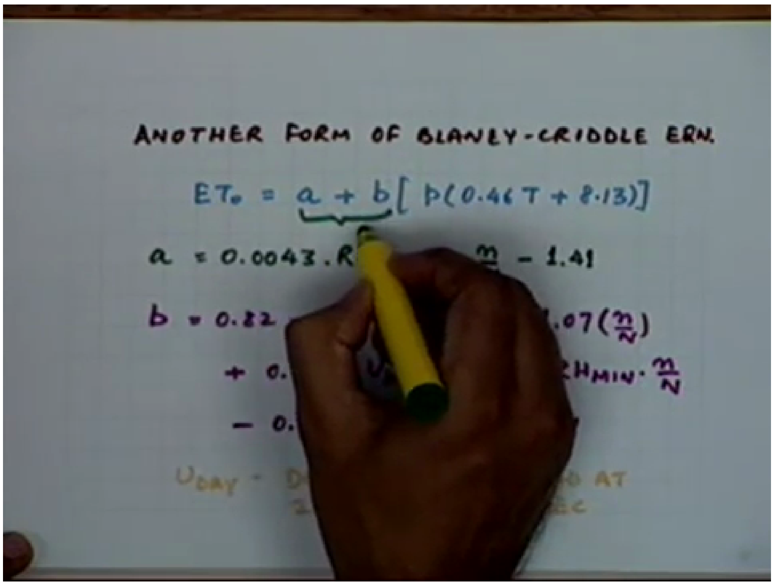

Now in this particular case and this instead of 8 point 13 it was 8 point 0. So that is the only difference. In this particular case your a and b they are expressed further in terms of some other parameters. For example a is expressed in terms of relative humidity minimum and the sunshine ratio n by N and b is also expressed in terms of relative humidity minimum n by N and U day, the wind speed at 2 metres height in metres per second.

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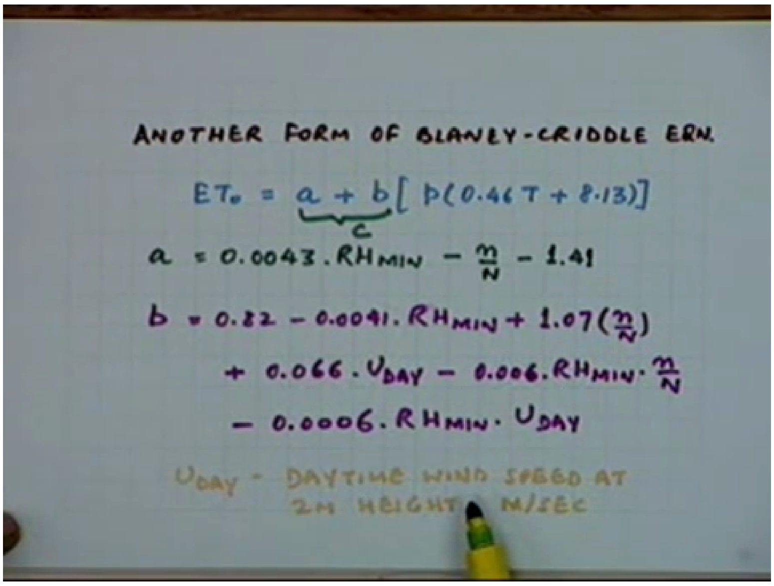

So that is the day time wind speed. These equations have been formed by using the regression analysis and they can also be used. For example in this particular case to find out the value of b, either you can use this relationship or there is another table which is provided. I have only written first part of the table. This table is extended. You have the values for U day of 2 metres per second and this goes up to 10 metres per second. So there are four more tables of this kind.

I have not given the full table. It is the first part where you have the n by N ratio from 0 to 1. The relative humidity minimum is from 0 to 100 and U day 0 metres per second. Similarly for 2, 4, 6 and so on those tables are available. So you can either use this table to write the value of b and interpolate if you have value of these parameters in between or you can use directly this relationship and find out.

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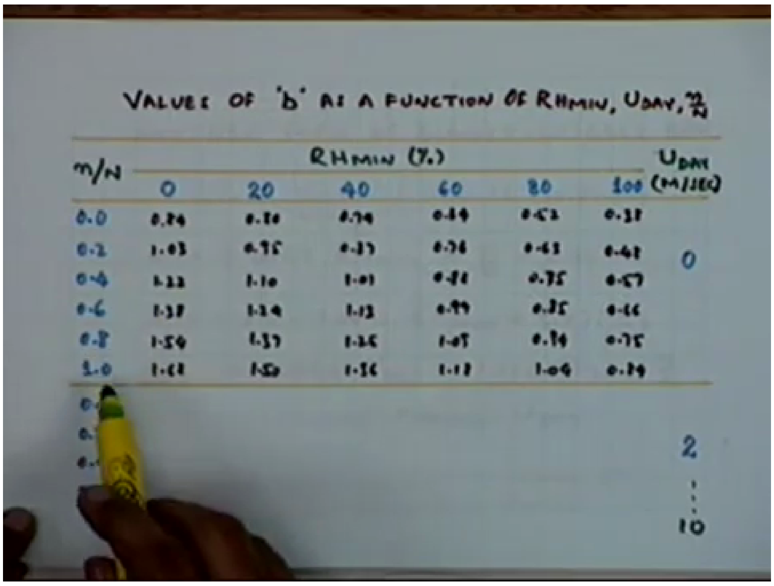

So there are similarly in other situations, in other cases, in other formulations there are the options available. You can use a simpler tabular form or if you want to computerize, if you want to use a computer program you might need equation which is much easier to use and that can be resorted to. The values or the results which you get there are quite similar. The percentage of error might be within 5 percent.

Now we had started in the last class the (pen) Penman method and we had said that what is the basis behind, we had mentioned that it has two terms. It has the energy balance as well as it includes the aerodynamic term and that is why since it takes care of both the options or all the influencing factors because the radiation is one influencing factor, the other is the climate in terms of the wind conditions or the humidity level.

Those two things, the predominance of those two things or those two items can change from place to place.

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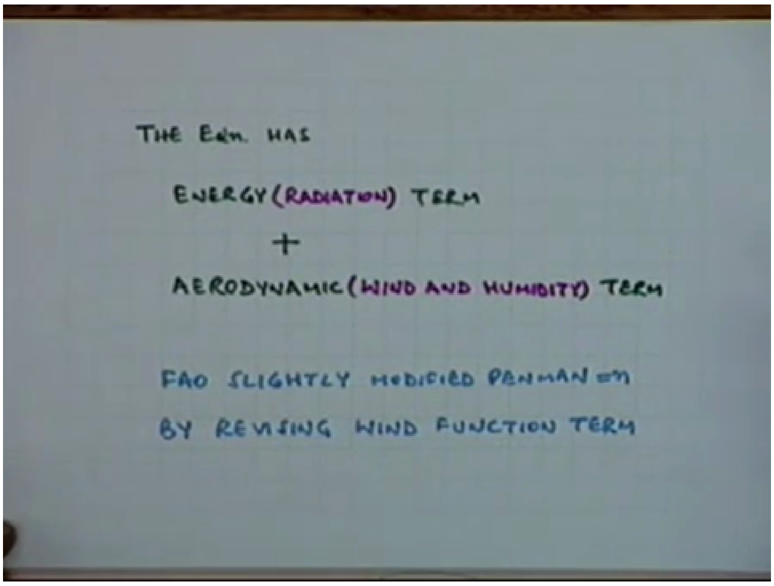

So if you have an equation which can take care of both these major influencing elements then you can certainly come out with the results which are quite close to the actual which are very realistic, the errors are minimised. This is the original Penman equation which is almost similar to what the FAO has recommended and this term we are using as weighting factor W, this is a ratio between delta, delta plus gamma where delta is the slope of saturation vapour pressure versus temperature curve at T mean.

Now this is the same curve which we have discussed just now, the psychometric curve, okay, and gamma is the psychometric constant. So this is what makes the W which we have used in our expression which is recommended by FAO. It is the same thing only expressed in a different manner. This also has a term G which is the soil heat flux. That soil heat flux is positive if soil is warming otherwise is negative.

Now this controls what is the change of or the heat transferred from the soil into the atmosphere or vice versa. And this is the term which is the aerodynamic term which was again it was there in the original Penman equation and this term is nothing but 1 minus W.

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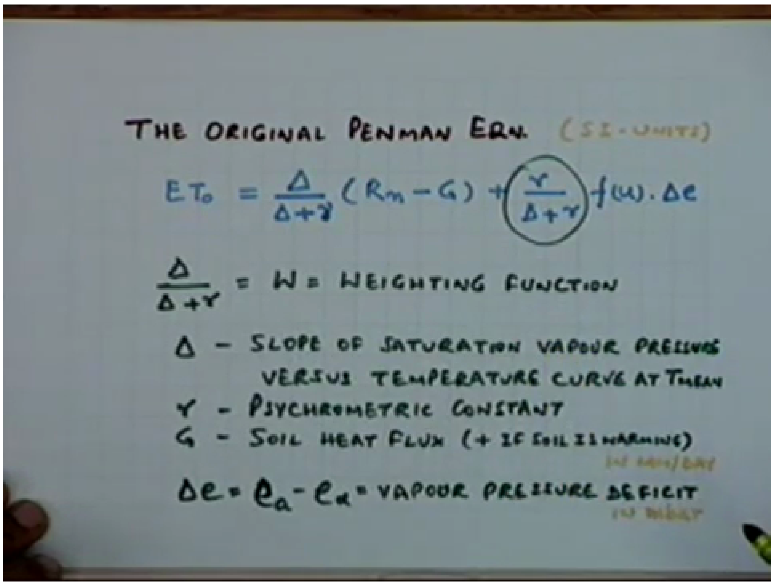

If you take this is delta divided by delta plus gamma, if you take 1 minus delta by delta plus gamma that is what is here and this is the vapour pressure deficit which you have just talked about. That is the difference between the saturation vapour pressure and the vapour pressure at the air temperature. This is the variation which is very slight variation in terms of the difference between the original Penman equation and the modified one.

In the modification they have only given more emphasis on the C parameter which is the adjustment factor which is to compensate the conditions which have been assumed in the original Penman equation. So there are some situations, there are some conditions which can be prevalent in some areas which are not the same as have been assumed in the original Penman equation. So when you take care of those conditions and you apply the correction factor that is done through the correction factor C.

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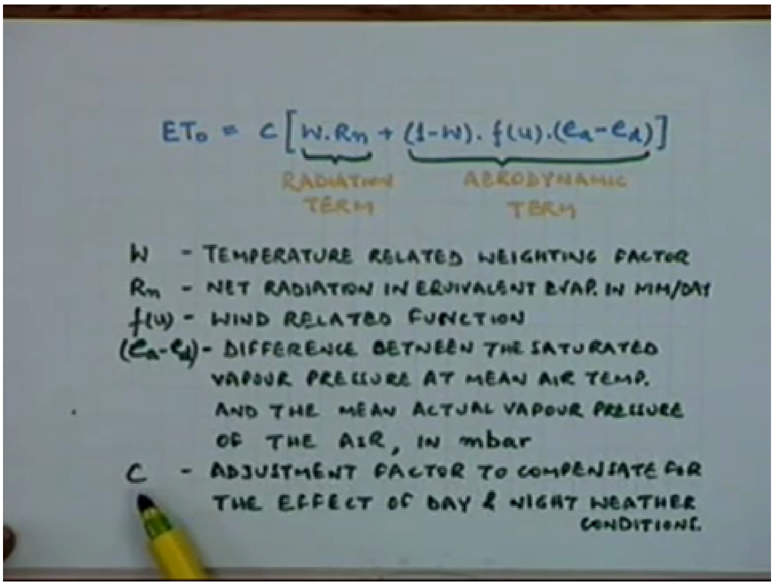

Let us try to go through the various elements of this equation and try to look into how we compute those elements? How we calculate those elements? What are the various relationships available? What are the various requirements in terms of the basic data which is needed to compute these different elements of the Penman equation? So, we will start one by one.

The first one is the vapour pressure deficit which is e a minus e d and since we know that this affects the air humidity which in turn affects the ET not. how to compute this deficit in actual practice?

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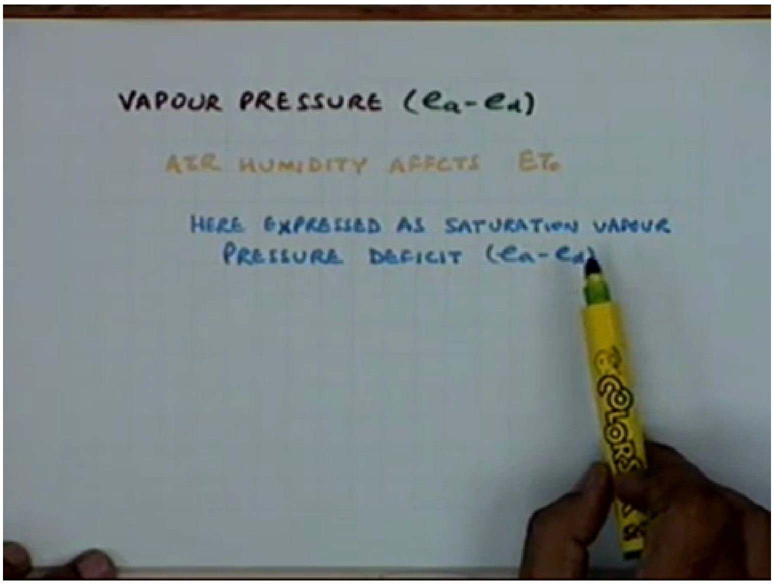

There are many ways of doing the same and the method to be adopted will be a function of what you have available? What type of data is available? Let us look at these different cases which can be possible or which can be used depending on what type of data you have available with you. The first case is when you have the data on maximum temperature, minimum temperature, the data on maximum relative humidity and the (rela) minimum relative humidity. These are the various data which are available.

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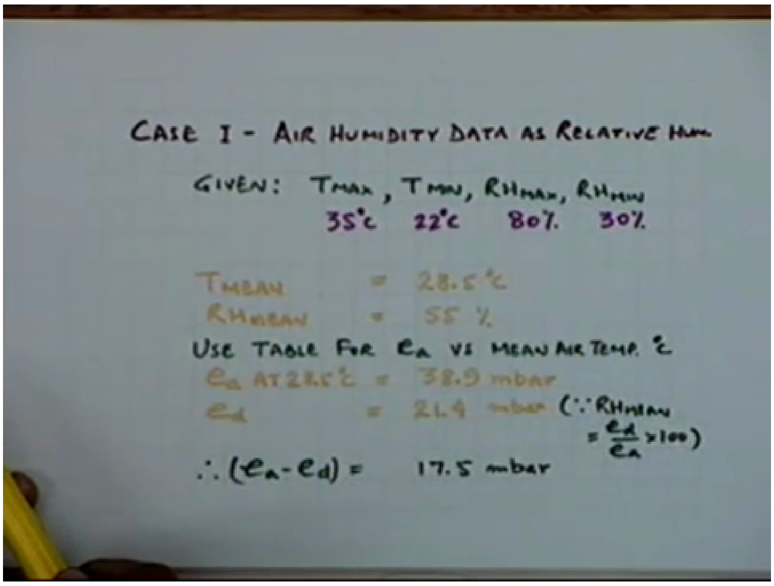

Then you can use a relationship, you can find out what is the mean temperature, you can find out the mean relative humidity and examples have been taken where the actual values have been taken just for assumption sake and these are the values which have been shown here so that you can better understand the computations.

So if you take the mean temperature, mean temperature is the mean of these two temperatures, the maximum and the minimum temperature that is 28 point 5 degrees centigrade in this particular case. And the relative humidity can also be found out by taking the mean of these two values which is 55 percent.

Now the psychometric table or the psychometric curve which I have shown you just now that is also available in form of a table because it is a unique curve, it is an envelope curve which is a universal curve. Now that gives you the saturation vapour pressure at any temperature.

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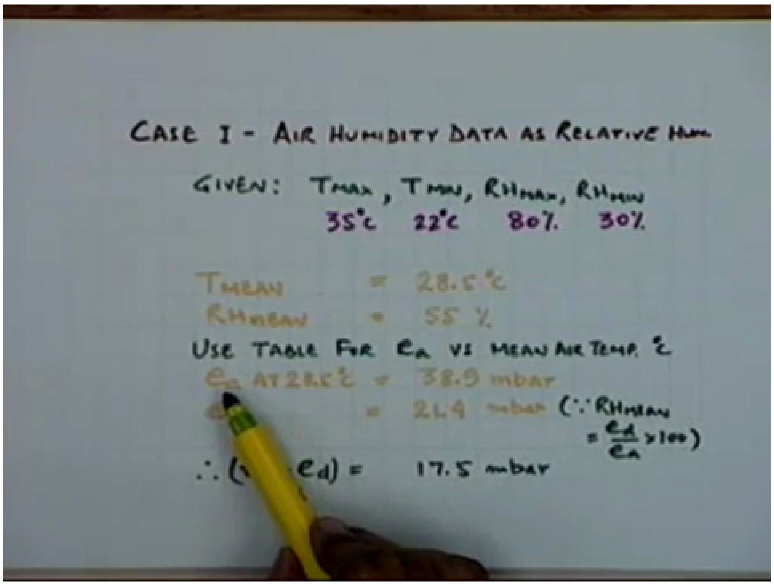

So this is a table which is the table between the temperature in degrees centigrade and saturation vapour pressure e a which gives for different temperature what is the value of e a. Is this visible? Anyway I mean it is not important. I just in the resource material which we are giving, you will have all these tables available.

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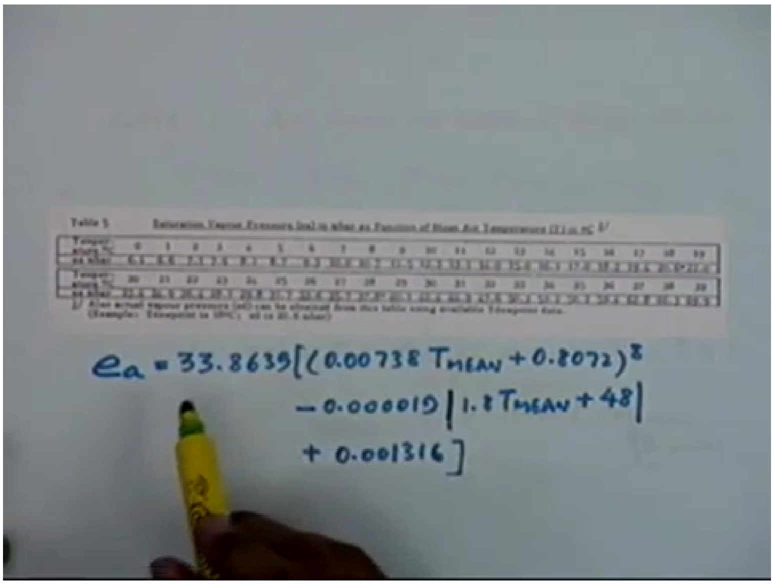

But suppose if this table is not available you can still use this equation can be used. There is a relationship between the saturation vapour pressure and the mean temperature and this relationship can be used to get the value of the saturation vapour pressure, okay. Now this is alternative to using the table but this table is quite easily available table. One can find in any standard resource material or the textbook.

Once you find out the saturation vapour pressure then the actual vapour pressure can be found out by using the relationship between the relative humidity and the vapour pressure. So relative humidity is e d by e a. You know the e a value, you can find out e d. You know the relative humidity, the mean relative humidity you know so e d can be found out, e d is 21 point 4 millibars in this particular case so you can find out the deficit.

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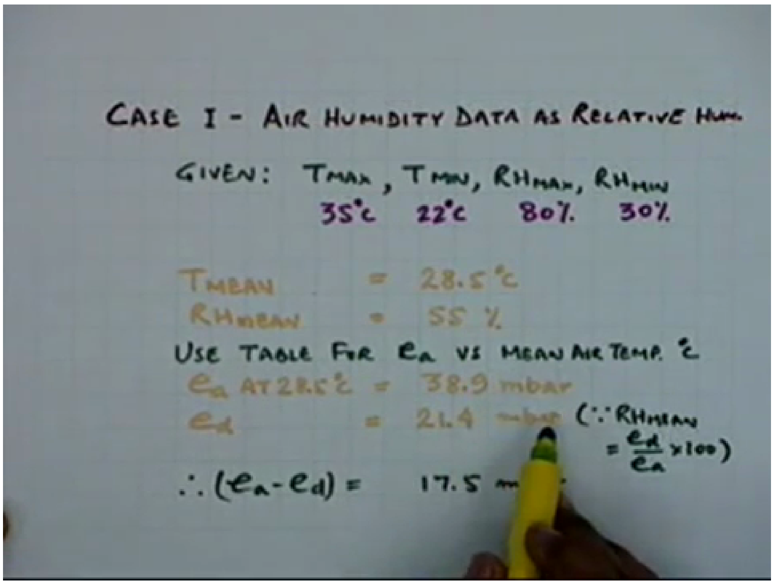

That is one situation in which you have these data available and you can find out what is the saturation vapour pressure deficit? Let us look at another case where you have the data available on maximum temperature, minimum temperature and the psychometric readings. Do you know what psychrometer is? It is the instrument which we use to observe the wet bulb and the dry bulb temperatures. It is something like there are different kinds of equipments which are in use.

The one which is aspirated is where you can use the ventilation. That is the one which is something like the (())(25:59). You have a (())(26:01) where you have two thermometers, one is for the reading of the air temperature and the other one is for the wet bulb in which case you are taking a porcelain cloth, slightly wet it with water and wrap it around the second thermometers bulb, okay. So when you do that what happens?

It evaporates that moisture which is available in the damp cloth and that evaporation reduces the temperature because of the loss of the latent heat of evaporation, okay. So when you lose that temperature, how much temperature you will use will be a function of what? It will be depending on what is the humidity level?

What is the temperature so that these two temperatures, the wet bulb temperature and the dry bulb temperature, these two temperatures are obtained from the psychometric readings? There are the other kinds of psychrometers also which are not ventilated, which are non ventilated psychrometers and that correction can be applied because if you create that ventilation it will have more evaporation.

If you do not create the ventilation it will have less evaporation because of the fact that the air mass which is immediately closer to that wet bulb which will be after sometime if it is latent with the water vapours then unless that air is replaced it would not be in a position to evaporate any further. It is because you have seen that in the case of air mass, the air mass reaches. Let me give you an example. Suppose this is the body where the evaporation is taking place.

So the water vapours they go into this particular volume of air. Now this air mass if it becomes saturated and this is not replaced by another air mass which is having less water molecules then the evaporation activity will stop there because this air mass has been totally saturated and you know that at that particular temperature the air mass is not in a position to absorb anymore vapours.

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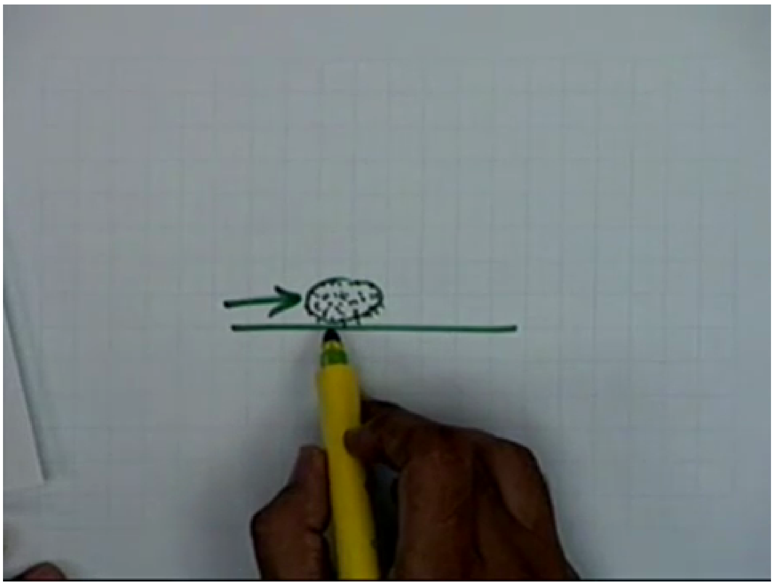

So that is how the wind affects the evaporation. That is where the wind effect comes into evaporation. The wind influences the air mass which is absorbed with the water vapours to replace that air mass with a fresh air mass which might be having much less amount of water vapours. If that happens then the evaporation activity will proceed at a very faster rate, at a very higher rate. Otherwise the activity might stop after sometime because of the higher level of humidity, okay.

So from that angle if we have these dry bulb and the wet bulb temperatures available then again you can find out what is the mean temperature and you can also find out what is the saturation vapour pressure at that temperature that is using that relationship or using that table. You can find out there is a table which again, it might not be visible to you, if this can be enlarged you might be in a position to see this part.

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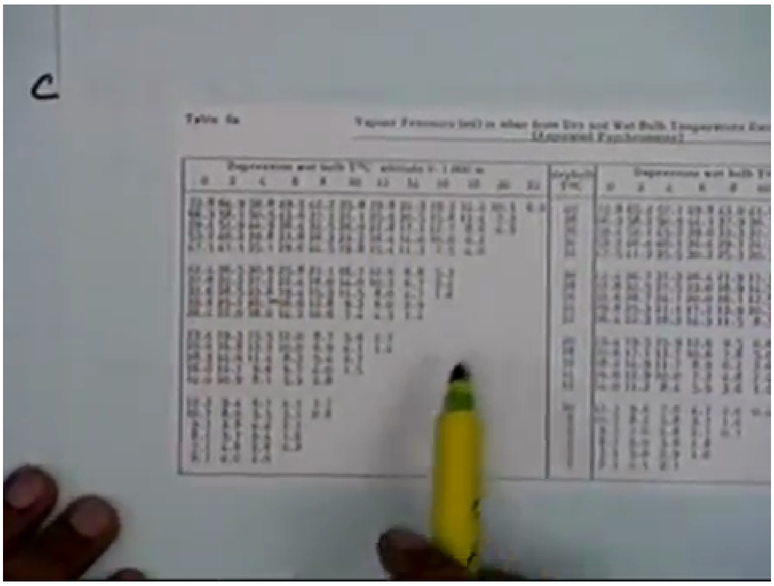

This is a table between the vapour pressure and dry and wet bulb temperatures. Now this is dry bulb temperature in degrees centigrade which is given from 0 to 40 here and on this side is the depression in the wet bulb in degrees centigrade. What does that mean? The difference between the dry bulb and the wet bulb temperature.

So this goes from 0 to 22 degree centigrade and this part of the table is for altitudes between 0 and 1000 metres whereas this part of the table is the same thing but for the altitudes between 1000 and 2000 metres.

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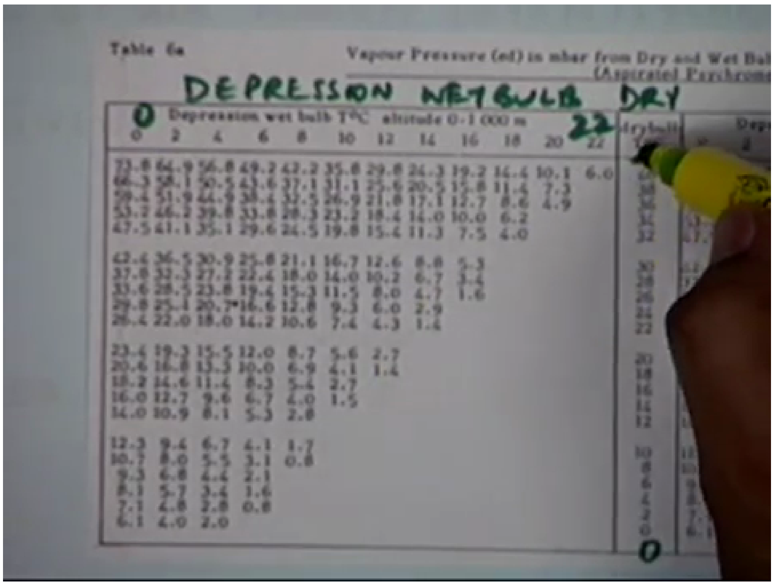

So if you know the dry bulb temperature and you also know what is the depression in the wet bulb or what is the difference between the two, knowing these two and knowing what is the altitude of the location at which you are applying this, you can read out what is the actual vapour pressure e d. That actual vapour pressure can be directly read using this table and this is for aspirated psychrometer. This table is for that.

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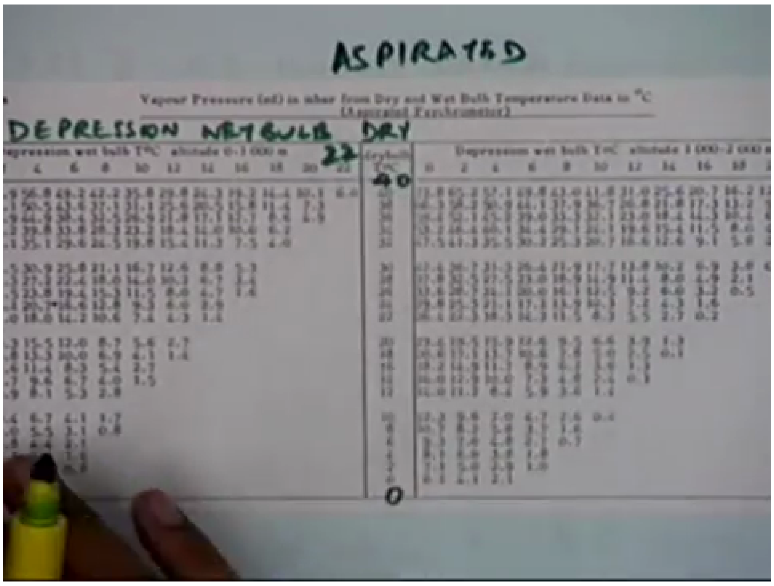

There is another table which is to be used in case you are using a non ventilated psychrometer. It is the similar table which give the vapour pressure with respect to the dry bulb temperature and the wet bulb temperature but for a non ventilated psychrometer.

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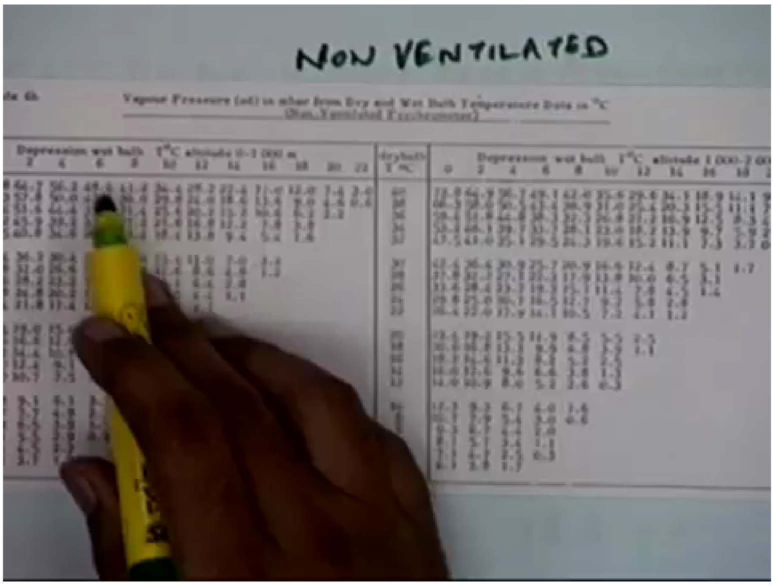

So knowing these two values you can read the e d value, the vapour pressure at the dry bulb temperature and the wet bulb depression. In this particular case the difference between the dry bulb and the wet bulb is 4 degree centigrade. You are reading the value at dry bulb temperature of 24 degree centigrade with a wet bulb depression of 4 degree centigrade and that value is 20 point 7 millibars and you can find out the deficit.

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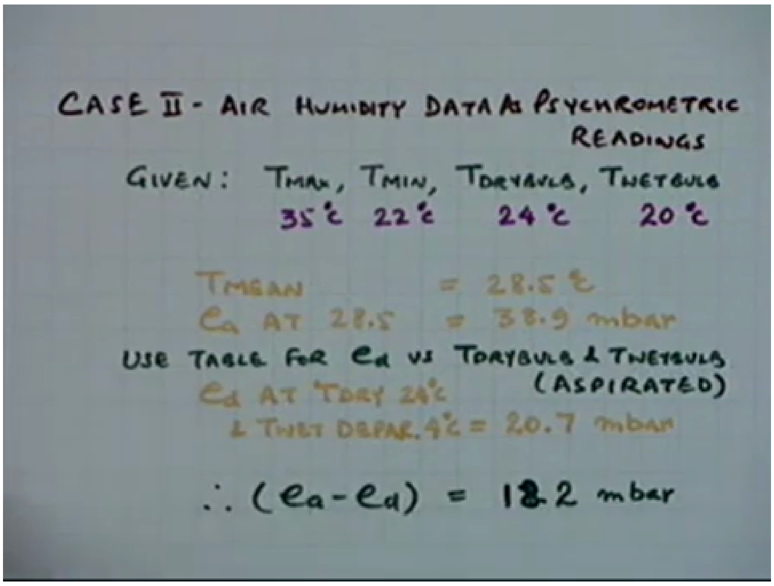

There is a third case you might not have the written psychrometric readings available. You might not have the relative humidity available. But instead you have the dew point temperature which is available. The data on dew point temperature is available along with the maximum and the minimum temperature. Again the first two parts are the same that you can find out using the mean temperature. You can find out the saturation vapour pressure but to find out the e d you can do that if your relative humidity of the area is close to 100 percent.

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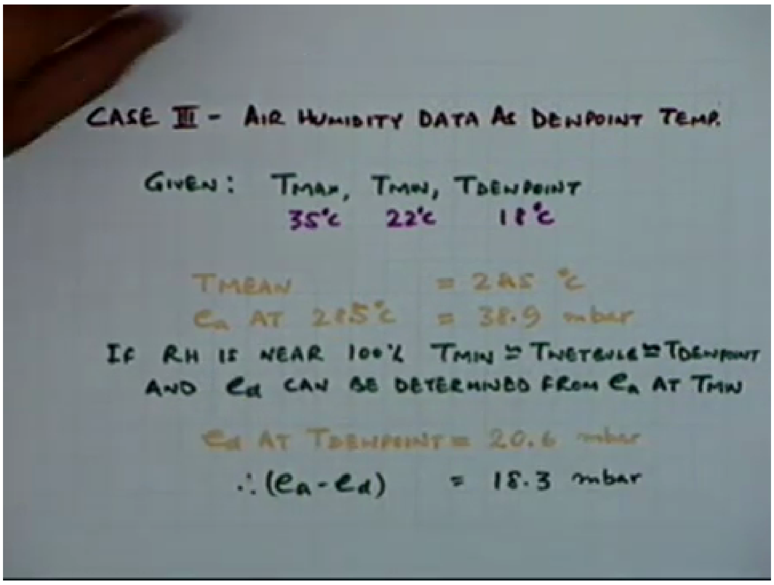

You must have seen in this case where I was trying to explain the psychrometric curve, what happens in the psychrometer curve which is this curve, if you know the dew point temperature, if this is the dew point temperature and this was the air mass.

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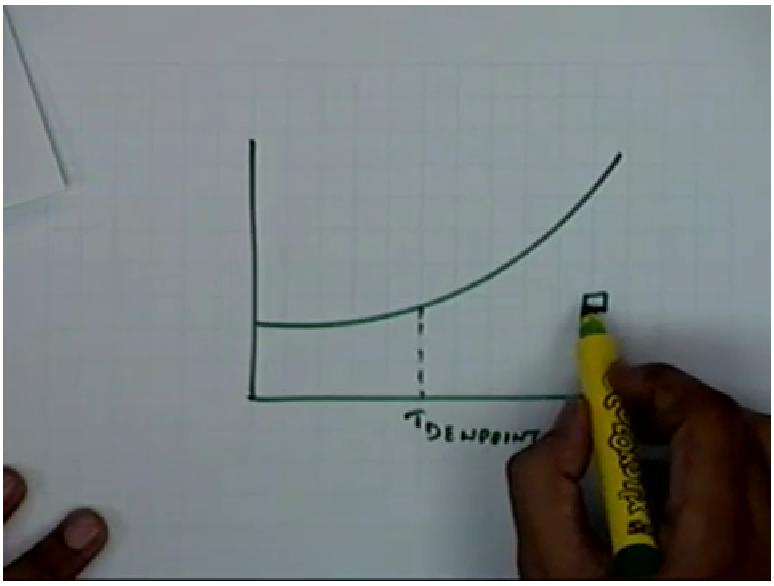

Now if the relative humidity at that level is quite close to 100 percent then it is very likely that the dew point temperature and the wet bulb temperature they will be same. The dew point temperature it will be quite close to the wet bulb temperature and which will be approximately same as minimum temperature. These three temperatures provided the humidity level, the relative humidity is close to 100 percent.

That means you are somewhere in the near vicinity and in this particular case it will not happen because in this particular case if this is my e d then it is quite likely because there is lot of deficit is there. It is very likely that the relative humidity will not be 100 percent because the relative humidity to be 100 percent what is the e d? This e d has to be quite close to e a. The ratio of e d and e a has to be close to 1. So that means this deficit will be quite minimum. So the closer you are, if I am somewhere here then the two will be quite close.

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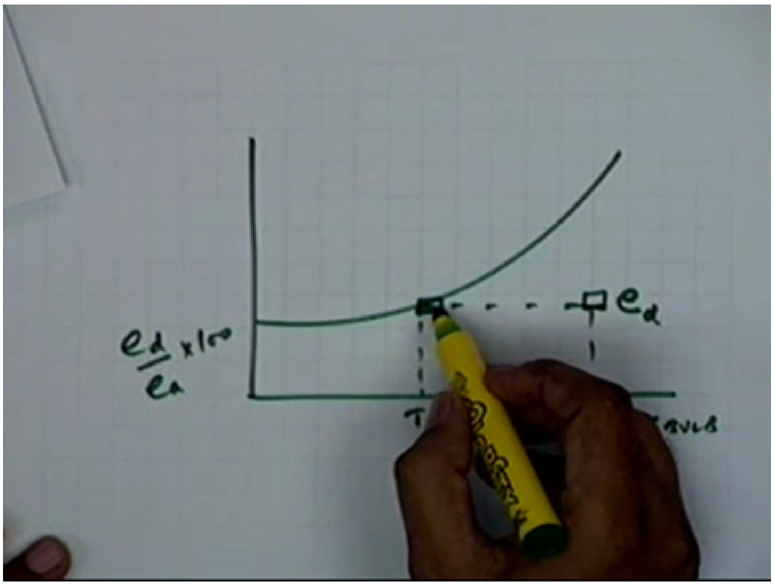

The e a and e d they will be quite close, is it clear? So in that situation this case or you can use this only in a situation where you have relative humidity which is close to 100 percent. In that situation your minimum temperature, the wet bulb temperature and dew point temperature they will be quite close to each other and if that is so, you can use the psychrometric curve to find out what is e d. So e d will be close to the saturation vapour pressure at the dew point.

E d in that case will be nothing but the saturation vapour pressure at the dew point temperature. And once you have that you can find out what is the deficit?

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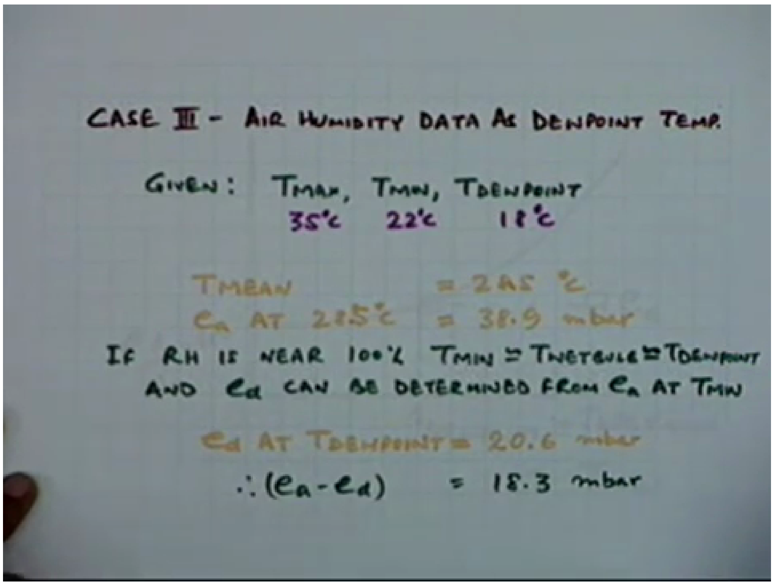

So these are the various situations which can be utilised to find out the saturation vapour pressure deficit. Next let us look at the wind function which is used in the case of, this is the wind function here and this is part of the aerodynamic term.

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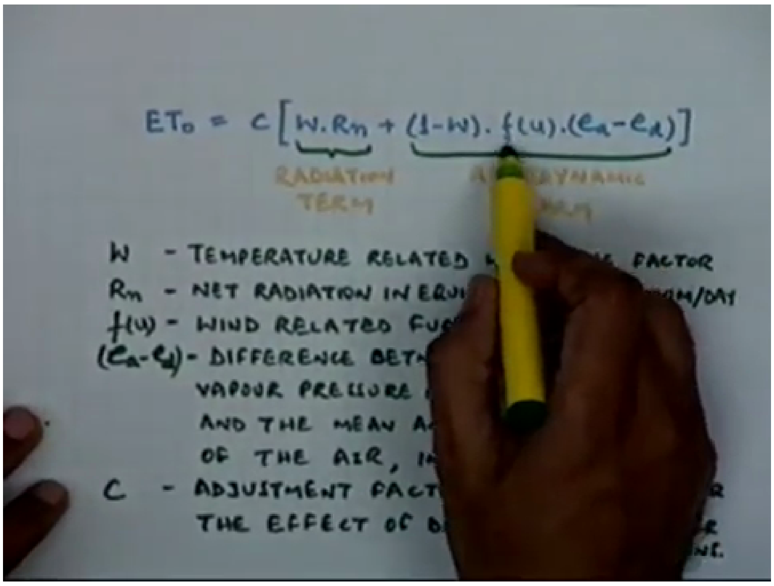

That wind function we have already looked at e a minus e d. There is the next part which we are trying to look at right now. Now in this particular case the wind function is expressed as this expression in which capital U is the 24 hours wind run in kilometres per day at 2 metres height.

So in many cases you might find that the actual observation of the wind speed which is being done in the field it might not be available at 2 metres height because of various reasons. The instrument which is installed it might be installed at a height which is different from the standard 2 metre height which is to be used.

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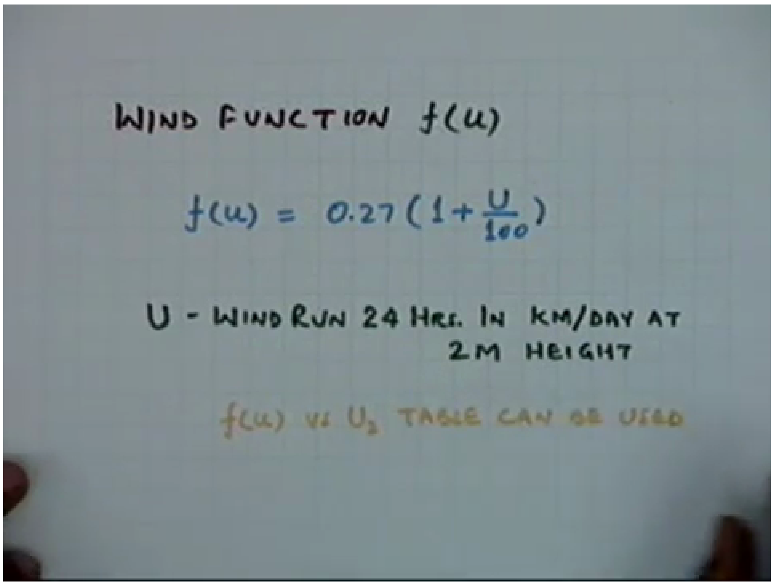

Then for that the correction factor has been recommended. You can use this correction factor which is between the measurement height and at 2 metres it is 1. If it is less than 2 metres then the correction factor which is more than 1 has to be used. If it is more than 2 metres, the correction factor which is less than 1 which has to be used which is quite obvious because if you are very close to the surface it will be more resistance. The actual wind speed which we are measuring will be much less than the prevailing wind conditions.

So the correction factor has to be greater than 1. On the contrary if you are going above that then again you might be overestimating the conditions. So you have to apply a correction factor accordingly. So this is the correction factor which is recommended by FAO.

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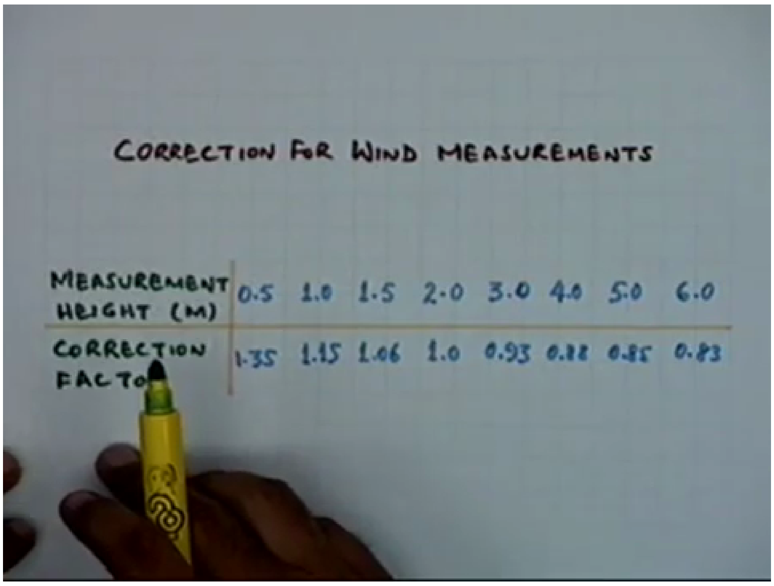

For the wind function there is the table which is available which gives the wind function with respect to that formula which we had just written which is this. 1 plus U by 100, okay, and this is the wind in kilometres per day ranging from 100 to 900 and on this side you have the fractions available. If it is 110 you can use this. This is from 10 to 90.

So if it is between 100 and 200 and it is some values which are between 0 and 90 you can use this table and you can still interpolate if you have some value which is between 20 and 30. So the 10s are given here, the lower digits can be interpolated.

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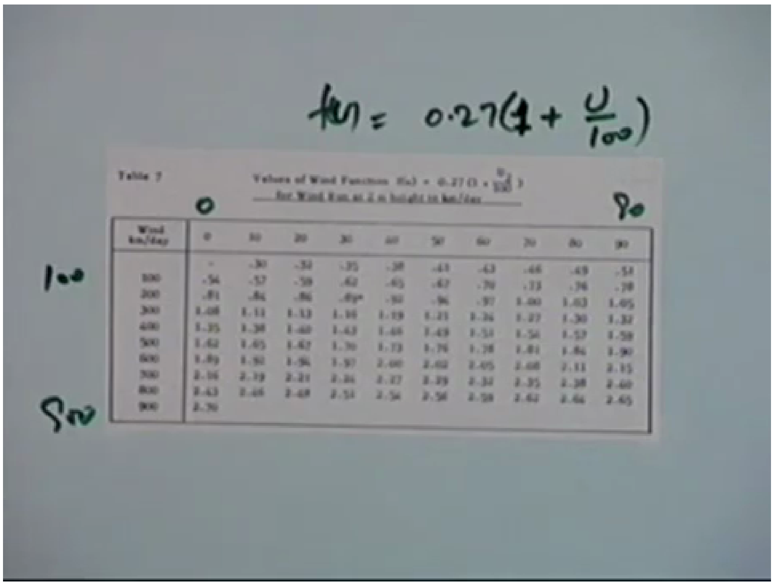

Now next is the weighting factor which is this factor 1 minus W. This weighting factor is to incorporate the effect of wind and humidity in the ET O.

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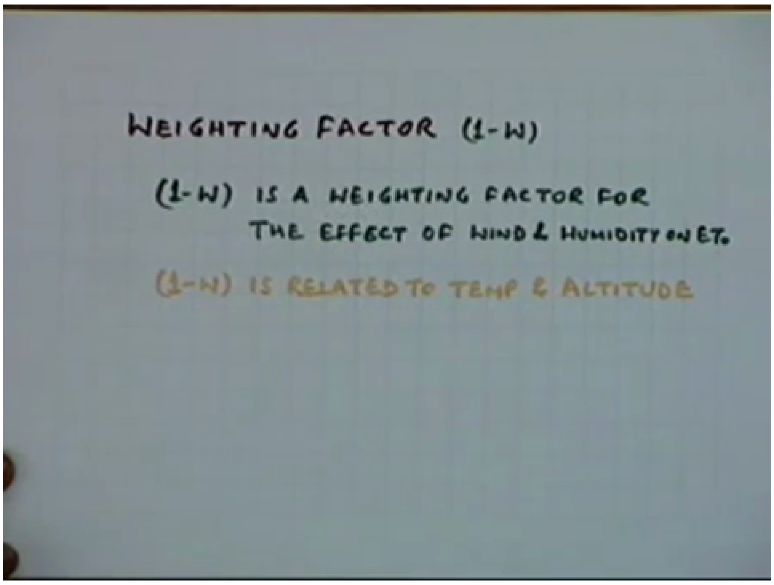

And again there is a standard table which is available which gives the values of the weighting factor 1 minus W and this is the temperature from 2 degree centigrade to 40 degree centigrade and the altitude is on this side from 0 to 4000. So for different altitudes and for different temperatures you can read out the value of the weighting factor 1 minus W.

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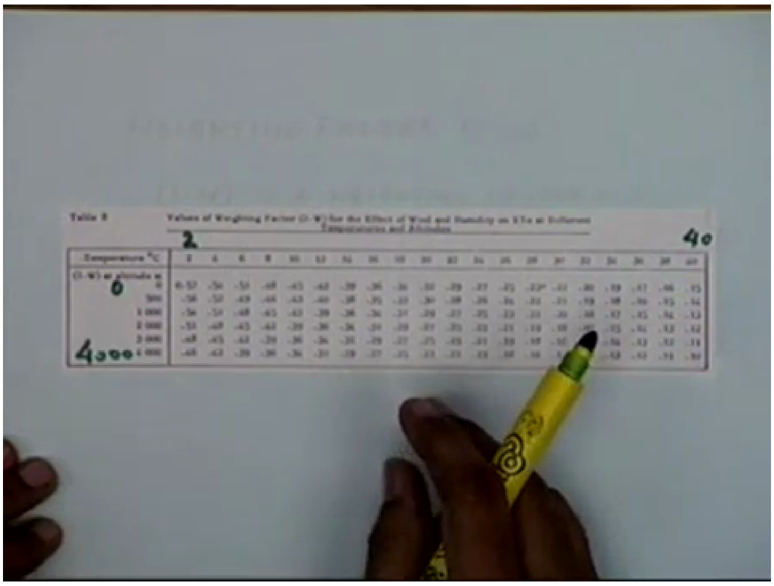

Similarly the weighting factor W which is the component in the radiation term, this weighting factor is also related to the temperature in the altitude.

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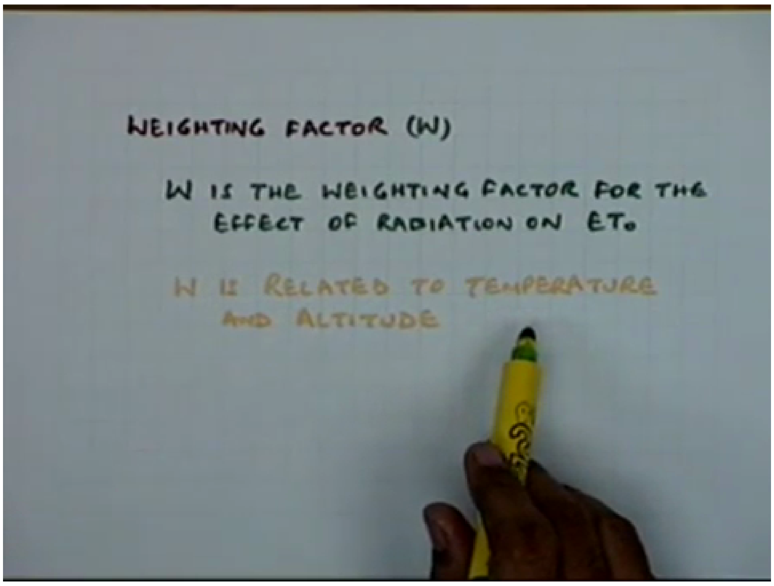

And this is the replica of the earlier table. It is the same thing but it is 1 minus the values of the previous tables. So it is the same table with a slight modification because the total weightage is 1. Whatsoever the weighting is given to the radiation term, the remaining weightage is given to the aerodynamic term.

Now this is very simple if you are using these tables but there are procedures available, there are expressions available where if you have the available data you can use those required data and you can find out the weightages yourself by using the relationships directly instead of going to the tables.

So if you are again writing a program, you are writing a software, you might find that these relationships are much easier to model then to use those tables. The way we had define the weightage factor W this was delta, slope of the saturation vapour pressure curve and this is given in terms of this equation.

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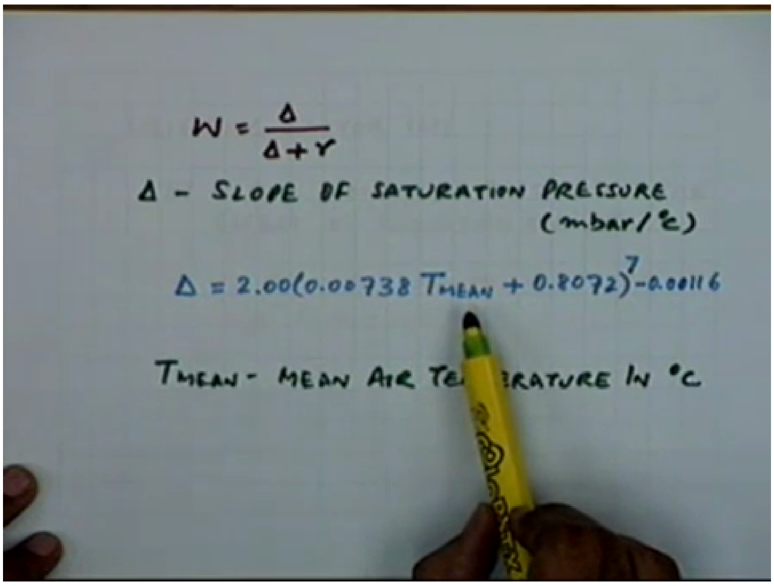

Delta can be directly found out using the mean temperature of the air in degree centigrade and the psychrometric constant is nothing but is the ratio between the vapour pressure deficit and the wet bulb depression. It can also be expressed in a simpler form in which this P is the atmospheric pressure in millibars and L is the latent heat of vaporization, okay.

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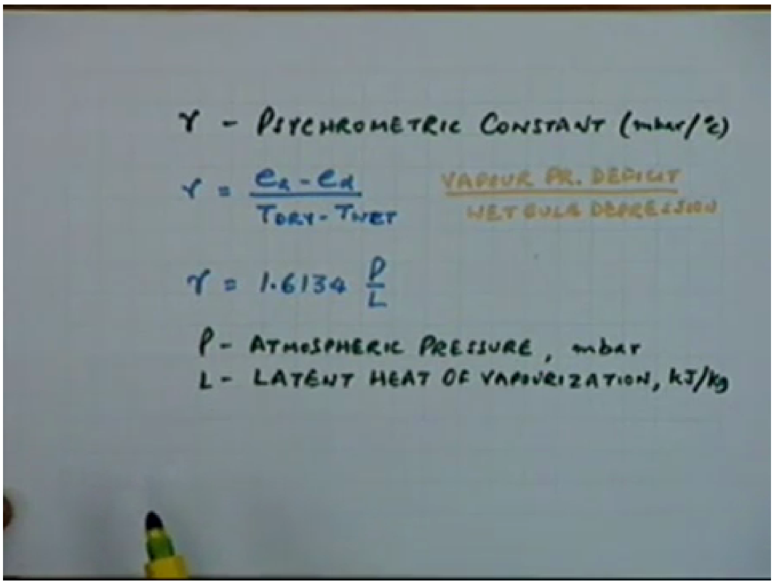

Now further there are expressions available to find out what is the value of atmospheric pressure and that is given in terms of these variables. P 0 is the standard sea level atmospheric pressure, T 0 is the standard sea level temperature and this is in kelvins and delta is the standard lapse rate in kelvins per metre, R is the universal gas constant for air which is 287 joules per kilogram kelvin, g is the acceleration due to gravity, E not is the base elevation in metres and E is the elevation of the location in which you are interested.

Similarly there is an expression for latent heat of vaporization which is a function of the air temperature. That can be used to find out L.

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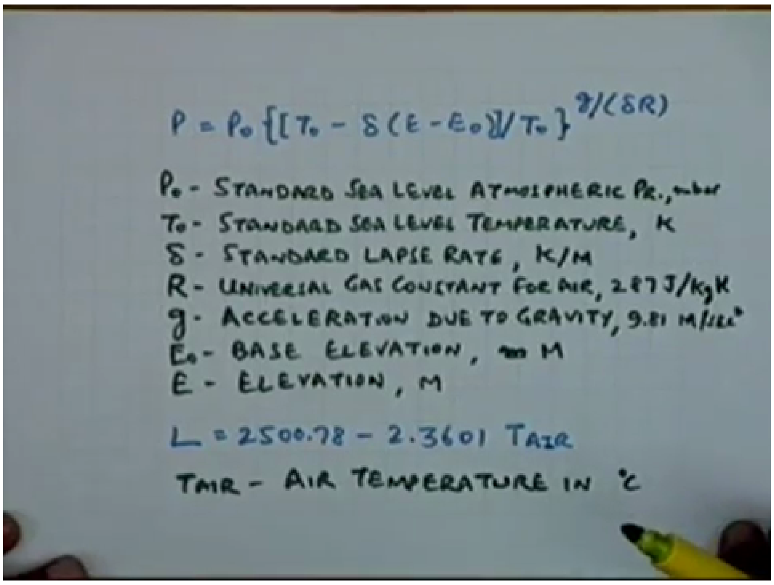

Now if you have all these data which is required in this particular case which means that data on all these variables, you can certainly use this expression for finding out the weightage factor yourself otherwise it is very convenient to use the tables, so there is no restriction. The tables can be used if you feel that the tables are much easier to be used.

If your accuracy because in that case you will have to interpolate and in some cases it is recommended that the table should be preferably used because all these equations where the regression analysis has been used, the accuracy is not as good as you can get in the case of tables because when you have used the regression analysis, the goodness of the fate is another criteria which has to be looked into. It depends how many data has been used?

How many different conditions have been incorporated in doing those regression analysis and what was the goodness of it? So I think it is just a function of availability. If you have the data available you can use either of the things with the slight loss of accuracy but it will be more dependent on where you are using? Whether you are using in a system or you are doing it manually? So that will be making the basic difference and I think we can stop here for today. Any question?