Grower Summary

CP 085

Securing skills and expertise in crop light responses for UK protected horticulture, with specific reference to exploitation of LED technology (EMT/HDC/HTA Fellowship)

Final Report 2017

Horticultural Fellowship Awards

Final Report Form

Project title:	Securing skills and expertise in crop light responses for UK protected horticulture, with specific reference to exploitation of LED technology (EMT/AHDB/HTA Fellowship)
Project number:	CP 085
Project leader:	Dr G M McPherson, STC
Report:	Final report, 2017
Previous report:	4th Annual report, Nov 2016
Fellowship staff:	Dr Martin McPherson, Science Director, STC (Lead Fellowship mentor) Prof. Nigel Paul, Lancaster University (Mentor)
(“Trainees”)	Dr Phillip Davis, Business Manager,
Location of project:	Stockbridge Technology Centre
Industry Representative:	Chis Plackett, FEC Russel Woodcock, Bordonhill James Bean, Crystal Heart Salads Neal Wright, Micropropagation Services Simon Budge, VHB Ltd (Herbs) Colin Frampton, Consultant Steve Carter, PO Geoffrey Smith, Mapleton Growers (PE - Lettuce)
Date project commenced:	1 October 2012
Date project completed	30th September 2017

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Dr Phillip Davis
Project Manager
Stockbridge Technology Centre

Signature .... Date ....

Report authorised by:

Dr Martin McPherson
Science Director
Stockbridge Technology Centre

Signature .... Date ....

Progress Against Objectives

Objectives

Training

Objective T1. To provide the Fellow with the knowledge, understanding and practical skills to undertake applied plant science in the area of plant light responses, lighting and cladding materials.

Objective T2. To establish the Fellow with a network of contacts within the major commercial producers of horticultural LEDs (and cladding plastics).

Objective T3. To establish the Fellow with a network of contacts in the science base in fundamental and applied plant photobiology in Europe and beyond.

Objective T4. To provide the Fellow with a solid appreciation of the “business basis” for horticultural R&D, including aspects such as staffing, costings and the range of possible funding routes.

Objective T5. To establish the Fellow with a network of contacts from the industry, including applied horticultural consultants currently active in supporting UK protected cropping, and through their respective technical groups, representatives of the major protected cropping sectors in the UK.

Objective T6. To expand the training objective of the fellowship program enabling Dr Davis to train other members of the team at STC. Much of this training, during 2015 and 2016, was given to Dr Beynon-Davies. This training has been highly successful and Rhydian moved to a new role at G’s/Harper Adams. This fellowship has also provided opportunities for several students at different stages of their careers to gain experience in the use of LEDs for horticultural purposes. Tom Watkins, an under graduate student at Askham Bryan College performed a research project titled “A study on the benefits of using LED for HPS lighting systems in ornamental plant production” at STC in parallel with some of the trials that were performed in the CP125 project. We have hosted several undergraduate students for 9 month placements at STC during which they have gained experience with LED lighting systems. Dr Davis has co-supervised three PhD students during the fellowship, Dr Richard Boyle at Lancaster University (an AHDB studentship), Kayla McCarthy at York University and Gulce Onbasili (an AHDB studentship) at Lincoln University.

Research

Objective R1. For the fellow to undertake an initial, objective review of current developments and progress in lighting technology with support from the leading manufacturers and including a brief fact-finding tour overseas.

Objective R2. To objectively assess the properties of a selection of LEDs currently available or proposed for use in UK horticulture in terms of total irradiance (intensity), spectrum, efficiency and response to dimming.

Objective R3. Based on R1 and R2 to identify gaps in current scientific knowledge with respect to crop responses (using existing Arabidopsis light response knowledge) to LEDs relevant to UK production and to undertake pilot-scale experiments into the responses of selected UK protected crops (particularly leafy salads, ornamentals & herbs) to LEDs found to have useful properties in R2. Information obtained under R3 will identify the potential of appropriate lighting systems for specific UK crops. The knowledge gained will be used to design further R&D studies, subject to additional external funding, for future commercial implementation in the UK (See Objective R5).

Objective R4. In addition to the Fellowship reports, to produce (i) a technical review of the "state-of-art" of LED lighting in Horticulture, (ii) an article in HDC News summarising the results of the Fellowship and the current status of LED lighting in horticulture and (iii) to participate in a programme of visits, workshops and conferences for growers, including those at the new STC facility.

Objective R5. This fellowship is intended as being a major element in securing long-term R&D in to LEDs (and other light-based approaches to production) in UK horticulture, but does not in itself deliver a major "stand-alone" research programme.

Objective R6. In the current research environment, there is a growing need to increase collaboration between organisations like STC, Universities and industry. In order to develop links with Universities it is necessary to further develop my scientific credentials through publication of our research in academic journals. This will both boost awareness of our research in academic circles but also demonstrate our scientific expertise in a manner that can be quantified.

Objective R7. The skills necessary to acquire project funding and run lighting projects are currently in development under objective R5 and through management of the 'Understanding crop and pest responses to LED lighting to maximise horticultural crop quality and reduce the use of PGRs' (CP125) project. However, this program will be expanded to encompass development of collaborative projects with Universities and companies both within the UK and as part of EU projects. Developing collaborative projects will require increased interactions with the network of contacts developed in training objectives T2-T5.

Objective	Original Completion Date	Actual Completion Date	Revised Completion Date
Objective T1.	December 2012	December 2012	
Objective T2.	December 2013	This is an on-going exercise as new companies move into the area.	September 2017 and beyond.
Objective T3.	December 2013	Trainees have made many contacts across the industry and this will be an ongoing exercise.	September 2017 and beyond.
Objective T4.	December 2013	This process will continue throughout the fellowship	September 2017 and beyond.
Objective T5.	December 2013	This process will continue throughout the fellowship	September 2017 and beyond.
Objective T6	September 2017	September 2017	-
Objective R1	December 2013	February 2013	-
Objective R2	January 2013	March 2013. Completed at Lancaster university and continued through contribution to CP 139 with Prof. Pearson (Lincoln Uni).	-
Objective R3	December 2013	This work contributed to the development of the CP125 research project as well as other efforts to gain research funding via multiple routes including commercial, EU, N8, research council and CHAP projects.	
Objective R4	December 2016	August 2015 and ongoing. This work resulted in the AHDB Lighting Technical guide package, published in 2015, an	

		academic publication (Davis & Burns 2016) and several AHDB grower articles.
Objective R5	September 2017	Dr Davis developed the CP125 project and is continuing to develop new projects based on ongoing research activities, interactions with growers, other researchers (in UK and beyond) and as new technologies hit the market.
Objective R6	September 2017	Considerable efforts have been made to create new links with UK researchers and develop collaborative research efforts. We have received funding for three N8 research projects and are planning future research council funding bids.
Objective R7	September 2017	Dr Davis's efforts have resulted in STC receiving funding via 3 EU projects. Additional EU projects are currently under review. Political changes in the last year have created some challenges in this area but we will continue to explore routes for new funding opportunities.

Summary of Progress

In its final year, this Fellowship has continued to progress well and a substantial amount of knowledge has been gained regarding plant light responses as well as the economic implications that LED lighting systems have on the industry. Dr Davis has completed a three-year AHDB funded research program CP125 which has answered many questions regarding crop and insect responses and highlights relevant areas of future research. Dr Davis has become the go to person for information on LED lighting systems for horticulture and is regularly contacted by companies and growers for information. Dr Davis has developed a network of contacts at UK Universities and has several collaborative projects underway and in development. Dr Davis is currently co supervisor of two PhD students. Dr Davis has also continued to develop his network of contacts at research centres throughout Europe and has been involved in several applications for EU funded projects. He is involved in the EUVRIN network as a steering committee member for the working group on Greenhouse Crops. Dr Davis has engaged with several University research groups to explore opportunities for new research projects. To date he has received funding for three N8 research projects which will hopefully lead to further funding opportunities. STC's involvement in the Crop Health and Protection (CHAP) innovation centre has provided Dr Davis with additional networking opportunities and has provided funding for the development of a new LED facility providing additional capabilities to STC facilities.

Milestones not being reached

None

Do remaining milestones look realistic?

NA

Training undertaken

Conferences attended (those attended in the last 12 months)

September 2016.

Dr Phillip Davis attended the LpS 2016 conference and present at the Hi LED project workshop. *Plant light responses and their manipulation for horticultural purposes*

October 2017

Dr Phillip Davis presented at the CGA. *An update of LED work at STC.*

February 2017

Dr Phillip Davis gave a presentation at Liverpool University. *Lighting the future of horticulture.*

May 2017

Dr Davis gave a presentation at the Horticulture Technologies event held at Teagasc, Dublin. *Lighting the future of horticulture.*

Dr Davis presented at the Horticulture Lighting conference Europe . *Lighting the future of horticulture.*

Dr Davis presented at the Waitrose Farm Assurance Meeting. *Lighting the future of horticulture.*

June 2017

Dr Davis presented at CRD. *Urban Farming*

July 2017

Dr Davis attended an N8 conference at Durham University.

Expertise gained by trainees

The work performed for the fellowship this year has increased Dr Davis understanding of the economic impacts of LED lighting systems.

Dr Davis has developed the skills to lead and direct commercial R&D projects and manage research teams. Through these interactions he has gained the ability to build collaborations and make links between companies that have common business goals.

Dr Davis has kept up to date with the advances in LED technology and the growing availability and diversity of lighting systems for horticulture.

Involvement in bids for EU funding has helped develop Dr Davis' understanding of international collaboration and funding. The political issues that have been created in the last year has created considerable uncertainty in this area but we will continue our efforts to remain involved in the EU R&D and maintain our contacts.

Dr Davis has continued to keep up to speed with changes in funding strategies at AHDB to ensure he is able to make successful applications as part of collaborative projects.

Other achievements in the last year not originally in the objectives

Dr Davis has received EU funding as part of a larger international project called TomRES. This project will be investigating breeding new tomato varieties with resistance to combined water and nutrient stress.

Dr Davis has received Innovate funding as part of team aiming to develop a robot tomato harvester. This project encountered difficulties due to the withdrawal of the main project partner. Dr Davis used his growing contact base to rebuild the project with new partners, this project is ongoing and will be completed in February 2019.

Dr Davis is involved in a small EU funded cereal trial examining the use of biopesticides to control wheat fungal diseases.

Dr Davis has performed several consultancy contracts on highly diverse range of projects involving lighting systems.

Dr Davis has engaged with several research groups in the N8 Universities and has received funding for three projects. These small-scale projects will create preliminary results that will enable development of larger project proposals to AHDB or research councils.

Through STCs involvement in the CHAP innovation centre, we have received funding to build a new LED R&D facility. This facility will consist of 2-4 large compartments suitable for production of large quantities of plants and will be able to perform economic assessments of Urban Farms that the current facility was not designed to perform.

Dr Davis is also using his expertise in lighting to aid AHDB-Pork team with their work on optimisation of lighting for different stages of the pig production cycle.

Changes to Project

Are the current objectives still appropriate for the Fellowship?

NA

GROWER SUMMARY 1: Implications of ongoing increases in LED efficacy.

Headline

LEDs continue to increase in efficacy resulting in reduced electricity bills. We have assessed how advances in LED technology impact current and future installation and running costs.

Updated LED calculators have been created that will be available on the GrowSave website.

Background

The use of lighting in horticulture provides many benefits for season extension or year round production. However, while crop yields and quality can be improved with lighting, the costs associated with installing and operating those lights impact on profitability. LED lighting systems have gained considerable interest in recent years due to the potential for reduced electricity usage. The best way to compare different lighting systems is to examine how much light (assessed as numbers of photons) they produce per watt of electricity. This parameter is referred to as lamp efficacy and has units of micro-moles per joule (µmol J^{-1}). The efficacy of LED lighting systems continues to improve and the most advanced LED lamps now achieve an efficacy of 3.0 µmol J^{-1}. However, not all LED systems are made equal and efficacy varies considerably with design and spectrum (AHDB Technical guide, 2015, Lighting: In Practice).

Understanding how the differences in efficacy effect the installation and running cost as well as total electrical load are important when planning large installations. Here we have examined several aspects of LED design and how they influence those costs. In making these calculations we have also revised the calculators on the GrowSave website to account for advances in LED technology.

The energy savings provided by LEDs have created the potential for urban farms (controlled environment rooms with no sunlight) to compete financially with traditional growth systems for production of certain crops. While these systems allow crops to be produced in locations where they could not otherwise be produced, sunlight is free and rising energy costs could disrupt urban farm economics. Solar panels form one renewable source of electricity that could be compatible with urban farms and potentially reduce energy bills. Solar panel technology is advancing at a similar pace to LED technology. While sunlight is free, only 42% of its energy is available for photosynthesis. The best solar panels can convert 46% of the energy in sunlight into electricity (affordable solar panels are currently able to convert up to

22% of solar energy). Here we have explored the potential for combined solar panel and LED technologies to generate more PAR photons than are available directly from sunlight.

Summary

We calculated the maximum theoretical LED efficacy for all colours of light. Red LEDs have the potential to produce almost 50% more photons than blue LEDs because red photons contain less energy than blue photons. Current, red and blue LED technologies achieve efficacies that are about half the theoretical maximum demonstrating the potential for considerable future improvements in LED efficacy. Current green LEDs have considerably lower efficacies and inclusion of green LEDs in lighting systems would be expected to reduce lamp light output. White LEDs currently provide the most energy efficient source of green light, and produce a more favourable light environment for human workers.

As lamp efficacy increases, energy consumption decreases non-linearly (Figure GS1). This means that each increase in efficacy provides a smaller energy saving. So increasing efficacy from 2 to 3 µmol J^{-1} provides an energy saving of 33% but increasing from 3 to 4 µmol J^{-1} provides a smaller, though still favourable, additional 25% saving. In addition to reduced energy saving, increased LED efficacy can result in an increased light output per lamp (assuming the wattage of the lamp remains the same). This means that as efficacy increases, fewer lamps are required to achieve the same light level at the crop canopy (Figure GS2). This should result in reduced installation costs for a given type of lamp.

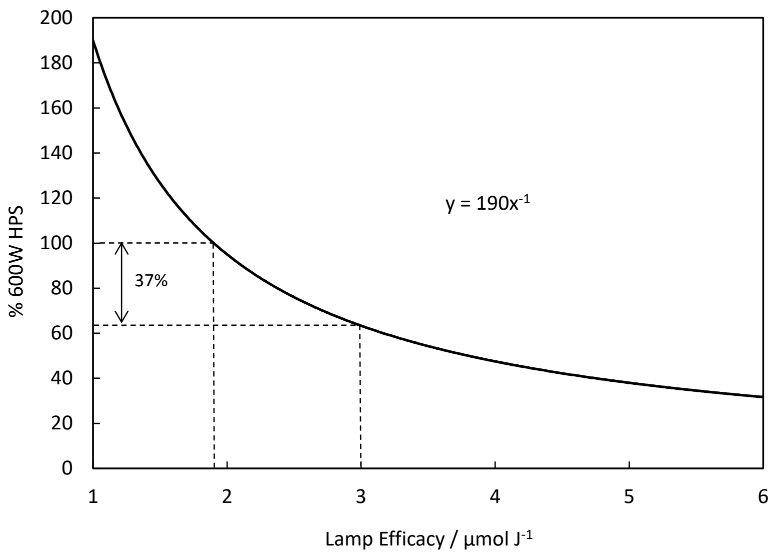

Figure GS1. The influence of lamp efficacy on the electricity requirements expressed as a percentage of the energy used by a 600W HPS lamp. Increasing efficacy from 1.92 (HPS lamp) to 3.0 µmol m^{-2} (Philips Gen 3 inter-light) reduces energy consumption by 36.7%. Note these values are independent of light intensity.

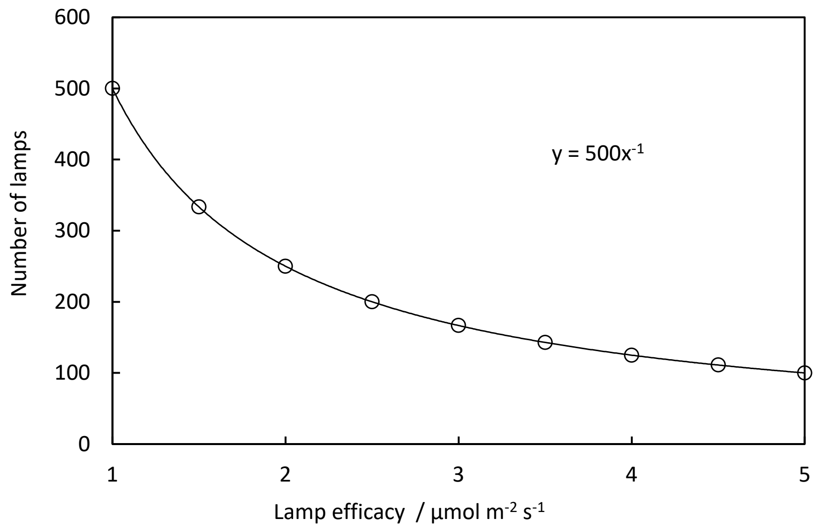

Figure GS2. The influence of lamp efficacy on the number of 40W lamps required to illuminate a $100m^2$ growing area to an intensity of 200 µmol m^{-2} s^{-1}.

While performing the calculations used in this report we have created updated calculators that will be made available via the GrowSave website. These calculators can be used to determine the numbers of lamps required to light a crop to a certain light intensity, how much electricity they would consume and their lifetime cost.

To provide a compelling argument that LEDs and solar panels could provide better crop performance than sunlight alone, the system would need to create at least the same number of PAR photons as sunlight, this is referred to here as 'solar equivalence'. Current commercial technology (LEDs with an efficacy of 3 µmol J^{-1} and solar panels and efficiency of 22%) would only be capable of producing 33% of the PAR photons available in sunlight. The most efficient solar panels (efficiency = 46%) with the best currently available LEDs could produce 70% of the PAR photons available in sunlight. If LED efficacy can be increased to 4 µmol J^{-1}, solar equivalence could be achieved with solar panels converting 48% of the energy in sunlight. While it is expected to be some time before such systems are affordable there is scope in the future for increasing food production through the application of technology.

Financial Benefits

While lighting systems can open new market opportunities or help develop new product ranges, there are significant operating costs due to increased input requirements (installation, electricity and heating costs). The decision to install lighting systems to extend growing seasons has a profound influence on business economics. However, comparing lights with different technologies can be challenging.

The information in this report will help growers understand the implications of different aspects of lighting technologies and how it is expected to alter installation and running costs. It will also help growers put manufacture's claims in perspective with other technologies and make informed decisions regarding selection of appropriate lighting systems.

The extrapolations of the potential future developments in LED technology will help businesses plan for the future. For example, for companies where the economics of winter production do not currently add up, the information in this report could help them determine at what point in the future (at what LED efficacy) the economics shift in favour of installing lamps. Equally, for companies that already have lighting installations, this work can help them decide if or when a new installation makes sense.

The updated calculators (to be made available via the GrowSave website) will help growers to quantify the lifetime costs associated with different lighting systems. Lifetime costs are an important consideration when deciding on large-scale installations as they allow a thorough evaluation of the long term impact on business economics. These calculators will help growers make informed decisions and help them avoid making costly mistakes. The calculators have been revised so they will not go out of date and will remain continually useful.

Action Points

1. Define the aim of the proposed lighting installation. The best choice of lighting system will differ between crops and production systems. If the main aim is to drive biomass and yield, lights with lower percentages of blue light will provide the best choice of lighting. If compact plant morphology is required, a higher proportion of blue light will be required (see CP125 final report and the AHDB lighting guides for more information). As highlighted in this report, the efficacy of lamps is strongly influenced by their spectra and when assessing installation and running costs, the data for the specific model of lamp should be used, don't assume two similar LED systems have the same efficacy.

2. Read the full report including the evaluation of economics of glasshouse supplemental lighting. Additional information can be found in the AHDB lighting Guides. Consult with specialists to help you through the process.

3. Go to the GrowSave website and download the relevant calculator, three are provided, each examining different growing systems (multi-tiered systems, glasshouse supplemental, night break lighting). Follow the instruction on how to use the calculators.

4. The calculators require several bits of information that must be manually inserted (including lamp efficacy in $\mu mol\ J^{-1}$, wattage of each lamp, cost of lamps, cost of installing the lamps, size of production area and duration of lamp usage) they have been created like this so the information within them does not go out of date. All of this information

should be relatively easy to gather from a reputable lamp manufacturer and/or installer companies.

5. Consider small-scale test installations to confirm the lights and crops perform as desired before making large-scale investments. If crop performance is suboptimal, consider whether the spectrum or intensity of the light is appropriate. More information on the effects of light spectrum and intensity can be found in the CP125 project reports and in the AHDB grower guides. If necessary, seek expert support to ensure lighting systems will meet your crops requirements.

GROWER SUMMARY 2: Economics of using supplemental LED lighting in glasshouses

Headline

Advances in lighting technology have the potential to reduce energy bills making winter production more profitable. Such lighting systems will, however, only make economic sense if crop sales are sufficient to cover the costs or deliver some other economic advantage. We have combined a supplemental lighting simulator with a tomato crop model to quantify the cost and yield implications of year round crop production with different lighting systems and energy pricing models.

Background

The use of lighting in horticulture provides many benefits for season extension or year round production. However, while crop yields and quality can be improved with lighting, the costs associated with installing and operating those lights impact on profitability. LED lighting systems have gained considerable interest in recent years due to the potential for reduced electricity usage. The efficacy of LED lighting systems continues to improve; the most advanced lamps now achieve an efficacy of 3.0 µmol J^{-1} which provides a 36% energy saving over 600W HPS lamps. However, reduced energy bills alone may not be sufficient for winter production to return a profit. Many factors impact business economics and many of these factors are site specific. Variability in sunlight is a major factor that impacts crop production and the number of hours supplemental lighting must be operated for to maintain plant yield and quality. Assessing the interactions between sunlight, supplemental lighting requirements and crop yields can be complex but accurate simulations could help businesses decide if or when to invest in lighting technology.

Summary

We have developed a model that can be used to simulate the supplemental lighting requirements of glasshouses based on site-specific light measurements and assess crop yields. The models have been used to simulate the effects of different lighting strategies on cost of production of a tomato crop. Running costs are proportional to the amount of time the lights are turned on and the cost of the electricity. The influence of changing electricity price on operational costs can be easily assessed as running costs vary linearly with cost per kWh. Different lighting strategies, however, result in nonlinear changes in running costs because solar light levels vary nonlinearly through the seasons (Figure GS5). Increasing the efficacy of the lamps reduced costs nonlinearly are shown in grower summary one. With variable electricity pricing, electricity costs were found to peak at 5pm. Avoiding turning the lights on at 5pm had little effect on the overall running costs in these simulations, though these simulations don't account for any penalties that may be encountered by lighting during these periods nor do they account for the potential benefits of exporting electricity during these hours.

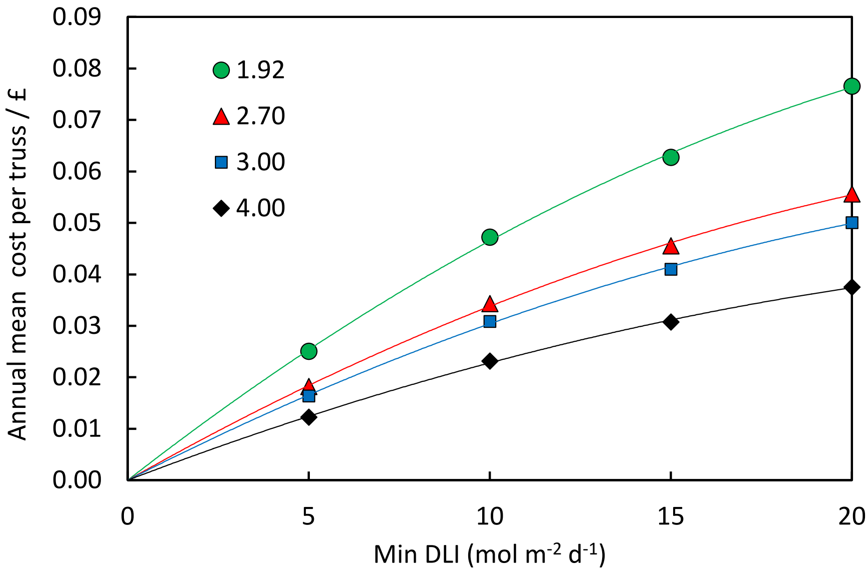

Figure GS 5. Effect of lighting strategy and lamp efficacy (different colours), on the mean annual electricity cost per truss. Electricity price was set to 4.8 p kWh^{-1} for these simulations.

Financial benefits

In the first science section of this report (Implications of ongoing increases in LED efficacy) we examined the running costs of different lighting systems based on their efficacy and provided updated calculators for comparing lighting systems. While those simple calculators provide useful information for comparing different lighting systems they are too simple to assess expected running costs in specific glasshouse systems. Here we have developed a more detailed model that includes a crop performance model. The simulator uses natural light levels to determine the hours of supplemental lighting required to maintain crop performance based on crop light requirements. The simulator includes various electricity costing structures, fixed or variable pricing, and can be used to assess the benefits and costs associated with different lighting systems, lighting strategies and energy costing models.

These models can be used to help businesses quantify the costs of operating lights based on the natural lighting environment at their location. The model is currently parameterised for a tomato crop but can potentially be applied to any crop if sufficient data is available. Energy costs can be calculated based on glasshouse area or on a per sales unit basis (in this case cost per tomato truss). Where lighting systems have been installed and crop data is already available the model can be validated and used to help refine lighting strategies and assess benefits of updating lighting systems or assessing the potential impacts of different energy pricing models.

Action Points

The simulations presented in this report aim to demonstrate the potential of this modelling approach and to highlight the potential for using site specific information to examine the likely impact of different lighting strategies on yield and production costs. To gain insights directly relevant to your site/business the models should be applied to data gathered at your site and be based on likely electricity pricing structures. For access to the models and support, contact STC. For the model to be successfully implemented the following data should be collated:

1) Light data from your site. Half hourly data is ideal but the models can be implemented based on daily light integrals if that is the only data available. If no measurements have been made at the site, other sources of light data may be available.
2) Crop performance data can be used to assess the crop lighting requirements if data can be compared to light measurements made over the cropping period. Data for at least one complete cropping season would be required but model accuracy will be increased if more data is available.
3) An indication of which lighting systems are of interest. STC can also provide advice regarding the benefits of different lighting systems if necessary.
4) Information regarding the energy pricing at your site. This is not necessary but is useful as a starting point. The models can be used to explore how electricity prices impact profits.