Project title:	Protected Ornamentals: Improved guidelines for humidity control and measurement and control when using advanced climate control strategies
Project number:	PC 207
Project leader:	C.W. Plackett FEC Services Ltd, Stoneleigh Park, Kenilworth, Warwickshire
Report:	Year 1 annual report, June 004
Key workers:	**FEC Services Ltd:** C.W. Plackett — Project leader C.T. Pratt — Project manager **Independent consultants:** H. Kitchener — Plant recording protocols & reporting Dr A. Langton — Plant physiology **Warwick HRI:** — Disease control strategy & assessment G. Hanks — Shelf life testing
Location:	Coletta & Tyson, Millbeck Nursery, East Yorkshire
Project co-ordinator:	A. Fuller, WJ Findon Ltd, Stratford upon Avon
Date project commenced:	1 August 2003
Date completion due	31st March 2005
Keywords:	Temperature Integration, Energy, Poinsettia, Humidity, Climate Control Computer, Ornamentals

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Grower Summary

1 Headline

Work on a commercial nursery in East Yorkshire during the 2003 production season has shown that temperature integration (TI) can be used to save energy and produce a successful Poinsettia crop. Energy savings of 16 kWh/m^2 (12%) were achieved.

No humidity control problems were experienced with either the TI strategy or the conventional control.

A comparison of a number of methods of humidity measurement shows that more accurate indications of the conditions being experienced by the plant can be achieved by taking measurements from within the crop canopy. Additional work to be carried out in year 2 of the project will continue to investigate crop canopy measurement methods and their use as a control input for a climate control system.

2 Background & expected deliverables

The Climate Change Levy, rising fuel costs and increasing pressure (both legislative and customer driven) to reduce energy use means that energy efficient production continues to be an important issue for all producers of protected crops.

A study trip to Denmark and Holland in 2001 (PC 172) concluded that the use of advanced control methods is an effective way of improving energy efficiency. Following this, work at HRI Efford in 2001 (PC 190) showed that the principles of temperature integration (TI) could be applied to a crop of pot chrysanthemum with minimal effect on plant quality and scheduling whilst delivering energy savings as high as 25 %. This was replicated on a commercial nursery on the south coast over the 2002 - 2003 heating season (PC 197) where energy savings of 12 % were recorded. Project PC 190 was also extended in 2002 to study Poinsettia production.

Whilst this work has adequately demonstrated the energy savings that can be achieved with TI control strategies, the technique has yet to achieve widespread commercial uptake. This is thought to be due to growers' fears that humidity control can be problematic with TI despite no such problems being encountered in the above projects.

This project builds on the findings of PC 190 by demonstrating the application of temperature integration strategies on a commercial nursery and concentrating on humidity measurement and control.

The objectives of the project were to:

- Develop improved guidelines for measuring and controlling humidity in commercial greenhouses producing ornamental crops.
- Demonstrate that, when used in conjunction with advanced climate control strategies (eg temperature integration), improved humidity and disease control and energy savings can be achieved.
- Promote an understanding of the fundamental principles that are applied when controlling humidity in a commercial greenhouse.
- Generate new information that can be used to train protected crop growers in better greenhouse environmental control methods and energy management.

3 *Summary of project and main conclusions*

3.1 Research method

A commercial Poinsettia crop was grown under two different climate control strategies (TI and a 'conventional' control) over the period August to December 2003. The work was carried out at Coletta & Tyson Ltd, Millbeck Nursery, South Cave, East Yorkshire. Treatments were applied to greenhouses with separate heating and ventilation systems. The area of crop grown under each treatment was 4,570 m^2.

Detailed greenhouse environment data was collected throughout the trial. Heat meters in each of the trial greenhouses were also used to record the energy use in each treatment. All energy use and environment data was collected and stored for future analysis using the host site's climate control computer.

A crop diary and a formal assessment of plant quality (at marketing) and shelf life were used to determine the effect of the two treatments on crop performance. Data from the host site's own crop records was used to support these formal analyses.

The performance of a number of alternative temperature and humidity measurement techniques were assessed. The methods used were:

- A conventional measuring box comprising aspirated wet and dry bulb temperature sensors. (*Normal*)
- A conventional measuring box modified to extract air from within the crop canopy. (*Canopy*)
- An electronic humidity sensor fitted to the *Canopy*. This allowed a comparison to be made with a conventional sensor within the same air stream. (*Electronic*)
- An infra-red camera located above the crop to measure the canopy temperature. (*Infra-red*)
- Solid state temperature probes located within the crop canopy. (*Probes*)

In addition two 'software sensor' measurements were taken. These were:

1. Crop temperature and the associated humidity. (*Plant*)
2. Top of Plant temperature and the associated humidity. (*Top of Plant*)

Both of these measurements are derived using software embedded within the Priva Integro (v722) climate control computer used on the trial site. These use a combination of calculations and measurements to determine the plant temperature and Top of Plant temperature. These temperatures are also used to compute the associated humidity values.

Throughout the project, data was analysed and compared in order that environmental control, crop performance and energy saving could be optimised within the commercial constraints that were imposed.

3.2 Results

Energy

The TI controlled glass used 16 kWh/m^2 (12 %) less than the conventionally controlled glass.

Humidity and temperature measurement

All the measurements recorded showed general agreement with those which could have been predicted through general analysis and calculation derived from the application of simple heat and mass transfer principles.

Specific findings for each of the measurement methods were as follows:

Conventional measuring box

The conventional measuring box output was shown not to be a true representation of the conditions experienced by the plant, especially when the crop canopy was fully developed.

Canopy measuring box

The *Canopy* measuring box gave a better match to the true conditions within the crop canopy. However the difference between this and the conventionally located measuring box was only significant once the crop canopy was fully developed and air exchange between the canopy area and airspace above it became restricted. Although this pattern was very much as expected, the project has proven the ability to measure it using standard equipment.

Electronic humidity sensor

The *Electronic* humidity sensor gave reliable and accurate information when compared with the wet & dry bulb sensor. However, long term stability and reliability is yet to be proven. A better indication of this will be available after the second year of this project.

Infra-red camera temperature sensor

The infra-red camera was found to work best once a full crop canopy had developed. Prior to this point the camera was only able to measure a combination of plants, pots and floor temperature. The camera also needed careful positioning (and re-positioning as the crop grew) to be effective. This aside, the most significant differences were seen during high light or rapidly changing light conditions. The ability to have an effect on these differences due to heat or vent is limited. Under these circumstances the value of IR temperature as a direct control parameter is questionable. However it may prove to be a useful indicator of plant activity or stress that a grower can use to modify their growing strategy.

Canopy probes

These *Probes* gave reliable and accurate information following the trends indicated by the other systems used. They can be considered to be a useful tool for assessing the accuracy of other measurements. Their application as a hybrid hard / soft sensor will be explored further in year 2.

Calculated *Plant* and *Top of Plant* temperatures

These calculated values showed some agreement with measured values (ie the *Infra-red cameral* and the C*anopy* measuring box). However, consistent correlation could not be achieved throughout the entire duration of the trial. Results indicated that a combination of *Plant* and *Top of Plant* values are required to be of practical use. Fine tuning of the software inputs is also required to provide reliable information.

Crop performance

Height measurements taken throughout the trial showed there to be no difference between plants grown in the conventional and TI treatments.

The crop assessments carried out at marketing produced some conflicting results. The in-house measurements made by Coletta & Tyson staff showed the conventional crop to have less colour than the TI crop. On the other hand an independent assessment carried out by a third party crop consultant gave the TI crop a quality score of 1.5 against the conventional crop with 1.8 (2 being the maximum and best possible score).

Independently conducted shelf life trials showed no statistical difference between the treatments with both crops performing well above the minimum requirement.

The commercial assessment concluded the overall quality to be good and no financial penalty was incurred as a result of using TI.

3.3 Conclusions

1. This project has again demonstrated that TI is a reliable way of reducing energy consumption without compromising commercial crop quality.
2. The humidity control limits commonly in use when growing a commercial crop of Poinsettia can be satisfactorily achieved when using TI.
3. A conventional measuring box does not give information that accurately characterises the conditions within the crop canopy of a Poinsettia crop. This is most notable once the

crop canopy is fully developed. Methods that sample in the crop canopy give more representative information.

4. Infra-red cameras are only of use when a full crop canopy has developed. Prior to this they measure an ‘average’ of plant, pot and floor temperatures. As such, infra-red cameras are of limited value as an input to environmental control. However, if positioned correctly they have the potential to provide feedback to the grower about plant condition and aid more general climate control strategy decisions.
5. The use of simple devices, such as a measuring box modified to sample air from the crop canopy or additional temperature probes within the canopy, can give a good indication of crop conditions and have potential for supporting climate control decisions and actions. However practical issues when using moveable benches may limit the ease with which they can be applied.
6. ‘Software sensors’ like those packaged with the Priva Integro system can give useful information to support climate control actions. However, they need to be carefully tuned to provide useful information and they can not be considered as being reliable throughout the full cropping cycle.
7. Based on the results obtained in 2003, a second year of the trial will be conducted in 2004. This will focus on two treatments, both based on TI climate control. Two humidity control methods will be used, one based on a conventional air sampling point and a second based on a sampling point within the crop canopy.

4 Financial issues

Energy saving

Typical energy use for a Poinsettia crop is around 140-160kWh $/m^2$/crop. The results of this project show energy savings of 16kWh/m^2 worth around 21p $/m^2$ (1.3p/kWh) can be achieved by successfully using TI. This is therefore worth a total of £2,100 /Ha/crop.

Crop performance

There were no statistically significant differences in the quality or scheduling of the crop between conventional and TI treatments.

Cost of implementation

Growers with relatively modern climate control computers may already have TI software installed. In these circumstances no additional capital investment is required to use TI and apply the recommendations from this project. However, some training of staff is likely to be needed and additional time will need to be devoted to the implementation and review of new climate control settings.

For other growers, software or hardware upgrades may be required, depending on the age and capabilities of the existing control system. The costs of these upgrades will range from approximately £5,000 /Ha for an upgrade to £15,000 /Ha for a new system.

Based on a gross benefit of £2,100 /Ha, payback times of between 2.5 and 7 years can therefore be expected. This calculation is based on a Poinsettia crop only. In practice growers are likely to be growing other crops at other times of the year, all of which will use energy and benefit from TI. If these are considered then the value of the saving is likely to be around £6,500 /Ha/annum. On this basis the payback will be between 1 and 2.5 years.

It is possible to apply TI control principles to climate control computers that do not have specialist TI software built in. Although there is no capital investment in this case, increased management time is required to ensure that the correct conditions are maintained. Energy savings are also likely to be less.

Upgrading a climate control computer will bring other long term benefits beyond those directly associated with TI. These include better crop management. These benefits can also be factored into the return from a new system reducing the payback on investment.

5 Action points for growers

- Growers should investigate how TI can be applied to their own individual facilities.
- Staff should be trained and updated in climate control issues, particularly humidity control.
- Growers should await the results from year 2 of this project for further guidance on improved humidity measurement and control procedures. These results will also provide further information on crop performance and energy efficiency.

Science Section

6 *Introduction*

6.1 Background

All protected horticultural businesses are under increasing pressure to reduce energy use. This is due to a range of factors including:

- **Economics –** particularly rising costs from higher fuel prices.
- **Legislation and Taxation –** such as Climate Change Levy (CCL) and the associated energy saving agreements.
- **Consumer Pressures –** customer expectations relating to reduced environmental pollution.

DEFRA statistics indicate that there is around 90 Ha of heated pot plant production in the UK. Typical energy costs are around £50,000 / Ha / annum. Therefore, the total energy cost for this sub-sector is around £4.5 million / annum.

A study trip to Denmark and Holland in 2001 (HDC project PC 172) concluded that the use of advanced greenhouse environmental control methods is an effective way of improving energy efficiency without compromising crop yield or quality. However some doubts remained regarding the level of savings that could be achieved and the limits on how far environmental control settings could be pushed without compromising crop quality. On this basis, HDC have supported a range of work to determine answers to some of these key questions.

Work has included a project carried out at HRI Efford (PC 190) which showed that temperature integration could be applied to a crop of pot chrysanthemum with minimal effect on plant quality and scheduling. The energy savings in this work were as high as 25 %. This work was replicated on a commercial nursery on the south coast of the UK over the 2002 - 2003 heating season (PC 197). Results showed energy savings to be 12 % with no recorded effect on plant quality. PC 190 was also extended to study a crop of Poinsettia in 2002.

Despite this background of research, the principles of TI have still yet to be widely exploited commercially. Up to now, the main reasons for the low level of uptake seem to be that growers continue to lack confidence in the technique, especially the ability to control humidity.

This project was designed to build on the results of projects PC 190 and PC 197 and accelerate the uptake of temperature integration by further demonstrating its application on commercial ornamentals nurseries growing a Poinsettia crop. The nursery participating in the trial was specifically chosen because of its northerly location and heating and control facilities available at the site. Both were considered to contribute to a difficult humidity control situation that stretch the likely limits for humidity control settings and determine subsequent energy savings.

6.2 Objectives

The objectives were as follows:

- To develop improved guidelines for measuring and controlling humidity in commercial greenhouses producing ornamental crops.

- Demonstrate that, when used in conjunction with advanced climate control strategies (eg temperature integration), improved humidity and disease control and energy savings can be achieved.

- To promote an understanding of the fundamental principles that are applied when controlling humidity within a commercial greenhouse.

- Generate new information that can be used to train protected crop growers in better greenhouse environmental control methods and energy management.

7 What is temperature integration and how does it work?

Previous work has shown that many plant species can be grown successfully at temperatures both above and below the optimum without detrimental effect, as long as the average temperature over a given period is maintained. There are clearly limits to the extremes of temperature and the time period over which the average is measured. However as long as these limits are adhered to it is possible to grow a plant at a higher temperature than is considered optimum as long as it is compensated for by a period of lower temperature.

Work previously carried out in this area is reviewed in the report for HDC project PC 188 - Part A (Plackett, Adams & Cockshull, 2002). This concept has been developed into a technique known as temperature integration (TI). Detailed information on TI, how energy is saved and its practical application are given in the final report for HDC project PC 197 (Pratt & Plackett, 2003). As background, the basic concept behind TI is described below.

7.1 Basic concept

To understand how TI reduces the energy required for heating we first need to look at the conventional approach to greenhouse temperature control.

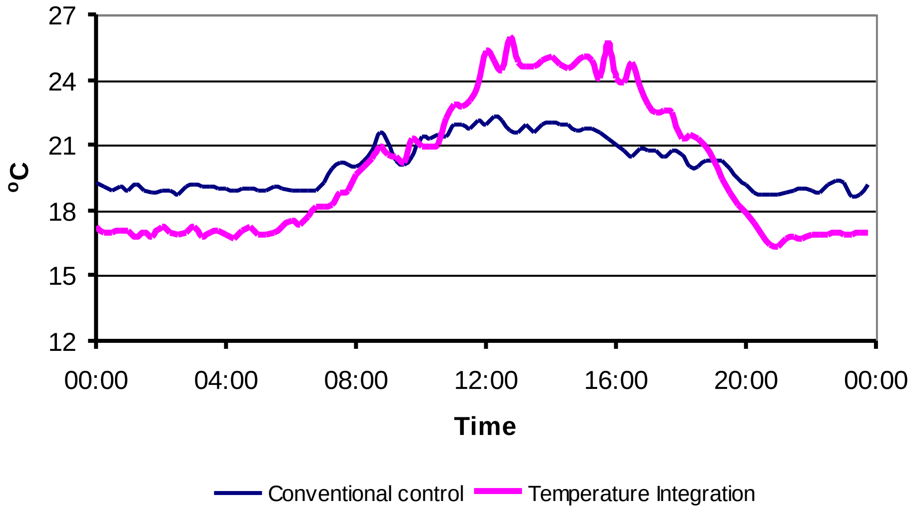
- During the daytime when solar gain in a greenhouse is high and the temperature rises above the heating set point, the vents in the roof open to help control the temperature.
- During poor weather conditions and during the night when heat loss from the glasshouse is high, heat is required to maintain the temperature.
- In both cases the temperature at which the vents start to open (ventilation temperature) is typically 1 – 2 ^{o}C higher than the heating set point. This helps to give accurate, responsive control of both temperature and humidity.

In contrast the approach taken with TI in its simplest form is as follows:

- The ventilation temperature is increased in relation to the heating temperature.
- During the daytime, the vents do not open until the temperature rises significantly above the heating temperature. Any increase above the heating temperature is the result of solar radiation which is effectively free energy.
- During the night-time, assuming that conditions during the day have been good and degree-hours are in surplus, the heating temperature is reduced so that the average temperature remains the same. Therefore reducing the energy requirement to heat the glasshouse.

Fig 1 below shows a classic temperature profile for both a conventionally operated and TI operated greenhouse. The area between the lines during the middle of the day when the TI greenhouse is warmer than the conventional one is offset by the area between the lines during the night when the TI greenhouse is cooler. The average temperature in both cases is 20 ^{o}C.

Fig 1 - A comparison between conventional and TI greenhouse temperatures



From the description above it can be seen that the fluctuation in temperature inside the greenhouse with TI is somewhat different to that experienced with a conventional strategy. It is this change in temperature profile that alarms growers when considering humidity control.

Growers of ornamental crops almost exclusively control humidity based on relative humidity (RH) set points. RH is a measure of how close the air inside the greenhouse is to saturation. The closer the air is to saturation (100 % RH), the greater the risk of condensation.

To control humidity levels, the grower uses either heating or ventilation (or a combination of the two). This has the effect of either increasing the moisture carrying ability of the air (heating) or exhausting the moisture to atmosphere (ventilation). Both these actions will have an effect on the energy use of the greenhouse and are likely to lead to a higher demand for energy.

As TI tends to employ a wider operational temperature band and greater temperature swings than conventional control, there is greater inherent potential for the RH in the glass house to be pushed towards unacceptable (higher) levels.

The existence of localised micro-environments, within the crop canopy and at different positions around the glass, means that generalised control based on 'average' air conditions above the crop may well be too ‘coarse’ to consistently and reliably avoid ‘risky’ RH conditions.

8 *Review of humidity measurement methods*

During the initial phases of this project the current best practice for commercial greenhouse humidity measurement was reviewed. This included consideration of any recent developments in equipment.

8.1 Conventional methods

The majority of systems continue to rely on the wet and dry bulb aspirated screen (commonly known as a measuring box) as the primary method of determining greenhouse humidity. Electronic humidity sensors are now commercially available but their use on commercial nurseries is limited because of:

- Poor reliability – this stems principally from the fact that some sensors can be ‘poisoned’ by certain crop protection chemicals.
- Accuracy of measurement – commercial experience has shown older sensors to be less accurate at high RH (>90 %).
- Cost – both initial purchase and maintenance. With no serviceable parts, complete replacement is the only option when a fault occurs.

Manufacturers claim to have addressed both the reliability and accuracy issues. However the cost remains high.

The potential benefits of electronic sensors are:

- Reduced regular maintenance – no replacing wicks, or topping up water reservoirs.
- Improved accuracy and reliability – the main cause of problems with wet / dry sensors is the lack of regular checks on the wick and water level. Removing the need for this should therefore improve accuracy.

Some electronic sensors can be retrofitted to existing wet / dry measuring boxes, thereby aiding the ease of conversion to the newer system.

8.1.1 Measuring box location

The position of the measuring box is of paramount importance as the air sampled must be representative of the conditions in the greenhouse. Also the data obtained must be relevant to the reason for its collection. For example, is the system there to determine the risk of disease, or to manage the glasshouse environment to maximise crop growth or both?

It is possible that a location that best reflects potential disease development is not the best for crop growth. In a tall crop canopy, for instance (eg tomatoes, cucumbers and stem flowers) the point of greatest disease risk may be at the base of the stem. But, the point of greatest growth and photosynthetic activity is in the upper part of the crop. Even with compact, dense canopy pot plants such as Poinsettia, the air condition measured just above the crop is likely to give better information to the climate control computer to optimise growth, than if air was sampled within the crop canopy itself. The conditions in the canopy would be of greatest importance when considering disease development.

The ideal solution would be to have measuring boxes sampling both positions. Both measurement positions would influence heating and ventilation but with different settings to achieve their specific objectives.

Most common designs of measuring box do not facilitate drawing air from within the canopy of crops such as Poinsettia. They are generally too large and cause an excessive amount of air movement at the sampling point. This disturbance affects the condition of the air to such an extent that it may no longer represent the true conditions in the canopy.

The measuring box should not be positioned where it can be influenced by heating pipes, vents, screens, lights etc. These items adversely affect the condition of the air being sampled. For example:

- Heating pipes – warm air rising from pipes leading to a higher temperature and lower RH being measured.
- Vents – a location directly under a vent will normally lead to a lower measured temperature when the vent is open. This will also distort the humidity measurement. Completely avoiding the positioning of measuring boxes near to vents can be difficult in modern Venlo type glasshouses. If this is a problem a location furthest from a lee side vent should be chosen. The wind side vent will only normally be open when glasshouse temperature is especially high and will therefore have least impact.
- Lights – these have a similar effect to heating pipes. Most commercial measuring boxes are coloured white to reflect radiant heat from lights and avoid solar gain.
- Screens – it is common to see measuring boxes suspended from a trellis beam, directly below the gap created when a screen opens. When the screen is opened (or gapped) the cold air from the gap drops directly onto the measuring box. This produces an erroneous reading and the potential for energy waste.

Typical current commercial practice is to:

- Position the measuring box 20 to 40 cm above the canopy of an ornamental crop.
- Suspend the box from the trellis beam.
- Locate the box close to a path for easy access.

So, practical considerations are often put before the need to measure accurate and repeatable data that best represents the greenhouse environment.

8.1.2 New developments

A number of new techniques have been recently developed that have the potential to improve the accuracy of humidity measurement. All of the techniques are based on the requirement to characterise the conditions within the crop micro-environment as opposed to the global environment in the greenhouse. Key methods are as follows.

8.1.3 Infra-red cameras

An infra-red camera determines the plant temperature through measurement of the infra-red radiation being emitted by the plant. This is done without making physical contact. This has several benefits including:

- No distortion of plant temperature from the thermal inertia of a physical ‘sensor’.
- No distortion of measured plant temperature by the effect of air conditions around the plant.
- Fast response with no lag caused by the thermal mass of a physical ‘sensor’.
- Only limited physical repositioning of the sensor is required as a result of plant growth and movement.

Despite the widespread commercial availability of infra-red cameras, information on their specific application in greenhouse environmental control is limited.

8.1.4 Calculated plant temperature & humidity

Some climate control computers use embedded software to calculate the temperature of the plant. This is subsequently used to determine the humidity within the plant canopy. The software is based on heat and mass transfer models which work in combination with measured air condition and global radiation values. These systems are sometimes referred to as ‘soft sensors’. A number of edibles growers with Priva Integro climate control computers use the ‘plant humidity deficit’ facility on that equipment. This is an example of the commercial use of one of these software based approaches.

The host nursery for this project uses a Priva Integro computer with this facility. As a result the following values were calculated and recorded throughout the trial.

8.1.4.1 *Plant* temperature

This is essentially the calculated temperature of the plant where it is not in direct sunlight. The software model takes account of the plant’s thermal inertia and changes in general greenhouse temperature. So, if the air temperature changes rapidly, the plant temperature changes more slowly leading to a transient difference in temperature between the air and the plant. These effects are shown in Fig 2

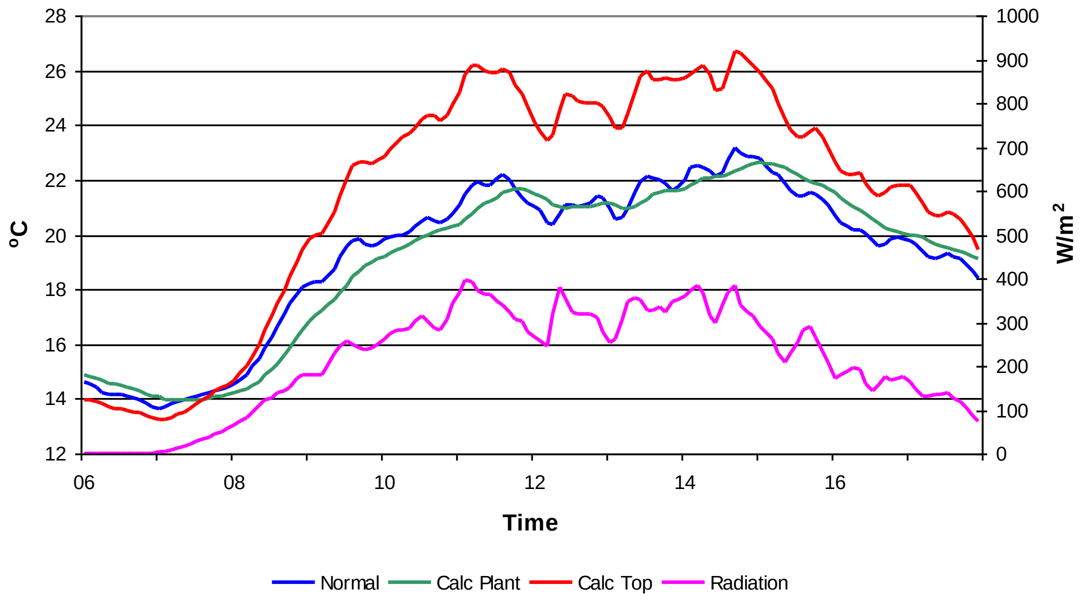
8.1.4.2 *Top of Plant* temperature

This is the temperature of the plant in direct sunlight. Therefore in addition to the thermal inertia of the plant (as accounted for by the plant temperature) the heating effect of solar radiation is taken into account. This means that the *Top of Plant* temperature can be higher than the air temperature when solar radiation is high and when it suddenly rises.

A second effect that is taken into consideration is the plant radiating heat during the night. This can give a plant temperature lower than the air temperature in the greenhouse.

Fig 2 below shows how calculated *Plant* and *Top of Plant* temperatures vary compared to the conventional temperature measurement.

Fig 2 – Calculated Plant & Top of Plant temperature



8.1.4.3 *Plant* RH & HD, *Top of Plant* RH & HD

In all these cases the calculated *Plant* or *Top of Plant* temperature is used in conjunction with the condition of the air (as measured by the measuring box). The humidity conditions at the *Plant* or *Top of Plant* are calculated by taking the absolute humidity (AH) from the measured air conditions. The temperature used in the calculation is assumed to be the same as the *Plant* or *Top of Plant*. The RH or HD can then be determined by calculation. The same calculation can be carried out using the temperature measurement made by an infra-red camera.

For example, assume that the following air conditions are determined at a measuring box.

- Air temperature 20 °C.
- RH 85 %.
- AH 14.8 g/m^3.

Under these circumstances the ‘soft sensor’ Plant temperature might be 19 °C. This is because the measured air temperature has risen rapidly in the morning and plant temperature is lagging behind. The climate control computer assumes that the AH around the plant is the same as that measured by the measuring box. Therefore the conditions at the surface of the plant are assumed to be 19 °C with an AH of 14.8 g/m^3. This equates to an equivalent RH of 90 %.

In the same situation the calculated Top of Plant temperature may be in the order of 22 °C. Assuming the same AH, the equivalent RH here would be 76 %.

Depending on which measurement is taken, and what the critical RH is judged to be, corrective action may or not be necessary.

8.2 Measurement system assessment

Based on the information reviewed and bearing in mind both the objectives of the project and the technology that is commercially available, the following measurement systems were used to carry out the trials described in this report:

- Wet & dry measuring box suspended 30 cm above the crop canopy, in the middle of a bay (*Normal*).
- Wet & dry measuring box modified to extract air from within the canopy whilst causing the least air disturbance (*Canopy*).
- An electronic humidity sensor fitted to the *Canopy* measuring box. This allowed a comparison to be made between the two sensor types within the same air stream (*Electronic*).
- Infra-red camera located above the crop to measure the canopy temperature (*Infra-red*).
- Solid state temperature sensors located within the crop canopy. This allowed an assessment of their suitability as a robust, low tech, low cost means of measuring canopy temperature to be carried out (*Probes*).

Fig 3 shows a close up of the *Canopy* measuring box. The white plastic pipe was 50 mm in diameter and 3 m long. A total of 60 x 12 mm diameter holes were spaced on the underside along its length to ensure even air sampling along its length and minimal restriction of airflow to the measuring box. An additional sensor can also be seen mounted through the side of the measuring box. This is the electronic RH sensor.

Fig 3 – Canopy measuring box

Fig 4 – Infra-red camera

Fig 5 – *Normal* next to C*anopy* with infra-red camera in foreground

9 *Research Method*

9.1 Overview of location, facilities and cropping

The project was carried out at Coletta & Tyson Ltd's Millbeck Nursery, South Cave, East Yorkshire.

Two greenhouse blocks (Block A and Block B) were used for the work. Each of these blocks cover a ground area of 9,542 m^2. The greenhouses are of a Venlo design and were constructed approximately 30 years ago. Gutter height is approximately 3 m.

The greenhouses were originally built for cucumber production. Following the purchase of the site by Coletta & Tyson Ltd in 2002, modifications were made to make them suitable for ornamental crop production. This included moving the 'pipe rail' heating pipes to a mounting point on the greenhouse stanchions and laying black 'Mypex' material on the greenhouse floor. Modifications were also made to the irrigation system.

No thermal screens are installed in the house and despite the availability of CO_2 enrichment facilities, these have been de-commissioned.

2003 was the first year that a Poinsettia crop had been grown in the facility and, because of the greenhouse design and its northern location, it was envisaged that humidity control problems might be experienced. For this reason this site and facility were judged to be ideal for this project.

The climate control computer at the site is a Priva Integro v721. This computer comes with temperature integration (TI) facilities as a standard feature. In addition the 'software sensor' facilities previously described in Section 8.1.4 were also available.

9.2 Data collection

Glasshouse environment and energy use data was recorded using the site climate control computer. Information was downloaded via modem connection at weekly intervals throughout the project. This was done remotely from the FEC office in Warwickshire. Data recorded included the following:

Weather data

- Outside temperature.
- Global radiation.
- Wind speed.

Glasshouse control and equipment data

- Set points – calculated heating & ventilation temperature.
- Heating system – calculated & measured heating pipe temperatures.
- Ventilation system – measured vent position.

Energy use

- Heat meters were installed in each heating circuit. This enabled energy use to be accurately determined.

Crop data

- Routine measurements relating to crop development (height) were taken by nursery staff.
- Graphical tracking of crop development was carried out using the HDC Poinsettia Tracker software.
- Plant quality was formally assessed at the time of marketing by Mr H Kitchener.
- Shelf life assessment was carried out at HRI Kirton.

Glasshouse environmental data

The measuring equipment as detailed in Section 8 was installed. Table 1 below lists the measurements and the recorded / calculated data derived from each piece of equipment.

Table 1 – Glasshouse environmental data recorded

	Normal	***Canopy***	***Infra-red* camera**	**Canopy *Probes***
Dry bulb temperature (^{o}C)	□	□	□	□
Relative Humidity (RH -%)	□	□		
Humidity Deficit (HD – g/m^3)	□	□		
Dew point temperature (^{o}C)	□	□		
Calculated plant temperature (^{o}C)	□			
Calculated Top temperature (^{o}C)	□			
Calculated RH (plant -%)	□			
Calculated HD (plant-g/m^3)	□			
Calculated RH (Top - %)	□			
Calculated HD (Top – g/m^3)	□			
Calculated RH (infra-red - %)	□		□	
Calculated HD (infra-red – g/m^3)	□		□	

9.3 Treatments

There were two different environmental control treatments:

1. Conventional.
2. Temperature Integration (TI).

Common elements applied to both treatments were as follows:

- Both were controlled according to the temperature and RH as measured by the conventional measuring box (*Normal*).
- The target average temperature was the same in both treatments. In practice this meant adjusting settings in the TI treatment to achieve the same average as that achieved in the conventional control.

- Drop was applied using identical heat and vent set points in both treatments. In practice this meant turning TI off for the duration of the Drop period.
- The same RH control thresholds were applied in both treatments. In practice this meant that settings were applied to ensure that the RH was not allowed to exceed 88 % for more than 30 minutes.

9.3.1 Temperature Integration

The TI settings were regularly reviewed and modified where necessary to:

- Achieve the same average temperature as in the control treatment.
- Achieve RH control as defined above.

The operating ranges that were allowed were as follows:

- The day time heating temperature was equal to that used in the control treatment.
- A minimum greenhouse temperature was set to 15 ^{o}C for the period from 1 hour before sunset to the start of the Drop period.
- Ventilation temperature was set to a maximum of 26 ^{o}C when the RH was <75 %.
- The integrating period was 7 days.

10 Results & discussion

10.1 Climate control

10.1.1 Climate control diary

Table 2 below gives an overview of the significant events in the 2003 cropping season.

Table 2 – Climate control diary (2003)

Week	Notes
34	Plants moved from rooting to trial glasshouse compartments.
36	TI turned on mid-week.
37	Active RH control required in the TI treatment especially during the night due to low heat demand and a developing crop.
38	No minimum pipe temperature used during the Drop period in the control treatment to help get a better Drop effect. Note TI treatment did this from the start.
39	Active RH control required in the control treatment.
40	RH control fully optimised in both treatments.
45	TI turned off, deteriorating weather meant there was no ‘free’ energy for simple TI to use. This also served as a benchmarking period.
46	Continually deteriorating weather conditions meant that heat demand for temperature control adequately controlled RH by default. Therefore no active RH control was required from this week onwards.
47	No venting required from now on in both treatments due to low outside temperature and low light levels.
48	Drop period used in TI but not in the control treatment.
49	Crop sold.

10.1.2 Climate control strategy

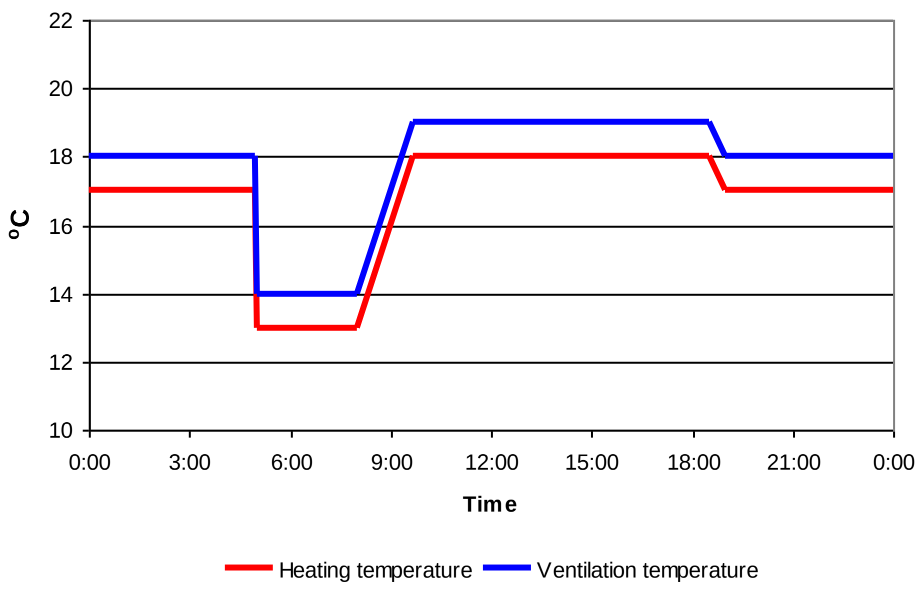
The following describes the basic approach to climate control (both temperature and humidity) in both treatments. The absolute values of the set points, particularly heating and ventilation temperatures, are indicative only as those applied in practice were varied according to crop requirements.

10.1.2.1 Control treatment

Fig 6 below shows the heating and ventilation strategy as typically applied to the control treatment. Key features were:

- The heating temperature was normally higher during the day than at night.
- The Drop period started 30 minutes before dawn and gave an instant reduction in both heating and ventilation temperature.
- Following the end of the Drop period the temperature was allowed to rise slowly to the day temperature (20 minutes / ^{o}C). This was to avoid rapid rises in temperature that might ultimately cause condensation on cold plants or pots.
- At the end of the daytime period the temperature was reduced at a rate of 2 ^{o}C / hour. This was to allow the temperature to fall naturally through heat loss rather than through additional venting.
- As long as the RH was at an acceptable level, the ventilation temperature was 1 ^{o}C higher than the heating temperature.
- The daytime heating temperature was increased using a radiation influence. The value of the influence was determined by nursery staff according to plant development.

Fig 6 – Typical control treatment heat & vent strategy



10.1.2.2 TI treatment

As previously described in Section 10.3.1, the aim of the heating and ventilation strategy in the TI treatment was to deliver the same average temperature as achieved in the control treatment. In addition to this general aim a number of specific 'rules' were applied. Again these are detailed in Section 10.3.1.

Drop

Using heat to maintain a specific night time temperature, and then opening the vents to rapidly reduce it, clearly wastes energy. A much better approach is to gradually reduce the heat & vent temperatures so that the temperature naturally decays to the level required by sunrise. Where screens are installed, most of this reduction in temperature can be achieved by simply opening the screen.

It is a common misconception that it is the rapid reduction in temperature that achieves plant height control. Advice from Dr Allen Langton suggested that Drop works as a result of sustained lower temperatures between dawn and dawn +3 hours and is not linked to the rate at which Drop temperature is achieved. Therefore in the TI treatment the heating and ventilation temperatures were not reduced instantly (as was used in the control treatment). Heating and ventilation temperatures were gradually reduced to the same level as used in the control treatment to avoid the need for venting.

Fig 7 – Typical TI treatment heat & vent strategy

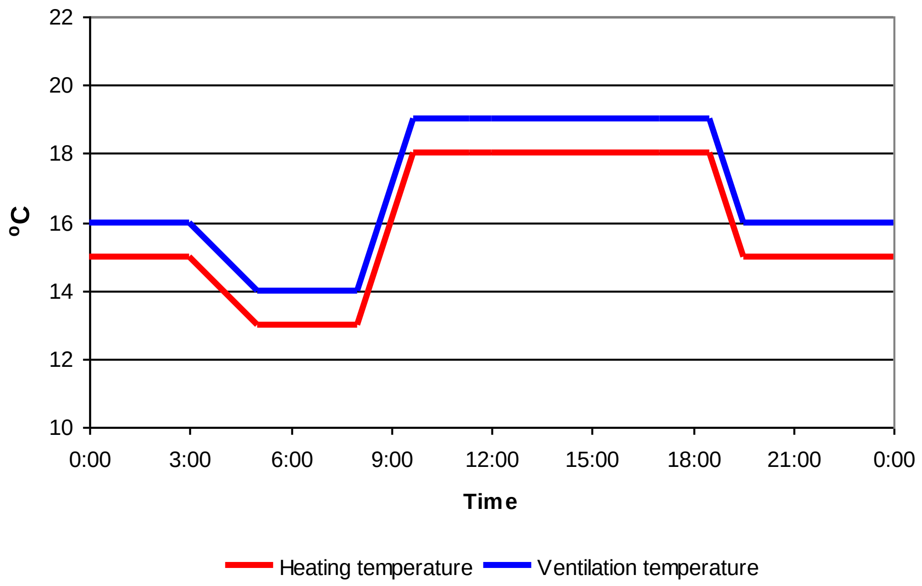


Fig 7 shows a heating temperature during the night equal to the minimum allowed (15 ^oC). This only occurred when sufficient spare degree-hours had been accumulated. It should be noted that the graph does not show any increase or decrease in ventilation temperature due to humidity influences as discussed in Section 10.1.2.3.

10.1.2.3 Humidity control

The settings used to control humidity were chosen based on a 'vent then heat' approach rather than the more conventional 'heat then vent' used by many growers. In practice a true 'vent then heat' approach is not possible but the underlying principles can be applied to achieve energy savings.

Coletta & Tyson's technical manager and the site manager set the following humidity control target:

- An RH of 85 % or less is ideal.
- A steady RH of up to 88 % is acceptable.
- As the RH rises above 85 % humidity control settings should start to take effect.
- The RH should only exceed 90 % for short periods – typically less than 30 minutes.

These settings were modified to achieve the required level of control with fine tuning, as the crop developed. At week 40 the same humidity control settings were applied to both treatments. They then remained unchanged for the remainder of the project.

The settings used from week 40 onwards are detailed below.

Pump On / Off control

Pump control remained at the default settings of:

- Pump On if the calculated pipe temperature was more than 5 ^{o}C above the glasshouse temperature.
- Pump Off if the calculated pipe temperature was more than 3 ^{o}C below the glasshouse temperature.

Minimum pipe temperature ('minimum pipe')

The basic minimum pipe setting was 10 ^{o}C. Humidity influences were then applied as follows:

RH %	Increase in MP ^{o}C	Resulting minimum pipe set point ^{o}C
80	0	10
85	5	15
90	12	22
95	20	30

A minimum pipe temperature of 22 ^{o}C may seem to be very low. In practice, as soon as the pump turned on, a pipe temperature of 30 - 35 ^{o}C was delivered. This was because the mixing valve did not fully close. As a result the settings described above were essentially used as a means of humidity related pump control and the minimum pipe temperature actually delivered by the heating system was 35 °C.

Ventilation temperature

The basic heating and ventilation strategy, excluding any influences, was set so that the ventilation temperature was 1 °C above the heating temperature. The following humidity influences were then applied.

RH %	Influence on ventilation temperature °C	Resulting heat – vent differential °C
* 75	+3.0	4.0
85	0	1.0
90	-0.5	0.5
95	-1.0	0

* This influence was only applied to the TI treatment. The actual amount the ventilation temperature was increased by was determined by the average temperature achieved. For example, if the average temperature in the TI treatment was higher than in the control then the size of this influence was reduced and vice-versa. The absolute maximum ventilation temperature allowed in the TI treatment, including all influences, was 26 °C.

No minimum vent settings were used.

10.2 Glasshouse environmental data

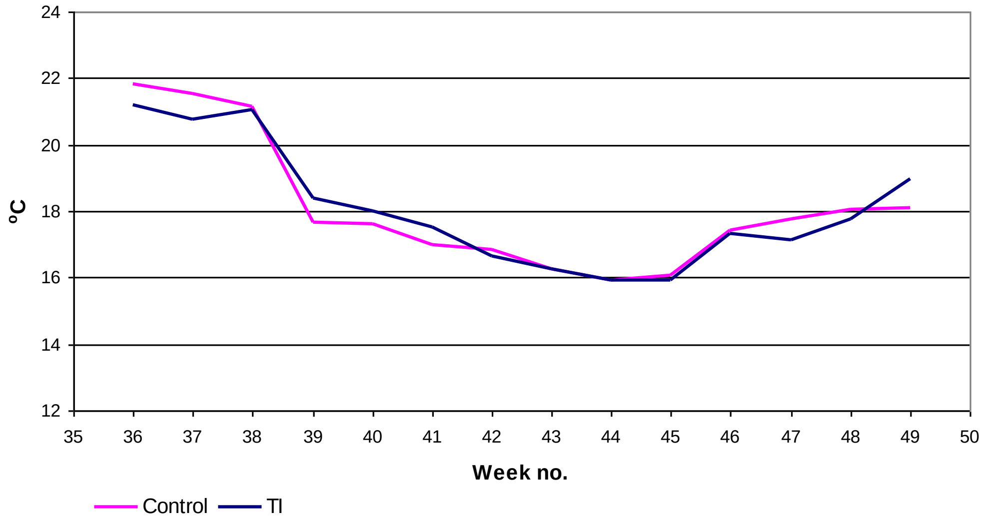
10.2.1 Temperature

All of the data in this section relates to the temperature measured by the conventionally positioned measuring box.

Fig 8 overleaf shows the average temperature in each treatment on a week by week basis. Over the complete production period (week 36 - week 49) the average temperature in both treatments was 18.1 °C. Between weeks 36 - 38 high outside temperatures coupled with high light levels meant that the vents were fully open in both treatments during the daytime to keep the temperature as low as possible. However TI applied a much lower heating temperature during the night which resulted in a lower average temperature.

The only significant difference after this period was towards the end of the trial (week 49). At this point TI was no longer being applied and the Drop period had been removed from the control treatment for cropping reasons. This had the effect of increasing the average temperature achieved in the control treatment. As the Drop period spanned sunrise it also had the effect of increasing the average day and night temperatures.

Fig 8 – Average 24h temperature



The average day temperatures in Fig 9 below show that the TI treatment consistently achieved a higher daytime temperature between weeks 39 – 42. This coincides with the period when the greatest energy savings were made. From week 43 onwards there was little difference due to the deteriorating weather conditions. As a result TI was turned off in week 45.

Fig 9 – Average day temperature

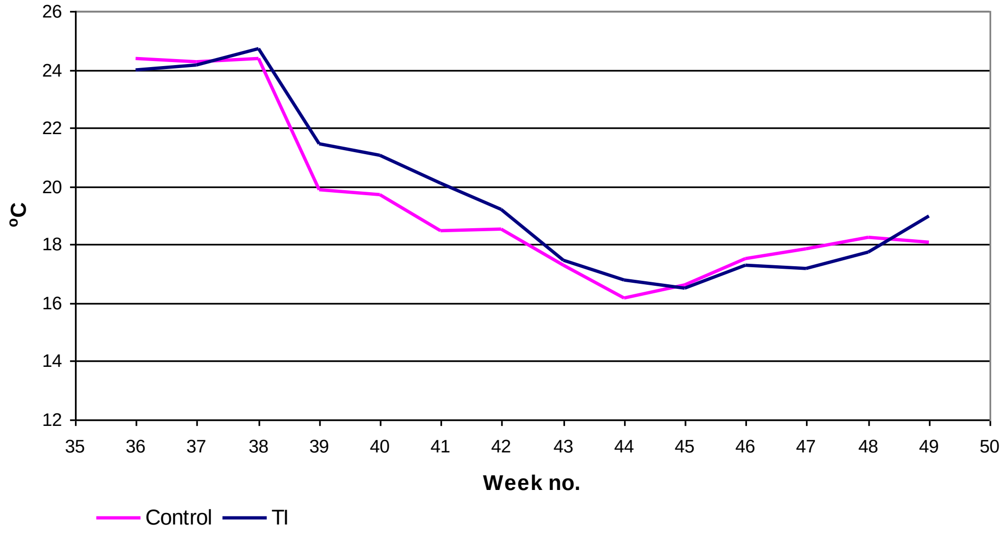


Fig 10 – Average night temperature

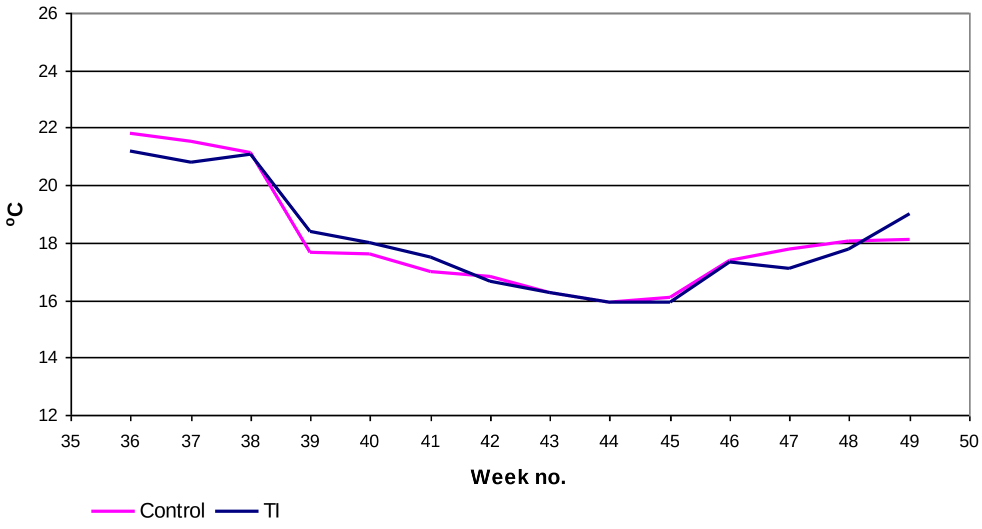
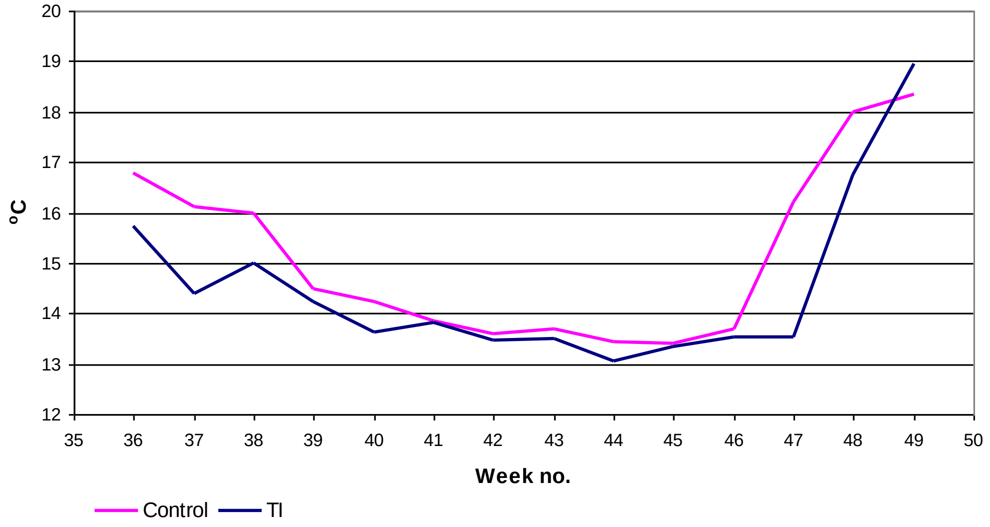


Fig 10 above shows the average night time temperature. Apart from weeks 36 – 38 there appears to be little difference between treatments. This is surprising as a lower temperature in the TI treatment would have been expected. This is mainly the result of higher temperatures being carried over from the daytime period into the night in the TI treatment. This compares to the control treatment where some venting tended to occur as the night time settings were applied.

Fig 11 overleaf shows the average glasshouse temperature from sunrise to sunrise + 2 hours. This gives an indication of the conditions where Drop is most effective.

Up to week 40 the TI treatment achieved a much lower temperature during this period than the control. This is because the temperature prior to the Drop period was normally lower and therefore the target temperature was more easily achieved. In addition, until week 38, a 30°C minimum pipe temperature was retained in the control treatment. From week 41 onwards, much reduced outside temperatures during this period meant that the target heating temperature was consistently reached in both treatments. During weeks 47 - 48 the temperature was much lower in the TI treatment. This was because the Drop period was removed from the control treatment in week 47 whereas it was not removed until the end of week 48 in the TI treatment.

Fig 11 – Average temperature during the first 2 hours of the Drop period



10.2.2 Humidity

All of the data in this section relates to conditions measured by the conventionally positioned measuring box and is shown in figs 12 – 14.

As would be expected in the TI treatment the RH was consistently higher when TI was most active. This is due to reduced venting during the daytime and reduced heating during the night. However it never exceeded the levels specified by the nursery.

As weather conditions deteriorated, increasing heat demand and the decreasing ability of TI to save energy meant that the RH became very similar in both treatments.

Fig 12 – Average RH

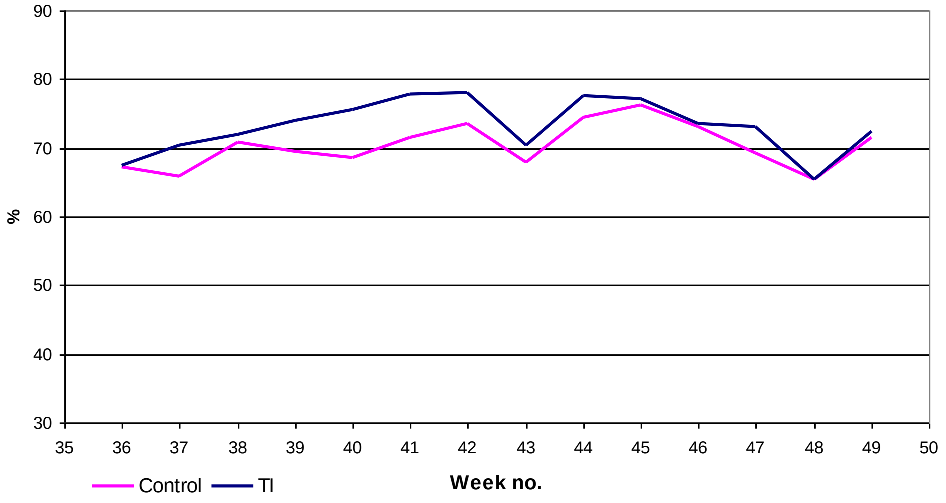


Fig 13 – Average day RH

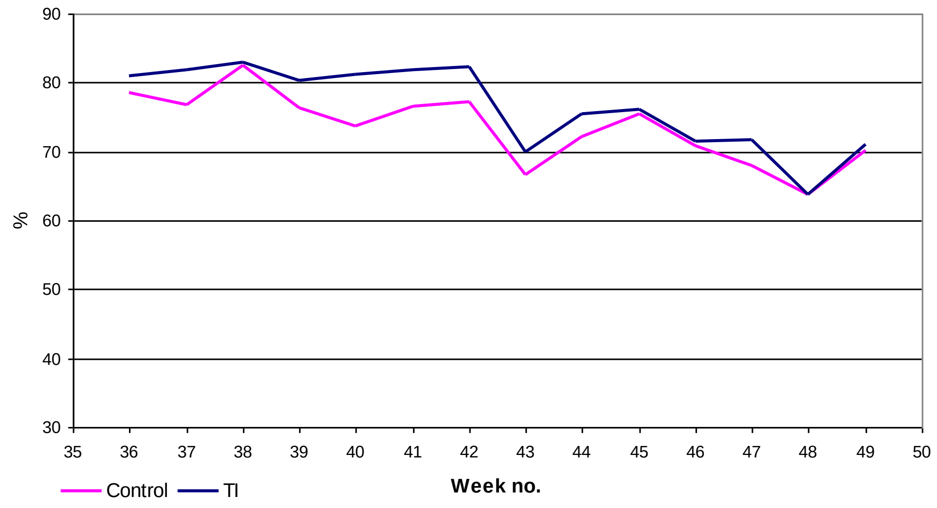
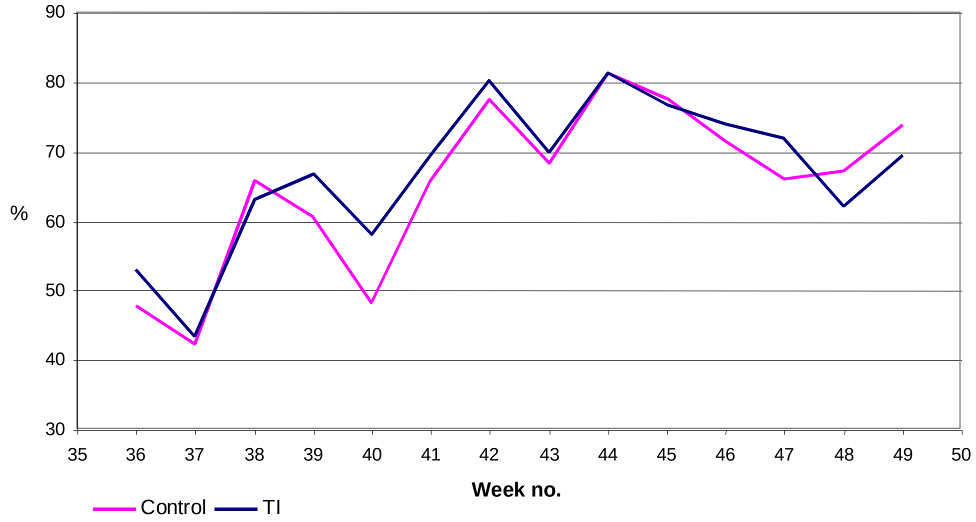


Fig 14 – Average night RH



10.2.3 Alternative environmental measurement methods

10.2.3.1 Temperature

Four different temperature measurement systems were used:

1. Air temperature – conventionally located measuring box. (*Normal*)
2. Air temperature – measuring box extracting air from within the crop canopy. (*Canopy*)
3. Air temperature – measured using a simple probe located within the crop canopy. (*Probes*)
4. Plant temperature – using an infra-red camera. (*Infra-red*)

In addition two calculated temperatures were also recorded:

1. Calculated plant temperature. (*Plant*)
2. Calculated Top temperature.(*Top of Plant*)

More detailed descriptions of these measurements are given in Section 8.1.4.

The following comparisons have been made with the temperature measured by the conventional measuring box.

Infra-red* & *Top of Plant

Infra-red measures the surface temperature of the crop canopy whereas *Top of Plant* is the canopy surface temperature as calculated by the climate control computer. Therefore if these two methods are both accurate the data should be identical.

Fig 15 overleaf shows a typical week early in the trial when light levels were still high and crop canopy development was still minimal. First impressions suggest that the *Top of Plant* temperature is overestimated whenever radiation exceeds 100 W/m^2. However spot readings with a handheld infra-red thermometer in high light conditions showed that a single leaf in direct sunlight could easily have a temperature > 30 ^oC even when the air temperature was <30 ^oC. Therefore suggesting that *Top of Plant* is more accurate than *Infra-red*. Add to this the fact that the part developed crop canopy meant that some of the area measured by the *Infra-red* camera included a proportion of greenhouse floor, compost and pot and questions are raised about the validity of the *Infra-red* measurement in these conditions. Care must therefore be taken when using an *Infra-red* measurement and it must be ensured that a representative measurement is being made.

Fig 15 – Week 38 control treatment

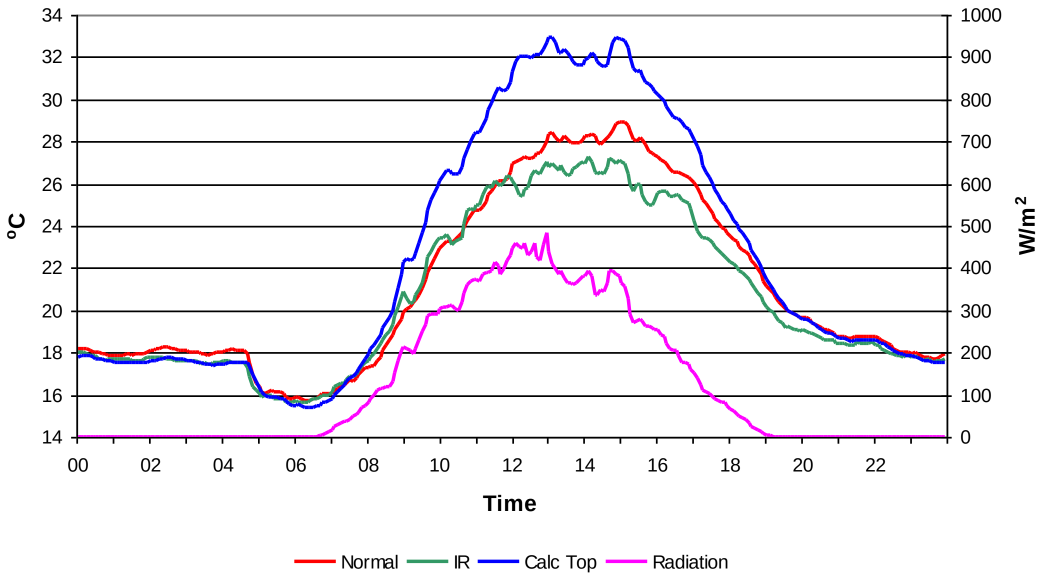
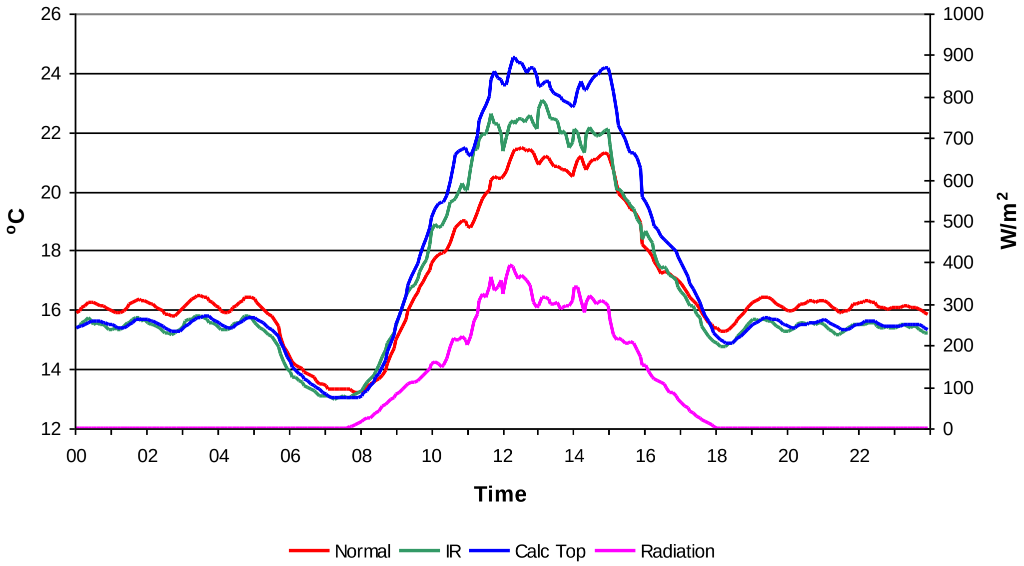


Fig 16 below shows the same measurements but 4 weeks later when the crop canopy was fully developed. *Infra-red* and *Top of Plant* temperatures are now closer but *Infra-red* is still around 2 °C lower in the middle of the day.

Fig 16 – Week 42 control treatment

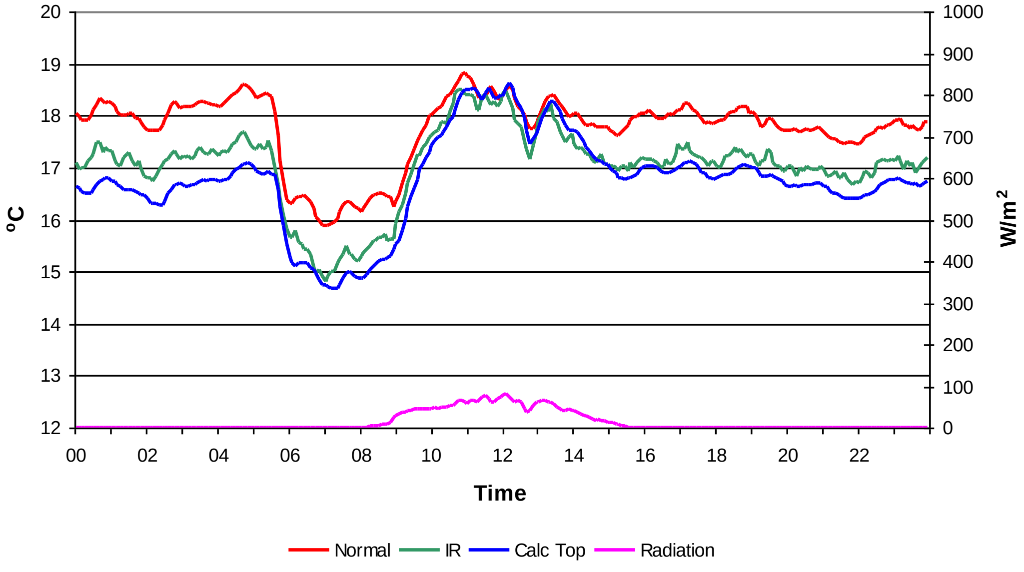


In both examples there was good agreement between *Infra-red* and *Top of Plant* during the night and both were consistently lower than the normal temperature measurement. This was very much as expected and can be explained by the radiated heat loss from the crop during the night. The difference averaged around 0.6 ^oC.

Moving on towards the end of the 2003 trial in week 47, further differences became evident. This is shown in Fig 17 below. During the night time the *Infra-red* temperature was typically 0.9 ^oC lower than the *Normal*. Calculated *Top of Plant* was a further 0.6 ^oC lower. In this case the previously good correlation between *Top of Plant* and *Infra-red* had become worse and, although the lower *Infra-red* temperature can be accounted for by a lower outside temperature (and the resulting increased radiant heat loss), the only explanation for the change has to be errors in how the software-based *Top of Plant* temperature is calculated.

During the brief daytime period in week 47 there is only a small difference between all the temperatures and the *Infra-red* and *Top of Plant* temperatures agree well. However low light levels at this stage meant that the effect of solar radiation on plant temperature was minimal.

Fig 17– Week 47 control treatment



Canopy measurement, *Probe* & calculated *Plant*

Early in the trial when canopy development was minimal there was little difference between the *Normal*, *Canopy* and *Probe* measurements. However some predictable trends were apparent even at this stage.

- Although the *Normal* temperature fell to less than 14 °C during some of the Drop period, the temperature within the canopy was kept at around 0.5 °C higher.
- During the morning ‘warm up’ period the calculated *Plant* temperature responded more slowly than the other measurements.
- During the middle of the day both the *Canopy* and *Probe* temperatures were higher than the normal temperature.
- During the early evening ‘cool down’ period *Canopy*, *Probe* & *Plant* were essentially identical and all fell more slowly than *Normal*.
- During the night all measurements were essentially the same.

The true leaf temperature of a plant could be expected to lag behind surrounding air temperature due to its thermal inertia. However this is complicated by the effect of radiant heat gain from the sun which, although only impacting directly on the surface of the crop canopy, will be re-radiated and conducted to within the crop canopy. This explains why the temperature is higher within the canopy than the *Normal* temperature during the day when solar gain is high and the vents are open.

Fig 18 – Week 40 control treatment

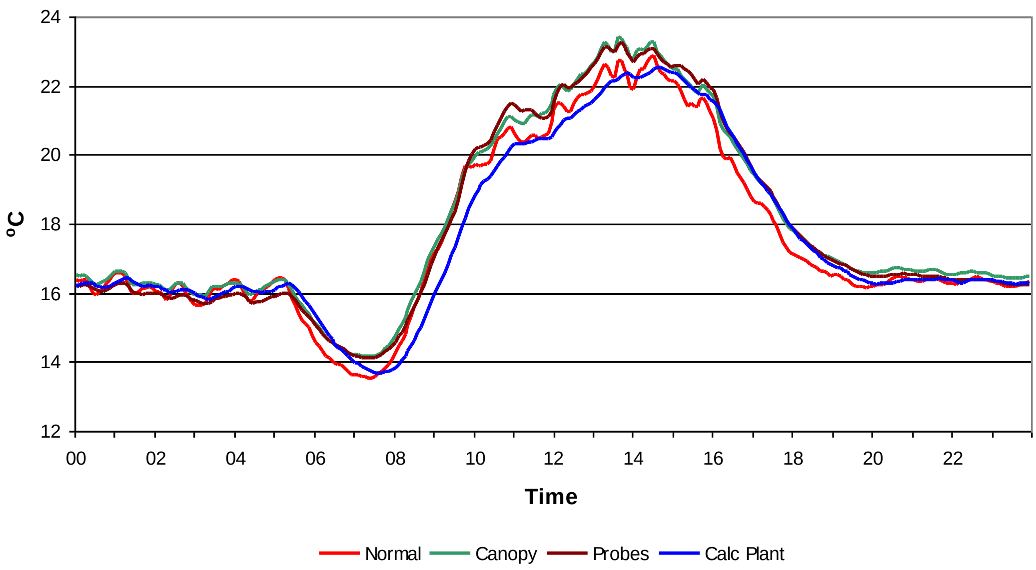


Fig 19 – Week 47 control treatment

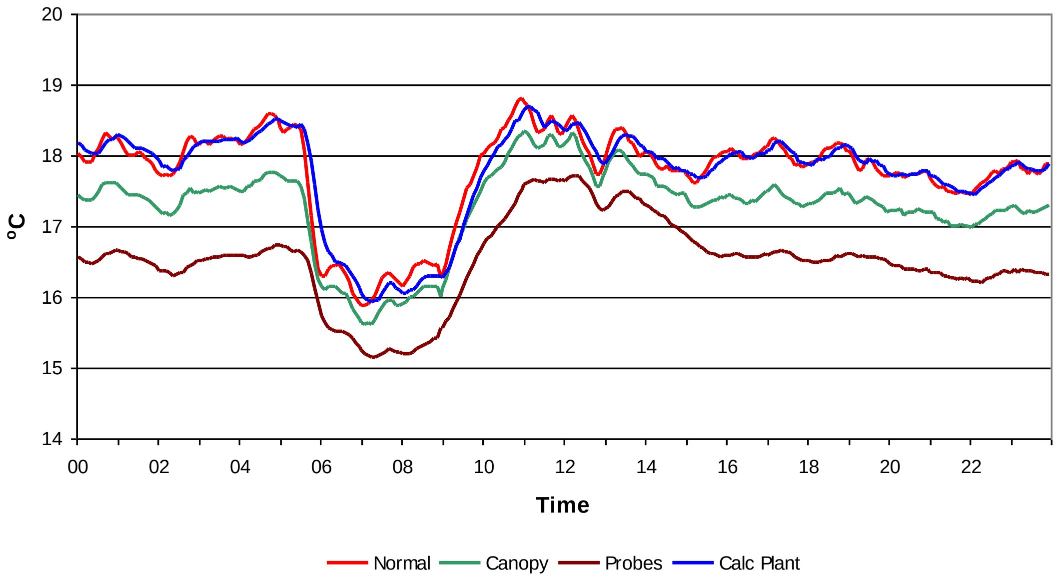


Fig 19 shows week 47 with a complete crop canopy. At this time outside temperatures are much reduced and light levels are low. Under these conditions the calculated *Plant* temperature slightly lags the *Normal* temperature. This is as expected. However there is significant difference between *Normal*, *Canopy* & *Probe*.

Considering the *Probe* temperature initially, this is the most accurate measurement of the temperature within the crop. As it does not involve disturbing the microclimate as is the case with *Canopy* which uses a manifold connected to a measuring box. The greater difference between *Probe* and *Normal* compared to earlier weeks can be expected as consistently lower outside temperatures will gradually reduce the ground temperature and therefore cool the air trapped within the canopy. Plant transpiration also has a cooling effect and this may be a contributing factor.

The *Canopy* temperature, measured by extracting air from a manifold within the crop, lies almost half way between *Normal* and *Probe*. This suggests that although considerable steps were taken to minimise the disturbance caused by sampling air from within the crop canopy, it was only partially successful.

10.2.3.2 Humidity

Three RH measurements were recorded from two sampling points:

1. Air RH – conventionally located measuring box (*Normal*).
2. Air RH – using the modified measuring box extracting air from within the crop canopy (*Canopy*).
3. Air RH (measured with an electronic sensor) – measuring box extracting air from within the crop canopy (*Electronic*).

In addition two calculated RH measurements were also recorded:

1. Calculated plant RH (*Plant*).
2. Calculated top RH (*Top of Plant*).

Electronic* vs *Canopy

The *Electronic* RH sensor was mounted in the *Canopy* measuring box. Therefore comparing the two measurements gave an indication of their relative performance.

Fig 20 shows the two measurements when the electronic sensor was new and it can be seen that the two methods are in very good agreement. Fig 21 shows the same data for week 49. Again this shows good agreement between the measurements. Closer scrutiny suggests that there may be a slower response time with the electronic sensor but it is considered that this is minimal. A true indication of the electronic sensor's reliability will only be possible at the end of the project in December 2004.

Fig 20 – Week 36 electronic vs canopy RH

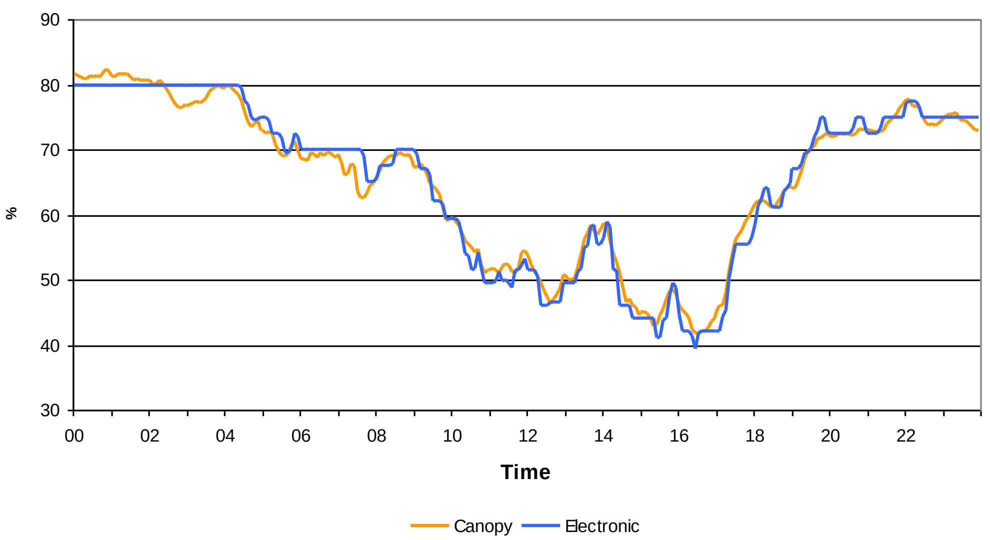
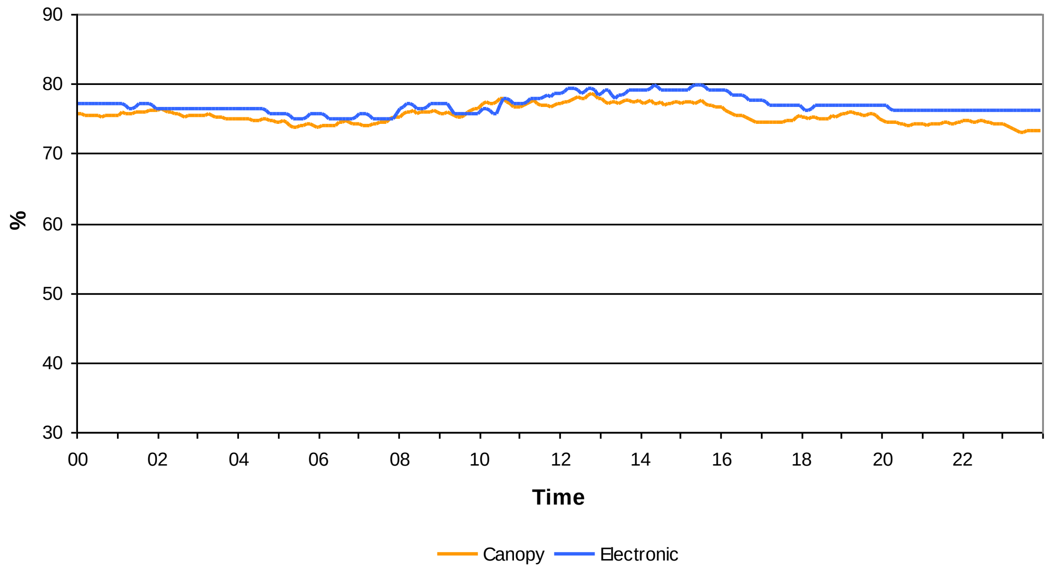


Fig 21 – Week 49 electronic vs canopy RH

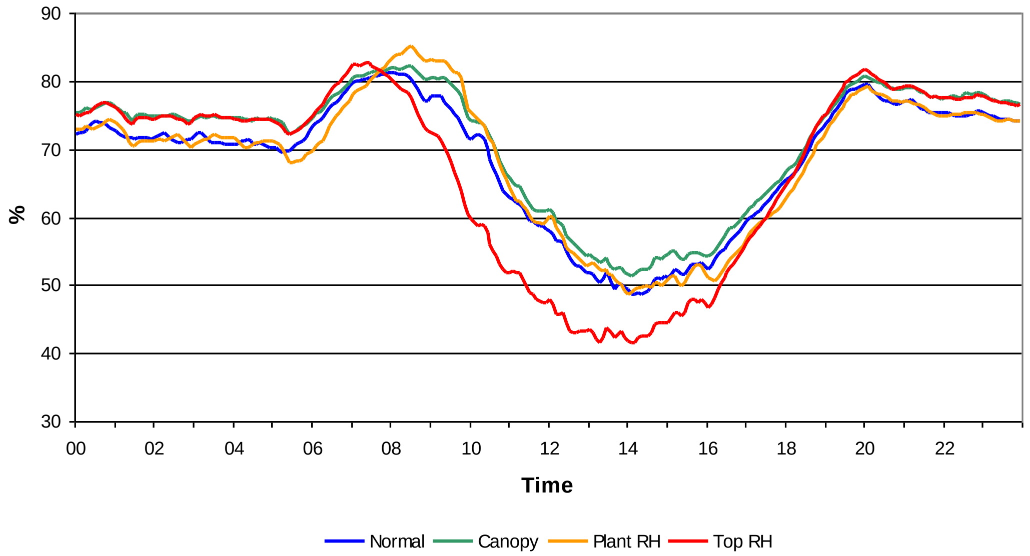


Normal* vs *Plant, Top of Plant & Canopy

Plant and *Top of Plant RH* are determined by the calculated *Plant* and *Top of Plant* temperatures and the air conditions (as measured by the *Normal*). Therefore any limitations in the calculated temperatures discussed in Section 10.2.3.1 earlier are likely to also impact on the reliability of the RH calculation. Fig 22 overleaf shows:

- A consistent 3 – 5 % difference between the *Normal* and *Canopy* measurements.
- Good agreement between the *Normal* and *Plant* RH under stable conditions. However when *Normal* RH is falling the *Plant* RH is a higher value. On the other hand when *Normal* RH is rising the *Plant* RH is a lower value. This response is as expected due to the 'time delay' effect of the model used on plant temperature.
- Good agreement between *Canopy* and *Top of Plant* during the night but not during the day. Once again this is a reflection of the differences in the measured and calculated temperatures.

Fig 22 – Week 40 RH



Towards the end of the trial (week 49, Fig 23) there was no venting and RH was being controlled by the heat demand needed to maintain temperature within the greenhouse. During the night, when heat input was at it's greatest, the difference between canopy RH and *Normal* RH was also greatest. This can be explained by the layout of the heating system which delivers heat above the crop and not within it. This arrangement gives poor air movement within the canopy compared to an installation with heating positioned within the crop.

During the daytime the RH rises due to lower heat demand and a transpiring crop. In addition the difference between *Normal* and *Canopy* measurements is smaller due to reduced heat input and air movement within the canopy stimulated by radiant heat from solar gain.

The trends previously discussed about *Plant* and *Top of Plant* RH remain the same.

Fig 23 – Week 49 RH

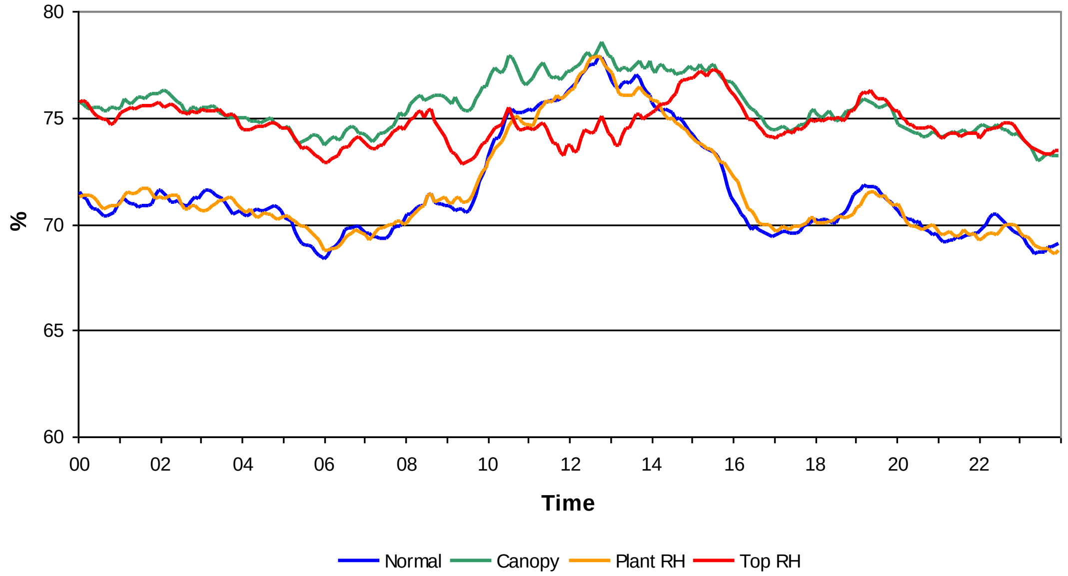
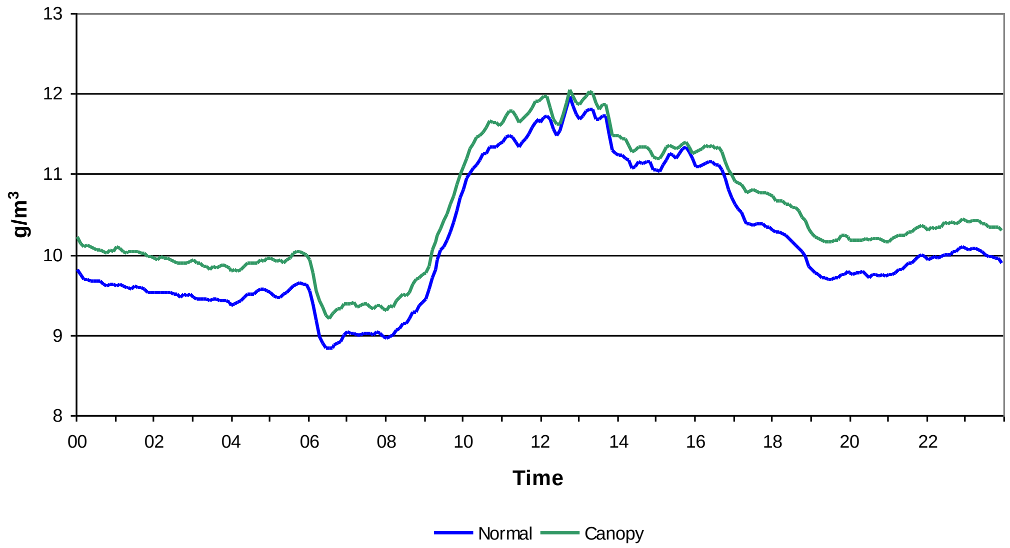


Fig 24 below shows the absolute humidity of the air in week 44 as measured by the *Normal* and canopy measuring boxes. During the middle of the day (when solar gain is high,) the vents are open and air movement is good. Under these conditions the difference is small. However during the night the difference is typically 0.5 g/m^3. The calculated *Plant* and *Top of Plant* RH are both derived by assuming that the air within the canopy has the same absolute humidity as measured by the *Normal*. This is rarely the case. As a result the reliability of the *Plant* and *Top of plant RH* calculation is dependent on good air movement between the glasshouse and crop canopy airspace.

Fig 24 – Week 44 absolute humidity



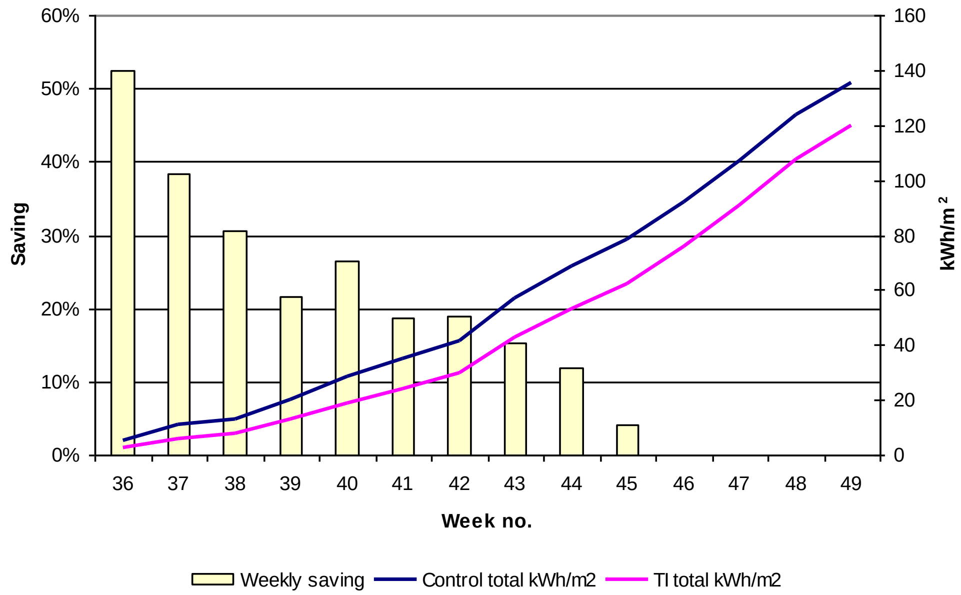
10.2.4 Energy

Fig 25 below shows the total amount of energy used in each treatment. Weekly savings (%) made in the TI treatment (when compared to the control) are also shown.

During the early part of the trial savings exceeded 30 %. However due to the low actual energy use, the saving in kWh/m^2 was small. The majority of the savings were made in weeks 39 – 43. After this period the savings rapidly fell to nothing as the radiation levels fell and temperatures became colder.

During weeks 46 – 47, when identical settings were applied to both treatments, energy use was compared to benchmark the recorded data. Block 4 (the TI treatment area) was shown to use 1.5 % less than Block 2 (control). All the energy data quoted has been corrected to allow for this. The energy used (kWh/m^2) was also converted into the equivalent amount of gas, assuming a heating system efficiency of 85 %.

Fig 25 – Total energy use and weekly savings



The total amount of energy used (as gas) between weeks 36 – 49 in the control treatment was 136 kWh/m^2 compared to 120 kWh/m^2 in the TI treatment. This represents a saving of 16 kWh/m^2 (12 %).

10.3 Crop data

10.3.1 Production diary

- Potting dates week 29 and week 30.
- Variety – Sonora.
- Plants transferred into final growing on (trial) area – week 34.
- Marketing – week 50.

Crop spacing dates and growth regulator applications were the same in both treatments and according to standard commercial practice.

10.3.1.1 Height tracker

Crop development (height) was tracked against target using the HDC Poinsettia Tracker™ software. Figs 26 & 27 below show the measured height against track for the week 29 & 30 plantings respectively. Higher than average light levels early in the growing period meant that crop height in both plantings and treatments tended to be ahead of schedule. As a result average growing temperatures were reduced in addition to the use of growth regulators and Drop. Although the TI treatment potted in week 29 appeared to have better height control, the crop was also slightly shorter at the start. At the point of marketing (week 49) there was no significant difference between the treatments or the different planting dates.

Fig 26 – Week 29 planting height track

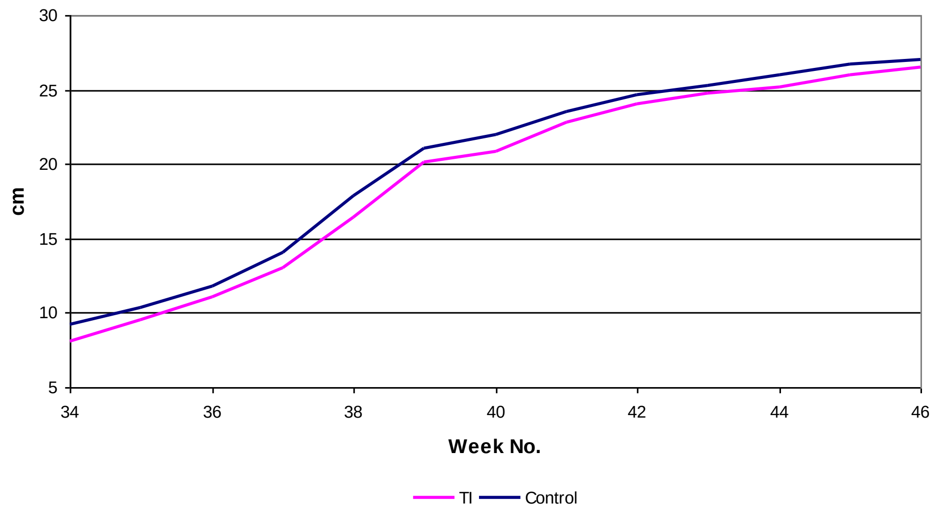
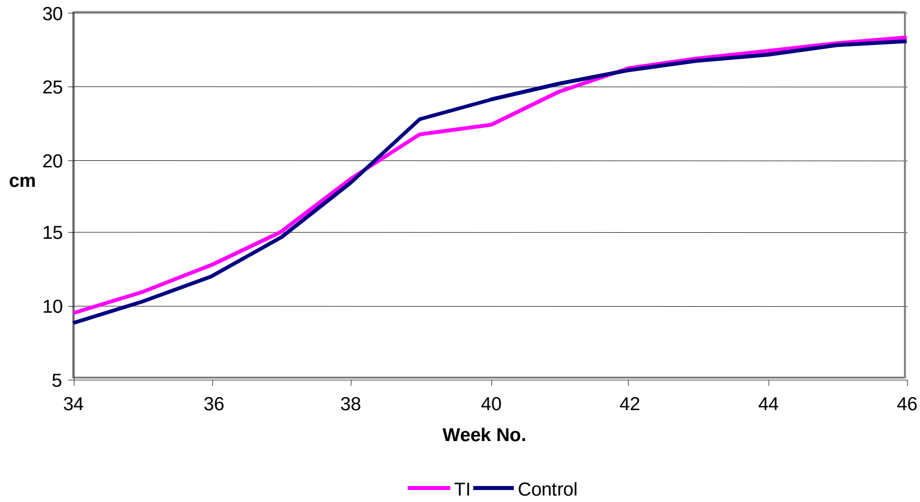


Fig 27 – Week 30 planting height track



10.3.1.2 Assessment prior to marketing

A crop assessment was carried out by Mr H Kitchener prior to marketing. The assessment protocols used were those used in the HDC annual variety trials. A summary of his findings is given below. Further information is also given in Table 3 where the actual figures recorded are presented.

Summary

The height and width of the plants was slightly bigger in the control treatment compared to the TI treatment. There were a few more breaks overall as primaries and bracts in category 4 were greater. Cyathia size, development, sleevability and plant quality were marginally lower in the TI treatment.

Both crops had dense canopies which are thought to be responsible for higher than average lower leaf yellowing and abscission. This appeared worse in the TI crop. Bracts were also smaller and less well presented at the time of assessment.

The layout of heating pipes and operation of the TI treatment could have resulted in lower compost temperature with possible effects on the root system. However no root death was observed in either treatment.

Table 3 – Marketing assessment data

			Control Week 29	Control Week 30	Control average Weeks 29&30	TI Week 29	TI Week 30	TI average Weeks 29&30
Height (cm)			27.9	28.8	28.4	25.9	28.3	27.1
Spread (cm)			42.3	41.8	42.1	37.9	41.2	39.6
No. of primary breaks			6.0	6.0	6.0	5.8	6.1	6.0
No. of secondary breaks			2.4	2.6	2.5	3.5	3.1	3.3
No. of breaks in size category	1	<150	1.8	1.9	1.9	2.3	2.9	2.6
	2	150 - 200	3.4	3.0	3.2	3.2	3.1	3.2
	3	200 – 225	2.5	2.7	2.6	3.0	3.0	3.0
	4	>225	0.7	1.0	0.9	0.8	0.2	0.5
Avg. Cyathia size (1, 2, 3)			2.1	1.9	2.0	2.0	1.9	2.0
Avg. stage of Cyathia development			2.6	2.8	2.7	2.5	2.3	2.4
Grassy growth (0, 1, 3) 3 poor			0.4	0.6	0.5	0.2	0.7	0.5
Sleevability (1, 3, 5) 5 good			4.2	4.3	4.3	3.9	4.1	4.0
Plant quality (0, 1, 2) 2 good			1.7	1.9	1.8	1.6	1.4	1.5

10.3.1.3 Shelf life test

Test protocol

After the marketing stage assessment, pots were sleeved and packed as normal by the nursery. The plants were collected from the nursery and taken to Kirton by van (ambient temperatures). At Kirton the plants remained overnight in the van (parked in a shed), until 24 hours after the initial collection, when they were unpacked and removed from their sleeves. The pots were placed on flower-pot saucers on benching in a shelf-life test room, at a pot density of 7 /m^2 of bench. There were five replicate pots for each treatment combination, arranged in five randomised blocks. The standard shelf-life conditions were 18 ± 1 °C and ca. 55 – 65 % RH, with cool white fluorescent tubular lighting providing about 1000 lux at plant height for 14 h per day. RH was kept in the required range through the damping down of the floor. Free-standing humidifier and de-humidifier plant were also used when needed. Temperature and RH were logged throughout. All pots were watered according to individual need using plain tap water.

The plants were recorded weekly, pots being discarded when they were considered to have reached the end of their shelf-life. The test was concluded after 8 weeks. The records taken weekly were:

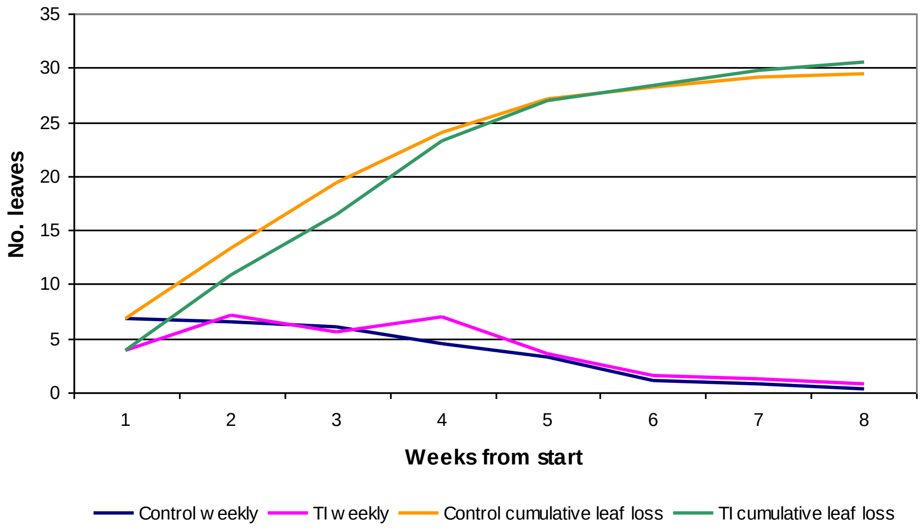
- Numbers of leaves dropped per plant per week.
- Number of bracts lost per plant per week.
- Cyathia number and losses on one tagged break per plant.
- Mechanical damage (mainly branch breaks due to sleeving / de-sleeving) on a 0 – 5 scale: 0 = none 1 = slight 3 = moderate 5 = severe.
- Leaf yellowing score for upper and lower foliage separately on a 0 – 5 scale: 0 = dark green 1 = slightly pale 3 = moderately pale 5 = severe yellowing.
- Bract-edge blackening (BEB) on a scale from 0 (none) to 5 (severe).
- Bract colour (using the RHS colour chart and assigning decimals to shades a, b, c and d in each colour range, eg colour 46a was recorded as 46.1).
- Overall plant quality on a scale from 5 (high quality) through 3 (acceptable) to 1 (end of shelf-life), using 0 to denote pots already discarded.
- Plant longevity, determined as the time (weeks) up to which a plant was considered fit to remain on display.

Results

Figs 28 & 29 overleaf show two of the main shelf life criteria, a complete set of results is shown in Appendix 1.

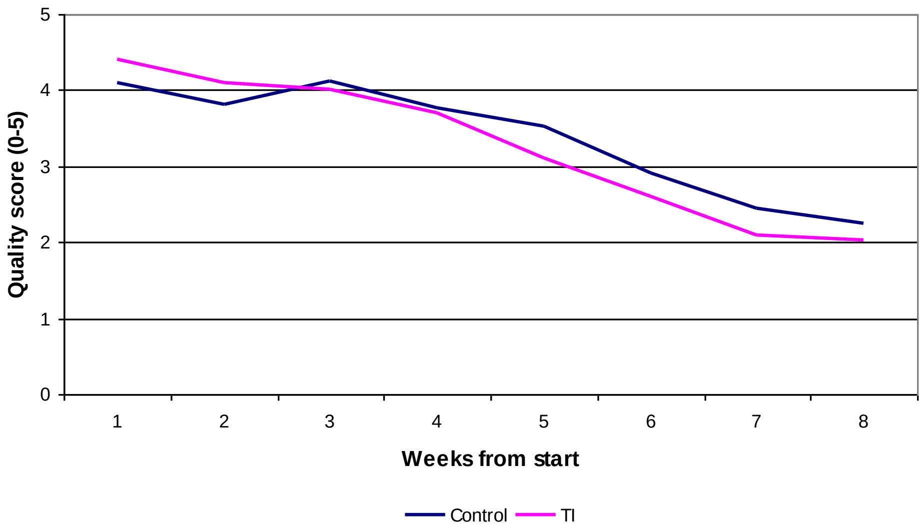
Leaf loss in the TI treatment was lower in the first week but overall there was little difference. Bearing in mind comments made by Mr H Kitchener relating to poorer lower leaf quality in the TI treatment, a possible explanation is that more lower leaves were taken off the TI treatment prior to sleeving. This would therefore give a lower initial loss in the first week of shelf life tests.

Fig 28 – Shelf life leaf loss



The trend is for the TI crop to have a marginally lower overall quality score after week 4. However the difference is small and the TI crop was still considered to be of good quality. The final quality score after 8 weeks is distorted by the fact that one of the control plants was removed at the end of week 7 because it was scored <2, ie was no longer of acceptable quality. Had it been retained it would clearly have lowered the average score of the control crop to similar levels as the TI crop. The plants from both treatments easily exceeded the minimum shelf life requirement expected by all the major retailers in the UK.

Fig 29 – Shelf life quality score



11 Discussion & summary of key findings

Energy

As with all previous projects applying the principles of TI, it has been shown to save energy. In this particular case 12 %.

Crop quality

The crop quality assessments at marketing produced some conflicting results. Prior to the assessment carried out by Mr H Kitchener, Coletta & Tyson's own staff believed that the control crop showed less colour than the TI crop. As a result a commercial decision was taken to remove the Drop period from the control strategy only. However Mr Kitchener's assessment concluded that the TI crop was not as well developed as the conventional crop.

The overall quality assessment carried out on site concluded that the TI crop was of lower quality, scoring 1.5 vs. 1.8 for the control. Again this is in conflict with the nursery's own grade out data and the shelf life testing which showed no difference.

Humidity & temperature measurement

All the measurements recorded showed general agreement with those which could have been predicted through general analysis and calculation derived from the application of simple heat and mass transfer principles. It is clear that the conventional location of a measuring box is far from ideal as it does not truly represent the conditions experienced by the crop.

The second measuring box, which was configured to draw air from within the crop canopy, was shown to give a better indication of the actual conditions experienced by the crop. However this was only significant once the crop canopy was fully developed and air exchange between the canopy and air above it was restricted. Comparison with the *simple* temperature probes mounted within the crop showed that attempts to minimise air disturbance by using a 3 m long sampling pipe were only partially successful.

Comparing the calculated crop environment (Priva 'software sensors', *Plant and Top of Plant*) to true readings (from the *Canopy* measuring box, simple temperature *probes* and *Infra-red* camera) gave mixed correlation.

The temperature measured by the *Infra-red* camera was initially affected by the incomplete crop canopy. This meant that the temperature measured was a combination of floor, pot and plant. During this period the calculated plant temperature was consistently higher and spot readings of individual leaves in direct sunlight were in closer agreement to the calculated figure. However, spot readings also showed that even adjacent leaves (one in direct light and the other not) were at significantly different temperatures. The best and most consistent comparison between calculated *Top of Plant* and *Infrared* temperature was during the night when both showed the canopy surface temperature to be between 0.5 – 1.0 °C below the air temperature as measured at the conventional measuring box location.

The calculated *Plant* temperature, which takes account of the thermal inertia of the plant, showed good agreement with the simple temperature *Probes* during the critical morning warm up period. However this was only after software tuning had taken place using information gained from the *Probes*. This begs the question as to how a grower using a software-sensor knows whether it is configured correctly.

Once the crop canopy was fully developed there was good agreement between the measured *Canopy* RH and calculated *Top of Plant* RH during the night time period. However this was not the case during the day.

Towards the end of the trial (when RH was always under control due to the high heat demand) the most notable point was the difference between the *Normal* and *Probe* temperatures. On occasions the difference was as high as 2 °C, and was regularly greater than 1 °C. This was no doubt exaggerated by the lack of heating within the crop and the fact that the crop was being grown on the floor. A comparison of the temperature difference in different growing systems could yield useful results that provide answers to the commonly accepted fact that it is more difficult to grow crops on the floor than on benches.

12 Conclusions

As this is an interim report, any conclusions drawn at this stage are limited.

Energy

Once again applying the principles of TI has been show to save energy. In this case 12 % or 16 kWh/m^2. In percentage terms this compares well with previous work carried out on commercial nurseries with a range of ornamental and salad crops.

Crop

There were contradicting assessments of crop quality at marketing. However irrespective of this:

- The nursery's own grade out figures showed no difference between treatments.
- Shelf life assessments showed no difference between treatments and in both cases shelf life was well in excess of the standard required.

Humidity & temperature measurements

Additional sensors

Electronic RH

- Good agreement with traditional wet & dry bulb system.
- Limited operating time to date, reliability will be better assessed in year 2.

Canopy measuring box

- Gives a more accurate assessment of the actual conditions within the canopy.
- True accuracy of the measurement is affected by localised air movement caused by the sampling system.

Simple temperature *Probes* within canopy

- Simple & relatively cheap.
- Good agreement with expected trends.
- A useful aid when assessing accuracy of canopy measuring box and calculated plant temperatures.

Infra-red camera

- Great care needs to be taken in its positioning, particularly with incomplete crop canopies. Otherwise the measured temperature will be a mixture of plant, pot & floor temperature.

- Spot readings of individual leaves in the sun and in the shade show differences up to 8 ^{o}C. This brings into question the usefulness, at a commercial level, of an average temperature from the IR camera.

Software-sensors

- Some agreement between *Top of plant* and *Infra-red*, and *Canopy* and *Plant*.
- No single calculated software-sensor value is correct all the time. A combination of measured and calculated temperature could be the best solution.
- Fine tuning of calculated values is possible within climate control computer software when true values are known (*Infra-red*, *Probes*).

13 Year 2

Based on the first year results from this project, the second year work programme will be based on:

Treatment 1

- Temperature integration.
- Greenhouse environment controlled using a *Normal* measuring box (both RH and temperature).

This treatment will be used as the 'control' and performance (both energy use and humidity control) will be compared to the following treatment.

Treatment 2

- Temperature integration.
- Greenhouse temperature controlled using a *Normal* measuring box.
- Greenhouse humidity controlled using a *Canopy* measuring box.

Although the year 1 results showed that the *Canopy* measuring box was not completely representative of the true conditions within the canopy, it gave the most consistent and reliable measurement. However, compared with measurements taken by a normal measuring box, information collected from canopy based devices are much less dynamic in response. This treatment will explore the practicality and potential problems of using canopy conditions to control the greenhouse environment.

The comparison of actual measurements and calculated conditions will continue. This will build on the knowledge gained to date and identify opportunities for improving the accuracy, cost, practicality and reliability of measurement systems.

Appendix 1 – Shelf life data

		Leaves dropped	Red bract leaves dropped	No. of Cyathia	No. of Cyathia lost	Mechanical damage	Upper canopy leaf colour	Lower canopy leaf colour	Bract colour score	Dark bract margins score	Overall quality score
Week 1											
29	Control	6	2.8	9.4	0.2	1.8	0	1	4.8	4.4	4
29	TI	5.6	0.4	9.4	0	0.2	0	1	5	4.6	4.6
30	Control	7.6	0.6	8.4	0.4	0.4	0	1	5	4.4	4.2
30	TI	2	0.2	9	0.6	0.2	0	1	4.8	4.4	4.2
Average control		6.8	1.7	8.9	0.3	1.1	0	1	4.9	4.4	4.1
Average TI		3.8	0.3	9.2	0.3	0.2	0	1	4.9	4.5	4.4
Week 2											
29	Control	6.8	2.4	11.2	0.8	1.8	0	1	4.8	4.4	3.6
29	TI	8.8	1.6	9.4	0.4	0.2	0	1.2	5	3.8	4.4
30	Control	6.2	4.4	8.4	1.6	0.4	0	1.4	5	3.4	4
30	TI	5.4	1.6	10.2	0.6	1	0	1.2	4.8	4.2	3.8
Average control		6.5	3.4	9.8	1.2	1.1	0	1.2	4.9	3.9	3.8
Average TI		7.1	1.6	9.8	0.5	0.6	0	1.2	4.9	4	4.1
Week 3											
29	Control	5	3.5	12.25	1	1	0	1	4.75	4.25	4.25
29	TI	4.4	5.8	9	1.6	0.2	0	1.2	4.8	4.4	4.4
30	Control	7.2	7.4	8.2	1.6	0.6	0	1.2	4.8	3.8	4
30	TI	6.6	2.4	10.6	0.4	1	0	1.2	4.6	3.8	3.6
Average control		6.1	5.45	10.225	1.3	0.8	0	1.1	4.775	4.025	4.125
Average TI		5.5	4.1	9.8	1	0.6	0	1.2	4.7	4.1	4

		Leaves dropped	Red bract leaves dropped	No. of Cyathia	No. of Cyathia lost	Mechanical damage	Upper canopy leaf colour	Lower canopy leaf colour	Bract colour score	Dark bract margins score	Overall quality score
Week 4											
29	Control	4.5	5.3	9.5	3.0	1.3	0.0	1.8	4.8	4.0	3.8
29	TI	10.6	3.8	6.4	3.8	0.2	0.8	2.6	4.6	4.0	3.8
30	Control	4.6	7.4	5.4	4.0	0.4	0.2	2.2	4.8	3.8	3.8
30	TI	3.2	2.8	9.8	1.2	1.2	0.4	2.2	4.6	3.8	3.6
Average control		4.6	6.3	7.5	3.5	0.8	0.1	2.0	4.8	3.9	3.8
Average TI		6.9	3.3	8.1	2.5	0.7	0.6	2.4	4.6	3.9	3.7
Week 5											
29	Control	2.8	4.3	7.3	5.3	1.3	0.5	2.5	4.3	3.5	3.3
29	TI	4.4	7.2	4.4	6.0	0.2	1.2	3.2	4.4	3.4	3.6
30	Control	3.6	2.4	3.0	6.4	1.0	0.6	2.6	4.8	3.8	3.8
30	TI	2.8	5.0	6.0	5.0	1.2	0.8	2.6	4.0	3.2	2.6
Average control		3.2	3.3	5.1	5.8	1.1	0.6	2.6	4.5	3.7	3.5
Average TI		3.6	6.1	5.2	5.5	0.7	1.0	2.9	4.2	3.3	3.1
Week 6											
29	Control	1.3	3.0	5.8	6.8	1.5	1.0	2.8	3.3	3.0	3.0
29	TI	1.0	3.0	3.6	7.2	0.0	2.0	3.6	3.4	3.0	3.0
30	Control	1.0	2.2	2.2	7.2	1.0	1.2	2.8	3.8	3.4	2.8
30	TI	2.0	6.0	3.8	7.2	1.2	1.6	3.4	3.2	2.8	2.2
Average control		1.1	2.6	4.0	7.0	1.3	1.1	2.8	3.5	3.2	2.9
Average TI		1.5	4.5	3.7	7.2	0.6	1.8	3.5	3.3	2.9	2.6

		Leaves dropped	Red bract leaves dropped	No. of Cyathia	No. of Cyathia lost	Mechanical damage	Upper canopy leaf colour	Lower canopy leaf colour	Bract colour score	Dark bract margins score	Overall quality score
Week 7											
29	Control	1.0	4.5	4.8	8.5	1.3	1.8	3.0	3.3	2.5	2.5
29	TI	2.2	2.4	2.4	8.8	0.2	1.8	3.6	3.4	2.4	2.2
30	Control	0.6	1.4	1.6	9.4	1.4	1.8	3.4	3.4	3.0	2.4
30	TI	0.4	2.0	3.0	7.8	1.4	2.0	3.6	2.8	2.4	2.0
Average control		0.8	3.0	3.2	9.0	1.3	1.8	3.2	3.3	2.8	2.5
Average TI		1.3	2.2	2.7	8.3	0.8	1.9	3.6	3.1	2.4	2.1
Week 8											
29	Control	0.3	0.5	4.0	9.5	1.3	2.0	3.0	3.3	2.5	2.0
29	TI	0.3	3.3	2.3	8.5	0.8	2.0	3.5	3.5	2.3	2.3
30	Control	0.5	1.8	2.8	8.8	1.0	1.5	3.3	3.5	3.3	2.5
30	TI	1.4	3.4	1.8	9.0	1.4	2.0	3.6	2.8	2.2	1.8
Average control		0.4	1.1	3.4	9.1	1.1	1.8	3.1	3.4	2.9	2.3
Average TI		0.8	3.3	2.0	8.8	1.1	2.0	3.6	3.2	2.2	2.0

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