Light measuring protocol

A protocol to measure LED lighting in horticulture

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1 Light measuring protocol

This protocol describes how to assimilation light in greenhouses should be measured. This protocol is a revision of a light measuring protocol published in 2010 in Dutch[1], incorporating the significant changes in lighting technology that occurred in the last 15 years. Nowadays, LED fixtures can be equipped with multiple (dimmable) channels, allowing for dynamic control of the spectral composition of the LED fixtures. This requires a different approach to measuring assimilation light in the greenhouse. Next to that, the selection of the right light sensors is crucial to measure light accurately.

This chapter describes how and where to perform light measurements for a specific light spectrum and light intensity after a lighting system has been delivered. The purpose of the light measurements is to verify whether the lighting system conforms to the agreed-upon requirements and calculations in the lighting calculation plan. Step-by-step instructions are provided to perform these measurements, and which calculations need to be done. The light measurement protocol can be completed in approximately 1.5 hours. A separate chapter describes additional measurements involving multiple light intensities and light spectra. If a customer wants to use the LED installation dynamically and wants to have multiple light recipes measured, these additional measurements can be performed according to these guidelines.

The light measuring protocol was developed based on the results of the project "LED lighting: revision of the measuring protocol and sensors used," funded by Kas als Energiebron (Greenhouse as a source of energy[2]). This project was initiated by several LED manufacturers who also supervised it: Henk Vollebregt (Hortilux), Theo Tekstra (Signify/Fluence), Peter Barentsen (Oreon), Gert-Jan Dekker, and Mohamed Amin Tlili (Agrolux/Gavita). In addition, we obtained valuable information from Jordi van der Meijden (Ledgnd), René van der Sar (Orance), Paul Blom (Multi-meet), and André Flinterman (Groeilicht advies) during the interviews. We thank them all for their valuable input into this protocol.

1.1 Preparations for the light measurements

When the light calculation plan is verified, it is important that the light measurements are taken under similar conditions and at the same locations as specified in the light calculation plan. A light calculation plan specifies the light intensity of PAR light in µmol/m²/s, which is the combined amount of blue, green, and red light (400 to 700 nm). If far-red light is also present, the far-red light intensity is specified separately in µmol/m²/s (700-800 nm). Light calculation plans are generally calculated without the use of screens, without sunlight, and without a crop. Ideally, light measurements are taken under these conditions. However, the situation is often different. Below are some important points when taking the light measurements. At the time of the measurements, you can enter the details in the forms (section 1.3) and record any deviations you observe from the light calculation plan. You can then follow the steps described in section 1.4.

1. Check the light calculation plan for the following points. If the conditions under which you will be measuring differ from the light calculation plan, note this in the checklist (section 1.3):
    a) Presence and (approximate) height of the crop.
    b) Presence of crop wires and spools (in the case of high-wire cultivation).
    c) Screens open or closed.
    d) Position of the two measurement fields according to the light calculation plan (non-contiguous fields; different positions in the greenhouse without any structures or equipment nearby, not next to a concrete path, and not next to a facade).

[1] Lichtmeetprotocol 2010, https://edepot.wur.nl/178465
[2] Dieleman et al. 2025. Het meten van LED-licht in de glastuinbouw: onderzoek en resultaten voor het opstellen van een lichtmeetprotocol. WPR 1484. https://doi.org/ 10.18174/702485

e) Height(s) of the light calculations (distance between the sensor and the bottom of the LED fixtures).
f) Number of rows of LED fixtures that are on in the compartment.
g) Uniformity of PAR light is always calculated in the light calculation plan. Make sure that the uniformity of other light colors has also been calculated and enter this color in the table if you are going to measure this specific color.

2. Determine the number of measurement points; preferably the same measurement points as in the light calculation plan:
   a) At least 40 measurement points per measurement field.
   b) 4 points perpendicular to 4 LED fixtures; the other points form a grid between the 4 LED fixtures.
   c) An odd number of measurement points, for example, 9x5, 9x7.
   d) The distance between two measurement points must be less than 1 meter.
3. If the lighting system is delivered, a power measurement is also required to calculate the lamp efficiency. This protocol does not explain how to measure power. It only describes how to perform the light measurements.

1.2 Light sensor

- Use a spectral light sensor to measure LED light. The following spectral sensors have been tested and found suitable: Jeti Specbos 1211, UPRtek-PG200N, LI-180 (Licor), MS100 (Apogee), and HPCS-330P (Hopoocolor)[3].
- A PAR-FAR sensor (Apogee) can be used to measure far-red light. A PAR sensor cannot measure spectral distribution and slightly overestimates light intensity in the red and slightly underestimates light intensity in the blue, and is therefore not recommended.
- The above mentioned light sensors have an inaccuracy of approximately 5%, according to the manufacturers; a 5% deviation in measurements can therefore be explained by the inaccuracy of the light sensor; an exception is the Jeti Specbos, which has an inaccuracy of 2.4%.
- This also means that a deviation of 5% can occur for each light color (blue, green, red, and far-red).
- Check whether the light sensor has been calibrated within the manufacturer's recommended interval (usually annually) and record this in the checklist.
- Check that the light is measured in µmol/m²/s (and not in W/m² or lux).
- All spectral meters measure light per nm; check that the light colors are properly defined in your sensor and adjust this if necessary. Light colors are defined as follows:
  - PAR: 400-700 nm
  - Blue: 400-500 nm
  - Green: 500-600 nm
  - Red: 600-700 nm
  - Far-red: 700-800 nm

1.3 Check list

Fill in the company information and the conditions under which the light measurements will be performed in the first tab of the Excel calculation tool: https://www.wur.nl/nl/onderzoek/producten-diensten/software-voor-plantonderzoek. You can enter some information in advance, and other information during the measurements. Note: Some cells have a dropdown menu; you can see the options by clicking the arrow in the relevant empty cell.

[3] These are spectral (hand held) sensors that were available in January 2025

General data	
Name of the company	
Name contact person	
Street	
City	
Phone number	
Email address	
Measurements executed by (company)	
Measurements executed by (name)	
Date light measurement	
Type of measurement (at installation or verification)	
Light calculation plan made by (company)	
Light supplier	
Type of LED fixture	
Efficiency lamp (µmol/W)	
Production date LED fixtures	
Distance between LED fixtures (m)	
Does this match the light calculation plan?	
Light intensity PAR according to light calculation plan (µmol/m^2/s)	
Light intensity far-red according to light calculation plan (µmol/m^2/s)	
Uniformity PAR: Min/Max	
Uniformity PAR: Min/Average	
Uniformity far-red: Min/Max	
Uniformity far-red: Min/Average	
Spectrum according to light calculation plan (B/G/R together 100%) and additional % FR)	
Deviating conditions from light calculation plan during measurements	

Measurement data	
Light measurement in greenhouse (number or code)	
Location in the greenhouse	
Screen	Open or closed
Screen (type/color)	
If present 2nd screen (type/color)	
Crop present?/which crop	
Height crop (measured from floor)	
Channell 1 - color	
Channel 1 – % power during measurements	
Channell 2 - color	
Channel 2 – % power during measurements	
Channell 3 - color	
Channel 3 – % power during measurements	
Channell 4 - color	
Channel 4 – % power during measurements	
Height LED fixtures (from floor)	
Measuring height (distance between sensor and bottom of LED fixture)	
Time LED fixtures were on	

Number of rows LED fixtures on next to measuring area	
Does this match the light calculation plan?	
Greenhouse air temperature start of measurements	Temperature sensor[4]
Greenhouse air temperature end of measurements	Temperature sensor
Light sensor:	
Type	
Date of last calibration	
Light sensor (if 2nd sensor is used):	
Type	
Date of last calibration	

Uniformity other colors	
Extra individual colors verified? Fill in the data of the color:	
Light intensity Blue according to light calculation plan (µmol/m²/s)	
Uniformity Blue: Min/Max	
Uniformity Blue: Min/Average	
Light intensity Green according to light calculation plan (µmol/m²/s)	
Uniformity Green: Min/Max	
Uniformity Green: Min/Average	
Light intensity Red according to light calculation plan (µmol/m²/s)	
Uniformity Red: Min/Max	
Uniformity Red: Min/Average	

Measurement field 1 in the greenhouse	
Length of measurement field (rounded to whole meters)	
Width of measurement field (rounded to whole meters)	
Number of measurement points (rows)	
Number of measurement points (columns)	
Start time of measurements	
End time of measurements	
Measurement field 2 in the greenhouse	
Length of measurement field (rounded to whole meters)	
Width of measurement field (rounded to whole meters)	
Number of measurement points (rows)	
Number of measurement points (columns)	
Start time of measurements	
End time of measurements	

1.4 Execution of light measurements

- Make sure the LED fixtures are turned on for at least 30 minutes before measuring.
- Make sure the spectrum you want to measure is set.
- Make sure the sensor isn't cold before measuring (don't store it in the trunk overnight).
- Check with the grower that the LED fixtures are set correctly (correct spectrum, correct light intensity, and not dimmed if not intended).

[4] Between 13° and 32 °C, the spectral sensors did not respond to temperature

- Check whether you can perform the measurements as described in the light calculation plan. If this isn't possible, record the deviations in the table.
- Always measure without sunlight, preferably in the dark (from one hour after sunset or until one hour before sunrise).
- Make sure all LED fixtures are on in the greenhouse section where you will be measuring, not just a few rows. Record the number of rows of LEDs that are on in the checklist; this number should be the same as used in the light calculation plan.
- Turn on the sensor.
- Select measurement field 1 between 4 LED fixtures. Make sure there are no disruptive influences from the measuring box, column, or other structures in the greenhouse. If there are, choose a measurement field without disruptive influences and note that you have chosen a different field.
- Determine the correct measurement height under the LED fixtures. Note that the measurement height cannot be determined at the concrete path, as it is often higher; measure the correct height in the measurement field.
- Take a photo of the measurement location and any unusual details.
- Record the time and temperature in the checklist when you start measuring in field 1.
- Start the light measurements in field 1 and check the following:
    - Make sure you don't cast a shadow on the sensor: use an extension rod.
    - Keep the sensor as horizontal as possible or check the built-in spirit level (UPRtek).
- Record the time and temperature when you have finished measuring field 1.
- Select measuring field 2 between 4 LED fixtures. Ensure there are no disruptive influences from the measuring box, column, or other structures in the greenhouse.
- Redetermine the correct measurement height under the LED fixtures.
- Record the time and temperature in the checklist.
- Take a photo of the measuring location and any unusual details.
- Start the light measurements in measurement field 2.
- Record the time and temperature when you have finished measuring field 2.
- Record any unusual details.
- If you want to measure multiple light intensities and spectra: see additional measurements in Chapter 2.

1.5 Results

- A calculation tool has been created (Excel) where you can enter the light measurements: https://www.wur.nl/nl/onderzoek/producten-diensten/software-voor-plantonderzoek. The results are then generated automatically. Enter the number of measurement fields and grids in the "General sheet" tab of the calculation tool (for example, two measurement fields with grids of 9 x 5)
- Then, enter the following for each measurement field (Input tabs Measurement Field 1 and 2) and measurement point:
    - PAR, B, G, R, FR (µmol/m²/s).
    - Start by entering data in field 1.1 of the calculation tool.

The calculation tool generates and presents the following light measurement results:

1. For each measurement point per measurement field:
    - PAR in µmol/m²/s.
    - Far-red in µmol/m²/s.
    - Spectrum in % blue, green, and red.
    - The relative far-red percentage per measurement point (FR/PAR*100%).
2. Average for each measurement field (applies to PAR, blue, green, red, and far-red):
    - Weighted average[5] in µmol/m²/s.
    - Uniformity: minimum and maximum PAR values and min-max.

[5] For a weighted average, the 4 measurements perpendicular to the lights count for 25%; the light measurements at the edges count for 50%; the remaining measurements count for 100% to calculate the average.

- Uniformity: min/max, excluding the highest and lowest values.
- Uniformity: min/average.

Spectral composition:

- Light intensity of the different light colors in µmol/m²/s.
- Red/far-red ratio.
- Relative spectrum as a percentage of blue, green, and red (totaling 100%).
- Far-red percentage as an additional percentage of the 100% PAR.
- Relative spectrum as a percentage of blue, green, red, and far-red (totaling 100%).

3. Average for both measurement fields: the same as the average for each measurement field.

The "Summary" tab of the calculation tool shows all average light intensities of PAR and light colors, uniformity, and spectral composition. The data from the lighting calculation plan (which was entered in the form) is also included in the summary so that the light measurements can be compared with the lighting calculation plan.

2. Additional measurements: measuring different dimming levels and spectra

Dynamic LED fixtures allow for different light spectra and light intensities by dimming and/or switching off channels. Measuring these settings takes more time than the standard light measurement protocol (Chapter 1), as multiple settings must be measured consecutively. In principle, the steps described in Chapter 1 are to be followed. Use a new checklist and a new version of the calculation tool for each new measurement. There are several points to consider when measuring different light intensities and spectra. These are described below.

2.1 Light intensity (use of dimming)

- Start the light measurements at the highest light intensity.
- Make sure the LED fixtures have been on for 30 minutes before measuring.
- Measure the light intensity in two measurement fields as described in section 1.4.
- Dim the LED fixtures and record the setting as a percentage of power after dimming.
- Measure the light intensity again in two measurement fields. You can take the measurements immediately, although the LED fixtures will cool down slightly (this has a minimal effect on the light measurement).

2.2 Dynamic spectrum

It's important to measure the spectral composition of the light when all channels of the LED fixtures are set according to the correct settings, as the grower intends to use them. It's not correct to measure far-red, for example, and turn off the other channels if the LED fixtures aren't actually being used[6].

- Make sure the LED fixtures are turned on for 30 minutes before measuring.
- First, perform the light measurements for one light recipe (spectral composition) as described in Chapter 1.
- Adjust the light recipe for the next set of measurements.

[6] Depending on how the lights are controlled, energy is distributed differently between the channels when they are dimmed or not. This means, for example, that the far-red channel provides more light intensity when other channels are off compared to using all channels simultaneously. Therefore, it's important to set the lights according to the light recipe used by the grower.

- You can perform the measurements immediately; repeat the measurements as described in Chapter 1.

Annex Definitions light and light measurements

Terms	**Definition**
PAR	Photosynthetic Active Radiation: part of the spectrum that plants use for photosynthesis, in the range of 400 to 700 nm.
Blue light (B)	Light of wave lengths between 400 and 500 nm.
Green light (G)	Light of wave lengths between 500 and 600 nm.
Red light (R)	Light of wave lengths between 600 and 700 nm.
White light (W)	What we perceive as white light is a combination of different colors in the PAR region (400-700 nm).
Far-red light (FR)	Light of wave lengths between 700 and 800 nm.
PFD	Photon Flux Density: amount of photons (broader than PAR region) that his a certain surface per unit of time, expressed in µmol/m^2/s.
PPFD	Photosynthetic Photon Flux Density: amount of photons in the PAR region that his a certain surface per unit of time, expressed in µmol/m^2/s.
ePAR	Extended Photosynthetically Active Radiation. An extension of the traditional PAR region (400–700 nm) to include wavelengths up to 750 nm. In this light measuring protocol, this term is not used, since PAR and FR are measured separately.
Spectral light sensor	Light sensor that can measure the spectrum of a lamp, divided into different light colors. Most spectral light sensors measure light intensity per nanometer and then automatically calculate the light intensity of the light colors blue, green, red, and far-red. The Jeti Specbos 1211 UV can also measure UV light from 230 nm.
Measuring the light intensity	Light measurements (described in this protocol) are performed to measure light intensity in greenhouse horticulture.
Installation light measurement	Light measurements (described in this light measurement protocol) done immediately after installation, that are related to the power consumption of the lamps so that efficiency can be calculated.
Weighted average light intensity	Weighted average of the light intensity of a measuring field is calculated by weighting the corners for 25%, the edges for 50%, and all other measurements for 100%.
Uniformity (light distribution)	Uniformity (light distribution) indicates how evenly the light is distributed over a specific measuring area. This can be calculated in various ways, such as min/max, min/max excluding extreme values, and min/average.
Min/Max	The minimum measured light intensity in a measurement field divided by the maximum measured light intensity in that same measurement field.
Min/Max - extremes	The two extreme light intensities (minimum and maximum values) in a measurement field are not included in the Min/Max calculation. For example, if two equal minimum values occur, neither of these two minimum values is included. The same applies to the maximum measured values.
Min/average	The minimum measured light intensity is divided by the weighted average light intensity of a measurement field.
Red/Far-red	The light intensity of red light divided by the light intensity of far-red light (600-700 nm / 700-800 nm).
Spectral distribution PAR	The spectral distribution indicates the proportions of blue, green, and red in the PAR range. The sum is 100%. The far-red proportion is indicated as light intensity FR/PAR*100%. For example, 10/10/80 (B/G/R) + 10% FR.
Spectral distribution PAR+FR	The spectral distribution indicates the proportions of blue, green, red, and far-red. The sum is 100%. The far-red portion is therefore included in this 100%.

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