This factsheet in a series on energy management, highlights the savings to be made by effective glasshouse temperature (Figure 1).

### Summary points

- Reducing the heating set-point by 1°C can typically save around 10–13% energy. However, account needs to be taken of the effects of lower temperature on crop timing, yield and quality. The approach may be best suited at present to ornamental spot crops such as poinsettias.

- Temperature Integration (TI) saves energy with little impact on yield and quality. In Basic TI, vent temperature is raised to gain energy ‘credits’ from solar gain, and these are ‘spent’ by lowering heating set-points at other times when energy use would have been high. Trials incorporating best-practice humidity control have given energy savings of 6–12%.

- Greater savings are provided by routinely incorporating a low day heating set-point, and preferentially heating the glasshouse at night under thermal screens (Extended TI). This gives savings in the winter months when there is little solar gain. Adverse effects on crop yield and quality can be overcome with good crop management.

- Regulating temperature on the basis of wind speed can save 5–10% energy in older houses without screens.

- Using DROP may save up to 1.5–2% of energy and reduce the need for PGR treatment. The temperature is allowed to fall at dawn or before screens are removed, but is increased again several hours later so as to maintain the average 24 hour temperature.

1 Temperature manipulation is an important element in reducing glasshouse energy use
Lower-temperature growing

Reducing the heating set-point temperature can save energy and is not dependent on having up-to-date environmental control systems. However, potential savings have to be balanced against the effects of lower temperature on crop timing, yield and quality.

Potential energy saving

Indications of potential energy savings by reducing the set-point temperature can be derived from Graph 1 which shows simulated relationships between set-point temperature and energy use for low-input ornamentals, pot chrysanthemums and tomatoes. These have been derived using a glasshouse energy-use model developed by Dr Paul Hamer (HH3611SPC). The model has been run with weather data for Bedfordshire and takes account of such factors as inside and outside temperatures, solar radiation and wind speed, greenhouse design and condition. The following parameters were set:

**Ornamentals**
Set-point heating temperatures from 14°C down to 8°C with venting at 16°C, no humidity control, no minimum pipe temperature, no lights and no thermal screen.

**Pot chrysanthemums**
Set-point heating temperatures from 18°C down to 12°C with venting at 20°C, humidity control at 90% RH, no minimum pipe temperature, supplementary lighting at 9.6 W/m² and a blackout (thermal) screen.

**Tomatoes**
Set-point heating temperatures from 18°C down to 12°C with venting at 19°C, humidity control at 90% RH, no minimum pipe temperature, no lights but with an energy screen. The simulations show:

- Glasshouse energy use decreases progressively with reduction in set-point temperature. A reduction of 1°C from the highest settings (in Graph 1) will give approximately a 13% reduction in energy use in ornamentals and pot chrysanthemum production, and a 10% reduction in tomato production. On the basis of the parameters set, pot chrysanthemum production will consume less heating energy than tomato for a given heating set-point because the supplementary lighting will, in part, substitute for pipe heating. Also, blackout screens tend to have better insulation properties than energy screens, and lower rates of transpiration (because of smaller leaves) will reduce the energy expended on humidity control.

**Effects on production**

Lowering the heating set-point will, for most crops, give sub-optimal growing temperatures and will increase production time and/or depress yield. Whether such effects are acceptable will depend on their magnitude and on market requirements, and the strategy of lower-temperature growing will be more suited to some crops than to others. Particular care will need to be taken to keep Botrytis in check, since lower-temperature growing will tend to increase glasshouse humidity (see Factsheet 07/09).

Energy-intensive edible crops

The growth and development of edible crops such as tomato are adversely affected by reduction in growing temperature as shown in Figure 2, and this will result in reduced yield. Trials at Littlehampton in the 1980s concluded that the financial cost of such yield losses was greater than the value of the energy savings, and that this approach was not viable. Since then, however, fuel costs have risen more than tomato prices and lower-temperature growing for tomato is becoming an increasingly attractive option. Recent Dutch simulations suggest that reducing the day and night heating set-points by 2°C could reduce energy use from 440 to 370 kWh/m² and reduce yield from 58.9 to 57.1 kg/m². On this basis, and assuming a tomato price of £1 per kg, fuel will need to exceed 2.5 p per kWh to make the strategy worthwhile. Even then, potential cost savings and

---

**Graph 1** Relationships between heating set-point and glasshouse heating energy for ornamentals, pot chrysanthemums (excluding lighting energy) and tomatoes (simulated using a model developed in HH3611SPC)
impact on the crop will need to be carefully considered before such an approach is embarked upon.

**Energy-intensive ornamental crops**

For ornamental crops, the biggest impact of lower-temperature growing is likely to be on throughput. Graph 2 illustrates this for pot chrysanthemum, using published relationships between achieved temperature and rate of flowering, and taking account of pot spacing practices used in commerce. Based on this, and on simulated relationships between set-point temperature and achieved temperature given by the Hamer energy model (HH3611SPC), reducing the set-point from 18°C to 16°C is likely to reduce annual throughput of pot chrysanthemums by around 2.2 pots/m². With a gas price of 2.5 p/kWh and a pot value of £1, this lower-temperature strategy will, therefore, give an energy saving of £1.63 per m², but with a reduced throughput of pots valued at £2.20 per m². There would be associated savings on cuttings, compost and pots, but these are unlikely to compensate fully for lost income.

Lower-temperature growing may however be better suited to ornamentals such as poinsettias grown as Christmas spot crops. Trials with cultivars such as ‘Freedom Red’ (Figure 3) have shown that lowering the set-point at ‘pinching’ from 20°C to 15°C and retaining this through to marketing will give crops of sufficient size and quality, so long as potting is at least three weeks earlier than usual (PC 71c). This may fit in with greenhouse space requirements for the summer but, if not, cool-temperature finishing may be a better option. Reducing the set-point only from week 43 will give high quality crops and potting needs only to be 7–10 days earlier than usual (PC 71d). However, the energy saving will probably be halved. It is important in the case of poinsettias that the minimum achieved temperature prior to marketing does not fall below 14–15°C, since lower temperatures can reduce keeping quality.
Temperature integration

Glasshouse crops have conventionally been grown with similar day/night set-point temperatures. However, plants are able to tolerate considerable temperature fluctuations (as happens in nature, for example), and growth and flowering generally reflects the average 24 hour temperature (see Figure 4). This ability of plants to respond to the average temperature, whilst tolerating considerable fluctuations around this average, has led to the development of Temperature Integration (TI) as an energy-saving strategy.

Basic TI – exploitation of solar gain

Basic TI is implemented by raising the glasshouse vent temperature setting and allowing solar gain to give higher than usual day temperatures. This enables ‘energy credits’ to be accumulated, and these are then ‘spent’ by reducing the heating set-point to lower than usual at times when the heating demand would otherwise have been high, such as at night or on cloudy days. Graph 3 shows typical temperature profiles over a 24 hour period for conventional and Basic TI growing regimes. The gain in temperature during the middle of the day in the TI glasshouse (from solar gain) is compensated for by using a lower heating set-point temperature than normal at other times. Both profiles give the same average temperature, 20°C, and crop responses can be expected to be similar (other than for height). However, the TI regime requires a smaller heating input.

In practice, a running average temperature is maintained over several days (the ‘integration period’) since it is not always possible to fully use energy credits within the 24 hour period in which they are generated. Any credits that remain at the end of the period are ‘discarded’. At times the temperature will be above the optimum for cropping (supra-optimal), and at other times it will be below the optimum (sub-optimal). Both of these are associated with slower development but, in practice, a large degree of mutual compensation occurs and cropping delays tend to be minor. PGR treatments have frequently to be increased because the combination of high day temperatures and low night temperatures (‘positive DIF’) gives rise to taller plants.

Energy-saving aspects and humidity control

Three main elements can be manipulated in Basic TI to save energy – the length of the integration period, the vent temperature setting and the minimum permitted temperature.

Graph 3 Typical daily temperature profiles for conventional and Basic TI crops

![Graph 3](image)

4 Plants of Impatiens growing at an average temperature of 18°C showing that flowering is regulated by average 24 hour temperature rather than by day (D) or night (N) temperature (HH1330SPC)
Simulation studies (HH1330SPC and HH3611SPC) have shown that:

- Increasing the integration period up to around 10 days saves progressively more energy. Weather forecasting will indicate when energy credits are likely to accrue, but will not increase the overall energy saving so long as the integration period is of reasonable duration.

- Increasing the vent temperature setting from a conventional 19°C to 26°C by 1°C stages saves progressively more energy (Graph 4).

- Allowing a low minimum temperature setting (14°C rather than 16°C in Graph 4) will give more opportunity for using energy credits and will give greater energy savings. Best practice is to adjust the minimum temperature setting to more or less balance the accumulation and expenditure of credits.

- Because of temperature fluctuations, humidity levels frequently tend to be higher in Basic TI than in conventional regimes, and this needs to be countered in an effective, but energy-efficient manner (see Factsheet 07/09). This is because humidity control incurs direct energy costs, and also reduces the potential of Basic TI to save energy. In Graph 4, preventing the RH rising above 90% using a vent then heat strategy, effectively halves the predicted savings.

- Energy savings are greatest in spring, summer and autumn when there are high levels of solar gain. Total energy use in summer is relatively small, but absolute savings given by TI at this time will be at least as high as at any other time (and are at their greatest in percentage terms). Savings are minimal in the winter months when there is little or no solar gain. A similar pattern of energy use is shown in Graph 7 (see later) for pot chrysanthemum.

- On an annual basis, Basic TI gave annual energy savings of around 7% and 12% for modest and aggressive regimes respectively.

**Running Basic TI**

Basic TI is ideally run using a modern climate control computer with inbuilt TI software. For growers without such equipment, software or hardware upgrades will cost around £5,000–£15,000/ha with a payback time of 1–3 years. Basic TI can be applied without having TI software, but increased management time will be required to ensure that the correct conditions are maintained, and energy savings are likely to be less. Staff training to appreciate the dynamics of the greenhouse environment is likely to be beneficial.

**Getting started**

Be conservative with the settings when using Basic TI for the first time. Energy savings will be relatively small, but so too the risks to crop yield and quality. Suggested starter limits are:

- Integration Period – 3 days.
- Minimum Heating Temperature – Day and night the same at 1°C below normal night set-point.
- Ventilation Temperature – 1°C above normal set-point.

More ambitious settings can be applied as confidence is gained.

**Graph 4** Effects on energy saving in Basic TI of varying the minimum heating and vent temperature settings (simulated using a model for tomato developed in HH3611SPC)
Seasonal changes
In practice, Basic TI set-points need to be modified through the year to take account of changing weather conditions:

**Winter** – raise the minimum heating set-point when solar radiation levels are low. This allows any accumulated energy credits to be used over several days. It also results in more stable temperature conditions in the glasshouse.

**Spring** – lower the minimum heating set-point to allow accumulated energy credits to be fully utilised.

**Summer** – reduce the ventilation set-point temperature to avoid accumulating credits that cannot be used.

When TI is working well and credits are being utilised (spring, autumn), the achieved average temperature will be close to the normal heating set-point temperature. However, this will be lower than the average temperature achieved in conventional regimes with the same heating set-point. This lower average can be avoided by raising the normal TI heating set-point.

**Crop trials of Basic TI**
Commercial trials of Basic TI have been carried out on several high-input crops, incorporating best-practice humidity control. Heating temperatures have been set so as to prevent the day temperature falling below 18°C and the night temperature below 15°C. The day temperature has been allowed to rise to 26°C, but only when humidity conditions have allowed. The temperature integration period has been 7 days.

*Pot chrysanthemum*
Commercial trials in Hampshire in 2002/3 (PC 197) were followed up with semi-commercial trials at Wellesbourne in 2004/5 (PC 206):

- Basic TI applied from final spacing to marketing gave a heating energy saving (weeks 43 to 21) of around 12% (65 kWh/m²). Savings in individual weeks ranged from zero to 35% (see Graph 6).
- Humidity levels tended to rise especially high at night in late autumn and early spring. However, active humidity control ensured no detrimental effects on crop timing, growth, post-harvest quality or on the incidence of Botrytis.
- Reduced boiler use during the day (and no heat store) in the TI regime meant there was less flue gas CO₂ available for enrichment. This decreased plant dry weight but had no obvious impact on perceived commercial quality or post-harvest longevity.

*Poinsettia*
Trials of Basic TI were carried out on a commercial nursery in East Yorkshire in 2003/5 (PC 207). TI was ended after week 45 when the potential for further savings was minimal.

- High quality plants were produced with no adverse effects on quality or post-harvest longevity. However, extra PGR applications were needed for height control.
- Energy savings averaged around 15% during the first eight weeks when there were high levels of solar gain. However, savings declined greatly after this, especially as the need for active humidity control increased.

---

**Graph 5 Monthly energy savings for an ornamental crop given by Basic TI – see text for details (simulated using a model developed in HH3611SPC)**

![Graph 5](image-url)
Overall, the energy saving was around 12%.

- Basic TI ought to work especially well with cool-temperature finishing to achieve a greater energy saving than by either method alone.

Other ornamental crops
Basic TI should work on most ornamental crops. Trials in PC 197 have shown, for example:

- Begonias can be grown successfully with Basic TI, giving energy savings (week 5 to week 21) of around 10% (15 kWh/m²). Issues relating to humidity control, growth regulation etc are essentially the same as for pot chrysanthemum and poinsettia.

- Lower input crops such as pot bedding (including zonal pelargonium) can also be grown successfully with Basic TI. In this trial, TI was applied manually by adjusting the heating temperature to reflect the average temperature over the previous three days.

Tomato
Basic TI was tested on a commercial nursery in Lancashire growing classic rounds in 2002/4 (PC 188a):

- Energy savings of 8.4% were given in year 1, and 5.9% in year 2, with no loss of yield or quality (average annual saving of 39 kWh/m²) (Figure 5, overleaf). These savings were achieved without compromising humidity control (or increased Botrytis) since the TI settings were overridden whenever the humidity reached what was considered to be an unsafe level.

Lower input crops such as pot bedding (including zonal pelargonium) can also be grown successfully with Basic TI. Reduced daytime ventilation in the Basic TI treatment in year 1 gave better CO₂ utilisation and an increased yield of 4.3%.

Other high-input edible crops
An aspect that is currently being addressed is whether TI during propagation subsequently increases the risk of bolting in crops such as endive, escarole, celery and Chinese cabbage, where low temperatures are inductive (FV/PC 311). Results from year 2 suggest that this is not the case and that TI can be used safely; low night temperatures (10°C) did not increase the risk of bolting in the field provided that a suitable mean temperature was maintained by high day temperature. However, this will be investigated further in 2009. There are no reasons to believe that Basic TI cannot be adapted for use on any high-input edible crop. Peppers have been grown successfully with TI (PC 227a) with an integration period of 3 days and a minimum night temperature of 16°C.

Graph 6  Cumulative heating energy use and weekly heating energy savings given by Basic TI on pot chrysanthemums (PC 197)
Extended TI – exploiting solar gain and screens

A limitation of Basic TI is that solar gain is a pre-requisite, and little energy is saved in the dull winter months when energy use is greatest (see Graph 5). However, so long as thermally efficient screens are fitted, energy savings can be made in winter by incorporating a routine low day set-point heating temperature into the Basic TI protocol (regardless of whether or not energy credits have been accumulated). By maintaining a high vent set-point, any solar gain is exploited under sunny conditions in the normal way, but any heating that is needed to maintain the average temperature on dull days is given preferentially at night when heat losses under the screen are reduced. Such Extended TI regimes can be implemented using conventional TI software.

Monthly savings

Graph 7 shows the simulated monthly patterns of energy use for pot chrysanthemums growing in Extended TI, a conventional regime and in modest and aggressive Basic TI regimes:

**Conventional** – set-point temperature of 18°C day and night, with 20°C venting.

**Modest Basic TI** – minimum heating temperature (when credits allow) of 16°C and venting at 23°C.

**Aggressive Basic TI** – minimum heating temperature (when credits allow) of 12°C and venting at 26°C.

**Extended TI** – minimum heating set-point (at all times) of 12°C and venting at 26°C.

Black-outs and supplementary lighting were assumed in all cases, together with humidity control at 90% RH. Integration was over 7 days. The simulations show:

- Extended TI gives energy savings during the winter months when none are made using Basic TI. Extended TI also increases the energy savings in spring and autumn. Little or no heating energy is used with Extended TI (and Aggressive Basic TI) in June, July and August.
- On an annual basis, Extended TI saved around 18% of the energy used in conventional growing. This contrasts with 8% and 13% for the modest and aggressive Basic TI regimes respectively.
- Humidity control is particularly important in Extended TI regimes since humidity will tend to increase with fall in day temperature. Had humidity control not been factored into the simulation shown in Graph 7, the 18% saving would have been risen to around 25%.
- In general, energy savings given by Extended TI will be lower for crops grown with screens that are less thermally-efficient than the blackouts used in pot chrysanthemum production. Energy savings will also tend to be lower for crops such as tomato with large leaf areas and which transpire more. This is because a greater heating input is required in such crops to counter the cooling effect of transpiration, and the energy use for humidity control will be greater.

Trials of Extended TI

Semi-commercial trials at Wellesbourne (HH3611SPC) have shown that:

- Tomatoes can be grown successfully with a 14°C day temperature set-point and an elevated vent temperature so long as the achieved average temperature is comparable to that of a conventional regime. Early yields were actually enhanced when a 24°C vent was set. In practice, the achieved day temperature was usually well in excess of the minimum heating set-point. However, to test the effects of a very cold winter/spring with little or no solar gain, a follow-up trial was done with active venting during the day at 15°C. This reduced early yields, but the cumulative yield over the year was unaffected. Extended TI increased fruit size, so care is needed to maintain plant balance.

- Good quality pot chrysanthemums can also be produced in Extended TI with the day heating set-point reduced from 18°C to 12°C and vent temperature raised to 26°C. Flowering was delayed by only 1–2 days and plants tended to be

5 High quality tomatoes can be grown with Basic TI
Graph 7 Monthly energy savings for pot chrysanthemums growing with Extended TI and other heating regimes (simulated using a model developed in HH3611SPC)
larger and heavier (Figure 6) as a consequence of the actual day temperature being frequently much higher than the set-point. A follow-up trial tested the effects of Extended TI with achieved low-day temperatures (average of 15–16°C) by setting the vent temperature to 14°C and using high night temperatures to maintain the overall average. In this case, delays of up to two weeks were experienced, indicating that Extended TI cannot be taken to extremes.

- Pansy and petunia can also be grown successfully with Extended TI, both as plugs and after potting on, and a high vent set-point increased day temperature and hastened flowering. Plants grown in a trial with low achieved day temperatures were generally shorter and more compact than control plants, and required less PGR treatment (Figure 7). This reflected ‘negative DIF’ conditions (day temperature lower than night temperature). Extended TI plants grown with low achieved day temperatures showed a flowering delay of up to one day in pansy and up to three days in petunia.

Wind speed

Wind increases glasshouse heat losses, and commercial trials in the 1990s demonstrated the feasibility of growing tomatoes in a temperature-averaging regime where the set-point heating temperature was varied continuously to reflect wind speed (PC 49) (Figure 8). Energy was saved by lowering the heating set-point as the wind speed increased, and raising it again as the wind speed dropped (wind speed modulation).

Wind speed modulation is a form of TI and can be carried out manually or by the climate control computer if this feature is installed. Savings in older glass will be around 5–10%, but will be less in better sealed glasshouses or when screens are in use.
DROP

It can be expensive in energy terms trying to prevent the glasshouse air temperature falling when screens are removed in the morning and the warm air under the screen is replaced by unheated air from above. Best practice is to allow the glasshouse temperature to start falling around one hour before the screens are removed, allow it to remain low for a period, then to gradually increase it, making full use of solar gain, so that the average 24 hour temperature is maintained. This planned temperature reduction is known as DROP and its total daily duration (after screens are removed) is usually around 3 hours. It is a specialised form of TI and may save up to 1.5–2% of energy. In addition, by giving more compact plants, it reduces the need for PGR treatments. Its value in this latter regard is such that DROP is frequently used at dawn even in unscreened glasshouses.

Trials of DROP have been carried out using poinsettia (PC 41, 155), pot chrysanthemum (PC 92/92a) and bedding plants (PC 41a):

**Poinsettia** – DROP reduced the need for PGR treatment and advanced marketing by around 7 days. Paler-green leaves resulted when DROP was given continuously, but leaves quickly regained colour once treatment ended around week 43–46 (to prevent undesirable reductions in the size of coloured leaves and bracts). There were no adverse effects of DROP on quality or post-harvest longevity.

**Pot chrysanthemum** – DROP reduced the height of winter-stuck pots lit continuously at 4.8 W/m² by around 11%, and appeared not to interfere with speed of flowering.

**Bedding plants** – DROP reduced height in all four species tested: impatiens, geranium, petunia and salvia (Figure 9). The most effective treatment was a two-hour reduction in temperature starting at sunrise. There were no subsequent adverse effects when the young plants were grown on.

Further information

Factsheets in this series

- HDC Factsheet 05/09 – Energy management in protected cropping: Good housekeeping
- HDC Factsheet 06/09 – Energy management in protected cropping: Manipulation of glasshouse temperature
- HDC Factsheet 07/09 – Energy management in protected cropping: Humidity control
- HDC Factsheet 08/09 – Energy management in protected cropping: The use of screens
- HDC Factsheet 09/09 – Energy management in protected cropping: Horticultural lighting
- HDC Factsheet 10/09 – Energy management in protected cropping: Management of CO₂ enrichment