Understanding energy influences for UK soft fruit production

Project details:

Project leader:
Jon Swain, FEC Energy

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Key staff:
Jon Swain
Ed Hardy

Location of project:
UK, Belgium, Netherlands

Industry representatives:
Colin Frampton, Hall Hunter Partnership
Sandy Booth, New Forest Fruits

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Grower summary

Headline

Soft fruit growers can use lessons learned in the high temperature greenhouse sector to improve control over climatic conditions and reduce energy costs whilst maintaining crop quality and output.

Background and expected deliverables

Soft fruit production in the UK is dominated by strawberries, blackcurrants and raspberries, which account for over 90% of cropping area. The rest includes blueberries and blackberries both of which continue to gain in popularity. In total, around 9,400 hectares of land is used for growing soft fruit. An estimated 85% (Raffle, 2017) of this area is protected by polytunnels. 225 hectares of soft fruit is currently grown under glass (DEFRA, 2016). The remainder is mostly uncovered. This is an expanding sector and over the past 20 years, soft fruit production in the UK has grown by 131% (Pelham, 2017). Growers have moved towards covered cropping, driven principally by supermarkets' demand for dependable and high quality produce over an extended season. As this trend looks set to continue, perhaps with more growers opting for glasshouses rather than polytunnels, energy consumption within the sector, largely in the form of heating and automation, will increase.

It is probably fair to say that the soft fruit sector has less experience in using heating and automated environmental control than, for instance, the 'high temperature' protected edibles or ornamentals sectors. As such, the development of systems, knowledge and the imparting of technical information to users has some catching up to do to match these more mature, energy intensive sectors. The good news is that much of the development in hardware, control and techniques has already been done in the other sectors; much of what is left to do is tied up in knowledge transfer and training.

In view of the increasing importance of energy based systems, the brief of this project was to:

- Determine the current skills / expertise levels of UK growers relating to energy and glasshouse environmental control in the soft fruit sector
- Identify where information from either GrowSave or the Netherlands can be used to bridge current skills gaps and improve the performance of UK based facilities

The information and answers to these questions was gathered by several means:

- Interviews with major players in the industry and the equipment supply trade were undertaken. The resulting information was recorded to produce an overview of the current status of energy use and the knowledge base associated with energy management in the soft fruit sector
- Current climate control practice in glasshouse soft fruit production was investigated through the remote monitoring of two participating sites, as well as through discussions with industry representatives. The remote monitoring identified potential energy savings which might be implemented
- GrowSave organised a grower study tour of a research centre and commercial production sites in Belgium and the Netherlands, with the aim of gleaning an insight to the latest industry developments and 'best practice' techniques. The tour provided an opportunity to see various technologies being used in practice and to gain grower feedback on their efficacy

Summary of the project and main conclusions

An overview of the current status of energy use and the knowledge base associated with energy management in the soft fruit sector has been undertaken in this project.

A structural overview of the sector suggests that around 8,000 hectares of production is in polytunnels and 225 hectares under glass. It is not possible to say with any degree of accuracy what proportion of this area is heated or to what average period or temperature, so the overall energy consumption is largely unknown. What is certain is that the market requires longer season production and the need for the infrastructure to provide this is becoming more and more common.

This project has identified some areas where energy and water use efficiency might be improved – specifically, reducing energy use in glasshouses growing soft fruit – without compromising growing conditions or crop quality.

Potential areas of improvement in current practice include recommendations on how to reduce energy losses and overall consumption from structures and heating infrastructure, as well as better hardware and soft system technologies. The use of inefficient operational practices, albeit still delivering a good crop environment, was also identified as an area which leads to a significant proportion of energy being wasted. For example, growers have been observed trying to maintain relative humidity within a tight band while both heating and venting simultaneously. Much can be achieved to improve this through better specialist training and demonstration of best practice methods. Specific findings are set out in the 'On-site monitoring' information in the Science Section of this report.

Much expertise in the control and implementation of protected environmental systems already exists in the protected edibles and ornamentals industry and is being used for soft fruit. Some of this experience can be sourced in the UK, but much comes from, or was originated in, Europe, mainly in the Netherlands.

This project has included a study tour to Belgium and the Netherlands which offered a good insight into how technology can be used to improve growing conditions and crop quality in a more technically advanced environment compared with the UK. The widespread use of LED lighting and water recycling in these countries has resulted in growers making considerable savings, both financial and in terms of energy used. Investigations are also taking place as to the performance of diffuse glass and air movement technology.

Despite the differences between the UK and other nations (e.g. climate, economy etc.), it is not unreasonable to believe that what works for growers in relatively similar countries such as the Netherlands will also work in the UK.

Back in the UK, discussions with soft fruit growers and industry representatives highlighted several gaps in knowledge and suggested topics for further investigation. These are:

- Humidity control
- Sources of CO_2
- Best control of CO_2
- Automation

Automation was mentioned by several of those questioned, particularly in regard to increasing labour costs and the impact of Brexit on the industry. It is believed that a potentially reduced labour market, together with an ever-increasing wage bill, will have a significant impact on the cost of production. To help mitigate this, machines and the automation of laborious tasks could be key.

Research in these areas could be of great benefit to the industry in terms of reduced energy consumption and costs. It was apparent, though, that crop yield and quality is the foremost consideration for growers, with energy saving methods often neglected, perhaps through a lack of understanding in how best to apply the principles behind the theory. A focus on training growers in best practice energy saving techniques could help address the issue.

Detailed findings from the industry consultation, the remote monitoring of energy use on UK production sites and the grower study tour to Belgium and the Netherlands can be read in the Science Section of this report.

Financial benefits and the role of GrowSave

GrowSave is a long term knowledge transfer (KT) project funded by AHDB which has focussed on financial energy savings and environmental issues and has been running for 10 years. To date, it has been mainly concerned with high energy users in the protected horticultural industry. Clearly, high temperature edible crops like tomatoes, peppers and cucumbers have benefitted mostly from this work. A possible extension of GrowSave to soft fruit (mostly protected soft fruit) is a natural move, as it is clear that all of the enabling technologies (e.g. control systems, supplementary lighting, screens etc.) are, in essence, no different to those from the other sectors.

There is no need to 'reinvent the wheel', either from a technological or a communication perspective. The technologies and techniques which have served the protected edible industry over the years can easily make the jump to soft fruit; details which pertain to soft fruit, such as set points and crop requirement, may have to be tweaked, but the fundamentals are the same. Recycling of information in this way is very cost-effective.

For soft fruit it is recommended that sector specific events and workshops are carried out, while relevant website content and technical updates continue to be produced in the tried and tested way. At each stage, the material which has already been produced for the protected edibles sector could be examined, modified if necessary and repackaged to serve the needs of the soft fruit sector. The dissemination of existing knowledge in this way will be a particularly cost-effective solution to help the industry save energy and increase its profitability.

Action points for growers

Soft fruit growers should consider the following technical solutions to reduce energy use and cut costs:

- Careful monitoring of glasshouse climate conditions through the effective use of a climate control computer
- Ensure set-points are well defined and can be achieved effectively
- Efficient use of CO_2 and understanding the cost differences between pure CO_2 and on-site production from a boiler
- The use of fans for air distribution and humidity control in favour of heating and venting
- Using screens for longer to reduce radiative heat loss
- Utilising water recycling systems to minimise loss of irrigation water and fertiliser
- Using HPS and LED lighting for out of season growth
- More sophisticated methods of humidity control that incorporate heat/vent strategies
- Night-break lighting

Science section

Introduction

The soft fruit sector of horticulture is becoming more energy intensive, driven mainly by supermarkets' demand for consistent, high quality produce over an extended season. Soft fruit growers are increasingly producing under heated glasshouses and polytunnels with more sophisticated environmental control. Energy consumption within the sector, largely in the form of heating and automation, has increased and will continue to do so.

A structural overview of the sector suggests that around 8,000 hectares of production is in polytunnels and 225 hectares under glass. It is not possible to say with any degree of accuracy what proportion of this area is heated or to what average period or temperature, so the overall energy consumption is largely unknown. What is certain is that the market is demanding longer season production and the need for the infrastructure to provide this is increasing.

This project seeks to ascertain if the knowledge and information dissemination programme developed through GrowSave for the high temperature fruit, vegetables and horticultural sectors can be used to advantage within the soft fruit sector in a cost-effective way. Undoubtedly, on first examination, it would be sensible to use existing resources and knowledge to extend the programme into the soft fruit sector and make the most of the information and skills which have been gained from the programme to date.

The main questions to be answered are:

- To what extent is this knowledge transferrable?
- What shared technology exists between sectors?

To ascertain this, an overview of the current status of energy use and the knowledge of energy management in the soft fruit sector has been undertaken. Information has been gathered from conversations with major players in the industry and the equipment supply trade. Some site monitoring has been undertaken to reveal anecdotal indicators of what might be achieved by improvements in energy efficiency. To this end, current climate control practice was investigated through the remote monitoring of two participating sites, as well as through discussions with industry representatives.

A key part of the project was a study tour, organised by GrowSave for a group of UK growers and industry consultants. The trip visited a research centre and several glasshouses in Belgium and the Netherlands, with the aim of gleaning an insight to the latest industry developments and 'best practice' techniques. The tour provided an opportunity to see various technologies being used in practice and to gain feedback on their efficacy.

Materials and methods

The nature of this project – an investigation into the technical status of energy efficiency and how it could be developed in the soft fruit sector – did not lend itself to a classical scientific approach.

To form the general investigation, information has been gathered from a variety of sources to develop a picture of the issues. Work has included:

- A review of the market size and facilities
- Visits to sector specific sites as part of a study tour
- Discussions with growers on the tour
- Discussions with the focus growers
- Remote monitoring of sites through access to climate control computers
- An overview of new applicable technologies
- Discussions with crop and climate consultants

The results from these investigations are set out in the following sections.

A summary of the sources of information used in this report is listed in Table 1.

Table 1: Summary of Data Sources

No.	Source	Details / Location	Information gathered
1	Scott Raffle	AHDB Soft Fruit Knowledge Exchange Manager	Industry insight and developments
2	Sandy Booth	Project Industry representative	Feedback on current industry standing and a view towards future developments
3	Colin Frampton	Project Industry representative	Feedback on current industry standing and a view towards future developments
4	W B Chambers	South of England	Study tour take-home messages; comparison of growing practices in the UK and Belgium / the Netherlands
5	Monitored Site 1	North of England	Glasshouse climate data monitoring (8 months)
6	Monitored Site 2	South of England	Glasshouse climate data monitoring (5 months)
7	Proefcentrum Hoogstraten	Research Institute in Belgium with 2.4ha of glass	Cultivation techniques for year-round production; use of LED lighting
8	Red Star	KUBO Ultra-Clima glasshouse growing protected edibles over 10ha in the Netherlands	Semi-closed climate system using forced-air ventilation and cooling
9	Wilbert van Oers	Independent strawberry grower with 7ha in the Netherlands	High-tech glasshouses with advanced climate control, assimilation lighting, biological water recycling system, air circulation
10	Kenis	Independent strawberry grower with 2ha in the Netherlands	Modern glasshouse with diffuse glass
11	Lieven Colembie	Independent strawberry grower with 1ha in the Netherlands	New glasshouse with assimilation lighting

Results

Brief market overview

The number of growers producing soft fruit has declined markedly over the past 20 years, decreasing from an estimated 300-400 in the mid-1990s to 190 companies at present (Raffle, 2017). A similar trend has been observed among strawberry farms in the Netherlands, which has seen a 46% decrease in numbers over the past decade (Centraal Bureau voor de Statistiek, 2017). In the UK, at least, it is believed that as growers have retired, their production has been taken over by the remaining members of the industry. Both small and medium scale producers have gone out of business, leaving only large scale operators, many of whom have several farm production units. The largest have 10-12 farms, including glasshouse units (Raffle, 2017). Although the number of growers has decreased over the last quarter of a century, total soft fruit production has actually increased over the same period (DEFRA, 2016). This is due to rising yields, brought about, in part, through changes in growing methods. The UK currently sits sixth on the list of EU countries by strawberry production (Centraal Bureau voor de Statistiek, 2017).

There has been a major shift to soilless substrate in strawberry and raspberry production. For strawberries, this has happened partly to avoid soil-borne diseases and partly to create table-top production and reduce picking costs. In raspberry, this has happened largely to avoid raspberry root rot (caused by *Phytophthora Rubi*), which has spread widely across soils in all fruit growing regions of the country. Blackberries and other cane fruits are still largely grown in soils, but mainly because they are less affected by Phytophthora, although they can be affected by Verticillium wilt on some soils. Blueberries are largely grown in soilless substrates, but there is still some production in soils (Raffle, 2017).

There has also been a major shift in the use of protected cropping; it is estimated that only 10-20% of the UK crop was covered in 1995, compared to 85% today. This has come about as fewer growers are prepared to risk growing in the open, where quality can be reduced drastically in poor weather, meaning produce is unsaleable to supermarkets. Protected cropping looks set to remain the standard production method for the immediate future (Raffle, 2017). Through discussions with crop and climate consultants, some areas of potential improvement were identified on the study tour.

Study tour

As part of the project, a group of UK growers and consultants attended a study tour in Belgium and the Netherlands. The aim of the trip was to study the technology and methods used by growers in these countries, with regard to optimising energy usage and growing conditions. The tour included visits to the Proefcentrum Hoogstraten research facility in Belgium, as well as to sector specific sites growing a mix of soft fruit and protected edibles. In-depth discussions were held with the European growers to establish their growing methods and experiences with different technologies. The tour also facilitated discussion among the UK growers, while also allowing FEC Energy consultants to gain an insight into both UK and European practices.

Proefcentrum Hoogstraten, Belgium

The first visit of the study tour was to the research facility in Hoogstraten. Originally founded in the 1950s, the centre has been carrying out scientific research since 1967. Over the last two decades, the site has been rebuilt and expanded. The glasshouse area totals 2.4 hectares, with heat supplied by a Cummins 1.2MW gas, combined heat and power (CHP) engine. Two large buffer tanks, totalling around 1,500m^3, are used to store heat for use when required.

The choice of growing techniques used for strawberries aim to maximise yield. Heat is supplied via 38mm pipes at a maximum temperature of 55°C, while thermal screens are used for insulation. Importantly, these screens do not block all natural light. They are pulled across when the external temperature drops to 6°C and retracted when radiation exceeds 40Wm^{-2}. Carbon dioxide (CO_2) is supplied from the CHP engine and piped to the crop via plastic tubes. This means there is no need to purchase pure CO_2 from an external supplier. CO_2 levels are controlled by sensors and are maintained at 900ppm during daylight hours. When the CHP is running primarily for CO_2 generation, the large buffer tank capacity allows heat to be stored for later use. For the effective uptake of CO_2 by the crop, high temperatures and low relative humidity (RH) are required.

Relative humidity is controlled through the use of vents. A target of 75% RH is desired in the mornings, dropping to 65% during the day. Increasing RH to 80%, however, can help to improve root pressure.

New cultivation techniques enable year-round production of strawberries. The main crop is produced between May and August, but through the use of lighting between October and February, the growing period can be lengthened and the season advanced. The aim is to be able to crop during the winter period when prices are highest during lower volumes of supply. At the time of the visit, an ongoing trial was using far-red Light Emitting Diodes (LEDs) from sunset to sunrise, ensuring there is no dark period for the crop for a total of 30 days of the year. Between the hours of 03:00 and 18:00, lights are on until sunlight exceeds 400Wm^2.

Trials carried out with tomatoes at Proefcentrum Hoogstraten have investigated the effects of light intensity, using a mix of High Pressure Sodium (HPS) lamps and LEDs. Dr Merkens, a researcher at the centre, reported that LEDs can help to increase crop yield, while reducing electricity consumption, when compared to the equivalent light output supplied by HPS lamps. However, it should be noted that the reduced use of HPS lighting in favour of LEDs could mean an increase in heat requirement from the primary source. The positioning of LEDs is also important, as the top of the crop (i.e. the leaves) photosynthesises higher levels of light (Merkens, 2017). The setup of LEDs ensures 139µmol m^{-2} of light reaches the crop at leaf level.

In addition to strawberries, the research centre also carries out trials in other crops, including peppers and tomatoes. One trial block comprises a closed glasshouse growing peppers. When necessary, warm, humid air from the glasshouse is exchanged with cooler, drier air from outside. An air-to-air heat exchanger is used to transfer heat from the outgoing to the incoming air to prevent as much heat loss as possible and to maintain efficient operation. Some additional heat is usually required to bring the incoming air up to the correct temperature before it is returned to the glasshouse. It was estimated that the use of a heat recovery unit results in a 20% energy saving.

Red Star

The study tour visited a semi-closed KUBO glasshouse, which grows tomatoes, cucumbers and peppers. The Ultra-Clima structure (see Figure 1) was built in 2012, took seven months to construct and covers 10.3 hectares. Heat and power are supplied by two 7.5MW CHP engines, coupled with a large buffer tank of around 10,000m^3.

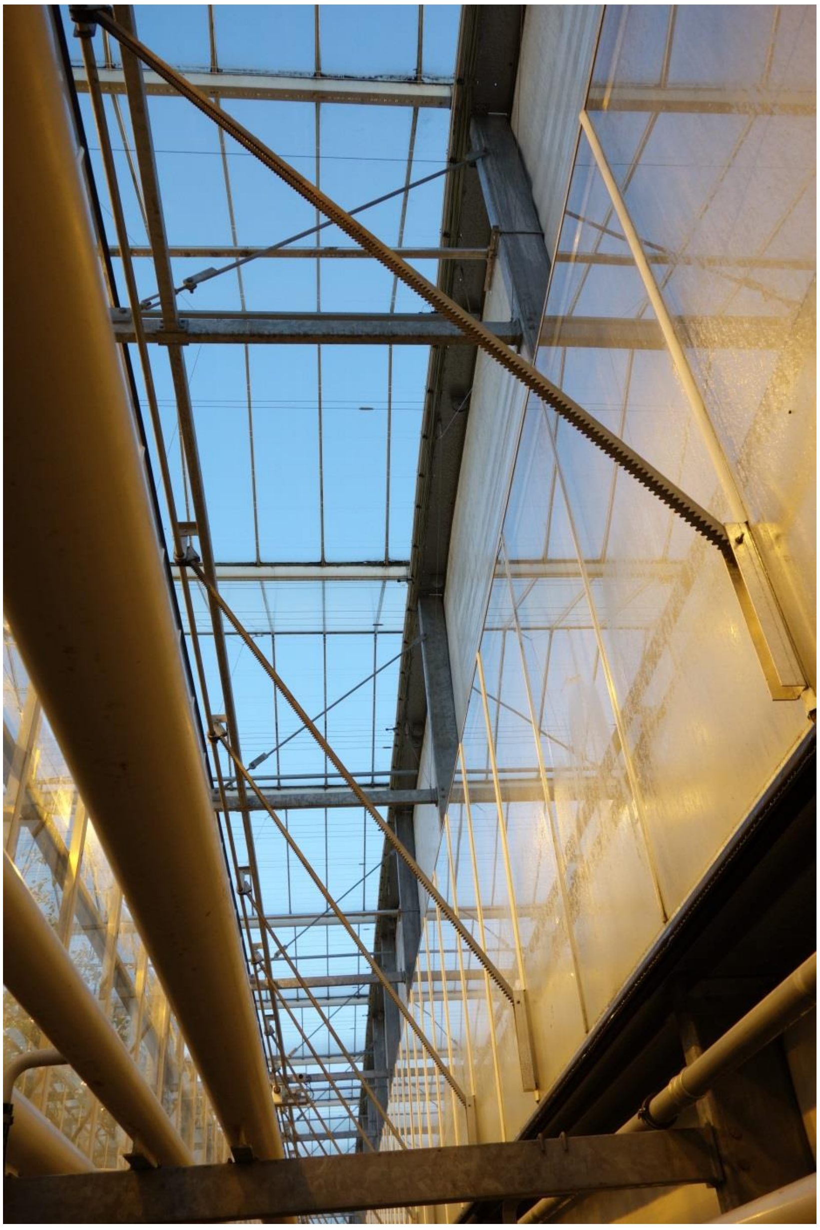

Figure 1: Semi-closed glasshouse

Lighting, forced air ventilation (see Figure 2) and cooling are all utilised for crop production. The semi-closed nature of the glasshouse allows air to be conditioned and recirculated, with minimal fresh air input, which creates a pressurised system. When fresh air is required, the air inlet is opened. To prevent over-pressure, vents in the roof, located every 30 metres, are also opened. Circulation of air is carried out by the fans, with seven in each 12m long bay.

Figure 2: Forced air ventilation system in KUBO glasshouse

Independent growers

Several independent growers were kind enough to host the group and provide a brief tour of their sites. Ranging from two up to 10 hectares, there was a good mix of scale and technology. The general consensus from the group was that these nurseries were more advanced than the equivalent in the UK. This is believed to be representative of the differences in growing practice between the UK and the Benelux region.

In this sense, advancement refers to the uptake of technology and modern growing methods, such as the use of diffuse glass, LEDs and water recycling. However, that is not to say that these necessarily constitute 'best practice'; anecdotal evidence from some of the host sites suggested that diffuse glass had little measurable impact on crop production, for example. The opinion of the growers was that diffuse glass is less effective for crops such as strawberries than, say, tomatoes.

Nursery: Wilbert van Oers

The first site the group visited was owned by Wilbert van Oers, an independent strawberry grower. The site operated a 5MW natural gas CHP engine to heat a total of seven hectares under glass, comprising three hectares of lit crop and four hectares unlit. A Priva climate control and irrigation system was in place to manage the growing environment. The lit portion of the crop utilised 4MW of SON-T (HPS) lighting, providing 180µmol m^{-2} s^{-1} (equivalent to around 15,000 lux). It was estimated that 2,000,000m^3 of gas was required for lighting alone.

Night-break lighting was operated on a profile of 15 minutes on, 15 minutes off, between 15:00 and 10:00 the following day. During the visit, it was observed that the lighting was switching on and off, despite good levels of daylight. The finer control of using LEDs is still in development, so the long periods of lighting are a result of 'generous' use to make sure maximum benefit is derived.

Nursery: Kenis
The nursery is home to a modern glasshouse growing strawberries over two hectares. The grower was keen to make use of the technologies available, meaning the glasshouse was a high-tech structure. Hanging gutters with deep channels contained strawberry plants in 17cm deep pots, with a two-pipe heating system underneath.

The grower had installed diffuse glass in one compartment, but remained sceptical about its efficacy for strawberries. In his experience, the strawberry yield under diffuse glass was no greater than under normal glass.

Nursery: Lieven Colembie
The smallest of the nurseries visited, the site has one hectare of glass used for strawberries. The grower uses assimilation lighting to promote crop yield.

Study Tour: Take-home messages
The key message from the study tour is how technology can be used to improve growing conditions and crop quality. The widespread use of LED lighting and water recycling, for example, in Belgium and the Netherlands is testament to the efficacy of the technologies. The concept of recycling irrigation water, although considered a controversial idea by some, has proven itself as a viable option both economically and practically. The evidence behind improved crop production under diffuse glass, however, was insufficient to convince many of the growers in attendance that it is worth the investment at this stage.

The benefit of growing under LEDs was also hard to quantify. Many of the sites visited had adopted the technology on a trial basis, but were not yet able to quantify savings associated with reduced energy consumption or cropping enhancement.

There are a couple of factors that make a direct comparison between the UK and the Netherlands more difficult. Differences in climate will obviously play a role in the operating profiles of heating and lighting, which may affect which crop varieties can be grown best. Economics also plays a role, with the cost of glass in the UK higher than the Netherlands, for example. This, together with, perhaps, a different attitude to infrastructure investment, means Dutch glasshouses tend to be much newer, with an average age estimated at 7-10 years, compared to 20-25 years for a typical UK structure.

Discussions with growers and consultants
Discussions with growers highlighted that market economics play a significant part in the structure of the growing season. At times of low supply, such as during the winter months, high levels of demand can drive up market prices. Growers, therefore, often aim to produce a winter crop to take advantage of these higher prices, as demand exceeds supply.

Industry representatives and growers alike consider that labour costs are a substantial factor in overall cost and profitability. One industry representative expressed an interest in potential developments in robotics and automation, as this could reduce the ongoing cost of labour, which, he believes, will increase further over time. Given that much of the work is seasonal, with labourers often coming from Eastern Europe, growers are concerned about the impact Brexit may have on the availability of the workforce. Automation of tasks that can be carried out by a machine would mean round-the-clock working becomes a possibility. There is a concern, however, that if large organisations adopt new technologies early, smaller growers would not be able to compete with the reduced production costs. In the USA, many sites are already using machines to pick tomatoes and grapes, but delicate crops, such as strawberries are still a challenge (The Economist, No. 9051, pp. 35-36).

The topic of humidity control was also discussed. Growers admitted that heat was frequently used to drive moisture out of the glasshouse through open vents. They generally accept this as a necessary use of heat, determined by a tight range of RH levels. Circulation fans, instead of using heat, were mentioned as a possible alternative to help redistribute humid air and maintain a good plant balance. It was suggested that further investigation in this area could be of economic benefit to the industry, as it could result in considerable energy and financial savings. Growers were quick to point out, however, that CO_2 production is a welcome by-product of boiler operation, and by reducing the running time of the heating system, less CO_2 would be available to the crop. Whether or not the crop is able to take up the quantities of carbon dioxide available to it under current conditions is largely unknown. Careful monitoring of CO_2 levels in a closed glasshouse might help with understanding on this issue. Based on the outcome, it would be possible to advise on the cost implications of buying pure CO_2 versus running a boiler.

Another topic suggested for investigation was the effectiveness of diffuse glass. Although many Dutch growers have already installed diffuse glass, the benefits to certain types of crop have been difficult to quantify. Uptake in the UK has been slow, as those questioned (growers and industry representatives alike) remain unconvinced of the financial benefit.

Key messages

Through conversations with those involved with the soft fruit sector, several topics came to the fore as requiring further investigation: humidity control, sources of CO_2 and automation. Research in these areas could be of great benefit to the industry in terms of reduced energy consumption and costs. It was apparent, though, that crop yield and quality is the foremost consideration for most growers, with energy saving methods often taking a lower priority, perhaps through a lack of understanding in how best to apply the principles behind the theory. A focus on training growers in best practice energy saving techniques could help address the issue, but what is regarded as best practice can also differ between growers and crop/variety.

On-site monitoring

Over a period of several months, climate control strategies were remotely monitored at two carefully selected sites in the UK. These sites were considered representative of the Soft Fruit sector. Remote monitoring was carried out using TeamViewer software to connect to the host computers and access the data. Priva and Hoogendoorn systems are used to control the climates of the glasshouses. Through analysis of the data, it has been possible to identify times when the climate control conditions could have been adjusted to achieve energy saving and more efficient operation of the system. Due to the commercial sensitivity of the data collected, the sites are anonymous in this report. The findings were reported separately to the individual sites.

When considering energy efficiency, regard was given to the operation of the heating system (e.g. gas boiler) compared with the desired temperature profile. Additional factors such as the use of vents and screens were also of interest, as were measurements of relative humidity (RH) and carbon dioxide (CO_2).

Temperature

Glasshouse temperature is probably the biggest factor affecting energy consumption. Whether heat is provided by a fossil fuelled or biomass system, such as a boiler or CHP engine, or even a heat pump, an input of energy to the system is required.

Most growers will be familiar with the heating profile they wish to achieve for a particular crop. This will vary between crops and even between growing strategies, but an example of a weekly heating profile for strawberries is shown in Figure 3.

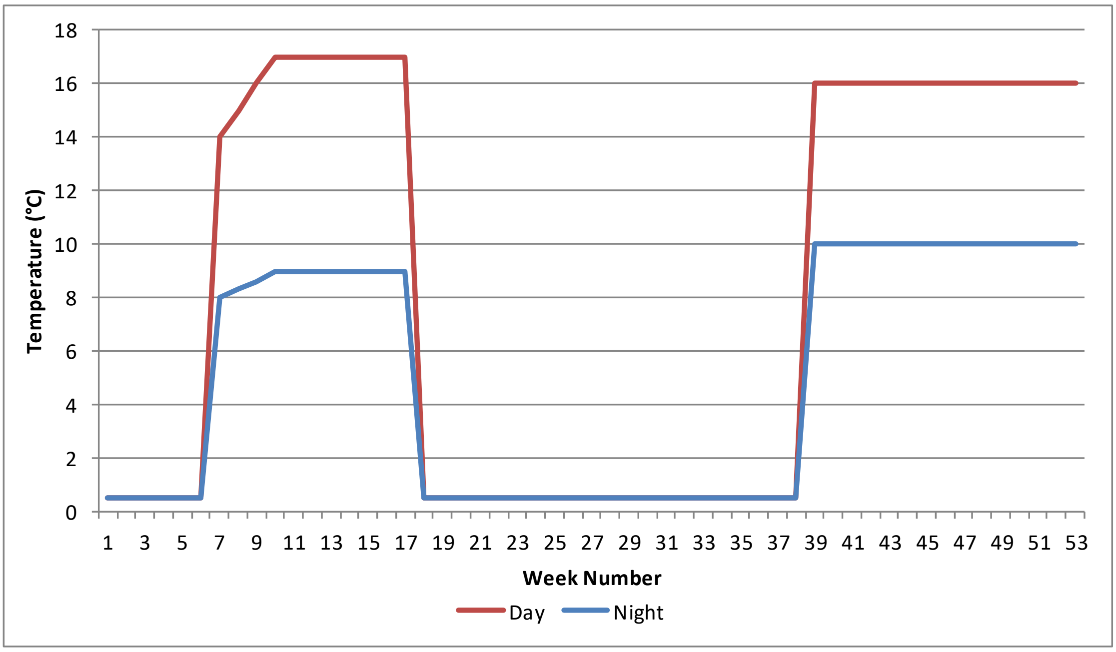

Figure 3: Example weekly heating profile

Figure 3 illustrates temperature regimes for two growing periods during the year, with a period of frost protection in between. Average day and night temperatures are also specified.

Breaking this down to view a given day, it is possible to see how temperature varies on an hourly basis; an example is shown in Figure 4. Control over the temperature can be achieved by entering the desired profile into the climate computer, which then operates the heating system to ensure the target temperature is achieved.

Figure 4: Example daily heating profile

Depending on conditions and external factors (a bright, sunny day, for example), it may be desirable to increase the glasshouse temperature to stimulate transpiration. The climate computer set-points can be defined such that, when light intensity reaches a pre-set level, the target glasshouse temperature is increased.

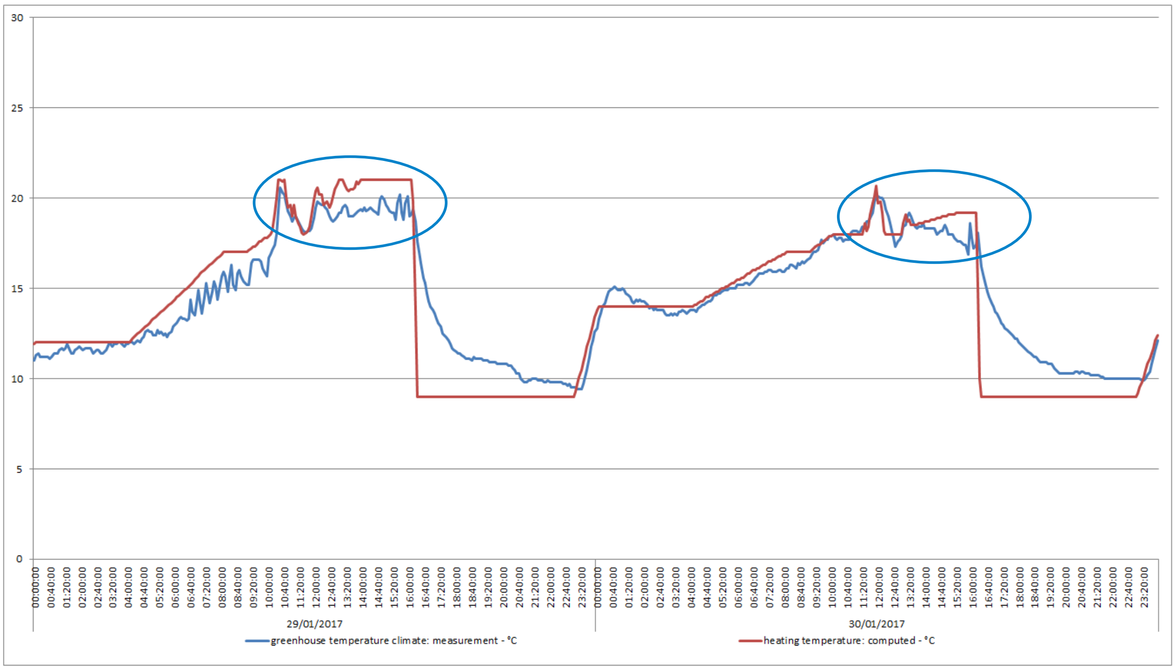

Figure 5: Changes to heating profile due to external factors

Figure 5 illustrates two instances where target temperature is increased in response to ambient conditions. Good control ensures actual glasshouse temperature closely matches the target profile.

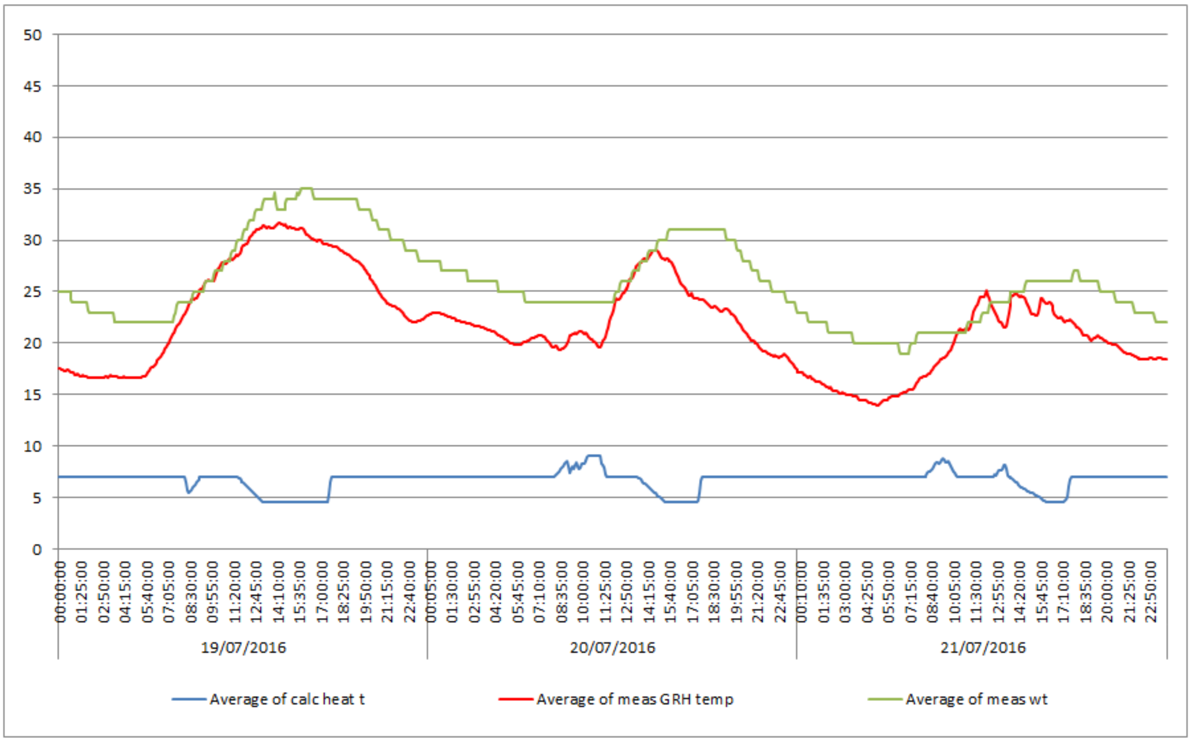

Figure 6: Effect of hot ambient conditions on glasshouse temperature

When the external temperature is higher than that required by the glasshouse, internal temperature can be difficult to control. This is shown in Figure 6 with glasshouse temperatures rising as high as 35°C. Research by Ledesma & Kawabata has shown that prolonged heat stress negatively affects fruit set and development in strawberry (Ledesma & Kawabata, 2016). Better ventilation can help to suppress these high temperatures. Consideration should also be given to the irrigation strategy during these periods.

Relative humidity

Another factor affecting the heating profile is humidity control. When controlling humidity within the glasshouse, relative humidity (RH) is usually considered, as opposed to absolute humidity (AH) or humidity deficit (HD).

At high levels of RH, air approaches saturation – the point at which the moisture carrying capacity of the air has been reached. Saturation moisture conditions can have an adverse effect on growing conditions, as, when RH increases, rate of transpiration decreases. Therefore, plants are less able to take up nutrients and are at higher risk of disease.

Relative humidity is often reduced by increasing temperature. Air can hold more moisture at higher temperatures, so its relative level of saturation is lower for the same moisture content; absolute humidity (AH) remains constant. Modifying RH in this way is often necessary, but can lead to problems where high temperature and low humidity result in slowed crop growth. Furthermore, using heating for RH modification can lead to heat being 'wasted'. As growers try to reach optimum levels of RH (potentially 65-70%), this can result in simultaneous heating and venting. An example is shown in Figure 7 where it is clear that the open vent positions during the day (orange line) are erratic and also simultaneous to higher heating pipe temperatures (green line). Better control strategies during these periods can help to reduce the see-saw of ventilation and reduce heating needs. Such wide variation of ventilation can be problematic, as the warm air escapes too quickly, being replaced by ambient air, which could be colder and at a higher RH and could lead to local high RH conditions.

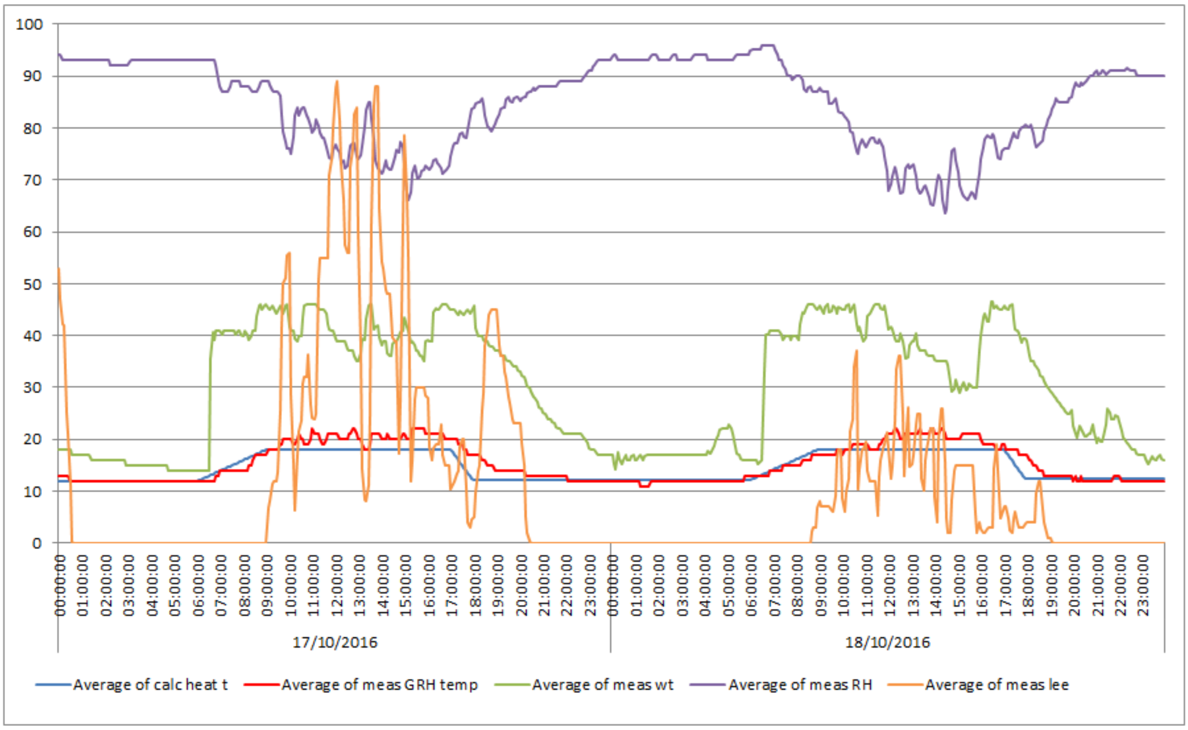

Figure 7: Simultaneous heating and venting

Air movement

Even if humidity levels are under control, the use of vents is an essential part of a good climate control strategy. Vents can be used when the glasshouse is too hot and humid, and the outside air is drier and cooler. Figure 8 shows another example on a monitored site of vents being opened and closed throughout the day to manage RH.

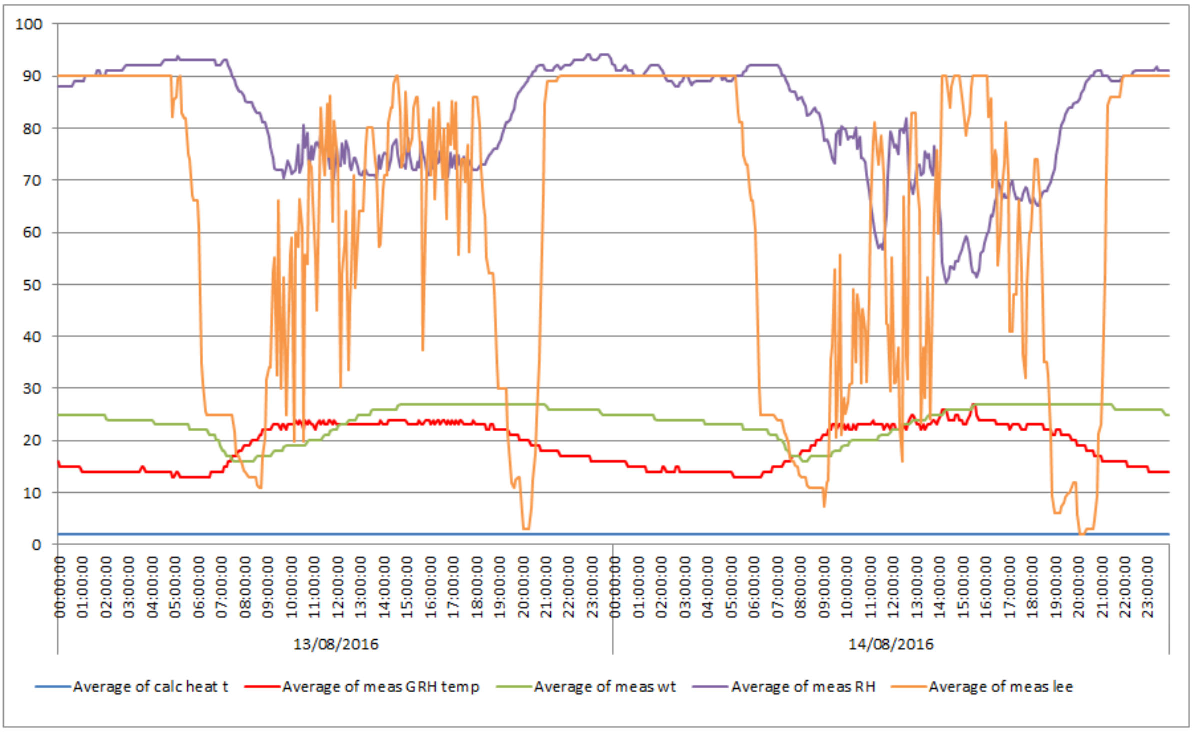

Figure 8: Use of vents for humidity control

The use of vents is sometimes necessary to exhaust humid air from the glasshouse. However, unless the temperature and relative humidity of the outside air is being monitored, leaving the vents open might not be the best option. If internal RH becomes too high and heat is used to reduce it, the vents are likely to open to suppress temperature rather than control humidity, thus wasting heat. Unless the air outside has lower water content, opening the vents could make the problem worse. If warm, moist air is replaced with more of the same, there is no benefit and the heat used is wasted.

While vents allow the exchange of air between the glasshouse and the outside world, fans can also be used to keep air moving. Combining the use of vents and fans, airflow can be controlled to maintain a balanced climate.

Horizontally orientated fans can help to maintain an even temperature across the whole glasshouse. They need not be particularly powerful, but just large enough to overcome turbulence and friction losses to keep the air moving (Bartok & Grubinger, 2015). Horizontal fans, however, may not be as effective at correcting vertical temperature variations as air tubes or vertical fans (GrowSave, 2015).

Screens

The purpose of screens is twofold: to keep heat in and to block light out. Overnight, when there is no light, thermal screens can be used to provide an additional layer of insulation, thus reducing heat loss. This can be particularly beneficial at low outside temperatures, when heat loss is high. An example of good use of screens overnight is shown in Figure 9. The graph shows that the screens are brought over once the temperature has dropped to the overnight target. The measured water temperature is already dropping, indicating that the boiler is not running, only turning on when measured glasshouse temperature drops below target. The screens are retracted in the morning, once the glasshouse is at the target daytime temperature.

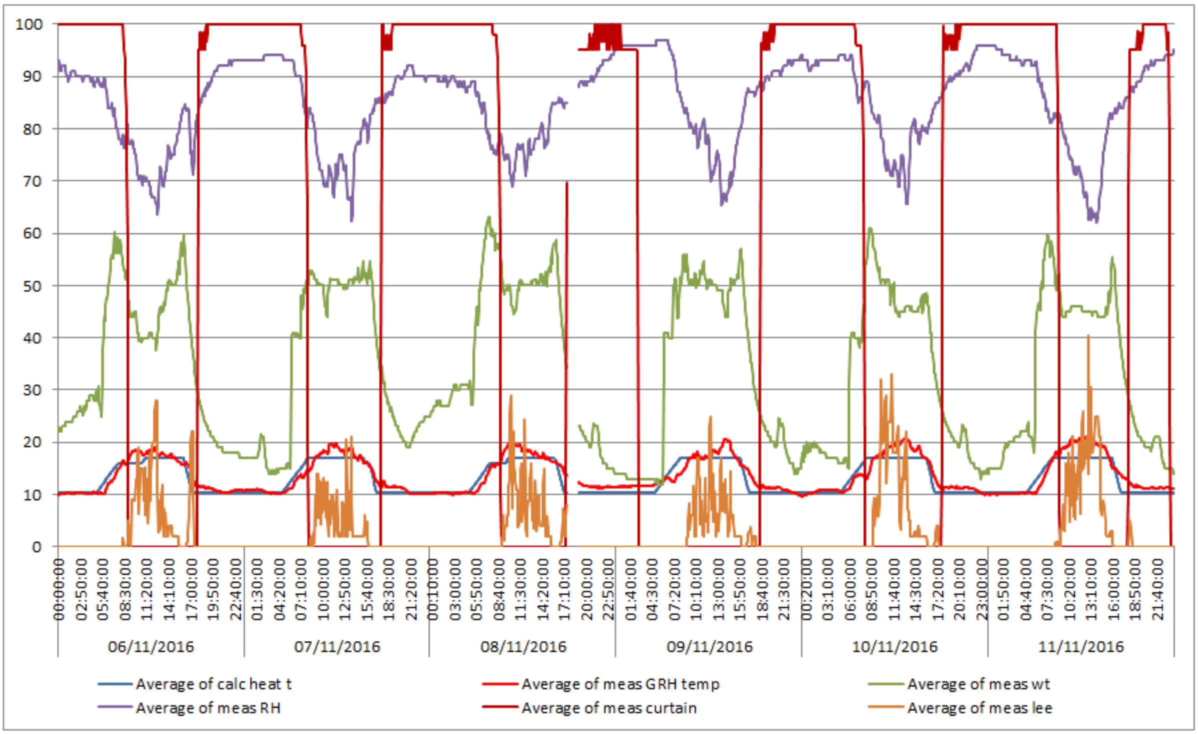

Figure 9: Overnight use of screens

Although the graph represents good control, there is still a tendency for the glasshouse temperature to overshoot the target. The response is to vent the excess heat, in effect wasting it, thus reducing the efficiency of the system. Potentially, this overshoot could be anticipated and the screens retracted slightly earlier or the heating turned off earlier.

Thermal screens are good for insulation and reducing heat loss, but can also be used to prevent excessive thermal gain. During the daytime, especially in the height of summer, temperature management can be difficult. The intensity of the sun can raise the glasshouse temperature to undesirably high levels. Although sunlight is required, effective use of screens could help to prevent the temperature rising too high. Plant health can be adversely affected to a greater extent due to heat than cold.

Figure 10 shows an example of several hot days during the summer. Although vents are open for the majority of the time, screens are not used at all during the day to mitigate extreme temperatures. It would be interesting to monitor the effects of screens on glasshouse temperature and whether or not the reduced light levels have an adverse effect on crop quality or yield.

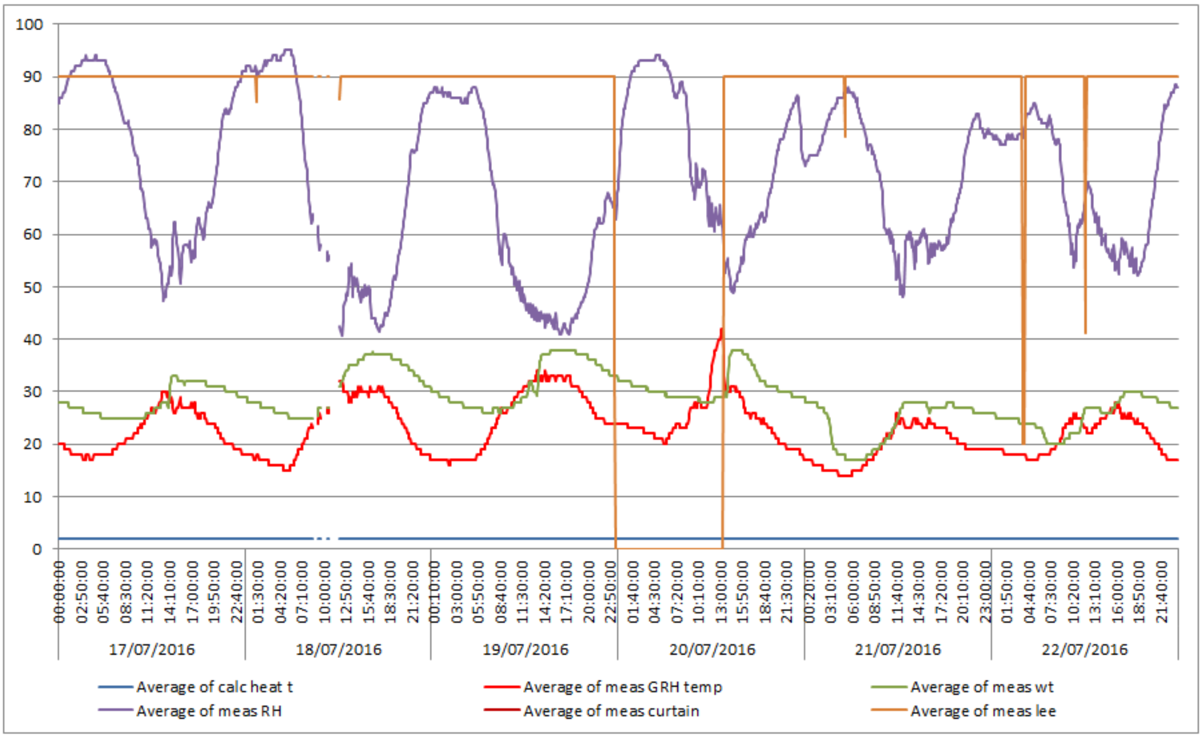

Figure 10: No use of screens to manage excess heat

The careful use of screens is also important to reduce the impact of radiative cooling, caused by outgoing long-wave radiation (OLR) through glass under clear night skies. Although glasshouse temperature may remain relatively unaffected, this form of heat loss can lead to low crop temperatures, which reduces transpiration and nutrient uptake. Furthermore, the risk of condensation and diseases is increased. OLR can be reduced by using a pyrgeometer to measure heat loss to the sky and then closing the screens when a pre-set value is exceeded, typically around 125W m^{-2}.

Carbon dioxide

Carbon dioxide (CO_2) is required by plants for growth, particularly in the early part of the growing season. At such times, growers might wish to increase the level of CO_2 available to the plants, usually supplied to the crop via a network of pipes. The source of the gas can either be external (e.g. pure CO_2 bought in), or from an on-site source, such as flue gas from a boiler. These sources are explained in more detail in the section CO2 enrichment (p22).

There will be times when *carbon* dioxide is required, but heat is not. If CO_2 is supplied directly from the heating system flue gas, the heat can be stored in a buffer tank when not required immediately. However, where a buffer tank is not available or is already at capacity, the heat will be sent directly to the glasshouse, which can lead to higher temperatures than desired. As a result, the climate control system is likely to react by opening the vents to reduce the temperature. Although CO_2 is denser than air, warmer air will carry some of the CO_2 upwards and out of the open vents. The whole process then becomes pointless: not only is fuel being burned to produce unwanted heat, but the CO_2, which was required, cannot be utilised. Instead, vents should be kept closed when CO_2 is being supplied. Any unwanted heat produced by the boiler should be stored in a buffer tank. If there is no buffer tank, alternative sources of CO_2 should be considered.

Figure 11 illustrates an example situation where it appears the heating is being operated simply for the production of CO_2. The glasshouse temperature is well above the target, yet heat is continuously supplied. To counteract the rising temperature, vents are wide open.

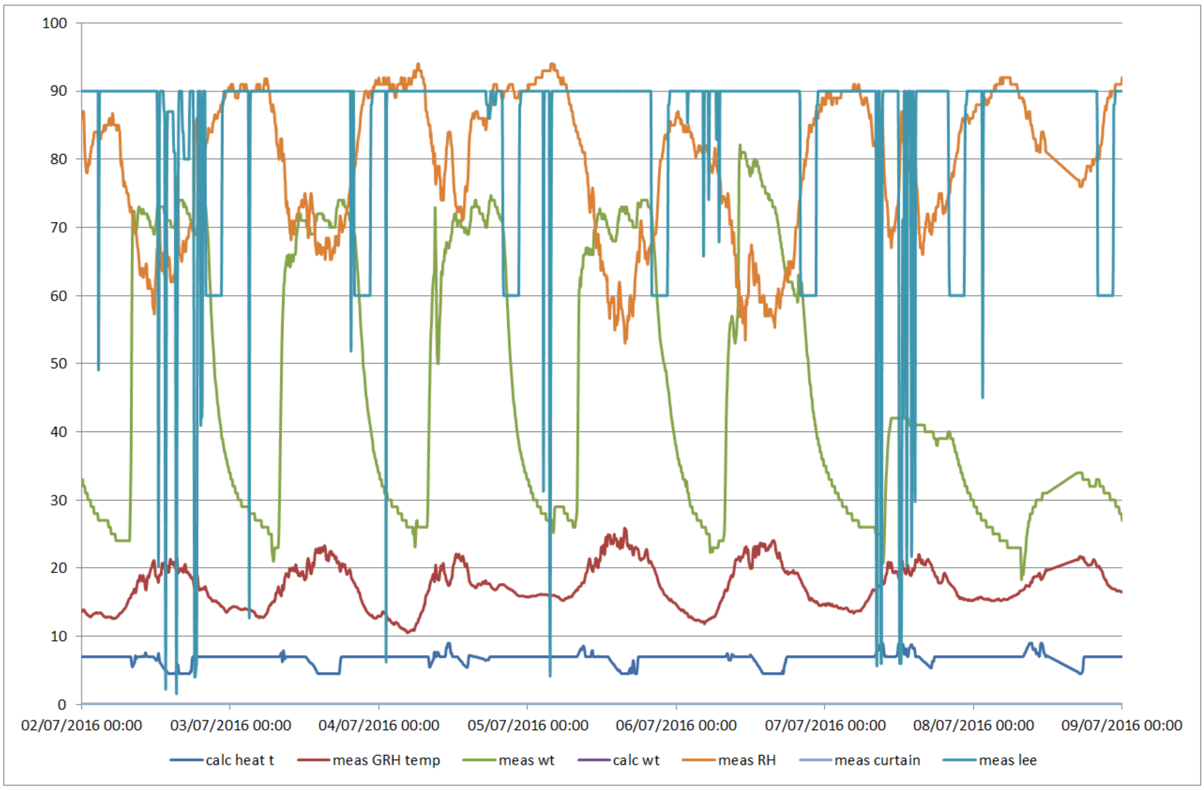

Figure 11: Example of heating for CO_2

Discussion

Analysis of the data collected from the monitored sites showed various climate settings that could be optimised. The climate data were considered primarily with regard to potential energy savings, which could be achievable through improved climate control strategies. Some examples of how the controls could be improved are given in this section.

On-site monitoring

Both of the observed sites had several blocks of glasshouses, each with their own boiler and heat distribution system. However, not every block had the same level of system monitoring in place. For some, no boiler or heating pipe temperatures were available, so the system operating profile could not be determined from the data. Without this information, it is difficult to evaluate how efficiently the system is being operated. **It is recommended that each boiler is monitored by the system to allow each glasshouse to be optimised individually.**

From the data collected, it was possible to see instances of target temperatures being exceeded. On a hot summer's day, this might be unavoidable, despite the use of vents and screens. On such occasions, however, the heating system is not operating. Of more concern, from an energy efficiency perspective, are the days when the heating system is running and glasshouse temperatures exceed the target. The collected data have shown that it is fairly common practice to vent the excess heat, allowing the internal temperature to fall. In essence, this heat has been wasted. Even more extreme scenarios have also been observed: with the heating system operating continuously, vents are left open, leading to a constant flow of heated air out of the greenhouse. It is difficult to quantify the amount and value of heat lost in this way over any given period of time, but there is certainly a significant financial cost.

Some growers argue that this method of operation is necessary, as it is for control of humidity rather than temperature alone. For some, relative humidity is the primary factor in climate control, and glasshouse managers strive to ensure RH stays within a tight band (e.g. 65-70%). While this may be the optimal level for the plant, some consideration should still be given to the financial cost of this way of working. **An economic evaluation should be carried out comparing the cost of energy for RH suppression versus the value added in terms of crop quality and yield. While it might not be best practice from the perspective of energy conservation, it may be financially more profitable.**

Nevertheless, **alternative and improved methods of humidity control should still be investigated**. These should include:

- **Dehumidifiers in the glasshouse and both their capital and ongoing running costs.** Dehumidifiers convert the latent heat from high humidity air to sensible heat and remove moisture directly from the air without the need for venting
- **Fans (vertical and/or horizontal) to achieve a more even temperature and humidity distribution**. Regions of warm air are typically found around the heating and grow pipes. Although this warm air will rise naturally through convection, there can still be a temperature gradient across the glasshouse. The continuous movement of air around the glasshouse can help to eliminate these issues. In addition, a more even distribution of temperature should result in more even humidity. Problems potentially arise when there is humid air around the plant, especially if the plant temperature begins to drop, allowing condensation to form on the leaves. This can lead to various diseases and loss of the crop
- **Optimised temperature sensing.** If a temperature sensor is located close to a heat source, this could lead to vents opening or the heating system shutting off early, before the ambient temperature has truly reached its target. Conversely, if a sensor is located in a colder region, the heating system could continue to run beyond what is required, ultimately using more fuel than necessary
- **Optimised use of screens.** The use of screens can play an important role in controlling temperature and humidity. Closing the screens will reduce heat loss through outgoing longwave radiation, but can cause humidity and temperature to rise to undesirable levels. Therefore, it is advisable to leave a gap of around 10% between the screens – sufficient to reduce heat loss while maintaining plant activity and to prevent humidity from rising to problematic levels

An overview of new applicable technologies

In discussion with growers and suppliers and during the study tour, it soon became evident that there is significant overlap in technology which can be utilised by both protected edible and soft fruit sectors. The degree to which this overlap increases is linked to the adoption of more controlled environment techniques and the drive towards all-year-round production of crop. Some of these applicable technologies and the rationale for their use is set out here.

Lighting

Light is generally considered to be one of the most important factors for production in glasshouses. It is a source of information for plants, with intensity, direction, day length and spectral composition all playing a role. During the course of the growing season, it might be desirable to increase the amount of light a crop receives. This can be achieved through assimilation lighting, which is used to promote crop growth, lengthen the cultivation period and to advance the season, often with the aim of harvesting the crop during the winter when prices are highest.

High pressure sodium (HPS) lamps are still the industry standard at present, but LEDs are growing in popularity. In regions where light emissions are regulated (e.g. the Netherlands), many growers opt to keep screens closed at night when the lights are on. With HPS lighting, however, this can lead to a build-up of heat, sometimes in excess of what is good for the crop. Quality issues can arise if plant temperatures become too high.

Whereas HPS lamps radiate significant amounts of heat, LEDs are cooler and can be placed much closer to the crop canopy. LEDs radiate much less heat to the front, but conduction should not be ignored. High-power LEDs may even require a cooling system (Horst, 2017).

Unlike HPS and other conventional lamps, LEDs allow a more versatile strategy of control, as they can be turned on and off rapidly, are dimmable and can be selected to output specific wavelengths.

It is important to consider the application for which assimilation lighting is required. A plant factory, for example, might be dependent solely on artificial lighting. A greenhouse, on the other hand, will make use of background solar light, but might require additional lighting when levels of natural light are low and at night.

Different lighting strategies are required at different points during the growing season. Photoperiodic lighting, used to change plant physiology by stretching the length of the day, is only used for three to four weeks of the year. Tungsten lamps remain the most economical choice, as the low usage figures preclude LEDs as a viable option.

Photosynthetic lighting, used to promote crop growth, is more likely to be used year-round. Both LEDs and HPS can be used, with setups often consisting of a combination of both.

Cyclic lighting favours LEDs. They are well-matched to this method of operation, which could see the lights being switched on and off every 15 minutes, for example. Full output is available from LEDs instantly, whereas filament lamps would take longer to respond.

A lighting profile during winter (January - March) could look as follows:

- 00:00 - 10:00 lights on
- 10:00 - 17:00 lights on if required
- 17:00 - 00:00 darkness

A minimum of seven hours of darkness is recommended, meaning a maximum of 17 hours of lighting per day (Fabri & Vandevelde, 2017). The timing of this profile avoids running during peak hours (17:00 - 20:00), when electricity prices are highest.

The colour and hence wavelength of light is a key factor. Plants require a combination of red and blue light for growth, although the proportion of each varies depending on the crop. Red light drives photosynthesis, while blue light stimulates the stomata to open so carbon dioxide can be absorbed (Davis & Gunn). However, timing is also important; during propagation of plants, the opening of the stomata can lead to dehydration and increased stress levels.

Typically, LEDs used for tomatoes emit 95% red light and 5% blue light, but recent trials have investigated the effects of using 10% far-red light, 85% red and 5% blue. Far-red light is important for plant development, tending to affect plant height in particular in sensitive crops (Davis & Gunn).

When considering lighting, regard should be given not only to lamp performance, but also to crop response. Energy efficiency and spectral output are important factors, as is cost, especially when compared with crop benefit and any necessary modifications to infrastructure.

CO_2 enrichment

Carbon dioxide is required for plant growth and is usually supplied to the crop through perforated plastic tubes. Sources include pure CO_2 from an external supply, and flue gases from on-site heat generation (e.g. CHP engines, gas/biomass boiler).

Pure CO_2 can be bought in liquid form and stored in large storage tanks, an example of which can be seen in Figure 12. From there it is vaporised, requiring a heat supply of around 80°C, and distributed around the site as required. Consideration should be given to the cost of the CO_2 itself, as well as storage costs, which typically include tank hire, maintenance and cooling. An advantage of using pure CO_2 over flue gases is that there is no associated heat production in the summer.

Figure 12: CO_2 storage tank

CO_2 can also be self-supplied, from an engine or boiler on site, where the flue gases contain significant levels of carbon dioxide. In order to make it suitable for distribution within an enclosed environment, it is essential that the CO_2 is extracted from the flue gases, or that the flue gases do not contain any harmful or undesired substances, such as carbon monoxide or nitrous oxides. In addition, the flue gases must also be cooled to an appropriate temperature before the CO_2 can be distributed through the plastic pipework. This is done either by mixing the flue gas with fresh air, or by passing it through a flue gas condenser. The latter has the advantage of removing most of the water vapour, which would otherwise contribute to increasing the humidity of the glasshouse (Adams, Langton, & Plackett, Energy management in protected cropping: management of CO_2 enrichment, 2009). The condenser pump needs to be kept running during this method of supply.

Although carbon dioxide is a by-product of heating, the cost of CO_2 can really only be calculated if the boiler is running solely for the purpose of CO_2 enrichment. This can greatly increase annual energy use, in which case it is important to ensure that the benefits outweigh the costs. Depending on the fuel type and price, the cost of self-production of carbon dioxide can vary widely; production through the combustion of natural gas, either in a CO_2 burner or a boiler, would cost, respectively, in the region of £74 - £84/tonne of CO_2 produced, based on a fuel price of 1.7p/kWh (GrowSave, 2017).

Enrichment of the crop through the supply of CO_2 is a complex process. Although monitoring CO_2 levels and the method of delivery are relatively simple processes, studies at Proefcentrum Hoogstraten emphasise the importance of understanding the growing conditions of the crop. While it might be desirable to maintain 900ppm during the day, with supply controlled by sensors, it is important that climate conditions are conducive to CO_2 uptake. When temperature is high and relative humidity is low, the plant stomata are likely to be closed. This means it is not possible for the plant to take up CO_2, so there is little point in supplying it under these conditions.

Diffuse glass

The principle of diffuse glass is to increase the penetration of light throughout the crop. It achieves this by increasing the rate at which light is scattered, referred to as haze; the higher the haze, the better the scattering through the crop. This can be advantageous for tomatoes, but not significantly for peppers or strawberries. Comparisons of diffuse and standard glass have found that the level of light transmission is approximately the same (Merkens, 2017). An example of a structure with diffuse glass can be seen in Figure 13.

Figure 13: Glasshouse with diffuse glass

Trials under diffuse glass at Proefcentrum Hoogstraten have seen an increase in production of around 3%, but this tends to be during the summer when the financial benefit is lowest. The economic viability of diffuse glass should be carefully considered. The increased cost over standard glass is significant; therefore, if crop yield is only increased by a small percentage, it could be difficult to justify the cost due to a lengthy payback period. However, where safety glass is currently used, as is required of growers in the Netherlands, the difference in price is considerably smaller. This could make diffuse glass a more attractive option if there is some increase in crop yield or quality.

Air circulation & exchange

Vents are frequently used as the primary method for dispelling excess heat and humidity from a glasshouse. Data collected from the monitored sites highlights this fact, showing simultaneous heating and venting, with the aim of reducing RH. From an energy consumption perspective, this is not efficient practice. Discussions with growers, however, indicate they may be prepared to make this trade-off of additional heat use (and cost) to facilitate more favourable growing conditions. Humidity control is certainly necessary to help prevent fungal disease and to ensure active plant growth, but there are alternative methods available.

When the exchange of air between the glasshouse and outside is desirable, vents should be used. This might be necessary when glasshouse humidity reaches a pre-determined level, although there is no control over the temperature of the incoming air. According to work by Adams et al., the most energy efficient way to control humidity is to vent first, then re-heat the air to maintain temperature (Adams, Langton, & Plackett, Energy management in protected cropping: Humidity control, 2009). The cost of heating air for humidity control is not insignificant. However, figures by Adams et al. indicate that overall energy use could be reduced by around

12% if control of target RH is relaxed from 85% to 90%. Frequent adjustment (i.e. opening and closing) of vents can also lead to high levels of wear and tear, reducing their working life.

An alternative approach to venting warm air and heating the cooler incoming air is to use a heat exchanger, an example of which is shown in Figure 14. This way, heat from the outgoing air from the glasshouse is transferred to the incoming ambient air, meaning considerably less energy is required to bring the glasshouse back up to temperature. Trials at Proefcentrum Hoogstraten suggest energy savings of up to 80%.

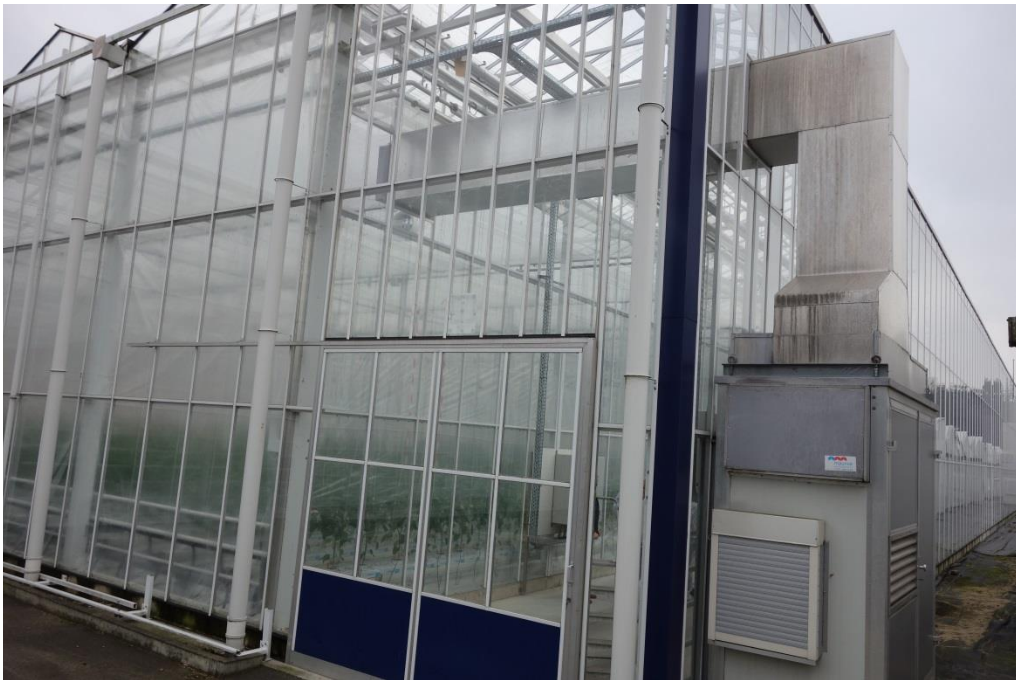

Figure 14: Incoming air heated through a heat exchanger

Another option is a semi-closed glasshouse, which reconditions and recirculates the air. While this style of operation is not necessarily the most energy-efficient option, it allows a homogenous climate within the glasshouse to be achieved. The primary benefit of a semi-closed system is better pest and disease control. Anecdotal evidence indicates that this can lead to higher quality produce, with small improvements in energy consumption and yield (Hortidaily, 2017).

Venting and air exchange is not always the ideal solution. Instead, air movement can be used to alleviate issues such as the build-up of air with high relative humidity around the crop. It is often the case that high RH is a localised problem, which, in fact, could be solved simply by mixing and redistributing the moist air around the glasshouse. If the majority of the glasshouse air is of an acceptable level of humidity, the use of fans (both vertical and horizontal) can help to even out RH. It is important to understand that fans have no effect on the moisture content of the air. Removing moisture is only possible by introducing cooler, drier air from outside or through dehumidification. Only when the average RH of the glasshouse becomes critical should air be either heated or vented. To achieve this, good placement and distribution of sensors is necessary.

Screens

Different types of screens exist for use within glasshouses, ranging from fixed blackout covers to retractable energy-saving (thermal) screens. The use of screens can contribute to significant energy savings, through reductions in heat demand. Modern screens can offer good insulation, while allowing transmission of light and moisture.

Retractable energy-saving screens can be very effective. Data from Adams et al. indicate that an instantaneous energy saving of around 40% is possible, while up to 80% of direct light is still transmitted through the screen (Adams, Langton, & Plackett, Energy management in protected cropping: The use of screens, 2009). It was also reported that trials of thermal screens in tomato resulted in a 13% energy saving, equating to an annual saving of around 100kWh m^{-2}. While not directly comparable with soft fruit, similar savings should be achievable.

Shade screens can help to protect vulnerable crops by reflecting solar radiation. This would help to reduce the risk of too high glasshouse temperatures, as was occasionally observed at the monitored sites.

When using screens, consideration should be given to their permeability (for the transmission of water vapour) and their anti-condensation properties. In addition, regard should be given to measuring box location. Adams et al. warn that warm air can collect just beneath the screen, while temperature at the crop can be lower. This can cause the pipe heating to switch off, thus affecting crop quality. Instead, sensors should be located closer to the crop and circulation fans should be used to maintain an even temperature throughout the glasshouse.

Water recycling, irrigation & fertilization

One of the biggest 'take-home' messages from the study tour was how European growers use irrigation and water recycling systems. In the Netherlands, legislation for strawberry production in 2017 limits annual nitrogen emissions from drain water discharge to 133kg ha^{-1} (Grodan & Priva, 2017). This means that water used for irrigation, with high concentrations of fertilizer and salts, is recycled. As a result, fertilizer and water consumption are dramatically reduced, leading to significant cost savings as a result. For reference, water usage per kilogram of tomato produced in a glasshouse with water recycling is around 15 litres, compared with 22 litres without recycling (Grodan & Priva, 2017).

The widespread use of bio-beds (see Figure 15) and Vialux systems may have been led by legislation initially, but they have since proved their worth in terms of financial reward. Ongoing savings, through reduced consumption of consumables (e.g. water, fertilizer), mean such irrigation systems pay for themselves relatively quickly.

Figure 15: Bio-bed filtration system

Even though there is no mandate at present for growers in the UK to recycle their drain water, best practice guidelines recommend growers to utilise such methods.

Conclusions

In talking to leading growers, technology suppliers and reviewing the experiences from the project study tour, there is no doubt that the technological overlap between the soft fruit sector and the existing high temperature fruit/vegetable production sectors is significant and is increasing.

Essentially, technology requirement is driven by the requirement of the plant. When its production is extended beyond natural growing seasons, the infrastructure and techniques which are employed for tomatoes and peppers etc. become just as applicable to soft fruit.

Similarly, the environmental control management skills and understanding of the dynamics of psychrometry are equally important to soft fruit growers.

What is different between the sectors is the application curve of the technologies and skills. With the established high temperature protected edibles sector, the refinement of these components has been on-going for decades and, although still relentlessly progressing, can presently be regarded as being at a high level.

Soft fruit applications are not as mature, mainly because of the later development of the market, but it is clear that there is a growing demand and commercial need to catch-up. Conversations with the more forward-thinking growers and evidence of how overseas exponents are using technology reinforce this observation. However, environmental management skills are possibly lacking. The monitoring work on a small number of sites shows that energy is being wasted through choosing management practices which, although delivering a successful crop, might not be achieving the lowest energy cost.

There seems little doubt that the topics traditionally covered in GrowSave have almost universal application for soft fruit. In fact, there seems little point in listing technologies like lighting, climate control, combined heat and power, screens, CO_2 enrichment etc. to identify congruence, because they all seem to be relevant.

Possibly the only question is about the extent of influence in the UK soft fruit sector. No doubt, the bigger investors in technology can benefit from GrowSave information, but there will be many – perhaps the majority - who do not, at the present time, employ the hi-tech facilities of their larger production partners. Although a GrowSave push for soft fruit might only touch a small proportion of growers in terms of its day-to-day applicability, it may well have a more important role in leading the way: encouraging and giving confidence and capability for growers who are about to embark into extended season growing.

The study tour revealed a soft fruit sector in Belgium and the Netherlands which is more advanced in the use of glasshouse environmental technologies than the UK. The widespread use of technologies in European glasshouses, such as water recycling, LED lighting, control and CO_2 use suggests a high level of investment in modern growing techniques. The impact of these new techniques is measured by comparing crop yield and quality with historical data, before any modifications are made. The efficacy of each technology varies depending on the type of crop being grown. UK growers, meanwhile, tend to adopt more traditional methods, with considerably less reliance on technology.

It is reasonable to conclude that, if UK growers are to get the best information available on controlled environment growing technique in protected structures, then information exchange through study tours, technical reports and imported training needs to happen on a regular basis.

The monitoring of sites revealed some common mistakes in environmental management. It would be unfair to blame these necessarily on the inexperience of the sector, as some of these errors are not uncommon with the more developed high temperature edibles sector. Nevertheless, it seems likely that, where training on the subject of environmental technologies has not been targeted at this sector, basic skills are bound to be lacking.

Further work and recommendations

The conclusions arrived at here support an extension of GrowSave sector-based services to soft fruit. In simple terms:

1. The developed energy-based technologies promoted in the high temperature protected edibles sector are virtually identical to those being adopted by the soft fruit sector and, as such, GrowSave content is transferrable to soft fruit.
2. On existing content, work is needed to package GrowSave content in the context of soft fruit production, otherwise growers may not become engaged with the messages, as they might see them as irrelevant to their sector. A specific ‘soft fruit’ section of the website and communication targeting technical news and events at soft fruit growers is required to engage a soft fruit sector audience.
3. Data on energy use of performance needs to be gathered, so realistic benchmarking can be carried out within the sector. Sharing of climate data between growers can be useful, allowing them to learn from each other and assess the impact of different technologies. Possibly, some sponsored intensive studies of soft fruit energy use could be used as a talking point to engage growers.
4. Basic training on environmental concepts, control and equipment can be provided as part of GrowSave based on previous programmes in other sectors, with tweaks to make the content particularly relevant to the soft fruit sector; e.g. workshops on humidity control and air movement.

5. Site based workshops and study groups should be considered for the sector.
6. The proposed Next Generation Growing (NGG) study groups project, which GrowSave is planning to trial with participants from the Horticulture sector is another approach that could easily be transferred to the Soft Fruit sector. (The principles of NGG focus on improving crop growing conditions by providing the plant with what it needs at any given time, rather than trying to force the crop to grow under 'idealised' conditions.) While energy saving is not a target of NGG per se, it is often a by-product of more efficient and effective growing methods. The principles of Next Generation Growing can, broadly speaking, be applied to any crop grown under glass.
7. Some form of regular international technology 'barometer' needs to be instigated. European competitors in general would appear to be nearer the cutting edge of energy applications in protected horticulture and the study tour has revealed that developments in the high temperature vegetables sector quickly finds itself being trialled in soft fruit. Contact could take the form of an expert mentor, further specific study tours, organised visits to events and shows or guest experts in UK training events.

Impact assessment

The best available data for energy consumption in protected soft fruit production comes from participants in the Climate Change Levy Discount Scheme, operated by the NFU on behalf of energy intensive growers in horticulture. There is still a limited amount of data available within this scheme – 12 growers participate whose facilities have a majority of soft fruit production. The combined area of protected cropping of the growers in the scheme is 55 hectares, equivalent to 25% of the industry. The data available on energy consumption is shown in Figure 16.

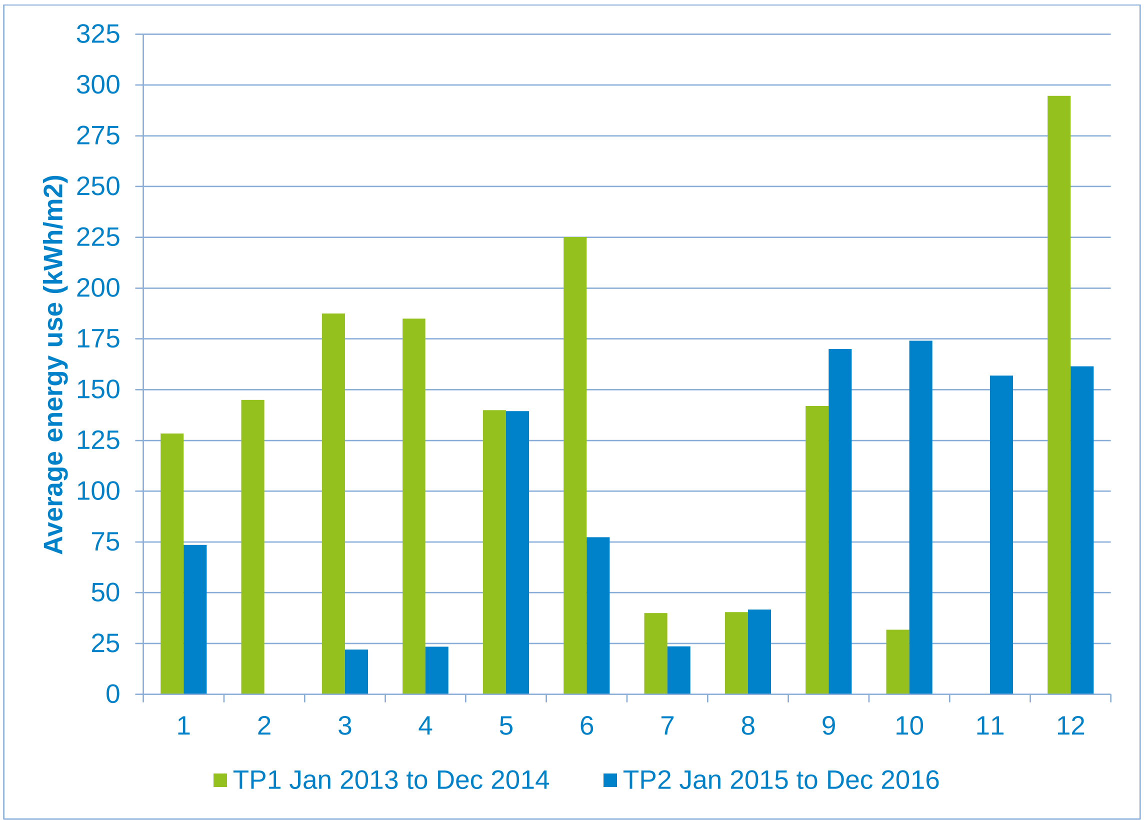

Figure 16: Annual energy consumption average for CCL scheme Target Periods 1 & 2

Figure 16 shows there is a big range in achieved energy consumptions with a difference of 250kWh m^{-2} in TP1 (January 2013 - December 2014) and 150kWh m^{-2} in TP2 (January 2015 - December 2016). The mean consumptions are 141kWh m^{-2} and 97kWh m^{-2}, whilst the median values are 141kWh m^{-2} and 77kWh m^{-2} for TP1 and TP2 respectively.

Assuming that, in the future, glasshouse soft fruit production has a mean consumption of around 125kWh m^{-2}, and applying this to 225 hectares of glasshouse production, the energy consumption of the sector can be estimated at around 281GWh per annum. At an energy cost of 2p/kWh, this is a cost to the industry of £5.6m. This assessment does not account for any energy use in polytunnels, which historically have been largely unheated, although the advent of the renewable heat incentive has caused a forward thinking subset of the industry to install biomass boilers to extend the growing season.

With this in mind, it is possible to apply some energy saving contributions to the sector. Next Generation Growing claims that 35% of the energy used in glasshouse production can be saved through wholescale implementation of the techniques. This would represent an annual saving of nearly £2m at today's energy prices, although there would need to be significant capital investment for some sites to achieve these levels. A more realistic aim to save energy through application of existing knowledge, benchmarking and targeting savings and practical implementation of low cost techniques could realise around 10% savings to the industry (circa £560k per annum). These savings would be those that GrowSave would target in the initial year's extension of the programme to the soft fruit sector.

A draft outline of how GrowSave could be expanded into the soft fruit sector is presented in Table 2 in the Appendix.

Appendix

Table 2: Outline of proposed GrowSave expansion into soft fruit

Title	Description	Quantity	When
Literature review, rewrite in SF terms	Review literature, specifically technical updates in first instance to re-focus in terms of SF production. Key topics include humidity control, CO_2, temperature control etc.	3 per year	Annually
GrowSave news	Expand the distribution list to SF (50 additional copies). No additional writing required.	3 per year	Annually
Website	Dedicated section of GrowSave website to SF sector. Requires adaptation of existing content.	Ongoing	From start
Benchmarking	Some simple data sharing (anonymous) required to gather benchmark data over and above what is currently available. New work required using existing metrics.	Ongoing	Year 2 onwards
Climate control workshops	Basic, fundamentals of energy use and energy management in glasshouse production. Delivered by FEC Energy staff using content from prior GrowSave events.	2 per year	Carried out in Year 1 and 2
Proefcentrum relationship	Establish a relationship with key personnel at Hoogstraten research centre to help bring EU knowledge to UK production.	Ongoing	Start in Year 1
Focus nurseries	Embark on a set of workshops, centred around focus nurseries highlighting areas for greater attention. Use model from past GrowSave events.	1 per year	Year 2 and 3
NGG dissemination and more advanced climate control	Translating information through study groups or extension of focus nurseries into practical steps to improve energy and climate control. These to piggyback on PE/PO groups where possible.	Study group	Year 3 onwards

LetsGrow.com integration	In support of the focus groups, NGG and benchmarking suggestions, to provide SF dedicated group for climate data sharing.	Ongoing	Year 2/3 onwards
Netherlands/Belgium study tours	Similar to study tour carried out in January 2017 to identify further knowledge gaps and collect new thinking.	1	Year 2/3

Glossary

AH Absolute Humidity

CHP Combined Heat and Power

CO_2 Carbon Dioxide

HPS High Pressure Sodium

LED Light Emitting Diode

NGG Next Generation Growing

OLR Outgoing Long-wave Radiation

ppm Parts per million

RH Relative Humidity

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