Project title:	LED Lighting for Horticultural Applications – Establishing the Economics of Current Hardware Offerings
Project number:	PO 010
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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.

Chris Plackett

Commercial Director

Farm Energy Centre

Signature . Date. …28th November 2012…

Report authorised by:

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Managing Director

Farm Energy Centre

Signature . Date. …28th November 2012…

CONTENTS

GROWER SUMMARY

Headline

- Multi-tier lighting is currently the most promising commercial option for Light Emitting Diodes (LEDs)
- Photoperiod and inter-crop LED lighting would need to demonstrate additional crop production benefits in order to generate the extra income warrant investment
- LED economic calculators can be downloaded from www.growsave.co.uk.

Background

There are currently a number of examples of commercially available LED light sources that manufacturers have developed specifically for horticultural applications. Several leading horticultural companies (located in countries like, The Netherlands, Denmark, Sweden and North America) are investing in these lighting technologies in the following applications:

- Day-length manipulation – as a direct replacement for tungsten lighting over flowering crops, soft fruit etc.
- Young plant lighting – as a replacement for fluorescent tubes in growing rooms or for multilayer growing on of small plants like cuttings, etc. It is also suggested that foliage crops such as herbs and lettuce can be successfully grown with these systems.
- Inter-crop lighting – here arrays of LEDs are placed deep in the crop canopy to stimulate activity from the parts of the plants that are shaded in traditional production systems. Applications are in both the ornamental and edible protected crops (PC) sector with cut flowers and vine crops (e.g. tomato) being the most suitable.

At the moment, little is understood about the economics of using these techniques on UK nurseries.

To provide indications of the likely economics of using the available equipment on UK nurseries, a number of example scenarios have been evaluated for the lighting techniques listed here. In all cases the LED solution has been compared to current commercial 'best practice' using conventional lighting equipment.

Summary

The findings of the work are:

1. **Photoperiodic lighting** - the switch from incandescent (tungsten) light bulbs to the equivalent LED is only financially viable if additional crop benefits worth at least £1.68 /m^2/year are achieved. The LED installation will give energy cost savings of £0.44 /m^2/year, and although this is the biggest contribution to repaying the capital cost of installing LEDs, it is insufficient to give a payback period of five years or less.
2. **Multi-tier lighting –** this is currently the most economically viable application as, when compared to an existing installation using tubular fluorescent lamps, the energy cost savings from LEDs are sufficient to give a payback inside five years. When appraised over a five year project, the costs for the LED installation (including capital purchase, energy and operation and maintenance) are around £13.50 /m^2/year less than the operating costs for the existing installation.
3. **Inter-crop lighting** – this technique is a new innovation that has come to the fore alongside the development of LEDs. When it is used alongside traditional supplementary lighting with high pressure sodium (HPS) lamps positioned overhead, it allows the rating of the HPS lamps to be reduced. This is because the LEDs can deliver light into the plant canopy rather than relying on the ability of the overhead lights to penetrate beyond the head of the crop. Currently the technique is restricted to growing vine salad crops like tomato and cucumber, and with these applications additional income in excess of £42.68 /m^2/year is needed for a project to repay in less than five years. This comparison is made based on the assumption that no supplementary lighting is being used at present.

It is worth noting that, if the lighting in this application is based on overhead HPS alone, and a project payback of five years or less is targeted, the additional income needed compared to ‘no lighting’ is £31.50 /m^2/year. This shows that inter-lighting with LEDs requires an additional £10.18 /m^2/year.

Financial Benefits

The financial benefits of the scenarios and applications tested in the project are given in summary above, however these are indicative only figures based on the assumptions made for the analysis. Growers are therefore advised to carry out similar calculations for their own circumstances using the calculators developed by this project. These are available as downloadable spreadsheets from www.growsave.co.uk. Spreadsheets are available for each of the three lighting applications studied by the project.

Action Points

1. The use of LED for multi-tier lighting is currently the most economically attractive proposition, with applications either in growing rooms or on multi-level benches in greenhouses. Growers currently using fluorescent bench lighting should look at the option of using LEDs, as the energy savings given by these lights can give commercially attractive paybacks. Also, with suitable crops, the option of increasing production capacity by adding additional tiers of benches with LED lighting could also be a cost effective alternative to expanding greenhouse area.
2. Photoperiodic lighting with LEDs is not economically viable at the moment as the energy cost saving from the lamps does not payback the capital investment in a commercially acceptable time (i.e. five years or less). However, growers should keep a watching brief on this technique as falls in capital cost (to just under £10 per lamp) could make this application economic.
3. Compared to crops produced with conventional lighting systems, LEDs need to provide additional income to be economically viable. This may be achieved through production improvements such as increased yield, higher quality, reduced disease incidence etc. Growers must look out for the results of research & development with crops grown under LEDs to asses if the improvements achieved are sufficient to justify investment.

SCIENCE SECTION

Introduction

Light emitting diode (LED) lighting has a number of technical characteristics that seemingly make it attractive for horticultural protected cropping (PC) applications. These include:

- The ability to tailor the spectral output of the lamps to the needs of different crops and /or plant species.
- Low radiant heat output; this means that the LED lights can be positioned close to plants.
- Energy saving when compared to traditional light sources.

Although LED light sources have been available for some time, hardware development is moving quickly and several horticulture specific products are commercially available. Some of these are from multi-national lighting manufacturers; the most notable being Philips. In addition, other niche LED lighting manufacturers such as Valoya are concentrating on the horticultural sector.

The HDC's GrowSave project team organised a study tour to Holland in January 2012 which looked at the development of LED lighting and visited some projects where LED lighting had been installed. The conclusions drawn from this study tour were that, whilst LED solutions for supplementary lighting are not yet a technical (or commercial) reality, other applications are 'here and now' and several leading horticultural companies (located in countries like, The Netherlands, Denmark, Sweden and North America) are aggressively investing in LED lighting. These applications are:

- Day-length manipulation – as a direct replacement for tungsten lighting over flowering crops, soft fruit etc.
- Young plant lighting – as a replacement for fluorescent tubes in growing rooms, germination rooms or for multilayer growing on of cuttings etc. It is also suggested that foliage crops such as herbs and lettuce can be successfully grown with these systems.
- Inter-crop lighting – here arrays of LEDs are placed deep in the crop canopy to stimulate activity from the parts of the plants that are shaded in traditional production systems. Applications are in both the ornamental and edible PC sector with cut flowers and vine crops (e.g. tomato) being the most suitable.

Whilst some of the early adopter uptake of these applications can be readily accessed for viewing, there is little sound independent information available about their economics. Also, as the installations are in countries outside the UK, local financial conditions and currency issues will have a significant effect on the relevance of the information to the UK.

This project has investigated these three applications and made calculations of the LED installation requirements needed. Capital and running costs have then been calculated so that the financial viability of switching from traditional lighting to LEDs can be assessed by growers.

Materials and Methods

This work was carried out as a desk based study that analysed data/information relating to three horticultural lighting techniques and the performance specification of both conventional and commercially available LED lighting equipment. Data was sourced from published horticultural lighting information and lighting equipment manufacturers and suppliers. The three lighting techniques considered in the study were:

1. Day length manipulation /night break lighting.
2. Multi-tier lighting (for growing rooms, multi-layer benches etc.).
3. Inter-canopy lighting.

The procedure used for assessing the various lighting techniques and the equipment options available was as follows:

1. Use the current knowledge/recommendations on lighting levels for specific crop groups and applications as the starting point for specifying the LED installation requirements[(1)]. Light requirements are specified in terms of photosynthetic photon flux (PPF) in $\mu mol/m^2/s$ and the duration of the lighting treatment.
2. Determine the layout of 'conventional' lamps that will meet the required lighting specification and, for this standard installation, calculate the energy consumption and energy running costs.
3. Use LED performance and output data obtained from manufacturers to determine an installation layout for LEDs that can provide an equivalent lighting output to the 'conventional ' set up. Calculate the energy consumption and running cost for this 'alternative' LED installation.
4. Use equipment prices obtained from the manufacturers to calculate the difference in purchase costs between the 'conventional' and LED solutions.

5. Consider the life expectancy of the conventional and LED lamps and factor in replacement cost differences.
6. Calculate project payback requirements for the upgrade options compared to conventional solutions. This has been done in terms of either a simple payback period or as the additional income required to give a financial return within a set project appraisal period. For the purposes of the analyses made in this project a five year appraisal period has been used.

A set of spreadsheets was written to carry out the evaluations described in the following sections of this report. These spreadsheets allowed different sets of assumptions to be tested and the economic effects quantified. In practice growers will be operating under constraints that are not the same as the assumptions made here. This means that the outcomes of the analyses will be different for different growers. In recognition of this, and to allow growers to test different scenarios for each of the applications investigated, the spreadsheet calculators have been made available to HDC members. Access to these is via the GrowSave project website www.growsave.co.uk from where they can be downloaded. A screenshot of one of the calculators is shown in Figure 1.

Instructions	
	These are user input cells
	These are cells that are not necessary for the calculation
	White cells are calculations and shouldn't be altered

About your site and supplementary light requirements		
Length	50	m
Width	100	m
Area	5,000	m2
Row spacing	1.6	m
ppf required	180	µmol/m2/s
Operation hrs/year	2200	# hrs
Electricity Cost	10	p/kWh
Appraisal period	5	years

About your lighting installation and proposed upgrade	Overhead only	Overhead with LED interlighting	
Fitting type	HPS		type
Fitting voltage	400		volts
Fitting ballast type	Electronic		type
Overhead ppf delivered	180	125	µmol/m2/s
LED fitting type		Phillps	type
LED fitting wattage		114	watts
LED ppf delivered		55.00	µmol/m2/s
LED lighting load		143	kW
Overhead lighting load	497	345	kW
Total lighting load	497	488	kW
Annual costs			
Annual electricity cost	£ 109,330	£ 107,274	£
Lamp replacement cost (annual equivelant)	£ 5,168	£ 14,279	£

Figure 1 – Screenshot of LED project economics calculator

Results – Analysis of Specific Applications

Photoperiodic and Day Length Lighting

Background

Photoperiodic lighting is commonly used to promote flowering in long-day plants or to prevent/delay it in short-day species and growers have long experience of using incandescent light bulbs (also known as GLS lamps or tungsten light bulbs) for this purpose. The spectral output of GLS lamps is dominated by red and far-red components of the electromagnetic spectrum, and light in these wavelengths is known to effectively control the day-length response of plants.

An EU wide ban on the manufacture and import of incandescent lamps has now been introduced which means that, over time, these lamps will not be available. As a result growers are now looking for a replacement light source that gives an equivalent performance. Some work has been carried out to look at the suitability of compact fluorescent lamps (CFLs)[(2)]. This work found that these lamps can't be used as a universal replacement for GLS on all species because of the different spectral output.

Using LEDs would seem to be a natural choice as the lamp can be designed to have the same spectral distribution as an incandescent lamp. Spectral imbalance can cause plant stretching and the predominance of the Far Red spectrum in GLS bulbs can heighten this. With the ability to tune LED spectral output to the plant's requirements there is a good chance that plant stretching can be well controlled and better quality plants produced.

The other big advantage of LED lamps is energy saving, but for many growers the energy consumption (and associated cost) of photoperiodic lighting is not a major concern.

In practice however, the economic viability of switching to LED is still dependent on the running cost saving, especially as the science of tailoring individual crop type requirements to LED spectral output is still in its infancy.

Installation specification and costs

Standard recommendations for photoperiodic lighting are to provide a photosynthetic photon flux density (PPFD) of between 2.5 and 5.0 $\mu mol/m^2/s$. These recommendations have been produced using incandescent light sources, and with this type of bulb this equates to a light intensity of between 125 and 250 lux (or 0.5 to 1.0 W/m^2 PAR). Because the spectral output of LED replacements has been engineered to match that of incandescent, it is reasonable to assume that these traditional recommendations can still be used.

The majority of existing photoperiodic lighting installations use either bayonet cap or Edison screw cap light bulbs installed into catenary cables. An example of recommendations for the spacing of the bulbs above the crop is shown in table 1 below.

Table 1. – Recommendations for the installation of incandescent lamps for photoperiodic lighting [(2)]

Lamp power (W)	*Mounting height above plants (m)*	*Spacing (either way, m)*	*Area / lamp (m^2)*
60	*0.6 to 0.9*	*1.2*	*1.4*
100	*1.2 to 1.4*	*1.8*	*3.2*
150	*1.5 to 1.8*	*3.1*	*9.6*

Most growers use either 100 W or 150 W bulbs and, to minimise the cost of change, a replacement lamp is needed that can be used in existing catenary cable installations. At the moment an obvious choice for an LED replacement that meets this requirement is available from Philips. Their 'Greenpower LED flowing lamp' has been designed as a direct replacement for incandescent lamps, and the bulb specification means that it is best suited to being used instead of 100 W incandescent lamps (especially those with an internal reflector such as the 'Flower-Power bulb previously produced by Philips).

The Philips LED is manufactured with three alternative spectral output designs, deep red/white, deep-red/white/far-red and far-red. It has an electrical rating of 18 W (16 W for the deep-red version).

The economics of switching from incandescent to LED has been calculated based on switching from a 100 W incandescent lamp (without a reflector) to the Philips LED (deep-red/white/far-red version) on an installation where the lamps are mounted on a 1.8 m x 1.8 m grid. The other assumptions used for the comparison were:

- Lighting level = 4 µmol/m^2/s.
- Operation time = 150 hours/year.
- Electricity cost = 10 p/kWh.
- Lit area = 40 m x 12.8 m.

LED lamp purchase cost = £30 each. This is a budget cost obtained from Philips. In practice capital cost will depend on individual quotation for a specific project and will depend on factors such as number of lamps etc.

The financial viability of this example was carried out using a five year appraisal period and it included all costs including electricity, maintenance and the replacement of any failed lamps.

The results of this analysis show that over five years, the LED installation costs an additional £1.61 /m^2/year to operate. This assumes that the capital expenditure of the LED lamps is fully depreciated over the five year appraisal period. Electricity cost savings are £0.44 /m^2/year, and this is the biggest contributor to repaying the capital investment in the LEDs. In addition there are some small savings in maintenance and replacement lamp costs.

With this example, the conclusion is that switching to LED lamps is only viable if additional cost savings or extra income can be achieved, and that the simple payback on the installation is in excess of 20 years.

Discussion

The various photoperiodic lighting scenarios tested indicate that, whilst there is LED hardware available that has been designed specifically for horticultural photoperiodic applications, the current economics will prohibit widespread uptake of the technology.

In many cases growers will need savings in running and maintenance costs to payback the capital costs needed to make the change from traditional incandescent lighting to LED. Even when bulbs are available that can be used directly in existing cabling, the current indicative purchase costs are so high that the energy and maintenance cost savings will typically take in excess of 20 years to pay back the capital expenditure. For paybacks to reduce to around five years, purchase costs will need to fall to around one third of the current selling price. For the Philips Greenpower LED flowing lamp that is currently on offer this means that it will need to sell for about £10 per lamp or less.

As highlighted above, using current bulb purchase and energy costs and appraising a project over five years, additional savings of £1.61 /m^2/year are needed if an LED installation is going to be cost neutral compared to an existing incandescent lamp set up. Two possibilities of how this cost might be recovered are if additional sales can be achieved through better plant performance under LEDs or, with a new installation, electrical cabling costs can be reduced. The electrical load of a traditional installation with incandescent bulbs will have a total electrical load of about 350 kW/hectare. In comparison an LED installation will only need about 65 kW/Ha (i.e. less than 20% of the total electrical load). As a result the size of cables, electrical panels and the associated switching can all be reduced when LED lamps are used.

As indicated above, this is only relevant when installations are being made in greenhouses where photoperiodic lighting has not been previously used. Unfortunately calculating electrical installation cost reductions is not straightforward as it is site and electrical supply dependent. However, in some cases recovering a significant proportion of the £80,000 per hectare needed to make LEDs more cost effective (when appraised over five years) could be feasible.

Multi-tier & Replacement Lighting

Background

Multi-tier or 'replacement lighting' is typically used in applications like growing rooms or over multiple level benches in greenhouses. The technique is usually used where there is little or no natural light; hence why the term 'replacement lighting' is often used.

Traditional installations use tubular fluorescent lights which are usually mounted end to end in banks covering the whole growing area. This type of light treatment is usually restricted to use during the early stages of plant growth, and applications such as establishing cuttings or accelerating the growth of germinated seedlings are examples of commercial uses of the technique.

Installation specification and costs

Figure 2: An example of LED linear fittings used in a multi-tier bench application

The economics of switching from fluorescent to LED has been calculated based on replacing 35 W, 1.5 m length T5 fluorescent tubes with a 1.53 m length linear deep-red/blue spectrum (manufactured by Philips). The other assumptions used for the comparison were:

- Lighting level = 130 µmol/m^2/s.
- Operation time = 18 hours per day for 75 days per year.
- Electricity cost = 10 p/kWh.
- Lit area = 3.2 m x 10 m.

LED lamp purchase cost = £70 each. This is a budget cost obtained from Philips. In practice capital cost will depend on individual quotation for a specific project and will depend on factors such as number of lamps etc.

LED lamp installation cost = £20 per lamp. Whilst the new lamps can be powered by the existing power infrastructure, modifications to the wiring and switchgear will be required. This is an estimate of the cost of this work.

The financial viability of this example was carried out using a five year appraisal period and it included all costs including electricity, maintenance and the replacement of any failed lamps.

The results of this analysis show that, over five years, the LED installation costs £13.49 /m^2/year less to operate. This assumes that the capital expenditure on the LED lamps is fully depreciated over the five year appraisal period. Electricity cost savings are £10.28 /m^2/year, and this is the biggest contributor to repaying the capital investment in the LEDs. In addition there are some small savings in maintenance and replacement lamps.

With this example, the conclusion is that switching to LED lamps is viable so long as the crop performance under the LED is at least equivalent to that currently being achieved with fluorescent.

Discussion

The various multi-tier scenarios tested indicate that the current LED hardware can make some significant savings if it is used in a replacement lighting/multi–tier lighting situation. In fact, this type of application is the most promising for commercial uptake given the current development of LED fixtures for horticulture.

This assessment is however based on a scenario where fluorescent lighting is currently being used, and the LED alternative provides equivalent performance to the currently used light source. Also, it assumes that the installation costs for the LED fixtures are minimal as the cabling and switching infrastructure can be directly transferred from fluorescent to LED.

In practice these assumptions are only going to be valid in a small number of circumstances, and for some growers the installation costs will make the switch from fluorescent to LED less economic. For example, in the example detailed above, if the installation costs rise to £45 per lamp, LEDs will then only break-even compared to fluorescent over the five year assessment period.

Also in some circumstances multi-tier lighting is not being used by growers and they may wish to investigate the viability of using the arrangement in conjunction with LED as a way to increase production. In this case the total cost of the installation has to be justified on the basis of increased revenue. Again, using the example above but assuming that no lighting is currently used, the additional revenue required to repay the project over five years is £267 /m^2/year. This assumes an installation cost of £50 per LED lamp but no account is taken of the capital cost of providing the benching or any additional running costs (other than the electricity for lighting).

Inter-crop Lighting

Background

Inter-crop lighting is not currently in use in the UK. Whilst there are some examples of the technique being used by growers of cucumbers and tomatoes in Scandinavia and Northern Europe, the economics and the availability of suitable lighting equipment have prohibited wide commercial uptake.

However, the advent of LEDs opens up the possibility of greater use of the technique as it now becomes possible to put a light source deep into the crop canopy. This gives the potential to use artificial lighting to stimulate additional growth from the parts of the crop that are shaded in traditional lighting arrangements.

With the equipment that is currently available, the most likely uses are on vine crops such as tomato and cucumber, and for this reason this is the application that has been investigated in this project.

Installation specification and costs

Figure 3 below shows a typical installation of inter-lighting LEDs in a tomato crop.

Figure 3: An example of inter-lighting with LED for lighting a tomato crop. Here two sets of LED fittings are being used in conjunction with overhead HPS lighting

This photograph shows how the rows of LEDs are arranged in linear fittings that are mounted end to end in the V formed by the stems of the growing crop. Depending on the light level that is desired, one or more rows of LEDs can be used. In the above example two rows have been installed.

With the R&D that has been carried out so far, the installations have used the inter-lighting LEDs in conjunction with overhead high pressure sodium (HPS) supplementary lighting. Normal light levels for these HPS installations are in the range of 130 to 190 $\mu mol/m^2/s$ (10,000 to 15,000 lux), and the suggestion is that the intensity of this overhead lighting can be reduced when inter-lighting is used. This assumes that moving the light directly to where the crop uses it (i.e. within the canopy) requires less light to be delivered at the head of the crop.

This approach has been used in the following example which has been used to illustrate the current economics of the technique.

The assumptions used for the example installation investigated were:

- Lighting level = 180 µmol/m^2/s (10,000 lux).
- Lit area = 50 m x 200 m = 10,000 m^2.
- Crop row spacing = 1.6 m.
- Operation time = 2,500 hours per year.
- Electricity cost = 10 p/kWh.
- LED purchase cost = £75 each.
- LED installation cost = £50 per fitting.

To carry out the evaluation, the total cost of purchase and operation has been calculated for the two alternative lighting arrangements:

1. Overhead supplementary lighting with HPS only.
2. A combination of overhead HPS and inter-lighting LED.

The HPS + LED combination is based on one row of LED only. In both cases the total delivered lighting level is as specified above.

This comparison shows that, over a five year appraisal period with full capital repayment, the additional income required from lighting is as follows:

1. Overhead HPS only = £31.50 /m^2/year.
2. Overhead HPS + LED inter-lighting combination = £42.68 /m^2/year.

After the end of the five year appraisal period (i.e. once the capital has been repaid) the additional income required to cover the operation and maintenance components alone reduces to the following:

1. Overhead HPS only = £26.02 /m^2/year.
2. Overhead HPS + LED inter-lighting combination = £27.62 /m^2/year.

Therefore, although the HPS + LED combination used less electricity, the savings are not sufficient to offset the additional maintenance/replacement costs and additional crop performance worth at least an extra £1.60 /m^2/year is needed to justify the additional investment in LED.

Discussion

The scenario tested in this example highlights that additional production benefits are again needed for LED based inter-lighting to be a viable option right now. As highlighted, current applications are most likely to be on vine salad vegetable crops (tomato and cucumber), and the economics of supplementary lighting is marginal with these crops in the UK anyway. The calculations made here show that introducing LEDs does not improve this situation, and during the repayment period for the capital installation it requires a greater performance from the HPS + LED combination. For most growers producing a crop that is worth an additional £42.68 /m^2/year is going to be a significant challenge. However, this is an appraisal that growers will need to make based on their own circumstances.

It could be argued that, for growers who currently do not have supplementary lighting, the HPS + LED option is the better solution as the extra £1.60 /m^2/year needed to pay for the additional investment should be achievable. However, there is currently no evidence to substantiate what extra yield inter-lighting can return, and until this information is available investment decisions will be difficult to make.

Based on these findings, the overall conclusion is that inter-lighting using the currently available hardware is not likely to be an attractive economic proposition for growers in the UK.

Conclusions

1. This study shows that, of the LED products that are currently available, linear fittings used in multi-tier bench or growing room applications are the most economically viable. If the LEDs are used to replace an existing installation based on fluorescent lamps considerable cost savings can be made and a payback in less than five years is realistic.
2. To be commercially attractive, photoperiodic lighting and inter-crop lighting needs to deliver additional production related benefits.
3. To pay back in less than five years, a photoperiodic lighting installation using LED needs to deliver an addition £1.61 /m^2/year in crop value compared to a conventional equivalent.
4. Compared to a conventionally grown unlit crop, a supplementary lighting installation using inter-crop LEDs, in conjunction with overhead HPS, needs to return £42.68 /m^2/year extra income to pay back in five years.
5. In all applications the LEDs make energy savings compared to the conventional light source alternatives. Some operation and maintenance cost savings are also made. However, in the majority of applications the magnitude of these savings is not sufficient to give commercially attractive paybacks (i.e. five years or less).
6. The findings of this study are based on a set of assumptions that are believed to be representative of the current commercial operation of growers. However, different circumstances will affect the outcome of the calculations that have been made and the conclusions that have been drawn.
7. To help growers asses the viability of LEDs based on inputs that are relevant to them, a set of spreadsheet calculators have been produced. These can be downloaded from the HDC GrowSave website www.growsave.co.uk.

All of the above conclusions are based on the premise that the lighting recommendations for conventional light sources transfer to LEDs. Further R&D is required to determine if this is the case, or to quantify the advantages of tailored spectral outputs that can be engineered with LEDs.

Knowledge and Technology Transfer

As described above, the calculators developed in this project are now available on the HDC's GrowSave energy saving information website www.growsave.co.uk. Individual growers can freely download and use these to apply the findings of this work to their own particular circumstances.

The findings of this work have also been communicated to growers through:

HDC News

HDC Energy News – December 2012-January 2013

HDC Focus Event - Light spectrum manipulation, 4th December 2012

HDC website – www.hdc.org.uk

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