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| **Project title:** | Optimising greenhouse environment and energy inputs for sweet pepper production in the UK – a commercial demonstration of the use of thermal screens and advanced climate control. |
| **Project number:** | PC 227 |
| **Project leader:** | C T Pratt<br>FEC Services Ltd, Stoneleigh Park, Kenilworth, CV8 2LS |
| **Annual Report:** | Final report, July 2006 |
| **Key workers:** | **FEC Services Ltd:**<br>C T Pratt — Project Leader<br>J G Swain — Data collection & analysis<br>**Other key workers**<br>Dr T O'Neill, ADAS Consulting Ltd — Plant pathology<br>Aad Vijverberg — Independent crop consultant<br>Gary Taylor — Managing Director, Valley Grown Nurseries Ltd |
| **Location:** | Valley Grown Nurseries Ltd, Essex & FEC Services Ltd, Warwickshire |
| **Project co-ordinator:** | J. Colletti, Glinwell Marketing plc |
| **Date project commenced:** | December 2004 |
| **Date completion due:** | March 2006 |
| **Keywords:** | Sweet pepper, temperature integration, thermal screens, energy efficiency, fusarium |

**Contents**

## Grower Summary

## 1 Headlines

Trials undertaken on a commercial sweet pepper nursery in Essex showed that a modern design of moveable thermal screen delivered additional energy savings of 52kWh/m$^2$ compared to a temporary screen. It was also shown that temperature integration can save energy when applied to a sweet pepper crop. However, yield can suffer if the correct crop balance is not maintained.

Summary of results:

- Moveable (permanent) screens saved an additional 52kWh/m$^2$ of gas compared to temporary screens.
- Refinement of thermal screen control set points increased the energy saving achieved from 29kWh/m$^2$ to 52kWh/m$^2$.
- Moveable (permanent) screens caused an early season yield reduction of up to 1kg/m$^2$. However, this was recovered by Week 26 and there was no difference in total yield at the end of the season.
- Temperature integration saved 24kWh/m$^2$ (6%) p.a. However, yield fell by 4.4%.
- The total amount of energy used to grow a crop of sweet peppers in a modern design of greenhouse with a moveable thermal screen (no TI) between Weeks 51 and 41 inclusive was 565kWh/m$^2$.

## 2 Background and expected deliverables

Escalating energy costs, the Climate Change Levy (CCL), and increasing pressure to reduce the environmental impact of energy use mean that energy saving continues to be an important issue for all producers of protected crops. The Horticultural Development Council has funded a number of energy saving projects for the protected cropping sector. This project uses knowledge gained from trials with other crops to demonstrate how it can be applied in sweet pepper production.

Specific objectives were:

1. To establish (and successfully apply) a range of environmental control set points that would fully exploit the energy saving potential of temperature integration whilst optimising crop response.
2. To establish the energy consumption (and energy cost) that could be realistically achieved on a commercial pepper nursery by introducing energy saving technologies.
3. To quantify any effect of these techniques on crop yield, quality, scheduling and disease levels.
4. To stimulate commercial uptake of advanced climate control techniques and thermal screens in the pepper sector by communicating the results of the work to growers in the UK.

# 3 Results

## 3.1 Research method

The project was undertaken at Valley Grown Nursery, Nazeing, Essex in a 4,000m$^2$ greenhouse built in 1999. A permanent (moveable) thermal screen using Ludvig Svensson SLS10 Ultra Plus material was installed ready for the 04/05 cropping season. The whole site is heated with low pressure hot water provided by a mains gas fired boiler and controlled by a Priva Integro v723 computer.

The performance of the trial greenhouse was compared to other compartments on the nursery. Historical energy, greenhouse environment and crop data was also used in the comparisons.

## 3.2 Results

### *3.2.1 Thermal screen*

Prior to the 04/05 season three greenhouse blocks on the nursery were fitted with temporary plastic screens at the start of each cropping year to save energy. These were usually removed around Week 5 to allow satisfactory humidity control to be maintained.

The installation of a moveable screen has allowed screening to be extended to later in the season. The moveable screen can be opened during the daytime when the heat demand is low and humidity control more difficult, but closed at night when heat demand is high, humidity control easier and when energy can be saved. Additionally the moveable screen can be reintroduced at the end of the season; an option not available with a fixed screen.

**Screen operation**

The thermal screen was closed 24 hours a day from planting (Week 51) until Week 3. From Week 3 onwards it was set to open during daylight hours as long as a maximum heating pipe temperature of 65$^{o}$C was able to maintain the required greenhouse temperature. The screen was closed overnight as long as satisfactory humidity control could be achieved. If conditions were such that the screen had to be constantly gapped with venting above it to control humidity, the screen was opened completely. Table 1 below gives an overview of the set points that were applied.

Table 1 – Thermal screen control set points

| Description | Time period | Value | Range |
|---|---|---|---|
| Inside – outside temperature difference | All the time | 7$^{o}$C | n.a. |
| Light influence on temperature difference | All the time | 10$^{o}$C increase | 0 – 200W/m$^2$ |
| Wind influence on temperature difference | All the time | 2$^{o}$C decrease | 0 – 6m/s |

The need for active humidity control began around Week 6 and the daytime screen operation set point for the inside – outside temperature difference was increased to 10°C whilst the night time set point remained at 7°C. These set points were fine tuned as the crop developed and the need for humidity control increased.

The humidity control strategy was to gap the screen first, then open the vents and finally increase the minimum heating pipe temperature. In practice, to achieve stable control, vent opening had to start before the screen reached the maximum gap allowed, and minimum pipe temperature increase had to be initiated at the same time that the vents started to open. Typical screen gap set points are shown in the table below.

Table 2 – Screen humidity gap

| Description | Time period | Value | Range |
|---|---|---|---|
| Humidity gap | Daytime | 10% | 3.5 – 2.8 $g/m^3$ |
| Humidity gap | Night time | 10% | 2.6 – 2.0 $g/m^3$ |
| Outside temperature influence on gap size | All the time | 75% | 3 – 10°C |

The target HD's were 3.0$g/m^3$ and 2.3$g/m^3$ during the day and night respectively. Gapping started before these levels were reached to give more stable control and avoid cyclical operation. The amount of screen gap required to achieve satisfactory humidity control in cold ambient conditions was less then when conditions were milder. This was automatically implemented using an outside temperature influence on screen gap size.

**Energy performance**

Energy use in the two greenhouse compartments where TI was not applied in 04/05 was compared to the energy used in previous years when temporary screens were used. This showed that the moveable (permanent) thermal screens saved an additional 52$kWh/m^2$ over that achieved by temporary screens.

The energy performance of a moveable screen that had been installed for several years was also assessed. This showed that the refined approach to screen control, as described above, delivered additional savings of 25$kWh/m^2$ compared to using a simple fixed outside temperature threshold of 8°C.

**Yield**

Early in the season, up to Week 22, a crop grown with moveable (permanent) screens tended to yield less than one grown with temporary screens. At one point the difference was as high as 1$kg/m^2$. However, permanent screens allowed more reliable climate control and therefore better control of plant balance. This allowed the yield to recover and from Week 26 onwards the total yield was almost identical.

### 3.2.2 *Temperature integration*

**Temperature control strategy**

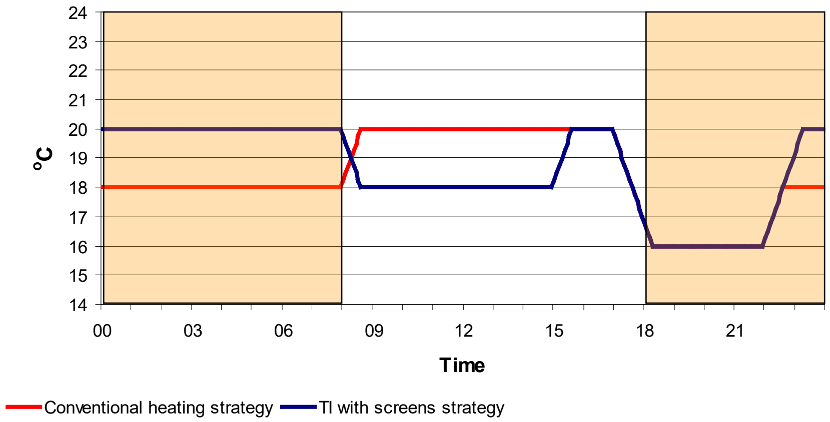
Temperature integration works on the basis that, within limits, plants grow according to the average temperature that they experience. As a result it is possible to save energy by operating a greenhouse at a higher temperature when heat loss is low and a lower temperature when it is high.

The common approach to applying TI is to restrict ventilation during the daytime when solar gain is high thus allowing the greenhouse temperature to rise without using fossil fuel energy. This helps to accumulate temperature 'credits' so that the heating temperature can be reduced during the night when heat loss is at its highest. However, this approach only delivers energy savings when solar gain is sufficiently high. In the UK this is generally from Week 8 onwards.

With thermal screens a different approach can help to save energy even when solar gain is low. When a screen is closed the energy required to keep the greenhouse at a set temperature can be over 40% less. So, to achieve a certain required average greenhouse temperature with minimum energy use the heating temperature should be higher when the screen closed (normally during the night) and lower when it is open (normally during the day). This is completely opposite to a conventional TI regime.

The heating strategy applied in the screen TI treatment is shown as the dark blue line in Figure 1 below. For convenience the conventional strategy (red line) is shown on the same figure. The shaded area indicates when the screens would normally be closed.

Figure 1 – TI with screens strategy




The TI screens strategy was operated with a minimum day temperature set 2°C lower than normal (ie 18°C) to allow energy saving whilst the screen was open and heat demand was high. Towards the end of the day period the temperature was increased to normal levels (20°C) to ensure that the pre-night effect remained the same. Following the pre-night period the temperature was increased above the conventional setting to 20°C whilst the screens were closed.

TI was allowed to integrate temperature credits over a 5 day period. The daytime temperature was automatically adjusted by TI depending on the temperature credits available. If temperature credits were plentiful the heating temperature was reduced to the minimum allowed (18ºC).

The ventilation temperature was set 1ºC higher than the heating temperature (ie 19ºC). The TI element of ventilation temperature control allowed this to increase to a maximum of 26ºC as the humidity deficit increased from 4.5 to 6.0 g/m$^3$. This applied at all times except during the pre-night period to ensure the required temperature reduction was consistently achieved.

This TI strategy was applied to a 4,000m$^2$ greenhouse from Week 3 until Week 13. A conventional approach to temperature control was adopted from Week 13 onwards according to the needs of the crop.

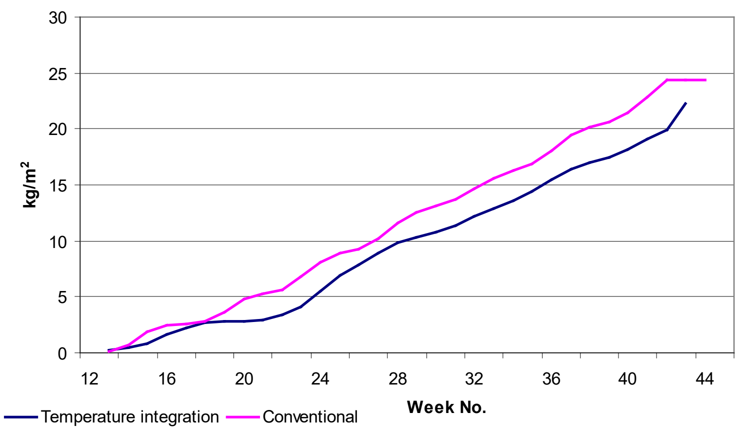
**Energy data**

Weather corrected energy data for the TI treatment was compared with that from other greenhouse compartments and with energy use data from previous years. This showed that using TI in combination with thermal screens gave an additional energy saving of 24kWh/m$^2$ compared to using screens alone.

**Crop data**

Before TI was applied, the crop in the TI compartment was stronger than a crop of the same variety (Special) grown in an adjacent conventionally controlled compartment. This continued after TI was applied and was the main factor behind the decision to leave three fruit on each plant in Week 8 rather than two fruit as in the conventionally controlled compartment. In Weeks 12 – 13 ambient light levels dropped to 25% of the normal seasonal average. The combination of low light, high fruit load and low daytime temperature caused the head of the plants to become very weak. As a result, no fruit was set in the TI treatment for five weeks. Cumulative yield is shown in Figure 2 below. The period around Week 18 to Week 22 when very little fruit was picked is clearly illustrated. Although this yield reduction was not recovered, weekly yields were comparable for the remainder of the season demonstrating that the crop did not suffer from any long-term damage.

Figure 2 – Yield 2005



### 3.2.3 Best practice energy use

Best practice techniques to achieve lowest energy use are currently considered to include:

- Modern, well maintained Venlo type greenhouse
- State of the art climate control computer.
- Moveable thermal screen.

(Note that TI is not yet established enough to be included in this list)

Adopting these best practice techniques delivered energy use for a complete cropping season (Week 51 to Week 41 in Essex) of 565kWh/m$^2$. It is believed that this can be reduced further by more aggressive use of the screen to save energy. This will be tested in year 2 of this project.

### 3.2.4 Disease monitoring

A major concern amongst all growers of protected crops when applying temperature integration is the effect on humidity and disease levels. To assess this in the trials, Tim O'Neill of ADAS Consulting Ltd carried out detailed monitoring of disease levels and sources of infection on the nursery. The disease of greatest interest, in view of its increasing prevalence in sweet pepper production, was Fusarium.

Overall the levels of Fusarium in the TI compartment were similar to those experienced on the rest of the nursery. Therefore it was concluded that the use of TI did not result in increased disease levels. This is consistent with findings from projects where TI was applied to tomatoes, pot chrysanthemum and poinsettia where levels of botrytis were shown to be unaffected.

Disease monitoring identified the prevailing strain of fusarium to be F. *oxysporum*. This was the first documented occurrence of this disease in the UK. It is suspected however that the disease has occurred, albeit unrecorded in the UK, for several years. The disease has been reported in the Netherlands previously. HDC Project PC 232a has since been commissioned to investigate its biology and methods of control.

# 4 Financial benefits for growers

**Thermal screens**

The installation of a moveable thermal screen was shown to give additional energy savings of 52kWh/m$^2$ compared to a temporary screen. There is also the additional saving on the annual cost of installing a temporary screen; the monetary saving of this is estimated to be 70p/m$^2$. The table below shows the total value of this for a range of gas prices.

Table 3 – Financial benefit of moveable screens

| Gas price p/kWh | Saving - £/m$^2$ |
|---|---|
| 2.0 | 1.74 |
| 2.25 | 1.87 |
| 2.5 | 2.00 |
| 2.75 | 2.13 |
| 3.0 | 2.26 |

The financial penalty associated with the early season yield reduction is dependent on a nursery's marketing agreement. However, a price differential of £0.40p/kg (early season minus mid season price) is considered to be typical. If this applies to a nursery's marketing agreement £0.40/$m^2$ should be subtracted from the saving figure in table 3 above.

The capital cost for the installation of a screen of the design used in this project is currently in the range of £4/$m^2$ to £5/$m^2$.

In some cases a major upgrade of the greenhouse climate control computer may also be required. This expenditure brings other benefits unrelated to the screen such as reduced energy use and improved cropping through better greenhouse climate control. Therefore, its costs have not been included as part of the payback calculations associated with the screen.

Based on current capital costs and a gas price of 2.0p/kWh, a simple payback on the screen investment is 28 – 36 months. This increases to 36 – 45 months when the early season yield reduction from this trial is taken into account but strategies in future could be employed to avoid this.

Note that, as an energy saving technology, thermal screen installations currently qualify for an enhanced capital allowance. This means that 100% of their cost can be set against tax in the year of installation. Further information about this is available from www.eca.gov.uk.

**Climate control computers**

In addition to improved control of the greenhouse environment, modern climate control computers have many features to help save energy. This was demonstrated in the additional energy saving of 25kWh/$m^2$ (worth £5,000/Ha) which was achieved as a direct result of the refinements in the thermal screen control. To make best use of these requires a good understanding of the physics of greenhouse climate control and a working knowledge of the application of the computer software.

The cost of upgrading or replacing an existing climate control computer is from £5,000 to £15,000 per Ha. However, even at the higher cost the saving delivered by improved screen control alone would pay back this investment in three years. One of the most important features to help fine tune set points is the ability to easily create and view graphs to show how the greenhouse environment changes over time and how the greenhouse itself (heat, vent, etc.) responds to the set points applied.

# 5 Conclusions

Conclusions reached at the end of the first year of this project are:

- The total saving (energy + annual replacement costs) achieved by replacing temporary screens with permanent screens gives a payback on investment in less than three years.
- Close attention to thermal screen control set points gives significant additional energy savings (25kWh/$m^2$, £5,000/Ha).
- Temperature integration gave energy savings of 24kWh/$m^2$ (6%) p.a. Yield was 4.4% lower, however it is expected that this can be corrected.
- The total amount of energy used to grow a crop of sweet peppers in a modern design of greenhouse with a moveable thermal screen (no TI) between Week 51 (2004) and Week 41 (2005) was 565kWh/$m^2$.
- A modern climate control computer will deliver enough energy savings to justify the investment. However, adequate training and time spent on refining its operation are required to realise the full benefits.

# 6 Action points for growers

At this half way point in the project, growers should consider the following actions:

- Investigate the feasibility and cost of installing moveable thermal screens.
- Invest in staff training to take full benefit of their existing climate control computer.
- Compare the features and ease of use of their existing climate control computer with those of new or upgraded systems.
- Consider implementing temperature integration.

# Science Section

## 7 Introduction & background

Recent dramatic increases in the cost of heating fuel (particularly gas) have seen energy costs for protected salad production rise from less than £5/m$^2$/annum in 2000 to over £10/m$^2$/annum in 2004/5. Reducing energy use is consequently a high priority if business viability is to be maintained.

A reduction in energy use is also a requirement of the Climate Change Levy Discount Scheme. The scheme, which allows growers to claim an 80% reduction in the Climate Change Levy (CCL), requires that they achieve a 12% reduction in energy use over the period 2004 to 2010. For a greenhouse consuming 600kWh/m$^2$ of gas per annum the 80% discount is worth £7,200/Ha excluding the value of the energy savings.

Industry statistics indicate that there are around 85Ha of heated pepper production in the UK. Taking this production area and assuming that 75% of it is heated by gas, the impact of securing and maintaining an 80% CCL rebate is estimated to be worth over £460,000 per annum to the pepper sector. Assuming that the same 75% of growers achieve the 12% reduction in energy use this is worth a further £1m per annum.

HDC work in other protected cropping sectors has shown that a number of ‘state of the art techniques’ are capable of providing energy and cost savings. The most promising techniques are dynamic climate control (based on temperature integration) and thermal screens. To date however little is known of the risks or benefits of applying these technologies to pepper production.

### 7.1 Related work

A number of projects funded by HDC are directly related to this project.

***Temperature integration***

A study tour of research and commercial organisations in Denmark and Holland (PC 172, 2001) highlighted the potential for using advanced climate control strategies to obtain energy efficiency improvements. In addition, work carried out by Silsoe Research Institute (PC 49, 1994) investigated the use of temperature integration in the production of tomato crops. Although this work was successful in achieving energy savings without compromising yield or quality, the results were not adopted by growers. The main reasons for this were the lack of commercial control systems incorporating temperature integration and the much lower energy costs.

Since 2001 a number of projects have been carried out to investigate and demonstrate the use of temperature integration on a range of greenhouse crops. These projects are:

**PC 188 –** this studied the use of temperature integration on a commercial tomato nursery in North West England. Results from this work showed that energy savings of 8 to 10% per annum could be achieved with no detrimental effect on the crop.

**PC 190 -** this involved trials on pot chrysanthemum and poinsettia at HRI Efford. Results showed that savings of the order of 25% could be achieved.

**PC 197** – this work built on the findings of PC 190 by applying the results to a commercial pot chrysanthemum nursery in southern England. The results showed that energy savings of 8% could be achieved with no effect on crop quality or scheduling.

**PC 205** – this involved trials of temperature integration with poinsettia on a commercial site in East Yorkshire. Energy savings of 12% were achieved whilst humidity control, plant quality and disease were kept to acceptable levels.

***Thermal Screens***

**PC 198** –the performance of a modern design of thermal screen with a commercial tomato crop was investigated. Results over three years gave an average energy saving of 100kWh/$m^2$ p.a. (13 %). Despite the fears of growers, crop yield and disease levels were not compromised by the use of a thermal screen. However, the effect of the screen on the greenhouse climate did require a different approach to growing strategies. The irrigation strategy was most significantly affected with a lower humidity deficit under the screen reducing the water requirement compared to a non screened crop.

## 7.2 Barriers to implementation with a sweet pepper crop

### Temperature Integration

At the simplest level TI results in higher greenhouse temperatures during the daytime and lower temperatures during the night time. Manipulating the difference between day and night temperatures is a key tool used by growers to control the development of plants. Big differences between day and night temperatures tend to cause:

- A stretched or taller plant.
- A more generative plant.

Although no notable effect in these areas was seen in any of the previously mentioned work, growers of sweet peppers are particularly aware of this as a potential problem. The vegetative/generative balance of sweet peppers is much more difficult to control. Poor control over the balance of the plant leads to flushes in fruit set and yield and is difficult to correct once it starts.

### Thermal screens

Sweet pepper growers have traditionally used temporary screens (plastic sheeting) during the first four to eight weeks of the cropping season. In addition to energy saving, screens bring benefits relating to reduced plant stress resulting from lower humidity deficit during plants establishment. There is therefore little concern in the introduction of moveable (permanent) thermal screens. However, concern remains about whether the additional energy saved justifies the investment required.

# 8 Objectives

The overall objectives of this project were to obtain independent information on the performance of a pepper crop and the energy savings that could be achieved when growing under moveable thermal screens and whilst using dynamic climate control.

Specific objectives were:

1. To establish (and successfully apply) ranges of environmental control set points that fully exploit the energy saving potential of temperature integrating control strategies whilst optimising crop response.
2. To establish the lowest energy consumption that could be realistically achieved on a commercial pepper nursery using screens and advanced control strategies.
3. To quantify the effect of these techniques, if any, on crop yield, disease, quality and scheduling.
4. To stimulate commercial uptake of advanced climate control techniques and thermal screens in the pepper sector by communicating the results of the work to growers in the UK.

# 9 Research method

## 9.1 Overview of location facilities and cropping

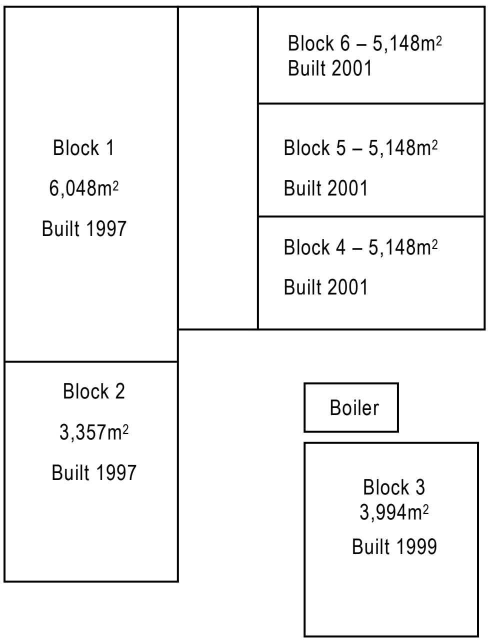
The glasshouse facilities were located at Valley Grown Nurseries, Nazeing, Essex. Data collection and analysis was carried out at FEC Services Ltd, Stoneleigh Park, Warwickshire. Routine on site data collection, meter readings and crop records in particular, was carried out by Gary Taylor, Managing Director, Valley Grown Salads.

**Greenhouse**

The layout of the nursery and the size of each greenhouse block are shown in Figure 3 below. Blocks 4-6 included a permanent thermal screen (Ludvig Svensson SLS10 Ultra Plus) when they were built. Blocks 1-3 used a temporary screen until the start of the 2004/05 cropping season when a permanent screen of the same type as the one used in blocks 4-6, was installed.

The temperature integration part of the project took place in Block 3.

Figure 3 – Valley Grown Nursery site layout



**Environmental control**

Each greenhouse block had its own independent heating and ventilation system and a separate measuring box containing standard wet & dry bulb sensors. The climate control computer was a Priva Integro version 723.

**Crop**

All plants were grown on the floor in mineral wool growing media. Greenhouse Block 3 was the focus of the project. The variety Special was grown in this block.

## 9.2 Data collection

### *9.2.1 Greenhouse environment and weather data*

Greenhouse internal environment and weather data was recorded using the site climate control computer. Data was downloaded via modem connection by FEC consultants.

Data collected and analysed included:

Greenhouse set points and equipment operation

- Set points – heating & ventilation temperature.
- Heating pipe temperature.
- Vent position.
- Screen position.

Greenhouse environment

- Temperature.
- Humidity deficit.
- $CO_2$.

Temperature and humidity deficit were measured at two locations:

1. 30cm below the top of the crop. These measurements were used by the climate control computer to control the heating, ventilation and screens.
2. 30cm above the growing media. These measurements were used to provide more information on conditions experienced by the crop.

Weather data

- Temperature.
- Solar radiation.

### *9.2.2 Energy*

A heat meter was installed in the final heating loop of Block 3 and measured the amount of heat energy delivered (as hot water). The heat meter was connected to the climate control computer which allowed energy data to be automatically recorded and downloaded using the same system used to collect environment and weather data. The site gas meter was also read on a weekly basis.

### *9.2.3 Crop data collected*

Nursery staff carried out weekly crop recording based on a sample of 20 plants in each greenhouse block.

- Growth – cm.
- Total plant height – cm.
- Fruit set each week.
- Number of fruit on each plant.
- The number of new flowers produced each week.
- The number of fruit picked each week.

Yield data was recorded daily.

Disease levels, principally fusarium, were assessed at key stages of the season by Dr Tim O'Neill, ADAS Consulting Ltd.

### *9.2.4 Historical data*

Comprehensive data from 2002 onwards was available from the host nursery. This included:

- Gas consumption – for the whole site.
- Average daily greenhouse temperature – in each block.
- Average daily pipe temperature – in each block.
- Weather conditions.

## 9.3 Test protocol

### *9.3.1 Comparison with previous years*

Data available allowed the amount of gas used by each greenhouse compartment to be calculated for 2002/03, 2003/04 and 2004/05. In addition, weather correction in the form of degree day analysis enabled comparison of different years' energy use by allowing for variations in greenhouse temperature and weather conditions.

### *9.3.2 Temperature integration*

Temperature integration control methods were applied in greenhouse Block 3. The energy saving achieved was assessed as described in section 9.3.1 above. The effect on yield was compared with blocks 4-6, where the same variety was grown. In addition the performance of the greenhouse blocks was compared with data from previous years.

# 10 Results

## 10.1 Climate control strategy

The climate control set points described in this report were derived specifically for the project and were periodically adjusted to adapt to prevailing conditions. As such they should not be assumed to deliver a satisfactory level of control in any other greenhouse. They may however serve as a useful starting point for any grower wishing to adopt this approach.

### *10.1.1 Thermal screen control*

**Week 50 (2004) to Week 2 (2005)**

The young plants arrived in Week 50 (2004). Avoiding plant stress from high heat input and high humidity deficit was a key objective during crop establishment. The thermal screen was therefore kept closed up to and including Week 2. This also provided maximum energy savings during the period.

**Week 3 to Week 6**

To reduce plant stress it is common for pepper growers to restrict the maximum heating pipe temperature to 65°C. Therefore, the screens were only opened during daylight hours when a pipe temperature of 65°C or less was capable of maintaining the required greenhouse temperature.

**Light limit**

The Priva Integro is configured to open the thermal screen when the measured outside light level exceeds its set point regardless of the outside temperature. If a relatively low set point (less than 100W/$m^2$) is applied early in the year, it is quite likely that the outside temperature will be so low that a 65°C pipe temperature is not able to maintain the required greenhouse temperature. However, opening the screens when light level exceeds a certain point is justifiable on the basis that the additional light received by the crop is more valuable than the cost of the extra heat needed to maintain temperature, or indeed the adverse effect of a reduction in greenhouse temperature when the heating system cannot deliver enough heat. Determining the light level limit for screen opening depends on balance of cost (heat) and benefit (light received by the crop). This is difficult to accurately quantify and the final decision ultimately comes down to the experience of the grower. In the case of this trial the light level at which the screen was set to open regardless of outside temperature was 175W/$m^2$.

**Outside temperature limit**

Screens were only allowed to open when a heating pipe temperature of 65°C or less was capable of maintaining the required greenhouse temperature. In a dynamic situation, it is necessary to modify set points and influences in such a way that the system can predict if the 65°C limit will be capable of maintaining the necessary greenhouse temperature. Elements which need to be considered in determining this are:

- The difference between the inside and outside temperature. The bigger the difference the greater the heating requirement.
- Wind speed. The higher the wind speed the greater the heating requirement.
- Light level. As light levels rise solar gain increases, therefore less heat is required.

A working suite of set points was developed by analysing the performance of the greenhouse using the climate control computers graphing facilities. The following points which relate to the daytime period were derived:

- The pipe temperature required when a screen is closed is 15-20°C lower than when a screen is open. Therefore, if the screen was closed and the pipe temperature was less than 45°C during daylight hours – the screen could be opened as a maximum pipe temperature of 65°C should be able to maintain the required greenhouse temperature.
- If the screen was closed and the greenhouse temperature was 1°C above target, driven by minimum pipe set points and solar gain, the screen should be open.
- If the screen had just opened and the pipe temperature stabilised at <60°C the screen should have opened earlier.
- If the pipe temperature was close to 65°C and the screen was open – the screen should be closed.

These helped to determine the set points used. The set points in the table below summarise the general approach taken.

Table 4 – thermal screen energy saving set points (Weeks 3-6)

| **Description** | **Time period** | **Value** | **Range** |
|---|---|---|---|
| Inside – outside temperature difference | All the time | 7°C | n.a. |
| Light influence on temperature difference | All the time | 10°C increase | 0 – 200W/m$^2$ |
| Wind influence on temperature difference | All the time | 2°C decrease | 0 – 6m/s |

Applied to an example heating temperature of 20°C with no light and no wind the screen would have closed when the outside temperature was 13°C or less (20 – 7°C). However, if the light level was above 200W/m$^2$ it would only have closed if the outside temperature was 3°C or less (20-7-10°C).

**Week 7 onwards**

A similar approach was taken to that between Weeks 3 and 6. The main difference was that the set points were split into a day and a night setting. This was to take account of the increasing need to actively control humidity during the day.

Table 5 - thermal screen energy saving set points (Week 7 onwards)

| **Description** | **Time period** | **Value** | **Range** |
|---|---|---|---|
| Inside – outside temperature difference | Daytime | 10°C | n.a. |
| Light influence on temperature difference | Daytime | 10°C increase | 0 – 200W/$m^2$ |
| Wind influence on temperature difference | Daytime | 2°C decrease | 0 – 6m/s |
| Inside – outside temperature difference | Night time | 7°C | n.a. |
| Light influence on temperature difference | Night time | n.a. | n.a. |
| Wind influence on temperature difference | Night time | 2°C decrease | 0 – 6m/s |

The actual set points used were fine tuned depending on the following:

- Occasional screen gapping for humidity control – energy still being saved, keep the screen closed.
- Constant gapping < 5% but no venting required - energy still being saved, keep the screen closed.
- Constant gapping >5% with venting – energy not being saved, open the screen.

### *10.1.2 Humidity control set points*

The target levels for humidity deficit control were:

Daytime

- >3.5 g/$m^3$ – satisfactory, no need for active humidity control.
- 3.5 – 2.8 g/$m^3$ – gradually increase active humidity control.
- <2.8 g/$m^3$ – all humidity control influences to the maximum.

Night time

- >2.6 g/$m^3$ – satisfactory, no need for active humidity control.
- 2.6 – 2.0 g/$m^3$ – gradually increase active humidity control.
- <2.0 g/$m^3$ – all humidity control influences to the maximum.

In response to the need for active humidity control actions were taken in the following order:

1. Gap the screen.
2. Open the vents.
3. Increase the minimum pipe temperature.

In practice waiting for the screen gap to reach the maximum allowed before opening the vents could cause unstable control. Therefore, vent opening was initiated beyond a screen gap of 5%. A similar approach applied to the sequencing of minimum pipe temperature and vent opening.

Table 6 - Screen gap set points

| **Description** | **Time period** | **Value** | **Range** |
|---|---|---|---|
| Humidity gap | Daytime | 10% | 3.5 – 2.8 g/m$^3$ |
| Humidity gap | Night time | 10% | 2.6 – 2.0 g/m$^3$ |
| Outside temperature influence on gap size | All the time | 75% | 3 – 10$^o$C |

The outside temperature influence on gap size worked as described in the following example.

- Measured night time humidity deficit of 2.0g/m$^3$, outside temperature of 3$^o$C.
- Initial humidity gap calculated as 10%
- Outside temperature reduction of 75%
- Final gap size = 10% - (10% x 75%) = 2.5%

This helped to automatically avoid 'over gapping' on cold nights when cyclical screen movement can occur. However, the full 10% gap was allowed when the outside temperature was higher. A simpler approach would have been to allow a maximum gap of 3% during the colder months and gradually increase it as weather conditions improved. However, highly variable temperatures that can occur during March and April in particular mean that the stability of control is better if an outside temperature influence is used.

**Venting**

Once active humidity control was required the ventilation temperature was set 1$^o$C above the heating temperature at all times. This helped to make the application of humidity influences to the ventilation temperature simpler because the difference between heat and vent was always the same regardless of the time of day.

Ventilation temperature – humidity influences

| **Description** | **Time period** | **Value** | **Range** |
|---|---|---|---|
| Humidity influence | Daytime | -1.0$^o$C | 4.0 – 2.8 g/m$^3$ |
| Humidity gap | Night time | -1.0$^o$C | 2.8 – 2.0 g/m$^3$ |

The humidity influences were configured to start to have an effect before the humidity deficits reached unsatisfactory levels. This was because applying an influence (-1.0$^o$C) over a small humidity range (say 3.0 – 2.8g/m$^3$) can give unstable control due to the rapidly varying ventilation temperature.

Minimum ventilation set points were applied to guarantee some air exchange and aid air movement when humidity conditions were especially poor regardless of greenhouse temperature. These were:

- Daytime – 1% minimum vent when the humidity was < 2.8 g/m$^3$.
- Night time – 1% minimum vent when the humidity was < 2.3 g/m$^3$.

**Minimum pipe temperature**

Table 7 – Minimum pipe temperature set points

| Description | Time period | Value | Range |
|---|---|---|---|
| Basic minimum pipe temperature | All the time | 30°C | n.a. |
| Humidity influence | Daytime | -6°C<br>+20°C | 4.0 – 4.5 g/m$^3$<br>3.5 – 2.8 g/m$^3$ |
| Humidity influence | Night time | +20°C | 2.8 – 2.0 g/m$^3$ |

These influences restricted the minimum pipe temperature to a maximum of 50°C. The -6°C influence during the daytime was to ensure that the circulation pump turned off when conditions were good.

## 10.2 Temperature integration strategy

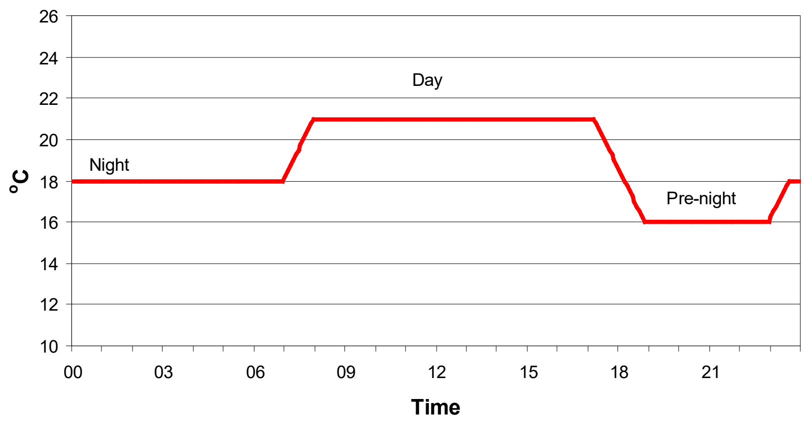
Temperature integration works on the basis that, within reason, plants grow according to the average temperature that they experience. As a result it is possible to operate a greenhouse at a higher temperature when the heat requirement is low and a lower temperature when the heat requirement is high.

The common approach to applying TI is to restrict ventilation during the daytime when solar gain is high to accumulate temperature credits that allow the heating temperature to be reduced during the night. This approach only delivers energy savings when solar gain is sufficiently high. In the UK this is generally from Week 8 to Week 42.

However, during the night time the screen will normally be closed. This coincides with the period when TI normally reduces the heating temperature to save energy. But since heat loss is reduced by the screen the level of saving achieved will also be less. In the winter daytime, with solar gain comparatively low, heat loss from the greenhouse can in fact be higher (screens open) than during the night (screens closed). In these conditions it therefore makes sense to operate with a low daytime and high night time heating temperature to deliver the required average greenhouse temperature and highest energy savings.

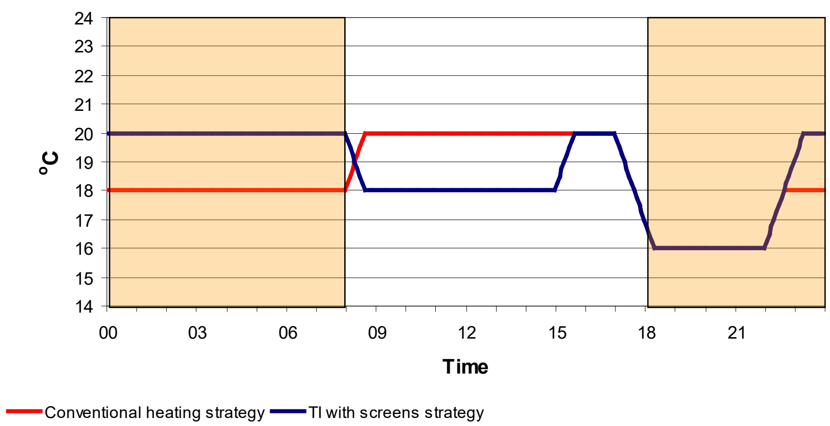
Figure 4 overleaf shows the conventional heating temperature strategy typically applied on the trial site. In addition to this, the daytime heating temperature had a 1 – 2°C influence increase when light levels were high. The actual temperature set points applied varied throughout the year according to the requirements of the crop.

Figure 4 – Conventional heating strategy




The heating strategy applied in the screened TI treatment is shown as the dark blue line in Figure 5 below. For comparison the conventional strategy (red line) is shown on the same figure. The shaded area shows when the screens were normally closed.

Figure 5 – TI with screens strategy




The TI screens strategy had a minimum day temperature 2°C lower than that used in the conventional strategy to save energy when the screen was open and heat demand was high. Towards the end of the day period the temperature was increased to conventional levels to ensure that the pre-night temperature effect remained the same. Following the pre-night period the temperature was increased above that of the conventional approach whilst the screen was closed and heat requirements were low.

TI was allowed to integrate temperature credits over a five day period. The daytime temperature was automatically adjusted by TI depending on the temperature credits available. If temperature credits were plentiful the heating temperature was reduced to the minimum allowed.

As described in the humidity control section the ventilation temperature was set to be 1°C higher than the heating temperature. The TI element of ventilation temperature control increased it to a maximum of 26°C as the humidity deficit increased from 4.5 to 6.0 g/m³. This applied at all times except the pre-night period to ensure that the required temperature reduction was consistently achieved.

The TI strategy described above was applied to greenhouse Block 3 from Week 3 until Week 13. A conventional approach to temperature control was adopted from Week 13 onwards in response to the needs of the crop.

## 10.3 Greenhouse environment

### *10.3.1 Temperature*

Figure 6 – Average weekly greenhouse temperature

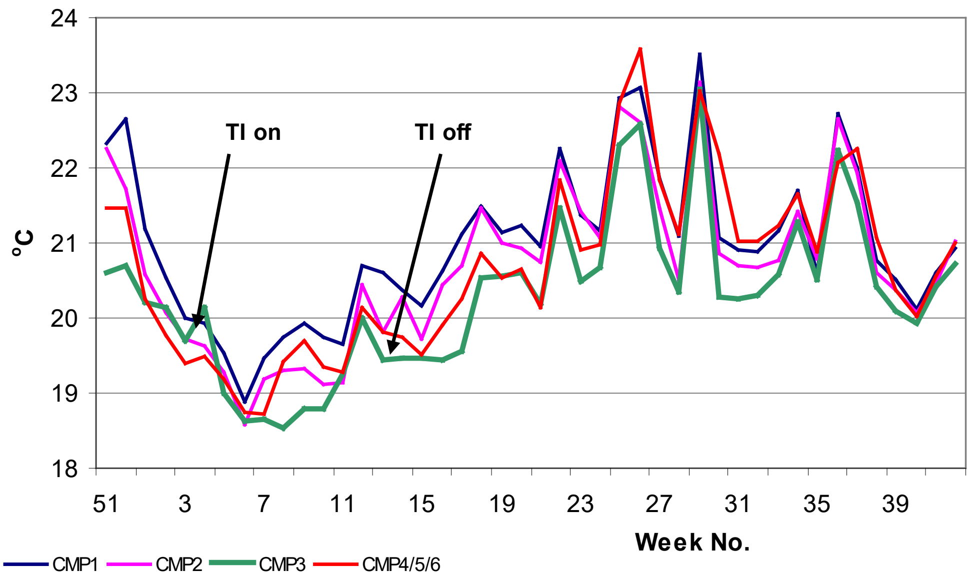


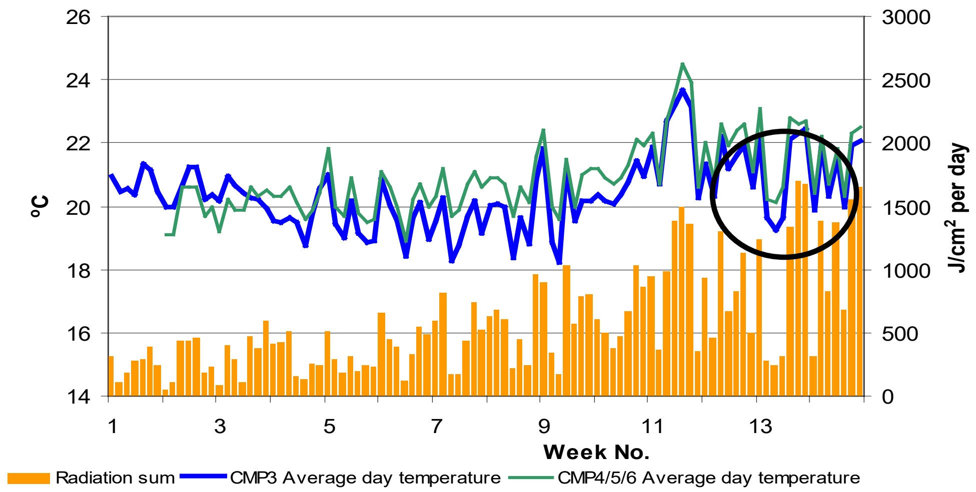

Figure 6 above shows the average temperature achieved in each greenhouse block. Blocks 4-6 were combined as they formed a single airspace. They also contained the same variety as Block 3 and therefore served as a useful comparison.

Looking at the temperature in Block 3 compared to Blocks 4/ 5/6, there was no consistent difference that could be related directly to when TI was applied. There were periods, Weeks 8 to 11 in particular, when Block 3 was notably colder. However, the average temperature achieved always matched the temperature required by the site manager.

The decision to turn TI off in Week 13 was taken in response to the head of the plant becoming too weak. One of the factors considered to have contributed to this effect was a lower daytime temperature. Figure 7 overleaf shows the average daytime temperature on a daily basis in Block 3 and 4, 5 & 6. Radiation sum data has also been included. As might be expected from the settings applied the daytime temperature in Block 3 was around 1°C lower than Blocks 4/5/6. As light levels improved at the end of Week 10 the difference reduced, with solar gain helping to lift the greenhouse temperature above the heating set point. This meant that an average temperature of around 21°C was achieved even though the heating temperature was only 18°C.

In Week 12 the light level dropped to less than 50% of the long term average. At the start of Week 13 there were three days when the light level was 25% of the average for the time of year. The sudden drop in solar gain combined with temperature credits carried over from better conditions allowed the TI strategy to take the temperature in Block 3 down to 19°C during these three days. The combined effect of low light and low daytime temperature on the crop resulted in the decision to turn off the TI control and return to a conventional temperature strategy.

Figure 7 – Average daytime temperature




### 10.3.2 *Humidity deficit*

Figure 8 – Average weekly humidity deficit

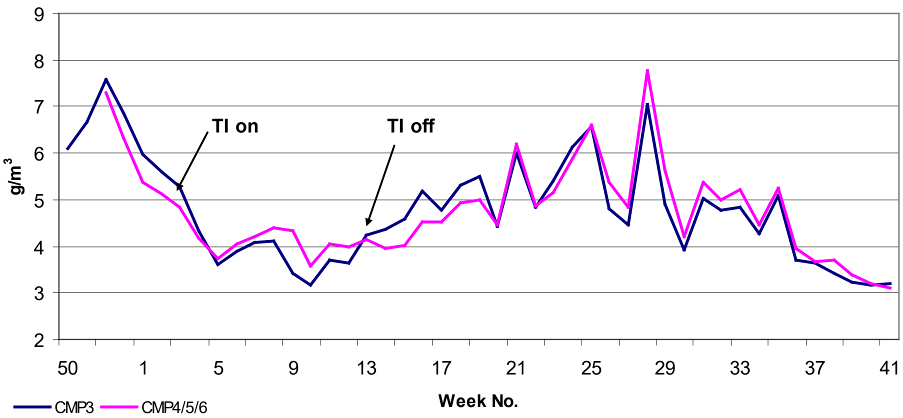



Figure 8 above shows the average HD in Block 3 (TI) and Blocks 4/5/6 (conventional). For the first four weeks after TI was turned on there was no significant effect on the HD achieved compared to that in Blocks 4/5/6. From Week 7, as light levels increased, the crop became more developed and TI had more temperature credits to work with, the HD in Block 3 tended to be lower than in Blocks 4, 5 & 6. This is a common effect of TI and is due to the reduced ventilation and heat demand.

## 10.4 Energy use

Both historical and current year energy use were analysed using:

- Degree-day heating to correct for differences in weather and greenhouse temperature.
- Average heating pipe temperature to allocate whole site gas use to each greenhouse block.

### *10.4.1 Analysis of each energy saving measure*

A number of factors affected energy use in different years and different blocks:

1. A refined approach to thermal screen control on the whole site.
2. The installation of moveable screens in Blocks 1, 2 & 3 for the 2004/05 season.
3. The application of temperature integration in Block 3 from Week 3 to 13 in 2004/05.
4. Focus on humidity control and no heat destroying in Block 3 between Weeks 19 to 37 in 2004/05.

***Refined approach to screen control***

Moveable screens were in place in Blocks 4, 5 & 6 during all three years for which data was available. In 2004/05 the thermal screens regularly closed for six hours or more per day from Week 51 to Week 20 and again from Week 39 to Week 42. Table 8 below shows the total degree-day heating requirement and the heat used during these periods for each year. Using 2002/03 as the benchmark, the degree-day heating requirement was used to correct the energy consumption data in each of the following years.

Table 8 – Blocks 4, 5 & 6 winter energy use

| | **2002/03** | **2003/04** | **2004/05** |
|---|---|---|---|
| Degree-day heating requirement | 1,785 | 1,731 | 1,699 |
| $kWh/m^2$ gas consumed | 441 | 398 | 366 |
| $kWh/m^2$ gas consumed (DD corrected to 02/03) | 441 | 410 | 385 |
| DD corrected $kWh/m^2$ as % of 02/03 | 100% | 93%<br>(7% less than 02/03) | 87%<br>(6% less than 03/04) |

The 2002/03 cropping year was the second year of production for Blocks 4, 5 & 6. As with any new facility it takes time to learn how it performs and fine tune its operation. The 7% reduction in energy use in 2003/04 is therefore attributed to an improved understanding of the operation of the glasshouse. It was therefore decided to use the 2003/04 winter season as the basis for comparison with 2004/05. In the 2004/05 season the nursery-wide focus on optimising screen control delivered an additional 6% (25kWh/m$^2$) reduction in energy use during the winter period.

***Moveable screens vs. temporary screens***

The same analysis as carried out for refined screen control was applied to the installation of moveable screens in Blocks 1 and 2.

Table 9 – Blocks 1 & 2 winter energy use

| | **Block 1** | | | **Block 2** | | |
|---|---|---|---|---|---|---|
| | **2002/03** | **2003/04** | **2004/05** | **2002/03** | **2003/04** | **2004/05** |
| Degree-day heating requirement | 1,831 | 1,856 | 1,784 | 1,817 | 1,798 | 1,728 |
| kWh/m$^2$ gas consumed | 464 | 433 | 373 | 485 | 451 | 377 |
| kWh/m$^2$ gas consumed (DD corrected to 02/03) | 464 | 427 | 383 | 485 | 456 | 396 |
| DD corrected kWh/m$^2$ as % of 02/03 | 100% | 92% | 83% | 100% | 94% | 82% |

Comparing 2002/03 to 2003/04 Block 1 and Block 2 showed reductions in energy use of 8% and 6% respectively. This is in line with the saving achieved in Blocks 4, 5 & 6. Taking 2003/04 as the base level energy use whilst using a temporary screen, the energy saving given by the moveable screen was 10% (44 kWh/m$^2$) for Block 1 and 13% (60 kWh/m$^2$) for Block 2. The average saving was 52kWh/m$^2$.

***Temperature integration***

In 2004/05 temperature integration was applied to Block 3 from Week 3 to Week 13. The nursery also trialled temperature integration in Block 3 up to Week 20 in 2003/04. Therefore the period over which TI based comparisons can be made is from the start of the crop (Week 51) through to Week 20. The average data for Blocks 1 & 2 has been used as these blocks had a moveable screen installed at the same time as Block 3.

Table 10 – Week 51 to week 20 (TI comparison)

| | Average of block 1 & 2 | | | Block 3 | | |
|---|---|---|---|---|---|---|
| | **2002/03** | **2003/04** | **2004/05** | **2002/03** | **2003/04** | **2004/05** |
| Degree-day heating requirement | 1,614 | 1,673 | 1,631 | 1,547 | 1,603 | 1,540 |
| $kWh/m^2$ gas consumed | 398 | 385 | 329 | 398 | 364 | 310 |
| $kWh/m^2$ gas consumed (DD corrected to 02/03) | 398 | 399 | 332 | 398 | 377 | 309 |
| DD corrected $kWh/m^2$ as % of 02/03 | 100% | 100% | 84% | 100% | 95% | 78% |

Comparing the degree-day corrected data, Blocks 1 & 2 used the same amount of energy in winter 2002/03 as in 2003/04. However, Block 3 used 5% less energy in 2003/04 compared to 2002/03. This suggests that the nursery's own TI trials delivered an energy saving of 5% during this period. In 2004/05 Blocks 1 & 2 showed a 16% reduction in energy use due to the installation of permanent screens. This compares to a 22% reduction in Block 3. This shows that the application of TI in 2004/05 gave a 6% ($24kWh/m^2$) energy saving during this period.

***Focus on humidity control***

More efficient humidity control techniques had the greatest impact, on energy use, between Weeks 21 and 38. During this period heating use to support temperature is minimal and energy use is dominated by that needed for humidity control. In Block 3 heat was only used for humidity control when absolutely necessary and no heat was forced into the greenhouse to empty the heat stores. However, in Blocks 4, 5 & 6 heat destruction was allowed. In this case a direct comparison of energy use in 2004/05 without degree-day correction was most appropriate.

Table 11 – Summer energy use

| | **$kWh/m^2$** |
|---|---|
| Block 3 | 171 |
| Blocks 4, 5 & 6 | 199 |
| Difference | 28 $kWh/m^2$ (14%) |

This showed that the destruction of heat to aid $CO_2$ enrichment was responsible for $28kWh/m^2$ of gas use. Note that this does not take account of heat loss from the nursery's uninsulated heat stores.

To summarise:

- Improved control of thermal screens saved an additional 25kWh/m$^2$ p.a.
- Moveable thermal screens (with improved control) saved 52kWh/m$^2$ compared to temporary screens.
- Temperature integration saved 24kWh/m$^2$.
- Improved humidity control and no heat destruction to empty the heat stores saved 28kWh/m$^2$.

A modern greenhouse (Blocks 4, 5 & 6) with a moveable thermal screen used a total of 565kWh/m$^2$ of gas from Week 51 (2004) to Week 41 (2005). Using TI and no heat destruction for $CO_2$ could reduce this to 513kWh/m$^2$.

## 10.5 Crop data – temperature integration

### *10.5.1 Crop registration data*

Crop registration is a system used to numerically track the development of the crop. Twenty plants were assessed in each greenhouse block on a weekly basis. The parameters recorded were:

- Growth – cm.
- Total plant height – cm.
- Fruit set in the week in question.
- The number of fruit on the plant.
- The number of new flowers produced in the week in question.
- The number of fruit picked in the week in question.

The most significant differences were those relating to fruit set and the total number of fruit on the plant. These are shown in Figures 9 and 10 below.

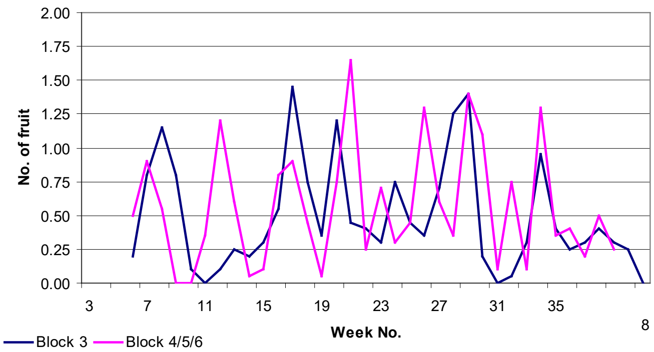



Figure 9 – No. of fruit set per week

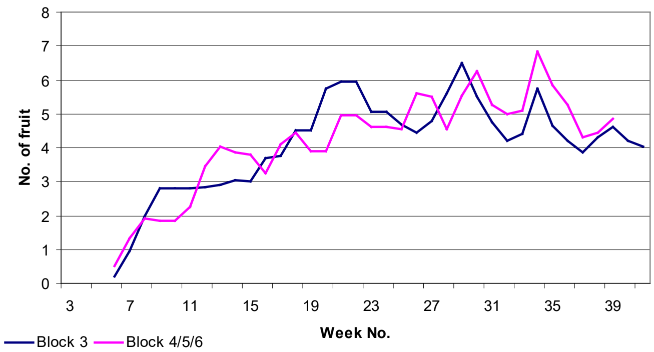



Figure 10 – No. of fruit per plant

At the start of Week 3, prior to implementing TI, the opinion of both the site manager and the crop consultant was that the plants in Block 3 appeared stronger than those in Blocks 4, 5 & 6. In Week 6 the decision was taken to allow two fruit to set and remain on the plants in Blocks 4, 5 & 6. However, the plants in Block 3 continued to appear stronger than those in Blocks 4, 5 & 6 and in Week 8 the decision was taken to leave three fruit on each plant rather than two as in Blocks 4, 5 & 6. The concern was that if two fruit had been left on each plant the fruit would have been too big, possibly miss-shaped and the plant would have continued to be too strong and ultimately too vegetative. The difference in the number of fruit per plant around this period can be seen on Figure 10 above.

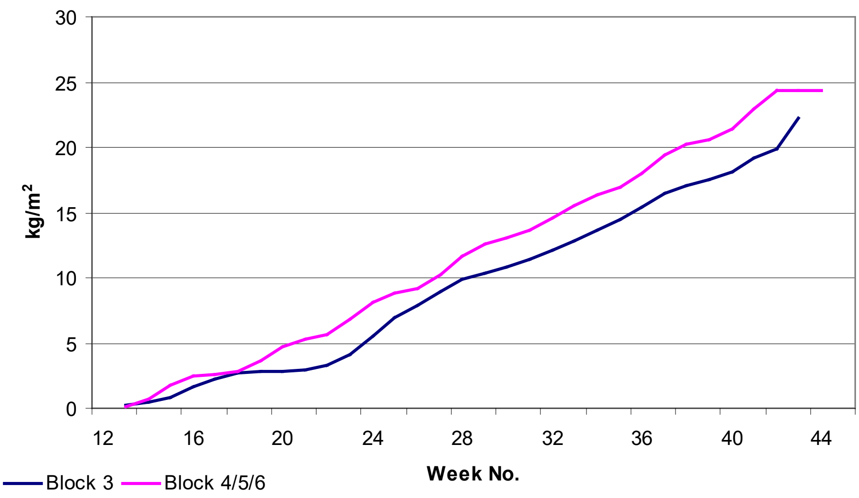
However, as highlighted in section 10.3.1 and Figure 7 light levels were significantly below average during Weeks 12 & 13. At this stage the size of the fruit was such that they placed a significant demand on the available assimilates but could not be aborted as is the case with smaller fruit. This caused a rapid weakening of the head of the plant. It is also believed that the lower day time temperature created by the use of TI during this period compounded the effect.

Long term trends are difficult to identify in Figure 9 due to the cyclical nature of fruit set on sweet pepper plants. However, a notable difference occurred between Weeks 11 and 15. The rapid loss of strength in the head of the crop in Block 3 meant that very few fruit were set throughout the whole of this period. As soon as some fruit were picked in Week 15 the head of the plant regained strength and further fruit were set. From Week 16 onwards fruit set was similar in both treatments.

### *10.5.2 Yield*

Figure 11 below shows the cumulative yield in each greenhouse block. Historically Blocks 4, 5 & 6 has tended to yield 3% more than Block 3.

Figure 11 – Yield 2005





The yield in both greenhouse blocks were similar up to Week 18 at which point Block 3 yielded very little fruit for five weeks. This was due to the effect noted in section 10.5.1 whereby very few fruit were set between Weeks 11 and 15.

Although the crop recovered fully, the loss in yield between Weeks 18 and 23 was not recouped during the remainder of the season. The total yield in each greenhouse block was:

- Block 3 (TI treatment) – 22.5 kg/m$^2$.
- Block 4/5/6 (conventional treatment) – 24.3 kg/m$^2$.

The TI treatment therefore yielded 1.8kg/m$^2$ (7.4%) less than the conventional treatment. Allowing for the historical yield difference this reduces to a difference of 4.4%.

### *10.5.3 Disease*

This section summarises the work carried out by Dr Tim O'Neill of ADAS Consulting Ltd. A complete version of his report is provided in Appendix 1.

**Disease monitoring**

Crops were examined for disease on 23 March, 21 April, 11 August and 13 October 2005. A minimum of three paths were walked in each block; samples of diseased stems, fruit or crop debris were collected by ADAS or the grower. The cause of disease symptoms was determined by laboratory examination.

Apart from the preventative treatment with sulphur, no other fungicides were applied.

**Results**

The main disease observed during the season was a fusarium fruit and stem rot, which occurred on crops in both the energy-saving and standard climate-control compartments.

**March**

Fusarium fruit rot was first observed in early March, with affected fruit found daily in each pick of red and yellow fruit on the nursery. Many but not all of the fruit rots started from the flower end. Occasional lesions were seen at the junction of fruit stalks and stem on plants where picking had not yet started. The fungus was confirmed as *F. oxysporum*.

**April**

Fusarium fruit and stem rot was found in all blocks on the nursery with a yellow variety, cv. Fiesta, affected most. No fusarium was found in a green variety. There was an increased incidence of stem lesions compared with March, occurring at sites where fruit had been picked. In mid-April the grower reported he was cutting out three or four stems lesions/row each week. Where stem lesions were present on a plant, there was no evidence of rot on fruit or leaf nodes above or below the infection site.

Examination of the crop revealed a small number of aborted fruit still attached to stems. Often, white and pink fungal growth was visible around the calyx and/or within the fruit. This was once again confirmed as *F. oxysporum*. Fallen aborted fruit, and fallen flowers, were also examined but no fusarium was found.

The grower reported that development of the problem on stems in 2005 was earlier and more widespread than in previous years; in 2004, the first plant death from fusarium did not occur until

10 May. There was no noticeable difference or reported difference in the occurrence of fusarium fruit and stem rot between the compartment with energy-saving climate control and the standard compartment.

**August**

Occasional plants showed pale brown lesions, sometimes with a dark border, extending 50-100cm along the stem and penetrating 1-2mm into the stem. *F. oxysporum* was recovered at nodes from these lesions. Other plants showed occasional lesions at the node, also affecting side shoots and leaves; *Botrytis cinerea* was confirmed in these tissues.

**October**

*B. cinerea* was confirmed associated with occasional nodal stem lesions. There was vascular staining around the lesion extending *c*. 10cm up and down the stem.

No powdery mildew was observed on the crops during the year.

**Discussion**

The most common disease affecting crops on the nursery in 2005 was a fusarium fruit and stem rot caused by *F. oxysporum*. This is the first documented case of the disease in the UK. Plant Health were informed and determined that no statutory action was necessary. The disease has previously been reported in the Netherlands, and very probably has occurred in the UK for at least three years. A new HDC project has been agreed (PC 232a) to investigate its biology and control.

Most of the fusarium-affected fruit were removed by nursery staff as they occurred and fusarium stem lesions were also promptly removed, by cutting them out. Occasionally it was necessary to remove a whole stem. There was therefore only a very low level of disease present within the crops at the four visits. At the end of cropping, relatively few plants had been removed from either compartment and there were no obvious areas of dead or missing plants.

There was no significant difference in disease levels between Block 3 (TI) and Blocks 4, 5 & 6.

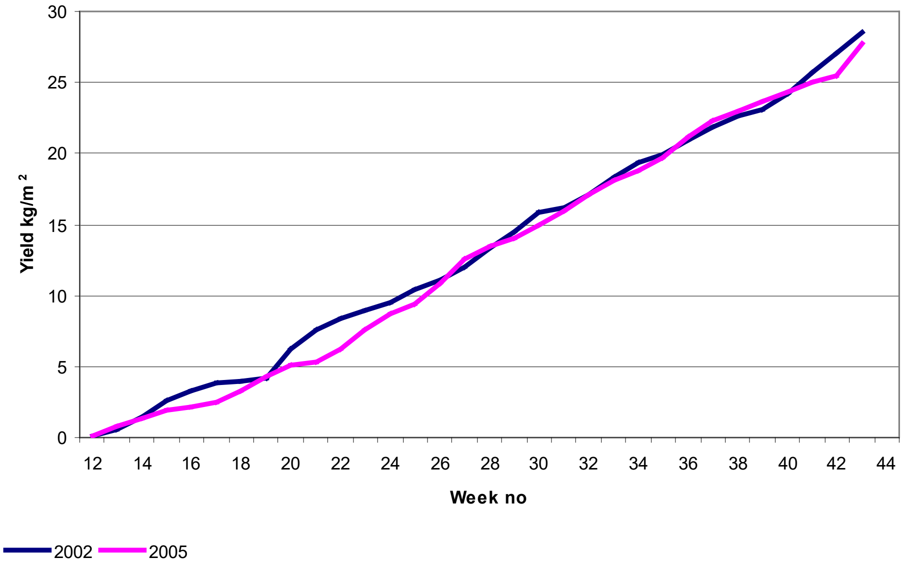
## 10.6 Crop data – thermal screens

A direct comparison of a crop grown with & without a thermal screen was not possible in 2005. However, historical data showed that light levels up to Week 26 were very similar in 2002 and 2005. In addition, the same variety (Fiesta) was grown in greenhouse block 1 in 2002 and 2005. In 2002 temporary screens were used, whereas in 2005 permanent screens were used. Therefore a comparison of yields in these years gives an indication of the effect of a thermal screen on the yield of peppers. The total yield in 2002 and 2005 is shown in figure 12 overleaf.

During the early part of the season there was clearly a yield penalty caused by using permanent thermal screens. By week 17 there was a difference of over 1kg/m$^2$. However, this difference was gradually recovered and from Week 26 onwards the yields were almost identical. There was a slight deviation around Week 42, this was considered to be due to differences in timing of when the crop was stopped.

The uniform increase in yield in 2005 compared to the more cyclical peaks and troughs in 2002 was notable up to Week 26. This was considered to be an additional benefit of permanent screens. They allow the correct greenhouse temperature to be achieved without requiring excessive heating pipe temperatures which can affect the balance of the crop. This can in turn cause cyclical fruit set and therefore yield.

Figure 12 – Yield with & without permanent screens




It can therefore be concluded that permanent screens do not have a long-term negative impact on yield in sweet peppers. However, they can cause a reduction in early season yield which could result in reduced income when early season prices are high.

## 11 Discussion

### Screens

There is no doubt that moveable (permanent) screens deliver greater energy savings than fixed (temporary) screens. However, growers are unsure whether the additional savings justify the investment required. The results show that a simple approach to permanent screen control delivers an additional saving of 25kWh/$m^2$ worth £0.50/$m^2$ (2p/kWh). There is also the saving associated with installing and disposing of a temporary screen every year estimated to be £0.70/$m^2$. Therefore the total cost saving resulting from the installation of a permanent screen using a simple control strategy is around £1.20/$m^2$ p.a. At a typical installed cost of £5/$m^2$ for a permanent screen this gives a payback of just over four years.

However, results from the project showed that the energy saving can more than double to 52kWh/$m^2$ when greater attention is paid to screen control set points. This increases the total cost saving to £1.74/$m^2$. This is worth an extra £5,400/Ha p.a. and reduces the payback time to less than three years. Therefore, if growers are to maximise the benefit of installing a permanent screen they need an up to date climate control computer, the knowledge and experience to use it and the time to check and modify the set points.

The screen control strategy applied in 2005 was designed to keep the screen closed during the daytime when the heating pipe temperature was above 65°C. Therefore additional savings should be possible in the second year of the project if the pipe temperature threshold is reduced further.

**Temperature integration**

The TI strategy adopted in this project was somewhat different to the warmer day - cooler night approach considered to be 'standard' TI. The availability of thermal screens meant that whilst solar gain was low the principles of TI could be adapted to deliver energy savings. This lead to the warm night (screens closed) – cooler day (screens open) approach that was applied in this project from Week 3 to Week 13. This was proven to work well until Week 13. The high fruit load, low light levels and low daytime greenhouse temperature combined to cause the head of the plant to become weak. The result was that few fruit were set for five weeks and a yield penalty was incurred. Although the crop was not permanently affected, the reduction in yield was not recovered during the rest of the season. The total yield in the TI treatment was 4.4% lower than a conventionally grown crop.

This confirms the concerns of pepper growers relating to the highly sensitive nature of pepper plants and the long term effect of any short-term imbalance. However, the project team believe that had the daytime temperature been at normal levels the problem would not have occurred. It is also possible that the fruit load was too high. However, at the point when the fruit load was set the plants were sufficiently strong to support the number of fruit left on them. Had less fruit been left on the plant at this stage the plants would have continued to be too strong and vegetative resulting in fewer, bigger fruit and also possibly leading to poor fruit set. Ultimately the fine balancing act of growing peppers was upset by the low light levels and compounded by the low daytime temperature.

**Humidity control & disease levels**

It is common practice to force heat into a greenhouse during the summer months even though it is not required to help to empty heat stores. This allows more gas to be burnt during the daytime which in turn provides more $CO_2$ for greenhouse enrichment. Results showed that this was responsible for an additional 28kWh/m$^2$ of energy use compared to the energy required to control humidity alone. It should be noted that this figure is dependent on the amount of heat storage available, $CO_2$ strategy etc. A purely subjective view is that this nursery is not a heavy user of $CO_2$ and therefore the figure of 28kWh/m$^2$ is likely to be low compared to other nurseries.

In spite of the application of TI and reduced heat use during the summer months the level of fusarium in the TI treatment was comparable with the remainder of the nursery.

Overall the energy savings achieved so far compare favourably with other HDC projects where TI and screens have been applied to other crops. The project team is confident that the cause of the reduction in yield is known. The second year of the project will focus on applying what has been learnt to achieve both energy savings and no yield penalty.

## 12 Focus areas for 2005/06

- Apply temperature integration in a more traditional way i.e. warmer day – cooler night.
- Greater focus on fruit load and crop balance.
- Maximise energy saving from the thermal screen.

## 13 Conclusions

Conclusions reached at the end of the first year of the project are:

- Moveable (permanent) screens save an additional 52kWh/m$^2$ of gas compared to temporary screens.
- A focus on thermal screen control set points increases the energy saving achieved from 29kWh/m$^2$ to 52kWh/m$^2$.
- The energy saving plus the saving on annual replacement costs for temporary screens mean that the payback on installing a permanent screen is less than three years.
- Heat destruction to allow greater levels of $CO_2$ enrichment increased energy use by 28kWh/m$^2$.
- Temperature integration gave energy savings of 24kWh/m$^2$ (6%) p.a. Yield was 4.4% lower, however it is expected that this can be corrected.
- The total amount of energy used to grow a crop of sweet peppers in a modern design of greenhouse with a moveable thermal screen (no TI) between Weeks 51 and 41 was 565kWh/m$^2$.

**Appendix 1 - Optimising greenhouse environment and energy inputs for sweet pepper production in the UK – disease monitoring, 2005 (PC 227)**

**Summary**

A glasshouse crop of sweet pepper, cv. Special, was examined for disease on four occasions between March and October 2005. The main disease was fusarium fruit and stem rot, caused by *F. oxysporum*, the first documented occurrence of this disease in the UK. A low incidence of botrytis stem rot was also found. No powdery mildew was observed. Occurrence of fusarium fruit and stem rot in a compartment using a thermal screen and advanced climate-control appeared similar to that in a standard climate-control compartment.

**Introduction**

The use of thermal screens and energy-saving environmental control set points that exploit temperature integration will lead to an altered glasshouse climate, notably of temperature and probably of humidity also. Both may influence the types of disease that occur and their speed of development in a crop. The objective of this study was to determine and compare the diseases occurring in crops in an energy-saving and a standard glasshouse block.

**Methods**

Crops

Two glasshouse blocks growing sweet pepper cv. Special, planted 19 December on rockwool slabs, were examined. The plants originated from Holland. The glasshouses differed in age and dimension. One block was subject to an energy-saving climate control strategy while the other followed the growers' standard practice. Air-circulation fans were used above the crop. Apart from the preventative treatment with sulphur, no other fungicides were applied.

Disease monitoring

Crops were examined for disease on 23 March, 21 April, 11 August and 13 October 2005. A minimum of three paths were walked in each block; samples of diseased stems, fruit or crop debris were collected by ADAS or the grower, and were examined. The cause of disease symptoms was determined by laboratory examination, with isolation onto agar plates and microscopic examination where required.

**Results**

The main disease observed during the season was a fusarium fruit and stem rot, which occurred on crops in both the energy-saving and standard climate-control compartments.

March

A fusarium fruit rot was first observed in early March, with affected fruit found daily in each pick of red and yellow fruit on the nursery. Many but not all of the fruit rots started from the flower end. Occasional lesions were also seen at the junction of fruit stalks and stem on plants where picking had not yet started. Isolations were made from affected fruit and stem lesions.

The morphology of the fungus recovered from both tissues was consistent with *F. oxysporum*. Identification was confirmed by mycologists at CSL (ref: 2005/05388).

April

Fusarium fruit and stem rot was found in all blocks on the nursery with a yellow variety, cv. Fiesta, affected most. No fusarium was found in a green variety. There was an increased incidence of stem lesions compared with March, occurring at sites where fruit had been picked. In mid-April the grower reported he was cutting out three or four stems lesions/row each week. Where stem lesions were present on a plant, there was no evidence of rot on fruit or leaf nodes above or below the infection site. On 21 April, it was reported that 20% of red fruit picked that day was affected by fusarium rot. Sunken brown lesions were also visible on fruit stalks. Isolations were made from these lesions in the laboratory and *F. oxysporum* was again recovered.

Examination of the crop revealed a small number of aborted fruit still attached to stems. Often, white and pink fungal growth was visible around the calyx and/or within the fruit. Isolations were made in the laboratory and the fungus recovered was identified as *F. oxysporum*. Fallen aborted fruit, and fallen flowers, were also examined but no fusarium was found.

The grower reported that development of the problem on stems in 2005 was earlier and more widespread than in previous years; in 2004, the first plant death from fusarium did not occur until 10 May. There was no noticeable difference or reported difference in the occurrence of fusarium fruit and stem rot between the compartment with energy-saving climate control and the standard compartment.

August

Occasional plants showed pale brown lesions, sometimes with a dark border, extending 50-100cm along the stem and penetrating 1-2mm into the stem. *F. oxysporum* was recovered at nodes from these lesions.

Other plants showed occasional lesions at the node, also affecting side shoots and leaves; *Botrytis cinerea* was confirmed in these tissues.

October

*B. cinerea* was confirmed associated with occasional nodal stem lesions. There was vascular staining around the lesion extending *c*. 10cm up and down the stem.

No powdery mildew was observed on the crops during the year.

**Discussion**

The most common disease affecting crops on the nursery in 2005 was a fusarium fruit and stem rot caused by *F. oxysporum*. This is the first documented case of the disease in the UK. Plant Health were informed and determined that no statutory action was necessary. The disease has previously been reported in the Netherlands, and very probably has occurred in the UK for at least three years. A new HDC project has been agreed (PC 232a) to investigate its biology and control.

Most of the fusarium-affected fruit were removed by nursery staff as they occurred and fusarium stem lesions were also promptly removed, by cutting them out. Occasionally it was necessary to remove a whole stem. There was therefore only a very low level of disease present within the crops at the four visits. At the end of cropping, relatively few plants had been removed from either compartment and there were no obvious areas of dead or missing plants.