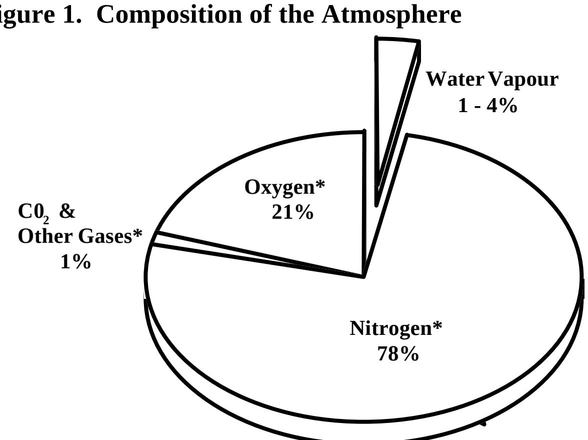
Understanding Humidity Control in Greenhouses

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 as possible as ever 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 varies between 1 - 4% of our atmosphere by volume (see Figure 1). Fogs, mists, and other tiny water droplets are not water vapour.

Figure 1. Composition of the Atmosphere



*** % in dry air**

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 #2). 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.

Floriculture FACTSHEET

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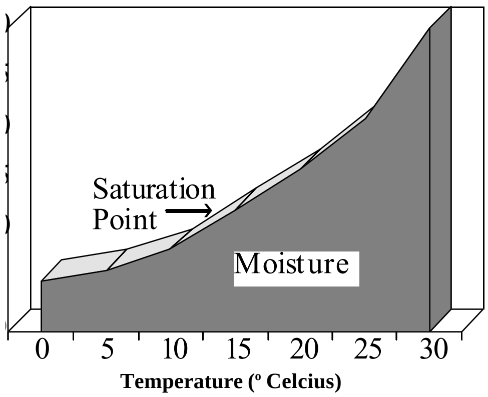
Figure 2. The maximum moisture content of air increases as temperatures increases.

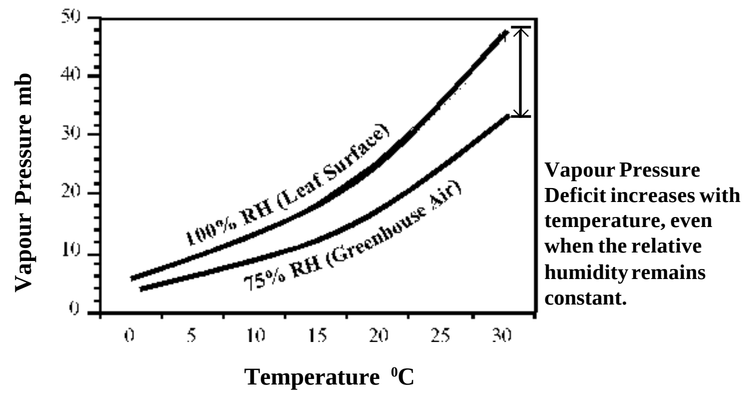


We usually talk of air moisture in terms of relative humidity. Because the absolute amount of water that can be held by air is constantly fluctuating with temperature, relative humidity is a handy way of describing the ratio of water vapour compared to the total amount of water that could be held in 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 the leaf stomata and the humidity levels of the surrounding air. At the same relative humidity levels, but at different temperatures, the transpiration demand for water from the leaves may be double (See Figure 3.) Therefore, another kind of measurement, called the Vapour Pressure Deficit is often used to measure plant/air moisture relationships. Some environmental control companies now offer VPD measurements as a part of their humidity management programs.

Figure 3. Vapour Pressure Deficit

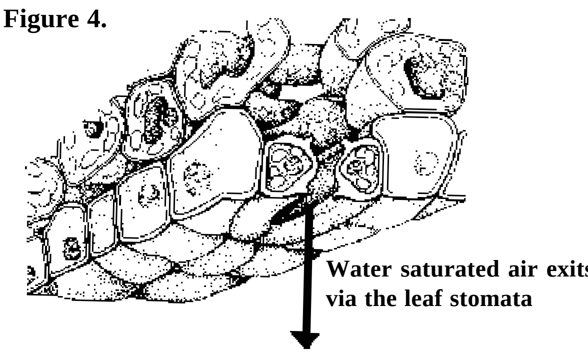


Tables 1 & 2 (See Page 8) outline vapour pressure deficits (the difference between saturated air and air at various relative humidities). Although different crops vary in their response to humidity levels, a VPD range of 8 - 10 mb has been suggested as an optimum range. VPD can be used for both dehumidifying and humidifying, but it is particularly useful for humidifying.

Role of Humidity

The main plant mechanism for coping with humidity is the adjustment of the leaf stomata. Stomata open and close in response to vapour pressure deficit, opening wider as humidity increases. When humidity levels drop to about 8 grams/m^3 (12 mb VPD) the stomata apertures on most plants close to about 50% to help guard against wilting. This also reduces the exchange of $C0_2$, thereby affecting photosynthesis.

Figure 4.



The difference in the amount of water vapour in the leaf (always assumed to be saturated or 100% RH) and the outside air is the VPD (Vapour Pressure Deficit). The higher the VPD, the greater the evaporation rate.

- **Transpiration** - Plants can control their rate of water loss. 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.

- **Photosynthesis** - Humidity levels indirectly affect the rate of photosynthesis because $C0_2$ is absorbed through the stomatal openings. At higher daytime humidity levels, the stomata are fully opened allowing more $C0_2$ to be absorbed for photosynthesis. Photosynthetic levels can vary by about 5% between VPD's of 2-10 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.

Quality Problems Due to Humidity

Too Low	**Too High**
Dry Tip Burn	Oedema
Wilting	Edge Burn (Guttation)
Small Leaves	Soft Growth
Stunted Plants	Mineral Deficiencies
Spider Mites	Disease Outbreaks
Leaf Curl	

Dehumidification

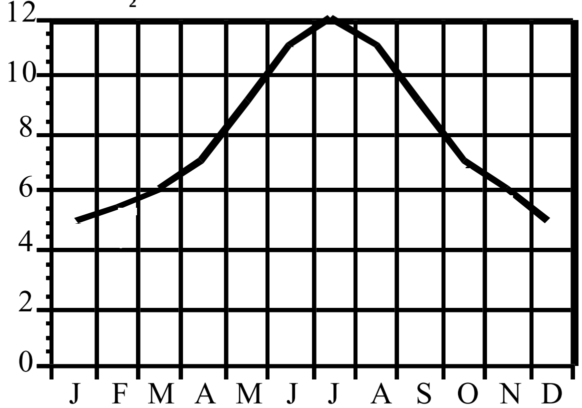
In greenhouses, we usually try to avoid humidity levels near the dewpoint***** since free water condensing onto plant surfaces can promote the growth of disease organisms. Under saturated humidity conditions plants cannot evaporate water from their leaves so the uptake of nutrients such as calcium and boron 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 dewpoint. 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 at high relative humidities will condense water vapour. 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 and other large waterfilled parts. 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 dewpoint. Cold surfaces within the greenhouse cool the air immediately surrounding them. If the cooling reaches the dewpoint temperature, water condensation occurs.

Excess humidity is usually more problematic in the spring and fall seasons when the weather is cool and moist. (See Figure 5.) High humidities are not likely to occur during freezing weather, since the relative humidity of the outside air is very low. A combination strategy of venting to exchange moist air with drier outside air, and heating to reduce the relative humidity levels, raise the temperature of plant surfaces, and warm the incoming air is usually employed. Glass panes and other cold surfaces in the greenhouse serve as natural dehumidifiers when the outside air is colder, but this, of course, can cause problems with dripping.

*** See page 6.**

Figure 5.
Average Monthly Water Content of Outdoor Air
H_20 Grams/m^3



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 spot to see that they are the same. 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 sunup 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 as close as possible to or slightly warmer than air temperatures.
- ✓ Use horizontal air flow fans or poly tubes to maintain even temperatures throughout the crop.
- ✓ Use a combination of venting and heating to reduce excessive humidities.
- ✓ Start dehumidifying at or about 85% RH. Relative humidities above this level are not easily managed without an increased risk of condensation problems and nutrient uptake interference due to inactive plants (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 some sort of evaporative device such as misters, fog units, or roof sprinklers, all of which add water vapour to the air, or screens that help hold in the water that is being evaporated from the plant canopy.

Evaporative devices accomplish 3 things: first, they cool the air, raising the humidity and relieving stress on the crop. Second, they add water vapour to the air, further increasing the relative humidity. And third, they reduce the vapour pressure deficit which is the force that evaporates water from the leaves. Screens may also reduce leaf temperatures and help to trap the large amount of water that the plants are evaporating. Evaporative cooling and screening are often used together. When humidifying under sunny conditions, some venting is necessary since the greenhouse would soon become a steam bath without the introduction of 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, knows that plants, by themselves, 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 allowing 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.

*** See Page 6.**

Using Screens

Impermeable moisture screens maintain higher humidities and can reduce night time transpiration rates by about 20% under low overall humidities and by about 60% when humidities are already high. They are normally employed in the winter months when crops are young, and humidity levels are very low.

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.

Closing vents during full sun to increase humidity

It has been suggested that limiting the ventilation rate under full sun conditions may actually reduce plant stress by raising humidity levels. Although at first, transpiration rates are reduced, 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.

Fogs, Mists, Roof Sprinklers, and Pan & Fan Systems

Many evaporative cooling and humidifying systems are available. They add water vapour to the air, and may subsequently reduce the amount of water that the plants need to transpire. Systems should be sized to permit a vapour pressure deficit of no greater than 7 grams/m^3 (11 millibars) when operated in conjunction with a transpiring crop.

Roof sprinklers add water vapour and cool the incoming air. On large ranges, it is possible to decrease the temperature by 3 - 5^{o}C and increase the humidity 5-10%. Pad and fan systems consist of porous wet pads at the inlet end of a fan ventilated greenhouse. As the exhaust fans draw air through the wet pads, water evaporates, cooling and humidifying the air. 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.

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, since evaporation from the soil is prevented.

- ✓ Heat and humidity levels are easier to manage in taller greenhouses.

- ✓ 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.

- ✓ To measure leaf vapour pressure deficit, accurate sensors for leaf and air temperature, as well as an accurate relative humidity sensor, are required.

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 independant 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 on the wet bulb. So by knowing both the wet and dry bulb temperatures, it is possible to determine the relative humidity of an air-vapour mixture. (See Figure 6, Page 7)

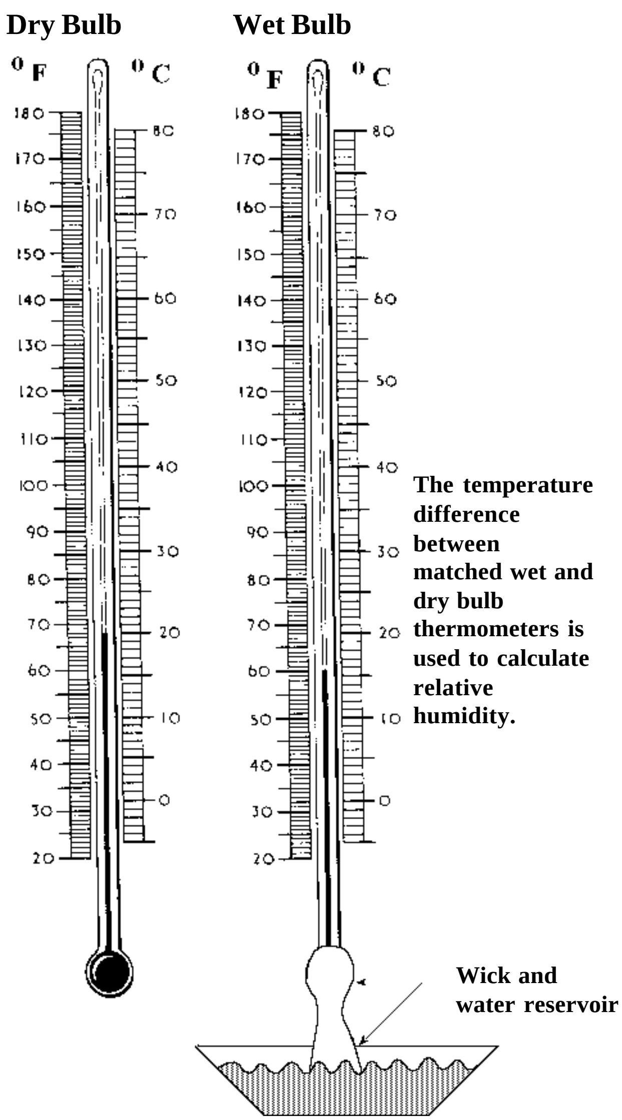
Enthalpy
Though not as important in humidity determinations, enthalpy describes the amount of heat contained in an air vapour mixture. It is used in heating and cooling calculations, since it takes more energy to raise or lower the temperature of moist air than dry air. Also, when moist air condenses 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 theses gasses including water vapour produce 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^{o}C and 100% RH.

Vapour Pressure Deficit
A measure of the atmospheric demand for water. At 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 temperatures of the leaves is known.

Figure 6.



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	=	.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 Humidities

Relative Humidity

Temp C	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	23.6	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 relative humidity and look up the nearest vapour pressure figure.
3. Subtract the air vapour pressure from the leaf vapour pressure

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

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

Relative Humidity

Temp C	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. 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.