Supplementary lighting: Equipment selection, installation, operation and maintenance

Filmed over 48 hours at Stockbridge Technology Centre
Until recently, the number of UK growers using greenhouse supplementary lighting has been relatively small. This contrasts with a higher uptake in northern European countries like The Netherlands, Germany and Denmark, all of which have similar climatic conditions to the UK and produce crops that compete our markets.

Previous research and development (R&D) based on plant growth trials has demonstrated many benefits of supplementary lighting. These include improved winter crop quality, all year round production and lower unit costs. Nevertheless, uncertainties surrounding equipment selection, installation details and cost have all proved to be major barriers to commercial uptake.

Recent reductions in the cost of electricity relative to other fuels have improved the economics of supplementary lighting. However, the problem of how to select the best supplementary lighting equipment remains. Many growers are therefore looking for practical guidelines that will enable them to select the best equipment and operate installations at optimum efficiency.
What is a supplementary lighting system?

A supplementary lighting system uses electrically powered lamps (light bulbs) to increase the amount of photosynthetic energy available inside a greenhouse. However, the lamps themselves are only one item in a complex assembly of components, all of which have an influence on the effectiveness of an installation.

The main system components can be identified as follows:

- **Lamps** – the light bulbs that are the source of light used to supplement naturally available light.
- **Luminaires** – the fittings that are used to hold the lamps and provide connections to the electrical system. The luminaires also incorporate the reflectors, which direct the light produced by the lamps downward towards the crop. The electrical components needed to ensure reliable operation of the lamps are also normally housed inside the luminaires.
- **Electricity supply components** – in order to operate, the lamps require an electricity supply. The associated cables, switches, transformers and/or generators all need to be carefully selected to ensure that the lamps operate efficiently.

How is light measured?

There are a number of methods that can be used to quantify supplementary lighting levels. The AHDB Horticulture grower guide – Supplementary lighting of pot chrysanthemums (Langton et al., 2001) is one of a number of publications that provide an excellent summary of the subject.

Light measurement is a subject involving numerous definitions and terms. Whilst the guide has been written using simple terms, other publications may introduce more complex definitions. To help understand these terms, appendix 1 outlines the most commonly used definitions and phrases associated with the topic.

It must be remembered that most lamps and lighting systems have been developed to help promote improved vision by the human eye. Lamps are therefore rated in terms of how bright they appear to the human eye (measured in lumens). Light intensity is measured in lux and is the amount of light per unit area (1 lux = 1 lumen/m²).

The eye responds to light energy in a different way to plants as shown in figures 1 and 2. Whilst both the eye and plants respond to light over the same range of the electromagnetic spectrum (between 400 and 700nm wavelength), the maximum response for the eye occurs in the green/yellow region. This is in contrast to plants that are responsive across the whole waveband, with peak sensitivity at the red end of the spectrum. Therefore, light that is best for the eye is not necessarily best from a plant growth perspective. For this reason the light units traditionally used by lighting equipment manufacturers and suppliers, such as lumens and lux, are inappropriate for use in horticulture.

The best measurements for plants quantify the amount of light energy over the 400–700nm waveband. This is known as Photosynthetically Active Radiation (PAR). The units are joules (J). More commonly the rate of energy flow is used which is measured in watts (W). Irradiance is the rate of energy flow over a given area which is measured in watts/m² (W/m²).

Suppliers of supplementary lighting invariably specify the performance of systems using lux. This is fine so long as the specification is used to compare the output from one type of light source. If different light sources are to be compared (like high pressure sodium lamps, metal halide lamps or daylight), then using lux will introduce errors and will not be satisfactory.

Conversion factors must therefore be used to translate lux levels to W/m² PAR (PAR irradiance) for each of the different lamp types.
Example:
A supplementary lighting system uses High Pressure Sodium lamps to produce 4,000 lux. It is operated for 12 hours per day. What is the PAR integral produced per day?

**Step 1:**
Calculate the PAR irradiance

\[ \text{PAR irradiance} = \frac{4,000 \text{ lux} \times \text{Conversion factor from Table 1}}{1,000} \times 2.4 = 9.6 \text{ W/m}^2 \]

**Step 2:**
Calculate the lighting time in seconds per day

\[ = 12 \times 3,600 = 43,200 \text{ seconds} \]

**Step 3:**
Calculate the PAR integral

\[ = \text{PAR irradiance (from Step 1)} \times \text{Time (from Step 2)} = 9.6 \times 43,200 = 414,720 \text{ J/m}^2/\text{day} \]

\[ = 0.41 \text{ MJ/m}^2/\text{day} \]

Table 1 shows the conversion factors for common types of lamp used for supplementary lighting.

<table>
<thead>
<tr>
<th>Type of Light Source</th>
<th>From</th>
<th>To</th>
<th>Divide by</th>
<th>Then multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pressure Sodium (SONT+)</td>
<td>lux</td>
<td>PAR W/m²</td>
<td>1,000</td>
<td>2.4</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>lux</td>
<td>PAR W/m²</td>
<td>1,000</td>
<td>3.5*</td>
</tr>
</tbody>
</table>

*Note – unlike High Pressure Sodium, the conversion factor for Metal Halide varies according to the specific make and model of lamp. The above factor is indicative of typical values.
How does this relate to solar radiation, which is normally measured in MJ/m²?

This is an area of some confusion so it warrants a special mention, especially as the contribution of a supplementary lighting system often needs to be compared with that from naturally available light.

Solar radiation (global radiation) consists of radiant energy with wavelengths between 300 and 3,000 nm. This range is much wider than the PAR range, and represents all of the solar energy which passes through glass and polythene and contributes to greenhouse heating. Measurements are normally made using the joule (J). One joule per second (J/s) is equal to one watt (W). Irradiance is the energy per unit area and is measured in W/m².

Solar radiation integral is the solar irradiance measured over time (e.g. per day, per week, etc) and it is normally measured using an outdoor mounted solarimeter such as a Kipp. This is the basis of measurements taken by greenhouse climate control computers and the data published for reference sites such as HRI Eefford, HRI Kirton, etc. Information is usually presented in MJ/m²/day.

As the solar irradiance is over a wider band of wavelengths than PAR, not all of the energy is useful in promoting plant growth and development. Determining the amount of PAR available is quite straightforward as it constitutes 45% of the total solar radiation.

Therefore:

**PAR radiation integral = solar radiation integral x 0.45**

All of the PAR radiation is not available inside the greenhouse. Therefore, a transmission factor has to be applied to take account of losses due to the glazing, etc. Values of between 50% and 65% have been measured in practice.

This shows that the PAR radiation integral inside the greenhouse can be as little as half that received outside. Such high losses substantiate the need to ensure high light transmission in design and operation of glasshouses, most importantly by thorough glass cleaning.

Calculating PAR integrals is quite simple as shown in the example opposite.

Having calculated the amount of PAR produced by the supplementary lighting system, it can be added to the solar PAR available inside the greenhouse. This gives the total amount of PAR available to the plant.

Published data on solar radiation is available for a number of sites throughout the UK and is available in a number of publications. This includes the AHDB Horticulture grower guide – Supplementary lighting of pot chrysanthemums (Langton et al., 2001).

### Table 2. Average solar radiation data for the HRI Kirton and HRI Efford during week 52 is as follows:

<table>
<thead>
<tr>
<th>Site</th>
<th>Outdoor Solar PAR (MJ/m²/day)</th>
<th>Internal Solar PAR assuming 60% transmission (= Outdoor PAR x 0.6) (MJ/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirton</td>
<td>0.77</td>
<td>0.46</td>
</tr>
<tr>
<td>Efford</td>
<td>1.02</td>
<td>0.61</td>
</tr>
</tbody>
</table>

With the supplementary lighting system detailed in the previous example, the total PAR at the two sites would be:

- **Kirton** = 0.46 + 0.41 = 0.87 MJ/m²/day
- **Efford** = 0.61 + 0.41 = 1.02 MJ/m²/day

Therefore, to achieve similar levels of total PAR, more supplementary lighting is required at Kirton. This could be achieved by increasing the light level to 5450 lux (13.1 W/m² PAR) whilst maintaining the same operating hours.

The amount of supplementary lighting required for optimum production at a given site is therefore dependent upon the background solar radiation and the requirements of the individual crop. Hence, growers must decide on their particular requirements using solar radiation data and information on crop response.

### Summary

- Successful supplementary lighting systems depend upon the correct integration of lamps, luminaires and electrical connection components.
- Although lux is the most commonly used unit of light measurement, PAR irradiance (measured in W/m²) gives a more accurate indication of plant response.
- Conversion factors must be used to translate lux to PAR irradiance.
- Using PAR irradiance allows the light from different sources (including solar radiation and different designs of lamp) to be compared in terms of their relative contribution to plant growth.
- When determining the requirements of a supplementary lighting installation, consideration must be given to background solar radiation levels and individual crop requirements.
Lamps

As lamps, luminaires and connection components contribute to the overall efficiency of an installation, careful consideration should be given to the selection of each of these. Neglecting any one will lead to a weak link and a reduction in performance.

Which lamps are best for supplementary lighting?

The two main issues relating to lamp selection are:

- The efficiency of PAR delivery
- Capital cost.

Gas filled high intensity discharge (HID) lamps give by far the best combination of these two factors. Of the many types of HID lamps available, only those using high pressure sodium gas mixtures and, in some cases, metal halide gases are suitable for plant growth use.

High pressure sodium lamps are the market leader, and come in various power ratings, the most popular being 400 watt (W) and 600 watt (W) versions. Metal halide is thought to have a superior spectral output but the economics of lamp purchase and operation are prohibitive at present.

What do HID lamps look like and how do they work?

Figure 3 shows a typical HID lamp and details of its construction. The heart of the lamp is the ceramic arc tube and its contents. In high pressure sodium lamps it contains a mixture of inert gases and metals such as argon, neon, xenon, sodium and mercury. It is the composition of the arc tube contents that affect the light output and its spectral composition.

Voltage is applied across the electrodes to stimulate an electrical arc. This excites the contents which in turn produce light. The glass envelope protects the arc tube from the atmosphere by excluding oxygen and insulating it from ambient conditions. Once stabilised the temperature of the arc tube can be around 1,250°C and the outer glass envelope up to 400°C.

When the lamp is cold (ie has been turned off for more than two to three minutes) all the metal within the arc tube is in the solid phase. The electrical resistance between the electrodes is dependent on the gas in the arc tube alone and is relatively high. Once the lamp is running the metal within the arc tube is vaporised and the electrical resistance between the electrodes falls. The hotter the lamp gets the lower its resistance becomes. Hence, if it were connected directly to the electricity supply it would draw increasing amounts of power as it became progressively hotter and would ultimately overheat and fail.

The electrical control gear built into the luminaire prevents this. It initially provides a high voltage pulse to start the lamp and then restricts the power drawn preventing overload. Further details on the electrical gear are contained in the following section on luminaire selection.

Are any designs of high pressure sodium lamp better for horticultural use?

A number of manufacturers produce models of a high pressure sodium lamp which claim to match the requirements of plants more accurately than standard models. Independent testing shows that the PAR output and efficiency of these lamps is almost identical to that of the standard SONT+ lamps (which are cheaper and more widely available).
Should I use 400 W or 600 W lamps?

Increasingly, 600 W lamps are being used in new installations. This is because:

• Equipment cost savings are made as fewer lamps and luminaires are needed for a given area. Consequently, installation costs are also reduced.

• Running cost savings are achieved because the 600 W lamp is around 10% more energy efficient than the 400 W version.

However, 600 W lamps can not be used in all cases. In older houses where mounting height is limited, good lighting uniformity may only be possible using the 400 W lamps.

What factors affect lamp output?

A wide range of factors affect lamp efficiency, independent testing as shown that the most important factors are:

• Initial lamp output – data is provided in manufacturers’ catalogues, which specifies the output of the lamp after 100 hours of operation. This data is normally given in lumens. Tests show that there can be considerable variation in this data and that, in practice, the output of a new lamp may be up to 10% lower than specified.

• Variations between manufacturers – nominally the same type of lamp from different manufacturers can vary output by up to 10%.

• Lamp ageing – after 10,000 hours of operation lamp output will fall to between 90% and 96% of its initial output.

• Electricity supply voltage – this has a major impact on the output of the lamp. For every 1% reduction in the specified voltage conditions the light output will fall by 3%.

Ignoring these factors can mean that even a new installation may produce only 80% of its design light output.

Summary

• High Pressure Sodium lamps offer the best compromise between energy efficiency and cost.

• 600 W high pressure sodium lamps are around 10% more efficient than the 400 W alternative. This makes the 600 W lamp the preferred option for new installations.

• 600 W lamps are not suitable for use in all situations. Where mounting height is limited (or low design light levels are required) 400 W lamps may be the only viable alternative if acceptable light uniformity is to be achieved.

• Lamp output can vary from the levels specified by manufacturers. Factors affecting the output include manufacturing tolerances and ageing.

• Supply voltage has a marked effect on the output of a lamp output. A 1% drop in the supply voltage will result in a 3% drop in light output.
What are the component parts of a luminaire?

Figure 4 shows a typical luminaire and its major component parts. Essentially a luminaire consists of:

- The body which houses the internal electrical gear
- The reflector.

Figure 5 illustrates that both the electrical gear and reflector introduce losses into a lighting system. Luminaires should therefore be selected to minimise these losses. This is achieved by:

- Selecting electrical gear that optimises the performance of the lamp
- Choosing a reflector that effectively directs light towards the crop in a uniform pattern.

What electrical gear is required to make the lamp operate?

The two essential electrical components making up the gear are:

- **Ignitor (or Starter)** – when the lamp is cold the resistance between the electrodes in the arc tube is so high that the mains voltage cannot generate an electric arc. The ignitor generates high voltage pulses to start the lamp.
- **Ballast** – on its own, a lamp will draw increasing amounts of power once it has started. The ballast limits this to prevent failure. Laminated iron core reactor ballasts are almost exclusively used in commercially available equipment. Other types of current limiting devices are available but these are generally regarded as uneconomic at present.

The electrical gear is selected according to the mains supply voltage. Some ballasts are multi-tapped which means that they can be tuned to electricity supply on a particular site and can be set to match 220/230/240 volt mains supplies. However, most models of luminaire are supplied with a ballast with a fixed voltage rating. So care has to be taken in choosing the right one.

It is advisable to have the expected voltage at the luminaire accurately predicted at the design stage. If the voltage is wrongly assumed and the wrong ballast used, lamp output could be less than anticipated and the performance of the installation will be below expectations.

Are there likely to be any other components housed in the luminaire body?

A power factor correction capacitor is included as standard practice in most designs. This is because a HID lamp will draw twice as much current as it needs to deliver its rated light output, (ie they have a power factor of 0.5). If nothing is done to correct this, larger electricity supply components (ie cables, switchgear and transformers) will be required.

![Figure 5. Energy balance of lamp and luminaire combination](image-url)
How does the electrical gear affect the efficiency of the installation?

Although essential, electrical gear introduces energy losses into the system. For example, a 400 W high pressure sodium lamp typically operates at 435 W when the gear losses are taken into account. Similarly, a 600 W lamp operates at 640 W. Gear from different manufacturers has different levels of loss so it is worth checking the specification for the design of luminaire being considered.

Is the electrical gear interchangeable?

The ballast and ignitor have to be selected to suit specific lamp types and sizes. Fortunately, all 400 W high pressure sodium lamps will work with the same electrical gear.

This is also the case for 600 W lamps but higher capacity components are needed. Hence 400 W and 600 W lamps are not interchangeable in a given luminaire.

Will a metal halide lamp work in a luminaire designed for a high pressure sodium lamp?

Yes, some metal halide lamps will work with high pressure sodium gear but their efficiency, output and longevity may suffer compared with use with properly matched components.

What is the role of the reflector and how it is made?

The role of the reflector is to:

- Protect the lamp from damage
- Direct as much of the light produced by the lamp downward towards the crop as possible
- Create a lighting distribution of acceptable uniformity.

Reflectors are made almost exclusively from two types of anodised aluminium namely:

- Hammered aluminium (known as Stucco)
- Deep drawn aluminium.

Stucco aluminium is dimpled material that is anodised before the reflector is formed. It can only be cut, rolled or folded. In contrast, deep drawn aluminium can be formed into a complex self-supporting shape prior to anodising. It has a smooth polished finish. The latter type tends to be more easily removed for cleaning as the Stucco aluminium is normally fixed within the body of the luminaire.

How is reflector performance assessed?

The simplest indicator of reflector performance is the Downwards Light Output Ratio (DLOR). This is simply the proportion of light produced by the lamp directed downwards to the crop, the rest of the light being absorbed or leaked by the reflector. The DLOR of a reflector (when new) may be as high as 90%.

The pattern of light output can be shown in an isolux diagram. These diagrams show a contour map of the light distribution and the shape of the footprint under a reflector. The information they provide is of little direct use to growers but they are a valuable tool for installation designers.

What different designs of reflector are available and where should they be used?

Crops require an even distribution of light over the cropping area otherwise the rate of plant development and yield may not be uniform. To get the best performance for different lighting levels and mounting heights, manufacturers produce a range of reflector designs.

Individual manufacturers have various names for the different types of reflector they produce, but they can be broadly categorised as follows:

- **Deep or focused** – produce a relatively narrow spread pattern. Suitable for high mounting heights. The DLOR of this type of reflector is usually very good indicating that this design is efficient.

- **Wide angle or low bay** – produce a wide-angle spread pattern. More suitable for lower mounting heights than deep reflectors because they achieve better uniformity. They can be used at higher mounting heights to give excellent uniformity but have a lower DLOR and hence lower overall efficiency.

- **Medium or midi** – a halfway house between deep and wide this design provides a compromise between an efficient luminaire and an acceptable uniformity.

How does the light distribution differ under different reflector types?

Figure 6 shows the contrasting light distribution between differing types of reflector. With the deep reflector the light is focused directly under the luminaire and the major concentration is directly under the centre of the reflector. With a wide reflector the angle of spread is much greater and areas of concentration occur towards the outside edges of the distribution area. Even light distribution must then be achieved by filling in the area directly under the reflector with light from adjacent units.

How do I calculate the true mounting height?

When selecting a reflector type (or specifying the requirements for an installation) the grower must consider both the mounting position of the luminaires and the height to which the crop will grow when being lit. Designs based on the distance from the mounting point to the ground can result in poor uniformity when the crop is at a mature stage of development. This is particularly significant when lighting a cut flower crop such as chrysanthemum. Figure 7 shows the consequence of this error and the likely result in terms of inconsistent crop quality.
How is light uniformity calculated and what should be the target figure?

Lighting designers use two common methods to assess uniformity, both of which use calculations to determine the variation in light intensity over the lit area. The methods are:

- $E_{\text{min}} / E_{\text{max}}$ – this compares the point of minimum intensity to the point of maximum intensity. As the value produced is the ratio of only two points, its use alone is of limited value when judging the performance of an installation.

- $E_{\text{min}} / E_{\text{average}}$ – this compares the point of minimum intensity to the average light level over a specified area. This ratio gives a better insight into the uniformity of the light distribution.

It is therefore recommended that $E_{\text{min}} / E_{\text{average}}$ is specified as a measure of uniformity. With flowering crops, where areas of high intensity could potentially cause problems with uneven crop development, there is some merit in using the ratio of $E_{\text{min}} / E_{\text{max}}$ alongside $E_{\text{min}} / E_{\text{average}}$.

Practical experience has shown that satisfactory results can be obtained if the light uniformity based on $E_{\text{min}} / E_{\text{average}}$ is 0.8 or greater. Take care when interpreting these results however, as in some cases manufacturers do not assess uniformity over an entire lit area. For example, data may only be provided for a small area in the middle of the greenhouse. This figure ignores the areas next to the sides of the greenhouse where the light uniformity will inevitably be worse. In practice (particularly with long narrow greenhouses) this can account for over 10% of the greenhouse area.

Summary

- Luminaires have a significant effect on the efficiency of lighting installation. This is because both the electrical gear (ballast and ignitor) and design of reflector both affect the efficiency.

- Ballasts should be selected to match the electricity supply voltage. Incorrect selection will affect the output of the lamp and could result in a poorly performing installation.

- A number of reflector designs are available to accommodate various mounting heights and the light intensity required.

- Deep reflectors can be used at high mounting heights and/or with high design light levels. The reflector efficiency with these designs is good.

- Wide reflectors can be used at lower mounting heights. Reflector efficiency is however reduced.

- Light uniformity should be assessed using the ratio of minimum intensity: average intensity ($E_{\text{min}} / E_{\text{average}}$). Practical experience shows that a ratio of 0.8 or better over the entire lit area produces acceptable results. With flowering crops the ratio of minimum intensity: maximum intensity ($E_{\text{min}} / E_{\text{max}}$) should also be considered to avoid premature flower development.

Example of an installation where the reflector produces a light distribution that is too narrow. Only at soil level is the uniformity acceptable. It is likely that the plants will be of unacceptable quality.
SECTION THREE
Installation Requirements

Electrical Installation Issues

Once lamps and luminaires have been selected, the component parts need to be brought together to produce a successful installation. This requires consideration of both mechanical and electrical installation practices.

What are the special requirements of a supplementary lighting installation?

The use of supplementary lighting in horticulture presents a particularly unusual electrical installation environment.

- Because many installations cover a large area, electrical cables are likely to be long. In these situations voltage drop along the cable must be carefully controlled otherwise lamp performance will suffer (remember that 1% drop in voltage leads to a 3% drop in lamp output).
- The high harmonic content of the electrical currents for HID lighting are a major departure from more conventional electrical systems and special provision have to be made to deal with consequential problems.

Figure 8. Luminaires should be positioned accurately to ensure an even level lighting.

What precautions should be taken to minimise voltage drop over the installation?

Conventional electrical wiring design allows for voltage drops of up to 4% between the site main switch and farthest electrical connection point. As a 1% drop in voltage leads to a 3% drop in lamp output, it is therefore possible for lamp output to vary by as much as 12% within an installation unless allowances are made. In some cases cable sizes may need to be increased to reduce the voltage drop along them. As detailed in the section on luminaires, multi-tapped ballasts can also be used to alleviate the detrimental effects of voltage variations.

What effect will third harmonics have?

Problems arising from harmonics are mainly associated with overheating of transformers and neutral cables, and interference with sensitive electrical equipment like computers. In exceptional cases high harmonics may also be detrimental to the output of the lamp and the longevity of some of the electrical gear components.

What measures should be taken to accommodate third harmonics in the system?

In dealing with electrical contractors it should not be assumed that they are aware of the special nature of this type of installation. Their attention should be drawn to the following points:

- The Institution of Electrical Engineers Wiring Regulations (BS 7671) specifically mentions the installation of discharge lighting circuits. (Refer to Regulations 524-02-03, and sizing of components).
- Multicore 3 phase cables will have to be de-rated by as much as 14% to cope with high neutral currents.
- Transformers (or generators) used for the supply of large installations have either to be specially constructed for high harmonic use or de-rated by about 10%. Your Electricity Distribution Company should be alerted to the possibility of harmonic currents of up to 25% of fundamental.
- When measuring voltage and currents in lighting circuits, meters that measure the true root mean square (RMS) values should always be used. Averaging meters may produce massive underestimates of the true conditions.

In very large systems, especially where generators are used, harmonic filters are an effective method of controlling harmonic currents. Filtration as near to the source of disturbance is preferable. However, good electrical design in the first place will produce a cheaper solution to harmonic problems than retrofit solutions.

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Summary

• Cables should be sized to minimise voltage drops. This will ensure that lamps operate at maximum efficiency and light output is not compromised. In some cases it may be necessary to oversize cables when compared to conventional installation practices.

• Third harmonic disturbance can cause problems with overheating of electrical components such as cables and transformers. Using good design practice can minimise problems. In the worst cases it may be necessary to use electrical filters to correct harmonic problems.

• Luminaires should be mounted such that they are accurately positioned and level. This will ensure that the light uniformity obtained is in line with that predicted by the supplier.

• Luminaires should be positioned so that obstructions such as structural members, heating pipe, irrigations lines, etc do not impede the light output.

Mechanical Installation Issues

How should the luminaires be positioned and supported?

Factors to bear in mind when choosing a mounting system are as follows:

• Accuracy of positioning – to ensure the best light uniformity possible

• Ease of access for maintenance

• Position of luminaires relative to heating pipes, irrigation lines, etc to reduce the interception of light (shading)

• The load bearing capability of the supporting structure.

Can the mounting system affect the light uniformity obtained?

If lighting uniformity and intensity is to be as predicted in the design, every effort should be made to position luminaires accurately. Bearers in the form of conduit or trunking are normally fixed permanently and therefore any potential error in lateral positioning is small. However, positioning along the length of the bearer can vary particularly when removing or replacing luminaires. The position of each luminaire along the bearer should be clearly marked.

Another aspect to bear in mind is the angle of the luminaire relative to the crop. This is most important for luminaires with focused reflectors and lower mounting heights.

Once installed, the luminaires on many installations are never removed unless they need to be repaired or replaced. However, as described in later sections of this guide, lamps and reflectors should be cleaned periodically to maintain their performance. The design of the luminaire, the mounting system and electrical connections all combine to determine the ease of carrying out maintenance operations.
SECTION FOUR
Operation and Maintenance

Should automatic switching be used to control a lighting installation?

Manual control of lighting systems is labour intensive and prone to mistakes. This obviously wastes energy and increases the running cost of the system. By using automatic controls the balance of crop performance and running costs can be optimised.

In many cases it is possible to integrate the control of a lighting installation with the climate control computer already being used.

All control systems should allow manual operation of the lighting installation close to each compartment or section of lighting. This is a fundamental safety requirement to avoid lamps automatically turning on whilst maintenance is being carried out. It also provides the facility to isolate a section of the greenhouse when the full area is not being cropped.

Many growers choose to operate lighting at times that coincide with cheap electricity tariff periods. As these times tend to coincide with antisocial working hours, a time switch based control system is a basic minimum requirement.

Can I turn all the lights on at once?

It is not sensible to turn all lights on at exactly the same time. This is because HID lamps can give a starting current of 1½ times the running current. This can lead to problems with overloading of electricity supply components. Switching should be staggered so that no more than 25% of the incoming electricity supply capacity is turned on at the same time. A delay of one minute between each bank of lights should be sufficient. This can be easily automated.

Fully automatic lighting control systems can incorporate staged power up as described earlier or it can be simply built into individual distribution boards/control panels at suitable points within the installation. The main feature of a fully automated control system is its ability to measure natural daylight levels and turn the lights on/off according to the crop requirements.

Can regular automatic switching of the lights cause problems?

Excessive on/off cycling of the lamps should be avoided as this has a significant effect on their ultimate life. For this reason automatic control settings should be chosen to minimise regular switching. It is also recommended that once switched on, lamps remain illuminated for at least 60 minutes.

Why is maintenance important?

From the first day of operation of a lighting system, light output will fall. This is due to factors like lamp ageing, dirt on the lamp and reflector and degradation of the reflector surface. To get the best performance from an installation regular maintenance must be carried out.

How long do lamps last?

As the total operating time of a lamp increases its total light output falls and the likelihood of failure increases. Manufacturers quote lamp life based on the number of operating hours after which 50% of the lamps have been replaced. Figure 9 gives an indication of the lifetime characteristics of high pressure sodium lamps.

From figure 9 it can be seen that it is not unreasonable to expect a lamp to last for 25,000 hours. However by this time the lamp output will have fallen significantly and up to 50% of the lamps in the installations will have failed. The resulting effect will be an installation with reduced light levels and poor uniformity.

In practice lamps may not last this long. The main factor affecting the life of a lamp is the number of on/off cycles. To start a lamp a high voltage has to be applied. This erodes the electrodes in the lamp at a much higher rate than during normal running. The effect of shorter run times per start can reduce the life of a lamp by over 50%.

Mains voltage also has a major influence on lamp life. If voltage is higher than the rating of ballast, the lamp will run at a higher temperature and risk increased failure due to thermal stresses in the arc tube. This is normally only a problem if the voltage is more than 10% higher than specified on the ballast.

Taking all of these factors into account it is quite reasonable to expect 85% of lamps to last in excess of 15,000 hours.

![Figure 9. Typical lamp life curves for high pressure sodium lamps](image-url)
So when should lamps be replaced?

As shown in figure 10, the light output of a high pressure sodium lamp falls with increased operating period. Typically after 10,000 hours the output will have fallen to between 90% and 95% of the original output.

In the past a figure of 8,000 hours has been used as the recommendation for the replacement of lamps. However, a reduction in electricity costs over recent years has changed the economics of lamp replacement to the point where it could be argued that this should be extended to 10–12,000 hours.

This recommendation is based on the assumption that the:

- Irradiance does not fall below a critical level
- The specific lighting period (number of hours per day) is not fixed and the operating period can be extended to compensate for the fall-off in light level
- Light uniformity does not fall to a level where crop quality suffers.

Is it therefore suggested that with crops where it is not possible to run the lamps for longer periods per day (e.g. chrysanthemum as day length is fixed) or uniformity is critical, lamps should be changed after 8,000 hours. In other less critical crops the replacement period can be extended to 12,000 hours.

To monitor the running time lamps should be date marked when installed or replaced. Facilities should be installed to measure running hours. This can be achieved by installing simple hours run meters in electrical switch panels or by using the facilities available on a climate control computer.

What about lamp disposal?

All high intensity discharge lamps contain small amounts of mercury and sodium which are toxic and flammable respectively. Whilst the amounts are so small that HID lamps are not considered to be a special waste it is good environmental practice to:

- Keep lamps separate from general waste
- Ensure that they are not broken
- Keep different lamp types separate (sodium, metal halide, fluorescent)
- Keep lamps dry in covered containers
- Use specialist contractors for safe disposal.

If a lamp is accidently broken, small amounts of mercury vapour will be released and the sodium will react with any vapour/moisture/water to generate small amounts of hydrogen and sodium hydroxide.

Useful references are:

- The Health and Safety Executive document: Disposal of Discharge Lamps (HSE 253)
- The Government Envirowise website: enviro-wise.co.uk.

What about lamp and reflector cleaning?

The Downwards Light Output Ratio (DLOR) of a reflector depreciates appreciably with time. Tests show that that typical reduction in efficiency is around 3–5% per year. This is due to both dirt on the reflector and degradation of the surface. Cleaning of the reflector will reduce the rate of degradation. High operating temperatures and the aggressive nature of the greenhouse environment can mean full performance is not restored by cleaning alone. This is demonstrated by the data in table 3.

Table 3. Measure DLOR for a typical medium reflector

<table>
<thead>
<tr>
<th>As New</th>
<th>1 Year Old</th>
<th>Cleaned</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81</td>
<td>0.75</td>
<td>0.79</td>
</tr>
</tbody>
</table>

The loss in light output due to dirt on lamps has a similar effect. It is not unreasonable to expect falls in light levels of a further 5% per year. Dirt on the lamp will also reduce its life due to the absorption of light and increased operating temperature.

What should be used to clean lamps and reflectors?

There are no universally specified materials and methods for cleaning lamps and reflectors. Some basic guidelines and recommendations are:

- Do not use anything that could scratch the surface
- A weak solution of acetic acid (vinegar) or other acid will help to remove lime-scale but care needs to be taken with any acid
- Commercial or domestic window cleaning products may be suitable
- Great care should be taken when using any cleaning product as resulting chemical reactions can generate toxic substances. If in any doubt check the chemical product data sheets or consult the manufacturer.

Always test any new cleaning product on a small area of a reflector or lamp before widespread use.

Figure 10. Depreciation in light output with age for high pressure lamps

Figure 11. Corroded reflectors should be replaced or re-anodised
What about re-anodising or replacing reflectors?

In practice, the overall effect of reflector degradation on efficiency and running costs can be just as big (if not bigger) than that of reduced lamp output. Reflector replacement or re-anodising (as appropriate) makes good sense. However, little data is available to determine suitable times after which this should be carried out. Manufacturers suggest that, depending on operation hours and the nature of the greenhouse environment, upgrades should take place every four to five years.

Summary

- Automatic controls should be used to optimise the balance between crop performance and running costs. Manual overrides should be provided to ensure that the system can be maintained without the lights turning on automatically.

- In many cases the existing climate control computer can be used to control the lights.

- To prolong lamp life, avoid excessive on/off switching and once switched on, keep illuminated for at least 60 minutes.

- When turning on supplementary lighting installation, switching of groups of lights should be staggered to ensure starting currents do not overload the electrical supply.

- Dirt and degradation of the reflector surface can reduce its efficiency by 3–5% per year and dirt on lamps can reduce light output by 5% per year. Regular cleaning of lamps and reflectors is therefore recommended.

- Lamps and reflectors should be date marked when installed/replaced and facilities should be incorporated to measure the running hours of an installation.

- At appropriate intervals, lamps should be replaced. In crops where day length is fixed or uniformity is critical, lamps should be changed after 8,000 hours. In less critical crops (where running hours can be extended to compensate for the fall in the light level), the replacement period can be extended to 12,000 hours.

- Reflectors should be re-anodised or replaced at appropriate intervals. For most systems in the UK the replacement interval is likely to be every four to five years.
SECTION FIVE
Recommendations for New or Existing Installations

Specifying a new installation

The performance of a supplementary lighting system can potentially be affected by numerous factors. However, if the simple recommendations highlighted in this guide are used, systems will operate efficiently for many years.

The following sections provide recommendations on the most important areas to consider with both new and existing installations.

When planning a new installation, it is advisable to draw up a specification that enables competing manufacturers and suppliers to provide proposals and quotations that have been prepared from a common benchmark. The information in the specification should include the following as a minimum:

- **Target lighting level** – what is the required PAR irradiance and at what point in the life of the installation should it be achieved? For example, an average lighting level of 9.6 PAR W/m² after 1,000 hours of operation.
- **Lighting uniformity** – a ratio of $E_{\text{min}} / E_{\text{average}}$ of 0.80 or better.
- **The dimensions of the greenhouse** – include as much details as possible including the position of structural members, heating pipes, irrigation lines, etc.
- **The likely mounting height** – this should be the distance from a suitable luminaire mounting point to the crop. Remember that this should consider the crop height at the time when supplementary lighting is going to be used.
- **Lamp type** – 600 W SONT+ are the preferred option for new installations. If mounting height is limited (i.e., less than 2.5m between the lamp and the crop) then 400 W lamps may be more appropriate.
- **Control requirements** – outline details of the requirements for automatic control of the installation. If an existing climate control computer is to be used, details of the make and model should be provided.
- **Nominal supply voltage** – the electrical gear in the luminaire can then be provided which meets the requirements of the site. If you have been advised by an electrical engineer that voltage variations could be a problem, multi-tapped ballasts should be specified, as they will help uniformity along a run of fittings.
- **Commissioning requirements** – details the requirements of a witnessed test, which determines that the required light level and uniformity have been achieved. It may also be worth including a requirement for the supplier to return on an annual basis to assess levels of performance.

Prospective supplies should be encouraged to visit the premises as a site survey is often required to determine all of the necessary background information.

Suppliers should be asked to provide information on the total installed electrical load at an early stage. This will help to assess the suitability of the existing electricity supply and, if required, in sizing any necessary upgrades. This information will also help when assessing the overall efficiency of the design.

Full details of the proposed electrical installation should also be requested. This information will enable an assessment of component specification to be carried out and highlight any potential problems that may result from the impact of harmonics and voltage drops within the system. As this is a complex area it may be advisable to seek professional assistance when examining the proposals received.

A number of operational issues also need to be addressed at the planning stage. These include:

- Implementation of a recording system to log lamp operating hours. This will help to ensure effective implementation of the lamp replacement policy once the installation is running.
- Develop lamp and reflector maintenance schedules together with suitable cleaning methods.

Managing existing installations

With existing installations the following actions should be carried out:

- Lamp replacement policy should be reviewed and systems put in place to record lamp operating hours to enable more accurate implementation.
- Develop lamp and reflector maintenance schedules and approved cleaning methods.
- If reflectors are more than five years old they are likely to have very poor performance levels. It is therefore recommended that replacement or re-anodising is carried out.
- Check the mains supply voltage and compare to the ballast specification. This should be carried out by a qualified and competent electrical engineer. Upgrading supply cables may improve the voltage but the advice of a qualified electrician should be sought before making final decisions.
- If light levels are still unsatisfactory following cleaning and lamp replacement the only option is to consider the installation of additional lamps. A new lighting design will have to be carried out to ensure uniformity is not compromised.
- If there is a harmonic problem consider resizing and upgrading of conductors and system components before resorting to the installation of harmonic filters.
SECTION SIX
New Technologies and Developments

Manufacturers are continually developing new technologies and improving existing equipment. The most interesting developments are as follows:

- **Electronic ballasts** are already commercially available for lower power HID lamps and larger ones are now being developed. They offer a variety of benefits including less variation in lamp output due to mains voltage effects, lower losses, improved starting, better power factor and lower harmonics.

- **Over powering of lamps**. Some luminaire manufacturers are operating 400 W lamps at up to 550 W and 600 W lamps at up to 750 W. The claimed advantage of this development is that the output is shifted toward the red (longer wavelength) end of the spectrum and PAR efficiency is improved. In some cases total PAR output can be increased by over 35%. However, running lamps at well over their rated power will significantly reduce their life. The precise effects on lamp life are currently unknown.

- **Internal reflector lamps**. A lamp with a built in reflector has recently been launched. The claims being made by the manufacturer include:
  
  1. An improvement in the effective Downwards Light Output Ratio (DLOR) of the lamp and luminaire combination.
  2. Easier maintenance.

  No independent data is currently available to substantiate these claims however.

- **New reflective materials**. Manufacturers are developing polymers that have the potential to improve the performance of reflectors and reduce the effects of ageing. There are currently difficulties in practical applications including problems with the manufacture of reflectors using deep drawing methods. Also the polymers cannot withstand the high operating temperatures associated with commercial supplementary lighting equipment.

![Figure 13. New technologies and developments include the use of harmonic filters like the one shown above](image-url)
When considering supplementary lighting it is important to understand the differences between the concepts of radiant energy (which determines plant response) and luminous energy (which determines eye response). The principle terms used in plant irradiation are described below together with their equivalent counterpart as used in illumination technology. Table 4 also summarises the comparison between each of the terms.

- **Nanometer (nm)** is the unit used to measure the wavelength of electromagnetic radiation. One nm = 10 m.

- **Irradiation** and its derivations are the nouns used to describe light as a form of electromagnetic radiation as far as its use in horticulture is concerned.

- **Radiant energy** is the energy emitted, transferred or received in the form of electromagnetic radiation. In plant irradiation only the part of the spectrum between 400 and 700 nm is considered. This is known as photosynthetically active radiation (PAR). The unit of radiant energy is the joule (J).

- **Radiant flux** is the rate of flow of energy from a source of radiation. Units are the joule per second (J/s) which is equal to the watt (W).

- **Irradiance** is the radiant flux received per unit area. Units are watts per square metre (W/m²). In many cases this unit is described with the prefix PAR W/m² to qualify that it refers to the photosynthetically active range.

- **Radiant efficiency** is the ration of the total radiant flux emitted by a source of radiation to the total energy consumed eg the conversion efficiency, by a lamp, of electrical energy into radiant energy. Units are PAR watts per watt (W/W or %).

- **Illumination** and its derivations are the nouns used to describe visible light as registered by the human eye.

- **Luminous energy** is the quantity of light, weighted for its action on the human eye, radiated or received for a period of time. Units are lumen seconds (lm.s).

- **Luminous flux** is the rate of emission of light. It is derived from the radiant flux but is weighted with respect to the human eye sensitivity curve. Units are the lumen (lm).

- **Illuminance** is the luminous flux density incident on a surface. Units are lumens per square metre, which is equivalent to lux (lx).

- **Luminous efficiency** is the ratio of the total luminous flux emitted by a lamp to the energy consumed. Units are lumens per watt (lm/W).

### Table 4. Comparison of units of irradiation and illumination

<table>
<thead>
<tr>
<th>Description</th>
<th>Units of Irradiation (plant response)</th>
<th>Units of Illumination (eye response)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Term</td>
<td>Units</td>
</tr>
<tr>
<td>Energy</td>
<td>Radiant energy</td>
<td>joule (J)</td>
</tr>
<tr>
<td>Flux</td>
<td>Radiant flux</td>
<td>watt (W)</td>
</tr>
<tr>
<td>Flux Density</td>
<td>Irradiance</td>
<td>W/m²</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Radiant efficiency per watt (W/W)</td>
<td></td>
</tr>
</tbody>
</table>

**Glossary**

TECHNICAL GUIDE    Supplementary lighting
This publication was produced in 2001, it has been re-branded not revised. Please note that the information provided within was current as of the date of production.

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