Project title:	The use of thermal screens for energy saving and greenhouse climate management in protected edible crop production – performance optimisation.	
Project number:	PC 198 / 198a	
Project leader:	C.W. Plackett FEC Services Ltd, Stoneleigh Park, Kenilworth, CV8 2LS	
Report:	Final report, February 2006	
Previous reports:	Year 1 (2004), Year 2 (2005) PC 198	
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Date project commenced:	1st November 2002	
Date completion due	31st January 2006	
Keywords:	Tomatoes, energy, thermal screen, climate control, humidity, infra-red camera, botrytis	

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Grower Summary

Headline

Trials undertaken over a three year period in a commercial tomato nursery showed that a modern design of thermal screen consistently delivered energy savings with no reduction in yield compared to an unscreened area.

Summary of results

- The average energy saving was 100kWh/m^2 pa (13%).
- At current gas prices the energy saving is worth at least £2.00/m^2 pa
- Acceptable humidity control can be achieved with thermal screens.
- No increase in botrytis levels was recorded.
- A greater focus on irrigation control is required when using a thermal screen.
- Thermal screens create a different greenhouse environment to that normally experienced in an unscreened structure. These differences need to be fully understood and appropriate measures implemented if crop performance and energy savings are to be maximised.

Background & 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 has become an important issue for all producers of protected crops. Screens (thermal, blackout and shade) are widely used in the ornamentals sector of greenhouse production and they have been proven to deliver significant energy savings. However, they are rarely used in the edible crop sector. This is due to concerns over their potential to reduce yield and cause an increase in botrytis.

The objectives of the project were:

- To determine the financial viability of a modern design of thermal screen material on a commercial tomato nursery in the UK.
- Establish a recommended operating strategy for thermal screens over tomatoes to optimise both energy saving and crop performance.
- To develop an improved understanding of the effect of thermal screens on the greenhouse climate
- To provide recommendations on the growing strategy which should be used when using a thermal screen.
- Obtain information on the durability and maintenance requirements of modern thermal screen materials and operating systems.

- Provide information that will allow growers to make well informed investment decisions about the installation of a thermal screen.
- Communicate the results of the project to UK growers.

Summary of project and main conclusions

Research method

The trial was carried out at G. de Lang & Sons, Mill Nursery, East Yorkshire in two adjacent 13,000m^2 greenhouse compartments. One compartment had no screen installed, the other was fitted with a modern design of thermal screen material (Ludvig Svensson SLS10 Ultra Plus).

A large vine tomato variety was grown in all three years of the trial (2003 – Cadance, 2004 & 2005 – Classy).

Data collected throughout the duration of the trial included:

- Energy use in each compartment.
- Crop performance – including yield and the incidence of any pests and diseases.
- Greenhouse environment –temperature, humidity and CO_2 levels.

Results

Energy

Table 1 – Year by year energy performance

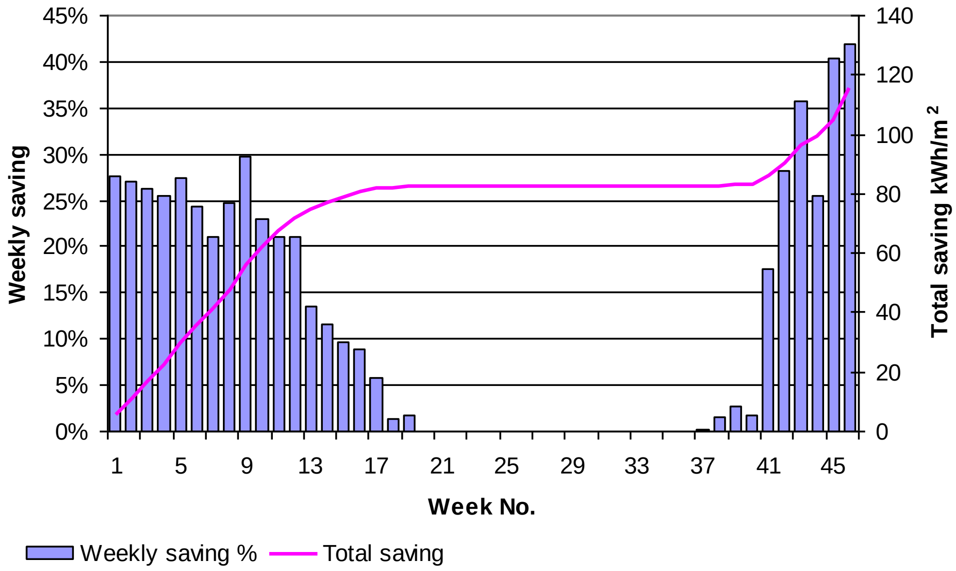
	Total energy use (gas equivalent) kWh/m^2		
Year	**No screen**	**With screen**	**Saving kWh/m^2**
2003	802	697	105 (13%)
2004	773	676	97 (13%)
2005	695	597	98 (14%)
Average	757	657	100 (13%)

Figure 1 overleaf shows the average energy saving over the three years of the trial. It is presented in two ways:

The energy saving on a weekly basis as a % of the energy used in the unscreened area (bar chart).

The cumulative amount of energy saved as the year progresses (line graph).

Figure 1 – Average energy savings over the 3 year trial



Note that the total energy saving shown in Figure 1 is 116kWh/m^2. This is higher than the average figure given in Table 1 because it incorporates the effect of the longer cropping season of 2003 and the improved energy saving achieved during the early part of the season in 2004/05.

For the purposes of estimating savings with new screen projects, it is recommended that growers should use an energy saving of 100kWh/m^2 as a conservative figure. In practice, a saving of over 110kWh/m^2 might well be achievable.

Thermal screen operating strategy

The following settings were successfully used to operate the thermal screen.

Radiation level

- Opened at a light level of 40W/m^2 or higher, regardless of the outside temperature.
- Closed at a light level of 40W/m^2 or lower when the measured outside temperature was below the outside temperature limit.

Outside temperature limit

- Close when the difference between the heating temperature and the outside temperature was greater or equal to 5^{o}C when the light level was 0W/m^2.
- Close when the difference between the heating temperature and the outside temperature was greater or equal to 8^{o}C when the light level was 40W/m^2 or above.
- Outside temperature limit was increased by 2^{o}C over a wind speed range of 2 to 6m/s.

The difference between inside and outside temperature was gradually increased as the plants grew and humidity control became more difficult (typically up to 10ºC at 0W/m^2 and 15ºC at 40W/m^2).

Humidity control

The screen was set to gap (open by a small amount) when the humidity deficit (HD) was considered to be too low. The greenhouse target HD depended on the condition of the crop but was typically 2.5g/m^3 during the night and 3.0g/m^3 during the day.

An example of typical operation is as follows,

- Target HD of 2.5g/m^3.
- Gapping started at 2.8g/m^3 increasing to 3% gap at an HD of 2.3g/m^3.

The maximum gap was set at 3% when the requirement for active humidity control was small and outside temperatures were low. Maximum gap was increased to 10% as the crop developed, outside temperatures increased and humidity control became increasingly difficult. Screen gapping was the first response to a low HD. The aim being to gap first, then vent, and finally increase the minimum pipe temperature.

Crop management & growing strategy

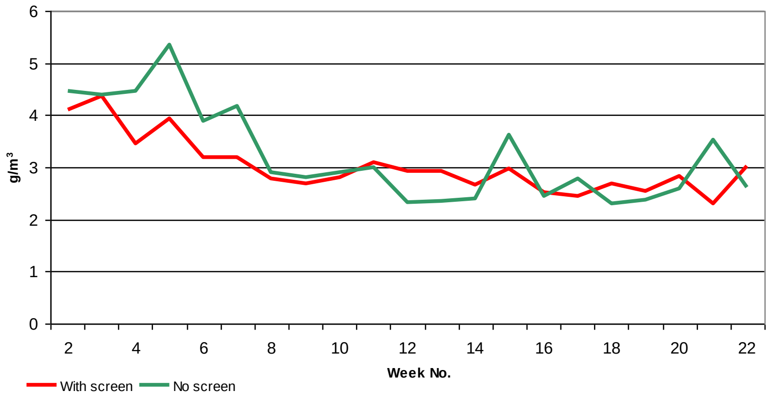
Temperature

No modifications to the heating temperature were applied as a result of using the thermal screen. All aspects of greenhouse temperature, that is to say, day temperature – night temperature differential and average temperatures achieved were identical in both the screened and unscreened areas.

Irrigation

Figure 2 below shows the average night-time HD during the first half of the season. This was the period when the most significant differences occurred between screened and unscreened treatments. The consistently lower HD in the screened treatment during the early part of the season resulted in lower passive water loss by the plant.

Figure 2 – Average night-time humidity deficit



As a result, the use of

‘radiation sum’ to control irrigation gave unsatisfactory slab moisture control in the screened area as it did not take account of the reduced night-time water loss. Manual irrigation control, supported by regular spot readings of slab moisture content, proved to be the most reliable method of achieving optimum slab moisture level.

General recommendations for irrigation are:

- Apply the first watering once the screens open in the morning.
- Stop watering when the screen closes in the afternoon.

During the early part of the season, when the screens were closed for long periods, the EC of the irrigation water in the screened area was increased to 0.5 over that used in the unscreened area. This was to compensate for the lower water uptake by the crop.

Conclusions

- Modern designs of thermal screens deliver worthwhile energy savings. Savings can be expected to be in the order of 100kWh/m^2 p.a.
- No reduction in yield was recorded during the trials as a result of the use of screens. However, experience of growing with a thermal screen is required to achieve this.
- Satisfactory humidity control is possible when using a thermal screen. However, active humidity control is required earlier in the season than would be the case where screens are not used.
- A well controlled glasshouse environment with screens does not result in an increased incidence of botrytis.
- Irrigation management is considerably different when using screens and is an important tool which can be used to compensate for the effect of a thermal screen on the greenhouse environment. Increased attention to detail is required in this area.
- Additional instrumentation such as infra-red cameras and strategically positioned measuring boxes can give a useful additional insight into the growing environment experienced by the crop.

Financial benefits

Energy saving

Assuming a typical heating energy price of 2.0p/kWh (gas purchased on an annual contract), the average energy saving of 100kWh/m^2 is worth £2.00/m^2/annum.

An increasing number of growers buy their energy on a monthly basis to take advantage of lower summer time prices. This typically means the winter gas price is 2.5p/kWh or more. In this scenario the value of the energy saved increases to £2.50 per m^2 per annum.

Cost of implementation

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. Exact costs are dependent on a number of factors including greenhouse design and age, greenhouse infrastructure (e.g. location of services such as heating pipes, ventilator actuators, etc) and the current exchange rate between the Euro and the Pound.

In some cases a major upgrade of the greenhouse climate control computer may also be required. Allocating this cost fully to the thermal screen installation is unrealistic as a computer upgrade on its own can be expected to deliver benefits unrelated to the screen such as reduced energy use and improved cropping through better greenhouse climate control.

Crop performance

No significant benefit (or penalty) was recorded.

Payback

Based on current capital costs and average energy prices the 'straight-line' payback on the screen investment is expected to be 24 – 30 months.

It should also be noted 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 on www.eca.gov.uk.

Action points for growers

- The results of this project have shown that at current energy costs, thermal screens are an essential part of any modern heated greenhouse. Growers should therefore:
- Assess the suitability of their greenhouses for the installation of a modern moveable thermal screen.
- Obtain quotes for the installation of thermal screens.
- Include thermal screens into their short to medium term capital investment plan.
- Ensure that they have a suitable climate control computer and train staff in their use. This is essential if both energy savings and crop yield are to be maximised.

Science Section

1 Introduction

1.1 Background

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

- Economics – particularly the continuing trend of rising fuel prices.
- Legislation and taxation – such as Climate Change Levy (CCL) and the associated energy saving agreements.
- Consumer pressures – customer expectations relating to reduced environmental pollution.

For tomato production in the UK, energy can account for up to 40% of the total costs of production. At current energy prices this can be over £10.00/m^2/annum. Defra statistics indicate that there is around 225Ha of heated tomato production in the UK so the total energy cost for the industry is in excess of £22 million per annum. In addition to this, other heated edible crops including Cucumber, Pepper and Aubergine account for an additional area totalling approximately 200Ha. With similar energy costs, this accounts for an additional energy cost of £20 million per annum.

By reducing glasshouse heat losses, thermal screens offer the potential to cut this energy cost significantly.

Additional savings can be achieved for businesses that reduce their energy use through the Climate Change Levy Discount Scheme. Growers can obtain an 80% reduction in the amount of climate change levy (CCL) paid on energy in return for meeting energy saving targets. The targets require a 12% reduction in energy use by 2010 compared to a base year of 2004. The reduction in CCL alone is worth as much as £2.5m to the edibles sector. Thermal screens have the potential to deliver the majority of the saving required.

Results from the first year of work on this project (2003) clearly demonstrated the energy savings that could be achieved with no significant impact on crop yield or quality. However, it was felt that this work did not achieve the maximum energy saving or maximise the performance of the crop. This was because operating strategies for the screen were conservative and tempered to maximise the light received by the crop and ensure energy savings were not secured at the expense of crop performance (e.g. yield, quality or disease). It also became clear that the different growing environment created by using a thermal screen required a significantly different approach to growing a tomato crop.

To extend the boundaries of current knowledge, fully determine the savings potential and demonstrate the commercial viability of the technique, the project was extended for a further two years (completion November 2005).

The science section of this final report focuses on the crop grown in 2005. For greater detail about the 2003 and 2004 crops refer to the previous annual reports.

1.2 Objectives

The objectives of the project as a whole were:

- To determine the financial viability, energy saving and effect on yield of a modern design of thermal screen material on a commercial tomato nursery in the UK.
- Establish a recommended operating strategy for a thermal screen over tomatoes to optimise both energy saving and crop performance.
- To develop an improved understanding of the differences in greenhouse climate caused by the use of a thermal screen.
- To identify and prove the key differences in growing strategy that are required when using a thermal screen.
- Obtain information on the durability and maintenance requirements of modern thermal screen materials and operating systems.
- Stimulate commercial uptake of thermal screens by communicating the results of the work to the protected edibles sector in the UK.

2 Control of thermal screens

The control strategy used in 2004 and 2005 seasons is described below.

2.1 Summary of thermal screen control set points

The set points described below provide an outline of the general approach taken. Fine tuning was required as the season progressed and the crop developed. These settings serve as the starting point for a grower using thermal screens for the first time, but they will need to be modified to take account of local conditions.

2.1.1 Energy saving set points

Outside global radiation level

- Open the screen at a light level of $40W/m^2$ or higher, regardless of the outside temperature.
- Close the screen at a light level of $40W/m^2$ or lower when the measured outside temperature was below the calculated outside temperature limit.

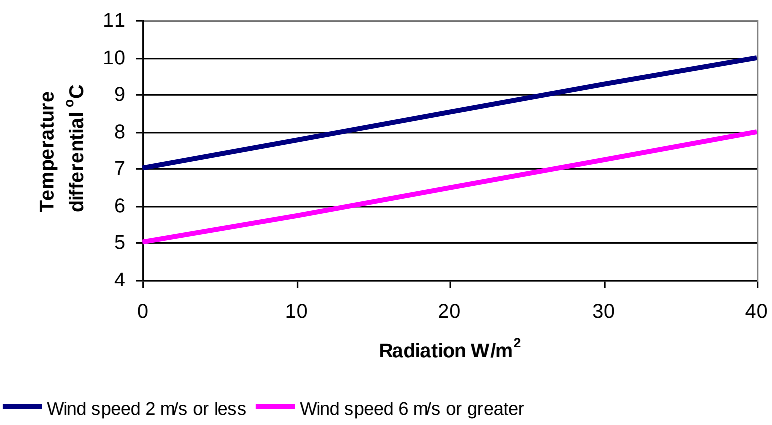
Outside temperature limit

- Close when the difference between the heating temperature and the outside temperature was greater or equal to 5ºC at 0W/m^2.
- Close the screen when the difference between the heating temperature and the outside temperature was greater or equal to 8ºC at 40W/m^2.
- Increase the outside temperature limit by 2ºC as wind speed rose from 2 to 6m/s.

The difference between inside – outside temperature differential was gradually increased as the plants grew and humidity control became more difficult. Typically up to 10ºC at 0W/m^2 and 15ºC at 40W/m^2.

The combined effect of the set points is shown in Figure 3 below. The actual temperature differential used (internal temperature – outside temperature) would fall somewhere between the two lines depending on the light level and wind speed.

Figure 3 – Thermal screen control set points (energy saving)



2.1.2 Humidity control

The screen was set to gap (open by a small amount) when the humidity deficit (HD) was considered to be too low. The target HD depended on the condition of the crop but was typically 2.5g/m^3 during the night and 3.0g/m^3 during the day.

An example of typical operation is as follows,

- Target HD of 2.5g/m^3.
- Gapping started at 2.8g/m^3 increasing to 3% gap at an HD of 2.3g/m^3.

The maximum gap was set at 3% when the requirement for active humidity control was small and outside temperatures were low. This was increased to 10% as the crop developed, outside temperatures increased and humidity control became increasingly difficult.

Screen gapping was the first response to a low HD. The aim being to gap first, then vent and finally increase the minimum pipe temperature.

Using this framework of settings it was shown that energy could still be saved even when the screen was gapped for HD control with occasional venting. Once a constant 10% gap with constant venting above the screen was in operation, there were no energy savings. The screen open/close (energy saving) set points were tuned to ensure that the screen opened fully if this was the case.

3 Research method

3.1 Overview of location, facilities and cropping

3.1.1 Greenhouse

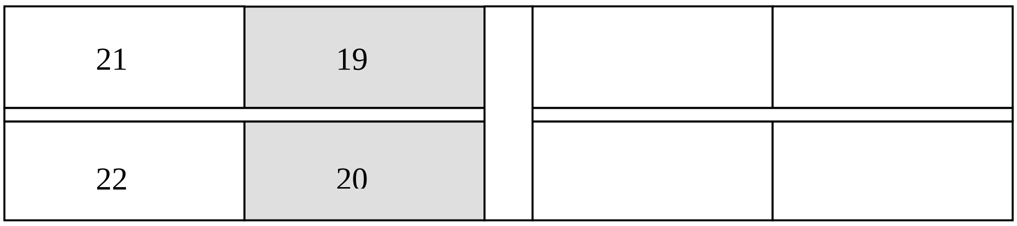
The project was carried out at the same location and facilities as in 2003 & 2004.

The site was G. de Lang & Sons, Mill Nursery, Keyingham, East Yorkshire. The total greenhouse area for the trial was 27,000m^2. Each numbered zone identified in Figure 4 below represents one quarter of the total floor area (6,750m^2).

A thermal screen, using Ludvig Svennson SLS10 Ultra Plus material, was installed in the roof and side walls of zones 19 and 20. A transparent polythene sheet was also fitted from gutter to floor where zone 19 meets 21 and zone 20 meets 22. This served to create two separate air spaces.

It should be noted that since the installation was carried out, ‘voided’ thermal screen material has been developed. The material used in this project was ‘solid’ or ‘non-voided’.

Figure 4 – Greenhouse layout



3.1.2 Environmental control

Each zone 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.

3.1.3 Crop

The crop was grown in mineral wool substrate blocks on hanging gutters. The tomato variety Classy (large vine) was grown in all compartments. Further detail on the crop is given in Section 5.6.

3.2 Data collection

3.2.1 Greenhouse environment and weather data

Greenhouse internal environment and weather 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 – heating & ventilation temperature.
- Heating system – measured heating pipe temperature.
- Ventilation system – measured vent position.
- Screen position.
- Greenhouse environment – temperature, humidity deficit & CO_2 via a measuring box mounted within the top 40cm of the crop.

Weather data

- Temperature.
- Solar radiation.
- Wind speed.

Additional instrumentation was installed in 2004 to examine more closely the difference in growing environment created by the thermal screen. This included:

- A second measuring box located approximately 40cm above the hanging gutter to determine the temperature and humidity at the base of the crop.
- An infra-red camera to measure the crop canopy temperature.

3.2.2 Energy

Ultrasonic heat meters were installed in the final heating loop of zones 20 and 22. These measured the amount of heat delivered (as hot water) to each of these zones. A digital output from each meter was connected to the climate control computer. This allowed energy data to be automatically recorded and downloaded using the same system that was used for collecting environment and weather data. By assuming a hot water heating system efficiency of 85%, this was converted into the equivalent amount of mains gas used.

3.2.3 Crop data collected

Site staff carried out weekly crop recording including:

- Growth.
- Height of flowering truss.
- Stem diameter.

Yield data was recorded daily when the fruit was picked. This was recorded as both number of punnets and total kilograms.

Disease levels, principally botrytis, were assessed in defined areas in two ways:

- Plants removed - recorded by nursery staff.
- Detailed assessment at key stages of the season - carried out by Dr Tim O'Neill, ADAS Consulting Ltd.

4 Results & discussion

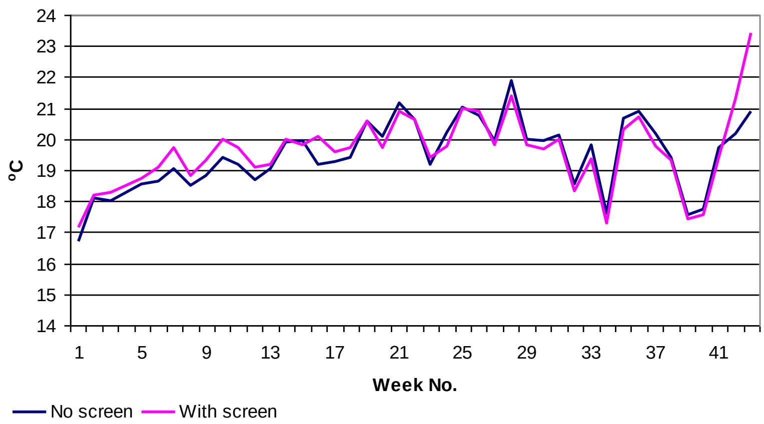
As a commercial demonstration project, the overriding objective was to ensure that a successful crop was grown in both the conventional and screened treatments. Against this background two basic aims for environmental control were set for the duration of the project:

1. If deemed necessary, from a crop management point of view, average temperatures were allowed to vary between treatments.
2. Target humidity levels were to be the same in both treatments and were to be determined by the site manager.

These principles were applied regardless of the impact on the energy saving performance of the screens.

4.1 Greenhouse environment

Figure 5 – Average greenhouse temperature

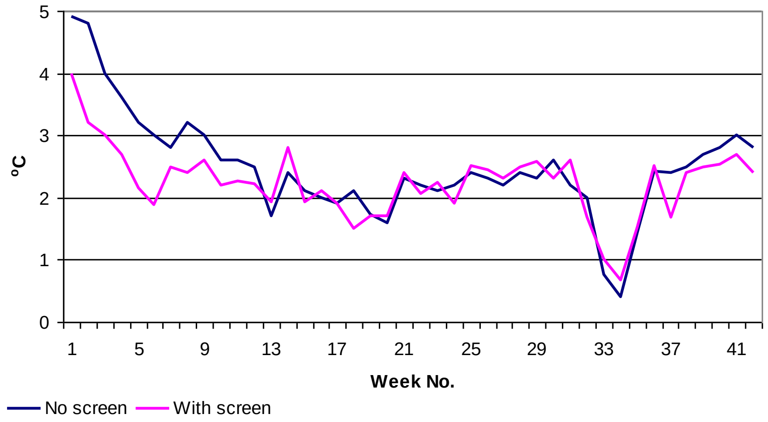


During the early part of the season, up to week 13, the screened treatment tended to be at a higher temperature than the unscreened treatment. This was mainly due to a higher heating temperature being applied to counter the slight delay in picking that had occurred in the first two years of the trial. The ability to always achieve the required temperature, regardless of weather conditions, also contributed to the difference.

A dip occurred in both areas between weeks 33 & 35 when the heating system was shut down on the whole site whilst modifications were made. The low temperatures around week 40 were imposed to slow down the speed of fruit ripening as much as possible due to marketing reasons. The greenhouse temperature was finally increased in week 41.

From week 42 onwards a relatively high minimum pipe temperature (40ºC) was applied 24-hours a day regardless of environmental conditions, to aid fruit ripening. In addition the screen was permanently closed. This meant that the temperature in the screened treatment was consistently above the heating set point of 19ºC whereas the unscreened treatment was not. This caused significantly higher greenhouse temperatures in the screened treatment compared to the unscreened.

Figure 6 – Average night-time humidity deficit



Thermal screens have the greatest effect on humidity during the night-time. Therefore focussing on the average night-time HD, (see Figure 6 above), helps to highlight the differences that occurred. The most significant point is the consistently lower HD in the screened treatment up to week 12. This is when the screens were closed for most of the night and energy savings were high. The lower HD helps to explain a reduced demand for irrigation in the screened treatment during the same period.

4.1.1 CO_2 levels

A single CO_2 enrichment system supplied both of the trial areas. Control was based on a single CO_2 measurement located in block 19. The screen control strategy used in the trial did not have any effect on CO_2 level.

4.1.2 Additional instrumentation

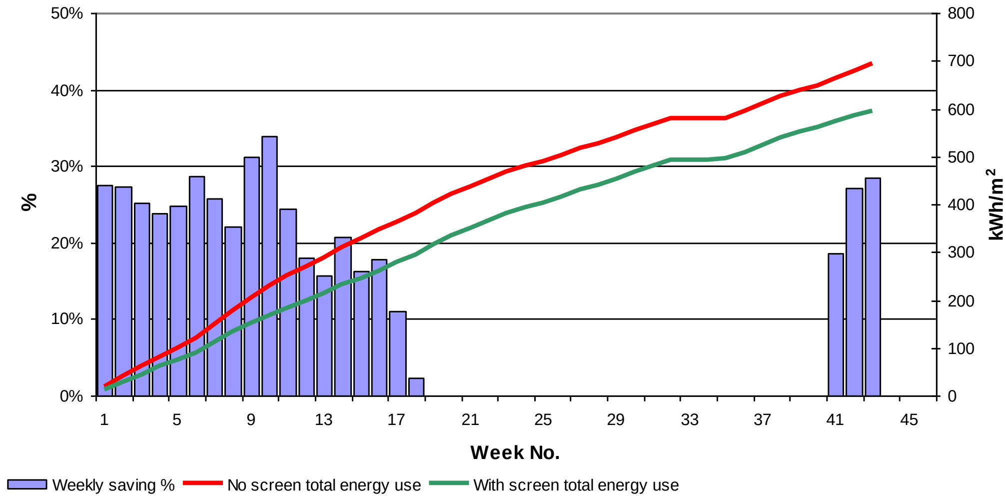
The trends identified in 2004 continued. These were:

- Radiant cooling – on a clear, cold night the head of the crop in the unscreened treatment was as much as 1ºC colder than the air around it. This was due to the radiant cooling effect of the sky. This contrasted with the screened treatment where crop temperature was always close to the air temperature. In this case the screen cut out the radiant cooling effect of the sky.
- Bottom heating – warm air rising from the heating pipes results in the air temperature at the bottom of the crop being around 1ºC higher than at the top. This effect is reduced when a thermal screen is used because less heat is required.

- Bottom drying – a similar effect to bottom heating. The HD of the air at the bottom of the crop can be as much as 1.0g/m^3 higher than at the top where no screen is used and heating demand is high. This reduces to 0.5g/m^3 when a screen is used.

4.2 Energy data

Figure 7 – Total energy use and weekly savings (2005)



Over the whole 2005 cropping season:

- The area without a thermal screen used the equivalent of 695kWh/m^2 of mains gas.
- The area with a thermal screen used 597kWh/m^2.
- This is gave a saving of 98kWh/m^2 mains gas (14%).

Table 2 below shows the total energy use and savings in each year.

Table 2 – Energy use in each year

	Total energy use (gas equivalent) kWh/m^2		
Year	**No screen**	**With screen**	**Saving kWh/m^2**
2003	802	697	105 (13%)
2004	773	676	97 (13%)
2005	695	597	98 (14%)
Average	757	657	100 (13%)

It should be noted that the total energy use in 2005 was significantly reduced due to:

- Zero heat use for three weeks during the summer (heating system modifications).
- Low greenhouse temperatures late in the season compared to previous years.
- The crop was removed two weeks earlier.

The last two points had the additional effect of reducing the energy saved by the screens in 2005.

4.3 Crop data

Information in this section has been provided by Derek Hargreaves, Independent Crop Consultant.

The two ends of the greenhouse used for the comparative trial have in the past produced slightly different results since the house was built in 2001. Prior to the installation of a thermal screen, what is now the screened area (zones 19 & 20) produced 2% less (recorded as punnets) than the unscreened (zones 20 & 21) area.

4.3.1 Establishment and general growing strategy

The young plants were delivered to the nursery in week one. They were the large vine variety Classy, grown in Vitagreen cubes and placed onto 20cm Grodan Master slabs. Irrigation was supplied by a single 4 litre per hour dripper to each two plant module. The planting density was slightly over $2/m^2$. This was doubled to $4.1/m^2$ on the first truss shoot.

As in previous years the aim was to have the same growth conditions in each of the treatment areas. This meant using slightly different control set points to give the same conditions. For example, the volume of irrigation applied was approximately 10 to 15% less in the screened area compared with the unscreened area. Humidity control set points were also different.

The aim was to produce a rapidly developing plant to get into production early and to aim for high yield. The growing temperature started at 18^{o}C in all periods. From first flower onwards the day temperature was increased up to 22^{o}C giving an approximate 19.5^{o}C, 24-hour average. From fruit swelling onwards the day temperature was increased to 26^{o}C by delayed venting to swell fruit rapidly. Humidity deficit control was aimed at 2.8 to $3.0g/m^3$ HD during the daytime with a view to conserving energy rather than having the ideal HD at all times.

A single CO_2 enrichment system supplied both the screened and unscreened area. The set point of 1000 vpm was maintained easily during periods of little ventilation. This level was reduced from May onwards as ventilation losses increased and the cost of achieving such high levels was considered to be excessive. Due to modifications to the heating system there was no carbon dioxide enrichment during the majority of August. This affected both the screened and un-screened areas equally.

4.3.2 Growing media moisture content

The aim was to achieve 50% moisture content after planting and then to start the control regime. This was achieved more easily in the unscreened area due to the higher heat demand and therefore higher humidity deficit. As a general rule, the start of irrigation in the screened area was one hour later than in the unscreened area. This was extended to two hours in periods of dull weather. The time of the final round of irrigation was also brought forward to maintain the moisture content at the desired level. The trigger for ending the irrigation period was the closing of the screen. These delays gave a more satisfactory control over early moisture content in the slab than had been achieved in previous years.

As the fruit began to swell the moisture content was allowed to rise from 60% to 75% on irrigation during the day.

Determining irrigation requirements in the screened crop continued to be difficult. Start times controlled by Radiation sum alone did not allow for the reduction in water demand caused by the lower night-time humidity deficit. Equipment to provide continuous growing media water content measurement was installed. However this did not prove to be a reliable or accurate system. Whilst the screens were being used extensively the slab moisture content was measured in 20 slabs using a hand held water content meter at the start and the end of each day. Irrigation was operated manually with the manual readings providing feedback to help fine tune the volume given. During the establishment phase the amount of irrigation water given in the screened area was approximately 10% less than in the unscreened area.

As the crop became established and the screens were used less the irrigation regime became the same in both treatments.

4.3.3 Conductivity

The initial drip EC was set at 4.0 aiming for a slab EC of 5.0 i.e. +1 EC unit above the drip. Due to the lower water uptake by the plants in the screened area the EC was set 0.5 higher (5.5) when the screen was being used for extended periods. As the period of screen use declined the applied EC was brought into line with the unscreened area.

From picking the applied EC was reduced to 3.2 with subsequent reductions to achieve a slab EC of 4.0 during picking to maintain fruit quality.

4.3.4 Humidity deficit

It was assumed from the outset of this project that HD control would be more difficult under the screen. The HD in the screened area was inherently lower because of the reduced natural air leakage caused by the closed screen. However, it was always possible to achieve the target HD required by the grower. This was achieved through a combination of screen gapping, ventilation and heat.

Night-time

The aim was to achieve average HD’s of around 2.5g/m^2 in both treatments. The HD was allowed to fall to a minimum of 2.3g/m^3, although there were periods, typically during the summer, when this was not possible to achieve in either treatment, without excessive energy use.

Daytime

The aim was to achieve a HD of at least 3.0g/m^3 between sunrise and one hour before sunset.

The average night-time HD and a discussion of the differences between the two treatments are given in section 4.1.

Some variation in plant development was seen under the screen that was not evident before the screen was installed. The nature and location suggested that this was due to less uniform temperature distribution. This was more than likely due to the fact that the air circulation fans could not be mounted under the screen as they were too close to the crop. They were therefore turned off until the summer when the thermal screen was not used.

4.3.5 Crop maintenance

Leaf picking, in the head, was carried out until the first week of April. One leaf in three was typically removed to help control plant vigour. The aim was to leave 15 to 18 leaves per head - giving 60 to 74/m^2. Regular lower leaf removal and layering was carried out as required.

Trusses were pruned to give six fruits per truss with no specific weight for individual fruits or for total truss weight specified by the market. Picking started 67 days after planting in the unscreened block with the screened area starting seven days later.

4.3.6 Crop yield

Figure 8 – 2005 yield comparison (punnets/m^2)

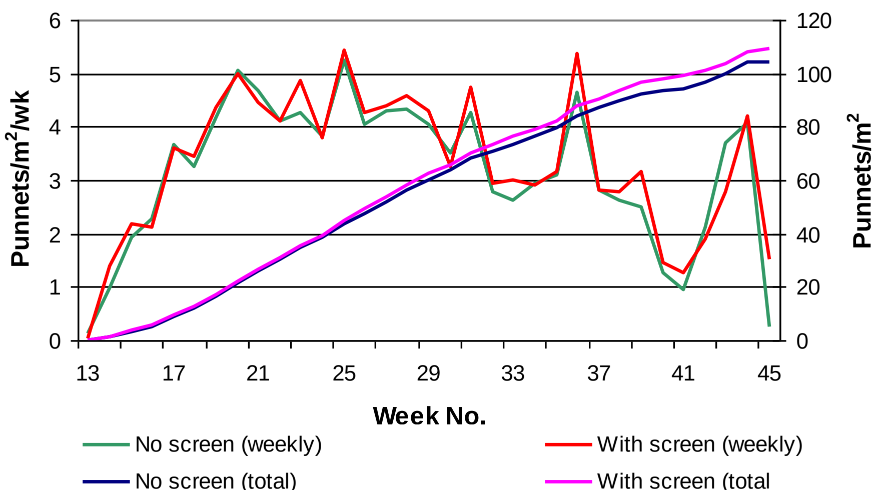
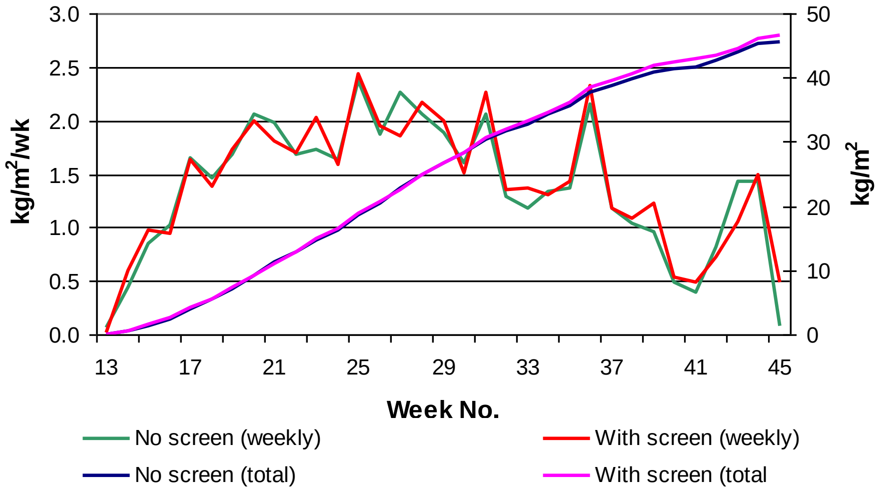


Figure 9 – 2005 yield comparison (kg/m^2)



Although the start of picking was slightly later in the screened crop this was quickly compensated for by higher yield. In terms of punnets, the screened crop consistently yielded slightly more than the unscreened crop especially from week 23 onwards. The final result was that the screened crop yielded 5% more punnets that the unscreened crop.

In terms of kilos the difference was smaller. However, the screened crop still yielded 3% more than the unscreened crop.

Table 3 below gives the total yield from each treatment for all 3 years of the project.

Table 3 – Total yield for the season

	2003		2004		2005	
	Punnets /m^2	kg/m^2	Punnets /m^2	kg/m^2	Punnets /m^2	kg/m^2
With thermal screen	94.6	n.a	108.2	55.8	109.5	46.6
No thermal screen	102.1	n.a.	110.6	56.2	104.4	45.5
Screened as % of unscreened	93%	n.a.	98%	99%	105%	103%

The 7% yield difference (punnets) in 2003 was mainly due to a pest problem not related to the use of screens. In 2004, although the yield was 2% less in the screened area this was similar to the difference before the screen was installed. The screened treatment achieved greater yields as both punnets and kilos in 2005 for the first time ever.

4.3.7 Pest & disease

Routine treatments for botrytis control were applied throughout the life of the crop. This consisted of a treatment with Rovral followed by Scala in the early part of the crop. The same treatment was applied in the late summer to protect the stems in the autumn. There were few disease problems in the crop. During the 2003 season there were more problems with botrytis in the screened area but this did not appear to be such a problem in subsequent years. There was some botrytis in 2005 but it was more evenly distributed amongst the whole area (screened & unscreened). A detailed assessment of botrytis incidence carried out by Dr Tim O'Neill is given in section 4.4.

The whole area was affected by Powdery Mildew but to a lesser extent than in 2004 and this was controlled with routine sprays of sulphur.

There were a few patches of pests in the crop but nothing on the scale of 2003. All areas were maintained using integrated techniques of biological control and minimal use of pesticides.

4.4 Detailed botrytis assessment

A detailed assessment of botrytis incidence was carried out by Dr Tim O'Neill. A summary of his findings is outlined below. A complete version of his report is included in Appendix 1.

4.4.1 Disease assessment

Crops were assessed for:

1. Incidence of botrytis stem lesions.
2. Incidence of latent botrytis in leaf stubs and fruit truss stubs.
3. Number of wilting or dead plants removed by nursery staff.

The incidence of stem botrytis was assessed on 27th July 2005 and 11th October 2005. Unlike previous years a number of rows in each compartment were not sprayed to allow an additional comparison to be made.

Latent botrytis was determined in the laboratory on 60 leaf and 60 truss stubs from each compartment. The number of dead or wilting plants removed from rows in the central 15 pathways either side of the main path in each block was recorded by nursery staff.

4.4.2 Results

Assessment 1 (27 July 2005)

A low level of botrytis stem lesions (0.3 – 1.2 per row of 188 plants) was observed in the crop and was similar in both treatments. There was also little difference between the sprayed and unsprayed rows.

Latent botrytis was detected in just 1 out of 20 leaves from the screened compartment and non at all from the unscreened compartment. No latent botrytis was detected in the leaf petiole or fruit truss stubs.

Assessment 2 (11 October 2005)

Increased levels of botrytis stem lesions (1.7 – 26.7 per row of 188 plants) were observed compared to the July assessment. The incidence on unsprayed plants was significantly greater in the unscreened area (26.7) than the screened area (1.7). In the fungicide treated rows, levels of botrytis were similar.

The number of plants removed was relatively low in all areas, ranging from 0.6% (unscreened, fungicides applied) to 1.9% (screened, fungicides applied).

Latent botrytis was detected in some of the leaves but not stem wounds. The occurrence of latent botrytis in leaves was significantly greater in the unscreened compartment (48.5% of leaves tested) compared to the screened compartment (10%).

Nursery records suggest that a greater number of dead stems were removed from the screened block, although incomplete data meant that firm conclusions could not be drawn.

4.4.3 Discussion

There was no evidence that the use of a thermal screen resulted in an increase in stem botrytis. This was true both in areas treated with fungicides (4-spray programme), and in untreated areas. In the areas not treated with fungicide, the incidence of botrytis stem lesions was significantly lower in the thermal-screened compartment. The removal of a greater number of dead plants from this compartment may explain, in part, the occurrence of fewer stem lesions here. In the unscreened compartment, where the greater level of stem botrytis occurred, the fungicide spray programme appeared to reduce the incidence of botrytis stem lesions by around 50%.

The numbers of botrytis stem lesions per row in October 2005 (1.7-26.7) were generally much greater than in 2004 (1.3-2.7). This was most probably due to the loss of heating in the glasshouse for 2.5 weeks, during weeks 31-33, because of a boiler problem.

5 Discussion

Energy

The energy saving achieved in 2005 was similar to that in the previous two years. Had the last six weeks of the season followed a similar pattern to previous years (no temperature reduction due to marketing and continuation up to week 45) the energy saving would have been greater. If this had been the case it is estimated that the saving would have been around 120kWh/m^2.

The average energy saving across all three years of the project was 100kWh/m^2. This represents 13% of the total energy use in the unscreened compartment. It is recommended that growers use the absolute figure of 100kW/m^2 for payback calculations rather than a percentage of their own energy use to calculate savings. This is because total annual energy use includes energy used during the summer months when the screens deliver no saving.

Yield

Although it is commonly believed that the installation of a thermal screen will give a reduction in yield, this was not proven. In fact, in the final year of the project the screened compartment produced more than the unscreened compartment for the first time since the greenhouse was built. This result highlights the value of extending this project from one to three years. There is no doubt that the growing environment with a screen is considerably different to without one and that it takes time and experience to learn how to get the best from a crop grown under these new conditions.

Disease

Many growers consider that humidity control is more difficult when a screen is used. Active humidity control in the form of screen gapping, venting and pipe heat was required earlier in the season in contrast with the requirement of the unscreened crop. However the required level of humidity deficit was always achieved when the screen was being used.

Levels of botrytis were slightly higher in the first year of the project (2003) but in the following years there was little difference.

Growing strategy

The temperature strategy applied in the screened compartment was identical to that used in the unscreened compartment. However irrigation management was different. The reduced night-time humidity deficit meant that passive transpiration by the plant was less in the screened compartment. This in turn resulted in a reduced water requirement when the screens were used in the early part of the season. Determining the water requirement under these conditions proved to be difficult. The most reliable approach was manual control supported by regular spot measurements of slab water content using a handheld meter.

The use of additional greenhouse environment sensors (infra-red camera, low level measuring box) helped to more accurately determine the difference in the growing environment caused by using screens. This information has proven to be of great value in demonstrating to growers how the greenhouse environment is affected by the use of a screen.

Screen operation

The initial cautious approach in 2003 was to open the screen as soon as light levels exceeded 20W/m^2 (regardless of the outside temperature). This approach was used to maximise light received by the crop. This was increased to 40W/m^2 in 2004 & 2005.

Initially, outside temperature set points used a simple measured outside temperature approach. This was refined to use the difference between inside and outside temperature. Light and wind speed influences were also added to maximise energy saving when the potential for saving was high but also to maximise light receipt when potential savings were lower.

Many growers consider humidity control with a screen to be problematic. However the basic principles and set points are similar to those already used by growers to control humidity using minimum vent control. Humidity control therefore proved to be relatively straightforward.

The production of a 'blueprint' thermal screen control strategy is difficult as it depends so much on the crop, the greenhouse characteristics and how each individual grower prefers to grow their crop. Learning the concepts behind the control of thermal screens is the key to allowing growers to develop their own successful control strategy. A series of HDC and Carbon Trust funded training courses have been instrumental in achieving this goal.

Since completion of this project rising energy prices have meant that many growers are using screen control set points that are more closely tuned to achieving higher energy saving than those used in this project. For example light thresholds of 80W/m^2 are now in common use.

Screen installation maintenance requirements

Prior to this project the maintenance requirements and lifetime of the screen material were unknown. After three years of operation the breakdowns and maintenance required have been limited to less than 10 broken monofil support wires and one broken pull wire. The screen material has developed some green patches (algal growth) where drips from the greenhouse structure have landed on the material. These tend to be worst after the summer when the material has been compressed in the open position. However, they gradually fade when the screen is closed and warm, low HD air dries them out. The screen material shows no obvious signs of physical damage or deterioration.

6 Conclusions

- The thermal screen installation used in this project has been shown to reliably deliver an average energy saving of 100kWh/m^2.
- At current energy prices a thermal screen can pay for itself within two years. Where growers buy gas on a monthly basis (high winter prices, low summer prices) the payback can be as short as four months.
- This trial has shown that a thermal screen does not cause a reduction in yield. In the final year, as experience growing a crop with a thermal screen was gained, yield from the screened compartment was 3% higher than the unscreened treatment.
- Humidity control, when using a thermal screen, was not a problem. Active humidity control was required earlier in the season when screens were used. However, the required humidity deficit was always achieved.
- Disease (botrytis) was no worse in the screened compartment.
- Irrigation management is considerably different when using screens. It is a major means by which the plant can be managed to compensate for the effect of a thermal screen on the greenhouse environment. Increased attention to detail is required.
- The maintenance requirements of the screen installed for this project were minimal. No major breakdowns or failures occurred during the three years of the project.

7 Technology transfer

- HDC/Carbon Trust workshops
- HDC News
- HDC Energy News

Appendix 1 – Botrytis assessment carried out by Dr Tim O'Neill

Effect of thermal screens on tomato stem botrytis – 2005 (PC 198 / PC 198a)

Summary

The effect of using a non-breathable thermal screen on stem botrytis was monitored in a large vine tomato crop (cv. Classy) in East Yorkshire. The occurrence of stem botrytis was very low in July but increased from late August after a temporary loss of glasshouse heating. Although most botrytis stem lesions occurred on horizontal layered stems, some occurred on upright sections, the rot progressing along leaf petioles into the stem. In October, in unsprayed areas of crop, there were significantly fewer botrytis stem lesions in the screened compartment than in the non-screened compartment. In sprayed areas, the incidence of stem lesions was similar in the two compartments. No latent botrytis was detected in de-leafing and fruit truss stubs. A low level of latent botrytis was detected in leaves in July and a greater level in October; high levels of latent botrytis were detected in the crop area where there was a high incidence of sporulating botrytis stem lesions. There was no evidence that the use of the thermal screen on this nursery in 2005 resulted in increased levels of botrytis.

Introduction

The use of thermal screens during tomato production could lead to a greater frequency of periods with a low vapour pressure deficit (VPD) (i.e. high relative humidity) and consequently an increase in occurrence of botrytis, a disease that is known to be favoured by high humidity. Severe stem botrytis was reported on one nursery in 2003, in a block where non-breathable thermal screens had been used for the first time. The objective of this monitoring study was to assess the effect of using a non-breathable thermal screen on the occurrence of botrytis.

Methods

Crop production

Two adjacent glasshouse compartments (each c. 14,000m^2) were assessed for visible and latent stem botrytis in July and October 2005. In both compartments, the crop was cv. Classy grown on mineral wool slabs on hanging gutters. Leaves and side-shoots were left on the floor beneath the gutters throughout the season. As stem botrytis had been severe in some previous years, preventative fungicide sprays were applied to limit losses from botrytis. Treatments were Rovral WP on 25 March (week 12), Scala on 22 April (week 16), Rovral WP on 27 May (week 21) and Rovral WP on 25 July (week 30). The same treatments were applied to both compartments. Three pathways in each compartment (34-36 and 109-111) were left unsprayed. No fans were used in the screened block due to insufficient height above the crop if lowered beneath the screen. Fruit was harvested on-the-truss. There was therefore no opportunity to assess dieback of spent fruit trusses. No paints were applied to stem lesions.

Disease assessment

Crops were assessed for:

Incidence of botrytis stem lesions.

Incidence of latent botrytis in leaf stubs and fruit truss stubs and leaves.

Number of wilting or dead plants removed by nursery staff.

The incidence of stem botrytis was assessed on 27 July and 11 October by examining plants in rows either side of the three unsprayed pathways and in a further six sprayed pathways, selected at random, in each block. There were 188 stem bases per pathway.

Latent botrytis was determined in 60 leaf and truss stubs and in 60 leaves in each compartment, selecting stubs at random from within the unsprayed areas, and cutting them from the plant with secateurs. The terminal leaflet was collected from the lowest leaf remaining on the plants and a 1cm diameter disc was taken from the centre of the leaflet. Tissues were treated in the laboratory with paraquat, incubated in damp chambers and examined for botrytis sporulation after 14 days. The occurrence of other fungi was also noted.

The number of dead or wilting plants removed from rows in each compartment was recorded by nursery staff.

Results

Assessment 1 (27 July)

A very low level of botrytis stem lesions (0.3 – 1.2 stem lesions per 188 plants) was observed in the crop (Table 1) and was similar in the two compartments, and in the sprayed and unsprayed rows. Latent botrytis was detected in just one out of 20 leaves from the screened compartment, nil from the unscreened compartment. No latent botrytis was detected in leaf petiole or fruit truss stubs. Interestingly, this test revealed the presence of a low level of *Verticillium* and *Fusarium*, especially in row 34.

Table 1. Occurrence of botrytis stem lesions and missing plants in screened and unscreened compartments of cv. Classy – 25 July 2005

Compartment and pathway	Botrytis fungicides applied	Mean number per pathway (188 plants):	
		Botrytis stem lesions	Missing stem bases
Screened			
34, 35, 36	No	0.67 (+ 0.58)	0.67 (+ 0.58)
44, 48, 51, 54, 60, 66	Yes	1.16 (+ 1.47)	0.67 (+ 1.53)
Unscreened			
109, 110, 111	No	0.33 (+ 0.58)	0.33 (+ 0.58)
98, 102, 106, 116, 120, 124	Yes	0.50 (+ 1.00)	0.67 (+ 0.59)

( ) - standard errors

Assessment 2 (11 October)

Increased levels of botrytis stem lesions (1.7 – 26.7 per 188 plants) and missing stem bases occurred in the crop compared with the July assessment (Table 2). Lesions occurred both on horizontal layered stems and on upright stems; botrytis sporulation was present on many of the lesions. Only one or two wilting plants were observed. The incidence of botrytis stem lesions on unsprayed plants was significantly greater in the unscreened (26.7) than in the screened compartment (1.7); using a t-test, the significance level was 0.02. In the fungicide-treated rows, levels of botrytis were similar in the two areas. The number of plants removed was still relatively low in all areas, ranging from 0.6% (unscreened, fungicides applied) to 1.9% (screened, fungicides applied).

Latent botrytis was detected in some of the leaves but not in stem wounds (Table 3). Latent botrytis in leaves occurred at a significantly greater incidence in the unscreened (48.5% of leaves tested) than in the screened areas (10%) (P=0.001), reflecting the greater incidence of stem lesion in the area of crop. Although no botrytis was recovered from leaf petiole and fruit truss stubs, a *Fusarium* sp. and *Penicillium* sp. developed on these quite commonly, in samples from both screened and unscreened crops.

Nursery records of the numbers of dead stems removed from each block are shown in Table 4. It is difficult to draw firm conclusions as records were incomplete. The data suggests a greater number of dead stems were removed from the screened than the unscreened compartment.

Table 2. Occurrence of botrytis stem lesions and missing plants in screened and unscreened blocks of cv. Classy – 11 October

Compartment and pathway	Fungicides applied for botrytis	Mean number per pathway (188 plants):	
		Botrytis stem lesions	Missing stem bases
Screened			
34,35,36	No	1.7 (0.88)	2.3 (2.52)
44,48,51,54,60,66	Yes	9.5 (1.73)	3.7 (2.50)
Unscreened			
109,110,111	No	26.7 (6.03)	1.3 (2.31)
98,102,106,116,120,124	Yes	12.3 (1.30)	1.2 (0.98)

Table 3. Occurrence of latent botrytis and other fungi in leaves and stem wounds (leaf and fruit truss scars) – 11 October 2005

Compartment and pathway	Fungicides applied for botrytis	Mean number leaves (of 20) developing botrytis	Mean number stem pieces (of 20) developing		
			Botrytis	Fusarium	Penicillium
Screened					
34,35,36	No	2.0	0	9.3	4.3
Unscreened					
109,110,111	No	9.7	0	8.0	6.3

Table 4. Nursery records of numbers of dead stems removed

Week number	Paths 1-75 (screened block)	Number of record sheets	Paths 76-150 (unscreened block)	Number of record sheet
23 (6 June)	46	3	4	2
24	28	3	28	2
25	40	3	6	2
26	24	1	2	2
32	37	3	47	2
33	68	3	24	1
34	62	4	29	3
35	50	3	8	1
36	15	1	32	1
39	130	3	-	-
40 (3 October	153	3	-	-
Undated	142	5	222	12
Total	795	34	402	28
Mean number/record	23.4	-	14.4	

Discussion and conclusions

There was no evidence that the use of a thermal screen resulted in an increase in stem botrytis. This was true both in areas treated with fungicides (4-spray programme), and in untreated areas. In the areas not treated with fungicide, the incidence of botrytis stem lesions was significantly lower in the thermal-screened compartment. The removal of a greater number of dead plants from this compartment may explain, in part, the occurrence of fewer stem lesions here. In the unscreened compartment, where the greater level of stem botrytis occurred, the fungicide spray programme appeared to reduce the incidence of botrytis stem lesions by around 50%.

The numbers of botrytis stem lesions per row in October 2005 (1.7-26.7) were generally much greater than in 2004 (1.3-2.7). This was most probably due to the loss of heating in the glasshouse for 2.5 weeks, during weeks 31-33, because of a boiler problem.

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