Project title: Protected Ornamentals: Investigation into the potential savings available from adopting energy optimisation principals in UK glasshouse production

Project number: PC 190

Project leader: Dr Ian Clarke, HRI Efford, Lymington, Hampshire, SO41 OLZ

Final Report: October 2002 (Pot chrysanthemums)

Key workers:

HRI Efford:

Dr I Clarke	Project leader
Miss J Basham	Project manager (climate computer)
Miss S Williams	Project assistant (trial co-ordination)
Mr M Veren	Glass foreman
Mr P Burnell	Nursery staff

HRI Wellesbourne:

Mr N. Parsons	Biometrics

Location: HRI Efford, Lymington, Hampshire, SO41 0LZ

Project co-ordinator: Mr D. Abbott, SGP Ltd
Mr M Holmes, Double H Nurseries

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GROWER SUMMARY

1. 1 Headline

The use of temperature integration in the production of protected ornamentals can save up to 25% of the energy for heating during the winter period (November to March).

1.2 Background and expected deliverables

The combination of recent increases in the cost of energy and the introduction of the climate change levy has meant that energy efficient production is an issue for all producers of protected crops. A recent study trip to Denmark and the Netherlands (HDC project PC 172) concluded that the use of advanced climate control methods is an effective way of improving energy efficiency. Climate control regimes that allow a move away from the traditional method of fixed 'set points' for temperature are claimed to allow for significant energy savings. These systems use control methods that allow the environment to change dynamically to meet the needs of the crop in accordance with external weather conditions.

This trial (PC 190) concentrated on commercially available climate control programmes that allow temperature integration to produce commercially relevant protected ornamentals and concentrated on pot chrysanthemums as a model crop as:

- They have been studied more than most other ornamental crops and response to temperature is well known.
- They are already grown commercially at temperatures, which appear to be near the biological optimum. This means energy saving may be hard to achieve without detriment to plant quality and schedule.
- If energy savings can be made on pot mums, without loss of quality or production it is likely that significant savings will be possible with many other species, particularly those that are normally grown at temperatures below their biological optimum.

Deliverables

- Potential energy savings of two modest temperature integration regimes will be determined for an important pot plant crop grown under semi-commercial conditions
- The effects of temperature integration on crop speed, quality and shelf life will be assessed for a range of pot mum cultivars

This trial would be unlikely to produce a blueprint or advice for every crop grown under protection, but would prove whether the principles of temperature integration could contribute towards energy savings. Further work may well be required to improve confidence in the principles over many seasons or crops as well as to continue to develop new and challenging ways to save energy.

1.3 Summary of project and main conclusions

What is temperature integration and how does it work?

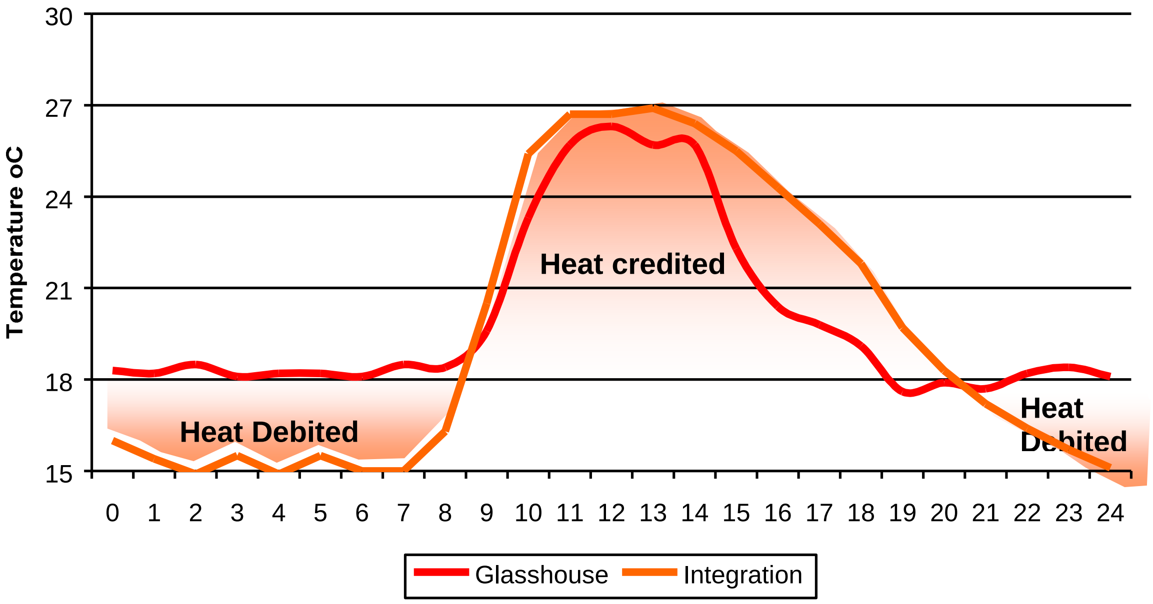


Figure A: Idealised heating profile from conventional and temperature integration set points of 18°C

Temperature integration works by allowing the temperature to vary, within grower defined limits, about a desired average that the climate control computer maintains. The degree hours gained from solar radiation during the day allow the temperature to fall below the average at some point in the future, often that night (Figure A above). This reduces the instantaneous heat demand and so also reduces energy inputs.

Looking at Figure A above, one can see that in a conventionally run greenhouse (red line), with a set point of 18°C, the average achieved temperature would actually be somewhat higher as a result of solar gain. It would be possible to manually adjust the set point at some time in the future, but in practice this is rarely done.

The integrated compartment (orange line) has an average achieved temperature of 18°C, and has actually compensated for the solar gain. At its simplest this means that the integration compartment has a lower heat demand and so uses less energy.

Experimental Work

Eight varieties of pot chrysanthemums were grown on each of three stick dates between November 2001 and March 2002. These were grown in one of three temperature environments, either:

- commercial control
- daytime integration
- 24hr integration

The Trial treatments

1. Commercial control

18°C day/night temperature, venting at 24°C

2. Daytime temperature integration

18°C night, 11.5hr daytime temperature integration, average set at 18°C, maximum positive deviation 8°C, maximum negative compensation 3°C. This means that the temperature can vary between 15°C and 26°C during the daytime depending on solar gain and accumulated degree hours.

3. 24hr temperature integration

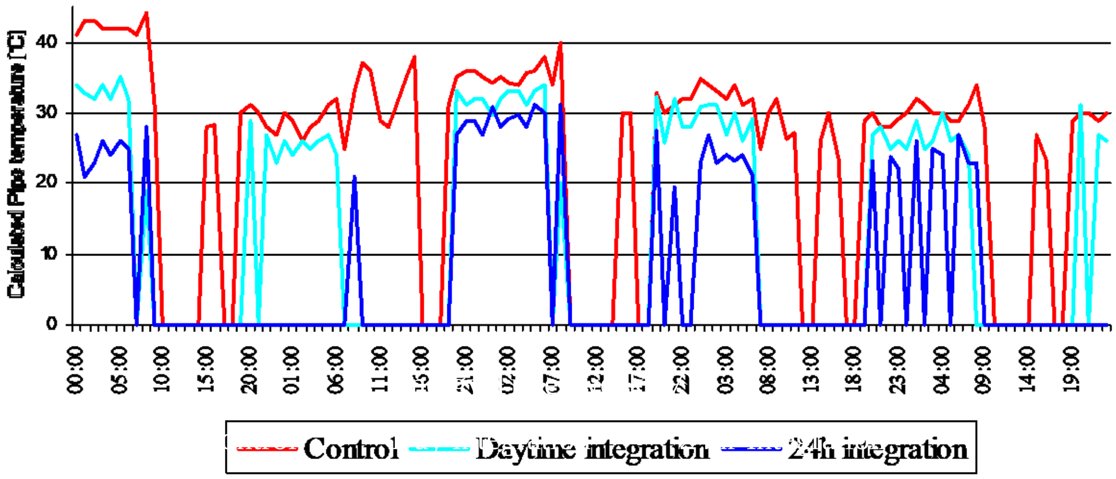
Average set at 18°C, maximum positive deviation 8°C, maximum negative compensation 3°C. This means that the temperature can vary between 15°C and 26°C depending on solar gain and accumulated degree hours.

All regimes

- 11.5 hours supplementary 1ighting at 9.6 W/m^2 (7.30-19.00)
- CO_2 enrichment to 1000vpm (from 8.00 to 17.00), none if vents exceeded 5%
- Humidity control: vents ramp between 75 and 85% RH (max 10% opening)
- Eight varieties: Dark Charm, Mirimar, San Anselmo, Yellow Kodiak, Grace Time, Ingot Time, Yellow Onyx Time, Energy Time

The trial demonstrated that energy savings between 13 and 35% were possible over the period of the trial. It would appear that by using 24hr integration over a three day period 25% of the energy used for heating could be saved. The key to energy saving that was demonstrated in the trial was the reduction in heat used to maintain the set point in a compartment. This is most clearly shown by the calculated pipe temperatures that indicate how often a treatment called for heat (see figure B).

December 15-19 2001



March 5-9 2002

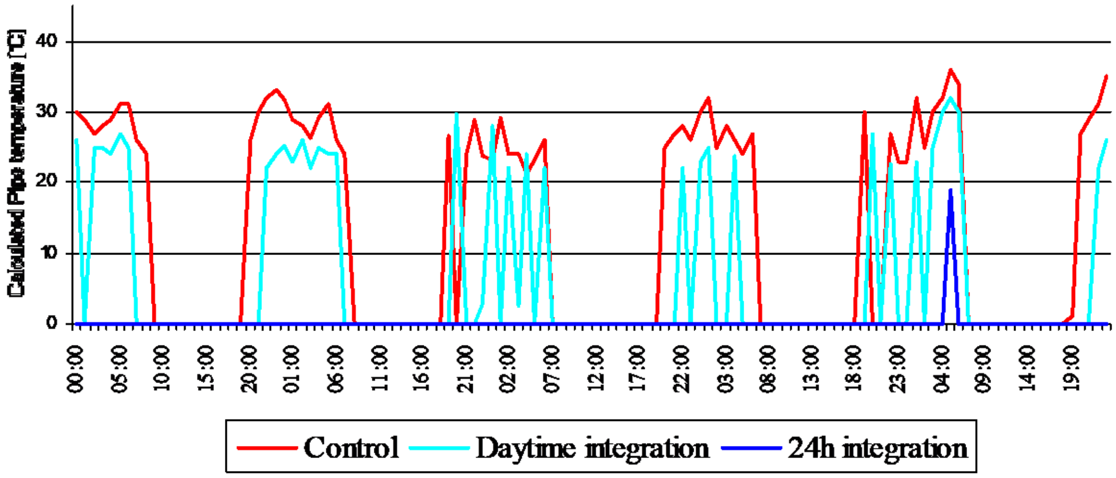


Figure B: The calculated pipe temperature showing the heat demand for all three temperature regimes from a week in December 2001 and March 2002. The significant reductions in the heat requirement in the 24hr integration regime are clear.

The trial also demonstrated that, with no change to current practice in commercial pot mum production, temperature integration could be used with confidence. On all measures made, the crop from the temperature integration treatments was comparable to that from the commercial control. The marketing quality and shelf life were as good as the control. Across all varieties, the schedule of the crop was never delayed more than three days and, compared to the energy savings, this delay is hardly significant (see Figure C).

Figure C: Pictures of Dark Charm stuck in week 50 (showing no delay) and Energy Time stuck in week 47 (showing slight delay) at marketing from the three temperature environments.

Conclusions

- The use of temperature integration in the production of protected ornamentals can save up to 25% of energy for heating during the winter period (November to March).

- The quality and post harvest performance of eight varieties of pot chrysanthemum grown in two temperature integration treatments were as good as the plants in the commercial control.

- The scheduling of crops in the integration treatments was delayed by as much as three days, but compared to the potential financial saving this is hardly significant.

- Temperature integration had no significant effect on the agronomy of the pot chrysanthemum crop, there was no increased incidence of pest or disease and no additional plant growth regulators were required.

- Additional uses of heat for disease control or minimum pipe temperatures will reduce the potential energy savings, but good housekeeping could reduce these to only essential use.

- A potential problem in the reduction in heat demand with the use of temperature integration is the reduced supply of CO_2 from boilers. However, growers using heat storage tanks will suffer less.

- The use of higher ventilation temperatures would appear to reduce the amount of CO_2 lost from venting, this may also reduce the CO_2 demand on a nursery.

- Alternative CO_2 sources have often been thought of as cost prohibitive. This may not be the case in the future when other technologies come on line.

- There is now scope to apply the findings from the pot chrysanthemum work to other energy intensive ornamental crops such as poinsettia, begonia, and cut flower chrysanthemum.

- A package of commercial-scale demonstration trials together with adequate education and training of growers in the use of climate control computers, should assist the widespread uptake and use of temperature integration to save energy.

1.4 Financial benefits

Each grower who implements temperature integration will reduce their heat demand and therefore fuel bill. However, the precise savings will depend on the individual grower's practices, crop range and their willingness to extend their set point boundaries.

The potential cost saving of using 25% less energy in the pot chrysanthemum industry in England and Wales alone is calculated to be worth £157,000 a year. This is based on estimates provided by the UKCGA; there are 12.54 hectares of pot chrysanthemum production in England and Wales. The average annual cost of heating is £50,000 per hectare. The total heating cost is therefore £627,000. A 25% reduction in this would be a saving of £156,750.

It may be possible to save more than 25% energy with other crops, whilst with some crops it may be difficult to achieve this much. As evidence accumulates and confidence grows in the technique more growers will undoubtedly adopt the practice.

Most modern climate control computers have been able to integrate temperatures for a number of years, and so many nurseries will already have the technology. For those that don't, the cost of a new computer may not be prohibitive when set against the potential savings on energy bills.

1.5 Action points for growers

- Begin to use temperature integration, taking advice from your climate control computer supplier on the best approach to integrating temperatures with the make and model of the computer that you have available.
- Begin with an average temperature close to your current standard set point and just vary 1°C either side of this.
- Consider increasing your ventilation set point temperature in the winter period to make use of additional thermal gains.
- Rethink your use of minimum pipe temperature to reduce unnecessary energy use.

2.0 SCIENCE SECTION

2.1 Introduction

The introduction of the climate change levy and rising fuel costs has meant that energy efficient production is an issue for all producers of protected crops.

The 15% voluntary reduction in energy use that the protected sector has agreed to deliver by 2011, in return for a 50% reduction of the climate change levy, until 2006, highlights the need to demonstrate and extend the potential energy savings available in this sector. A study trip to Denmark and Holland (PC 172) concluded that the use of advanced control methods is an effective way of improving energy efficiency. Control systems that allow a move away from the traditional method of fixed 'set points' for temperature are claimed to make significant energy savings. These systems use control methods that allow the environment to change dynamically to meet the needs of the crop according to external weather conditions. HDC project PC 172 looked at two specific systems, the Danish Intelligrow and the concept of Temperature Integration which is being used by two Dutch climate control computer manufacturers.

Essentially both Intelligrow and Temperature Integration use similar principles. These are to allow the temperature to rise as incident radiation rises, through higher ventilation temperatures. When incident radiation is low the temperature is allowed to fall below the traditional set point reducing the need for temperature lift from heating systems and therefore energy use. Temperature integration, but not Intelligrow, relies on the fact that plants grow and flower in response to average temperatures. Intelligrow is primarily concerned with reducing energy use and maximising photosynthesis at any given light level. Problems occur in Intelligrow when there are significant periods of poor light, whereas temperature integration may have problems if plant growth is affected by extreme temperature fluctuations or if plants cannot average over long periods.

It was concluded at the end of project PC 172 that immediate benefit could be obtained by a large number of UK growers if they could better understand and utilise the technology examined. It is unlikely that further work in Holland and Denmark will provide practical demonstrations or grower relevant data, largely because the crops and production systems that are common in these countries differ from those used in the UK. It was felt that a trial of commercially available systems was required to increase adoption by UK growers to demonstrate the principles available to protected ornamental growers.

This trial (PC190) concentrated on commercial protected ornamental production and concentrated on pot chrysanthemums as a model crop as:

- They have been studied more than most other ornamental crops and response to temperature is well known.
- They are already grown commercially at temperatures, which appear to be near the biological optimum. This means energy saving may be hard to achieve without detriment to plant quality and schedule.
- If energy savings can be made on pot mums, without loss of quality or production it is likely that many other species will have the potential for significant savings, particularly those that are typically grown at temperatures below the biological optimum.

The trial used the commercially available climate control programmes that facilitate temperature integration.

Temperature integration

Temperature integration allows the achieved compartment temperature to vary within prescribed limits that are set in the computer. The limits give the maximum and minimum temperatures permitted about a desired average temperature that the computer maintains. In commercial programmes the computer will maintain the average temperature over a one to seven day cycle as defined by the user. The positive deviations from the desired average occur by allowing the temperature to rise on thermal gain. The accumulated degree hours, above the average, are stored in the computers memory for the period the average is calculated over. The degree hours can then be used during periods of low or no solar gain to allow the temperatures to fall below the average but not below the minimum temperature limit. It is important to remember that as few as possible of the temperature changes are forced (either venting or heating). The aim is that the computer maintains the average over the period set by the grower. In this trial the period was set at 3 days.

Objectives

- to evaluate the potential energy savings of two temperature integration regimes compared to a commercial control
- to quantify crop speed, quality and shelf life of a range of pot mum cultivars grown under the three temperature regimes.

2.2 Methods and materials

2.2.1 Treatments

Three temperature regimes were used on three stick dates with 8 varieties to give 72 treatments in total:

Temperature:	control, daytime integration and 24hr integration
Stick weeks:	Weeks 47 and 50 of 2001, and week 1 of 2002
Cultivars:	Dark Charm, Mirimar, San Anselmo, Yellow Kodiak, Grace Time, Ingot Time, Yellow Onyx Time and Energy Time

The trial took place at HRI Efford, using three compartments in Q Block, where supplementary lighting at 9.6 W/m^2 was given using Philips 400W SON/T lamps for 11h 30m each day in all treatments.

The temperature integration treatments were carried out by a Priva Integro 720 climate control computer applying a three day integration period.

2.2.2 Cultural details

Plant material

Unrooted cuttings from 10 varieties were used during the trial from two suppliers (Table 1). On each stick date 8 varieties were used, although substitute varieties had to be used on two occasions. A complete list of the varieties used on each stick date is shown in Table 2.

Table 1: Cultivars used

Cultivar	Supplier	Flower Colour	Height class	Response (Weeks)
Charm	Yoder Toddington Ltd	Pink	Medium	8.5
Dark Charm	Yoder Toddington Ltd	Deep Pink	Medium	8.5
Mirimar	Yoder Toddington Ltd	Yellow	Medium	9
San Anselmo	Yoder Toddington Ltd	Purple	Short	9
Yellow Kodiak	Yoder Toddington Ltd	Yellow	S / M	8
Grace Time	Cleangro Ltd	Pink / Purple	Medium	7.5
Ingot Time	Cleangro Ltd	Yellow	Tall	6.5
Yellow Onyx Time	Cleangro Ltd	Yellow	Medium	7
Energy Time	Cleangro Ltd	Red	M/T	7.5
Swing Time	Cleangro Ltd	Bronze	M/T	7.5

Table 2: Varieties used on each stick date

Stick 1 (Week 47)	Stick 2 (Week 50)	Stick 3 (Week 1)
Charm & Dark Charm	Dark Charm	Dark Charm
Mirimar	Mirimar	Mirimar
San Anselmo	San Anselmo	San Anselmo
Yellow Kodiak	Yellow Kodiak	Yellow Kodiak
Grace Time	Grace Time	Grace Time
Ingot Time	Ingot Time	Ingot Time
Yellow Onyx Time	Yellow Onyx Time	Swing Time
Energy Time	Energy Time	Energy Time

Propagation and long day (LD) phase

Five cuttings were stuck in 14D pots filled with Levington M2C (40) compost. Bottom heating was applied to give a compost temperature of 20ºC. After sticking, pots were covered with clear polythene and left, in place for 9 days before weaning off. Supplementary lighting was given for 11h 30m each day with cyclic night-break lighting (50% cycle for 5 hours: 10:30pm - 03:30am) given for a total of 20 days from sticking. Night-breaking lighting was supplied using tungsten lighting, under an additional blackout cloche, at an illumination of 0.5 W/m^2 at canopy height. It was not possible to provide full long days under assimilation lighting, as the propagation took place in the same environments as the short day treatments.

Short day environment

Supplementary lighting was given continuously for 11h 30m each day, ensuring a night length of 12h 30m. The lighting came on at 07.30 when the black out screens were removed. Screens were drawn across again at dusk or 16.00 whichever was earlier.

Three heating treatments were set up to consider the effects of temperature integration. The three treatments were:

1. <u>Commercial control</u>: Heat to 18ºC day/night, venting at 23ºC
2. <u>Daytime temperature integration</u>: heat to 18ºC at night (when supplementary lights are off). 11½hr daytime temperature integration, average set at 18^{o}C, maximum positive deviation 8^{o}C and maximum negative compensation 3^{o}C. This means that during the day period only, the temperature will vary between 15^{o}C and 26 ^{o}C depending on solar gain and accumulated degree hours.

3. 24hr temperature integration: 24hr average set at 18°C, maximum positive deviation 8°C, and maximum negative compensation 3°C. This means that the temperature will vary between 15°C and 26°C depending on solar gain and accumulated degree hours.

The compartments were fitted with a Priva Integro 720 climate control computer. The integration period over which the computer could accumulate and use degree hours was set at 3 days. There was no minimum pipe temperature used in the trial, and no pipe heat related to humidity control. Thus the only pipe heat requirement was when the temperature in the compartment fell to or below the minimum set point that the integration program had currently calculated.

The CO_2 enrichment was applied via a forced air system blowing air through the crop via perforated clear plastic tubing, with the Priva environmental computer regulating the injection of CO_2. CO_2 enrichment was to 1000 vpm when the vents were less than 5% open. As the vents opened more than 5%, enrichment was ramped down to ambient (330 vpm) levels at 10% opening. CO_2 levels were never allowed to fall below ambient.

Humidity was controlled at low levels to avoid any risk of white rust or Botrytis. The vents began to open as relative humidity rose to 75% RH (vents 1%) to a maximum vent at 85% RH (vent 10%). This level of control may not be appropriate in all commercial situations but was possible in the trial and meant that there was little if any disease risk to the crop.

Growth regulation

Pots were pinched in SD to 8 expanded leaves at 20 – 25 days after sticking. Daminozide (as B-nine) was applied immediately after sticking (1g/l) then, as the crop required it for height control (2g/l) as detailed in the crop diary (Appendix 2). Applications were made, as each variety required it in each treatment; any differences between varieties or treatments are noted in the results.

Pot spacing

Pots were spaced at 41 per m^2 (pot thick) during propagation and the LD phase. They were half spaced to 27 per m^2 at the start of SD and to a final space of 13½ per m^2 as each variety required (see crop diary for specific timings).

Nutrition

Liquid feeding was given with each irrigation via seep hoses. The nutrient solution comprised: 300 mg/l N, 60 mg/l P_2O_3 (26 mg/l P), and 250 mg/l K_2O (207 mg/l K).

Pest and disease control

Pest control was monitored daily with a crop walk examining the plants and yellow and blue sticky traps. Once thrips were identified weekly applications of Nemasys F (250 million for all 3 compartments) were used as a control. Additional spot treatments as appropriate were applied throughout the trial as necessary (see crop diary, Appendix 2).

Home life phase

Six pots per treatment at marketing stage were put through a simulated transport run (21 hrs) and store life phase (10 days). This was then followed by up to 6 weeks in simulated home life conditions. The procedure was as follows:

Plants were sleeved, boxed and held at 15 ^{o}C for 15 hrs, before undergoing a simulated transport run of 6 hrs at 12 ^{o}C. Holding area simulation: 12 hrs at 18 ^{o}C, sleeved in boxes. Store life phase: plants taken out of boxes but remained sleeved for 10 days. Lighting was given at 600 lux (fluorescent tubes) for 12 hours a day. Temperature was controlled to a continuous 18 - 20 ^{o}C. The home life environment that followed was the same as the store life environment except that pots were not sleeved.

2.2.3 Assessments

Environmental records

Ambient light (external and internal) W per m^2

Running totals of degree hours deviation from 18^{o}C

Compartment temperature (^{o}C)

CO_2 levels achieved and logged inputs (vpm)

Humidity (% RH)

Comparisons of ‘actual’ achieved environment to the set-point environment

Logged energy use - based on logging the numbers of units of electricity used in each compartment with electricity meters and calculated gas use with heat flow meters in each compartment which monitor flow rates and pipe temperature, converted to kWh

Production records

Time to reach market stage 3 (HDC wall chart)

Number of flowers per pot at stages: 0, 1-3 (bud) and 4+(open flower)

Flower colour score (colour charts)

Plant height, width

Destructive sub samples to give fresh and dry weights

Compost and leaf nutrient analysis at harvest

Photographic records of each treatment at marketing

Shelf life records

Number of buds per pot at stage 4+

Number of distorted buds per pot

Qualitative assessment of foliage appearance, scored as follows:

1 = All green
2 = Green with a tinge of yellow
3 = Half green, half yellow
4 = Mostly yellow / brown
5 = Brown or leaves dropped

Qualitative assessment of flower appearance scored as:

1 = No deterioration
2 = Degeneration visible in flower centre
3 = Flower wilting / necrosis

An expert score: Mike Holmes, Double H Nurseries Ltd

2.3 Results and discussion

Plant responses: marketing

Each progressive stick took fewer short days to reach marketing for each cultivar in all treatments (Fig 1). This was to be expected, as daylength and light integral increased as the trial proceeded. The largest differences between marketing dates were between varieties (Appendix 1). Mirimar always took the longest, while varieties San Anselmo and Dark Charm were slower in stick one but by stick three were no slower than the majority of varieties.

Both integration treatments did slow the crop (Fig 2) and all varieties tended to take one to three days longer to reach full marketing (Appendix 1). However the spread between the first flower and marketing was 5 days regardless of treatment (for all stick dates). This means the commercial practice of picking over the crop daily would still be practical and the delay from the integration treatments is slight compared to the difference between the varieties grown.

Figure 1: The mean (across all varieties) number of short days (SD's) until first flower and full marketing for each stick date.

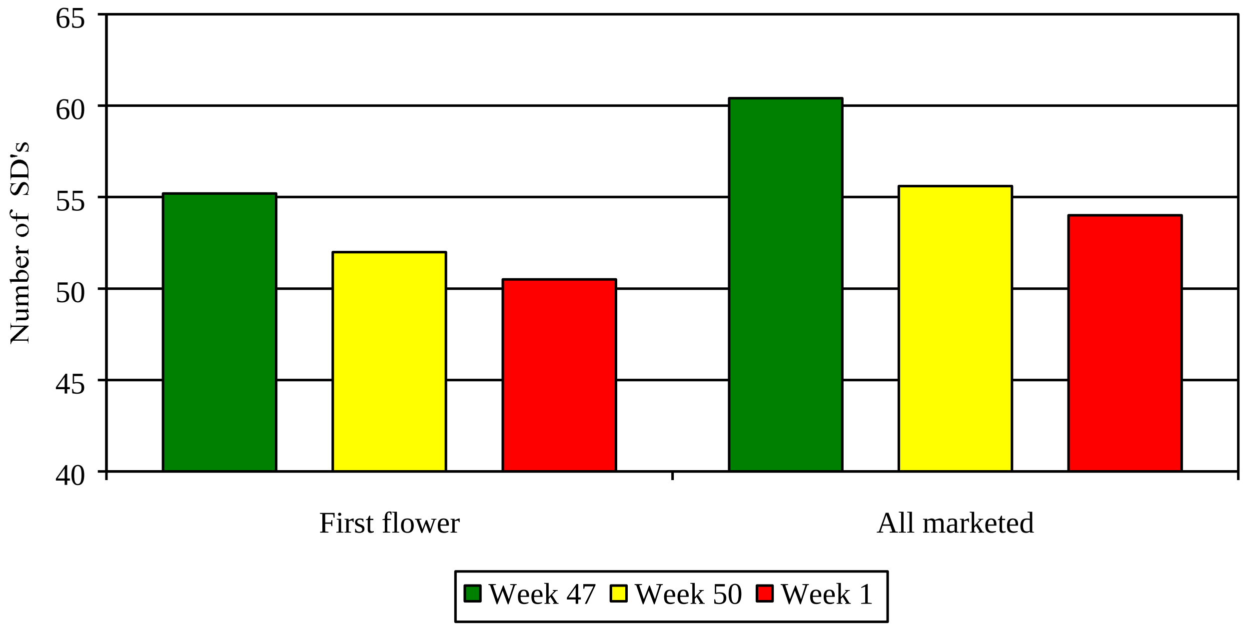
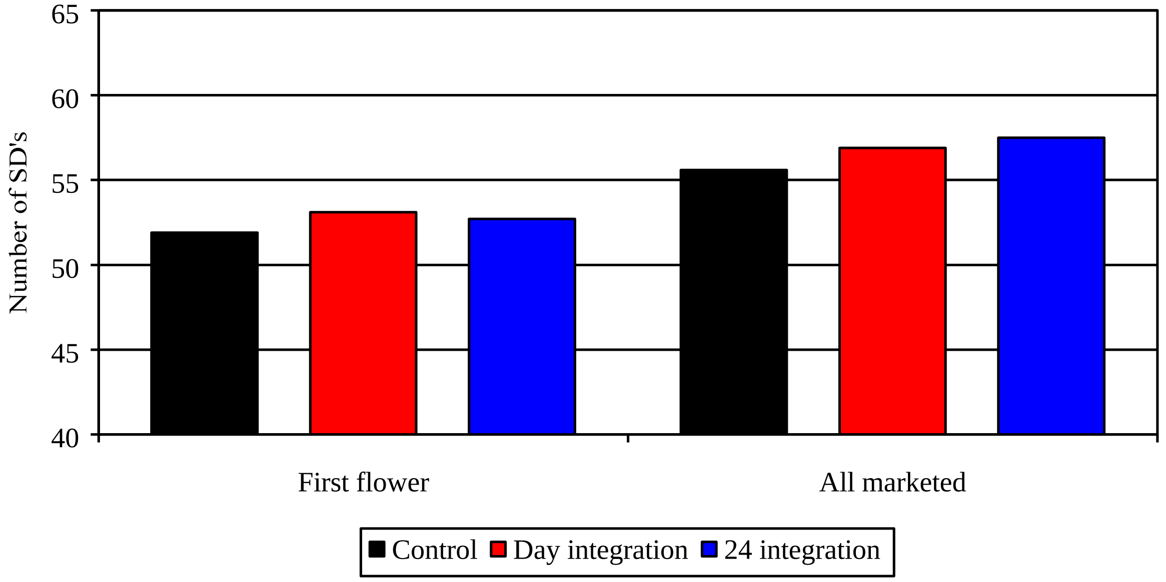


Figure 2: The mean (across all varieties and stick dates) number of short days (SD's) until first flower and full marketing for each integration treatment.



The winter height specification for pot chrysanthemums is 16 to 23 cm above the pot rim. All varieties grown in all treatments on each stick date made this height specification. The average height was 20cm, with a range of 18 to 22cm. All varieties also made the minimum width specification, which is 25cm. The crop diary (Appendix 2) shows that after pinching no variety received more than 5 applications of B-Nine. The two integration treatments required the same applications of PGR on average (Table 3). However not all varieties in integration treatments required as many applications as the control treatments (Appendix 2).

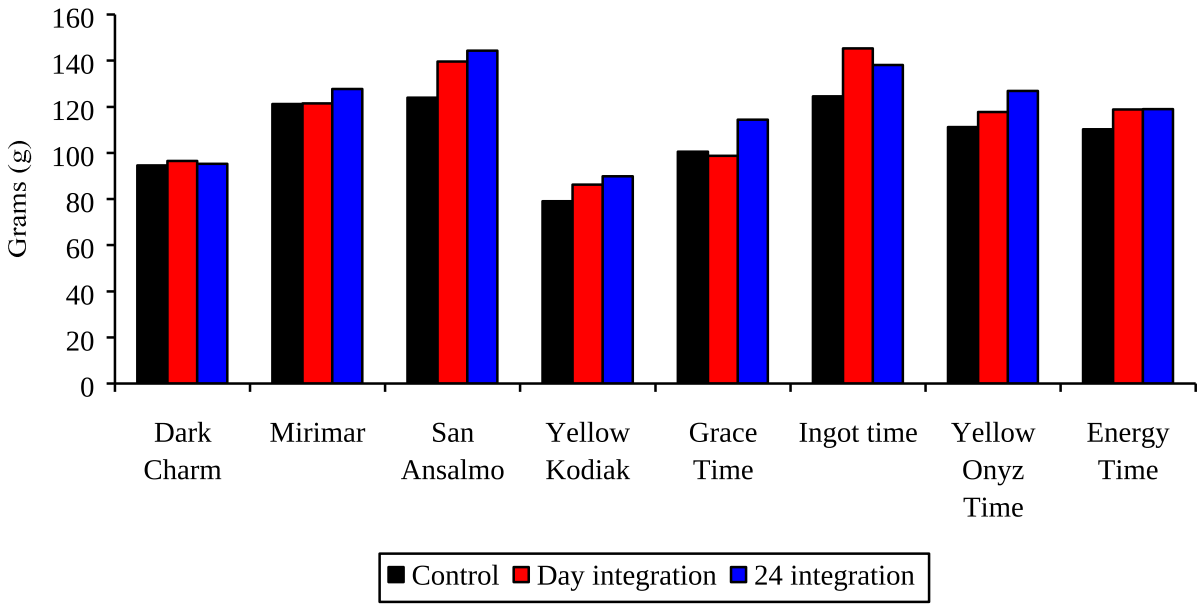
Table 3: Table showing the mean number of applications of PGR, after pinching, for each stick in the 3 temperature regimes.

	Control	Day integration	24h integration
Week 47	4	4	4
Week 50	4	4	4
Week 1	3	3	3

The differences between many of the other physiological records taken at marketing were also non-significant. This is important because it demonstrates that commercial crop specifications can be met in all temperature integration treatments. The fresh and dry weight data did show some interesting results. On the first two stick dates (weeks 47 and 50 of year 2001) the integration treatments produced heavier plants although neither flower and bud or leaf and stem weight was significantly different for any treatment. The fresh weight data was not significantly different for bud and flower weight, although again the earliest stick was heavier in the integration treatments. The stem and leaf fresh weight was significantly different for all stick dates especially the first (Fig 3).

The fact that the temperature integration treatments gave significantly heavier stems could be useful to the cut flower industry that market on stem weight. This is especially true of the first stick date (week 47) as this is often a poorer quality crop. Although the fresh weight increases the fact that the dry weight difference is not significant suggests that much of the extra weight is water and not assimilates. This may be due to the additional 2 or 3 days that some of the varieties took to reach a marketable quality (Appendix 1).

Figure 3: The fresh weight of all stems and leaves (grams per pot) for each variety from week 47 stick.



Plant responses: shelf life

The shelf life tests on the pot chrysanthemums in this trial are necessarily robust. They demonstrate the extreme conditions that chrysanthemums have to survive in the longest marketing chain, this means that pots under ideal conditions could be expected to last 4 weeks are often only considered acceptable for 3.

Records were taken each week on open flowers, juvenile flowers, dying flowers, dead flowers as well as coloured, dead and dying buds. From all these data the only significant result occurred in the second full week of home life, some 24 days after marketing, when on average the temperature integration treatments had lost more flowers (Fig 4). This trend was across all varieties on each stick date, but however was not detected by the expert scorer (Mike Holmes). This is important, because although a potential concern that after 2 weeks in the home less flowers are showing, if this is not reflected in an experts assessment the suggestion is that the plants are still acceptable. In fact in general the expert assessed the 24hr integration treatments at least as well as the control, and often higher for some varieties (Fig 5). The day integration treatment was not scored as consistently and this may be as a result of the way the temperature varied in the production of those plants (see next section).

Fig 4: The number of flowers remaining and flowers dropped in week 2 of shelf life for the temperature treatments (data across all varieties and stick dates).

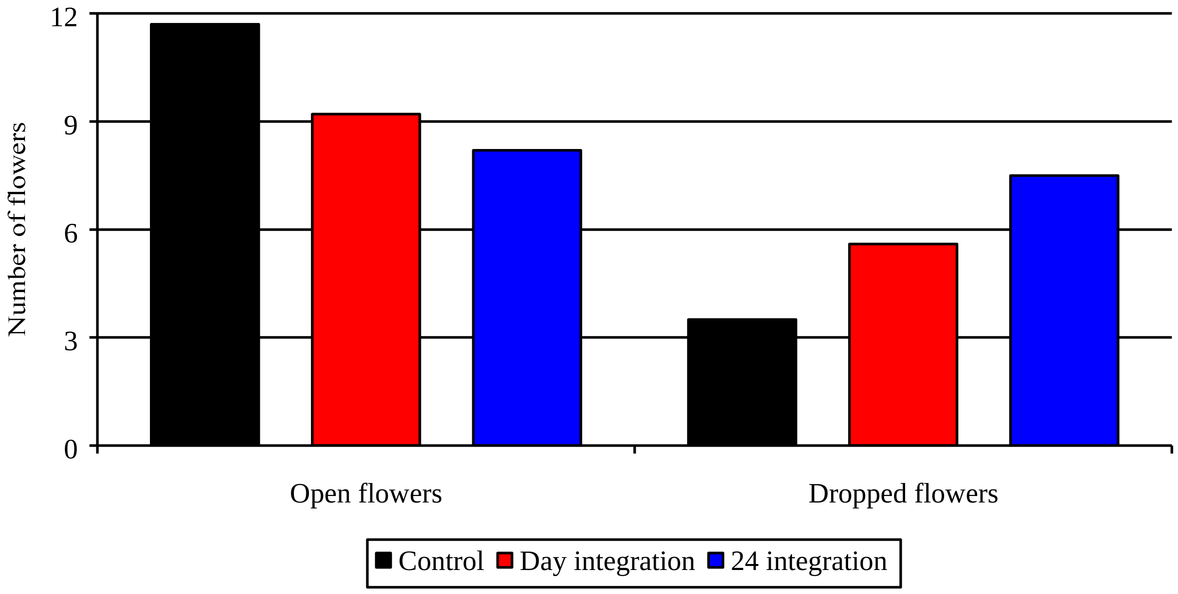
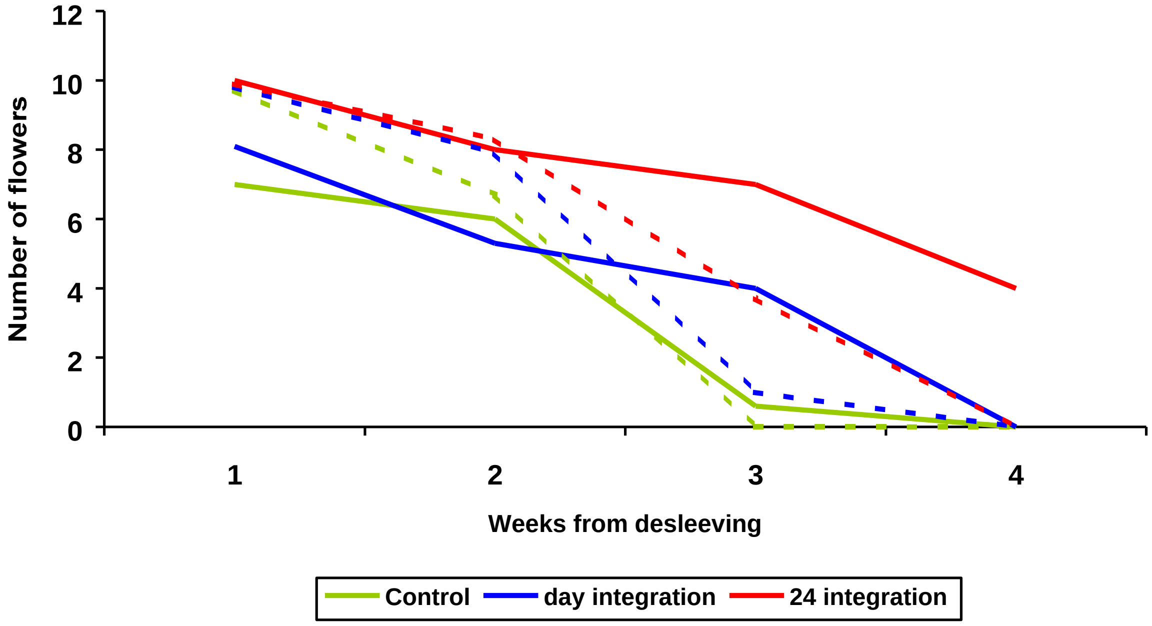


Fig 5: The expert scores for **Mirimar** for the 4 weeks of shelf life. The solid lines are for pots stuck in **week 50** and the dashed lines are for pots stuck in **week 1**.



Environmental conditions

The average temperature in each compartment over the duration of the trial was, commercial control: 19.0ºC, day integration: 19.2ºC and 24h integration: 18.7ºC. The average temperatures were different for each stick and the average 24hr temperature for each treatment and stick are shown in Table 4.

Table 4: The average 24 hr temperature for each treatment for each stick date (ºC)

	Control	Day integration	24h integration
Week 47	18.7	18.6	18.4
Week 50	18.7	18.6	18.1
Week 1	19.1	19.3	18.6

The deviation from 18ºC gives an indication of how different the treatments were from each other. It does not matter whether the deviation is positive or negative because if the theoretical optimum temperature for chrysanthemum is 18ºC, any temperature above or below that temperature is potentially negative on time to flowering. Calculating the average deviation for a week in each month of the trial (Table 5) shows the treatments are quite different in November and March, rather less different in December and February and very similar in January. Each stick of chrysanthemum grew for at least 2 months and so stick 1 experienced treatments becoming more similar, stick 2 would have had the most stable environment and stick 3 diverging treatments.

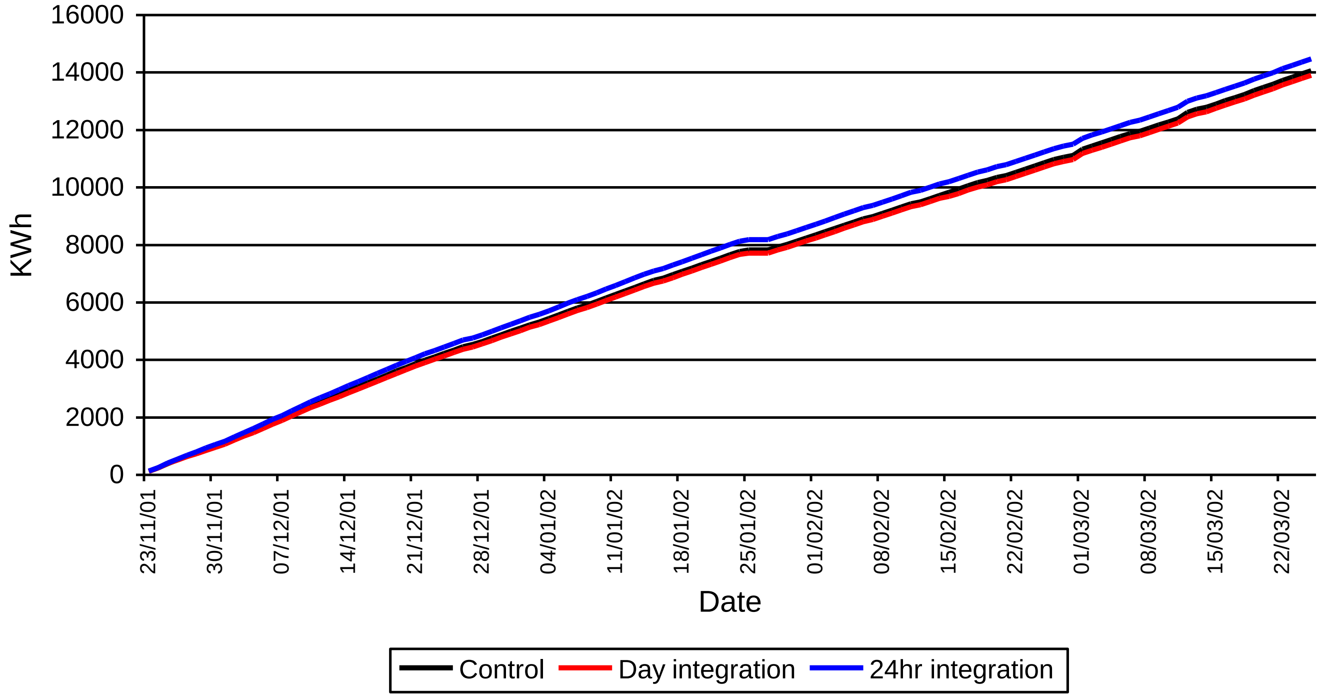
Table 5: The mean instantaneous temperature deviation (from 18ºC) for a week in each month for each treatment. Figures are in ºC.

	Control	Day integration	24h integration
November 25-29	1.96	3.26	4.18
December 15-19	1.49	1.90	2.20
January 5-9	0.63	0.84	0.84
February 13-17	2.70	3.87	4.18
March 5-9	3.19	4.54	4.60

The energy inputs into each treatment were carefully monitored from pulsed output meters attached to the electricity and gas (heat) inputs as well as the CO_2 inputs. These were logged both by the PRIVA environmental computer and by FEC Services Ltd. Both sets of logged figures showed the same energy use, and the independent FEC data added confidence to the data logged by the PRIVA computer.

The figures for the electricity use were not significantly different for any treatment (Fig 6). The primary use of electricity for this trial was the short day supplementary lighting. The additional electricity used for forced air CO_2 system, vents, night break lighting, blackout screens and propagation mats is minor compared to the supplementary lighting. Early in the trial the extra electrical use in the 24hr integration compartment caused some concern, however, this extra electrical use is not significant and was identified to be an installation error, caused by the same lighting set-up drawing different levels of power. This is due to age of lamps, efficiency of transformers and age of bulbs.

Figure 6: The cumulative electricity use for each treatment for the whole trial, November 2001 to March 2002.



The logged CO_2 use showed that the control treatment used significantly more CO_2 than the integration treatments (Fig 7), with the day integration using 7% less and the 24hr integration 12.5% less. When looking at the average daily achieved levels of CO_2 the levels are not significantly different so it is not thought that the integration treatments had a lower instantaneous vpm (Fig 8). This suggests that the control environment lost most of its CO_2 through the vents, either because of the lower vent point of 23ºC, compared to 26ºC in the integrated treatments or because there was more need to vent to control humidity levels.

Figure 7: The cumulative CO_2 use for each treatment for the whole trial December 2001 – March 2002.

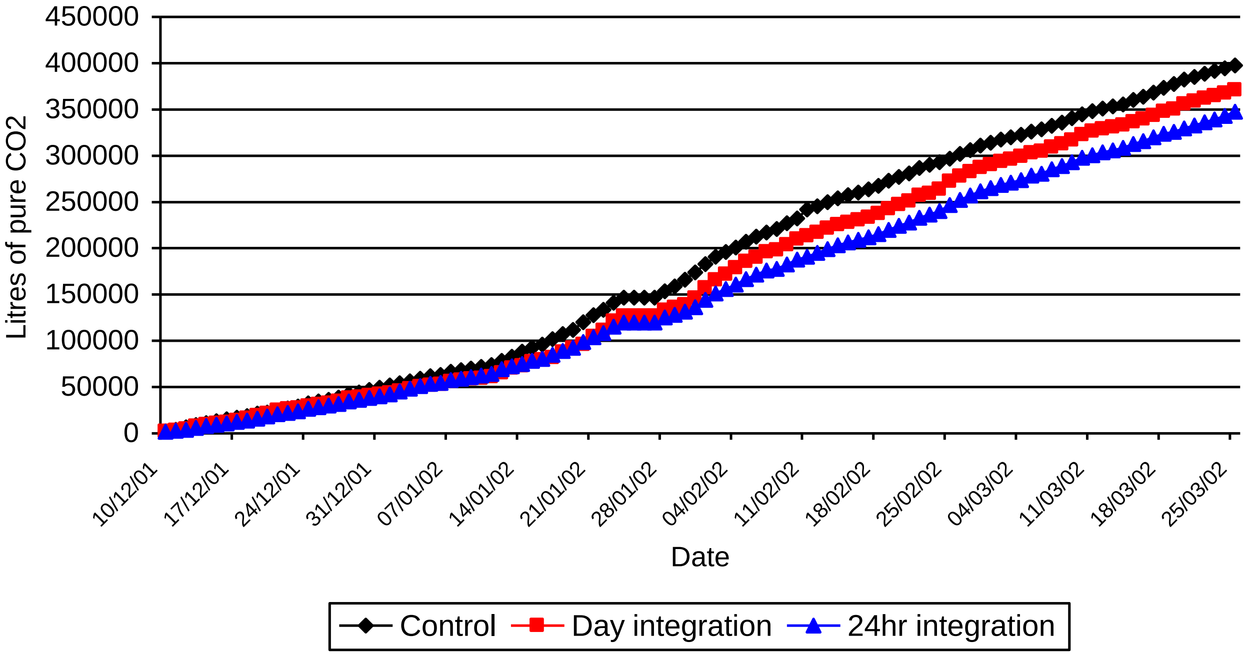
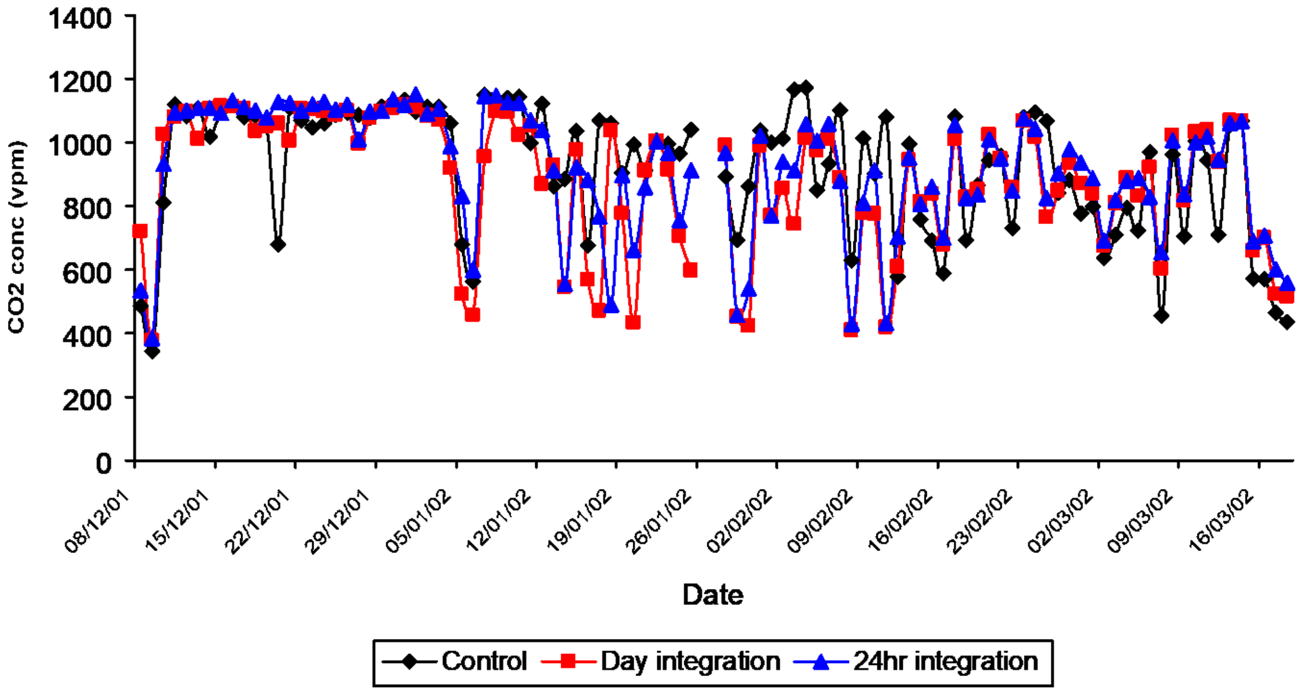


Figure 8: The daily achieved CO_2 vpm, for the whole trial December 2001 – March 2002.

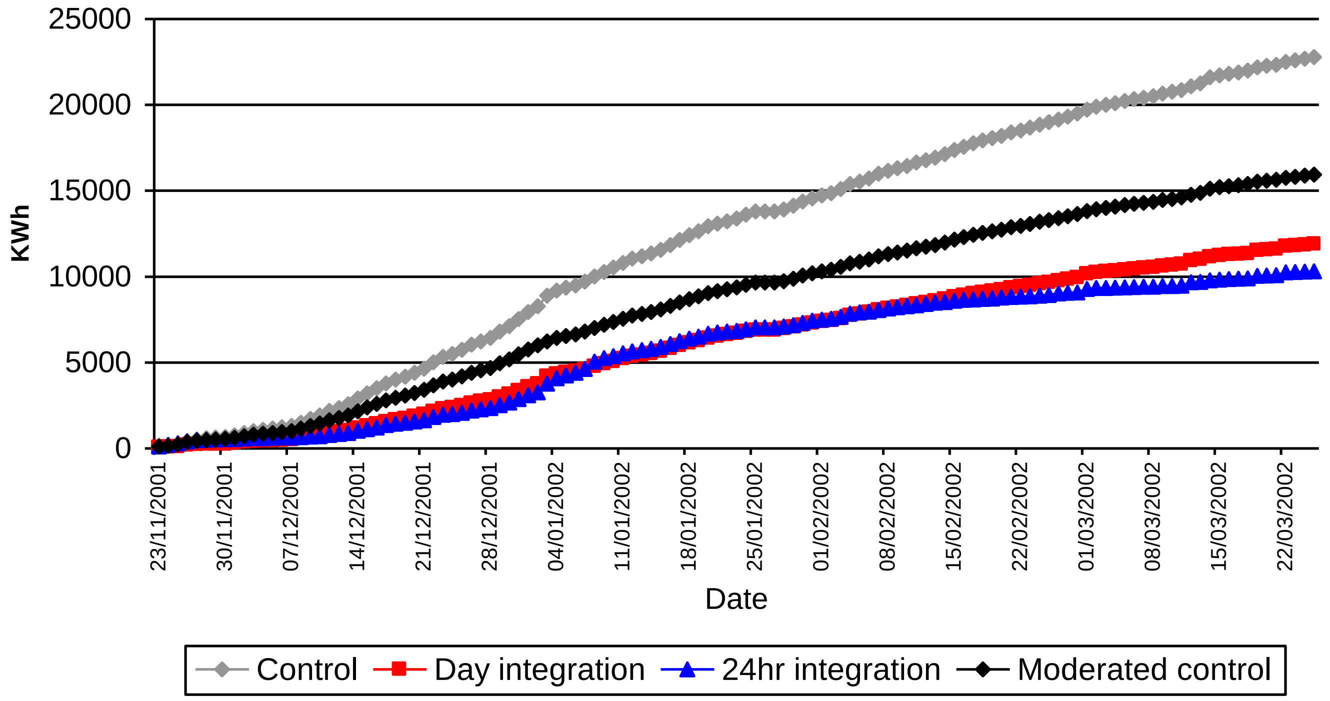


The main use of energy was in heating the compartments. The temperature of the hot water into and from each compartment was measured, as was the flow rate of the water, and these figures were converted to kWh for comparison. Although this raw data is ideal for comparison, there was no replication of treatment, and as such the control was in an outside compartment. This meat that the data had to be adjusted by a scaling factor to determine how much additional energy was being used due to the additional wall in the outside compartment.

Running all compartments at the same temperature strategy for several weeks enables a scaling to be carried out. This allows for comparisons of kWh used to achieve the same temperature. So that there is no influence of light the best data is from night periods, when the only other influence on temperature loss is the wind speed and the use of thermal blackout screens. By carrying out the scaling experiment on alternate nights with and without the thermal screen it is possible to derive a suitable scaling tool for an unreplicated trial of this sort.

When the scaling test was done it was found that the additional outside wall caused the control compartment to use as much as 30% more heat on some nights. This means that the logged data for the control compartment has to be scaled down before comparisons of energy saving can be made. Figure 9 shows the raw and scaled data for gas use converted to kWh for the whole trial.

Figure 9: The kWh use to achieve temperature regimes in the 3 treatments, showing the raw and scaled data. The data for the outside compartment (control treatment) has been reduced by 30% across the whole trial and is labelled as ‘modulated control’.



The energy savings that were achieved in the glasshouse compartment using temperature integration were very significant. The difference between the control and the day integration compartment is 25.4% and the difference between the control and the 24hr integration is 35.4%. These represent savings of a quarter to a third of the heating costs. As the scaling experiment was carried out over only 3 weeks to represent an entire trial, caution must be given to these figures. However, if the figures are rescaled assuming 40% additional heat due to the outside wall the savings are still 13.0% for the daytime integration and 24.6% for the 24hr integration (see summary in the table below).

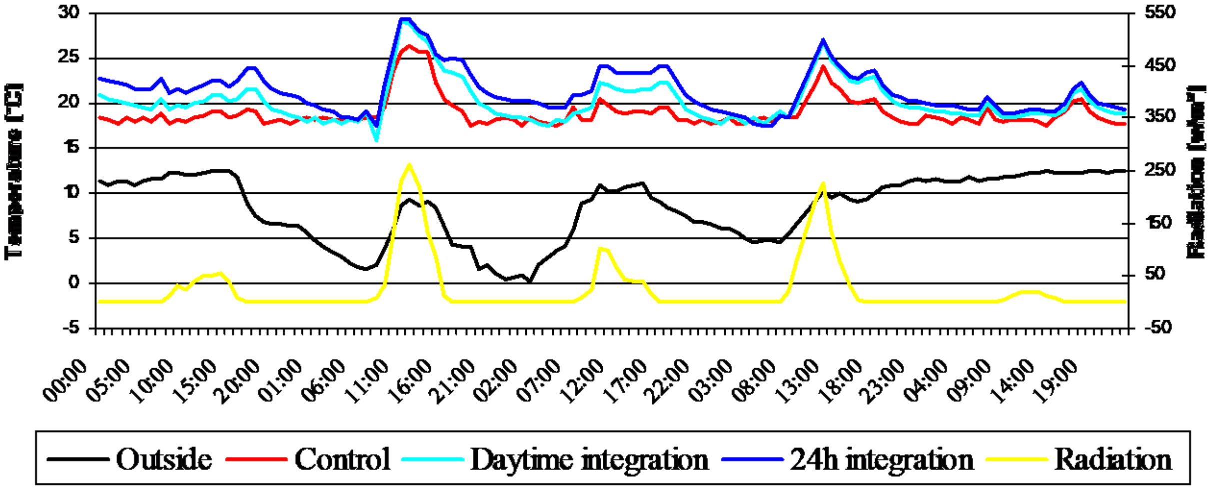
Efficiency of the control compartments	**Calculated reduction in heat use compared to the control compartment**	
	12h averaging	**24h averaging**
70% (0.7)	25.4%	35.4%
60% (0.6)	13.0%	24.6%

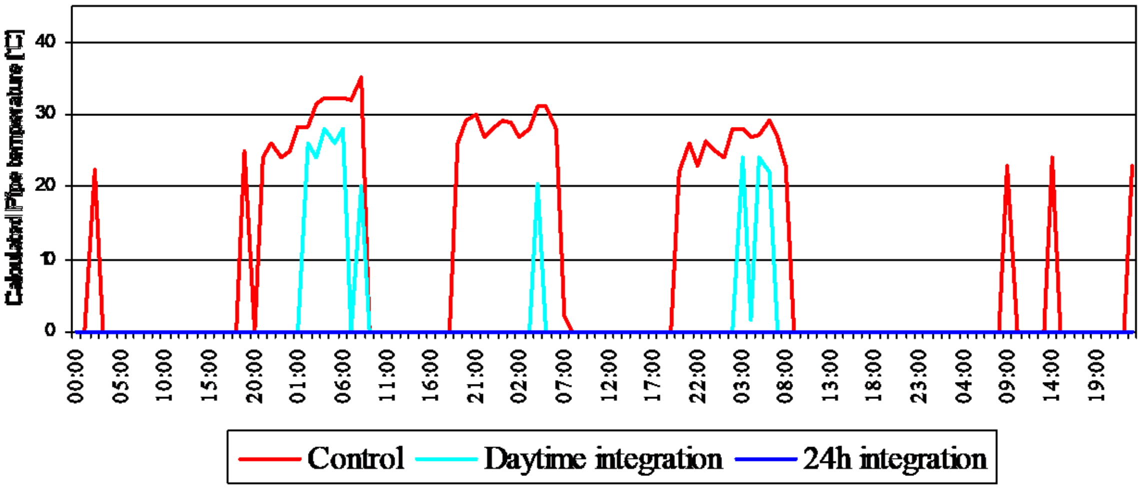
The way the heat is used and therefore how energy is saved, is easy to see when one looks at the achieved temperatures in each compartment as well as the calculated set point and calculated pipe temperature. In fact the calculated pipe temperature is the key to all the energy savings. As this trial did not use a minimum pipe temperature above ambient pipe water temperature and there was no humidity influencing the heating, the only reason for a high calculated pipe temperature is to heat a compartment that has fallen below its set point. Also because pure CO_2 was used and not flue gas we are able to be certain that the only reason to fire boilers was to provide heat to a compartment.

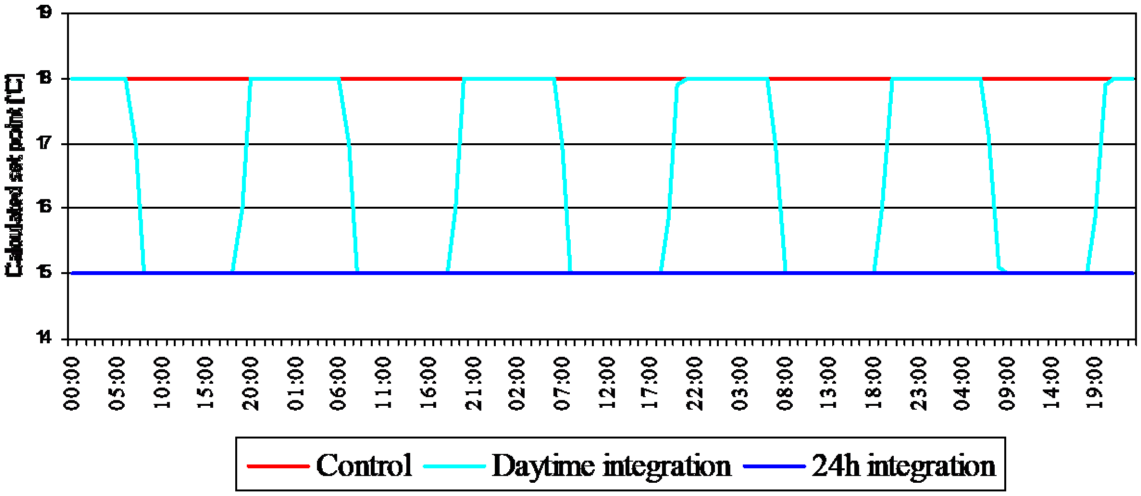
Figure 10 shows 5 sets of three graphs each representing one week in each month of the trial. Each of these graph sets contains the same three graphs. The first is the achieved compartment temperature for each temperature regime, along with the outside temperature and the radiation received on that day. The second graph shows the calculated pipe temperature for each compartment above 0ºC; the peaks show how hot the water is required to be to deliver the required temperature lift to a compartment and the length of the peak shows how often additional heating is required. The third graph shows the calculated set point as it varies during the week between 15ºC and 18ºC. If the line is at 15ºC it means that compartment will only call for heat if the temperature falls below 15ºC, when at 18ºC the heat is required once the temperature falls below 18ºC. This gives an indication of how the integrated compartments vary the set point continually in the computer.

Figure 10 (on subsequent pages): A series of graphs showing achieved treatment temperatures, calculated pipe heat and treatment calculated set points. The graphs are for a week each in November, December, January, February and March.

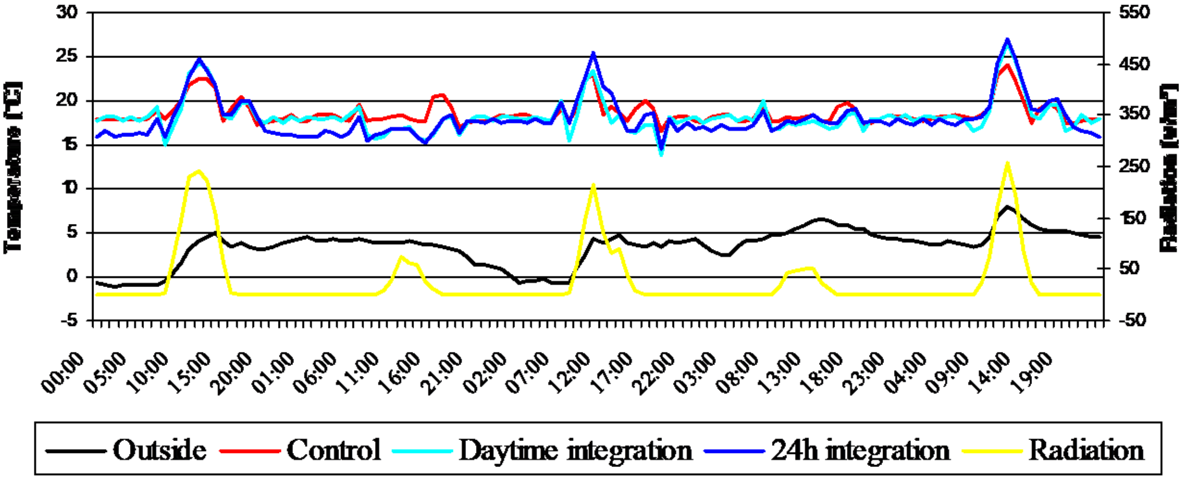
November 25-29 2001

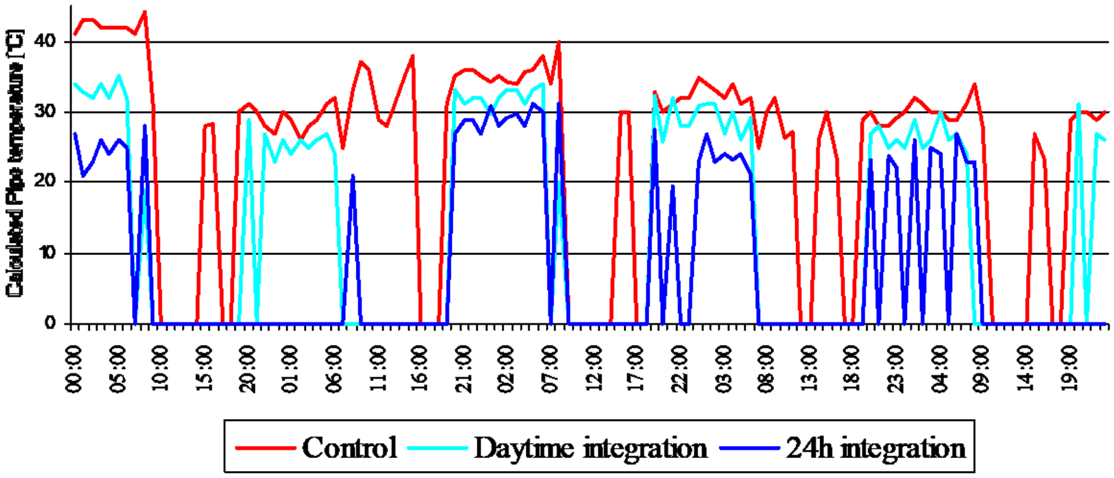


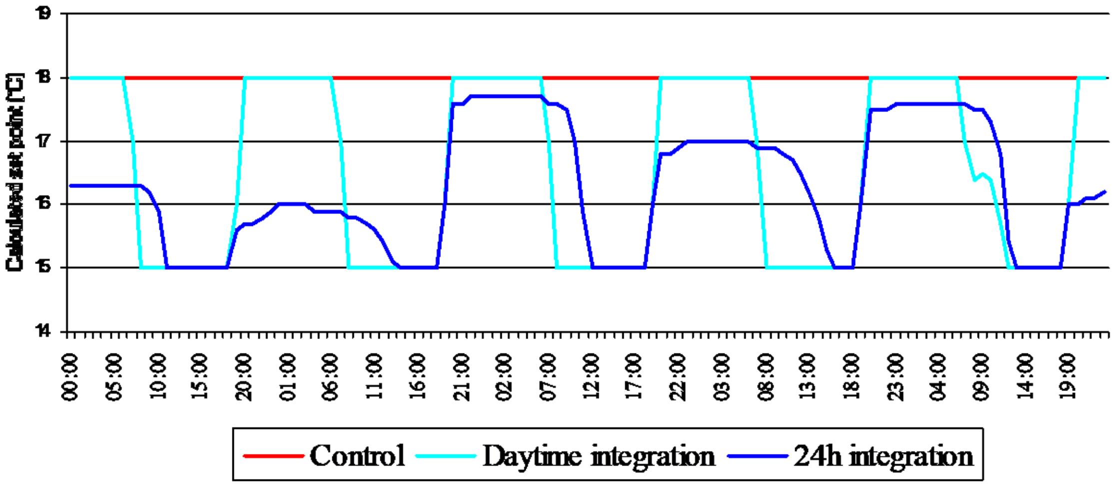




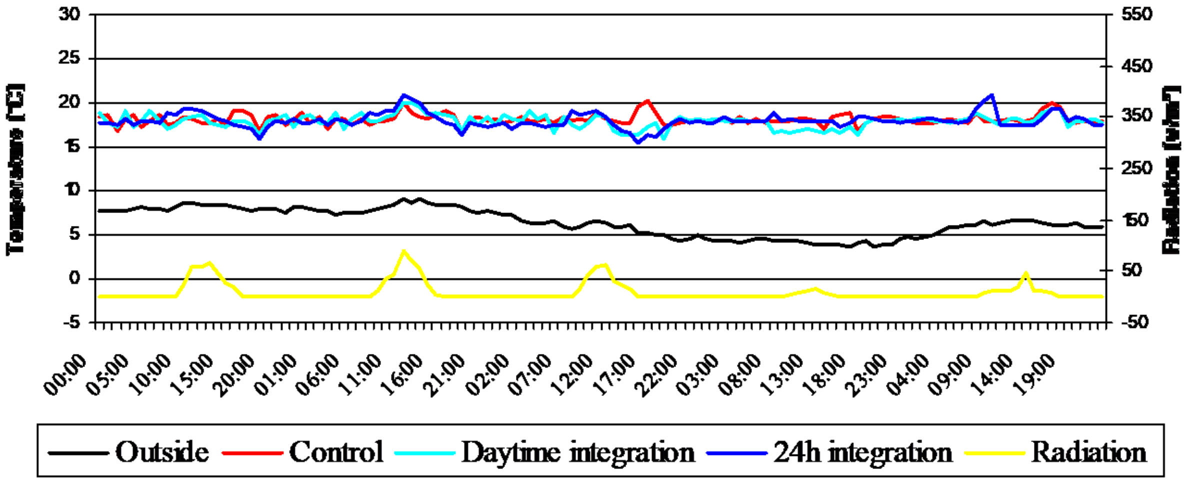
December 15-19 2001

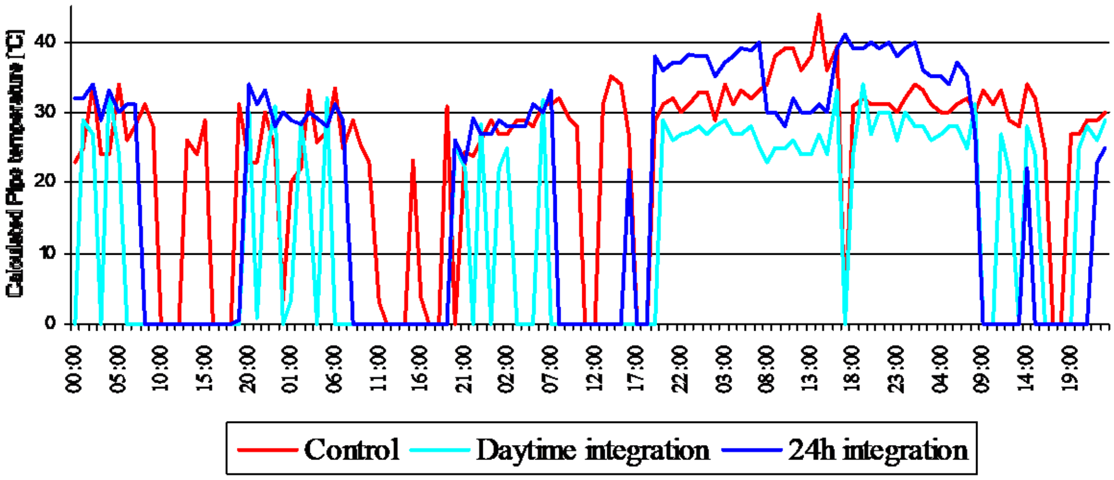


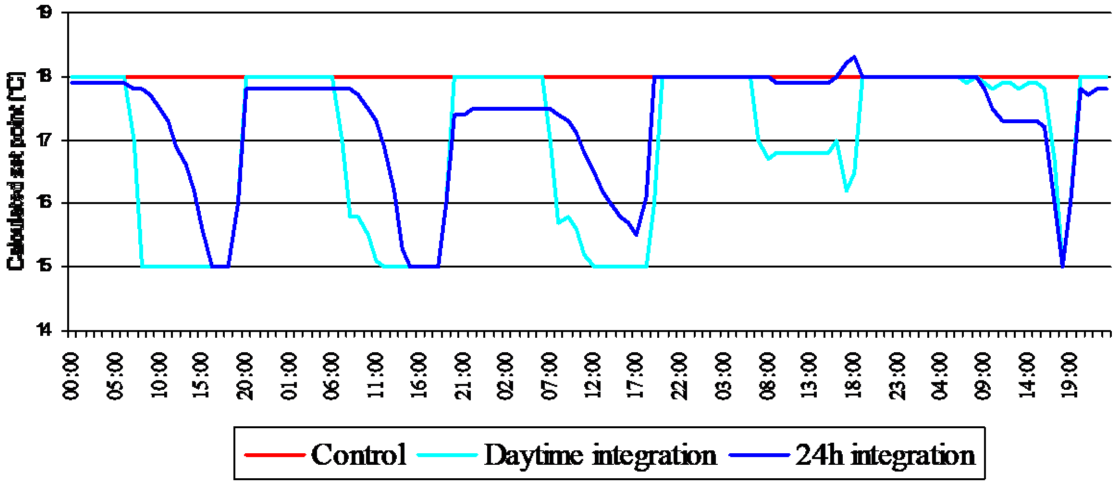




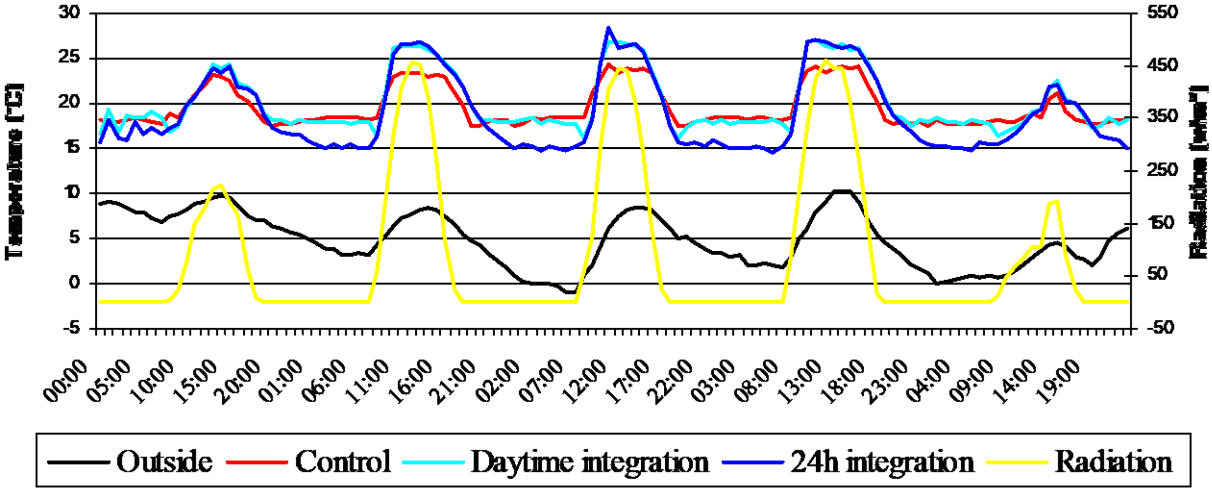
January 5-9 2002

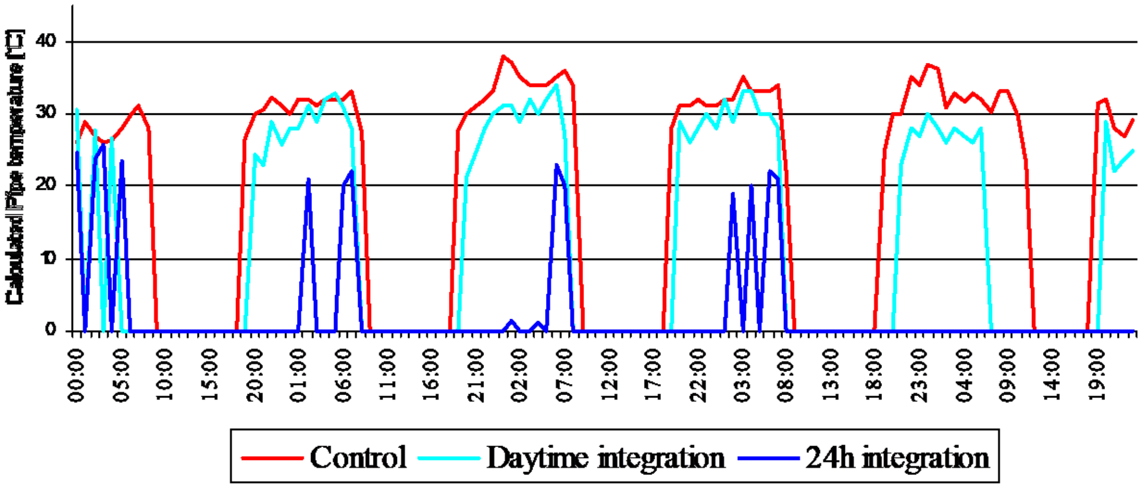


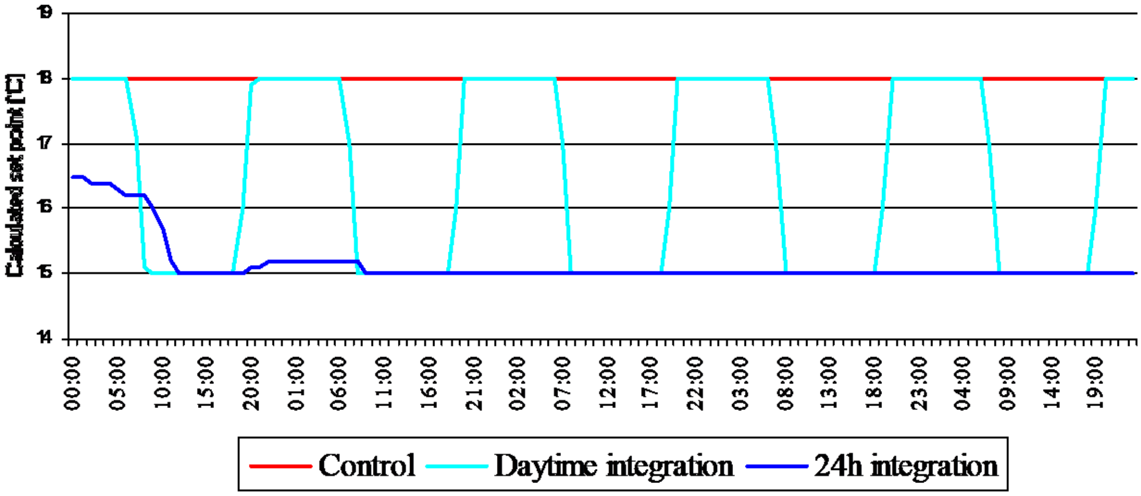




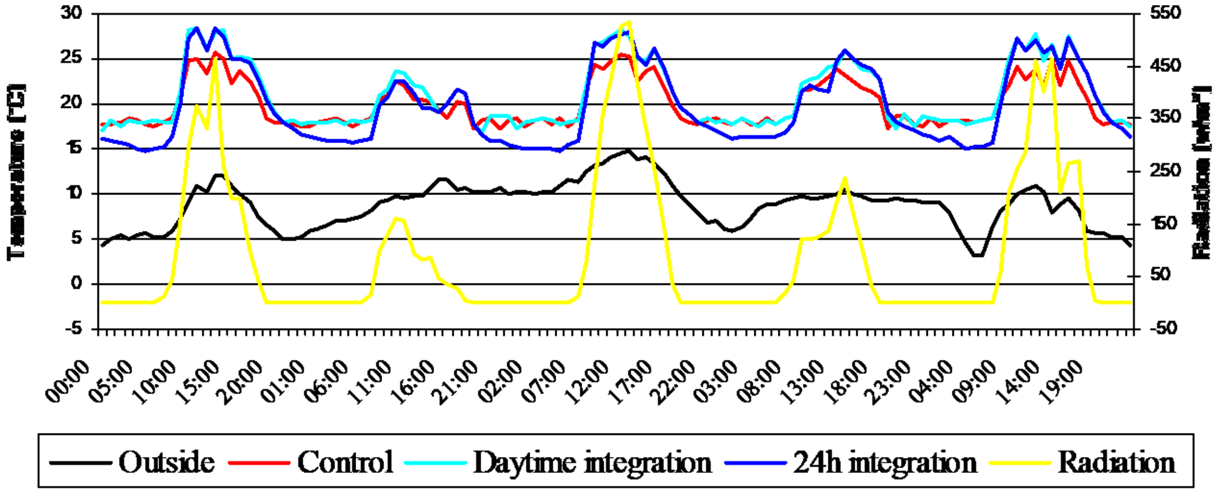
February 13-17 2002

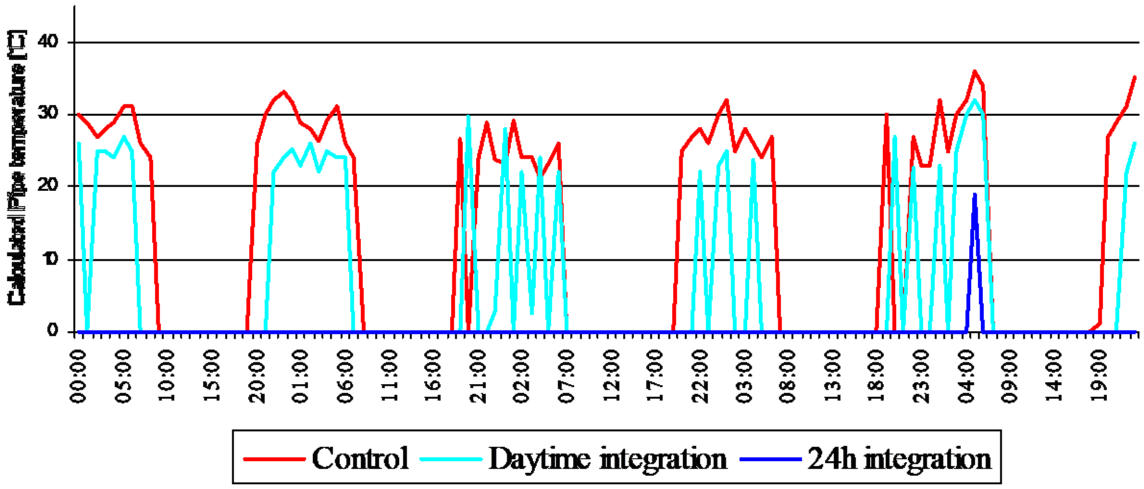


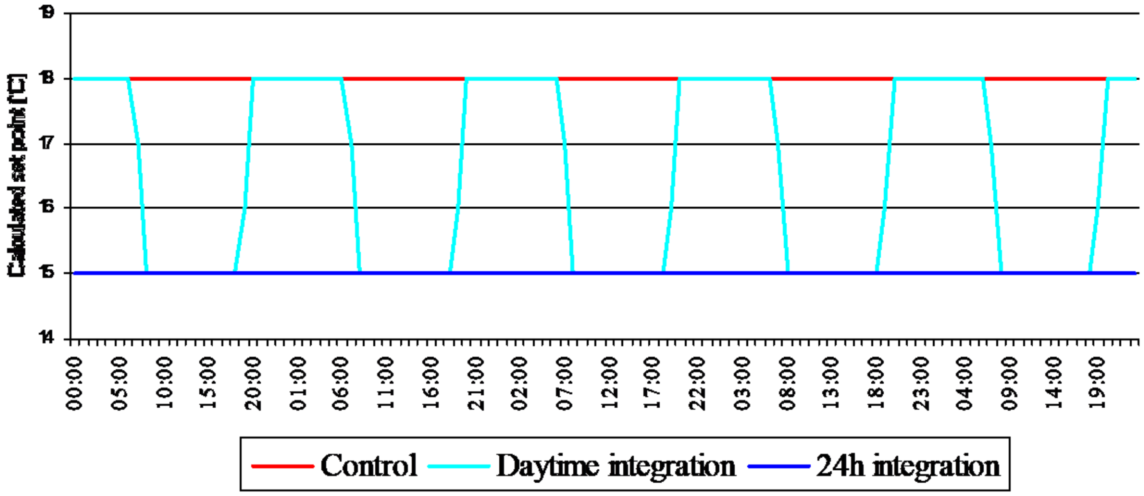




March 5-9 2002







The first point to note about the compartment temperature graphs is how important solar radiation is in raising the temperature above the desired average and thus contributes ‘degree hours’. It is clearly shown that the energy receipt of even the brightest days in November and December is half that of bright days in February and March. When the light levels are higher than 50 W/m^2 the increase in compartment temperature can be seen on the graphs, but levels above 100 W/m^2 would appear to be needed to bring the compartment temperatures near their vent points, probably subject to wind speed and direction.

The other point from the compartment temperatures is the integrated treatments tend to have a higher temperature as the light level falls towards evening (as the vent point is higher) and this means they reach their lower temperature, and therefore heat demand later in the night than the control. The December graph, and especially the February and March graphs show the 24hr integration compartment to have cooler nights than either the control or day integration compartment, which was the most common result from the trial. The December graph also has a good demonstration of the set point altering in the 24hr integration compartment, raising the set point after a low light day and lowering as light levels become higher. As the experiment used a 3 day integration period, the actual number of degree hours to compensate are not clear from a single graph.

The day integration compartment shows that although it gains degree hours from solar gain during bright days, it can rarely use these, as shown by the set point rarely moving from 15ºC (its lowest level) during the day and the fixed 18ºC at night. This fixed night set point actually means that this treatment tends to be warmer than the 24hr integration and more similar to the control. The only month this varies is in January when there are very low light levels with little thermal gain and heating is required during the day to maintain the desired average. The 24hr integration treatment is more variable in its set point because it can loose degree hours from its mean at both night and day. This means in January during a period of poor light the set point actually rises above 18ºC to maintain its 3 day average at 18ºC. Overall, the 24hr integration demonstrates that a computer can maintain average temperatures better than manually varying set points.

The possibilities to save energy are most clear from the calculated pipe temperature graph. The control treatment, which uses the most energy, was always the first to call for heat as the temperature fell below 18ºC. The day integration treatment does not demand heat until the ‘night’ period begins and the compartment must raise the temperature set point to 18ºC. The 24hr integration treatment clearly shows that by allowing the temperature to fluctuate the heat demand is reduced substantially. In fact in November and March there is essentially no demand for heat from this treatment. None of the temperature demands are great, rarely higher than 35ºC pipe temperatures. These are lower than commercial practice, but this is mainly because there is no minimum pipe. If a greenhouse is running minimum pipe and requires additional heat to lift the temperature, the 30ºC lift we show would need to be added to the minimum pipe to achieve the same response.

Implications for growers of protected ornamentals

The results have important and positive implications for growers of protected ornamentals. In the extreme this trial demonstrates that a third of fuel costs for heating could be saved over the five months of this trial (much more in some months), the most energy intensive period of production. However, for as much as half of that period the need for the boiler is slight, this may mean that the production of CO_2 needs to be by an alternative means. Anecdotally some protected crop producers will admit the reason they run their boilers during the summer months is solely to produce CO_2, the heat used is then used as minimum pipe. Growers with heat storage tanks would benefit from producing CO_2 but storing the heat until later, but essentially it would appear the CO_2 demand might be greater than the heat demand. There is research ongoing around the world and sequestering CO_2 from other industries, if this were to become a commercial possibility it may prove a viable alternative to pure CO_2 that is thought to be too expensive.

The potential cost saving of using 25% less energy in pot chrysanthemums alone can be calculated to be almost £157 000. This is based on the following estimations supplied by the UKCGA:
There are 12.54 hectares of pot chrysanthemums in production in England and Wales, and the average cost of heating is £50 000 a hectare. The heating cost is therefore £627 000. A 25% reduction in this would be £156 750.

The implications of fully commercialising the results from this trial must be tempered with caution. There was no replication of treatment and the trial is based on only 5 months in one year. The size of compartment means that in general the buffering capacity to temperature changes is lower than a commercial holding, this should mean that although nurseries will cool down more slowly, they will also heat up by thermal gain more slowly. This is likely to effect the total energy savings as will the crop grown as it effects the boundaries that can be set for integration.

Another point to be made is that in this trial the lighting was a contributor to heating a compartment as well. This was standardised for all treatments and as Figure 10 demonstrates for large parts of each day supplementary lights of 9.6 W/m^2 make a significant contribution to light levels. However, on a nursery without lights the heat demand would be greater, and although the principle of temperature integration would still save significant energy, crop speed and quality may be more compromised. It must be added that the light also contributes significantly to crop quality and there are many other positive reasons to have lights for winter production.

2.4 Conclusions

- The use of temperature integration in the production of protected ornamentals can save up to 25% of energy for heating during the winter period (November to March).

- The quality and post harvest performance of eight varieties of pot chrysanthemum grown in two temperature integration treatments were as good as the plants in the commercial control.

- The scheduling of crops in the integration treatments was delayed by as much as three days, but compared to the potential financial saving this is hardly significant.

- Temperature integration had no significant effect on the agronomy of the pot chrysanthemum crop, there was no increased incidence of pest or disease and no additional plant growth regulators were required.

- Additional uses of heat for disease control or minimum pipe temperatures will reduce the potential energy savings, but good housekeeping could reduce these to only essential use.

- A potential problem in the reduction in heat demand with the use of temperature integration is the reduced supply of CO_2 from boilers. However, growers using heat storage tanks will suffer less.

- The use of higher ventilation temperatures would appear to reduce the amount of CO_2 lost from venting, this may also reduce the CO_2 demand on a nursery.

- Alternative CO_2 sources have often been thought of as cost prohibitive. This may not be the case in the future when other technologies come on line.

- There is now scope to apply the findings from the pot chrysanthemum work to other energy intensive ornamental crops such as poinsettia, begonia, and cut flower chrysanthemum.

- A package of commercial-scale demonstration trials together with adequate education and training of growers in the use of climate control computers, should assist the widespread uptake and use of temperature integration to save energy.

Acknowledgements

The author would like to thank Dave Abbott, Mike Holmes, Gary Shorland, Chris Addis and Nick Field for their support, advice and input into this project. I would also like to thank Hollyacre Plants and Yoder Toddington for their support of the trial and advice over the varieties used.

2.5 Appendix 1: Plant physiological characteristics

Plant height (above rim of pot)

Stick week 47	Commercial	12hr integration	24hr integration
Dark Charm	20.35	21.35	20.85
Mirimar	21.3	20.15	20.5
San Anselmo	21.5	22.3	23.25
Yellow Kodiak	18	19.72	19.95
Grace Time	18.4	17.55	19.55
Ingot Time	21.85	22	21.55
YOT/ Swing Time	19	18	18.8
Energy Time	21.5	21.1	21.85

Stick week 50

Dark Charm	19.8	18.95	21.35
Mirimar	17.45	18.5	19.3
San Anselmo	18.75	19.2	20
Yellow Kodiak	18.65	17.85	18.75
Grace Time	18.5	18.3	20.05
Ingot Time	19.7	19.4	21.1
YOT/ Swing Time	19.85	19.15	20.75
Energy Time	19.85	19.35	20.9

Stick week 1

Dark Charm	20.05	20.25	21.75
Mirimar	20.95	20.05	21.10
San Anselmo	21.60	22.30	23.35
Yellow Kodiak	20	18.40	19.40
Grace Time	19.10	18.10	19.65
Ingot Time	19.2	18.50	21.35
YOT/ Swing Time	20.05	19.85	19.65
Energy Time	20.60	20.40	23.15

Number of short days to market

Stick week 47

	Commercial	12hr integration	24hr integration
Dark Charm	60.8	61.9	60.9
Mirimar	62.2	63.2	63.3
San Anselmo	61.1	62.5	64.1
Yellow Kodiak	57.5	58.66	57.9
Grace Time	58	62.2	61.7
Ingot Time	58	60.3	59.5
YOT/ Swing Time	59.2	61.5	61.4
Energy Time	57	58.7	59.2

Stick week 50

Dark Charm	55.4	56.7	57
Mirimar	58.5	59.6	60.1
San Anselmo	57.4	59.2	58.3
Yellow Kodiak	52.5	52.8	53.9
Grace Time	56	56	57.7
Ingot Time	51.7	52.3	53.9
YOT/ Swing Time	54.5	55.4	56.5
Energy Time	51.8	53.2	54.4

Stick week 1

Dark Charm	53.40	53.70	54
Mirimar	57.90	59.60	60
San Anselmo	53.20	55.60	55.80
Yellow Kodiak	51	51.60	53.10
Grace Time	53.60	54	56.20
Ingot Time	48.80	50.70	50.60
YOT/ Swing Time	54.30	55.90	57.40
Energy Time	51.10	52.30	52.30

Pot spread

Stick week 47

	Commercial	12hr integration	24hr integration
Dark Charm	35.1	34.55	35.15
Mirimar	36.6	36	37.35
San Anselmo	34.9	34.25	36
Yellow Kodiak	34	33.38	34.65
Grace Time	33.15	31.4	32.5
Ingot Time	35.15	35.1	35.25
YOT/ Swing Time	33.65	33	33.85
Energy Time	33.3	33.55	33.5

Stick week 50

Dark Charm	35.20	34.50	36.10
Mirimar	36.05	36.45	36
San Anselmo	34.80	35.40	35.55
Yellow Kodiak	33.05	33.80	34
Grace Time	34.45	34.20	34.80
Ingot Time	35.45	34.85	35.75
YOT/ Swing Time	36.30	34.35	35.40
Energy Time	34.05	33	35.20

Stick week 1

Dark Charm	36.05	36.30	35.35
Mirimar	37.70	37.40	36.55
San Anselmo	34.60	34.95	34.05
Yellow Kodiak	35.10	34.50	33.55
Grace Time	33.65	33.50	33.05
Ingot Time	34.90	33	33.85
YOT/ Swing Time	33.80	33.40	31.65
Energy Time	33.55	32.90	33.90

Number of open flowers (at harvest per pot)

Stick week 47

	Commercial	12hr integration	24hr integration
Dark Charm	7.2	6.2	5.6
Mirimar	7.8	7.6	7.6
San Anselmo	16.1	13.3	8.8
Yellow Kodiak	6.3	8.33	8.5
Grace Time	9.7	8.5	9.5
Ingot Time	44.5	40.3	48.3
YOT/ Swing Time	5.9	7.3	6.9
Energy Time	8.2	9.5	9.3

Stick week 50

Dark Charm	11.1	6.6	8.1
Mirimar	7.7	6.7	6.9
San Anselmo	9.1	7.3	9.6
Yellow Kodiak	7.5	8.6	9.9
Grace Time	10.2	12.1	10.6
Ingot Time	28.3	26.1	34.1
YOT/ Swing Time	10.5	8.8	6.8
Energy Time	8.1	8	10.7

Stick week 1

Dark Charm	7	6	6.10
Mirimar	7.10	6	5.90
San Anselmo	8.20	8	9.80
Yellow Kodiak	7	9.10	8.70
Grace Time	13.20	11.30	11.70
Ingot Time	22.10	30.70	28.60
YOT/ Swing Time	10.10	10.70	10
Energy Time	15.30	12	11.10

Total Fresh weight

Stick week 47

	Commercial	12hr integration	24hr integration
Dark Charm	150.97	150.80	149.31
Mirimar	181	182.55	181.78
San Anselmo	163.78	181.82	179.32
Yellow Kodiak	125.91	138.89	152.70
Grace Time	137.17	134.36	153.05
Ingot Time	152.03	176.52	170.86
YOT/ Swing Time	155.11	168.15	180.06
Energy Time	147.89	159.74	162.37

Stick week 50

Dark Charm	145.07	130.19	145.34
Mirimar	149.84	165.93	161.55
San Anselmo	147.06	148.72	150.45
Yellow Kodiak	124.16	115.09	132.61
Grace Time	152.11	150.56	154.96
Ingot Time	151.02	148.73	170.78
YOT/ Swing Time	177.24	164.53	186.44
Energy Time	148.83	138.17	153.04

Stick week 1

Dark Charm	152.20	160	167.35
Mirimar	198.79	202.99	198.49
San Anselmo	165.88	161.77	171.04
Yellow Kodiak	139.12	134.75	141.91
Grace Time	162.80	149.52	148.81
Ingot Time	165.46	149.55	165.24
YOT/ Swing Time	182.12	182.38	174.50
Energy Time	170.21	167.89	171.88

Total Dry weight

Stick week 47

	Commercial	12hr integration	24hr integration
Dark Charm	16.52	15.97	15.78
Mirimar	19.09	19.67	17.58
San Anselmo	17.52	19.48	17.87
Yellow Kodiak	13.15	14.64	16.26
Grace Time	14.43	13.68	15.30
Ingot Time	15.41	17.98	17.49
YOT/ Swing Time	14	15.37	16.14
Energy Time	16.23	17.19	17.69

Stick week 50

Dark Charm	17.52	15.41	16.69
Mirimar	17.59	18.86	18.50
San Anselmo	17.12	17.06	17.05
Yellow Kodiak	14.53	13.46	14.43
Grace Time	16.75	17.24	16.77
Ingot Time	17.51	17.51	19.07
YOT/ Swing Time	18.32	17.75	19.26
Energy Time	17.44	16.22	17.13

Stick week 1

Dark Charm	16.70	17.45	18.10
Mirimar	21.27	21.13	20.55
San Anselmo	19.23	17.78	18.76
Yellow Kodiak	15.45	15.11	15.47
Grace Time	17.04	16.25	15.93
Ingot Time	17.45	16.16	17.55
YOT/ Swing Time	18.75	18.82	17.54
Energy Time	18.49	17.72	18.31

Appendix 2: Crop Diary

Diary sheet for stick week 47

20.11.01	Stuck all Yoder and Ficor (stick 1)
21.11.01	Stuck Yoder (stick 2)
22.11.01	Stuck Ficor (stick 2)
22.11.01	Removed some plants due to poor quality (notes in original diary sheet)
23.11.01	B Nine all cuttings 1g/l
24.11.01	Base heat temperature 22-23C Q3. East bench turned temperature slightly down.
30.11.01	Uncovered all stick 1 plants, and all Yoder plants (stick 2). Rovral 1g/l
02.12.01	Uncovered all Ficor (stick 2)
05.12.01	B Nine all but not Yellow Kodiak 1/2g/l
10.12.01	Moved all plants to north end of benches
12.12.01	Pinched – IT,VT,ET,GT,MIR in compartments 3
12.12.01	Pinched – YOT, MIR, IT, VT,GT in compartment 2
12.12.01	Pinched – ET, VT, IT, GT, YOT, MIR in compartment 1
13.12.01	Pinched – SA, YK, YOT, CH in compartment 3
13.12.01	Pinched - SA, YK, ET, CH in compartment 2
13.12.01	Pinched – SA, YK, CH in compartment 1
27.12.01	B Nine all – 2g/l
03.01.02	B Nine all – 2g/l
08.01.02	B Nine – 2g/l – IT,VT,ET ,MIR, YOT, YK, CHS in all compartments
17.01.02	B Nine - 2g/l – IT, YOT

Diary sheet for stick week 50

11.12.01	Stuck all cuttings, and B Nine all 1g/l
19.12.01	Uncovered all cuttings
24.12.01	B Nine 1/2g/l – all except YK
31.12.01	Moved all plants
02.01.02	Pinched all Time varieties and YK in all compartments
03.01.02	Pinched MIR, SA in all compartments
14.01.02	Final space in all compartments
16.01.02	B Nine 2g/l all
29.01.02	B Nine 2g/l all bar GT and SA
07.02.02	B Nine all

Diary sheet for stick week 1

04.01.02	Stuck all cuttings. B Nine 1g/l all
14.01.02	Uncovered
18.01.02	B Nine 1/2g/l - not YK
24.01.02	Moved all plants
30.01.02	Pinched IT, YK, ET, DC, SW, GT, MIR
31.01.02	Pinched SA
08.02.02	Final space all compartments
12.02.02	B Nine all compartment 1. All compartment 2 & 3 bar SA and ET – 2g/l
15.02.02	B Nine SA and ET in compartments 2 & 3 only – 2g/l
19.02.02	B Nine ET, DC,IT 2g/l in compartment 1. DC and IT 2g/l in cments 2 & 3
21.02.02	Nemasys 250 million – all compartments
27.02.02	B Nine 2g/l – all compartments
28.02.02	Nemasys – 250 million - all compartments
07.03.02	Menasys – 250 million – all compartments
14.03.02	Aphox 1g/l