

Understanding Humidity Control in Greenhouses

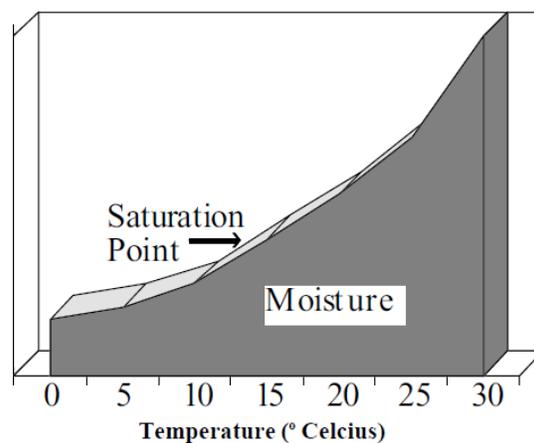
INTRODUCTION

Humidity can be the most difficult environmental factor to control in greenhouses. Maintaining setpoints and correcting for too little or too much humidity can be a challenge for even the most sophisticated monitoring and control equipment. Humidity levels fluctuate with changes in air temperature, and plants are constantly adding water to the air through transpiration. Although automated controls have added a higher level of precision to the art of sensing and correcting humidity levels, it is still important to have a good understanding of the dynamics of atmospheric water vapour. There is a natural tendency with sophisticated equipment to just 'set it and forget it'. However, lost yields, plant stress, disease outbreaks and wasted energy are still possible unless we realize the limitations of our equipment and the implications of environmental control decisions.

What is Humidity?

Humidity is an expression of the amount of water vapour in air. It is an invisible gas that accounts for 1% to 4% by volume of the atmosphere. Fogs, mists and other tiny water droplets are not water vapour. The maximum amount of water vapour in any given air sample is dependent on the temperature and to a lesser extent the air pressure (see Figure 1). The actual amount of water vapour present is also determined by the availability of free water to evaporate. Water vapour will always move from an area of high concentration (such as inside the leaf cavities) to an area of lower concentration (the greenhouse air). This is the principle behind evaporative transpiration.

Figure 1. The relationship between temperature and the maximum moisture content of air.

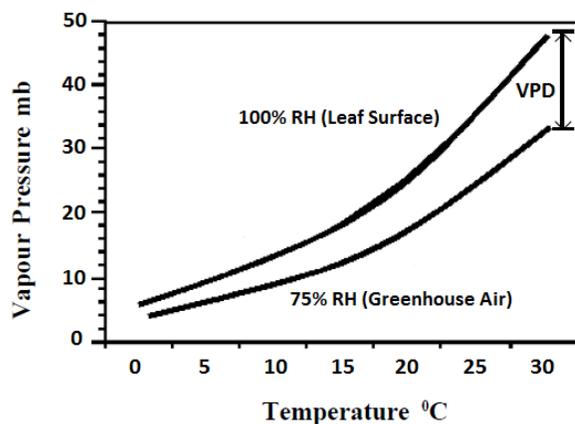


We usually talk of air moisture in terms of relative humidity. Because the absolute amount of water that can be held by air fluctuates with temperature, relative humidity is a handy way to describe the ratio of water vapour compared to the total amount of water that could be held in the air at saturation. Therefore, 50% relative humidity indicates that the air has half the water vapour that it could hold if it were completely saturated. As the air temperature rises, more water vapour can be held in a given amount of air. And as the air becomes warmer, more moisture must be added to the air to maintain the same relative humidity.

What is Vapour Pressure Deficit?

Relative humidity is still the most commonly used measurement for greenhouse control, even though it is not a perfect indication of what the plants 'feel'. Plants respond to the difference between humidity levels at the leaf stomata and the humidity levels of the surrounding air. At the same relative humidity level, but at different temperatures, the transpiration demand for water from the leaves may be double (see Figure 2).

Figure 2. Vapour Pressure Deficit (VPD) increases with temperature, even when the relative humidity remains constant.



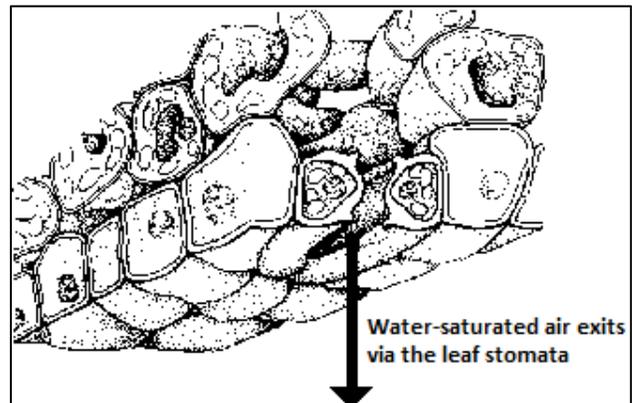
Another measurement called the Vapour Pressure Deficit (VPD) is often used to measure plant:air moisture relationships. The VPD equals the difference in the amount of water vapour in the leaf (always assumed to

be 100% RH) and the outside air. Environmental control companies offer VPD measurements as a part of their humidity management programs.

Role of Humidity

The main plant mechanism to cope with humidity is the adjustment of the leaf stomata. Stomata are pores in the underside of the leaf that open and close in response to vapour pressure deficit. When humidity levels drop to about 8 grams/m³ (12 mb VPD) the stomata apertures on most plants close to about 50% to help guard against wilting. This also reduces the exchange of CO₂, thereby negatively affecting photosynthesis.

Figure 3. Water vapour exits through pores called stomata on the underside of the leaf. There is a direct relationship between the VPD and the rate of transpiration or water loss from the plant.



Transpiration - Plants can control the rate of water loss by opening and closing the leaf pores or stomata. Because the leaf stomata have an ability to limit transpiration rates, a doubling of the moisture deficit may result in only a 15% increase in the transpiration rate. However, when humidity levels are very high, the total uptake of minerals is reduced since plants are unable to evaporate enough water to sustain adequate transpiration.

- **Photosynthesis** - Humidity levels indirectly affect the rate of photosynthesis because CO₂ is absorbed through the stomatal openings. At higher daytime humidity levels, the stomata are fully open, which allows more CO₂ to be absorbed for photosynthesis. Photosynthetic levels can vary by about 5% between VPD's of 2 to 10 mb.
- **Growth and Quality** - Most greenhouse plants tend to grow better at higher relative humidities. However, mineral deficiencies, disease outbreaks, smaller root systems and softer growth are possible consequences of excess humidity. There is no one level of humidity that is good for all crops.

Dehumidification

Greenhouse growers usually try to avoid humidity levels near the dew point since free water condensing onto plant surfaces can promote the growth of disease organisms. Under saturated humidity conditions plants cannot evaporate water from their leaves so the uptake of nutrients may be limited. It is important to remember that when the relative humidity reaches 90%, it takes only a slight drop in temperature to reach the dew point. The problem is compounded by the fact that not all surfaces in the greenhouse are necessarily at the same temperature as the air. Any surfaces that are cooler than the air will condense water vapour at high relative humidities. That is why dripping can be such a problem with glazing materials during the heating season.

Monitoring and controlling the relative humidity of the greenhouse air is not always a guarantee that the dew point will be avoided. Local condensation problems can still occur due to uneven heat distribution and the thermal mass of plant materials, particularly on plants with fruits. This causes their surface temperatures to lag behind when sudden changes in air temperature occur. It's the same reason a glass of ice water sweats even when the relative humidity of the room air is well below the dew point. Cold surfaces

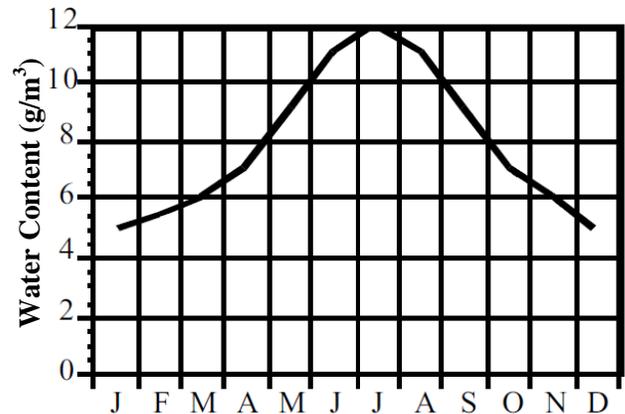
within the greenhouse cool the air immediately surrounding them. If the cooling reaches the dew point temperature, water condensation will occur.

Excess humidity is usually more problematic in the spring and fall seasons when the weather is cool and moist (see Figure 4). High humidity is not likely to occur during freezing weather, since the relative humidity of the outside air is very low. The common strategy used to reduce greenhouse humidity involves:

- venting to exchange moist greenhouse air with drier outside air, and
- heating to reduce the relative humidity levels, raise the temperature of plant surfaces and warm the incoming air.

Glass panes and other cold surfaces in the greenhouse serve as natural dehumidifiers when the outside air is colder, but this can cause problems with dripping.

Figure 4. Average monthly water content of outdoor air (grams of water per m³)



There are several steps you can take to help avoid crop condensation problems:

- ✓ Make sure your temperature and humidity sensors are accurate and located in the crop canopy. Test your temperature sensors regularly against an accurate thermometer. Bring various humidity sensors to one and observe whether they have the same readings. Relative humidity can be checked with a sling psychrometer.

- ✓ Use thermal screens at night to prevent radiative heat loss from plant surfaces.
- ✓ Avoid sudden temperature elevations at sunrise by programming a gradual pre-dawn temperature rise and dehumidification period. (Sudden temperature drops can cause condensation problems as well, particularly on cold glazing materials as the capacity of the air to hold water decreases. However, in this case, thermal lag should prevent condensation on plant surfaces, at least temporarily.)
- ✓ Place radiant heat sources near the crop to keep plant surfaces close to or slightly warmer than air temperature.
- ✓ Use horizontal air flow fans or poly tubes to maintain a uniform temperature throughout the crop.
- ✓ Use a combination of venting and heating to reduce excessive humidity.
- ✓ Start dehumidifying at or about 85% RH. Relative humidity levels above 85% are not easily managed without increasing the risk of condensation and interference of nutrient uptake due to a lack of transpiration.

Humidification

Although dehumidification is sometimes expensive, it is usually easier to reduce humidity levels than to increase them. Raising humidity levels without creating excessive free water requires an evaporative device such as a mister, fog unit, or roof sprinkler, or screens that help hold in the water that is being evaporated from the plant canopy. Evaporative cooling and screening are often used together.

Evaporative devices accomplish 3 things. First, they cool the air and thereby raise the humidity and relieve stress on the crop. Second, they add water vapour to the air, which further increases the relative humidity. And third, they reduce the VPD. Systems should be sized to permit a VPD of no greater

than 7 grams/m³ when operated in conjunction with a transpiring crop.

Many evaporative cooling and humidifying systems are available. Roof sprinklers add water vapour and cool the incoming air. On large ranges, it is possible to decrease the temperature by 3°C to 5°C and increase the humidity 5% to 10%. Pad and fan systems consist of porous wet pads at the inlet end of a fan ventilated greenhouse. As the exhaust fans draw outside air through the wet pads, the air is cooled and humidified through evaporation. Temperatures tend to be coolest nearer the fans and hottest at the exhaust when using these systems. Mist and fog systems produce tiny water droplets that evaporate, thereby cooling and humidifying the greenhouse air.

Screens can be used to reduce leaf temperature and help to trap the large amount of water evaporating from the crop. Impermeable moisture screens maintain a higher humidity and can reduce night time transpiration rates by about 20% under low overall humidity and by about 60% when humidity is already high. They are normally employed in the winter months when crops are young, and humidity levels are very low. In contrast, permeable screens block heat transport but allow moisture to escape. Plants under sun screens (shade cloth) tend to have lower transpiration needs due to less radiation heating. However, humidity levels are not significantly affected, since there is a corresponding reduction in transpiration rate. It is important to remember that crops vary in their ability to benefit from sun screens.

It has been suggested that limiting the ventilation rate under full sun conditions can reduce plant stress by raising the humidity level. Although transpiration rates are reduced initially, the rapid increase in air and leaf temperatures causes an increase in the VPD and the transpiration rates climb again. In this case, the only alternative is to increase the ventilation rate and provide additional cooling/humidification by fogging, roof sprinkling, etc. In general, some venting is necessary when humidifying under sunny

conditions. Venting will introduce fresh dry air to evaporate more water, and to cool, humidify and displace hot greenhouse air.

Anyone who has stood in an empty greenhouse on a hot summer's day will know that plants alone can do an excellent job of cooling and humidifying a greenhouse. Evaporative cooling equipment works with the plants, helping relieve some of the transpirational stress and allow them to grow at optimum rates. The benefits of maintaining a humidification set point include: better plant quality, faster cropping, and lower disease and insect problems.

Points to remember about humidification:

- ✓ Plants are the primary humidifiers/coolers of greenhouse air. Ensure adequate irrigation for evapotranspiration needs on hot days.
- ✓ Greenhouses with sealed floors tend to be drier because evaporation from the soil is prevented.
- ✓ Heat and humidity levels are easier to manage in taller greenhouses due to the larger volume of air.
- ✓ If wetting of floors or foliage occurs, stop humidifying in the late afternoon or early evening to allow enough time for drying.
- ✓ Evaporative cooling depends upon the total amount of water that can be evaporated. Evaporative cooling systems must therefore be engineering with water output needs in mind.
- ✓ Evaporative cooling devices require good ventilation rates. It is the evaporative process that does the cooling. Fresh air must be continually introduced and warm, humidified air exhausted.
- ✓ Accurate sensors for leaf and air temperature, as well as an accurate relative humidity sensor, are required to measure leaf vapour pressure deficit.

Water Vapour Basics

There are a bewildering number of terms and measurement units used in the discussion of humidity. Here are a few you may encounter:

Relative Humidity - The maximum amount of water that can be present in air as a vapour depends on the temperature of the air (assuming constant pressure). That is why we use the term relative humidity - it's a measure of water vapour capacity relative to the air temperature. As the air temperature rises, its capacity to hold water also increases. Therefore, warm air can hold a lot more water than cold air. Relative humidity is a measure, in percent, of the vapour in the air compared to the total amount of vapour that could be held in the air at a given temperature.

Dew-Point Temperature - At any given temperature and pressure, there is a maximum amount of water that can be held in the air. This is known as the saturation point. At any time when the air is nearly saturated with water vapour, all it takes is a slight drop in temperature to reach the dewpoint. At this point, liquid water begins to condense on surfaces. This is also the phenomenon responsible for rainfall. The higher the moisture content of the air, the higher the dewpoint temperature.

Absolute Humidity - Absolute humidity is a ratio of the weight of water vapour contained in a given weight of dry air. It is used in the calculation of relative humidity.

Dry Bulb Temperature - When you measure the air temperature using an ordinary thermometer, this is called dry bulb temperature. It is independent of the amount of moisture contained in the air.

Wet Bulb Temperature - A wet bulb temperature reading is obtained by measuring the degree of cooling effect, if any, on a thermometer wrapped in a wet cloth. Whenever the relative humidity is below 100% a certain amount of evaporative cooling will occur on a wet bulb producing a lower temperature than the dry bulb reading. At 100% relative humidity, the wet and dry bulb temperatures are equal because no

further evaporation is possible. The lower the relative humidity, the greater the temperature drop measured on the wet bulb. By knowing both the wet and dry bulb temperatures, it is possible to determine the relative humidity of an air-vapour mixture.

Enthalpy - Though not as important in humidity determinations, enthalpy describes the amount of heat contained in an air vapour mixture. It is used in heating and cooling calculations, since it takes more energy to raise or lower the temperature of moist air than dry air. Also, when moist air condenses onto greenhouse surfaces, it gives up a considerable amount of heat due to the latent heat of vapourization. Similarly, when water is evaporated from surfaces, it has a cooling effect on the air as well as adding to the humidity. Greenhouse evaporative cooling devices operate on this principle.

Sling Psychrometer (or Whirling Hygrometer) - A sling psychrometer is a wet bulb/dry bulb combination that is whirled about vigorously in the air. The resulting wet bulb temperature depression is then compared to a table of relative humidity values.

Vapour Pressure - All gasses in the air exert a pressure. The combination of these gasses, which includes water vapour, produces a pressure at sea level of 1013 millibars. Water vapour pressure accounts for about 2 mb of pressure under extremely dry and cold conditions to about 42 mb of pressure at 30°C and 100% RH.

Vapour Pressure Deficit - A measure of the atmospheric demand for water. Any time the humidity is below 100%, liquid water will evaporate. The lower the relative humidity, the greater the demand or rate of evaporation. Vapour pressure deficit measures the difference between the amount of water vapour that can be held in saturated air at a given temperature, and the actual amount of water that is held in a sample of air that is not saturated. VPD units are sometimes expressed in pressure units (millibars, kilo pascals, or pounds per square inch) or mass deficit concentration units (grams of water

per cubic meter of dry air, or grams of water per kilogram of dry air). Mass deficit is sometimes called humidity deficit. The air/water vapour mixture leaving the leaf stomata is always assumed to be at saturation. Consequently, it is the VPD of the surrounding greenhouse air compared to the leaf surface that causes water to evaporate. The greater the VPD, the greater the evaporative demand. VPD's for growing crops can only be calculated accurately when the surface temperature of the leaves is known.

Units and Equivalents used in Air and Humidity Measurement

1 atmosphere	=	14.696 pounds per square inch (psi) at sea level
	=	1.033 kilograms per square centimeter (kg/m ²)
	=	1013 millibars (Mb)
	=	101.3 kilopascals (kpa)
	=	760 millimeters of mercury (mm Hg)
	=	29.92 inches of mercury (in. Hg)
	=	the standard value for air pressure at sea level
1 millibar	=	0.1 kilopascals
	=	100 pascals
1 kilopascal	=	10 millibars
	=	1000 newtons/square meter
	=	1000 pascals
1 psi	=	68.95 mb
1 torr	=	1 mm Hg
1 pascal	=	1 newton/square meter
mass deficit (MD) g/kg	=	VPD (kpa) x 6.3

Table 1. Vapour Pressure of Water in Millibars at Various Temperatures and Relative Humidity Levels

Temp °C	Relative Humidity										
	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
15	17.0	16.2	15.3	14.5	13.6	12.8	11.9	11.1	10.2	9.4	8.5
16	18.2	17.3	16.4	15.4	14.5	13.6	12.7	11.8	10.9	10.0	9.1
17	19.4	18.4	17.4	16.5	15.5	14.5	13.6	12.6	11.6	10.6	9.7
18	20.6	19.6	18.6	17.5	16.5	15.5	14.4	13.4	12.4	11.3	10.3
19	22.0	20.9	19.8	18.7	17.6	16.5	15.4	14.3	13.2	12.1	11.0
20	23.4	22.2	21.0	19.9	18.7	17.5	16.4	15.2	14.0	12.8	11.7
21	24.8	23.5	22.4	21.1	19.9	18.6	17.4	16.2	14.9	13.7	12.4
22	26.4	25.1	23.8	22.5	21.1	19.8	18.5	17.2	15.9	14.5	13.2
23	28.1	26.7	25.3	23.9	22.5	21.1	19.6	18.2	16.8	15.4	14.0
24	29.8	28.3	26.8	25.3	23.9	22.4	20.9	19.4	17.9	16.4	14.9
25	31.7	30.1	28.5	26.9	25.3	23.7	22.2	20.6	19.0	17.4	15.8
26	33.6	31.9	30.2	28.5	26.9	25.2	23.5	21.8	20.2	18.5	16.8
27	35.6	33.8	32.1	30.3	28.5	26.7	24.9	23.2	21.4	19.6	17.8
28	37.8	35.9	34.0	32.1	30.2	28.3	26.4	24.5	22.7	20.8	18.9
29	40.0	38.0	36.0	34.0	32.0	30.0	28.0	26.0	24.0	22.0	20.0
30	42.4	40.3	38.2	36.0	33.9	31.8	29.7	27.6	25.4	23.3	21.2

To find the Leaf Vapour Pressure Deficit:

1. Measure the leaf temperature and look up the vapour pressure at 100% RH on the above table
2. Measure the air temperature and RH and look up the nearest vapour pressure figure.
3. Subtract the air pressure from the leaf vapour pressure.

Example: Leaf Temperature = 25°C (100% RH) Leaf VP: 31.7
 Air Temperature = 24°C @ 65% RH Air VP: 19.4
 VPD 12.3

Table 2. Vapour Pressure Deficit in Millibars at Various Temperatures and Humidity Levels

Temp °C	Relative Humidity										
	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
15	0.0	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6	8.5
16	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1
17	0.0	1.0	2.0	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7
18	0.0	1.0	2.0	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3
19	0.0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0
20	0.0	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7
21	0.0	1.2	2.4	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.4
22	0.0	1.3	2.6	3.9	5.3	6.6	7.9	9.2	10.5	11.9	13.2
23	0.0	1.4	2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1
24	0.0	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9	13.4	14.9
25	0.0	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9
26	0.0	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.4	15.1	16.8
27	0.0	1.8	3.5	5.3	7.1	8.9	10.7	12.4	14.2	16.0	17.8
28	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.1	17.0	18.9
29	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
30	0.0	2.1	4.2	6.4	8.5	10.6	12.7	14.8	17.0	19.1	21.2

Table 2 depicts a humidity control strategy based on vapour pressure deficit (VPD). A VPD between 8 and 10 millibars (the middle shaded area) has been chosen as ideal. About 4.5 mb and below (shaded area at the left) is the setpoint for active dehumidification. VPD's over 12.5 (shaded area at the bottom right) will trigger humidification devices such as fog systems. Notice that relative humidity alone is not a good indicator of the vapour pressure stress on plants.