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QUANTIFYING THE POTENTIAL IMPACT OF MAINTENANCE FACTORS ON LIGHTING UNIFORMITY IN HORTICULTURAL INSTALLATIONS

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Abstract

1. Motivation, specific objective

It is generally accepted that high uniformity is essential to the successful growth of plants in protected horticultural installations such as commercial greenhouses. However, there seems to be very few quantitative studies to determine the uniformities required and the impact of having uniformities beyond the preferred range.

As a first step to determine the impact of uniformity variations on the growth and development of plants under artificial lighting the authors have undertaken a study based on luminaires for ceramic metal halide (CMH) lamps and LED luminaires to estimate the through-life changes in uniformities.

The reduction in output from the luminaires with CMH lamps is dominated by the degradation of the source and lamp failures. For LED luminaires the combination of degradation of the LED chips constituting the arrays and the failure of the electronic drivers will determine the reduction in output of the installation.

While CMH lamps are expected to have an economic life <10,000 h, LED luminaires are employed with the anticipation of economic life >50,000 h.

2. Methods

Using initial luminous fluxes and lumen maintenance factors (LMFs) measured for CMH lamps, the reduction in the average illuminance for an installation can be calculated. However, it is the variations in the LMFs that will determine changes in uniformity as a function of operating time. The authors have simulated these changes by generating LMFs and variations at intervals between 1,000 and 10,000 h. These values have been used to predict the range of changes to the uniformity over the same operating period.

Based on values from several lumen maintenance studies of LED chips using the IES LM-80 and TM-21 standards, the rates of degradation have been estimated as a function of time to 50,000 h. LM-80 requires measurements to at least 6,000 h.

TM-21 calculations for estimating the useful life of LEDs at a specified temperature are based on computing the normalized average lumen maintenance over a specified measurement time and fitting an exponential curve to the data. This fit is extrapolated to estimate a time to a specified average lumen maintenance. Typically this is LMF of 70% and is quoted as the L70 parameter. An alternative approach is to fit an exponential curve to the normalized data for each individual chip in the LM-80 report. The average lumen maintenance computed in this way agrees with the specified methodology to <1%, but has the advantage of estimating the light output variability at times beyond the measurement points. Calculation shows that the lumen variability remains essentially constant over the useful life of the chips. The guiding principle is that the extrapolation is valid only for 6 times the length of the measurements.

Failure rates for LED drivers have been estimated on the assumption they are dominated by the operating temperature. The predicted failure rates and variations have been made using an exponential distribution.

Using the initial lumen outputs and the LMFs estimates of the impacts on uniformity can be calculated. These values are independent of the failures of the drivers.

Similarly, an estimation of the reduction in output of an installation due to driver failures can be made independent of the changes in the LED chips. Combinations of these two mechanisms provides a guide to the decline in output for the entire installation as a function of operating time and temperature.

The driver temperatures in a set of LED luminaires within a commercial greenhouse lighting installation has been recorded over an extended period. These values have been used as the basis for the prediction of the long term uniformity of the installation.

The analyses outlined above have not included the impact of the accumulation of dirt on the transparent parts of the luminaires.

3. Results

For an installation designed for uniformity 0.70 in a greenhouse measuring 81 x 50 m, mounting height 2 m, with luminaires suitable for 315 W CMH lamps, our calculations show that while the relative illuminance drops from 6,188 lx initially to 4,410 lx at 10,000 h, the uniformity will vary between 0.75-0.65. This apparently incongruous result, whereby the uniformity might improve with time, is due to the LMF variation and the random distribution of luminaires within the installation. These calculations do not include any lamp or ballast failures, these will be addressed in the next modelling phase.

LED luminaires have a major advantage over conventional light sources in that many individual chips are required for the arrays in the luminaire. The variability in light output between luminaires is reduced by the square root of the number of chips in the arrays compared with conventional light sources. This reduction can be highly significant. Many LED luminaires use 0.5 or 1.0 W chips. For luminaires rated between 150 and 250 W this translates to 150-500 chips. These numbers result in a reduction in variation of light output between luminaires by factors of 12.7 to 22.4.

The next models will include 10% LED driver failures at 50,000 h if there are operating within their design temperature range.

4. Conclusions

Like all light sources LEDs display variations in all measured parameters. A typical percentage coefficient of variation (standard deviation/average x100) of light output lies in the range 2.5 to 3.5%. Typically this leads to a 10% variation in output between chips. This number is comparable to that obtained for conventional light sources such as CMH lamps. With the lives of LED lamps extending far beyond the 6,000 to 10,000 h reported LM-80 reports, it is important to understand if the variability in LED chip output for lives beyond this time remains stable.

The calculated variation in installation uniformity is approximately 0.5 to 1.0 of the 2σ variability in light source output. This expected variability does not change significantly over life for the CMH lamps.