Factsheet 05/09

Protected crops

Project No. PC 198, 198a, 227, 278,
& Defra AC0401, AC0407

Written with funding
from Defra (AC0407)

Horticultural
Development
Company

Stoneleigh Park
Kenilworth
Warwickshire CV8 2TL
T: 0247 669 2051
E: hdc@hdc.org.uk

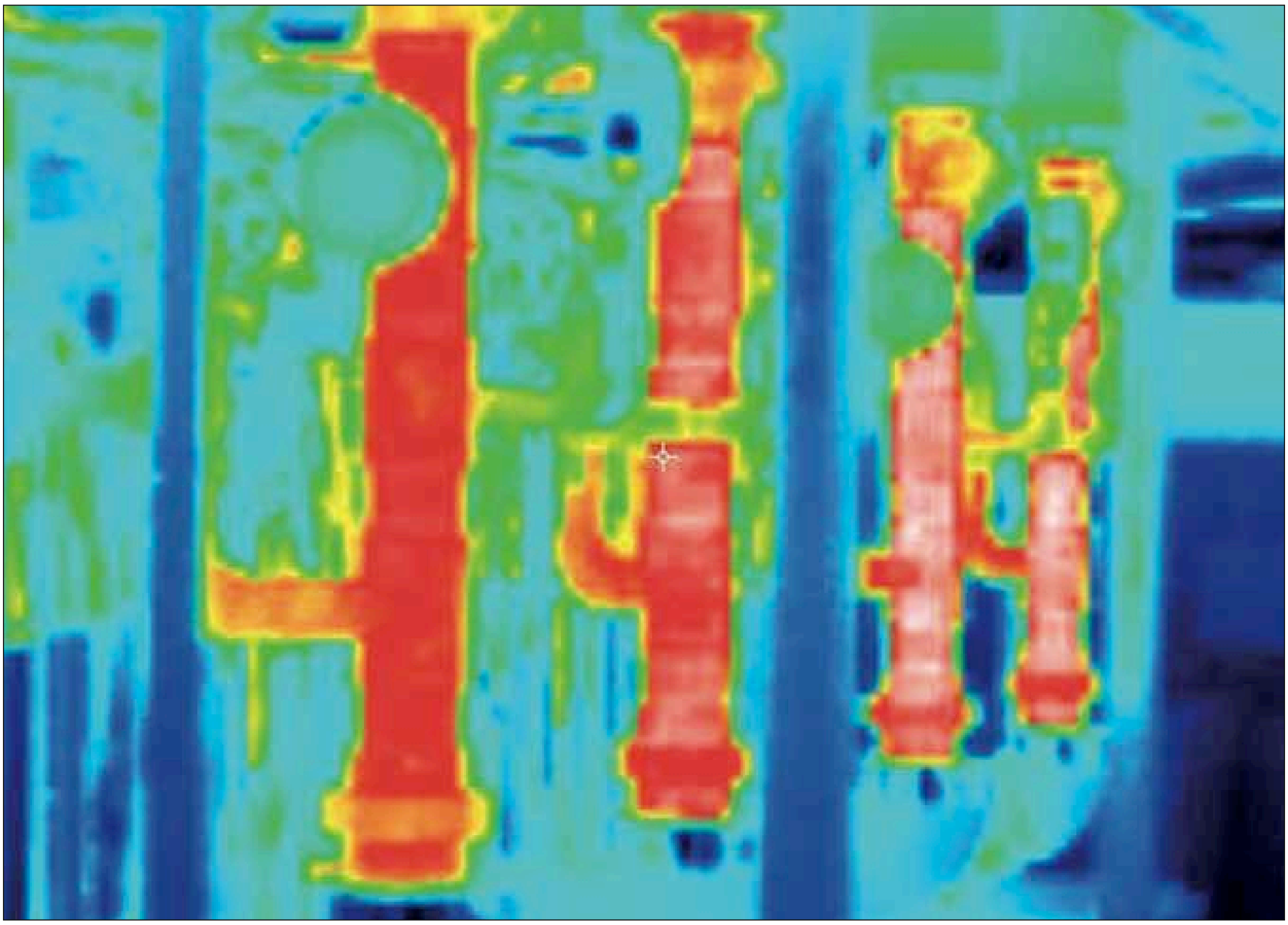
Energy management in protected cropping: Good housekeeping

Steve Adams and Allen Langton, Warwick HRI, and Chris Plackett, FEC Services Ltd

This factsheet, part of a series on energy management, highlights the benefits of good housekeeping, the first essential element in efficient energy management. The key is to appreciate where energy is being used (Figure 1), and to take steps to minimise waste.

Summary points

- Energy saving in protected cropping starts with good housekeeping. Regular equipment maintenance, and making essential repairs without delay can reduce energy use by up to 10% for little or no capital outlay.
- It is helpful to have someone in the organisation with specific responsibility for energy issues. Staff training in energy matters can be very beneficial.
- Energy-use data, preferably using sub-metering, should be assessed at least once each week. This will give a detailed insight into factors affecting energy use. Ideally, energy data should be compared alongside greenhouse climate data, weather data and cropping information. If possible, bench-mark performance against that of other growers.



1 Thermal image of un-insulated pipes (red) showing high heat loss

- Degree-day analysis is a simple, but effective technique that is useful in studying comparative energy use (between years, glasshouse units, growers etc).

- Control equipment including measuring boxes, outside weather stations and CO_2 sensors should be regularly maintained and calibrated. A measuring box that reads 0.5°C low can increase the annual greenhouse energy cost by around £5,000/ha.

- Single glazing is still the preferred option for greenhouse cladding, and thermal screens generally provide a better option for reducing heat loss than double glazing.

- Air leakage can account for 5–30% of instantaneous greenhouse heating demand, and energy efficiency can be improved in older structures by sealing the gaps between panes of glass, and by fitting seals to greenhouse doors and ventilators. Gaps around pipe, cable or duct entry points also need to be sealed, and damaged panes of glass replaced as soon as possible.

- Windbreaks will reduce heat loss from the greenhouse, particularly under windy conditions and when internal energy screens are not in use. However, care needs to be taken to prevent associated shading effects.

- The glass should be kept clean, inside and out. In tomato production, a 10% increase in light transmission has been predicted to result in a 2% reduction in energy use and an 8% improvement in energy use efficiency.

- Boiler upgrading has considerable energy-saving potential. The most efficient designs of boilers with condenser units can achieve seasonal efficiencies close to 90%. This compares to around 80% for modern boilers without a condenser, and less than 70% for older boilers (20+ years old).

- It can be more energy-efficient to install a number of smaller, localised heating systems rather than a single, large central boiler. This will improve boiler use efficiency and reduce energy transmission losses.

- Air heaters have some advantages over piped hot-water heating systems. However, heat distribution can be very uneven.

- Insulation applied to pipes, flanges and hot water valves, the boiler casing and the heat store will typically reduce heat losses from them by more than 90%, with a payback period that is typically less than two years.

Background

Despite the many sophisticated methods available for saving energy in horticultural production, the first and most cost-effective step is often good housekeeping. Good energy management requires an appropriate attitude of mind, recognising that significant waste can arise from a lack of awareness, and in some cases, simple carelessness.

Regular equipment maintenance and making essential repairs without delay can, typically, save up to 10% of energy for little or no capital outlay.

Responsibilities

It helps greatly if there is someone in the organisation with specific responsibility for energy issues, including the purchase of energy and related equipment, and efficient operation. Having a single person who is the energy champion gives the issue some consistent representation. Written energy policies are often regarded as an unnecessary bureaucratic detail, but they are useful in setting down just what are the aims and intentions of the business with regard to energy use. They are also a requirement of various crop assurance protocols. A policy should detail responsibilities and future plans pertaining to energy and be revised on a yearly basis.

Training in energy matters is also useful. This can extend from detailed technical training on the operation of heating and ventilation control systems for example, to simple awareness training on the importance of switching off basic pieces of equipment. Feeding back information on energy performance to staff is important in engaging interest in energy efficiency. Using graphs and charts to compare energy use over different periods or between sites can be especially useful.

Monitoring and benchmarking

It is impossible to determine whether an operation is energy efficient and to make rational decisions on ways of reducing energy unless energy use is measured and recorded over a period of time. It is not sufficient to rely on past energy bills, since the information is often unreliable (bills can be estimated for example), is too infrequent and is too general. Instead, it is recommended that actual energy-use data are collected and assessed at least weekly. Include all fuels - gas, electricity, oil etc – and aim to take meter readings and/or storage tank levels at the same time each week. Compare energy use with similar periods in previous seasons. To be of most use, energy data should be compared alongside greenhouse climate data (temperature, humidity and CO_2 concentration), weather data (temperature, windspeed and solar radiation) and cropping information. Used in this way, the data will give an understanding not only of where the energy is being used, but also of the factors leading to increases and decreases in consumption. Increases in energy use that cannot be accounted for by changes in growing conditions indicate a possible problem with the heating equipment, requiring immediate investigation and rectification. If possible, benchmark your performance against that of other growers. Energy use can vary greatly between growers of the same crop and informed comparisons can be very instructive!

By their very nature, energy bills cover energy use at a site level and not at an equipment or operational level. So, for example, where a site has multiple boilers or greenhouse structures, utility meters and bills are unable to indicate energy-efficiency shortcomings associated with those specific areas of operation. It is recommended, therefore, that sub-metering is installed for all major definable areas of energy use (Figure 2). Meters are surprisingly cheap and easy to install, and the best systems have a data-logging facility enabling energy-use profiles to be recorded over time. These meters can be read over a communications network, and the data from them can be analysed and graphed automatically. Many providers offer analysis and reporting facilities either as separate computer tools or as web-based information services. A technique called ‘monitoring and targeting’ can compare on-going energy use with that predicted by a simple model, and will quickly identify over-use problems.

Degree-day (DD) analysis

A simple, but effective technique that is useful in studying comparative energy use is degree-day (DD) analysis. This makes possible comparisons of actual greenhouse energy use (between years, greenhouse units, growers etc) by taking account of respective heating demand. Factors such as solar radiation and windspeed have an important influence on heating demand but, for the purposes of this analysis, the convenient and easy-to-use indicator that is used is the average difference between outside temperature and ‘inside’ greenhouse temperature, expressed in DD terms. Ideally, the inside temperature should be the heating set-point temperature since this minimises the influence of solar gain. However, actual inside temperatures can also be used, so long as there is consistency in this practice; DD figures used in analyses should always be calculated on the same basis. The temperature difference for a single day is calculated by subtracting the average outside temperature from the inside greenhouse temperature. For example, if the average outside temperature is 10°C and the inside temperature is 20°C, the temperature difference is 10 DD ([20°C–10°C] x 1 day). The temperature difference for a second day, when the average out-side temperature is 5°C and the inside temperature is 20°C, will be 50% greater (15 DD). Temperature differences over time are calculated by multiplying the average daily difference by the number of days concerned. For example, the average temperature difference over a period of five days when the average outside temperatures are 10°C, 11°C, 15°C, 16°C and 13°C, and the inside is 20°C, is 35 DD ([20°C - (10°C + 11°C + 15°C + 16°C + 13°C) /5] x 5 days).

The next step is to divide the actual energy use over time by the DD temperature difference over

2 Meter used to monitor the heating energy used in a specific greenhouse area

this same period. This value, energy use per DD unit, provides a better basis for making comparisons than, for example, unmodified records of direct energy use.

Graph 1 shows weekly DD values and actual energy use data for a pepper crop, plotted over a whole season of production (PC 227). The weekly variation in the two measures is closely matched between weeks 1 and 23 when energy use is dominated by glasshouse heating, and energy use per DD is, on average, 915 kWh. However, the relationship changes markedly during the summer (weeks 24 to 41) when the energy use per DD averages 2,419 kWh. Clearly, other factors, such as boiler use to generate CO$_2$, become proportionally more important in determining total glasshouse energy use during this period.

As noted above, the main value of DD analysis is in enabling comparisons of different years, glasshouse units etc. This can be illustrated using the data in Table 1 of annual energy use and average DD values (using achieved greenhouse temperatures) for a pepper crop in the year before the installation of an energy screen (2005) and in the year after (2006). Standardising the actual energy use in the two years by glasshouse area appears to indicate that the energy screen gave a 10% energy-use improvement (491.1 against 545.7 kWh/m^2). However, the DD value was around 6% greater in 2006 than in 2005, and taking this also into account shows that the screen actually gave an energy-use improve-ment closer to 15% (0.25 against 0.30 kWh/m^2/DD). These latter values, which take account of differences in both area and heating demand, may be referred to as energy efficiency ratios.

Maintaining control systems

The amount of capital tied up in the systems used to control the heating, ventilation and CO$_2$ supply is generally small compared to the value of the glasshouse, the crop and the energy used over a season. However, the effectiveness of these control systems is key to optimising the environment and minimising energy inputs. This can be illustrated by considering the effects on energy use of a measuring box that is inaccurate and reads 0.5°C below actual temperature. It is shown in Factsheet 06/09 in this series (Temperature manipulation) that a 1°C change in temperature can alter energy use by 10–13%, so a 0.5°C measurement error could increase heating costs by at least 5%. For an annual energy use of 400 kWh/m^2, this increase could equate to an additional annual energy expenditure of £5,000/ha (gas priced at 2.5 pence/kWh). The desired greenhouse environment will not be achieved and, whilst there may be some compensatory increase in crop yield from the higher achieved temperatures, it is far from certain that this would be sufficient to cover the extra cost. The higher actual temperatures could also reduce product quality.

As noted in Factsheet 07/09 (Humidity control), measuring boxes should be regularly maintained. In particular, the wet bulb sensor in a conventional box must always have a clean wick and a plentiful reservoir of clean, de-ionised water. The aspiration fan must be kept clean and the box itself must be suspended in a position within the glasshouse so that the measurements reflect the conditions experienced by the crop, but where obstructions do not hinder the airflow.

Graph 1 Relationship between weekly DD values (using achieved greenhouse temperatures) and actual energy use for a pepper crop plotted over a season of production (PC 227)

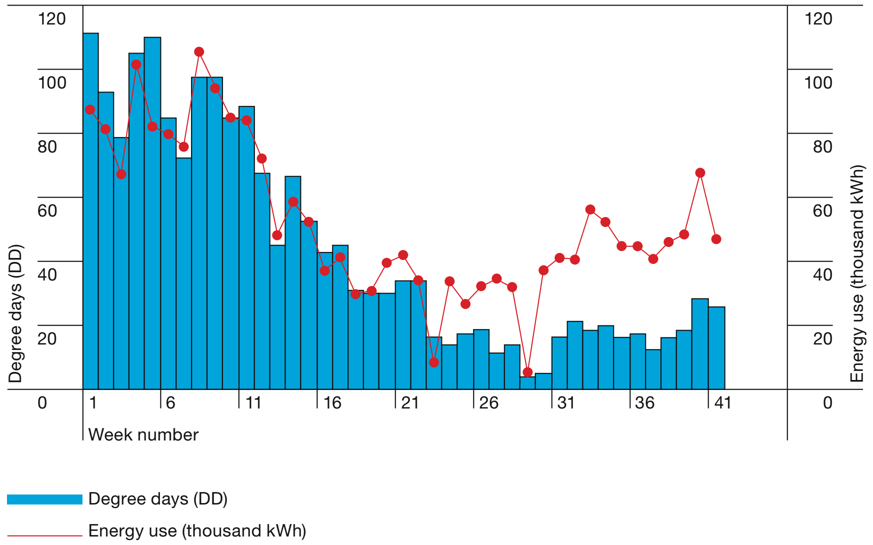


Table 1 DD analysis showing the influence on energy use of a thermal screen installed in 2006 (see text for details)

Year	Energy use (kWh)	Area cropped (m^2)	Energy use standardised by area (kWh/m^2)	Degree-day values (DD)	Energy efficiency ratio (kWh/m^2/DD)
2005 (no screen)	2,837,744	5,200	545.7	1,841	0.30
2006 (screen)	3,192,462	6,500	491.1	1,950	0.25

Similarly, care needs to be taken to ensure that measurements made by the weather station are accurate. Measurements of outside radiation, temperature and windspeed are key variables used in the control of the glasshouse environment. If these are inaccurate, energy will probably be wasted. CO$_2$ analysers also need to be calibrated regularly (Factsheet 10/09, CO$_2$ enrichment) and it is important to ensure that readings really do reflect CO$_2$ levels at the point of sampling when a single analyser is used to monitor CO$_2$ levels at multiple positions. Electronic humidity and CO$_2$ sensors can overcome some of the problems associated with more traditional equipment, but these must also be maintained and calibrated regularly.

Greenhouse heat loss

Some aspects of greenhouse heat loss can only sensibly be considered at the initial design stage, but others can apply to structures that are already in existence.

Greenhouse insulation

Table 2 shows average heat-loss coefficients (as ‘U values’) for a theoretical 0.5 ha greenhouse clad with various materials, together with associated light transmission characteristics. The lower the U value, the greater the potential for energy saving and, on this basis, double-skin claddings, particularly standard double polycarbonate, have obvious attractions over single glazing. However, these claddings also tend to have a higher initial capital cost and, most importantly, reduce light transmission into the house (relative to single glazing), so lowering crop yield and quality. Furthermore, there tends to be less condensation on the walls of double-skinned structures, and savings given by a reduced need for heating can be somewhat offset by the need to supply additional energy for dehumidification. For these reasons, full double-skin claddings have only found favour in UK horticulture in specialised situations such as in orchid production, where very high temperatures are sometimes needed and light levels are less important.

Single glazing using materials with high light transmission (typically glass or polyethylene film) is still the preferred option for greenhouse cladding. This is despite these materials having high U values which limit their ability to prevent greenhouse heat loss (Table 2). Some additional heat-saving can often be obtained in single-glazed glasshouses by temporarily attaching polyethylene sheeting or ‘bubble-wrap’ to the inside surfaces of the side walls. This is particularly effective for north-facing walls where the material can remain in place year round because very little light is lost.

Recent developments in glass and plastics technology have led to new glazing materials with high energy-saving potential becoming available. Low emissivity glass, for example, has superior energy-saving properties compared to traditional horticultural glass. However, whilst this glazing material is now being used in the commercial and domestic markets, its high capital cost makes it currently uneconomic for widespread uptake in horticulture. Similarly, a new twin-wall polycarbonate material (Lexan ZigZag) has recently been marketed with the claim that this has a light transmission similar to that of conventional single glass. However, this material has also failed to achieve widespread commercial uptake, principally because of its high capital cost.

Retractable thermal screens will generally provide a better option for reducing heat loss than double glazing, and this option applies

Table 2 Average heat-loss coefficients (U values) and light transmission characteristics of a theoretical 0.5 ha greenhouse clad with various materials (from Waaijenberg and van de Braak, 1995)

Cladding material	Average U value (W/m^2/°C)	Light transmission (%)	
		Diffuse	Direct
Single glass	8.8	83	89
Double glass – sidewalls only	7.9	-	-
Double glass throughout	5.2	72	82
Single polyethylene film	8.0	-	89-92
Double polyethylene film	6.0	-	-
Standard twin-wall polycarbonate	4.8	65	74

equally to new and existing structures. The materials themselves give instantaneous energy savings of up to 75%, and a commercial trial of energy screens in tomato production (with conservative settings) gave annual energy savings of around 13% (PC 198/198a). The use of screens is considered in detail in Factsheet 08/09.

Reducing air leakage

Between 5% and 30% of instantaneous greenhouse heating demand can be due to air leakage. A 'leaky' greenhouse structure may have two or more air changes/hour, whereas in a recently constructed greenhouse built to the highest standards this may be as low as 0.25 air changes/hour. Modern Venlo greenhouses are constructed so that the air loss through glass joins, closed ventilators and doors is minimised. In older structures, however, energy efficiency can be improved by using flexible sealant to seal the gaps between panes of glass, and by fitting rubber or brush seals to greenhouse doors and ventilators to ensure that they close properly. Some air exchange is desirable to keep humidity levels at an acceptable level, to promote good air movement around the crop and to remove atmospheric pollutants from the greenhouse (eg products of combustion from air heaters etc). However, this should be controlled using best practice, humidity control strategies (see Factsheet 07/09). No matter how old the greenhouse, gaps around pipe, cable or duct entry points need to be sealed. Broken or damaged panes of glass should also be replaced as rapidly as possible.

A missing pane of glass has been calculated to increase the annual heat loss in high-input glasshouse production by around 1,200 kWh and, at current energy prices, this will cost over £30 per year.

The installation of windbreaks is worth considering, since these minimise the airspeed over the greenhouse surface and can greatly reduce heat loss, particularly under windy conditions and when internal energy screens are not in use. Plastic screen materials can be used, but banks of trees or shrubs can be equally effective (Figure 3). However, it is important to ensure that the siting of windbreaks does not result in crop shading since this can more than negate the benefits of energy saving.

3 Well-sited windbreak of alder

Maximising light transmission

It is important to achieve maximum transmission of solar radiation into the glasshouse. This will maximise plant growth and will reduce energy use by lessening the need for heating to maintain glasshouse temperature. Clearly, geographical location, topography and glasshouse orientation affect the glasshouse light climate, along with glasshouse design, and these are all factors to be taken into account when a new glasshouse is being planned. Another important consideration at this stage is the glass. The transmission of horticultural glass is often reduced by 2–3% due to impurities, and selecting low-iron glass, for example, can improve the light transmission. However, much bigger improvements in light transmission can be obtained by the use of anti-reflective coatings (or etching). These are claimed to increase light transmission by up to 8% but the drawback is increased capital cost.

For the grower with an existing glasshouse, the most effective way of maximising light is to keep the glass clean, inside and out. Work carried out by ADAS is the late 1980s showed that the light loss due to dirty glass averaged 18% for growers in the Lea Valley area of the UK. The move to cleaner burning fuels will have undoubtedly improved the situation, but dirty glass can still be a problem, and glass cleaning can be highly beneficial. Recent studies in the Netherlands, for example, indicate that a 10% increase in light transmission can result in a 2% reduction in energy use in tomato production and an 8% improvement in energy use efficiency (Elings et al., 2005). Glass cleaning can be extremely labour intensive and there are important safety issues to take account of. As a consequence, automatic roof cleaning equipment can be an attractive option.

Heat generation and heat distribution

Boiler efficiency

Boiler efficiency is influenced by three key factors:

- Good fuel combustion – this requires a well designed burner which accurately controls the fuel/air mixture. The use of variable speed drives on the boiler fan motor will ensure that the correct fuel/air mix is maintained in all operating conditions.

- Good heat transfer to the piped water supply – this requires large heat exchangers that extract as much heat as possible from the flue gasses.

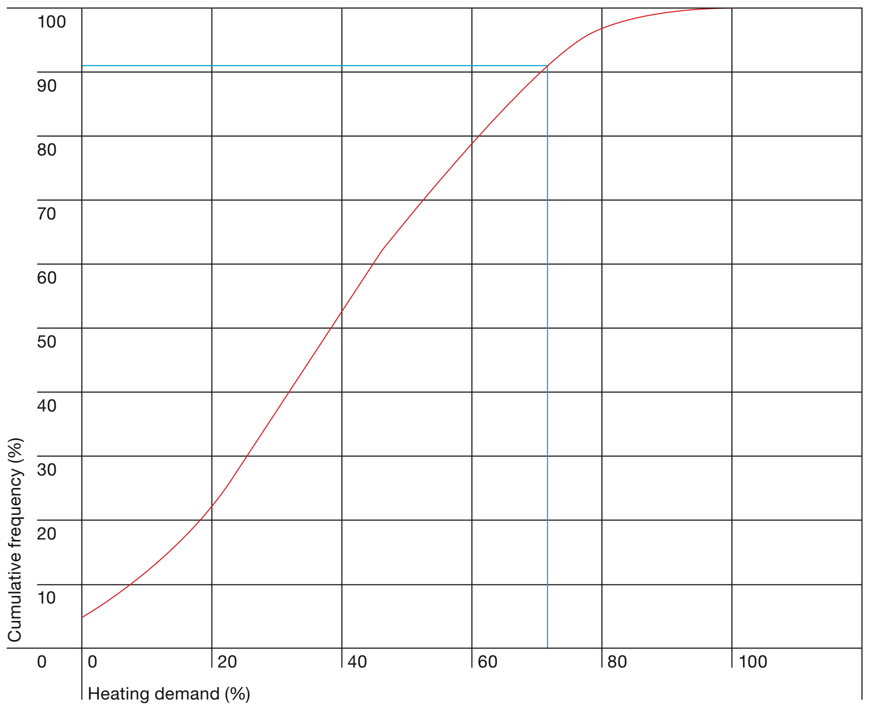
- Low standing heat losses – boilers should be compact and have high levels of insulation. As a minimum, there should be 50 mm of effective insulation on the boiler shell.

A flue gas condenser will ensure that the maximum amount of energy is extracted from the boiler flue gases. This uses a large heat exchanger that reduces the temperature of the flue gases to the point where the water vapour contained within them condenses out. Typically this occurs at or below 60°C. At this point, the latent heat contained within the water vapour is released, and the efficiency of the boiler is significantly increased.

The most efficient designs of boilers with condenser units can achieve seasonal efficiencies close to 90%. This compares to around 80% for modern boilers without a condenser, and less than 70% for older boilers (20+ years old). Boiler upgrading clearly has considerable energy-saving potential.

When a condenser is fitted, the temperature of the flue gases is closely related to the temperature of the water returning to the condenser. As a consequence, the returning water needs to be kept below 50°C, so that the temperature of the flue gases can fall below 60°C and condensation can occur. In practice, this situation can only be reliably achieved when there is a dedicated use for the hot water produced by the condenser. The hot water can be used for heating floors, benches or within the crops themselves (as in tomato and chrysanthemum production).

Graph 2 Simulated relationship between heating demand and frequency for a typical greenhouse in the UK



Single or multiple boilers?

Heating in the protected crops sector is mainly by large, centralised boilers serving several individual growing areas. The boiler will have a heating capacity sufficient to meet the peak demand of the site, but this arrangement may not be the best solution from an energy-use perspective. This is because a boiler operates at its optimum efficiency only when its output is constant and close to its rated capacity. Once a boiler is required to 'modulate' its output to meet a fluctuating requirement for heat that is frequently well below its rated output, its efficiency will fall. This is why the seasonal efficiency that is achieved in practice is always below the maximum that is quoted by the manufacturer. Maximum heat output will only ever be needed for a few days (or even hours) per year, when it is particularly cold and when wind speeds are especially high.

Graph 2 (previous page) shows the relationship between heating demand and frequency for a typical greenhouse in the UK. This shows that for 90% of the time, the greenhouse heat demand is only a little over 70% of the maximum.

A more energy-efficient approach may be to use multiple boilers. This way, the base heating load can be satisfied by a very efficient lead boiler, and peak loads can be met using subsidiary boilers. Another advantage of using several boilers is that this can potentially reduce the length of the heat distribution pipework on site and consequently reduce energy transmission losses. Systems should be engineered to ensure that boilers that are not operational are automatically isolated to prevent heat losses.

Air heaters

From the perspective of energy efficiency, the use of air heaters in greenhouses (Figure 4) offers some advantages over hot-water piped systems.

- Systems involving air heaters have a low thermal inertia and show rapid temperature response. This is in contrast to piped systems where heating response times of 20 minutes or more are normal. All of the products of combustion (including heat and CO_2) are delivered directly into the greenhouse atmosphere.
- Positive air movement, associated with air heaters, can be helpful in combating diseases, and capital costs of heaters tend to be relatively low.

On the other hand, air heating systems have a number of disadvantages:

- Temperature distribution tends to be uneven, especially when large temperature lifts are required in large greenhouses. Ducting systems are needed to ensure satisfactory air and temperature distribution, but light loss problems will be encountered unless the ducts can be accommodated at floor or bench level, or under the gutters.
- Without regular maintenance, fuel combustion can become inefficient and there can be a build up of injurious aerial pollutants (see section on CO_2 burners in Factsheet 10/09). Water vapour is also produced during combustion and this can raise humidity levels and encourage disease spread.
- Heating and CO_2 demand cannot be uncoupled (see also section on CO_2 burners in Factsheet 10/09).
- There is no associated radiant heating.

Recent developments involving heating and cooling systems in sealed and semi-sealed greenhouses has led to a resurgence of interest in ducted heating and ventilation systems. Current research is investigating the potential of using these in conjunction with novel heating systems, such as waste heat (PC 278) and heat pumps (Defra AC0407).

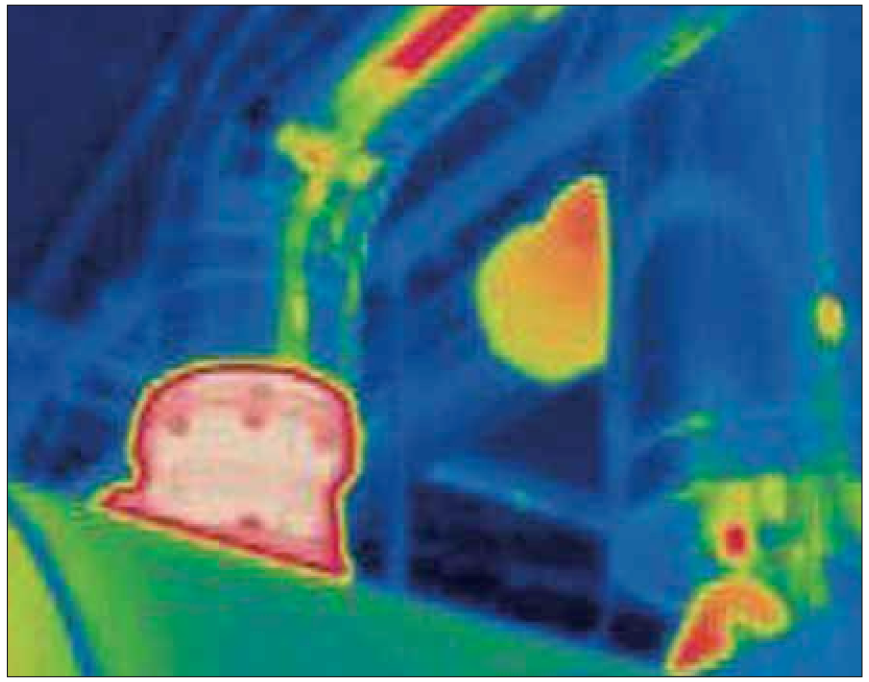
4 Air heater in use in a propagation house

Lagging

As Figure 1 shows (front cover), un-insulated pipework can waste considerable energy. Insulation should be applied to all warm surfaces, including pipes, flanges and valves for hot water, the boiler casing and heat store. Depending on the type and thickness of insulation applied, heat loss is typically reduced by more than 90% with payback periods typically being less than 2 years. As an example, the heat loss from 100 m of un-insulated 100 mm bore pipe, carrying hot water at 80°C, will be 260 W/m. Assuming a gas boiler operating at 75% efficiency, this energy loss will equate to an annual cost (at 2.5 pence/kWh) of £7,590. However, by insulating the pipe with 63 mm of glass mineral fibre insulation, the heat loss will be reduced to 18 W/m, and the annual cost will fall to £525. This represents an annual saving of £7,065 and, with installation costs of around £3,000, the payback period will be less than six months.

All hot surfaces lose heat and attention must be paid to the valves and flanges that are often left un-insulated for maintenance reasons.

An un-insulated valve (see Figure 5) loses about the same amount of heat as a metre of un-insulated pipe of the same diameter. Un-insulated flanges,



5 Heat loss (indicated by red colour) from a valve positioned at the head of a boiler

Table 3 Approved insulation materials and applications

Insulation material	Maximum temperature (°C)	Application
Glass mineral fibre, aluminium foil faced, pre-formed	230	Internal pipework and surfaces
Glass mineral fibre, aluminium clad	230	Internal pipework and surfaces exposed to potential damage, or external pipework and surfaces open to the weather (with joints sealed)
Rock mineral fibre, aluminium foil faced, pre-formed	830	Internal pipework and surfaces
Rock mineral fibre, aluminium clad	830	Internal pipework and surfaces exposed to potential damage, or external pipework and surfaces open to the weather (with joints sealed)

which have a smaller surface area, lose about half this amount.

A variety of materials are available for insulating hot surfaces as shown in Table 3, (previous page). These should comply with the requirements of BS5970. Straight pipework is normally insulated using pre-formed lengths of insulating material that are then secured in position by the use of metal bands or a suitable high-temperature tape. External pipework must be weather-proofed to prevent the insulation material absorbing moisture and losing its insulation properties. Valves are best insulated using flexible jackets, secured in position with quick release fixings. Figure 6 shows an example of the use of flexible insulation jackets.

BS5422 specifies the recommended thickness of insulation depending on the pipe size, service temperature and application and an example of the guidance given is shown in Table 4. It should not just be assumed that existing insulation is already providing optimal energy savings since, in many cases, thicker insulation could be well justified. This is particularly the case when insulation has become damaged and/or wet. Recent increases in energy prices also mean that thicker insulation is now more economic. Rigid, phenolic foam-based materials have recently been introduced and these give improved insulation for a given thickness. They are also less prone to damage and, since foam-based products can be preformed, tend to simplify installation. However, uptake has, so far, been very limited in horticulture. It is important to take advice from insulation specialists and vital to ensure that any insulation meets the requirements of BS5422.

6 A good example of how flexible jackets can be used to insulate pumps and valves

Table 4 Recommended insulation thickness (based on the Carbon Trust Implementation Guide CTL031)

Pipe diameter (mm)	Service temperature (°C)	Recommended thickness (mm)
32	75	38
32	100	54
100	75	46
100	100	64

Further information

Factsheets in this series

- 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 CO_2 enrichment

Additional information:

November 2009

Design and production: HDR Visual Communication