Factsheet 25/02

Controlling humidity

Project No. PC/HNS 121

Horticultural Development Council

Bradbourne House
East Malling
Kent ME19 6DZ
T: 01732 848383
F: 01732 848498
E: hdc@hdc.org.uk

Controlling humidity to minimise the incidence of grey mould (*Botrytis cinerea*) in container-grown ornamentals: heated glasshouse crops

Tim Pratt and Chris Plackett, FEC Services Ltd

Controlling the glasshouse environment to avoid long periods of high humidity has been shown to be vital to achieve effective control of botrytis disease on ornamental crops. This factsheet outlines the principles of humidity control, the importance of accurate humidity measurement and the strategies available to growers to help control glasshouse humidity levels.

Summary of action points

- Where space is available, separate plants so that air can circulate between them.
- Use fans to keep air moving over the plant surface.
- Ensure that humidity measurement is accurate and climate control computer set points consistently achieve the required humidity.
- Consider the use of heat boosts (drying periods) during periods of high risk.
- Avoid rapid rises in air temperature which leave a plant cold and increase the risk of condensation on the lower leaves.

Use fans to keep air moving over the plant surface

Introduction

Experiments on cyclamen leaves during a recent five year Horticulture LINK Project showed that relative humidity levels greater than 95% for a period of more than 3 hours, *is the critical threshold* for the germination of botrytis spores. Once this period is exceeded spore germination will continue even if the humidity is reduced to 80% or less. However, where high humidity periods are controlled to 3 hours or less, there should be little germination or disease development.

Further experiments using primula leaves showed that leaf wetness is important for the expression of botrytis symptoms with disease severity increasing with leaf wetness duration.

These results show humidity is a controlling factor for botrytis spore germination whereas leaf wetness encourages disease expression once the plant has been infected.

The key objective is therefore to prevent moisture lying on plant tissues for several hours, or an atmosphere of still, very humid air persisting around plants. Even lowering the humidity slightly can significantly reduce the incidence of botrytis. Various techniques can be used to reduce the humidity within and around crops and these are described in this factsheet.

Panel 1
Terms used to describe and quantify humidity

Humidity is a generic term describing the presence of water vapour in air. The humidity measurements that most growers are familiar with are relative humidity and humidity deficit.

Relative humidity
Expressed as a percentage, **Relative Humidity (RH)** is the ratio of the actual amount of water vapour in the air compared with the amount needed to make the air saturated at its current temperature. The relative humidity of saturated air is 100%.

The actual amount of water in the air at any time is called the **Absolute Humidity (AH)** and it is usually measured in g/m^3.

The maximum mass of water that air can hold at a given temperature is known as its **Saturated Moisture Content (SMC)** and it is also usually measured in g/m^3.

$$RH\ (\%) = \frac{AH\ (g/m^3)}{SMC\ (g/m^3)} \times 100$$

Humidity deficit (HD)
This is a measure of how much more water air can hold before it becomes saturated. The units of measurement are g/m^3.

HD = SMC – AH

For example, air at 20°C has an SMC of 17.4g/m^3. At a RH of 80% it would have an absolute humidity of 13.9g/m^3 (17.4 x 80%) and a humidity deficit of 3.5g/m^3 (17.4 – 13.9). This means that the air can hold a further 3.5g of water per m^3 before saturation occurs. The higher the HD value, the ‘drier’ the air, whereas with RH a higher value means ‘wetter’ air.

The complex relationship between temperature and the amount of water that air can hold means that there is no direct conversion from RH to HD. For example:

- Air at 20°C with an RH of 80% has a HD of 3.5g/m^3
- Air at 15°C with an RH of 80% has a HD of 2.6g/m^3

Dew point
This is the temperature at which air of a given absolute humidity will reach its saturated moisture content. The dew point is important in the glasshouse because it determines how far the air temperature can fall before condensation will occur.

Details on humidity measurement are included in Panel 2.

Understanding the properties of moist air

In order to understand how to achieve good humidity control, it is important to understand the properties of moist air first. Air can hold water vapour in varying concentrations up to what is termed ‘saturation’. The amount of water held will depend on the temperature and the pressure of the air. Warm air can hold more water vapour than cold air.

For example 1m^3 of saturated air at atmospheric pressure will hold:

- 12.8g of moisture at a temperature of 15 °C
- 21.9g of moisture at a temperature of 24 °C

Heating the air within a glasshouse does not therefore remove water vapour from the air, it simply allows the air to hold more water.

Principles of reducing humidity within the glasshouse

Ventilation
In horticulture, the most common method of reducing humidity is ventilation, which drives warm, damp air from the glasshouse replacing it with cooler, drier air. The way that this changes the humidity is illustrated opposite.

Opening the vents allows inside and outside air to mix creating air with a different water content. In the example opposite, exchanging 10% of the internal air volume with outside air reduces the actual amount of water in the air (AH), but the Relative Humidity (RH) is higher at 81% and the Saturated Moisture Content (SMC) is lower. This is because the air temper-ature has fallen to 19.0°C as a result of introducing colder air from outside.

To bring the temperature back to 20°C, heat has to be applied using the glasshouse heating system. This action leaves the same amount of water in the air but changes the SMC back to 17.4g/m^3. The effect on the RH is to reduce it to 76%.

The use of glasshouse heating can sometimes be avoided when the outside temperature and heat gained from solar radiation are high.

'Glasshouse' air	**'Outside' air**		**'Mixed glasshouse' air**		**'Mixed then heated glasshouse' air**
20°C	10°C		19°C		20°C
80% RH	80% RH	→ 10% air exchange →	81% RH	→ Heat →	76% RH
17.4 g/m^3 SMC	9.4 g/m^3 SMC		16.4 g/m^3 SMC		17.4 g/m^3 SMC
13.9 g/m^3 AH	7.5 g/m^3 AH		13.3 g/m^3 AH		13.3 g/m^3 AH

Heating without ventilation

Heating without ventilation reduces the relative humidity of the air and increases humidity deficit. However, it does not remove water from the air. Adding heat simply allows the air to hold more water.

Even so, heating alone during cold conditions can sometimes lead indirectly to a reduction in the amount of water in the air. This happens when air comes into contact with the inside surface of the cold glass. This air is cooled below its dew point temperature and moisture is released as condensation.

'Glasshouse' air		**'Glasshouse' air**
20°C		21°C
88% RH	→ Heat →	83.2% RH
2.1 g/m^3 HD		3.1 g/m^3 HD
15.3 g/m^3 AH		15.3 g/m^3 AH
17.4 g/m^3 SMC		18.4 g/m^3 SMC

What humidity control strategies are available?

In all cases (other than when moisture is released from glasshouse air in the form of condensation on the glass) reducing glasshouse humidity involves the venting of warm humid air, allowing it to be replaced by cooler, drier outside air.

As well as reducing humidity, this process reduces glasshouse temperature, so some compensatory heating is generally required to redress the balance.

Good control therefore needs to manipulate both the ventilation and heating system to give the correct humidity and temperature conditions without excessive energy use.

'Vent then heat' or 'Heat then vent'

Technically, the most logical and cost effective way to operate a ventilation and heating system for humidity control is to open the vents when humidity gets too high, close them and then compensate for the drop in temperature by adding heat. This is called a **'vent then heat'** strategy.

Although efficient, this approach has practical drawbacks mainly due to the design of heating systems found in glasshouses. Often based on piped hot water with enormous thermal inertia, these systems are slow to react to the quick fall in temperature caused by the inflow of cold air. Consequently, glasshouse temperatures can drop excessively following ventilation.

To get round this, **'heat then vent'** strategies have been developed. Here additional heat is introduced into the glasshouse, firstly to increase the moisture carrying ability of the air and then, finally to cause the temperature to rise enough to activate the operation of the ventilation system. Warm moist air is therefore vented and humidity falls. This system, although less efficient, tends to give air temperatures which are more stable.

Many growers favour this approach because it gives sensitive temperature control and avoids prolonged dips in glasshouse air temperature. However, adding heat and then venting some of it off wastes energy.

Choice of strategy

The decision on whether to use the 'vent then heat' or 'heat then vent' approach depends upon many factors including the type of control system available, time of year and the heating system response time.

In summer, 'vent then heat' tends to be more appropriate as outside air temperatures are generally high enough to prevent excessive drops in temperature. Solar gain also assists in any subsequent heating requirement. In the colder months of the year, 'heat then vent' is generally preferred.

Hot water systems are especially slow to respond and growers with this type of heating system usually opt for a 'heat then vent' strategy by increasing the minimum pipe temperature at times when high RH conditions prevail. However, growers should be wary of using minimum pipe setting which are too high as this can result in excessive air temperatures and humidity levels which are too low. Close attention to set points and the environment achieved will allow growers with hot water heating systems to adopt what is close to a vent then heat strategy.

Direct fired warm air heaters provide instant heat but their heat output is only available in large fixed steps. They are less able to provide the even heat distribution of a piped hot water system. However, the use of direct fired warm air heaters is more likely to allow a true 'vent then heat' strategy to be adopted, even in colder months.

Air movement

Fans are an essential tool to achieve effective air movement throughout a glasshouse and ensure thorough mixing of the air. A number of options are available:

- Traditional barrel fans – these should be placed in parallel or serial arrangements to avoid stagnant air in the centre of the glasshouse.
- Fans on warm air heaters – these can be used to assist in air circulation in conjunction with barrel fans.
- Large extraction fans – these can be installed on the end walls of glasshouses to achieve a positive air-movement across the crop. Air is drawn in through the vents, which must be kept to a minimum setting (15–20% of maximum opening) to achieve uniform air movement across the house.
- Slow-moving paddle fans – these should be positioned horizontally high in the roof space and are a good option for new, taller houses.

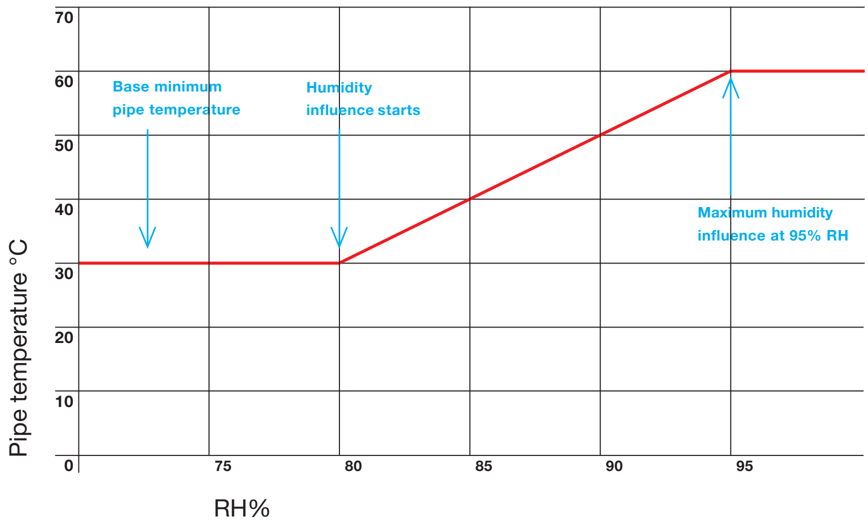
Implementing humidity control in practice

Recent experiments have shown that a RH of 95% or above, sustained for more than 3 hours is the critical threshold for the germination of botrytis spores on cyclamen leaves. Currently there is no commercial software available which responds to this specific situation. However, climate control computers facilitate an accurate and responsive means of humidity control by providing dynamic settings for heating and ventilation in relation to measured humidity.

Deviation from the required humidity can be used to influence the ventilation temperature, vent position and heating system output as described earlier.

Although the following section relates to RH, the principles are exactly the same if you are controlling using HD. Just remember that whilst we are trying to lower the RH in these examples, you would be trying to raise the HD.

Graph 1
Humidity influence on heat output
An example of how humidity can be used to influence minimum pipe temperature

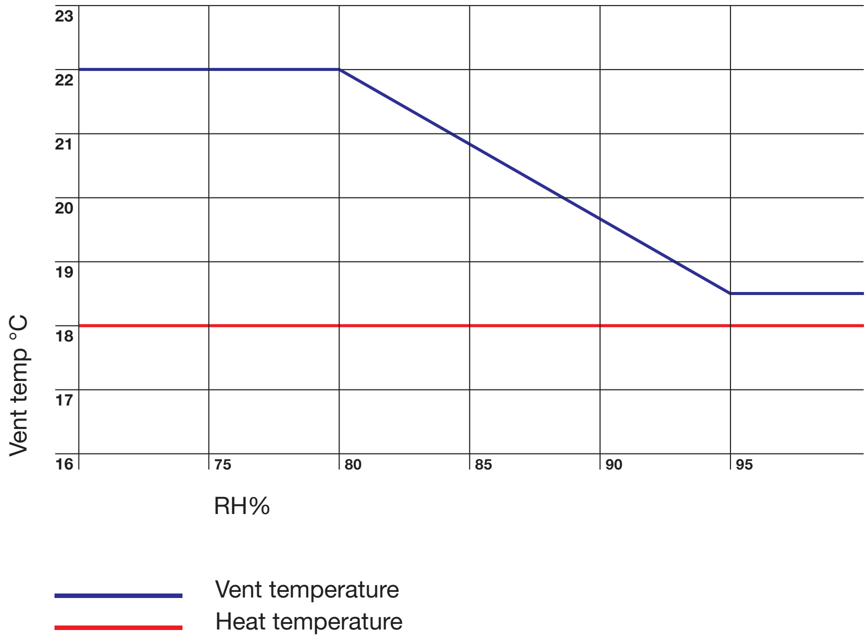


The above example shows how humidity can be used to influence minimum pipe temperature. In this case an influence of an additional 30°C is progressively applied to the minimum pipe temperature as the RH rises from 80% to 95%.

The effect of this setting is to raise the air temperature thus increasing the moisture holding capacity of the air and avoiding the critical RH of 95% for a prolonged period of time. Raising the air temperature will also stimulate ventilation, which will in turn reduce RH without risking sudden falls in air temperature.

Note, if a direct fired air heater is used this should be interpreted as a change from off, to low fire, to high fire or as a gradual increase in the heater operating period.

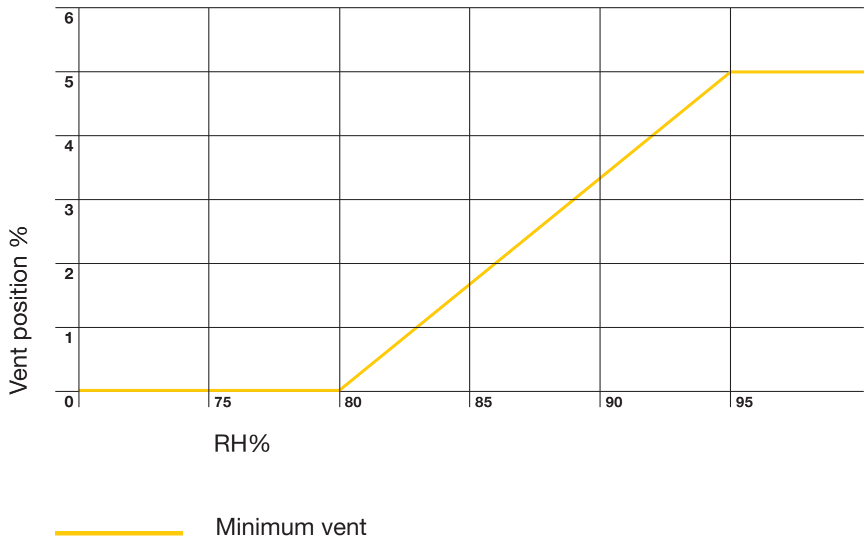
Graph 2
Humidity influence on ventilation temperature
An example of how humidity can be used to influence ventilation temperature



This example shows an influence of 3.5°C on the basic ventilation temperature set-point, reducing the setting from 22°C progressively down to 18.5°C as the RH rises from 80% to 95%.

The effect is that ventilation is used earlier at high RH levels, thus allowing moist air out of the glasshouse sooner.

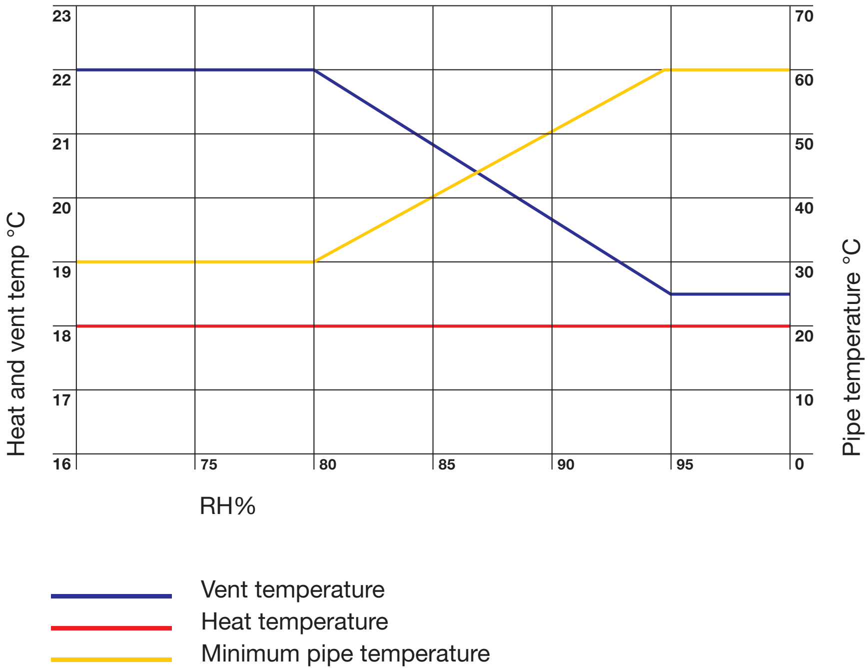
Graph 3
Humidity influence on vent position
An example of how humidity can be used to influence vent position



An example of how humidity can be used to influence the vent position is shown above. Here the minimum vent position is increased from 0 to 5% as the RH rises from 80% to 95%. This gives an increasing base ventilation rate as the humidity rises. (Where screens are used a similar profile can be used for gapping.)

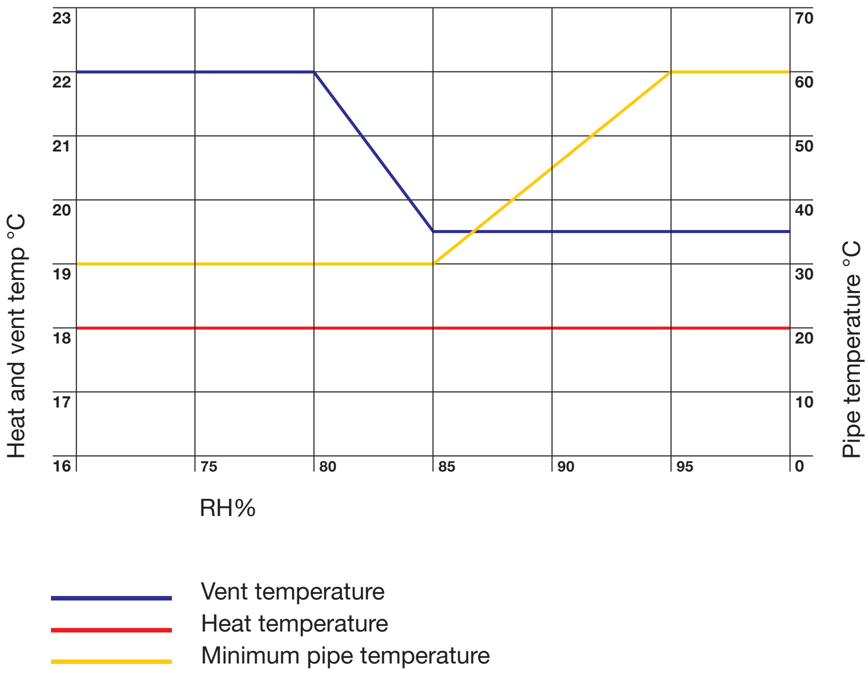
Growers should beware of using too much minimum vent, particularly during the winter. It can be easy to get into the situation when the humidity is high, vents are open, the temperature is below target and most of the heat added goes straight out of the vents. If the vents are simply closed and the temperature raised back to the required level, humidity control will be achieved.

Graph 4
Heat then vent approach
An example describing the elements of a heat then vent approach



Combined, the minimum pipe and ventilation temperature graphs describe the elements of a 'heat then vent' approach. The vents are only likely to open once the vent temperature is within 1.0 – 1.5°C of the heating temperature. At this stage the RH is over 90% and the minimum pipe temperature is over 50°C.

Graph 5
Vent then heat approach
An example describing the elements of a vent then heat approach



If settings are used to reduce the vent temperature earlier so that it is within 0.5°C of the heating temperature when the RH reaches 85%, and only then is the minimum pipe temperature increased, a 'vent then heat' approach results.

Which approach is best?
There is no simple rule that determines when either approach is most suitable. Gradual adjustment of the influences as the seasons and crop change is the best approach.

It is impossible to give recommendations on settings that will suit every situation. Armed with an understanding of the processes involved growers should be able to 'tune' their settings to achieve good humidity control at minimum energy cost. The following points should also help:

- Excessive cycling of temperature, humidity or even vent position are symptomatic of influence settings being too big and being applied over too small a humidity range

- Vents which spend most of their time open when the temperature is acceptable, and an internal humidity that is consistently below target both indicate excessive use of heat or minimum vent
- Air temperature that is consistently above heating temperature and/or poor humidity control are the result of too great a difference between heat and vent temperatures
- Air temperature close to the heating temperature, vents closed and poor humidity control are the result of too little heat being applied.

The importance of limiting the speed of temperature change

A quick rise in the air temperature within a glasshouse can leave the plant, pot and growing medium lagging behind by several degrees. As a result, even though the RH of the air may be acceptable, the temperature of the stem and lower leaves may be below the dew point of the air and condensation of water vapour on to the plant surfaces will occur. As mentioned earlier, leaf wetness encourages botrytis disease expression once the plant has been infected.

Early morning is the period of greatest risk. This is because solar gain can rapidly increase the glasshouse air temperature. By setting the ventilation temperature within 1°C of the heating temperature, rapid rises in air temperature can be suppressed. This will allow the plant, pot etc. to warm up gradually and reduce any risk of condensation.

Heat boosts or drying periods

To ensure that the critical threshold for botrytis spore germination (>95% RH for 3 hrs) is avoided, an additional strategy for controlling disease can be employed during times of greatest risk such as winter and spring months. This involves introducing heat boosts' or 'drying periods' to break up long periods of high humidity or tissue wetness.

Although effective, the use of heat boosts should not be used as a substitute for more considered humidity control. As this is a relatively new technique, there is currently no commercial software available to implement this approach. With this in mind growers should use their own expertise to recognise when problems are likely to occur and allocate a time period to apply this strategy.

Care must be taken when using heat boosts. If used inappropriately or applied incorrectly they can be of little effect and energy can be wasted unnecessarily. Never forget the underlying aim – to significantly reduce the RH (or increase the HD) and create a drying period. The strategies that can be employed to create this effect have already been discussed and are based on the approach of the addition of heat and opening the vents (as in 'heat and vent'). Heat boosts are simply an aggressive application of these techniques.

Practical settings, which can achieve an effective heat boost strategy, are:

- Increase the minimum pipe temperature to 60°C if the measured RH is above 75%

and

- Reduce the vent temperature to within 0.5°C of the heating temperature regardless of the measured RH

An alternative approach that is better suited to direct fired warm air heaters is:

- Apply a minimum vent position of 5 to 10%

- Force the heater to run regardless of air temperature

Always check that the required effect is being achieved. If the above settings are ineffective then increase the minimum pipe setting, air heater output level, reduce the vent temperature or increase the minimum vent setting.

Note – although the threshold for the germination of botrytis spores is 3 hours at 95% RH, it often takes some time for the environment to respond to the settings applied. It would therefore be wise to start to apply the heat boost when RH has been over 95% for 2 hours.

Operating the heat boost strategy described above with crops grown at 'warm' temperatures should not result in a significant air temperature rise in the glasshouse. The effect on scheduling or quality will therefore be minimal. Even with 'cold-grown' crops, the short duration of the resulting temperature rise will have little effect.

Trials showed that the additional energy cost for the application of a nightly heat-boost for the duration of a cyclamen crop could be as low as 14 p/m^2 (gas at 9 p/m^3). At these costs, and assuming a return to the grower of £16/m^2, a reduction of just 1% in the proportion of crop that is unmarketable due to botrytis would pay for the extra energy used.

Boiler equipment

Panel 2

Principles of humidity measurement and positioning and maintenance of humidity measuring equipment

Principles of humidity measurement

In glasshouses, humidity is determined using temperature readings taken from two thermometers. The two thermometers are housed in a complete unit known as a psychrometer.

One thermometer measures the 'dry bulb' temperature whilst the second measures the 'wet bulb' temperature. The wet bulb temperature is determined by surrounding the measuring point of the wet bulb thermometer with a wick immersed in a water reservoir. This keeps the wet-bulb thermometer moist. As long as the air passing over the wet bulb is at an RH of less than 100%, some of the water in the wick will be evaporated thus cooling the thermometer bulb. The lower the humidity the greater the cooling effect. For each dry bulb and wet bulb temperature combination, there is a corresponding air humidity.

Electronic humidity sensors

These have been available for some time and the accuracy of recent models at RH's of 85% and above has greatly improved. Their main benefit is that they operate dry with no wick to clean or reservoir to fill. Their major disadvantage is that they are more expensive. Cheaper, hand held electronic humidity sensors are available but they tend to be inaccurate at higher RH levels (>85%).

Position of the measuring box

Humidity conditions immediately around the crop affect both plant growth and the likelihood of disease development. The measuring box should therefore be located as close to the crop as possible but away from heating pipes, gas burners and supplementary lighting. All of these items may cause erroneous readings to be taken.

There are other practical issues to bear in mind such as:

- The likelihood of damage from moveable benches
- Proximity to dust and debris that may block the air inlet filter
- Inconvenience of having to move the measuring boxes when working on the crop or during chemical application

Maintenance

- At least once a season, check that the temperature readings from both wet and dry bulb thermometers are the same when the wick is removed from the wet bulb. Apply corrections using the procedures given in the climate control computer manual. A difference in measurement of 0.5ºC will give an inaccuracy of 4% RH.
- Check the water reservoir at regular intervals to ensure there is an uninterrupted supply of water. When there are visible signs of contamination, the wick should be replaced immediately. A new wick should be soaked during the replacement procedure, as this will aid the transport of water to the temperature sensor.
- Ensure a continuous airflow at the required rate through the measuring box and check, clean or replace the air inlet filter regularly. Although mounting the measuring box close to the crop is advisable to give a representative reading it can also mean that more plant and compost debris will be drawn into the filter. The fan in the measuring box runs non-stop and, although these are very reliable, fouling will reduce the airflow and cause overheating. This will reduce the life of the fan.
- Clean the complete unit at least once per year, experience will tell whether this should be more frequent. Consideration should also be given to switching off the fan during any pesticide application to reduce fouling and corrosion.
- Check measuring boxes at monthly intervals for water level, filter blockage etc. A poorly maintained measuring box will almost always give a humidity reading that is higher than is actually the case. Although the plants are unlikely to suffer as a consequence, a high measurement will mean higher energy use and a possible increase in precautionary crop protection chemical applications.

Information on strategies for managing botrytis on container-grown ornamentals in heated glasshouses is given in HDC factsheet 24/02.

An aspirated screen (left) which houses the wet and dry bulb thermometers (right) used for calculating relative humidity

Further information: A full copy of the final report for HDC project PC/HNS 121 is available from the HDC office (01732 848383).

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