Factsheet 07/09

Protected crops

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Energy management in protected cropping: Humidity control

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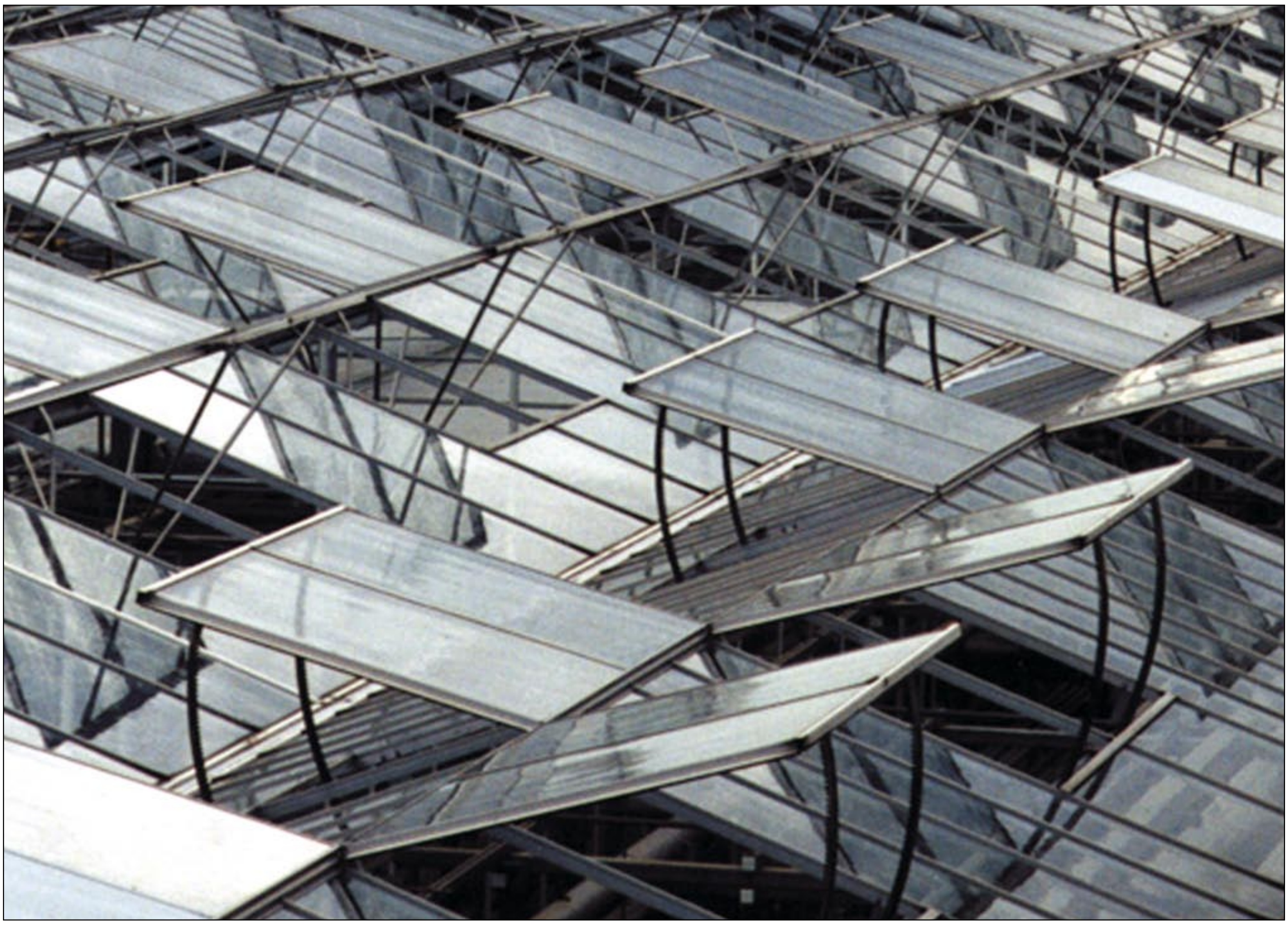
Controlling humidity can be expensive in energy terms, yet it is essential for the control of fungal disease and to ensure active plant growth. Humidity control also needs to be carefully targeted so as not to negate the energy savings from measures such as temperature integration (TI) and thermal screens. This factsheet in a series on energy management, focuses on the twin requirements of effective humidity control and energy saving.

Summary points

- Effective humidity control is essential to keep fungal disease in check and to promote active growth. Humidity deficit (HD) and relative humidity (RH) are both used routinely to monitor humidity, but RH may be the better indicator of disease risk.
- An effective humidity control strategy is to prevent the humidity rising above 90% whilst, at the same time, preventing condensation occurring on the plants. Condensation poses a particularly serious disease risk, and occurs when plant temperature is at or below the dew point temperature of the air.



1 Venting results in energy loss but is an essential element in humidity control

- Humidity control is expensive in heating energy terms and, in tomato production, can account for around 20% of energy usage when control is set at 85% RH. However, relaxing control from 85% to 90% RH can be expected to reduce overall energy use by around 12%, demonstrating that large energy savings can be made by adopting less aggressive (but effective) control strategies.

- Air humidity can be accurately measured using a traditional wet/dry bulb measuring box, but regular maintenance is essential. Because of this, electronic sensors are probably more reliable. Positioning of sensors relative to the crop is very important.

- The most energy-efficient way of controlling humidity is to vent first (Figure 1, previous page), then re-heat to maintain temperature. This can be done by having a humidity influence on the vent set-point and/or by introducing a minimum vent which is dependent on the humidity. Heating is then used to maintain temperature.

- Setting a permanent, minimum pipe temperature is wasteful in energy terms, since much of the pipe heat introduced into the greenhouse has to be vented away to avoid excess temperatures. However, the use of a minimum pipe operating with a humidity influence can be useful in preventing undesirable temperature fluctuations.

- Plant temperature measurements (or estimates) will help identify condensation risk periods, and RH values based on plant temperature rather than air temperature (plant humidities) can be especially useful when introduced into the control strategy.

- Thermal screens can make humidity control more problematic, but good operational practices can minimise their impact. For example, effective humidity control can often be achieved by controlled screen gapping to enable cold, dryer air from above the screen to mix with the moisture-laden air beneath.

- There is potential to reduce humidity levels and energy use associated with edible vine crops by reducing their leaf area and, within limits, this can be done without affecting yield.

Introduction

The atmospheric humidity in the glasshouse is a measure of how much water vapour is contained within the air. When levels of water vapour are very low (low humidity), plants experience water stress, their stomata close and growth is reduced. However, much more frequently there is a high level of water vapour in the glasshouse air (high humidity). High humidity promotes fungal infection and this tends to increase the incidence of disease caused by pathogens such as *Botrytis* and *Didymella*. High humidity also reduces plant transpiration and, if such conditions persist, calcium levels in the plant fall and growth may be depressed.

Controlling humidity is, therefore, essential for active plant growth and to keep fungal disease in check. However, the control of humidity can be expensive in energy terms, and an important element in good energy management is the adoption of measures that are effective in keeping humidity in check, but which are, at the same time, energy efficient. Humidity control also needs to be carefully targeted so as not to negate the energy savings from measures such as TI and thermal screens (see Factsheets 06/09 and 08/09).

Humidity measures

Humidity can be assessed in various ways including 'absolute humidity' (g moisture per kg or per m³ of moist air) and 'vapour pressure deficit' (expressed in kPa units). However, the two measures most commonly encountered in glasshouse production are 'relative humidity' and 'humidity deficit'. There are pros and cons associated with both of these, and the best option for humidity control may be to use a combination of the two. However, this is not always possible in practice.

Relative humidity (RH)

This is a measure of the moisture content of the glasshouse air, relative to that of saturated air at the same temperature. If, for example, the air has an RH of 50%, it contains one half of the moisture content of saturated air at that temperature (RH of 100%). The water vapour holding capacity of the air is greatly affected by temperature and whilst a cubic metre of air at 25°C is able to hold 23.0 g water vapour at saturation point (100% RH), it will only be able to hold 12.8 g at 15°C. Thus, if air at 25°C and 50% RH (holding 12.5 g water vapour) is reduced in temperature to 15°C, it will be close to saturation point. RH tends to be the humidity measure of choice for most growers of ornamental crops, and is thought to be a good indicator of disease risk.

Humidity deficit (HD)
This is a measure of 'the drying power of the air' and indicates how much more moisture a sample of air can hold before it becomes saturated. An HD of 2.6 g/m³, for example, means that each cubic metre of glasshouse air can take up a further 2.6 g of water. HD can be a key determinant of transpiration and values of 2.25 g/m³ and above are generally regarded as being ideal for the promotion of active plant transpiration. Given the importance of this to growth and yield, HD has become the humidity measure of choice for most growers of edible crops. However, HD may not be as good an indicator of disease risk as RH.

Conversions between RH and HD
Whilst a given HD will have much the same influence on transpiration regardless of temperature, this is not the case with RH. Air at 70% RH for example, will be able to accept much more water vapour at 20°C than at 15°C. Thus the relationship between HD and RH is strongly influenced by temperature as is evident in Tables 1a and 1b which show conversions between the two measures.

Table 1a Values of HD (g/m³) for various combinations of RH and air temperature

RH (%)	Temperature (°C)				
	10	**15**	**20**	**25**	**30**
100	0.00	0.00	0.00	0.00	0.00
90	0.94	1.28	1.72	2.28	2.99
80	1.87	2.55	3.44	4.57	6.00
70	2.81	3.83	5.16	6.86	9.01
60	3.75	5.11	6.88	9.15	12.03
50	4.69	6.40	8.61	11.46	15.06

Table 1b Values of RH (%) for various combinations of HD and air temperature

HD (g/m³)	Temperature (°C)				
	10	**15**	**20**	**25**	**30**
0	100.00	100.00	100.00	100.00	100.00
1	89.32	92.16	94.17	95.61	96.66
2	78.66	84.33	88.35	91.23	93.32
3	68.00	76.51	82.54	86.85	89.98
4	57.35	68.70	76.73	82.48	86.65
5	46.72	60.90	70.92	78.11	83.32
10	_	21.98	41.99	56.33	66.72

Humidity conditions to be avoided

1 Conditions favouring disease spread

It is generally agreed that glasshouse humidity control should aim to prevent the RH rising above 90%. This is because higher levels encourage the germination of spores of fungal pathogens such as *Botrytis* and *Didymella* (Figure 2) and promote disease spread. However, without plant damage, serious disease spread is unlikely to occur until the localised RH exceeds 95% since, as shown in Graph 1 based on the data of Dr Roy Kennedy, levels of *Botrytis* spore germination are still relatively low at this humidity. There is also probably little risk of serious infection even at the highest levels of RH so long as the duration of exposure is relatively brief. This is because spores appear to germinate only after around three hours in inductive conditions (PC/HNS 121). It is clear from Graph 1 that air temperature (within the range likely to be encountered in glasshouse growing) is relatively unimportant for *Botrytis* spore germination when control is based on RH.

Whilst surface wetness is not essential for disease spread, moisture films provide ideal environments for the germination of spores of fungi such as *Botrytis*, and are likely to increase levels of fungal infection and disease spread. For this reason, it is especially important to avoid conditions favouring the occurrence of condensation on plant surfaces (which can occur at RH levels below 90%, see later).

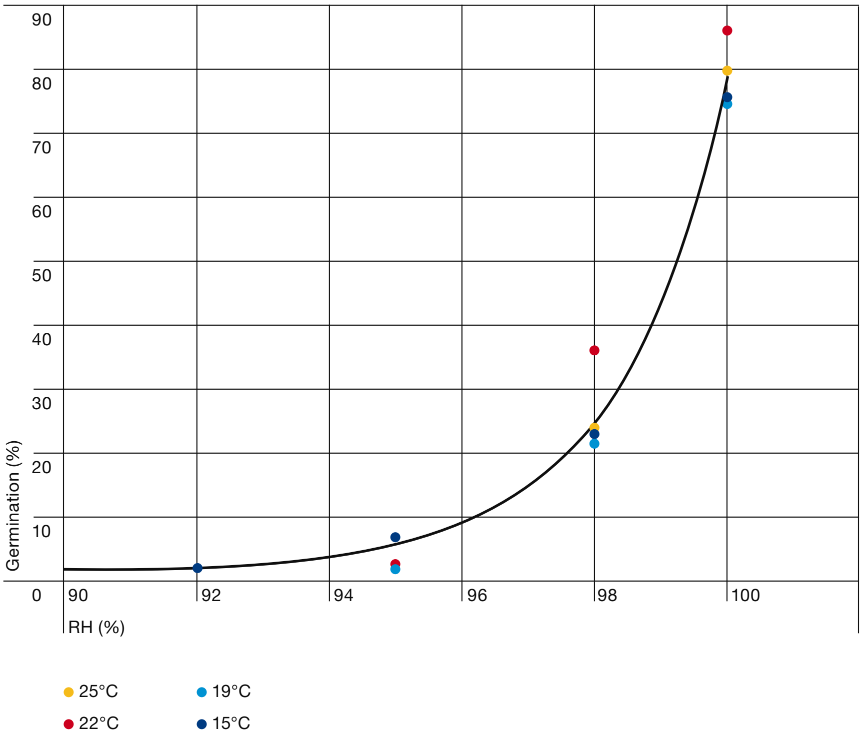
2 Conditions depressing growth

As a generality, HD levels between 2.0 and 7.5 are unlikely to have any noticeable effect on plant growth and yield. It is only levels outside of this band that can give potential problems. Studies have shown, for example, that the yield of tomatoes was reduced by 11% when grown continuously for 28 days at an HD averaging a little over 1.0 g/m³.

2 Higher levels of humidity allow the germination and development of fungal diseases such as *Botrytis* (top) and *Didymella* (bottom)

These are rather extreme conditions and they had to be sustained to have significant effect. It is the average HD that determines effects on crop physiology, and a low HD for a single night, for example, is likely to have negligible effect. In contrast, a very high RH for a single night could be highly detrimental for disease control. Thus, humidity control regimes that are effective in protecting against fungal disease can be expected to protect equally against the high-humidity depression of growth.

Graph 1 Effect of relative humidity (RH) at temperatures between 15°C and 25°C on the germination of spores of *Botrytis* after 24 hours (HH3611SPC)



Measuring humidity

Traditionally, humidity (both RH and HD) has been measured using conventional measuring boxes (Figure 3). These have aspirated sensors that measure ‘dry bulb’ and ‘wet bulb’ temperatures, and use standard relationships between these to determine the humidity. Such boxes work well and are accurate so long as they receive regular maintenance. In particular, the ‘wet bulb’ sensor must always have a clean wick and a plentiful reservoir of clean de-ionised water. The aspiration fan must also be kept clean and the measuring box must be suspended in a position within the glasshouse so that obstructions do not hinder airflow. Some of these maintenance issues are avoided by the use of electronic humidity sensors (Figure 4, overleaf). In these, the ‘wet bulb’ is replaced by an electronic sensor that measures humidity directly.

Where to measure humidity

Measuring boxes need to be positioned as close to the crop as possible

3 Conventional measuring box design with ‘wet’ and ‘dry bulb’ sensors

so that measurements reflect the conditions experienced by the crop. The ideal would probably be to position them directly within the crop canopy. However, free air movement is needed for effective operation, so normal commercial practice is to place boxes in the airspace just above the crop. It is inevitable, therefore, that measured humidities often reflect the conditions in the greenhouse airspace rather than those of the micro-climate next to the plants.

For vine crops such as tomato, it can be a good idea to site measuring boxes in different locations. For example, a measuring box positioned between the rows at the base of the plants gives humidity measurements that reflect the conditions experienced by the stem bundles, and measurements made in this position can be useful for disease control. However, the traditional measuring position at the crop head still needs to be retained because measurements made there best indicate the potential for adequate crop transpiration.

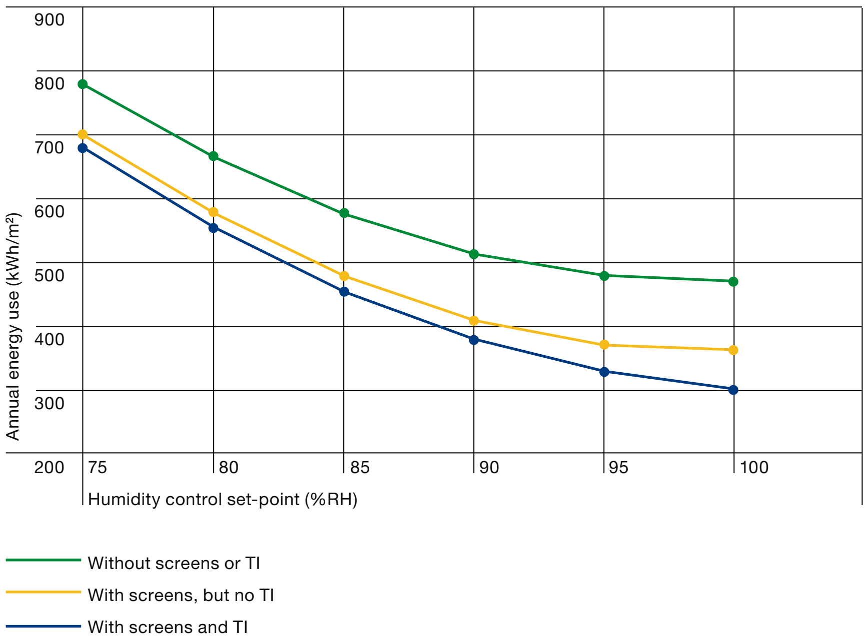
An alternative approach to humidity measurement is to base the estimates on plant temperature rather than air temperature. This has particular value for the avoidance of condensation and is discussed later.

4 Measuring box incorporating an electronic humidity sensor

Energy cost of humidity control

Aggressive humidity control increases energy use as shown in Graph 2. This is derived by simulation using an energy model for tomato developed by Dr Paul Hamer (HH3611SPC). Humidity control is by a vent then re-heat strategy, with the lee vent able to open fully for humidity control, and with no minimum pipe. Annual energy usage for a crop without screens or TI (see Factsheets 06/09 and 08/09), and with humidity control set at 85% RH, is estimated to be around 570 kWh/m². Of this, around 20% (118 kWh/m²) is expended directly on humidity control. However, relaxing the RH control set-point from 85% to 90% RH reduces total energy use by around 12% (67 kWh/m²),

Graph 2 The effects of humidity control set-point on the annual energy expenditure in tomato production (simulated using a model developed in HH3611SPC)



demonstrating that large energy savings can be made by adopting less aggressive humidity control strategies.

Humidity control also reduces the energy savings that can be made using TI and screens. Graph 2 indicates that without humidity control, TI and screens together reduce energy use by 39%. However, with an 85% RH set-point, the energy saving from these technologies is reduced to less that 30%. The savings from TI are especially sensitive to humidity control strategy. It is vital, therefore, to carefully target humidity control to ensure effectiveness and energy-efficiency.

The energy use for RH control will be less for many ornamental crops than that shown in Graph 2 (based on tomato) because ornamentals have smaller leaf areas and transpire less.

Humidity control

Vent then re-heat

In practice, it is often necessary to use a combination of heating and ventilation to control humidity and it is good energy efficiency practice to use ventilation first. This is because ventilation removes moisture by exchanging a proportion of the moisture-laden glasshouse air with drier air from outside. However, relying solely on ventilation can lead to a drop in glasshouse temperature, and heating has usually to be used after ventilation to restore the internal temperature.

The alternative approach, to heat first, only increases the moisture holding capacity of the glasshouse air and does not remove moisture. Ventilation will have to be used at some stage to remove moisture and to rectify the inevitable overheating of the glasshouse, and the result will be a loss of warm air which increases energy use.

Achieving stable humidity control for minimum energy use requires the use of settings that balance ventilation and heating. Good practice is to set a humidity influence on the vent set-point and/or introduce a minimum vent which is dependent on the humidity. In this case, the degree of opening is increased as humidity conditions progressively worsen, with the advantage that venting can be imposed for humidity control irrespective of the internal temperature. Heating is then used to maintain the temperature at an acceptable level.

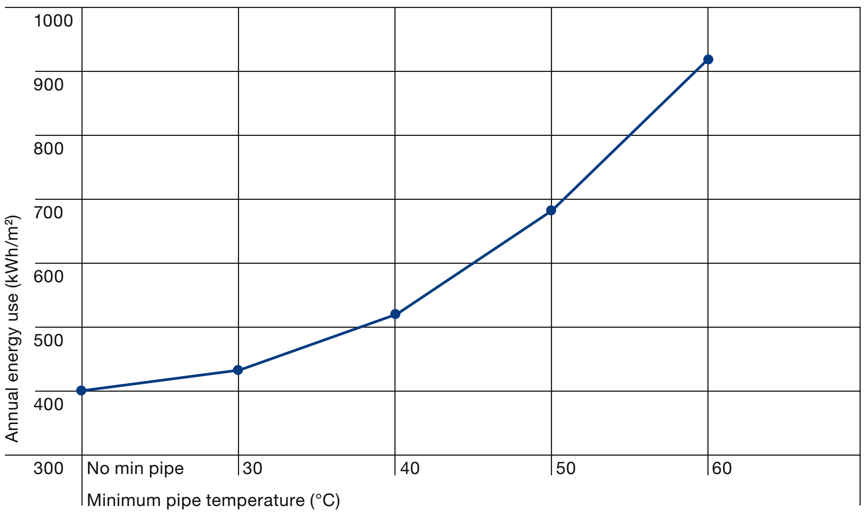
Minimum pipe temperature

It was common practice in the past, when energy prices were lower, to achieve humidity control by setting a permanent, minimum pipe temperature. This, together with compensatory venting, maintained the glasshouse temperature at the desired level, and had the knock-on effect of reducing the humidity by introducing external air with a lower moisture content. This approach worked well, but it was wasteful in energy terms since much of the pipe heat introduced into the greenhouse had to be vented away.

The effect of a permanent minimum pipe on energy use is simulated in Graph 3. This indicates that for a tomato crop growing with a screen and with venting at 90% RH, the inclusion of a 40°C minimum pipe will increase energy use by around 31%. Using a higher pipe temperature will have an increasingly large effect on energy use. The additional energy expenditure will be mainly in the summer, and this strategy should be avoided unless CO_2 is needed. However, in this case the CO_2 should not be considered as a free by-product, and its cost should be apportioned appropriately and weighed against the likely benefit in terms of yield (Factsheet 10/09).

A more energy-efficient way of using a minimum pipe temperature is to operate against a humidity influence. In this case, a minimum pipe temperature is introduced at an appropriate level and is increased as humidity rises. This is a more energy intensive strategy than relying solely on venting and reheating, as venting and heating are likely to operate in parallel. However, it could be useful at times of the year when the introduction of cold air into the glasshouse and a long lag time for the heating system to operate combine to give undesirable temperature fluctuations.

Graph 3 The influence of a permanent, minimum pipe temperature on energy use in tomato production with a screen, and with humidity controlled at 90% RH (simulated using a model developed in HH3611SPC)



Avoiding condensation on plants

A key aim of humidity control must be to avoid condensation occurring on the plants since, as noted earlier, moisture films are ideal for fungal spore germination and promote disease spread. Condensation occurs when plant temperature falls below the dew point of the surrounding air (the temperature at which the air would become fully saturated) and water condenses out of the air on the cooler plant surfaces. This situation can occur at apparently safe RH/HD levels, and stems and fruits are at greatest risk of attracting condensation because these have high thermal inertia and are likely to be cooler than the moisture-laden air at key times of the day.

It should be noted that it is not just edible crops that can be affected by condensation. Poinsettia crops, for example, are often grown with a temperature reduction at dawn (DROP, see Factsheet 06/09) and with a subsequent compensatory temperature lift to maintain the average temperature. However, plants do not warm up as rapidly as the surrounding air and, if unchecked, a marked differential in temperature can occur, providing ideal conditions for condensation. This can, in turn, increase the incidence of *Botrytis* which, for an ornamental crop, will greatly reduce its retail value.

Graph 4 illustrates how circumstances favouring condensation can come about. The graph shows tomato stem temperature (monitored using an infra-red sensor, see below), air temperature and dew point over a 24 hour period in late March, and identifies two occasions when the stem temperature was very close to the dew point. The first was in mid-morning when air temperature was increasing more rapidly than stem temperature, and the second was early in the afternoon when clouds came over, the air temperature suddenly fell and the vents closed.

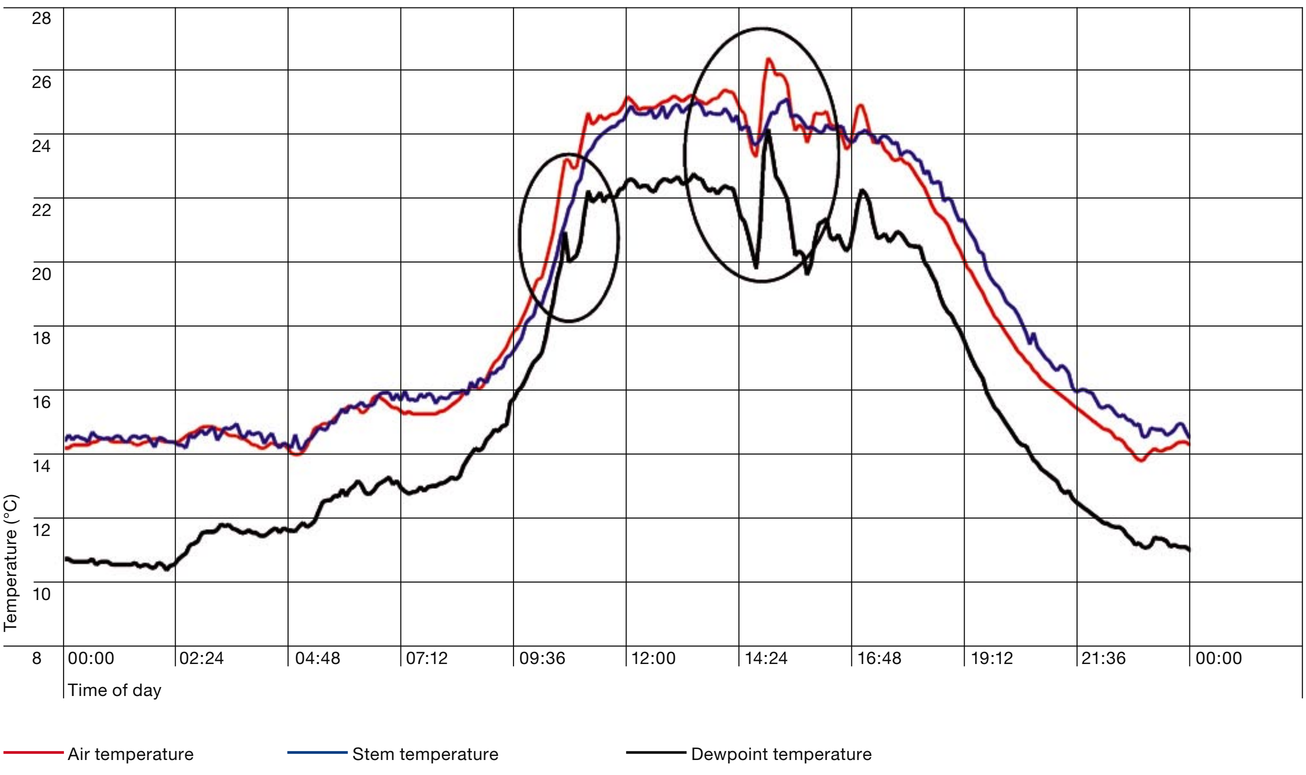
Monitoring plant temperature

Obtaining data as shown in Graph 4 requires the continuous monitoring of plant or plant organ temperature. This can be done by contact measurement, using infra-red sensors or using software models:

- Contact measurement – temperature sensors are mounted directly on the plant surface of interest (eg stems). This is a procedure that is used routinely in plant research, but which is not popular in commerce due to difficulties in fixing the sensors, the labour needed to mount and to move the sensors, and the fact that sensor cables can hinder efficient crop husbandry.

- Infra-red sensors – these are non-contact and monitor infra-red emissions from a distance (giving a temperature read-out). This is a positive advantage, but the sensors are more expensive and less accurate when compared with those for contact measurement, and they are not always easy to use in practice. Some current commercial designs are 'wide angle', and give the average temperature of everything in their 'field of view'. For an ornamental crop such as poinsettia, for example, this can include not only stems and leaves, but also pots and compost (PC 207). This means that the sensor is failing to monitor those specific plant parts where condensation is

Graph 4 Temperature traces over a 24 hour period showing two occasions when the tomato stem temperature and dew point were very similar, and condensation became a serious risk (HH3611SPC)



thought most likely to occur. 'Narrow angle' sensors (Figure 5) can be more easily 'focused' on specific target areas and these may ultimately prove to be more useful.

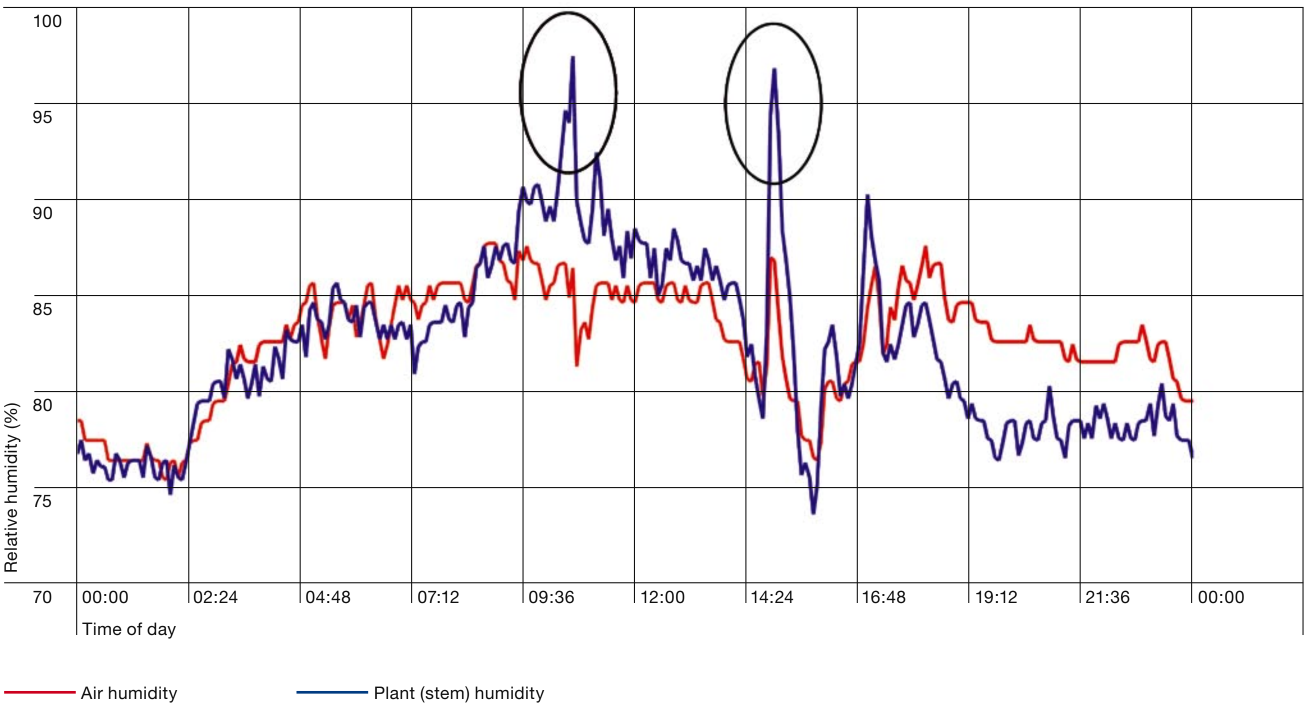
- Software models – perhaps the easiest approach to plant temperature monitoring is to use the computer models that are built into most modern climate control computers. They are easy to use, and there is no need for any specific installation work in the glasshouse or in the growing crop. It has to be borne in mind, however, that software models only give predictions of plant temperature, and their accuracy can be questionable.

Using plant temperature and plant humidity estimates for the avoidance of condensation

Air and plant temperatures can differ markedly as seen in Graph 4, and both can be used by modern environmental computers for the calculation and control of humidity. Using air temperature gives a humidity estimate representative of the air sampled in the measuring box (air humidity), but using plant temperature gives an estimate of humidity (plant humidity) close to the plants or the plant parts

5 Infra-red sensor used to measure plant or plant organ temperature

Graph 5 RH values calculated using the air temperatures (air humidity) and tomato stem temperatures (plant humidity) shown in Graph 4, with condensation risk periods indicated



being monitored. A plant humidity estimate of 100% RH, for example, will indicate that condensation on the plant surface is a real risk. The calculations for plant humidity assume that the absolute moisture content of the air near the plant is the same as that of the air passing through the measuring box. This is not always the case, but direct measurement in the canopy is presently judged not to be practical.

The potential value of using plant humidity for disease control is indicated in Graph 5 (previous page) which shows humidities based on the air and tomato stem temperature data in Graph 4 (previous page). It is very noticeable that the two estimates of RH frequently differ, and that the two critical near-condensation events show up only when humidity monitoring is based on stem temperature. A grower monitoring only air humidity would not have been aware of the potential disease risk!

Control based on the higher of either air humidity or plant (stem) humidity at any given time has been trialled with tomatoes at Warwick HRI (HH3611SPC). This combined strategy gives increased confidence that effective humidity control is being practiced at the plant surface, and enables a less aggressive approach than would otherwise be required for conventional control based on HD. Typically, the RH at night in the Wellesbourne trial was 5% higher than in the conventional regime giving energy savings, especially when combined with TI. However, by targeting the humidity control at times of increased risk of condensation, losses due to *Botrytis* were actually reduced.

Humidity control with thermal screens

Thermal screens can make humidity control in glasshouses more problematic than in ones without. However, good operational practices can minimise their impact. For example, screens can themselves be used as effective humidity control tools. This is because a screen in the closed position holds a significant amount of cold air above it and, like outside air, this 'sink' of cold air will have a lower moisture content than the air next to the crop. By allowing this dryer air to mix with the moisture-laden air below it, effective humidity control can often be achieved.

In practice, screen gapping is controlled in essentially the same way as minimum vent. Thus, a humidity influence is applied via the environmental computer so that the gap gradually increases to around 15% as humidity rises. Beyond this point, gapping has no further effect on humidity control and venting (with subsequent re-heating) is brought into play. Screen gapping and venting can be used together (Figure 6) but, it is common commercial practice to simply open the screen fully before moving on to venting and re-heating.

Reducing the leaf area

High leaf areas result in increased transpiration and, since energy is required to drive this process, the result is a higher humidity and a higher energy use. More energy will also need to be expended on such crops for humidity control.

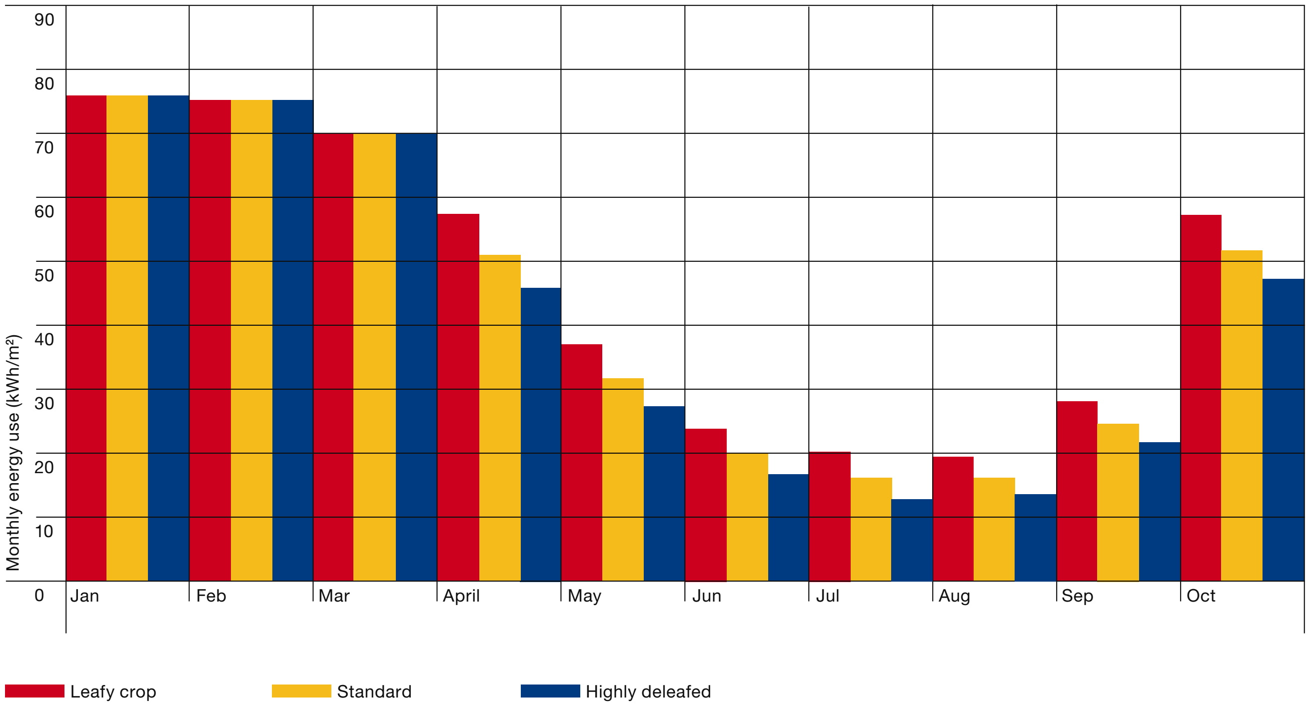
6 Screen gapping and venting in operation

It follows, therefore, that more aggressive de-leafing of high wire crops will result in energy savings. Simulations for tomato crops grown without humidity control show that taking off an additional six old leaves (to give a highly de-leafed crop with a leaf area reduced by an extra 35%), will reduce the energy use by 3.2%. However, when grown with a humidity control set-point of 90% RH (vent then re-heat), this saving rises to 5.8% (see Graph 6). The saving will be even greater when a more aggressive de-leafing strategy is applied to a particularly leafy crop.

This degree of de-leafing has been shown in trials at Wellesbourne to give no significant loss of yield, but it did show a slight increase in uneven fruit ripening. It can be expected that a more modest increase in the degree of de-leafing of old leaves of tomato will avoid this potential problem, and is worth trialling. It is probably also beneficial to leave more leaf on in summer to intercept the high light levels at this time of year. Furthermore, the additional transpiration will aid greenhouse cooling.

On-going HDC trials with pepper (PC 285) similarly indicate that leaf area can be reduced with no loss of yield, and the implications of this on energy use are to be investigated in 2009.

Graph 6 Effects of leaf area on monthly energy use in tomato (simulated using a model developed in HH3611SPC)



Further information

Factsheets in this series

- HDC Factsheet 05/09 – Energy management in protected cropping: Good housekeeping
- HDC Factsheet 06/09 – Energy management in protected cropping: Manipulation of glasshouse temperature
- HDC Factsheet 07/09 – Energy management in protected cropping: Humidity control
- HDC Factsheet 08/09 – Energy management in protected cropping: The use of screens
- HDC Factsheet 09/09 – Energy management in protected cropping: Horticultural lighting
- HDC Factsheet 10/09 – Energy management in protected cropping: Management of CO_2 enrichment

Additional information:

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