THE OHIO STATE UNIVERSITY EXTENSION

Extension FactSheet

AEX–804

Food, Agricultural and Biological Engineering, 1680 Madison Ave., Wooster, OH 44691

Greenhouse Condensation Control

Understanding and Using Vapor Pressure Deficit (VPD)

Jessica J. Prenger
Research Engineer

Peter P. Ling
Assistant Professor

Vapor pressure deficit (VPD) is a valuable way to measure greenhouse climate. VPD can be used to evaluate the disease threat, condensation potential, and irrigation needs of a greenhouse crop. An important step toward disease management is to prevent conditions that promote disease. Condensation prevention is important, since greenhouse pathogens often require a water film on the plant to develop and infect (see also Greenhouse Condensation Control Fact Sheet series AEX-800, 801, 802, 803). VPD can help identify when condensation is likely to occur. This fact sheet explains how VPD relates to relative humidity, temperature, and condensation potential, and how to apply this assessment tool for greenhouse disease management.

What does Vapor Pressure Deficit mean?

Removing moisture in a greenhouse is done with dehumidification, a process that adjusts the balance of water in the air and on greenhouse surfaces. Vapor pressure deficit (VPD) is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated. VPD functions as a convenient indicator of the condensation potential because it quantifies how close the greenhouse air is to *saturation*. The air is saturated when it reaches maximum water holding capacity at a given temperature (also called the dew point). Adding moisture to air beyond its holding capacity leads to deposition of liquid water somewhere in the system. *Vapor pressure* (vp_{air}) is a measurement of how much water vapor is in the air, that is, how much water in the gas form is present in the air. More water vapor in the air means greater water vapor pressure. When the air reaches maximum water vapor content, the vapor pressure is called the saturation vapor pressure (vp_{sat}), which is directly related to temperature. Thus, the difference between the saturation vapor pressure and the actual air vapor pressure ($vp_{sat} - vp_{air}$) is the mathematical definition of VPD. The size of the VPD gives an indication of how close to condensation, and subsequently to disease, the greenhouse environment is operating.

VPD can be used to identify healthy air moisture conditions for plant production, while taking into account different temperature levels.

Vapor Pressure Deficit

Advantages

- ➢ Expresses condensation threat explicitly, rather than as humidity range that changes with temperature
- ➢ Describes water vapor transfer from the plant canopy, identifying crop water needs

Calculation

- ➢ $VPD = VP_{sat} - VP_{air}$ VP – vapor pressure
  - Use the chart in Figure 2 to calculate VPD, or
  - Use a spreadsheet to calculate VPD using equations on page 3

Application

- ➢ Use VPD threshold (page 3) to evaluate whether to dehumidify
- ➢ Track VPD conditions (using a spreadsheet program) to estimate disease risk
- ➢ Understand VPD use in irrigation scheduling

How does VPD compare to relative humidity?

Figure 1 shows how VPD relates to the customary thinking about humidity. *Higher* VPD means that the air has a higher capacity to hold water, stimulating water vapor transfer (transpiration) into the air in this *low humidity* condition. *Lower* VPD, on the other hand, means the air is at or near saturation, so the air cannot accept moisture from the leaf in this *high humidity* condition.

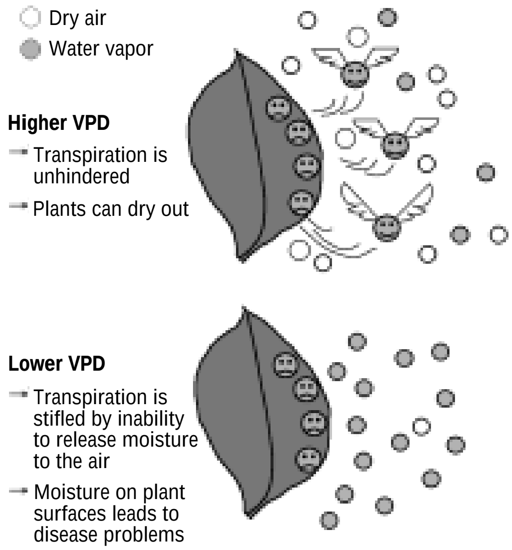

Figure 1. Vapor Pressure Deficit (VPD) enhances or inhibits the crop's ability to transpire.

Therefore, vapor pressure deficit is a useful way to express the vapor flow in the system, both for condensation and transpiration. Higher VPD increases the transpirational demand, influencing how much moisture from plant tissues is transferred into the greenhouse air. Consequently, VPD is being used to predict crop water needs in some commercial irrigation systems. In contrast, very low VPD indicates closer proximity to the dew point, meaning harmful condensation can begin to develop. Using the canopy temperature to determine VPD gives the best indication of condensation risk, showing particularly how close the canopy is to the dew point.

VPD calculation is an improvement over relative humidity (RH) measurement alone because VPD takes into account the effect of temperature on the water holding capacity of the air, which roughly doubles with every 20°F increase in temperature. Rather than giving a *relative* measure of the water content of the air, VPD gives an absolute measure of how much more water the air can hold, and how close it is to saturation. For example, a typical 100' long x 30' wide x 10' high greenhouse with 80% relative humidity has about 14 lb of water in the air at 50°F, while 70°F air holds about 28 lb of water at the same RH. This is reflected in the VPD values of 0.036 psi (0.25 kPa) and 0.072 psi (0.50 kPa), for the lower and higher temperature conditions, respectively (see Figure 2). Thus, VPD can be used to identify healthy air moisture conditions for plant production, while taking into account different temperature levels.

How can VPD be used in greenhouses?

The effects of greenhouse climate measurements on plant health and growth have been studied intensively. VPD can be used to identify disease-causing climate conditions. For example, several studies that explore disease pathogen survival at different climate levels reveal two critical values of VPD. Studies show that fungal pathogens survive best below 0.062 psi VPD (<0.43 kPa). Furthermore, disease infection is most damaging below 0.030 psi (0.20 kPa). Thus, the greenhouse climate should be kept *above* 0.030 psi (0.20 kPa), to prevent disease and damage to crops. Note that the climate control situation must be reevaluated when *biological control agents* are being used in the greenhouse, as these organisms require specific VPD conditions for growth and distribution. Table 1 shows a summary of the relative humidity thresholds at several temperatures, which correspond to the 0.030 psi (0.20 kPa) VPD disease prevention threshold.

Table 1. Relative humidity thresholds for disease prevention, corresponding to 0.030 psi (0.20 kPa) VPD.

Temperature °F	Temperature °C	Relative Humidity Threshold
50.0	10	83.0%
60.8	16	89.0%
68.0	20	91.5%
86.0	30	95.5%

How is VPD calculated?

There are two procedures that can be used to calculate VPD: (1) use a chart, and (2) use equations. Figure 2 shows a modified psychrometric chart of vapor pressure for a range of temperatures and a number of relative humidities. The chart can be used to find the VPD with the following procedure, and the equation calculation procedure follows.

To use the chart:

1) Measure air temperature and relative humidity inside the greenhouse. If possible, also measure air temperature within the plant canopy.
2) Find the temperature of the air on the horizontal scale, trace the temperature line straight up, stopping at the relative humidity line (darker curved lines) corresponding to the greenhouse RH (estimate between lines for the specific RH value),
3) From this point, trace straight left to the vertical axis and record the *vapor pressure* (vp_{air}) in psi,

4) Find the canopy temperature (or air temperature if canopy temperature is not available) on the horizontal axis, and trace up to the 100% RH line,
5) Trace straight left to the vertical axis and record the *saturated* vapor pressure (vp_{sat}) in psi,
6) Find the difference: VPD = $vp_{sat} - vp_{air}$.

To use calculations:

The following formulas can be used to calculate VPD either directly or by using computer spreadsheet software.

1) Measure air temperature and relative humidity inside the greenhouse. If possible, also measure air temperature within the plant canopy.

2a) Find the saturation vapor pressure of the air (vp_{sat}) in psi:

$$vp_{sat} = e^{(A/T + B + CT + DT^2 + ET^3 + F \ln T)}$$

where:

A = $-1.044\ 039\ 7 \times 10^{4}$
B = $-1.129\ 465\ 0 \times 10^{1}$
C = $-2.702\ 235\ 5 \times 10^{-2}$
D = $-1.289\ 036\ 0 \times 10^{-5}$
E = $-2.478\ 068\ 1 \times 10^{-9}$
F = $-6.545\ 967\ 3$
T – Temperature of the air in °R,
°R = °F + 459.67

2b) Calculate the vp_{sat} of the canopy in psi:

Same as above, T – Temperature of the canopy in °R. If canopy temperature is unknown, proceed to step 3.

3) Calculate vapor pressure in the air (vp_{air}) in psi at the actual relative humidity.

vp_{air} = vp_{sat} x RH ÷ 100

RH – relative humidity (%) of the greenhouse air

vp_{sat} – *air* saturation vapor pressure (psi)

4) Find the difference, VPD, in psi.

VPD = $vp_{sat} - vp_{air}$

vp_{sat} – canopy vp_{sat} if known, otherwise use air vp_{sat}

EXAMPLE

(Figure 2 shows A & B conditions)

A: 50°F, 80% RH
vp_{air} = 0.142 psi
vp_{sat} = 0.178 psi
VPD = 0.178 – 0.142
= *0.036 psi*

B: 70°F, 80% RH
vp_{air} = 0.291 psi
vp_{sat} = 0.363 psi
VPD = 0.363 – 0.291
= *0.072 psi*

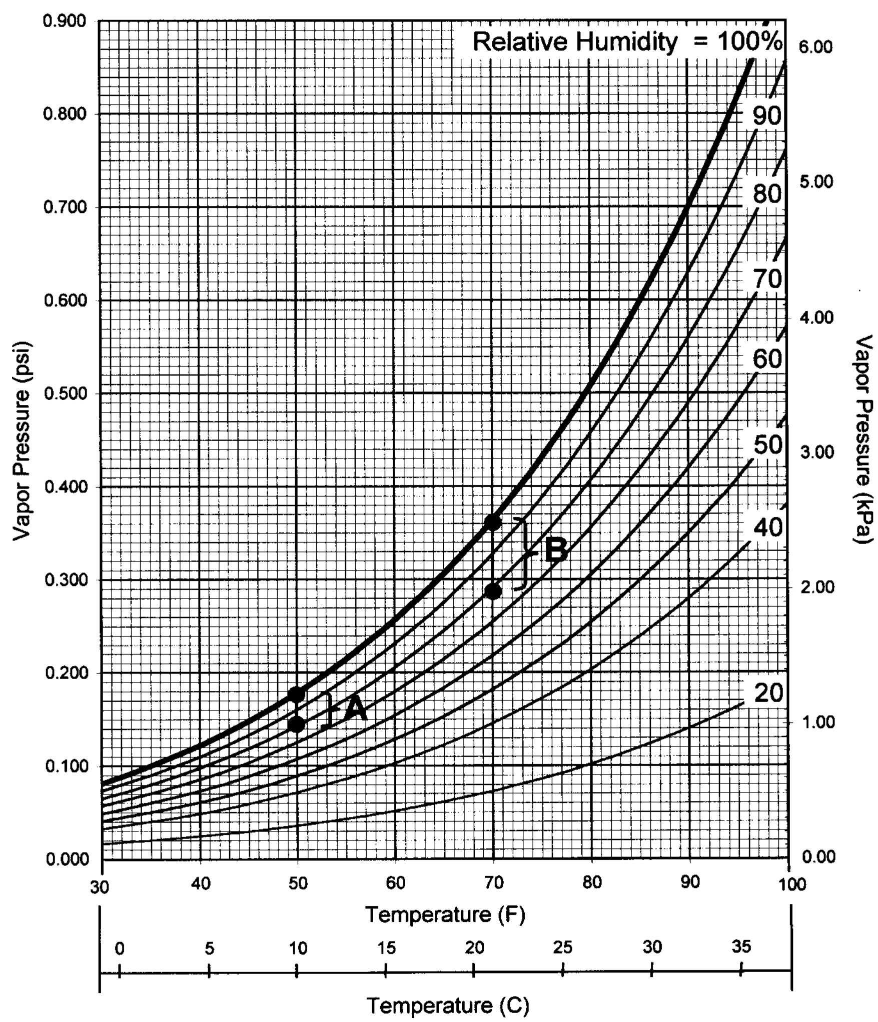

Figure 2. Modified psychrometric chart showing the vapor pressure values.

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