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Project number:	PC 197
Project leader:	Mr Chris Plackett FEC Services Ltd, Stoneleigh Park, Kenilworth, Warwickshire
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Key workers:	**FEC Services Ltd:** Mr C.W. Plackett — Project leader Mr C.T. Pratt — Project manager **HRI Efford:** Dr I. Clarke — Plant recording protocols & reporting **ADAS Consulting:** Dr T. O'Neill — Disease control strategy & assessment
Location:	Double H Nurseries Ltd – Sway & New Milton, Hampshire Rushmere Nursery, Bedfordshire
Project co-ordinators:	Mr Dave Abbott, SGP Ltd Mr Steve Morley, PA Moerman Ltd
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Grower Summary

Headline

The principles of temperature integration (TI) have been successfully applied on 3 separate commercial nurseries to three different ornamental crops, pot chrysanthemums, begonia and zonal perlargoniums.

- Energy savings of at least 10% were demonstrated, representing a saving of £5,000 per ha per annum to the average producer of heated pot plants
- There was no perceivable difference in crop quality or disease levels
- Satisfactory humidity control was achieved with TI. However greater attention does need to be paid to humidity control when using this technique.

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 (PC 172) concluded that the use of advanced control methods is an effective way of improving energy efficiency. Following this, work carried out at HRI Efford (PC 190) showed that the principles of temperature integration 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 project builds on the findings of PC 190 by demonstrating the application of temperature integration strategies on commercial nurseries. More specifically the objectives were to:

- Demonstrate the effectiveness of temperature integration on a commercial scale by monitoring energy use and crop performance
- Further illustrate to growers the commercial & economic advantages of making better use of energy saving environmental control technologies
- Extend the knowledge on temperature integration to a wider range of pot plant crops.

It is intended that, as a result of this project, growers will have increased confidence in temperature integration as an energy saving tool that does not compromise crop performance. Furthermore, it will quantify the financial benefits to be gained and provide a sound basis for investment decisions where this is required.

Practical experience gained during this project will also help growers to realise the full benefits of the technique more quickly.

Summary of Project and Main Conclusions

Research method

Temperature integration was compared with a conventional temperature control strategy on two commercial nurseries.

1. Double H Sway - producing pot chrysanthemum using a Priva Integro climate control computer including temperature integration software.
2. Double H New Milton - producing begonia using a Hoogendoorn climate control computer including temperature integration software.

Site 1 was chosen to provide continuity with previous work carried out on pot chrysanthemum (PC 190). Site 2 was chosen to demonstrate the effect of temperature integration on another main stream crop - begonia. Detailed data relating to glasshouse environment, energy consumption and crop performance were collected at both of these sites.

A third site, Rushmere Nursery in Bedfordshire, was chosen to show that the principles of temperature integration can be applied on a site where temperature integration software is not available. Detailed recording of energy use and crop performance was not carried out at this site.

Results

Double H Sway (pot chrysanthemums) grown under TI and conventional environments from final spacing to marketing

Crop

Assessments of plant quality and shelf life were as routinely carried out by Double H. In addition a detailed assessment of botrytis incidence was carried out by Dr Tim O'Neill.

- Standard shelf life assessment - the temperature integration crop averaged 12.6 days to loose 50% of the flowers compared to 12.0 days for the conventionally grown crop
- Botrytis incidence - the temperature integration crop averaged 9.9% compared to 8% for the conventionally grown crop.

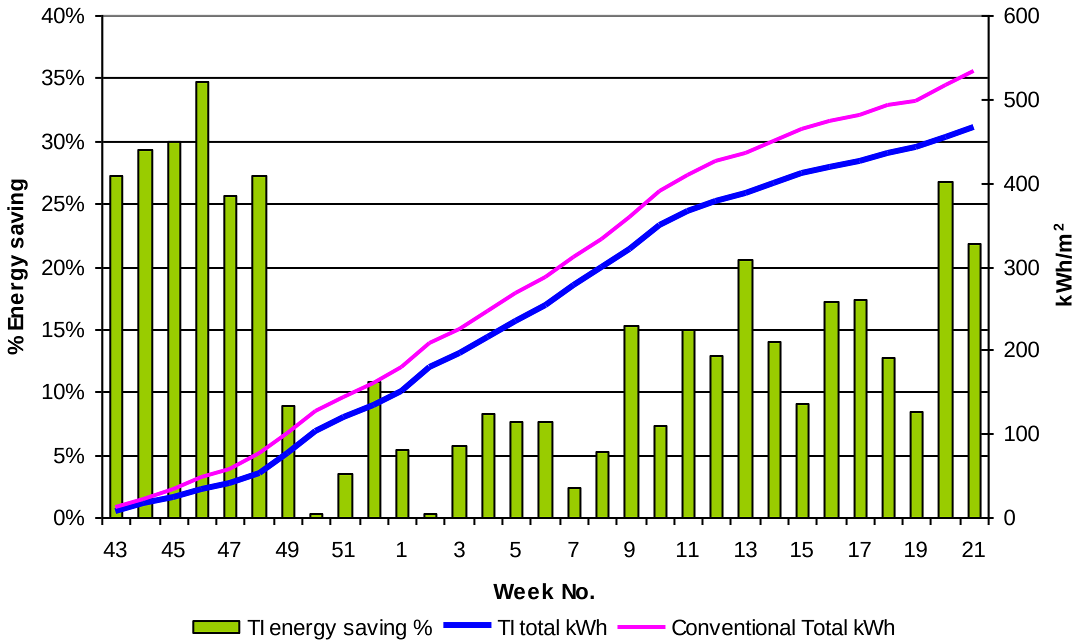
Differences of this level were considered to be insignificant. In all cases no difference in scheduling was noted and crop quality always exceeded the customer's specification.

Energy

Energy use was recorded throughout the duration of the project and is shown in Figure 1 below. All the data has been adjusted to allow for inherent differences between the trial glasshouses and expressed as kWh of gas consumed. Between Week 43 (2002) and Week 21 (2003):

- The temperature integration area used 467 kWh/m^2
- The conventional area used 532 kWh/m^2
- This represents a saving 65 kWh/m^2 (12.3%).

Figure 1 – Energy use at Double H Sway (pot chrysanthmemums)



<u>Double H New Milton (begonias) grown under TI and conventional environments from final spacing to marketing</u>

Crop

Assessments of plant quality and shelf life for the trial were as routinely carried out on the commercial crop by Double H. A botrytis assessment was not carried out. All the quality assessments showed little difference between the conventional and TI crops.

Energy

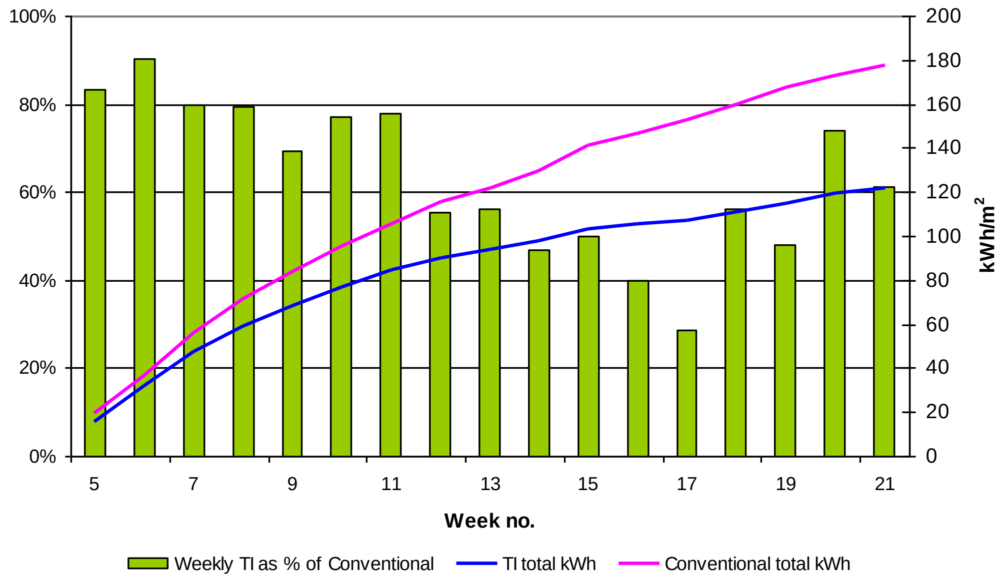
Energy use recorded throughout the duration of the project is shown in Figure 2 overleaf. Differences in the design of the glasshouses on this site made it difficult to give accurate baseline comparisons in energy use prior to the trial. The data used to form the graph is therefore unadjusted.

Between Week 5 (2003) and Week 21 (2003):

- The temperature integration area used 130 kWh/m^2
- The conventional area used 193 kWh/m^2.

Limited comparative data suggests that the glasshouse where temperature integration was applied used between 15 and 25% less energy compared to the conventional area even when identical control strategies were used. Assuming worst case (25%) the corrected energy use for the conventional area is 145kWh/m^2 i.e. a saving of 15kWh/m^2 (10%).

Figure 2 – Energy use at Double H New Milton (begonias)



Rushmere Nursery (pot bedding eg. Zonal pelargonium)

Temperature integration was successfully applied on this nursery with a climate control computer that was not equipped with TI software by:

- Increasing the ventilation temperature to help accumulate free degree-hours using humidity influences when the relative humidity was less than a critical value, typically 85%
- Manually assessing the measured temperature as a rolling average over the integrating period (three days) and modifying the heating temperature appropriately to ensure the desired average temperature was achieved.

Although there was no formal comparison of conventional vs. temperature integration regimes at this nursery, crop quality was considered to be good and disease levels low compared to previous years.

Conclusions

- TI has been shown to deliver savings in energy use of at least 10% during a major part of the heating season on two separate commercial nurseries. Based on these results, savings during the whole heating season are expected to be between 10 & 15%.
- Crop quality at marketing was not affected by the use of TI, although note must be taken that TI was only used in crop production from final spacing to marketing for the crops tested.
- A detailed assessment of botrytis levels on the site producing pot chrysanthemum showed no significant difference between the conventional and TI treatments.
- The principles of TI can be applied on nurseries where TI software is not available. However the full benefits are unlikely to be realised without a more state of the art climate control computer.
- Good humidity control can be achieved when using TI. However an understanding of the principles of humidity control and how to modify set points to achieve efficient humidity control is required.

Financial Benefits

Energy saving

Typical energy costs for heated pot plant production are around £5/m^2 p.a. Assuming that the lowest energy saving recorded of 10% when using temperature integration applies, savings will be £0.50/m^2 p.a. (£5,000/Ha p.a.). The saving realised on individual nurseries may vary from 5% to 20% depending on location, glasshouse facilities and current control strategy:

- Southerly locations should benefit the most due to the higher levels of solar radiation and therefore the potential to accumulate more free degree-hours
- Old, leaky glasshouses will not accumulate 'free' degree-hours as easily
- Growers already operating with a high heat/vent temperature differential (3^{o}C or more) are already using TI in a limited way by banking degree-hours but not actively burning them off.

DEFRA statistics indicate that there is around 90Ha of heated pot plant production in the UK. Therefore, if the above typical energy cost is applied to all of this production area, the total value of the energy saving to the sector would be £450,000.

No financial benefit other than energy saving has been identified. Although a reduction in heat demand can be expected to reduce maintenance costs on heating equipment to a small extent.

Cost of implementation

No cost relating to sub-standard crop performance has been identified.

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.

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 £5,000/Ha, payback times of between one and three years can therefore be expected.

It has been shown that it is possible to apply the principles of TI to climate control computers that do not have 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 for the crop. Energy savings are also likely to be less. Upgrading a climate control computer brings other long term benefits beyond those which would come from the application of TI. These include better energy efficiency and crop management. These benefits can also be factored into the return from a new system reducing the payback on investment.

Action Points for Growers

The results of this project clearly show the advantages of using temperature integration (TI) in order to save energy, reducing costs and helping to reduce carbon emissions.

- Growers should investigate how the principles of the technique can be applied on their nursery and establish the capabilities of their existing control system. They should determine what upgrades and capital investments, if any, are required to enable TI to be used.
- It is recommended that growers consider specific training in the fundamentals of environmental control and the detailed operation of climate control computers for key staff. Energy savings and crop performance can only be optimised through a full understanding of the greenhouse environment and the ways that it can be efficiently controlled.
- The potential for the production of poor humidity conditions is greater with TI than with conventional control strategies because of the reduced use of heat and venting. These conditions are easily avoidable but operators must be more aware of changing humidity conditions. Systems which enable them to view the environmental parameters in a graphical format can help considerably in determining when to take action and whether the actions being taken are having the required effect. Growers investing in a new climate control computer should ensure that this type of facility is available and that they find the user interface easy to work with.
- Growers will naturally be wary of the change to the growing strategy that TI introduces. However it can be introduced incrementally by starting with only a small increase in the ventilation temperature, (say 1^{o}C) and similar decrease in the heating temperature over a short integrating period (3 days). This will help to build confidence, the operating window available to TI can then be gradually increased.

The following settings framework is recommended for the application of TI. Two scenarios have been considered, one where humidity control using influences on ventilation temperature is used and the other where humidity influences on minimum vent position is used. HDC Fact Sheet 25/02 'Controlling Humidity to minimise the incidence of grey mould (Botrytis cinerea) in container-grown ornamentals: heated glasshouse crops' gives more detailed information about the principles behind controlling humidity in a glasshouse.

These settings should only be considered as guidelines. They will need to be adapted to meet a grower's own specific needs and the characteristics of their facilities.

In all cases the grower needs to decide:

- Target average temperature
- Heating temperature - when and how low to allow it to be reduced
- Ventilation temperature - how high to allow it to go
- Integrating period - how many days over which the temperature is averaged.

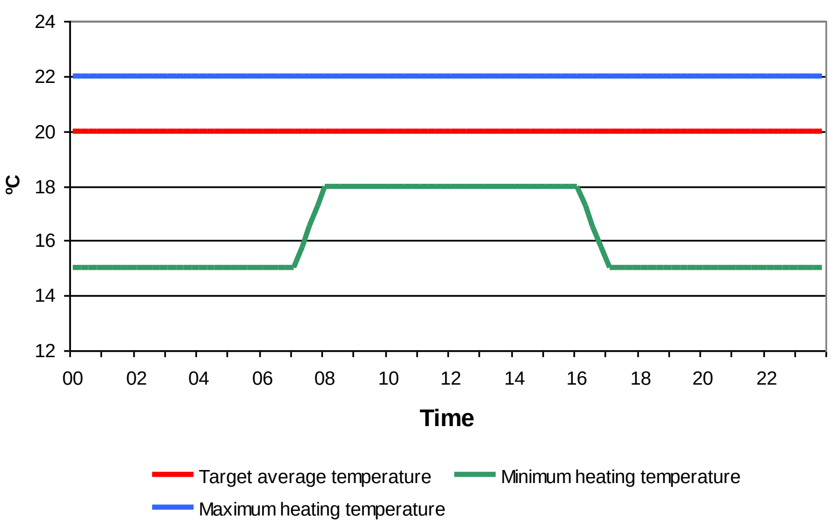
In the case of optimised TI the grower also needs to decide how high to allow the heating temperature to go. These will all vary depending on the crop being grown, the time of year and crop development. During this project, the target average temperature for the begonia was changed almost weekly in response to crop development and marketing schedules.

The following examples assume:

- A target average temperature of 20°C
- A minimum heating temperature of 15°C during the night and 18°C during the day
- A maximum heating temperature of 22°C (optimised TI only)
- A maximum ventilation temperature of 26°C.

Heating temperature

Figure 3 – Heating temperature settings



With simple TI when solar gain alone is used to accumulate degree-hours, the basic heating temperature should be set as 20°C (target average). Depending on the climate control computer being used the minimum heating temperature can be set as a specific heating strategy line or as an allowed deviation from the basic heating temperature. In the latter case a deviation (negative compensation) of 2°C should be allowed during the daytime and 5°C during the night time to achieve the effect shown in figure 3 above. The net result is that the effective heating temperature will vary anywhere between the target average temperature and the minimum heating temperature, depending on the degree-hours accumulated.

In the case of optimised TI the calculated heating temperature will vary anywhere between the maximum and minimum heating temperature lines. Although it rarely occurs in practice this gives the possibility of creating a daytime temperature that is lower than that used for the night. If the crop requires this to be avoided at all times reducing the maximum heating temperature to 18°C during the night will ensure this does not happen.

Ventilation temperature / minimum vent control

The same principles apply to ventilation temperature and minimum vent control regardless of whether simple or optimised TI is used.

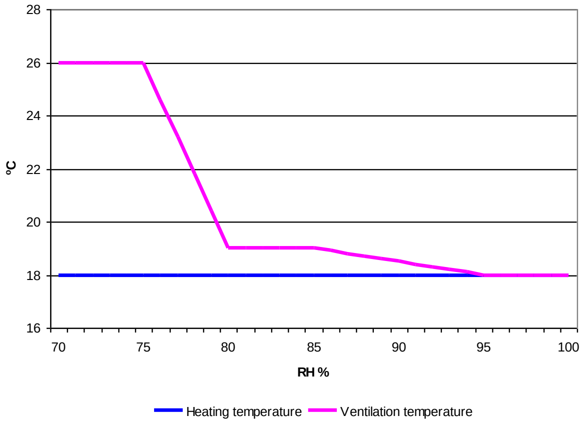
Many growers control humidity by reducing the difference between the heating and ventilation temperature when the RH is high. Therefore if TI reduces the heating temperature, the ventilation temperature must be reduced by the same amount so that difference between the two remains the same. In climate control computers with TI software this can be set to happen automatically.

To obtain maximum energy saving, the ventilation temperature needs to increase to the maximum allowed whenever the relative humidity in the glasshouse is considered to be safe from a disease risk point of view, regardless of the calculated heating temperature.

Figure 4 below shows how the ventilation temperature can be increased when the relative humidity is low. It assumes that an RH of around 85% is acceptable and that a heat-vent differential of 1°C (H 18°C/V 19°C) is used in the conventional approach. To give a safety margin, humidity influences are only allowed to increase the ventilation temperature once the RH falls below 80%. The ventilation temperature is then increased by 7°C (from 19 to 26°C) over the RH range 80 to 70%.

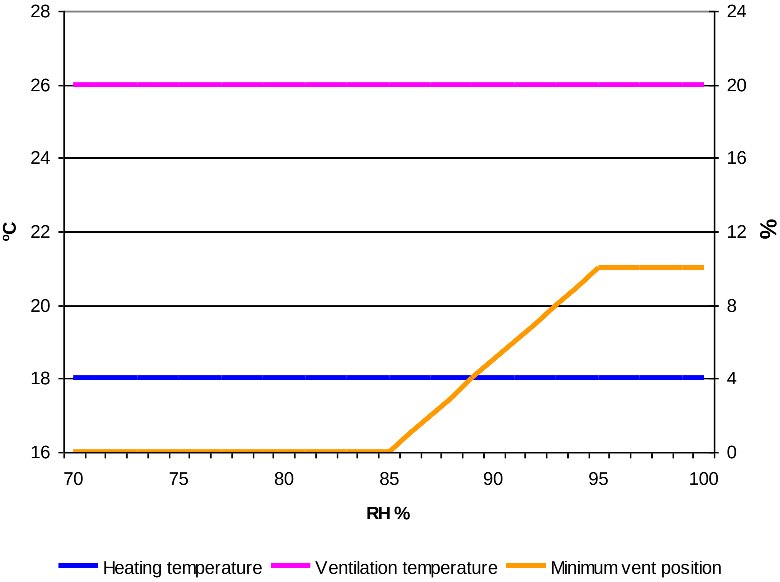
As the RH rises from 85 to 95% the ventilation temperature is reduced by 1°C to encourage venting when the RH is too high. The period of time over which the ventilation temperature changes is dependent on the specifics of the climate control computer. Although it is common for it to be wholly dependent on the rate of change of the measured humidity level.

Figure 4 – Ventilation temperature control



If minimum vent position is used as a means of humidity control things are much simpler. Figure 5 below helps to show this.

Figure 5 – Minimum vent control



Venting to aid humidity control is carried out independently of the temperature in the glasshouse. Therefore the vent temperature can simply be set to the maximum the grower is prepared to allow - in this case 26°C. In the example shown the humidity influence on minimum vent introduces ventilation gradually over the range 85 and 95% RH, to a maximum of level of 10%. Depending on external conditions 5% may be adequate. One risk with using minimum vent to control humidity is that too much vent can be applied. This causes the glasshouse temperature to fall below target and an excessive amount of heat is exhausted through the vents. If the vents were closed and the temperature allowed to rise, relative humidity would fall naturally and less energy would be used.

Minimum pipe temperature

A minimum pipe temperature is set for two main reasons:

1. To help humidity control. This works with influences on minimum vent and ventilation temperature delivering a constant supply of heat energy to the glasshouse regardless of the temperature within it.
2. To promote air movement and therefore uniform temperatures within the glasshouse.

Many growers use humidity influences on minimum pipe temperature as the primary method of humidity control. This tends to waste energy and limits the ability of TI to make energy savings. To realise the full benefits of TI growers must try to avoid the use of minimum pipe temperature and use ventilation as the primary method of humidity control, only increasing the minimum pipe temperature at the last possible moment. This alone can be quite a change to normal practice and may need to be introduced gradually to build confidence in this approach.

Applying TI without TI software

It is possible to apply all of the principles discussed earlier without the use of TI software. To do this, the grower must track the average temperature and modify the heating and ventilation temperatures manually. The following steps help to clarify the processes involved:

1. Record the average 24-hour temperature on a daily basis and calculate the rolling average over the integrating period to be used, e.g. three days.
2. Multiply the difference between the target average temperature and the rolling average temperature by 72 (3 days x 24 hours) to give the degree-hours accumulated.
3. Calculate the allowable reduction in temperature setting resulting from the accumulated degree-hours. For example, if the heating temperature is only allowed to be reduced during the night time which lasts for 10 hours divide the degree-hours from above by 30 (3 days x 10 hours). This gives the reduction (or increase) in night time heating temperature required to achieve the desired target temperature.

4. If the minimum heating temperature is reached during the night, the grower then needs to consider whether the day time heating temperature can be reduced. During prolonged good weather conditions (high light & high temperatures) the maximum ventilation temperature may also have to be reduced to ensure the target average temperature is achieved.
5. If humidity is controlled by relying on a small heat-vent differential any change to the heating temperature will have to be applied to the ventilation temperature to maintain a constant differential.

It should be noted that the full potential of TI can only be realised with the appropriate software and the ability to view the environment in the glasshouse graphically allowing fine tuning of set points.

Greater detail on the application of TI is given in the science section of this report. Fully replicated trials (PC 190) carried out with pot chrysanthemum and poinsettia at HRI Efford also give much greater detail regarding crop scheduling and quality.

Science Section

Introduction

Background

All businesses are under increasing pressure to reduce energy use due to a range of factors:

- **Economic**
  - Climate Change Levy
  - Rising fuel prices
- **Legislation & consumer driven**
  - To reduce the environmental impact of businesses

The protected cropping sector is very energy intensive so improving energy efficiency can have a large impact on both environmental and financial performance. DEFRA statistics indicate that there is around 90Ha of heated pot plant production in the UK. Typical energy costs are around £50,000/Ha p.a. Therefore, the total energy cost for this sub-sector is £4.5million p.a.

A study trip to Denmark and Holland (PC 172) concluded that the use of advanced climate control methods is an effective way of improving energy efficiency. Following this study tour, work carried out at HRI Efford (PC 190) showed that the principles of temperature integration 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%. Trials on a commercial tomato nursery (PC 188) gave energy savings of 10% and a 4% increase in yield. Even at the lower level of 10% energy saving, temperature integration has the potential to save pot plant producers ~£5,000/Ha p.a. (£450,000 p.a. nationally).

Despite this background of fundamental and applied research, the principles of TI have not yet been widely exploited commercially. Up to now, the main reasons for the low level of uptake seem to be that growers have lacked confidence in the technique, especially the ability to control humidity. Also they have been unsure of the financial benefits at a commercial level.

This project was designed to build on the results of the work in project PC 190 in particular, and accelerate the uptake of temperature integration by demonstrating its application on commercial ornamentals nurseries growing a range of pot plant species.

Objectives

The objectives were as follows:

- Demonstrate that temperature integration does not have any detrimental effect on crop yield, quality or production schedules
- Illustrate the energy savings that can be achieved by using temperature integration and improving the use of climate control equipment
- Show that the approach can be applied to a range of ornamental pot plant crops
- Promote an improved understanding of the important parameters that affect both the energy consumption of a greenhouse and the quality of the crop being grown
- Demonstrate that the principles of temperature integration can be applied to a wide range of climate control computers and illustrate that growers do not have to invest in new 'state of the art' systems to apply the basics of temperature integration.

What is temperature integration and how does it work?

It has been shown that many plants 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 remains at the required level. There are clearly limits to these 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.

Plackett, Adams, and Cockshull (2002) reviewed the work previously carried out in this area in HDC project PC 188 – Part A.

Basic concept

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

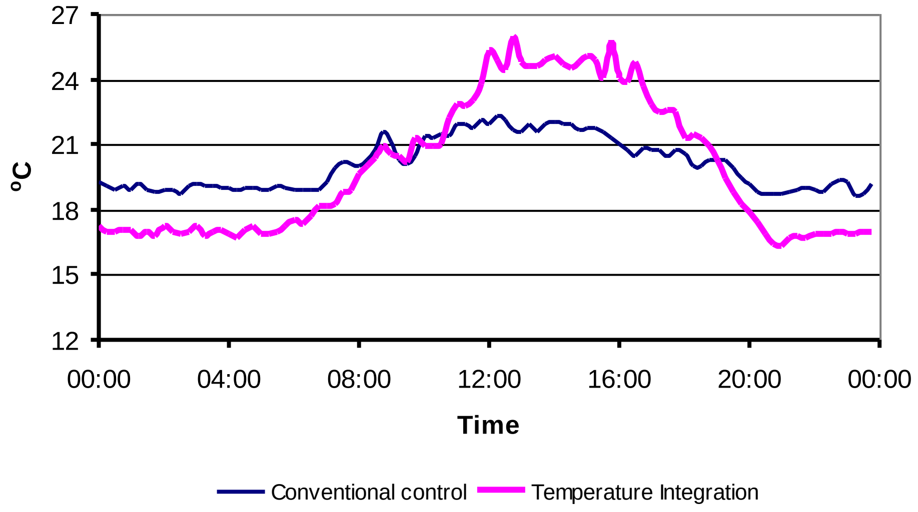
- During the daytime when solar gain in a greenhouse is high and the temperature rises above the heating set point, the vents in the roof open to help control the temperature
- During poor weather conditions and during the night when heat loss from the glasshouse is high, heat is required to maintain 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.

Figure 6 overleaf 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.

Figure 6 - A comparison between conventional and TI greenhouse temperatures

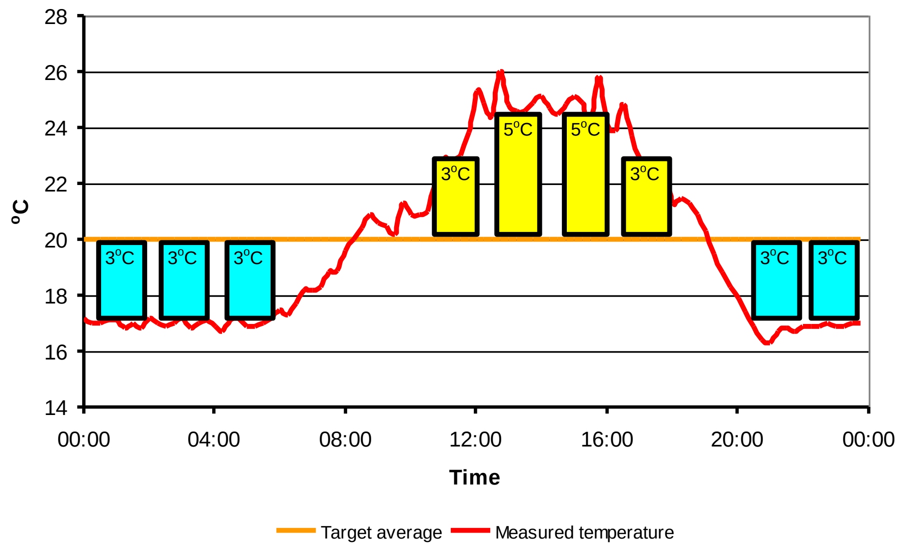


What are degree-hours?

When describing the principles of TI 'degree-hours' are regularly referred to. They are a way of tracking by how much and for how long the temperature in the glasshouse is either above or below the target average temperature. Figure 7 below helps to explain this. If the temperature is 3°C above the target for one hour +3 degree-hours are accumulated.

Conversely if the temperature is 3°C below the target –3 degree-hours result. This negative degree-hour effect is often called 'burning off' degree-hours. TI software keeps a running total of the degree-hours (positive or negative) and this is referred to as the temperature sum (Tsum). That way it knows if there is energy 'in the bank' (+ve Tsum) and in the case of optimised TI if heating above the target average is required (-ve Tsum). Simple TI does not actively allow a negative Tsum to occur.

Figure 7 – Degree-hours



How does TI save energy ?

The principles of TI can be applied in two fundamentally different ways.

Simple TI

Simple TI can be used to accumulate 'free' degree-hours during the daytime when weather conditions are favourable. These are then used the following night, or even several days later, by applying a lower heating temperature. The lower heating temperature leads to lower heating energy use. When weather conditions are poor and no 'free' degree-hours are accumulated, the heating temperature reverts to its normal setting and no energy is saved.

Optimised TI

This still uses the principles of Simple TI but takes things one step further by using thermodynamic modelling and weather forecast data to optimise the operation of the heating system. Optimised TI systems can judge when high and low cost heating periods are likely to occur and adjust temperature accordingly to save the maximum amount of energy.

For example, an optimised TI system might increase heating temperature during a period of relatively still mild weather when heating costs are low. This builds up a bank of 'cheap' degree hours which can be used to allow a lower heat temperature setting when weather becomes colder or windier and the cost of maintaining the glass house temperature is high.

What about humidity control?

If TI is applied as described under the section 'Basic concept' and the ventilation temperature is simply increased by several degrees, humidity control may suffer depending on the humidity control strategy in use. Humidity tends to be controlled by one, or sometimes a combination, of the following approaches:

- A humidity dependent minimum ventilation setting
- A reduction in ventilation temperature.

Both require the careful use of heat to achieve humidity control. It is common to have a humidity influence on heating system output. With hot water based heating systems this is done via a humidity influence on the minimum pipe temperature.

HDC Fact Sheet 25/02 'Controlling Humidity to minimise the incidence of grey mould (Botrytis cinerea) in container-grown ornamentals: heated glasshouse crops' gives more detailed information on humidity and disease control.

If TI is applied correctly, the humidity control strategy normally used will continue to provide the same level of control as previously achieved. Greater detail is given on how this is achieved later in the report.

Practical application of TI

The principles described previously relate to climate control computers that have TI software built in. However even those systems without TI software can be used to apply the principles discussed. The difference is that the user has to manually adjust heating temperature set points according to the average temperatures achieved.

Where appropriate each of the following sections is split into two parts:

1. Simple TI.
2. Optimised TI.

Integrating period

The integrating period applies equally to both simple and optimised TI. It is the time, usually measured in days, over which the temperature is averaged. If one day is used, TI will try to achieve the target average temperature within each 24-hour period. During good weather conditions when it is possible to accumulate more degree-hours than can be ‘burnt off’, any unused degree-hours are simply discarded at the end of the 24-hour period.

If two days are used, this allows spare degree hours from one day to be kept and used the next day. So if a day of bright sunshine is followed by a cold wet day, the average temperature achieved on Day 1 could be above target whereas on Day 2 it could be below. But the average temperature over the two days (integrating period) will still be on target.

From an energy saving point of view the longer the integrating period the more chance the control system has to use degree-hours accumulated during good weather before they are discarded and therefore more energy savings can be made. However there is a limit to how long the integrating period can be. If it is too long, a prolonged period of high temperatures could be followed by low temperatures causing imbalance in the crop and less predictable scheduling. Recent work has used integrating periods of between three and seven days without any discernible effect on a range of crops including both edible and ornamental crops.

Heating temperature

During the middle of the day solar gain will raise the temperature achieved in the glasshouse above the heating set point even on many days in the middle of winter. Therefore with the conventional approach to temperature control, the average air temperature actually achieved in the glasshouse will normally be higher than the average heating temperature in all but the worst weather conditions.

With TI, the computer automatically adjusts the heating set point within the limits set by the grower to achieve the required average.

Consider a conventionally grown crop as detailed below:

- Heating temperature 18°C, 24 hours/day
- Target average temperature 19°C.

Simple TI

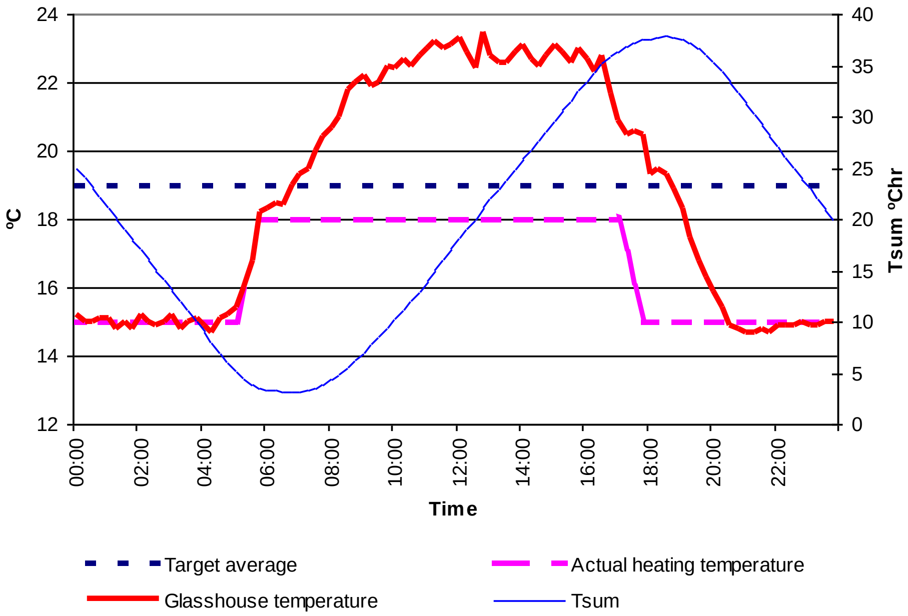
The target heating temperature should be set to 19°C. As a result even in the worst weather conditions an average temperature of 19°C will be consistently achieved.

When weather conditions are favourable and solar gain lifts the air temperature in the glasshouse above 19°C, degree-hours are accumulated and the Tsum rises. These can be used to reduce the heating temperature at another part of the day.

When the Tsum is >0 (degree-hours 'in the bank') the climate control computer automatically reduces the heating temperature. Note - the computer will only reduce the heating temperature when and by how much the grower allows. A grower just starting to apply TI may only allow the heating temperature to be reduced by 1°C during the hours of darkness whilst confidence in the technique develops.

A more 'aggressive' approach was used in HDC project PC 190 where one treatment allowed the heating temperature to be reduced to 15°C at any time of day. The example in Figure 8 below takes a 'middle of the road' approach.

Figure 8 – Example heating profile for simple TI



Daytime

In order to ensure that the crop is always close to the optimum temperature for photosynthesis only 1°C negative compensation has been allowed, giving a minimum working heating temperature of 18°C.

Night time

Greater negative compensation has been allowed during the hours of darkness, allowing TI to reduce the temperature to a minimum of 15°C.

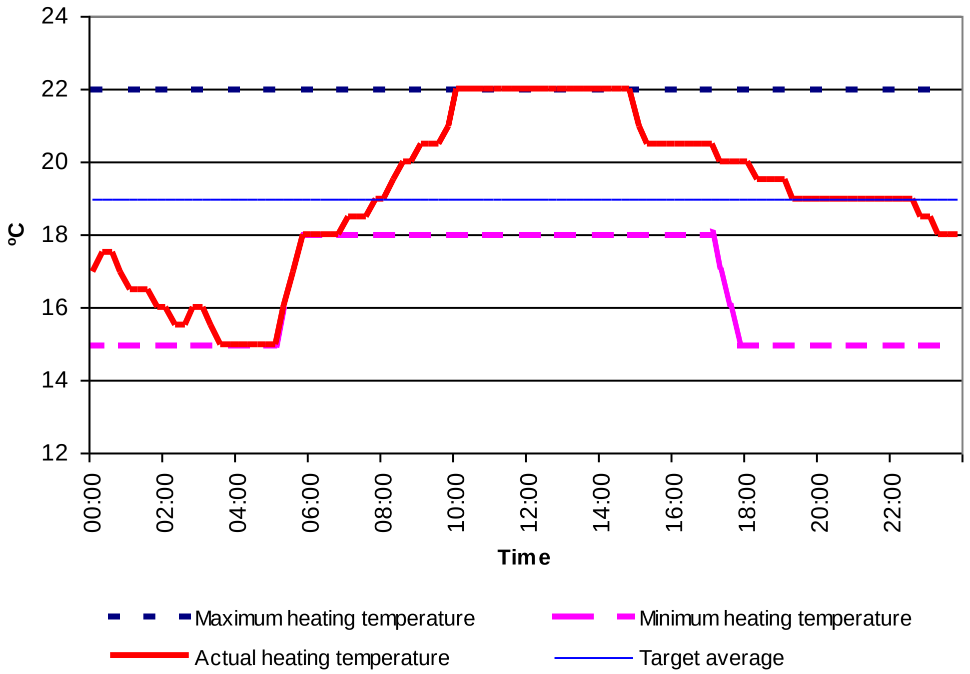
Optimised TI

This is an evolution of the approach taken with simple TI. There are essentially three heating temperature lines:

1. The desired average temperature.
2. The minimum allowable temperature.
3. The maximum allowable temperature.

Combined with the weather forecast and glasshouse thermodynamic model the actual heating temperature is calculated to minimise the heating requirement. A fundamental difference between simple and optimised TI is that optimised TI will use heat to actively heat above the target average temperature when heat loss is low to built up 'cheap' degree-hours. In Figure 9 below, this will more than likely be the case between 10:00 & 15:00 when the calculated heating temperature is 22°C.

Figure 9 - Example heating profile for optimised TI

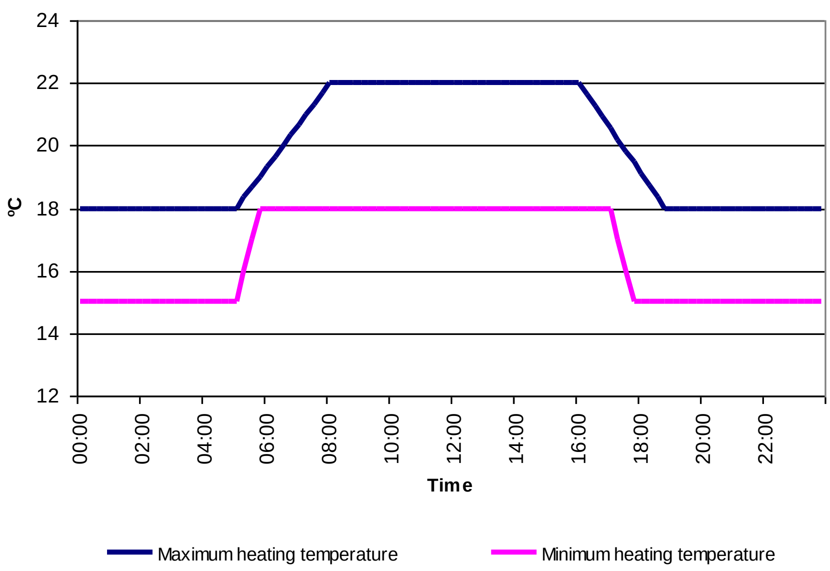


The actual heating temperature as shown in Figure 9 illustrates a number of points:

1. During the day time the heating temperature is higher than the target average. This shows that few free degree-hours are available and therefore 'cheap' degree-hours are being accumulated.
2. From 00:00 to 05:30 the heating temperature falls to the minimum allowed. This is common as the few hours immediately before dawn are normally the coldest part of the day.
3. The actual heating temperature towards the end of the 24-hours is much higher than at the start. This suggests that the weather conditions are more favourable at the end than they were at the beginning, possibly higher outside temperature and lower wind speed.

With the maximum and minimum heating temperatures shown it is possible for optimised TI to calculate a higher heating temperature during the night than during the day. This is normally only the case when thermal or blackout screens are used and even then only during extreme weather conditions. Some crops cannot be grown under constant high night / low day regimes. This rarely happens even with the settings shown in Figure 9 and in practice no such problems have been encountered. However, for peace of mind it is possible to stop this happening at all. An example of how to do this is shown in Figure 10 below. Some climate control computers with TI allow the grower to specify a minimum day – night temperature difference.

Figure 10 – How to avoid high night & low day temperatures with optimised TI



Applying set points as shown in Figure 10 above will ensure that the daytime temperature cannot go below 18^{o}C and the night time temperature cannot go above 18^{o}C. It should be noted that for both simple and optimised TI, restricting the range of heating temperatures will reduce the potential for energy savings.

Other influences and considerations

Many growers use radiation and even radiation-sum influences to change the heating temperature. These can still be applied although their effect on the calculated heating temperature may be less obvious due to the influence of TI.

Where DROP is used TI can effectively be turned off for the DROP period.

Ventilation temperature

The differences between optimised and simple TI relate to control of the heating temperature. Control of the ventilation temperature is the same for both systems.

Effective control of the ventilation temperature is important for two reasons:

1. It ensures good humidity control.
2. It helps to accumulate any free degree-hours that are available.

However, humidity control considerations must take priority over accumulating degree-hours.

Humidity tends to be controlled by one, or sometimes a combination, of the following approaches:

- Increasing the minimum vent position
- Reducing the temperature at which ventilation begins.

Plus the careful use of heat to achieve humidity control.

Minimum vent

Controlling humidity by opening the vents using a humidity influence on the minimum vent position is not affected by the difference between the heating temperature and ventilation temperature. Therefore raising the ventilation temperature to help accumulate as many free degree-hours as possible will not affect the ability to control humidity in this way.

Reduction in ventilation temperature

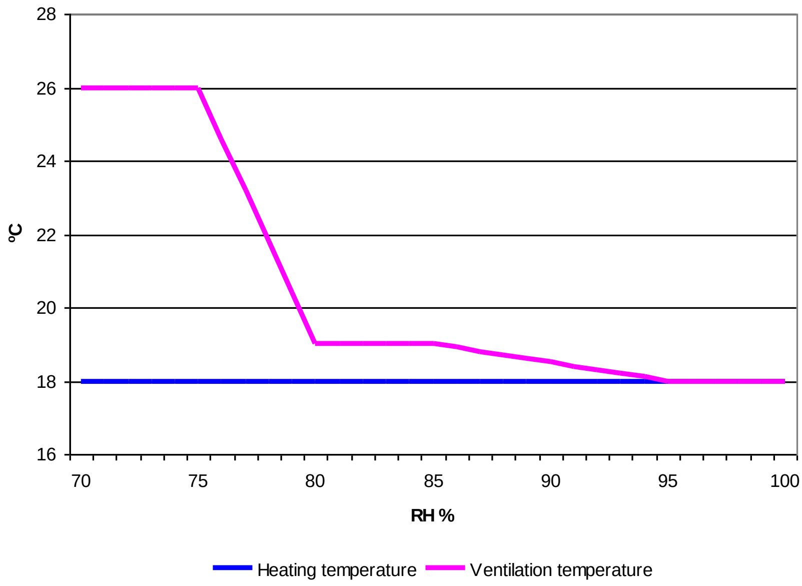
Controlling humidity by relying on a small difference between the heating and ventilation temperatures will be affected if the ventilation temperature is simply increased by several ^{o}C.

If TI automatically reduces the heating temperature the heat – vent differential will increase and humidity control may suffer. TI software can be set to reduce the ventilation temperature by the same amount as the heating temperature. Therefore if TI reduces the heating temperature by 1°C it will also reduce the ventilation temperature by 1°C keeping the heat – vent differential the same all the time. This will help to maintain adequate humidity control.

However keeping the ventilation temperature close to the heating temperature does not optimise the accumulation of free degree-hours when conditions are favourable. The solution is to build in an influence that increases the ventilation temperature when the relative humidity is below the maximum allowed (or above, if humidity deficit is used).

The example in Figure 11 below shows how such a humidity influence could be applied.

Figure 11 – Humidity influence on ventilation temperature



In the example it is assumed that a relative humidity of 85% is considered to be acceptable. However as it rises above this corrective action needs to be taken and the humidity influence reduces the heat – vent differential to 0°C once the RH rises to 95%. It may even be necessary to reduce the differential to 0°C at 90% depending on the level of humidity control achieved and the use of heat to help control humidity.

As the relative humidity falls below 80%, to give a safety margin, the heat – vent differential can be increased to help accumulate free degree-hours. Care must be taken to apply any influence gradually, changing the ventilation temperature by 5°C over a humidity range of 5% may cause instability in the control of temperature. Giving precise recommendations is not possible as every glasshouse will respond differently. However 1°C per 2% RH is a good starting point.

Minimum pipe temperature

The minimum pipe temperature is the minimum allowable water temperature within the heating pipes regardless of the temperature within the glasshouse. This is used in combination with venting to control humidity.

Ideally, to give the lowest energy costs, humidity control should be driven by ventilation. Only when glasshouse temperature falls to within 0.5°C of the heating temperature should heating be instigated.

Practically however, the slow speed of response of heating systems (particularly hot water systems) means that humidity control entirely driven by ventilation control can be unsatisfactory. With this short periods of low temperature and excessively high humidity can occur as the heating system 'catches-up' with the temperature drop caused by ventilating. To avoid this it is common to vent and heat at the same time. However, using excessive amounts of heat and maintaining a heat – vent differential of over 1°C even at high humidity will restrict the ability of TI to save energy.

Optimising minimum pipe settings and humidity control to work in harmony with TI requires:

- A good understanding of the fundamental processes involved
- The ability to interpret graphs on the climate control computer and identify the corrective actions necessary.

What if I don't have TI built into my computer?

TI can be applied with a climate control computer that does not have the software built in as long as you can:

- Apply different heating and ventilation strategies depending on the time of day
- Add humidity influences to the ventilation temperature.

Humidity and ventilation temperature control are just the same as described in the earlier sections. The only difference is that the grower has to manually calculate and apply any adjustment to the heating temperature. If humidity control is based on the heat – vent differential, the ventilation temperature also needs to be manually reduced by the same amount.

Table 1 overleaf demonstrates how a grower can apply the principles of TI manually. It is also possible to apply this approach using a spreadsheet so that all the calculations are done for you.

- In the table an integrating period of 3 days is being applied, hence calculating the 3-day rolling average temperature actually measured in the glasshouse
- The difference between the 3-day average and the target average is multiplied by 72 (72 hours in 3 days) to calculate the number of degree-hours in the bank
- It has been assumed that negative compensation is only allowed during the night and that the length of the night time period is 10 hours. Therefore the degree-hours in the bank can be spread across 30 hours (3 days x 10 hours/night). So on 03/04/2003, when there is 60 degree-hours in the bank, the correction to the night time heating temperature = 60 / 30 = 2^{o}C. The target average temperature, integrating period and length of the night period will need to be changed to suit the crop grown and prevailing conditions
- The new night time heating temperature setting for 04/04/2003 is therefore the previous setting (19^{o}C) minus the correction (2^{o}C) = 17^{o}C
- When the rolling 3-day average falls below the target, the degree-hours in the bank are negative and the night time heating temperature is increased

Table 1 – TI without the software

		Heating temperature ºC			Measured temperature ºC			
Date	**Target average temperature ºC**	**Day**	**Night**	**Length of night hours**	**24-hour average**	**3-day rolling average**	**Degree hours in the bank**	**Correction required ºC**
01/04/2003	19	19	19.0	10	20			
02/04/2003	19	19	19.0	10	20.5			
03/04/2003	19	19	19.0	10	19	19.8	60	-2.0
04/04/2003	19	19	17.0	10	18.5	19.3		
05/04/2003	19	19	17.0	10	19	18.8		
06/04/2003	19	19	17.0	10	19.5	19.0	0	0.0
07/04/2003	19	19	17.0	10	19	19.2		
08/04/2003	19	19	17.0	10	19.2	19.2		
09/04/2003	19	19	17.0	10	19	19.1	4.8	-0.2
10/04/2003	19	19	16.8	10	20	19.4		
11/04/2003	19	19	16.8	10	19	19.3		
12/04/2003	19	19	16.8	10	18.7	19.2	16.8	-0.6
13/04/2003	19	19	16.2	10	18.6	18.8		
14/04/2003	19	19	16.2	10	18.8	18.7		

Table 1 shows the calculation and changes made to the night time heating temperature every third day (equal to the integrating period). When first implementing TI it is preferable to check the average temperature daily even if no changes are made. Then further action can be taken if the rolling average temperature is not responding to the changes.

Practical points to bear in mind

When 'free' degree-hours are limited

Figure 8 shows a day when there are plenty of degree-hours in the bank. When using simple TI, if the Tsum is low the actual heating temperature is reduced evenly within the time window available. So, for example, the day and night time heating temperatures could be 18.5^{o}C and 17^{o}C respectively.

When degree-hours are limited growers can afford to be choosy about when TI is allowed to reduce the heating temperature. For example only allowing 1^{o}C negative compensation during the night time may be enough and it will give much more stable conditions for the crop. It will also allow degree-hours banked on one bright winter day to be spread across several nights and not used up on the first night.

An alternative is to only allow negative compensation between midnight and dawn as this is normally the coldest time of day. However the key to energy savings is to ensure that as many as possible of the accumulated degree-hours are 'burnt off'. Being too prescriptive can lead to degree-hours being wasted.

This is automatically handled by optimised TI using the glasshouse thermodynamic model and the ability to accumulate 'cheap' degree-hours. To get the most out of optimised TI the operating window within which it can work should be as big as possible regardless of the time of year.

When there are too many 'free' degree-hours

When good weather conditions prevail, it is possible to accumulate more free degree-hours than can be burnt off. First of all the grower needs to give TI as big a window as possible within which to reduce the heating temperature. This means allowing the lowest possible heating temperature for as much of the day as possible.

If excess free degree-hours are still accumulated, the maximum ventilation temperature should be reduced.

Avoiding excessively high temperatures

Although the ventilation temperature may be set at say 26°C, the temperature will not be controlled to exactly 26°C. It is common for the vents not to fully open until the temperature rises 3°C above the ventilation temperature i.e. 29°C. This is referred to as the P-band. Prolonged periods at this temperature are generally considered to be undesirable for most crops.

During the winter months this is rarely a problem, with low outside temperatures the smallest amount of ventilation will bring the greenhouse temperature to within 1°C of the ventilation temperature.

During the peak of summer, the ventilation temperature will be relatively low to reduce degree-hours accumulated. During the autumn and spring, variable weather conditions can mean that on odd days this will happen. However, on most days accumulating degree-hours will still be a priority. There are various ways of solving this depending on the facilities on the climate control computer. The most common are:

- Using an outside temperature influence to reduce the P-band during warm weather and increase it during cold weather
- Using a radiation influence to reduce the ventilation temperature.

As a guide, for a ventilation temperature of 26°C, if the outside temperature is 20°C or above, the P-band can be as low as 1°C during the warmest part of the day. This should be increased gradually to a P-band of 5°C as the outside temperature falls to 8°C.

Experience gained during this project showed that once outside temperatures consistently exceeded 15°C during the daytime, global radiation above 600W/m^2 meant that excessively high temperatures occurred in the glasshouse. Adding a radiation influence to reduce the ventilation temperature by even just 1°C as global radiation rises from 600 to 700W/m^2 can have a significant impact.

Depending on specific site circumstances these figures may need to be adjusted to fine tune their effect.

Research Method

Overview of location, facilities and cropping

This project was carried out at three different locations:

- Double H Nurseries, Sway, Hants.
- Double H Nurseries, New Milton, Hants.
- Rushmere Nursery, Bedfordshire.

Double H Sway (Pot chrysanthemums)

The site comprised three wide span glasshouses each covering an area of 4,000m^2 all built over 30 years ago. The site produces a range of varieties of pot chrysanthemum all year round. One glasshouse is used for propagation, the other two are used for growing on. The propagation area was controlled using conventional strategies and did not form part of the project.

Of the remaining two glasshouses, one was operated using a conventional control strategy and the other using TI. Control strategies were switched to isolate any difference between the glasshouses. This was carried out on a 9-week cycle, to match the production cycle. The climate control computer was a Priva Integro v721 which included simple TI software.

House A

A single air space with blackout screens, controlled as two separate heating and ventilation zones. The site was heated using a gas fired steam boiler. Heating systems in this glasshouse included:

- Floor heat – plastic pipe, maximum operating temperature 30^{o}C
- Side heat – pulsed steam
- Overhead heat beneath the screen – on / off steam.

Plants were grown on the floor on matting over sand and sub irrigated by lay flat tubes. CO_2 enrichment was provided by a natural gas fired blown air heater in each zone. Supplementary lighting delivering 9.6W/m^2 PAR (4,000 lux) was also installed. The control of both CO_2 enrichment and supplementary lighting was identical in both House A and House D. Operating hours for the CO_2 enrichment and lighting were dependent on crop scheduling and quality at any point in time but were exclusively during the winter months.

House C

Essentially the same as House B apart from two points:

1. There was no overhead heat.
2. Irrigation was via drip line to individual pots.

Double H New Milton (Begonias)

This site produces a wide range of pot plants according to season and customer requirements. At this site the project focussed on two crops of begonia one produced for Mothers Day and one follow-on crop. The project was carried out in two adjacent glasshouse compartments. Both were identically equipped as follows:

- Medium span house, 2.6m to gutter, 30 years old
- Crop grown on raised benches with capillary matting
- Shading / thermal screens
- Hot water heating with pipes underneath the benches
- Flood irrigation.

The glasshouse within which TI was applied was 1,866m^2 compared to 1,244m^2 for the conventional control strategy.

The climate control computer at this site was a Hoogendoorn Economic. This included Econaut temperature integration software allowing optimised TI to be applied.

Rushmere Nursery (pot bedding plants)

This site produces a range of pot and container grown plants for sale at local garden centres. The climate control computer was a Priva CD750 with no TI software. The project work carried out at this site was aimed at demonstrating that the principles of TI can be applied without the need for specific TI software.

The principles of TI were applied to a single glasshouse compartment covering 1,000 m^2. The glasshouse was a modern triple venlo type, built in 1990, with hot water heating, moveable benches, flood irrigation and thermal screens. The crop grown was zonal geranium.

Data collection

At the Double H Sway and New Milton sites all the glasshouse environmental and energy data was recorded by the climate control computer and downloaded via modem connection at weekly intervals throughout the project. This included:

Glasshouse data

- Set points – heating & ventilation temperature
- Heating system – measured heating pipe temperature, steam on/off (where applicable
- Ventilation system – measured vent position
- Screen position
- Glasshouse environment – temperature, relative humidity.

Energy use

- Hot water heat meters were installed in each heating circuit at New Milton
- Steam meters were installed for each glasshouse at Sway.

Crop data

- The nursery's own routine shelf life and quality recording
- An assessment of botrytis infection carried out by Dr Tim O'Neill of ADAS Consulting on the pot chrysanthemum crop.

At Rushmere Nursery data collection was limited to the average temperature and relative humidity achieved and printed out as a daily report. There was no direct comparison of conventional vs. TI strategies or energy use. The sole aim of the trial was to prove that TI principles could be applied without the use of dedicated software.

Results & discussion

As a commercial demonstration project, the overriding objective at all the sites was to ensure that a successful crop was grown in both the conventional and TI treatments. There were two overriding environmental control requirements:

1. To achieve the same average temperature in both treatments.
2. To control humidity to whatever level was required by the site manager regardless of the impact on energy savings delivered by TI.

Energy savings by applying TI were only to be made once these aims were satisfied.

Double H Sway (AYR pot chrysanthemums)

Control strategies applied

At the time of this trial the site manager was already using the principles of TI by closely following the results of HDC project PC 190. The approach developed was initially retained as, during favourable weather conditions, it proved to perform well. However as weather conditions deteriorated, by Week 48 of year 2002 humidity control was poor. The set points relating to humidity control were reassessed and modifications applied to all areas. These set points proved to be robust and once fine tuned remained fundamentally unchanged for the remainder of the project.

Weeks 43 to 49 (Year 2002)

Table 2 below details the basic set points applied between weeks 43 and 49 in the growing-on stage of crop production where TI was applied.

Table 2 – Control settings week 43 to 49

	Time period	Set point	Influences
Conventional strategy			
Heating temperature	All the time	18°C	None
Ventilation temperature	All the time	24°C	-1°C, 85-90% RH
Temperature integration			
Heating temperature	All the time	18°C	3°C negative compensation, giving a minimum heating temperature of 15°C
Ventilation temperature	All the time	26°C	-1°C, 85-90% RH
Integrating period	3 days		
Set points common to both areas			
Minimum vent position	All the time	0%	+5%, 90-95% RH
Screen control - blackout	17:00 – 07:00	100%	5% gap, 80-85% RH, between sunset & sunrise
Minimum pipe	All the time	20°C	+10°C, 80-85% RH

TI will always tend to achieve an average temperature equal to the average set heating temperature. This is in contrast with conventional control strategies, where the daytime temperature will almost always exceed the heating temperature due to solar gain, and so lift the average temperature above the set heating temperature. To help achieve similar average temperatures in both treatments, a radiation influence was added to the TI block to make the average heating temperature track the average temperature achieved in the conventional block. This would not be necessary when applying TI in a non research environment.

Second tier settings for minimum pipe temperature turned the pump off when the calculated pipe temperature fell to within 3°C of the glasshouse temperature. So for example, if the glasshouse temperature was 18°C and the minimum pipe temperature was 20°C, the pump would turn off.

As the heat output of the floor heating system at 30°C was minimal, the humidity influence on minimum pipe temperature was brought in at a lower RH than might normally be expected.

It is arguable that the conventional strategy used at this nursery incorporated an element of TI by using a relatively high heat-vent differential. It was, in effect, banking some free degree-hours but not burning them off during the night time.

Figure 11 shows a typical day in the TI area in Week 46. Good weather dominated and there were plenty of degree-hours in the bank. Therefore TI reduced the heating temperature by the maximum allowed to 15°C all the time. An RH of around 70% prior to screen closure helped to carry dry air into the night time period. During the night time the RH stabilised at around 82% and was adequately controlled by a small amount of minimum pipe temperature and slight gapping of the blackout screen.

Figure 12 shows a day in Week 48. By this stage in the season less favourable conditions during the day time resulted in a high RH going into the night time period. The limited amount of minimum pipe heat available in combination with screen gapping was unable to adequately control the RH and it stabilised at around 90%.

Figure 11 – TI a day in Week 46

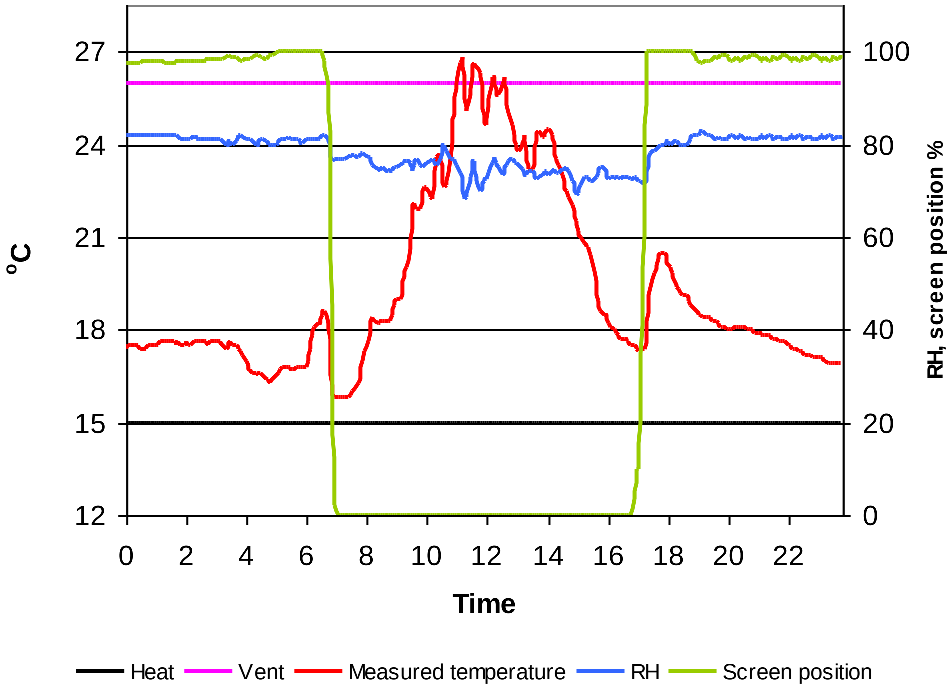
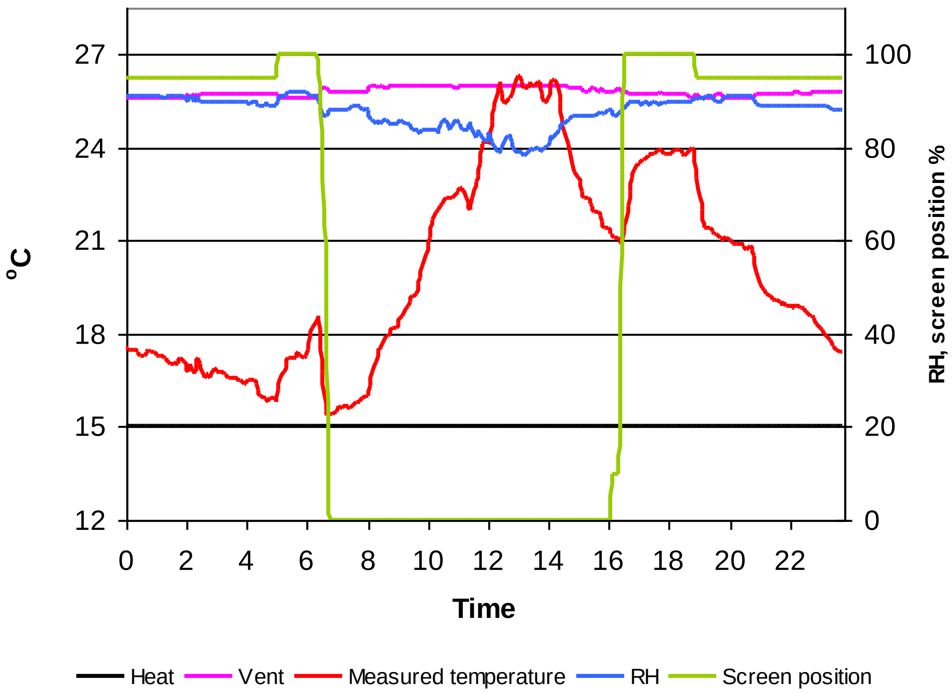


Figure 12 – TI a day in Week 48



Weeks 49 to 21 (Year 2002/2003)

The high RH conditions that developed by Week 48 occurred most consistently in the TI block because of the reduced requirement for heat to maintain temperature. There were also occasions when high RH occurred in the conventionally controlled block. Therefore to ensure reliable control of RH the following approach was applied to all areas.

As heat output from the floor mounted hot water system was limited, the original settings for this were retained. The rapid response of the steam heating system allowed a vent then heat approach to humidity control to be taken without risking a dip in temperatures which can be the case with slower responding hot water systems.

Figure 13 below shows the effect of the RH influences applied to the ventilation temperature in the TI and conventional areas. At an RH of 85% the influences are identical and the ventilation temperature is 19°C, only 1°C higher than the heating temperature. At 100% RH the ventilation temperature is reduced further to 18°C, the same as the heating temperature. This causes the venting of warm, high water content air which is replaced with colder dryer outside air. When the temperature within the glasshouse falls to the heating temperature and heat is applied the temperature is maintained at the required level and the RH is controlled.

These influences were successful in controlling the RH to the required level in these areas of glass. They could be adopted by other growers as a starting point for humidity control but they may require some fine tuning to suit local conditions. The heat-vent differential may need to be reduced to 0°C at a lower RH if adequate control is not achieved.

The ventilation temperature regime in the two trial areas only differed once the RH fell below 85%. At 75% RH the conventional strategy ventilation temperature peaks at 23°C whereas the TI strategy peaks at 26°C. Therefore the higher heat – vent temperature differential is only allowed when the RH is below the critical level.

Figure 13 – Effect of RH influences on ventilation temperature

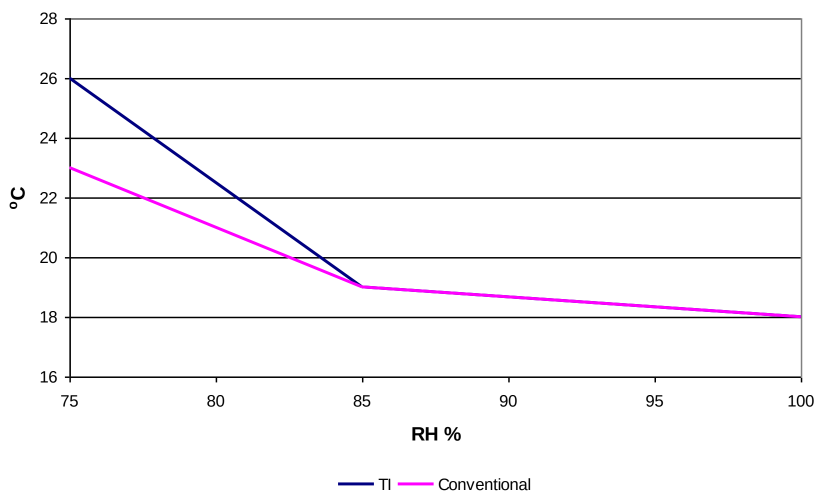


Table 3 – Control settings week 49 to 21 (Year 2002/2003)

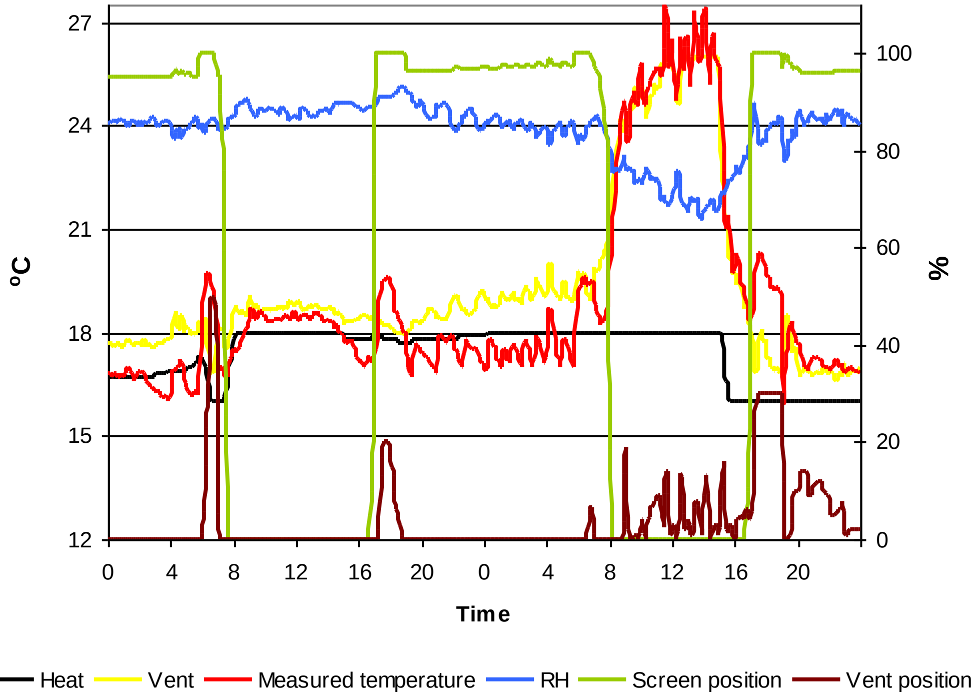
	Time period	Set point	Influences
Conventional strategy			
Heating temperature	24-hours	18°C	None
Ventilation temperature	24-hours	23°C	18°C at 100% RH 19°C at 85% RH 23°C at 75% RH
Temperature integration			
Heating temperature	07:00 – 16:00	18°C	None
Heating temperature	16:00 – 07:00	18°C	Up to 3°C negative compensation when adequate degree-hours, giving a minimum heating temperature of 15°C
Ventilation temperature	24-hours	26°C	18°C at 100% RH 19°C at 85% RH 26°C at 75% RH
Integrating period	5 days		
Set points common to both areas			
Minimum vent position	Not used		
Screen control - blackout	17:00 – 07:00	100%	5% gap, 85-90% RH, between sunset & sunrise
Minimum pipe	All the time	20°C	+10°C, 80-85% RH

The amount of negative compensation allowed was reduced when the degree-hours accumulated were low. During weeks 1 to 4 of year 2003 when weather conditions were particularly poor it was reduced to 1°C. By Week 12 it was back to 3°C.

Due to increased confidence in TI and no adverse effect on crop quality or scheduling the integrating period was increased to five days. Towards the end of the project it was increased further to seven days.

Figure 14 below shows a 48-hour period when these set points were applied.

Figure 14 – A day in Week 10 in the TI block



- During the first night-time period (midnight – dawn) the RH averaged 83%. It was adequately controlled by gapping of the screen and the heat used to maintain the target temperature
- During the following daytime period weather conditions were poor. This was reflected in the temperature only just rising above target. The high RH (88% average) was considered by site management to be tolerable as it rarely occurred for more than 2 hours. Figure 14 shows that, the ventilation temperature is very close to the measured temperature but they never cross i.e. no venting occurs. Had better control been required this could have been achieved by changing the humidity influence on vent temperature to reduce the heat-vent differential at a lower RH. This would cause the vents to open and so help to control humidity . Taking the TI set points in Table 3, changing from -8°C at 100% to –8°C at 95% should have the required effect.

- The following night time period has a heating temperature that is barely affected by TI because there are few degree hours in the bank. Once sunset passes and the screens are allowed to gap, heat demand for temperature control adequately controls humidity. The average RH is 86%
- Weather conditions during the following day time period are good and this is reflected in higher temperatures and low RH's. A point to note is how the vent temperature only rises as the RH falls, peaking at 26^{o}C
- The final night time period on this graph shows a heating temperature of 16^{o}C. In combination with a relatively high outside temperature this meant that no heat was required to maintain the glasshouse temperature. Gapping of the screen with some venting and floor heating controlled the RH during the first half of the night to an average of 86%
- The spiky temperature control achieved during the middle night time period is a characteristic of the steam heating and associated control system.

<u>Glasshouse environmental data – weekly averages</u>

Temperature

Figure 15 – Average 24-hour temperature

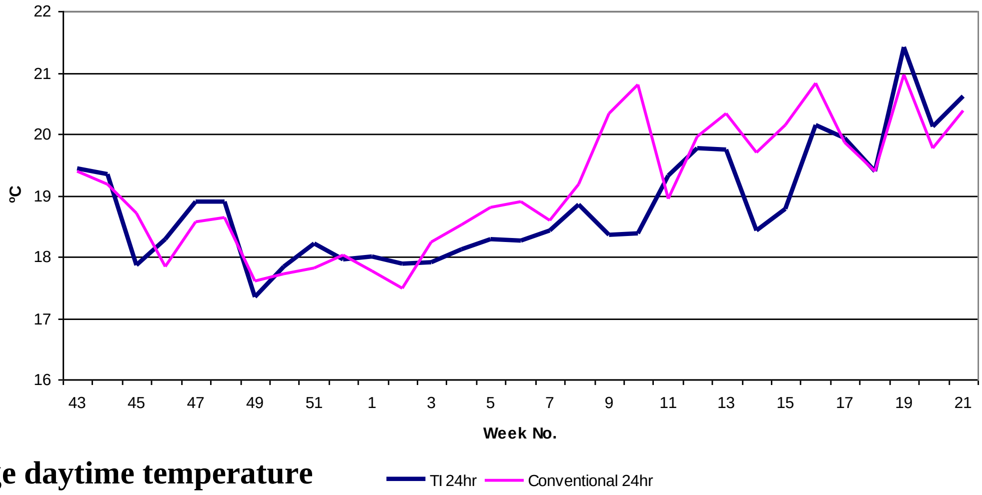


Figure 16 – Average daytime temperature

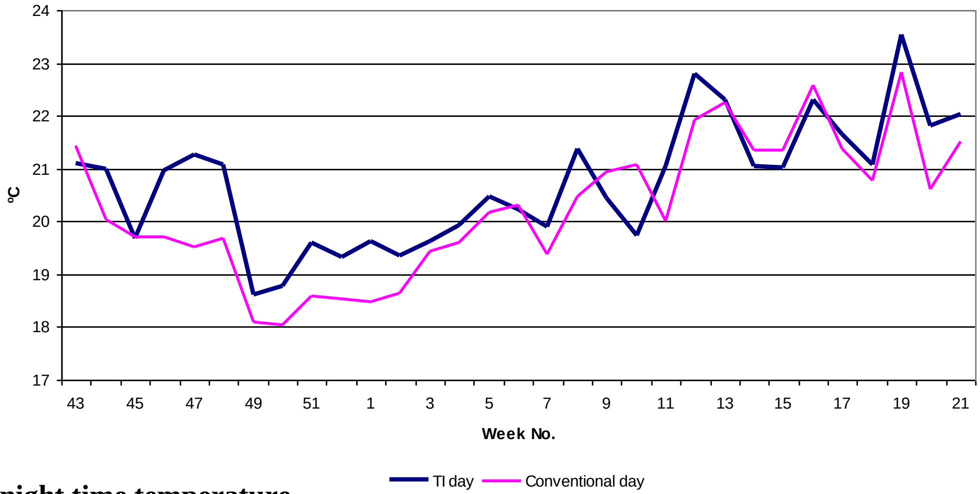
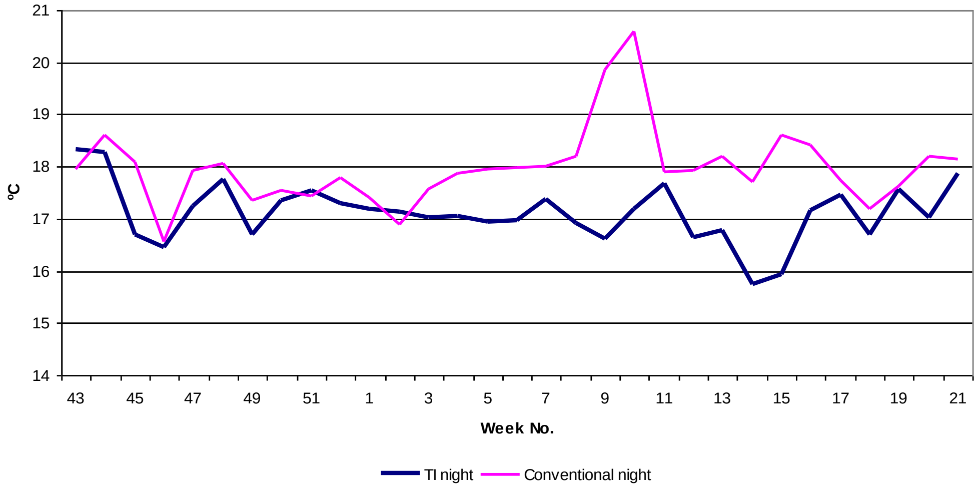


Figure 17 – Average night time temperature



Average

Generally speaking the average 24-hour temperatures achieved in each treatment remained within 0.5°C of each other. However there were a number of notable exceptions:

1. Week 45 – damaged measuring box in the TI area
2. Week 47/48 – intermittent vent motor fault, leaving vent slightly open in the conventional area
3. Weeks 9/10 – steam bypass valve mistakenly left open in the conventional area
4. Weeks 14/15 – steam valve not turned on again after maintenance was carried out in the TI area.

Day time

The average daytime temperature achieved in the TI area was generally higher than in the conventional area. This is a result of the higher ventilation temperature applied in the TI area to help accumulate free degree-hours. There are notable exceptions in line with points 1 & 3 above.

There was a drop in the average daytime temperature in both areas around Week 49. This is due to the change in set points) implemented to improve humidity control, coinciding with a significant drop in outside temperature (see Figure 21).

From Week 9 onwards the trend is difficult to follow due to equipment issues (point 3 & 4 above) and the difficulty in trying to pre-empt and respond to the effect of weather conditions on the average temperature achieved in the conventional block.

Night-time

The night-time temperature in the conventional area should have always averaged at least 18°C. Discounting the periods when equipment failure affected the average temperature measured there was still a period between Week 49 and Week 3 when 18°C was not achieved. This was mainly due to limitations of the control system rather than limited boiler capacity. Control of the side and roof heat was only proportional. This works as follows:

- If the temperature is 0.5°C below target the side heat turns on for X minutes in every 5 minute period
- If it is 1.5°C below target it is set to turn on for Y minutes (where $Y > X$) every 5 minute period
- Linear variation is applied between the two extremes.

Values of X and Y that performed adequately when the outside temperature was say 8°C, if unchanged, would not maintain the target temperature when the outside temperature dropped. This limitation of the control system only became apparent towards the end of the year and it took a certain amount of trial and error adjustment to correct.

The average temperature achieved in the TI area was almost always less than 18°C. This is as would normally be expected with TI. However even though there were periods when 15°C was consistently the target night time heating temperature the average temperature rarely fell below 16°C. The small amount of heat delivered by the floor heat in response to high RH held the temperature above 15°C. Once gapping was allowed the temperature gradually decayed to 15°C. At each end of the trial period the average night time temperature was close to, or even higher than, 18°C. This was due to the slow fall from daytime temperatures especially when outside temperatures were relatively high.

Relative humidity

The same equipment issues described in section 0 also affected the RH. Due to the difference in irrigation systems the average 24-hour RH shows few recognisable trends. On balance you would expect the RH in the TI area to be higher than the conventional areas due to reduced venting.

The RH during the night time shows the most consistent patterns. Generally , the RH in the TI area was higher than in the conventional area. Between weeks 47 – 49 the RH was too high (over 90%). This was rapidly brought under control following a review of set points. From then onwards, although the RH was higher in the TI area, it was always controlled within the limits required by Double H management.

Between weeks 4 – 9 when the heating system was operating correctly and with high heat demand due to low outside temperatures, RH was effectively over controlled. As weather conditions improved and the heating demand reduced, the night time RH in the conventional area gradually increased to similar levels to those measured in the TI area.

Figure 18 – Average 24-hour RH

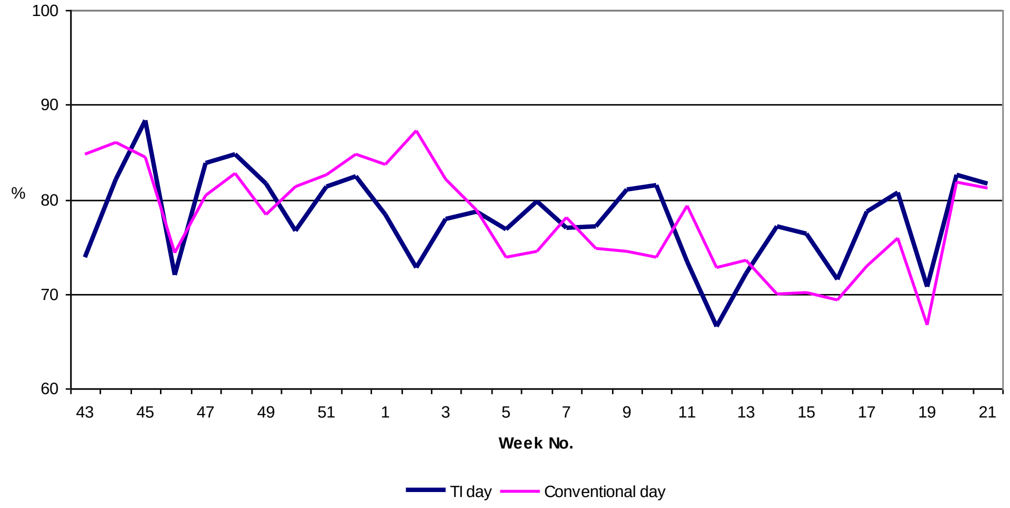


Figure 19 – Average daytime RH

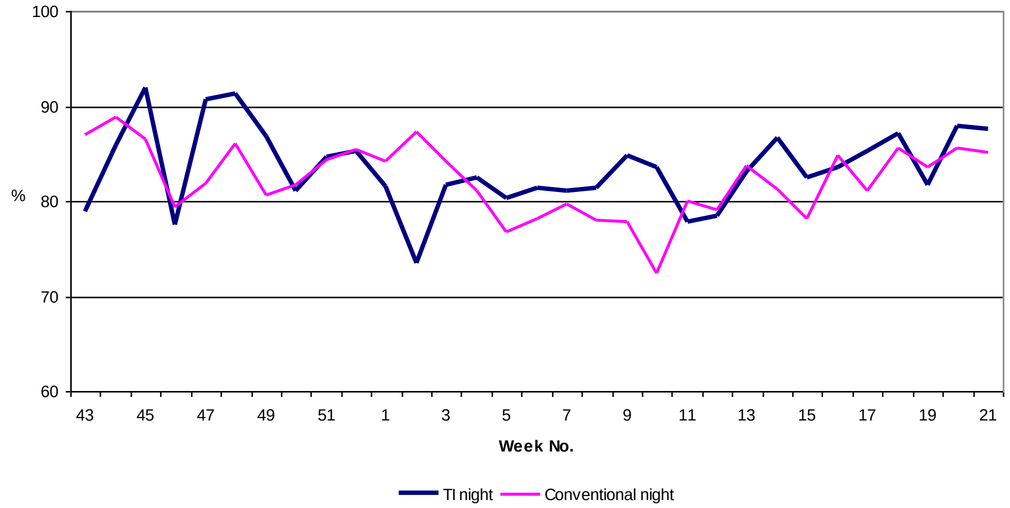


Figure 20 – Average night time RH

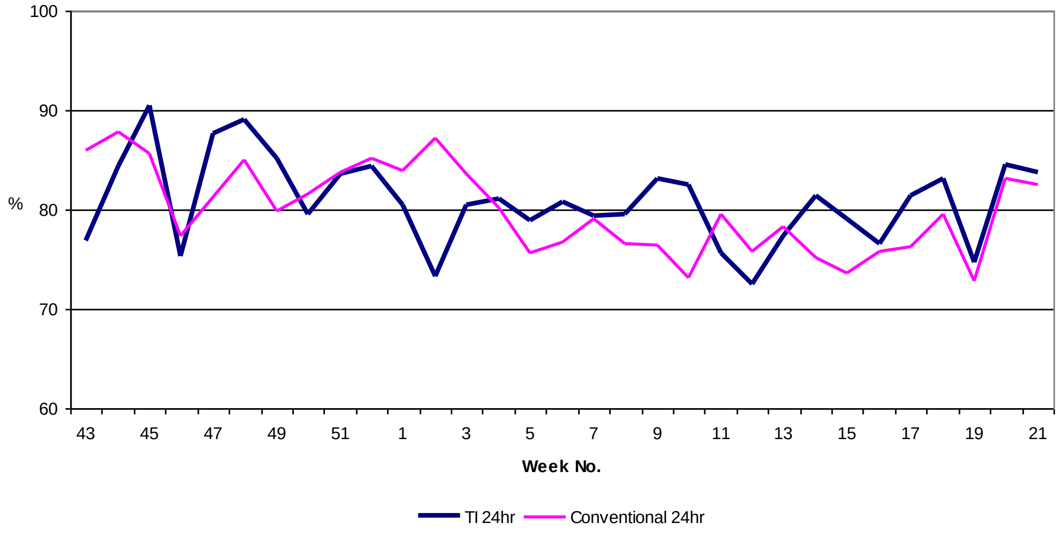
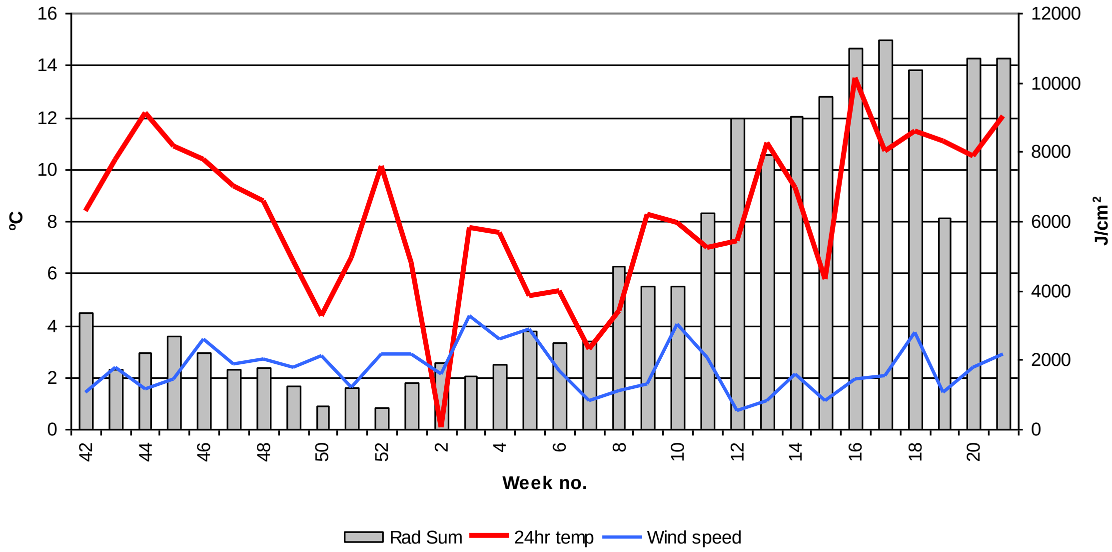


Figure 21 – Weekly weather data



<u>Energy consumption</u>

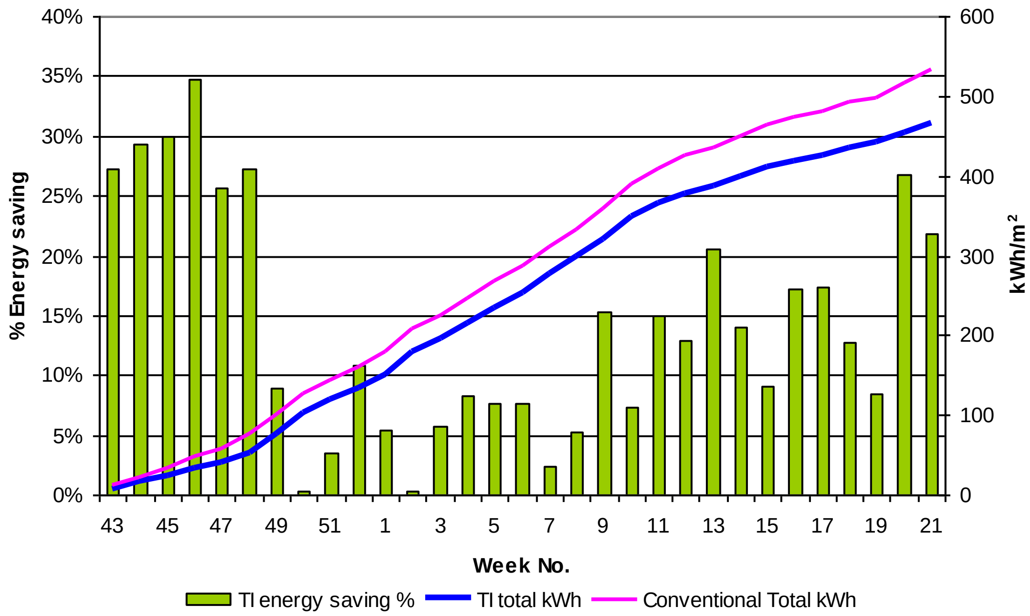
The amount of 'steam' heat delivered to each glasshouse was recorded. Energy, glasshouse and weather data was used to normalise the energy data from the two glasshouses. The results are shown in Figure 22 followed by the total energy used (kWh/m^2) and the week by week savings. In the period from Week 43 (2002) to Week 21 (2003):

- TI area used 467kWh/m^2
- Conventional area used 532kWh/m^2
- Saving 65kWh/m^2 or 12.3%.

Note all figures have been converted into kWh of gas.

Between weeks 43 - 48 good weather conditions and a relaxed approach to humidity control delivered savings that averaged 29%. The modifications made to set points in Week 49 in order to give improved humidity control coincided with a rapid decline in weather conditions. This meant that weekly energy savings fell significantly and between weeks 49 and 8 savings averaged 6%. From Week 9 through to the end of the trial savings averaged 15%. During this last period, two weeks stand out as having a particularly low % saving (Week 15 and Week 19). This is explained by reference to Figure 21, Week 15 which shows a significant drop in outside temperature compared to the weeks immediately before and after it. Week 19 had a similarly low radiation sum.

Figure 22 – Energy data



Double H New Milton (Begonias)

The specific objective relating to this part of the project was to apply the principles of TI to a crop other than pot chrysanthemum. The two glasshouse areas used had identical equipment levels i.e. same type of heating, irrigation, etc. However, constraints relating to production planning and scheduling in particular, meant that the trial areas chosen had some constructional and therefore thermal differences. One area was a corner block with two external walls with the other only having one external wall. This meant that a comparison of energy use was more difficult. This consequential difference in heat loss was also expected to affect humidity control.

Under identical control strategies the following effects would have been expected in the area with the least external wall:

- Daytime – greater rise in temperature due to solar gain therefore more venting and lower RH
- Night time – lower requirement for heat to maintain temperature therefore less inherent RH control from the operation of the heating, and an increased need for active RH control i.e. screen gapping, venting and heating due to humidity influences.

TI was applied in the area with only one external wall. This would provide the most difficult conditions for humidity control during the night and the greatest possible variation in temperature. Applying TI in this glasshouse area was expected to provide the most challenging test of the ability of the system to deliver good plant quality and acceptable scheduling.

All plants were grown in the same conventional environment until final spacing. The following information relates to the period from final spacing to marketing only.

Control strategy applied

During Week 5 both areas were filled with plants and were operated using an identical conventional control strategy.

Weeks 6 to 9 (Year 2003)

The control strategies applied during this period are detailed in Table 4 below. Settings relating to humidity and screen control were common to both areas and were set by the site manager. However, during this period the relative humidity was rarely high enough for these settings to come into effect.

Optimised TI was applied in this part of the project. The set points used allowed the climate control computer to vary the heating temperature between the maximum and minimum at any time of day. It was therefore technically possible for the climate control computer to run cold days and warm nights. This happened on odd days but even then the night time average was only a maximum of 1°C higher than the daytime. Looking at the weekly average temperatures in section 0, the daytime temperature was always higher than the night time.

Table 4 – Control settings week 6 to 9 (Year 2003)

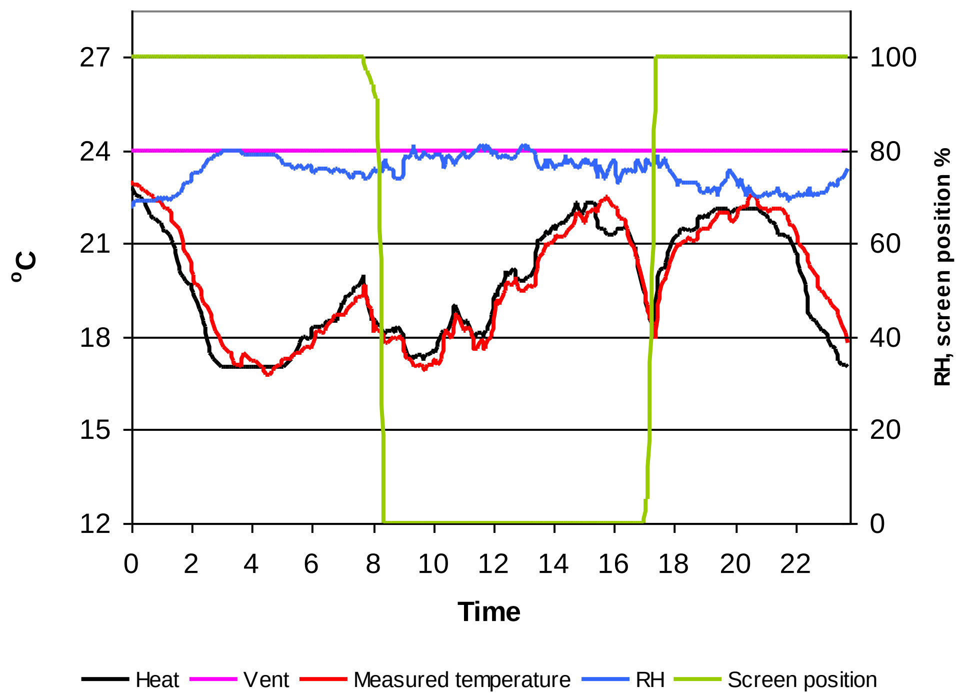
	Time period	Set point	Influences
Conventional strategy			
Heating temperature	24-hour	20°C	None
Ventilation temperature	24-hour	23°C	None
Temperature integration			
Target average	Adjusted manually to track the average achieved in the conventional area but was typically around 20°C		
Heating temperature	24-hour	Min 17°C Max 23°C	None
Ventilation temperature	24-hour	24°C	None
Integrating period	3 days		
Set points common to both areas			
Minimum vent position	0 to 5% at 90 to 95% RH		
Screen control - blackout	All the time. Energy saving, opening and closing based on solar radiation		0 to 5% gap, 90-95% RH
Minimum pipe	All the time	30°C	+0 to 10°C between 87-95% RH -40°C, 100-300W/m^2 (removes minimum pipe completely during good light conditions)

Figure 23 below shows one day during this period in the TI trial area where the target average temperature was 20°C. The weather conditions were very cold on this day with day and night time average ambient temperatures of 1.6°C and 0.1°C, respectively, and a radiation sum of 268J/cm^2. The 24-hour average outside temperature was only 0.7°C.

Applying simple TI on a day like this would not have lead to the accumulation of free degree hours and the target heating temperature would have been unaffected by TI. However with optimised TI cheap degree-hours could be accumulated by actively heating to a temperature above the desired average (20°C) when heat loss was lowest. These could then be used to operate at a lower temperature when heat loss from the glasshouse was highest. So, in this example day, heat was always required to achieve the target heating temperature requested by the climate control computer.

Due to the high heat demand during this period RH rarely exceeded 80%.

Figure 23 – A day in Week 7



Weeks 10 to 13 (Year 2003)

By Week 10 crop development was ahead of schedule, and as a result, the average temperature in both areas was gradually reduced. TI continued to be used until Week 11 when both areas were set to slow crop development as much as possible by applying a 16°C day and 14°C night heating temperature and a heat-vent differential of only 1°C.

Weeks 14 to 21 (Year 2003)

Once Week 14 was reached both areas had been re-filled with begonia and TI was turned on again. Increased confidence in TI following the achievement of good crop quality in the early trial period meant that the integration period was increased to five days and the minimum heating temperature was reduced to 15^{o}C. The maximum heating and ventilation temperature were both reduced by 1^{o}C as more favourable weather conditions meant lower set points were adequate and helped to avoid excessively high temperatures.

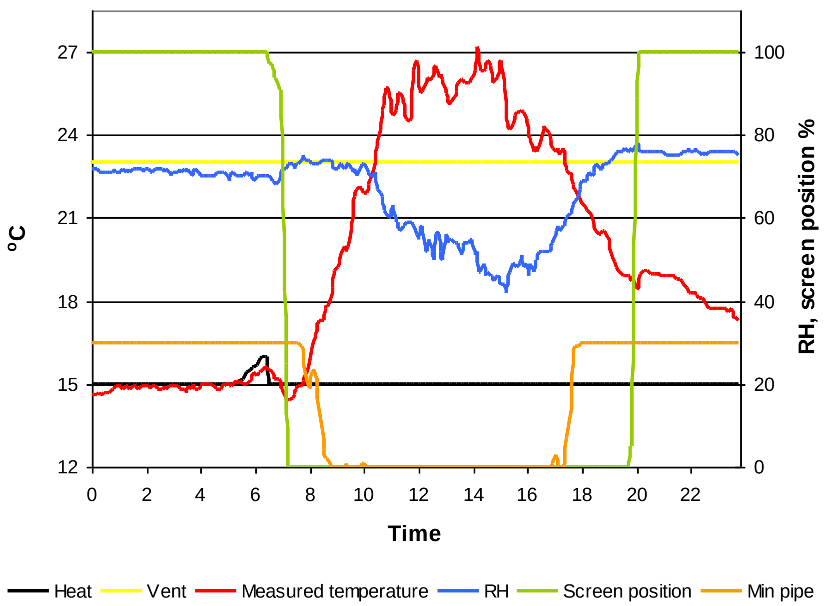
Initially the same settings relating to humidity control were retained.

Table 5 – Control settings week 14 to 21 (Year 2003)

	Time period	**Set point**	**Influences**
Conventional strategy			
Heating temperature	24-hour	18^{o}C	None
Ventilation temperature	24-hour	20^{o}C	None
Temperature integration			
Target average	Adjusted manually to track the average achieved in the conventional area but was typically around 20^{o}C		
Heating temperature	24-hour	Min 15^{o}C Max 22^{o}C	None
Ventilation temperature	24-hour	23^{o}C	None
Integrating period	5 days		
Set points common to both areas			
Minimum vent position	0 to 5% at 90 to 95% RH		
Screen control	All the time. Energy saving, opening and closing based on solar radiation		5% gap, 90-95% RH
Minimum pipe	24-hour	30^{o}C	+0 to 10^{o}C between 87-95% RH -40^{o}C, 100-300W/m^{2} (removes minimum pipe completely during good conditions)

Figure 24 below shows a day in Week 15 with these settings applied when weather conditions were good. Note the high daytime temperature & constantly low heating temperature which seldom gets above the minimum allowed. In the run up to dawn, the measured glasshouse temperature is at the set heating temperature, i.e. heat is being used to maintain temperature. At this point the minimum pipe temperature of 30°C is having no effect. As the solar radiation rises the minimum pipe temperature reduces to zero. However going into the following evening outside temperatures are higher and a 30°C minimum pipe temperature holds the glasshouse temperature well above the heating temperature. The screen is not gapping because the RH is below 80%. In this case the minimum pipe temperature could have been safely reduced without risking high RH.

Figure 24 – A day in Week 15



In Week 16 the set points were reviewed in both areas to ensure adequate RH control whilst using minimum pipe as little as possible. The order of priority was:

- Gap the screens first
- Then add some minimum vent
- Finally increase the minimum pipe temperature.

Using a minimum vent setting to control humidity can be inefficient if too much is applied. It is possible to have the RH too high, the vents open, heat being applied and the temperature still below target. The heat being supplied is simply vented without having the chance to reduce the RH. Closing the vents and allowing the temperature in the glasshouse to rise to the required level will control the humidity in this situation.

The climate control computer on this site has an additional influence that can reduce the minimum vent if the glasshouse temperature is below target, therefore overcoming this potential drawback. The set points changed were as shown in Table 6.

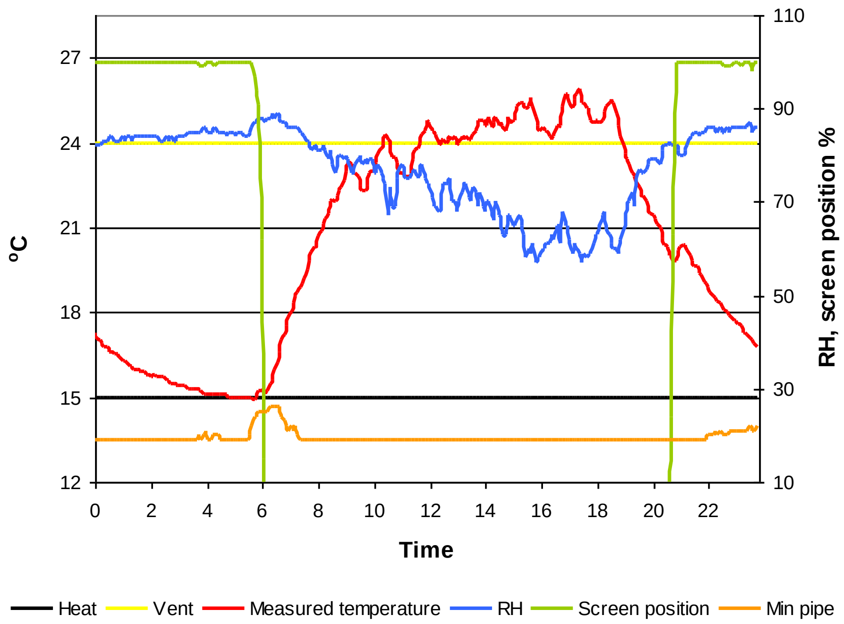
Table 6 – Week 16 revised humidity control set points

Screen gapping	0 to 10% gap, 83-88% RH
Minimum vent position	0 to 5% vent at 85 to 90% RH 0 to -5% at a measure greenhouse temperature between 0 to 0.5°C below target heating temperature
Minimum pipe	19°C +0 to 10°C between 87-95% RH

A basic minimum pipe temperature of 19°C was used as the pumps were set to turn off at anything <20°C i.e. water is not circulated.

Figure 25 below shows a day with these revised settings applied. In this example, the RH is always less than 90%, only a small amount of screen gapping is required and the minimum pipe temperature rarely rises above 20°C. Heat is only used when the measured temperature drops to the heating temperature i.e. 15°C. This is only the case for around two hours just before sunrise. In the conventionally controlled glasshouse heat would have been required as soon as the measured temperature fell to 18°C. In this case it would have meant heating for as much as seven hours.

Figure 25 – A day in Week 19



Glasshouse environmental data – weekly averages

Temperature

Figure 26 - Average 24-hour temperature

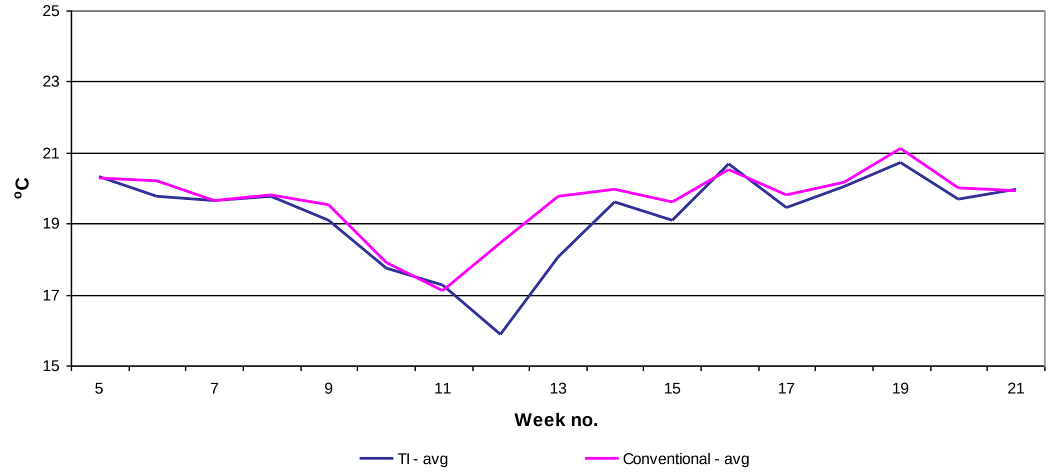


Figure 27 - Average daytime temperature

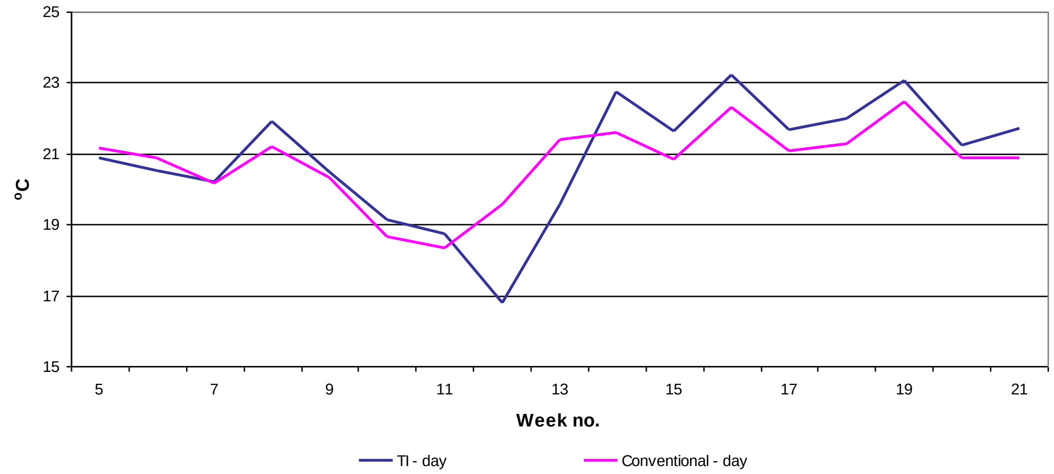
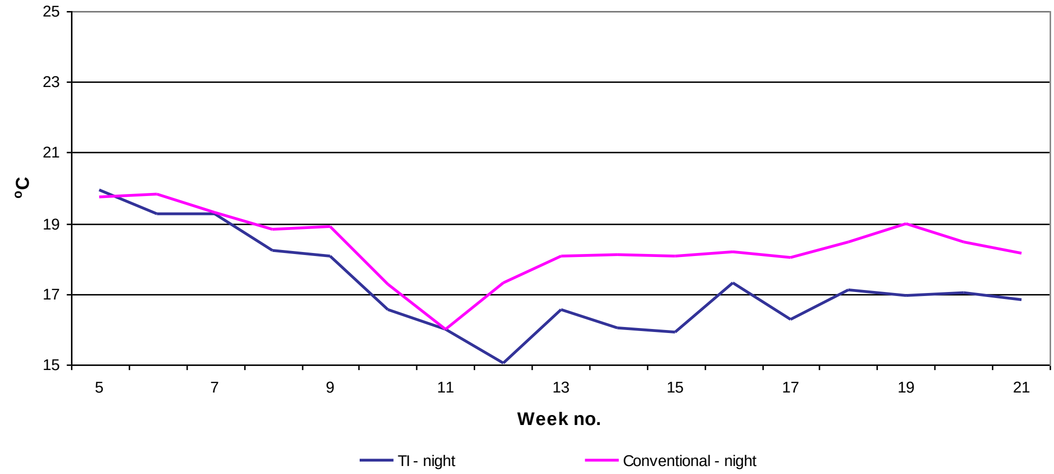


Figure 28 - Average night time temperature



Average

Due to the above average amount of natural light available early in the year, crop development was significantly ahead of schedule in both treatments. This led to a reduction in target average temperature from Week 8 to Week 11. Deliveries to customers meant that the conventionally grown area was emptied and refilled first (Week 13), with the TI area being refilled one week later. This emptying order was entirely driven by logistics issues and not was not influenced by any perceived difference in crop development. During this period the average temperatures achieved were within 0.5^{o}C of each other.

Day time

During weeks 5 to 7 there was virtually no difference between the two treatments. This could have been expected to some extent because poor weather conditions gave little solar gain and therefore few ‘free’ degree-hours. However this does mask what happened on some days (Figure 23) where the TI area operated at a lower temperature early in the day but actively heated to a much higher temperature later when outside conditions improved.

During weeks 8 to 11 the average daytime temperature was marginally higher in the TI area. The difference would have been greater, but in order to slow down crop development the daytime temperature in the TI area was reduced to such an extent that TI had little potential to accumulate degree hours. From Week 14 onwards once both areas were refilled, weather conditions had improved and TI was given a greater operating window. This is reflected in the consistently higher daytime average temperature in the TI area.

Night time

During weeks 5 to 7 there appears to be little difference in the average night time temperature. As with the daytime temperature, the variation in temperature within the night time period is masked by looking at the average achieved. Depending on the prevailing weather conditions, there could be one cold night followed by a relatively warm night. During weeks 5 to 7 in particular a single night time period could comprise temperatures both above and below the target average which are hidden within the weekly average figure in the graphs.

During weeks 8 to 11 the average night time temperature was marginally lower in the TI area. The difference would have been greater, but in order to slow down crop development the daytime temperature in the TI area was reduced to such an extent that to maintain the same longer term average in both areas the night temperature could not be reduced too much.

From Week 14 onwards, once both areas were refilled, weather conditions improved and TI was given a greater operating window. This is reflected in the consistently higher daytime average temperature in the TI area from Week 14 onwards. This, in turn, allowed consistently lower night time temperatures whilst maintaining the same long term average.

Relative Humidity

Figure 29 - Average 24-hour RH

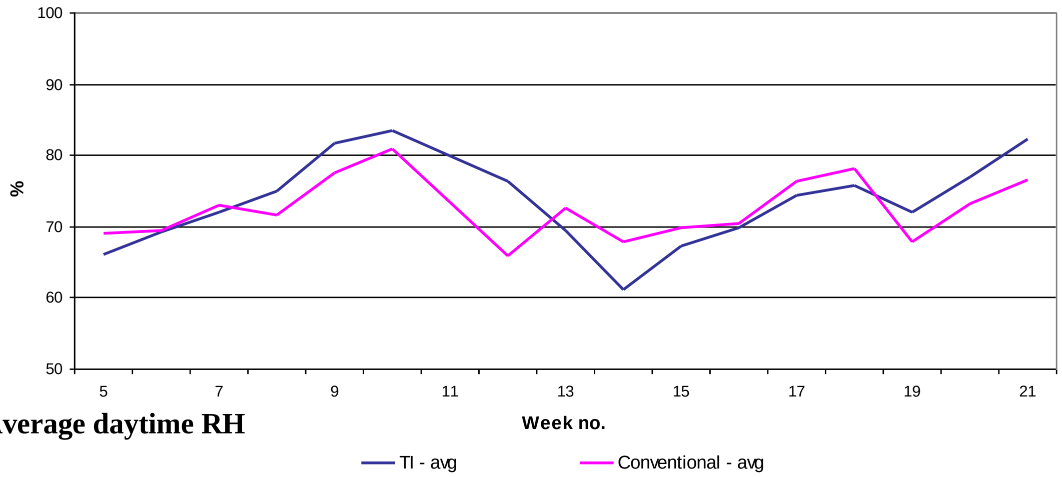


Figure 30 - Average daytime RH

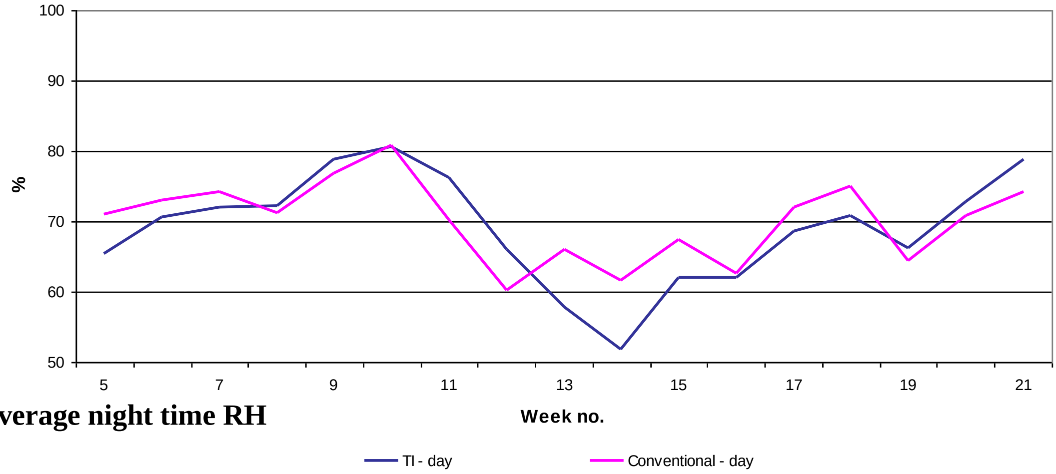
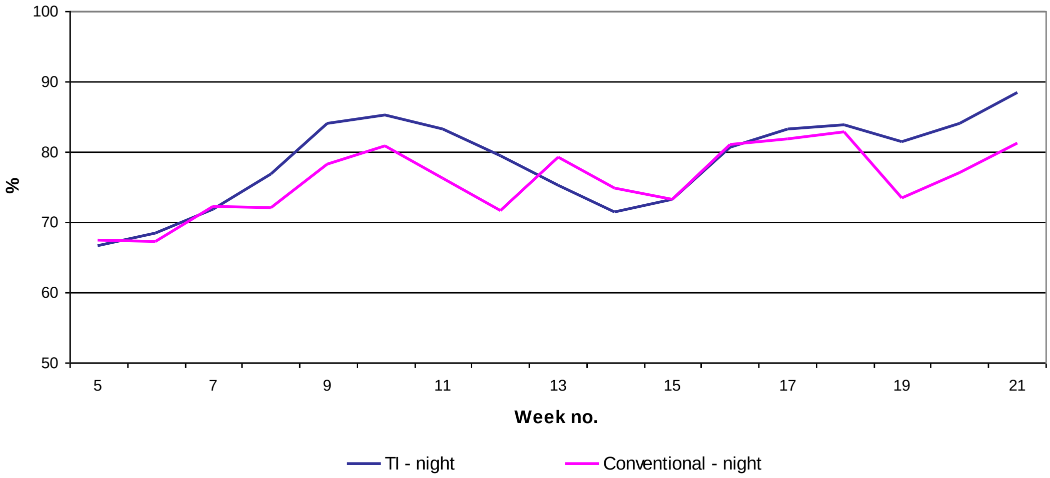


Figure 31 - Average night time RH



As discussed previously, the different glasshouse characteristics were expected to have a marked effect on humidity control. The area where TI was applied was chosen partly because of the greater challenge it posed for night time humidity control.

As a result the average and daytime RH figures showed few trends attributable to the difference in control strategy. However the RH during the night was generally higher in the TI area. The immediate conclusion would be that RH control in the TI area was worse. However, this is not the case. RH in the TI area was always satisfactorily controlled to the level required by site management. RH was effectively "over-controlled" in the conventional area due to the higher heat demand required to maintain temperature.

Energy consumption

Maintaining good crop performance was the sole aim of this part of the project. However in spite of the physical difference between each glasshouse area energy monitoring produced some interesting results.

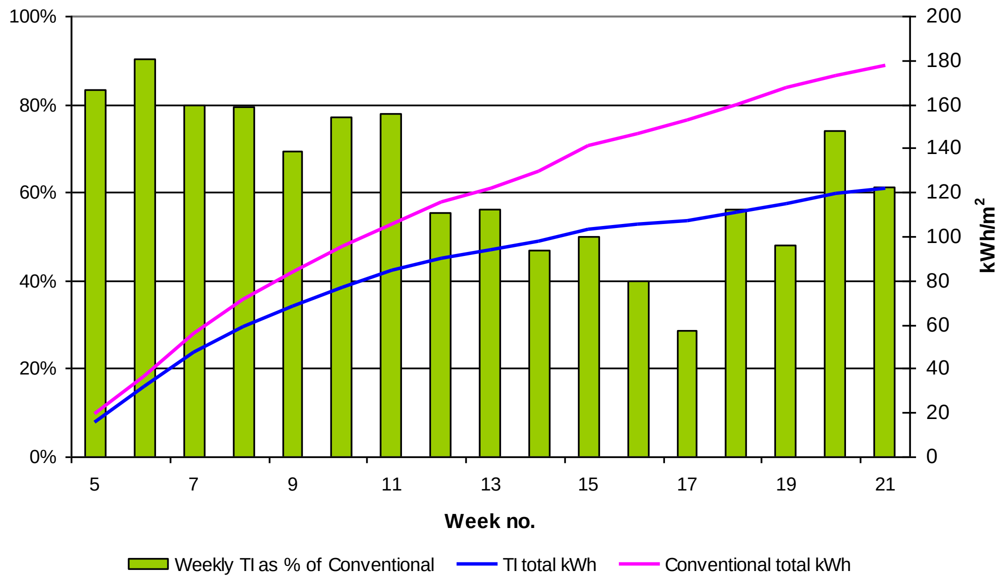
For the whole of Week 5, and for three days during Week 13, both compartments were operated under identical conventional control strategies. However during Week 5 the heating system in the conventional area could not maintain the target temperature all the time, therefore invalidating any comparison. The comparison during the three days of Week 13 showed that the area used for the conventional strategy used 25% more energy than the TI area.

Taken on face value this 25% difference suggests that TI actually used more energy between weeks 6 & 11 where the TI area only used 20% less. However the limited heating capacity in the conventional area continued to affect total energy use up to Week 8, thereby invalidating the comparison during this period.

From Week 9 onwards heat demand fell below the limited heating capacity in the conventional area, and savings from TI became evident, with a saving in Week 9 of 6%. TI was only applied to a limited extent in weeks 10 to 13 and was, in fact, turned off in Week 11. Valid energy use comparisons were then available from Week 14 onwards once both areas were refilled with plants. From Week 14 onwards the overall energy use in the TI area was 50% of that in the conventional area i.e. an adjusted saving of 25%. Towards the end of the trial period energy use to maintain temperature was minimal and total energy use became dominated by the need to control humidity and the savings fell.

Comparing the total energy use of each area gives 193kWh/m^2 and 130kWh/m^2 for the conventionally and TI controlled areas respectively. Correcting for an inherent difference of 25% due to the physical characteristics of each glasshouse area gives 145kWh/m^2 for the conventional area. This gives a net saving of 15kWh/m^2 (10%) through TI. This does not taken into account the effect of the limited heating capacity in the conventional area or the period when TI was turned off. Therefore the saving of 10% is thought to be very conservative. This compares well with the results obtained at the Sway Nursery.

Figure 32 – Energy data



Rushmere Nursery (pot bedding plants)

The aim of this part of the project was to prove that the principles of TI could be applied on a nursery without TI software on the climate control computer. No comparative energy monitoring or crop recording was carried out.

The approach described in Section 0 was used and shown to provide adequate control of the glasshouse environment. Crop quality and scheduling was considered to be at least as good as in previous years by the nursery owner.

Plant data

Shelf life and quality assessment

Shelf life and quality assessments were carried out on the pot chrysanthemum and begonia crops at Double H Sway and New Milton respectively. All plant recording was carried out by nursery staff and analysed by Dr I. Clarke of HRI Efford. A complete version of his report is included in Appendix 1.

At marketing, assessments were made of both the pot chrysanthemums and begonias in line with standard assessments set out in HDC project PC 190. Routine shelf life assessments were carried out for both species. At each assessment, 10 plants from four varieties in each treatment of each begonia and chrysanthemum were sampled.

Assessments began in February for the pot chrysanthemums and March for the begonia. Assessments continued with each successive potting.

At the first assessment there were no significant differences in marketing quality for either the Begonia or the Chrysanthemum in any criteria measured. This was also the case for the assessments made for the next two potting dates. After this no further formal assessment took place. There was a very low incidence of disease noted in either crop. This was the subject of a separate study by Dr T. O'Neill.

The shelf life of the begonia and chrysanthemum was not significantly different. Loss of flower quality is seen by the multiples to be critical to shelf life after plants leave the store. The average number of days for begonia to loose 50% of flowers after de-sleeving was 12 days in the control compartment and 12.6 days in the temperature integration compartment. Because the differences in shelf life were so slight, the nursery reduced recording to the number they would normally routinely sample for a non-trial crop. They continued to see no difference between plants from the two treatments.

Disease assessment carried out at Double H Sway

Tim O'Neill of ADAS Consulting Ltd carried out an assessment of disease levels in the spring of 2003. A complete version of his report is included in Appendix 2.

At 2-3 weeks before marketing, occasional necrotic leaves were present on the compost surface; no sporing botrytis was visible on them but damp incubation in the laboratory confirmed B. cinerea with most of them. The mean incidence of plants with necrotic leaves was 8.0% in the control house and 9.9% in the temperature integration house.

At the point of marketing, the mean incidence of plants with necrotic leaves or rotting stems had increased to around 23%, with no difference between the two houses. The severity of botrytis remained very low, with a mean index of 0.34 (on a 0-5 scale) in the control house and 0.31 in the temperature integration house. Comparing individual varieties, there was no consistent effect of temperature integration on the incidence or severity of leaf necrosis.

Discussion

Previous research work applying the principles of TI to a wide range of crops has consistently shown that energy can be saved whilst continuing to produce a crop on schedule and of good quality. It is generally accepted that TI can help to save energy. However growers remain unconvinced that it can be successfully applied on a commercial nursery. The greatest concern is that humidity control will suffer and as a result crop quality will be poor.

Conventional temperature control strategies tend to naturally suppress high humidity to a greater extent than when TI is used. This is due to steadier heat demand during the night and increased venting during the day. Therefore greater attention needs to be paid to humidity control when using TI. However, increasing minimum pipe temperature to achieve this , a common response to poor humidity, can wipe away all the energy savings achieved through TI and will not necessarily control humidity. To get the most out of TI, growers need a good understanding of the principles behind humidity control. They also need to be able to check that the settings they apply achieve the humidity control required and do not just result in wasted energy. This can only be fully optimised if growers have the ability to view the glasshouse environment, heating system status and vent position in graphical form.

During the course of this project TI has been applied on three different nurseries with three different climate control computers (one of which did not have TI software) and to three different ornamental crops. On the sites where a comparison between conventional and TI grown plants was possible no differences in shelf life or disease levels were recorded.

A further indication of the successful application of TI during this project and the confidence that the project partners have gained is that Double H Nurseries continue to use TI on all of its pot chrysanthemum production at Sway. In addition its use has been expanded to a wider range of ornamental crops at their New Milton Nursery.

Conclusions

This project confirms the results of research work on temperature integration (TI) carried out at HRI Efford and many other research establishments. In particular:

- TI has been shown to deliver savings in energy use of 8 to 12.3% during the main heating season on two separate commercial nurseries
- TI had no discernible effect on crop quality at marketing
- A detailed assessment of botrytis levels on one site showed no difference between the conventional and TI treatments
- The principles of TI can be applied on nurseries where TI software is not available
- Good humidity control can be achieved when using TI. However a good understanding of the principles of humidity control and how to modify set points to achieve humidity control is required.

Appendix 1

Effect of temperature integration on plant quality and shelf life in Begonia and pot Chrysanthemum – 2003

Summary

During 2003 the commercial production of pot chrysanthemums and begonia were studied at nurseries adopting the use of temperature integration. Two similar glasshouses were used for each crop to allow the comparison of plants grown with and without temperature integration. The findings demonstrate that there is little if any perceptible differences between crops grown under an integration regime at marketing or during shelf life.

Objective

To determine if the use of temperature integration on a commercial nursery for the production of pot chrysanthemum and begonia affected plant quality or shelf life.

Experimental

Pot Chrysanthemum

The commercial crops of pot chrysanthemums were grown at Double H Nurseries, Sway, Hants. Two Cambridge 27m single span glasshouses were used for the experiment. The heating was controlled by a Priva Integro computer. CO_2 was provided from burning gas and the target for both treatments (houses) was 1000vpm.

The chrysanthemums were stuck and grown on in a common environment for long days (21 days in winter reducing to 10 days in summer). In this common environment long days are achieved by 150W fluorescent tube lighting and with supplementary lighting of 10.8W/m^2 PAR (4.5Klux) over the propagation area and 9.6W/m^2 PAR (4Klux) for the growing on at half space area. All plants in this long day area are grown on aluminium flood benches.

At final spacing the plants were spaced at 14 pots m^{-2} into one of the two single span glasshouses where the temperature integration comparison work was carried out. Thus the effect of temperature integration was tested on the final quality and shelf life of pot chrysanthemum after final spacing.

Pot Begonia

The commercial crop of pot begonia Elatior was grown at Double H nurseries, New Milton, Hants. Two glasshouse units were used identified as Block H and F. The heating is controlled by a Hoogendorn computer.

The young plant material was potted in a common environment at Double H in 13cm pots and Sinclair begonia compost. Plants were grown pot think for two weeks in long days and pinched approximately one week after potting. After this the begonia were given 10 days of short days at pot thick then half spaced and moved to the trial areas for final spacing.

Final spacing was at 23 pots m^{-2}. Blocks H and F have fixed benches with capillary matting that are overhead watered with capillary matting on the flood benches.

TI was applied in block F and the environment in block H was controlled according to a conventional temperature control strategy.

Assessments

At marketing assessments were made of both the pot chrysanthemums and begonias in line with standard assessments that were set out in PC 190. There was also some assessment of the shelf life of both species as part of the routine sampling for shelf life at Double H. At each assessment 10 plants from four varieties in each treatment of each begonia and chrysanthemums were sampled.

Assessments began in February for the pot chrysanthemums and March for the begonia. Assessments continued with each successive potting in comparative compartments.

Table 1: The varieties sampled at marketing at commercial trial at Double H

Varieties used	
Chrysanthemum	***Begonia***
Mirimar	Blitz
Dark Charm	Mariette
San Ansalmo	Nelly

Table 2: The assessments made on the chrysanthemums and begonias at the commercial trial at Double H

	Chrysanthemum	**Begonia**
At marketing		
	Plant height Plant width Number of flowers Comments on colour, chlorosis, disease	Plant height Plant width Number of flowers Comments on colour, chlorosis, disease
Shelf life		
	First flower death 50% flower loss Date with no ornamental value	First flower death 50% flower loss Date with no ornamental value

Results

At the first assessment of marketing quality there were no significant differences for either the begonia or the chrysanthemum in any criteria measured. This pattern continued at the next two potting dates after which the nursery became more sporadic in taking measurements as the height of the season was reached.

There was a very low incidence of disease noted in either crop, but this was the subject of a separate study by Dr T. O'Neill.

The shelf life of the begonia and chrysanthemum was identical irrespective of treatments. The loss of flower quality is seen by the multiples to be critical to shelf life after plants leave the store. The average number of days for begonia to loose 50% of flowers after de-sleeving was 12 days in the control compartment and 12.6 days in the temperature integration compartment. Again because the differences in shelf life were so slight the nursery reduced the recording to only those plants they would routinely sample for their own shelf life monitoring purposes; however they still did not see any difference between plants from the two treatments.

Discussion

Trials at HRI Efford have demonstrated that both pot chrysanthemum and poinsettia can be grown with temperature integration with no detrimental effects at marketing (PC 190). In this project the shelf life of chrysanthemum was shown to be no worse in temperature integration treatments but the poinsettia appeared to have poorer shelf life.

In this commercial trial there was no evidence of poor performance at marketing or reduced shelf life in either begonia or chrysanthemum. It is important to remember that the nature of this commercial trial was that young plants were grown in a common (conventional) environment before being moved to the two different treatments. This means growers can be confident that for the growing-on phase of pot plant production there is no perceptible difference between treatments. Finishing the crop may still require energy inputs to ensure market dates are met.

At Double H the potting and growing-on phase of the begonia trial were in a propagation area where low levels of temperature integration were used. This suggests that begonia could be grown for their entire life under temperature integration with no loss in quality. Temperature integration was not used in the propagation area at Double H Sway, but were in the experiments at Efford where no effect on rooting was seen. Growers would be advised to be cautious in their set points in adopting integration in their propagation areas.

On grower walks and open days the comments of growers seeing and comparing the crops was useful. The consensus of a number of grower groups appeared to be that the begonia looked a more even and more compact crop under temperature integration, and the pot chrysanthemum were slightly taller in the integration compartment. These observations were not supported by the data, or the previous work on poinsettia and pot chrysanthemum at Efford. However growers would be advised to attempt to track their crop height when adopting integration to ensure judicious use of plant growth regulators.

Appendix 2

Effect of temperature integration on grey mould (*Botrytis cinerea*) in pot chrysanthemum – 2003

Summary

In spring 2003, grey mould (*Botrytis cinerea*) was monitored on pot chrysanthemums on a nursery in Hampshire where temperature integration was being implemented in one of two similar glasshouses units. Disease levels were low and no consistent effect from temperature integration was observed on the incidence or severity of botrytis on plants assessed 2-3 weeks pre-marketing and at marketing.

Objective

To determine if use of temperature integration on a commercial pot chrysanthemum nursery increases the incidence or severity of grey mould.

Experimental

Temperature integration was implemented in one of two glasshouses producing pot chrysanthemum at Double H Nurseries, Sway, Hants. The crop was grown on the floor in both glasshouses, on matting over sand, although irrigation and heating differed between the houses. In House 2 (Temperature Integration [TI] glasshouse), plants were sub-irrigated by lay-flat tubes and there was a minimal amount of floor heat (plastic pipes, 30°C maximum) with pulsed steam providing side heat and roof heat; in House 4 (Control glasshouse), plants were irrigated by individual drip line into pots and did not have the roof heat.

Batches of plants of several varieties, chosen as being more botrytis–susceptible than other varieties, were rooted in the propagation house. One spray of Bravo 500 (chlorothalonil) was applied to all plants after sticking, and no fungicides for control of botrytis were applied thereafter. The plants were all grown in the same house until final spacing (at 13.5 plants/m^2) when 100 plants of each chosen variety were moved to each treatment for the final 5-7 weeks of crop production. Thus, the effect of temperature integration was tested on the development of botrytis after final spacing. The plants to be assessed for botrytis were placed in similar relative positions in the two houses, away from side and end walls and towards the centre of the house.

Assessment of botrytis

Fifty plants of each variety were individually assessed for botrytis at 2-3 weeks before marketing (assessment 1) and at the point of marketing (assessment 2). Plants were categorised using the following index:

0 – No botrytis

1 – Necrotic leaf on compost surface

2 – Necrotic leaf above compost surface

3 – Two or more necrotic leaves

4 – One stem rotting

5 – Two or more stems rotting (plant unmarketable)

Samples of necrotic leaves and rotting stems were examined in the laboratory for confirmation of *B. cinerea*

Results

At 2-3 weeks before marketing, occasional necrotic leaves were present on the compost surface; no sporing botrytis was visible on them but damp incubation in the laboratory confirmed *B. cinerea* associated with most of them. The mean incidence of plants with necrotic leaves was 8.0% in the control house and 9.9% in the temperature integration house (Table 1).

At the point of marketing, the mean incidence of plants with necrotic leaves or rotting stems had increased to around 23%, with no difference between the two houses (Table 2). The severity of botrytis remained very low, with a mean index of 0.34 (on a 0-5 scale) in the control house and 0.31 in the temperature integration house. Comparing individual varieties, there was no consistent effect of temperature integration on the incidence or severity of leaf necrosis. One group of around 10 plants of cv. Covington in the control house showed severe stem botrytis on one stem per plant.

The saprophytic fungus *Botryosporium* was frequent on necrotic leaves in both houses, and crown gall was present at a low level on cv. Covington in both houses. No white rust was observed.

Discussion

Leaf necrosis occurred almost exclusively on basal leaves, and it is probable that this was natural senescence associated with lack of light rather than due to direct attack by botrytis. Recovery of botrytis from some of these leaves probably reflects the widespread occurrence of *B. cinerea* and its ability to colonise necrotic tissue. The plants of cv. Covington in the control compartment with visible stem botrytis appeared to have been over-irrigated by the drip-lines. Increased botrytis in pot plants associated with excessive irrigation via drip-lines has been noted previously.

No firm conclusions can be drawn on the effect of temperature integration on *B. cinerea* in pot chrysanthemum because of (i) the low level of disease that occurred; (ii) the different irrigation systems used in the two houses, which might be expected to have an effect on botrytis development. However, the results obtained do suggest that temperature integration, as applied on this nursery, did not markedly worsen the level of botrytis incidence. In order to obtain more substantive results it is suggested the work be repeated on a site where identical irrigation and heating systems are available in adjacent glasshouses.

Table 1. Incidence of chrysanthemum plants with dead leaves – 24 March 2003

Mean % plants affected		
Variety	**TI**	**Control**
Covington	7.2	3.6
Ridgeway	3.6	5.5
Rapture	12.7	20.8
Irvine	12.9	6.4
Chesapeake	14.5	4.3
Mean:	9.9	8.0

Table 2. Incidence and severity of botrytis on pot chrysanthemum – 17 April 2003

Sticking week and variety	Mean % plants affected		Disease index (0-5)	
	TI	Control	TI	Control
Week 6				
Covington	-	18	-	0.22
Ridgeway	-	20	-	0.28
Rapture	-	20	-	0.28
Irvine	-	34	-	0.42
Chesapeake	-	24	-	0.38
Mean:	-	23.2	-	0.32
Week 7				
Covington	-	48	-	0.74
Ridgeway	8	8	0.10	0.14
Rapture	20	28	0.22	0.44
Irvine	32	-	0.38	-
San Anselmo	8	24	0.10	0.30
Happy Esperanto	18	26	0.28	0.03
Mean:	17.2	16.4	0.22	0.33
Week 8				
Covington	40	34	0.44	0.70
Ridgeway	2	18	0.02	0.26
Rapture	24	12	0.28	0.12
San Anselmo	28	10	0.56	0.12
Esperanto	0	42	0.24	0.48
Mean:	22.8	23.2	0.31	0.34

- Plants no longer present on the nursery (had been marketed)

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