The Psychrometric chart and greenhouse climate control

Mr. J.O. Voogt

June 2013

Introduction

What is the Psychrometric chart?
We all know that the temperature and moisture content of the air is important for our respiration. Warm humid air is better for our airways and lungs than cold dry air. However, if we have to exercise strenuously, like running a marathon, then a moderate temperature and a not too high humidity is more favourable, because we are able to release our excess body heat through perspiration and cooling. This is because of the energy content of the air.

The Psychrometric chart describes the properties of air at different temperatures and moisture contents, in order for us to understand the physical backdrop to the transfer of moisture and energy in our environment. One of the particular properties of air is, for example, that it can contain no more than a fixed amount of water vapour at a specific temperature. If humid air cools, then at some point the water vapour condenses and water drops are formed. If the temperature and humidity above the sea is known to us as well as the temperature above the land, then the Psychrometric chart is able to show us whether the sea air above the land will remain clear, whether it will become foggy or even whether it will rain.

Why is the Psychrometric chart important for Greenhouse climate control?
Most gardeners rely on their feelings in regulating the greenhouse climate. If it is too hot and/or too humid in the greenhouse, the ventilation windows are opened more and the temperature and humidity will then usually decrease. If the air outdoors is very dry then the humidity in the greenhouse will drop much quicker than the temperature. This is detrimental to the plants because the stomata then close to prevent dehydration. It is more difficult for the CO2 to be absorbed through the closed stomata and the growth will come to a halt. In that case, it is better to take the humidity into greater account than the temperature. We are able to learn when and why this is so from the Psychrometric chart.

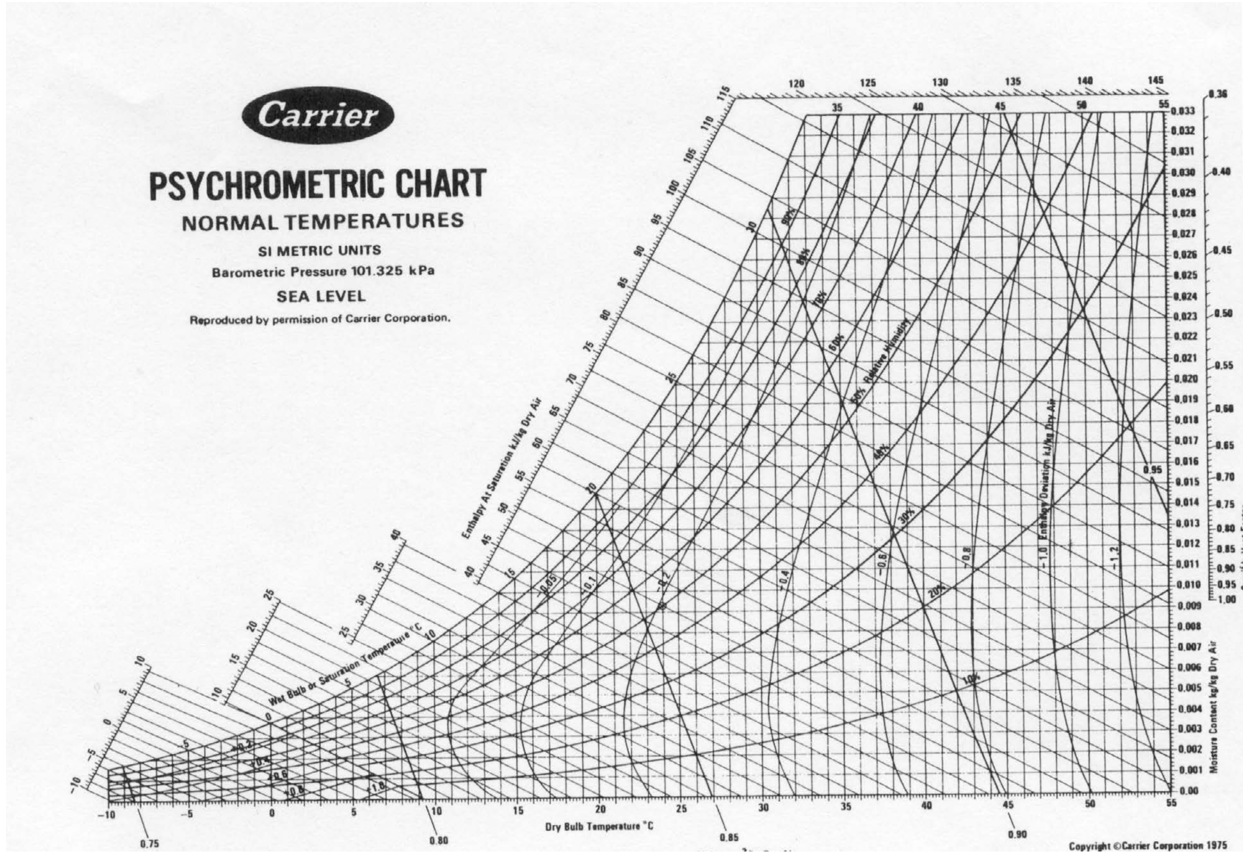
If we take the physical properties of air into account in regulating the greenhouse environment, we can often achieve a better result than if we only rely on our feelings. A better understanding of physics can furthermore lend a hand in saving energy and water, producing a greater yield and a better quality plant.

What does the Psychrometric chart looks like and why are there different types?
A fair amount of background information about the Psychometric chart can be found on the internet. Look at Wikipedia (reference 1) among other things. I will therefore confine myself to adding only a few comments.

There are many ways to display the properties of humid air in tables or graphs. The two best known are the Mollier diagram and the Psychrometric chart. Application and tradition are reasons for there being various forms.

The Psychrometric chart is mostly used worldwide for various applications, such as air conditioning and refrigeration.

The Mollier diagram was drawn up by the German physicist Richard Mollier (1863 - 1935), who had played an important role in the development of steam engines (reference 2). The Mollier diagram is still widely used in Scandinavia, Eastern Europe and Russia. The content represented is essentially the same as that of the Psychrometric chart, but from a different perspective. The Psychrometric chart below is such as the one used in most countries. The horizontal X-axis depicts the temperature in °Celsius (°C). The vertical Y-axis represents the humidity in the air in g/kg.



The Psychrometric chart, as found frequently on the Internet in an edition of Carrier Corporation. This view is in SI-values and on sea level. There are other versions with USA values, but also on higher heights above sea level.

Westlandseweg 190
3131HX Vlaardingen
The Netherlands
T +31 10 460 81 45
info@24green.com
www.24green.com

What can the Psychrometric chart show us?

Some important parts of the Psychrometric chart are explained below.

The X and Y axes
The X-axis depicts the temperature in °C which is also known as the "Dry-bulb" temperature. The Y-axis represents the moisture content in the air in g/kg which is also known as Absolute Humidity (AH).

The saturation curve
The curve on the far left of the chart indicates the maximum water vapour content of the air in g/kg at every temperature. This line is known as the saturation curve.

Example 1
We find that the air at 30 °C may contain an approximate maximum of 27 g/kg of water vapour. At 0 °C it is only about 3.5 g/kg. This means that as saturated air of 30 °C is cooled to 0 °C, (27 - 3.5) = 23.5 grams of water vapour will need to be condensed.

The Relative Humidity (RH %) curves
A number of curved lines are marked with 90%, 80%, 70% and so on. The lines represent the relative humidity, or the RH in short, of the air at a specific temperature and humidity. The RH is the ratio of the actual moisture content to the maximum moisture content.

Example 2
At 20 °C, the air can contain an approximate maximum of 14.7 g/kg of water vapour. If the actual moisture content is 10 g/kg, then we show that with an RH of 10/14.7 * 100% = 68%.

Reading the Absolute Humidity (AH g/kg)
Conversely, the absolute moisture content of the air can therefore also be determined from the temperature and the RH. Suppose that the air temperature is 16 °C and the RH is 60%. From the graph, we are able to determine that the moisture content of the air is approximately 6.5 g/kg.

Note: g/m3 is an alternative unit of Absolute Humidity, which can be obtained by means of conversion. At 20 °C, the weight of 1 m3 of air is approximately 1.2 kg.

Reading the dew point (Td oC)
The dew point is the temperature at which the water vapour in the air starts to condense. This can be determined from the Psychrometric chart if the temperature and the RH are known.

Example 3
The air temperature is 21 °C and the RH = 80%. The moisture content is then about 12.5 g/kg. By going along the line on the left we find the point at which it intersects with the saturation curve and then read the corresponding temperature from the X-axis. This is the dew point and has a value of about 17.5 °C.

The energy content of the air (enthalpy) kJ/kg
Another property of air is its energy content, also known as enthalpy. This is expressed in kJ/kg (kilojoule / kilogram).

The energy content consists of two parts, namely perceptible energy and latent energy. The perceptible energy is the energy required to heat the air from 0 °C to its current temperature. The latent energy is the energy required to evaporate the water vapour present in the air. Completely dry air (RH = 0%) at a temperature of 0 °C therefore, by definition, has an energy content of 0 kJ/kg.

From the graph we find that the energy content of dry air at 20 °C is approximately 20 kJ/kg. The heating energy of dry air is therefore about 1 kJ/kg. The energy content of the same temperature and a moisture content of 15 g/kg is almost 60 kJ/kg, meaning that the evaporation of the 15 grams of water has taken approximately 60 - 20 = 40 kJ. This indicates that the latent part of the energy is often higher than the perceptible part. The energy content of the air is important in determining the ventilation capacity required for greenhouses. See the applications mentioned below.

If the structure of the greenhouse is colder than the dew point temperature then water vapour from the air condenses.

Application of the Psychrometric chart in regulating the greenhouse climate
Evapotranspiration of the plants plays an important role in controlling the environment for growth in the greenhouse. The plant needs evaporation not only to cool itself from the sun's excess radiation, but also to absorb nutrients from the soil. Due to plants' evapotranspiration, moisture occurs in the greenhouse. This can lead to problems if insufficient moisture is simultaneously eliminated from the roof of the glasshouse through condensation or by means of ventilation. Furthermore, the greenhouse temperature is important because the plants are not to become too cold nor too hot

Therefore, in practically any kind of climate control, the air temperature and the RH is measured in order to monitor and, if necessary, correct the conditions of the greenhouse. These measurements can, however, create a false impression of what is happening in the greenhouse.

In order to prevent the condensation of water vapour on the fruit, the absolute humidity in the greenhouse ought not to rise too quickly.

Westlandseweg 190
3131HX Vlaardingen
The Netherlands
T +31 10 460 81 45
info@24green.com
www.24green.com

Example 4
Suppose it is 16 °C with a RH value of 90% in the morning. The greenhouse is heated to 20 °C by solar radiation and the RH then decreases to 85%. One would have then thought that the moisture content in the greenhouse would decrease. However, a look at the Psychrometric chart shows something different. As it happens, the Absolute Humidity (AH) at 16 °C and 90% RH is approximately 10 g/kg. At 20 °C and 85% RH, the AH is nearly 12.5 g/kg. In reality, the humidity has not decreased, but rather has increased by 2.5 g/kg! As a result of the plants' evapotranspiration, more moisture is to be found in the air than has been dissipated.

This might not appear to be a problem, but it can become one if the air temperature increases rapidly due to solar radiation. Initially, the dew point of the air (16 °C and 90% RH) was equal to about 14 °C. Later on, the dew point (20 °C and 85% RH) had risen to 17.5 °C. The plants and large fruit, such as tomatoes, cucumbers or melons, in particular, heat up much less quickly at the bottom of the greenhouse where the solar radiation has less penetration, than the air temperature of the greenhouse. This causes the moisture in the greenhouse air to condense on the cooler plants and fruits, which can give rise to considerable damage because fungus and diseases, such as Botrytis, will develop rapidly as a result.

In order to prevent this, we must therefore ensure that the increase in the dew point of the air does not occur quicker than the warming of the cold plants and/or fruits. In particular, this means that the AH of the air in g/kg (or g/m3) ought not to increase too rapidly. This can be determined from the Psychrometric chart if the temperature and the RH are known.

If, at the end of the day, the greenhouse cools as the sun is setting then there should not be a problem. The plants and the fruit are subsequently heated up and they will usually cool down slower than the greenhouse air and thereby reduce the risk of condensation. Along with this, however, another risk comes into play: cooling due to long-wave heat radiation. This phenomenon is beyond the scope of this document and will not be commented on further.

There are also other situations where being acquainted with the Psychrometric chart is important in providing a good understanding of the workings of the greenhouse environment. One of these occurs at low exterior temperatures. It may happen that the exterior temperature is significantly lower than the greenhouse temperature and that the humidity outside is quite high.

Example 5
It is 18 °C with an RH of 70% inside the greenhouse and 5 °C with an RH of 70% outside. When the sun shines, some gardeners are inclined to open the ventilation windows a little in order to remove the moisture from plant evapotranspiration. They, however, expect it to be ineffective because both the indoor and the outdoor RH are equal to 70%. Nevertheless, in reality they notice than the RH in the greenhouse diminishes rapidly which is unfavourable for the growth environment. The explanation is of course that the Absolute Humidity inside is much higher than outside. It is approximately 9 g/kg at 18 °C and 70% RH. At 5 °C and 70% RH, the AH is approximately 3.5 g/kg. Even a small vent will allow a considerable amount of moisture to be eliminated from the greenhouse. When there is a large difference between the interior and exterior AH, ventilation ought to be done very carefully.

Example 6
A final situation concerns the calculation of the ventilation rate should the greenhouse become too hot due to solar radiation. We will use a simplified calculation example to show how this can be done.

Imagine that 500 W/m2 of energy is placed in the greenhouse through solar radiation. The temperature is 27 °C and the RH is 75% in the greenhouse. Outside, the temperature is 25 °C and the RH is 60%. The question we now ask is how much energy is lost by exchanging 1 kg of greenhouse air with 1 kg of outside air.

For this we need to calculate the energy content of the air. In the greenhouse, the energy content (enthalpy) is approximately 69 kJ/kg.

The energy content outside is approximately 55 kJ/kg. Therefore, (69-55) = 14 kJ/kg is lost by exchanging greenhouse air with outside air.

This means that per hour and per m2 of greenhouse surface a quantity of air equal to: 500 [W/m2] x 60 [sec] x 60 [min] / 14.000 [J/kg] = 128 [kg/m2.hrs] needs to be exchanged.

This quantity is equal to approximately 107 m3/m2.hour (divide by 1.2 kg/m3). In a 5 metre high greenhouse this means that the entire contents of the greenhouse will need to be completely replaced with outside air approximately 21 times an hour.

The Psychrometric chart shows us that the dissipation of energy through ventilation depends not only on the interior and exterior air temperature of the greenhouse, but also on the humidity both inside and outside. In fact, humidity often has a stronger influence than the temperature. Consequently, a high RH in the greenhouse together with and a low ventilation rate has the same effect on the greenhouse temperature as a low RH together with a high ventilation rate. However, a high RH together with plenty of solar radiation is more favourable for the plants. Many gardeners, however, are inclined to widely open the ventilation windows in hot weather because they fear that it will become too hot in the greenhouse.

Westlandseweg 190
3131HX Vlaardingen
The Netherlands
T +31 10 460 81 45
info@24green.com
www.24green.com

Conclusions and recommendations

The abovementioned examples show how applying the information given by the Psychrometric chart is important for controlling the greenhouse environment. It provides a better insight into what is actually happening in the transfer of moisture and energy in the greenhouse. The effects of taking specific measures also become much clearer. These effects sometimes are in direct opposition to what we "feel".

As a horticulturist, it is therefore worthwhile to gain more insight into the scientific background of the greenhouse environment and the relationship between temperature, humidity and energy, in particular, according to the Psychrometric chart.

The result is a higher production and better quality due to a better environment for plant growth, which includes less plant condensation problems and also less plant stress during intensive solar radiation.

> *"Every grower should know the Psychrometric chart by heart."*

We can use the Psychrometric chart to gain more insight into the physical processes in and around the greenhouse. But always having to read the chart is sometimes inconvenient.

It is therefore useful that various digital Psychrometric charts are available on the internet. These digital versions calculate all kinds of psychrometric data based on the temperature and humidity entered.

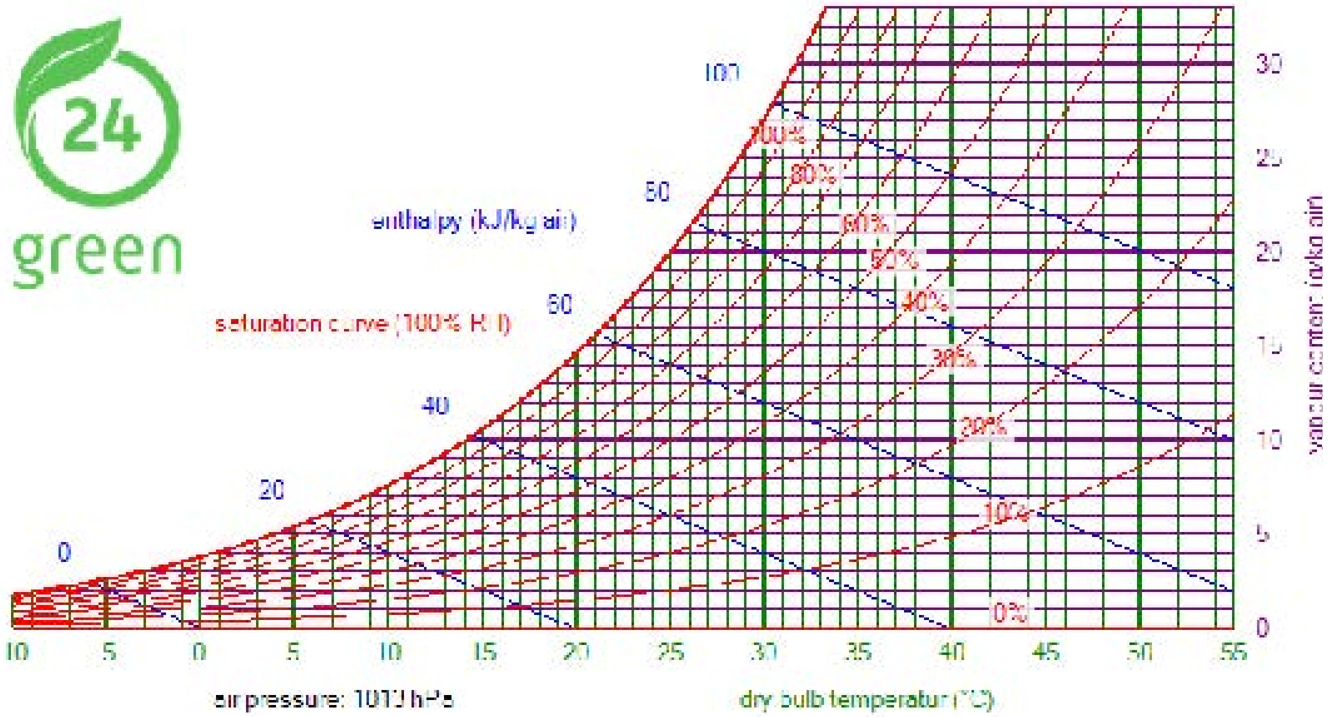
Unfortunately, these calculation programmes are not always intended for use in the agricultural sector, but rather for people working with refrigeration or air conditioning in office buildings, for example. They also sometimes operate in different units which makes them difficult to use.

A digital Psychrometric chart, specially developed for horticulture and greenhouse climate control can be found on the LetsGrow.com website (reference 3). This digital psychrometric chart can be used to separately calculate the data in the greenhouse, outside, and even relating to the plant as well as any differences. An example is the difference between interior and exterior absolute humidity. It, therefore, provides many insights into climate control.

An application derived from it has been made available by the innovative company 24green.com: the PsychroCalc App. Because this psychrometric chart runs on so-called App technology, it is available on your PC and/or Smartphone anytime and anywhere and is quite handy for everyday use (reference 4).

Westlandseweg 190
3131HX Vlaardingen
The Netherlands
T +31 10 460 81 45
info@24green.com
www.24green.com

PsychroCalc app
The PsychroCalc App makes it possible to enter temperature and humidity in and outside the greenhouse. As a result a number of data like AH, dew point and enthalpy, are shown. The difference between greenhouse air and outdoor air are automatically calculated.



Westlandseweg 190
3131HX Vlaardingen
The Netherlands
T +31 10 460 81 45
info@24green.com
www.24green.com

About the author

Mr J. (Jan) O. Voogt has a vast experience on automatic control of both climate and irrigation in greenhouses. In 1978 he graduated at the Technical University of Delft The Netherlands on electronics and sensor technology During more than twenty years he has been involved in the development of hardware and software for climate control systems at Hoogendoorn Growth Management, the world's first and most innovative company in the field of computerized greenhouse process control. From 2004 on, his special fields of interest are the physical backgrounds of plant behaviour and the interaction with climate conditions based on the water and energy balance. He is one of the leading researchers and consultants in the current transition of the Dutch greenhouse industry towards "The next generation cultivation" which combines better yields and quality of the crops with lower energy and water consumption.

References

Ref 1) Wikipedia ; background information on the Psychrometric chart
en.wikipedia.org/wiki/Psychrometrics

Ref 2) Wikipedia ; about Richard Mollier and the Mollier diagram
en.wikipedia.org/wiki/Richard_Mollier

Ref 3) Digital Psychrometric chart on internet by LetsGrow.com
hnt.letsgrow.com/psychro

Ref 4) PsychroCalc app
24green.com/product-category/apps/

Westlandseweg 190
3131HX Vlaardingen
The Netherlands

T +31 10 460 81 45
info@24green.com

www.24green.com