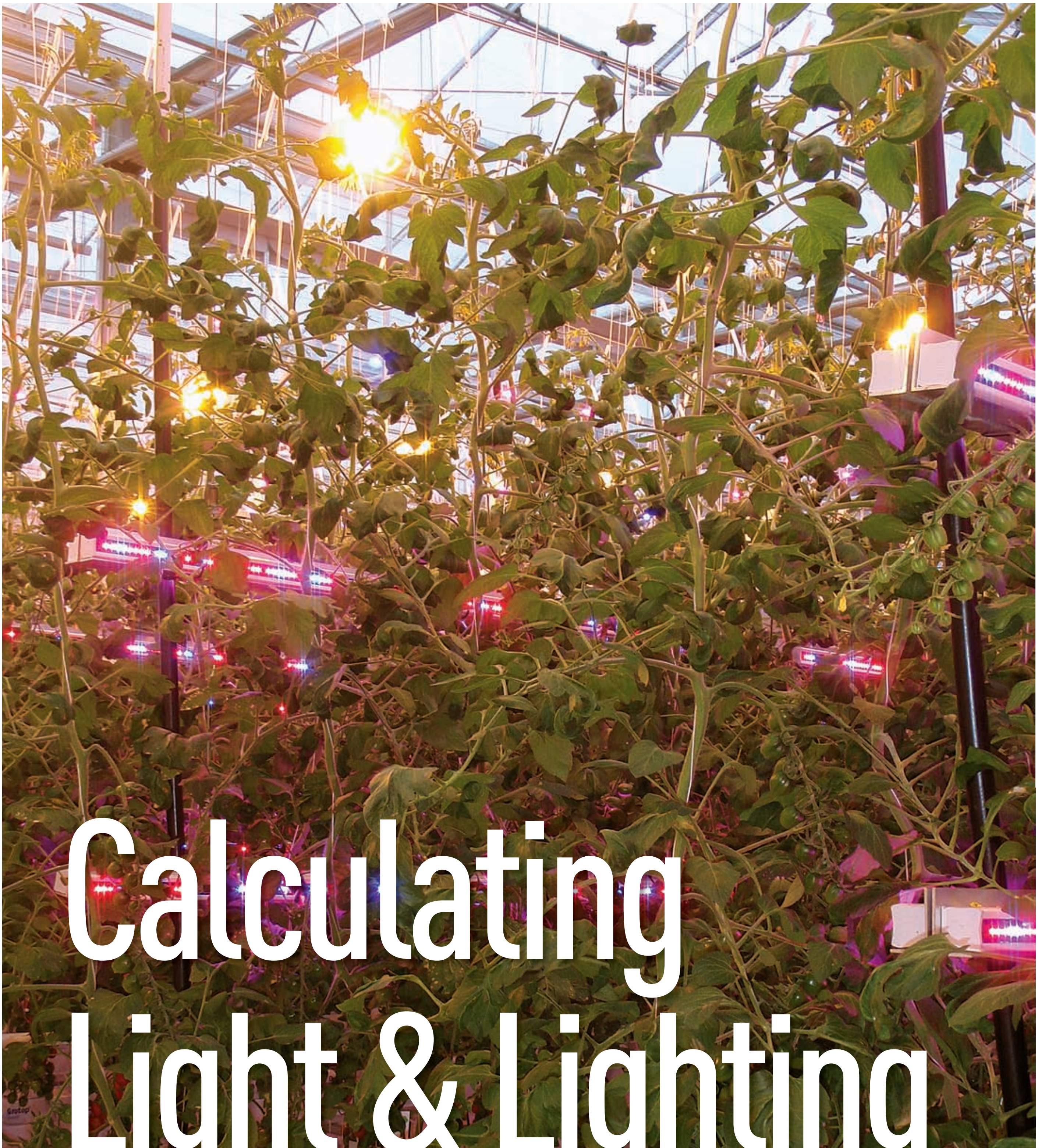


Calculating Light & Lighting

Lighting in a greenhouse is surrounded by questions. How much light to supply and when? What intensity and light sum to aim for? Is it radiation, light, growlight, PAR, photons or quanta? How much is joule, watt, mol, lux? What does wavelength, nanometer, spectrum, UV, IR and NIR mean? ELLY NEDERHOFF and LEO MARCELIS (from Wageningen) shine some light on the subject.

Light is essential for plant growth and crop production. When the natural light level is too low to allow good crop growth, growers of greenhouse crops can opt to supply additional light. In regions with dull (winter) climates, artificial lighting in greenhouses has become common practice. Modern lighting installations are controllable: they can be dimmed or partly switched off in order to supply the optimal amount of light. So the intensity and the duration of lighting can be chosen so that it is best for the plants or best from an economic point of view.

Lighting is very expensive, both in investments and in running costs. Too much lighting will cost more than it yields. Therefore it is important to know exactly how much natural light prevails, and how much artificial light is supplied. Comparing amounts of lamp light and natural light can be very complicated because the two light sources are measured with different methods and in separate units. Comparisons can easily go wrong leading to flawed decisions. In this article we explain the differences between various sensors and units. We show how light measurements can be compared and summed, and we present tables for converting light readings from one unit to other units.

Comparing light measurements

The base light in a greenhouse is the natural light with its diurnal and seasonal variations. It is important to know the prevailing light levels and light sums and to know how much light the plants need. If a grower has decided that lighting is required, the next question is how much capacity (light intensity) is required: is it 20 or 200 micromol/m^2/s? When lighting is in place, the grower has to decide when to switch the lamps on and off. Such decisions are guided by the prevailing amount of natural light, and it is important that light can be measured correctly.

Artificial light in a greenhouse is measured often with a hand-held device in a one-off measurement. In contrast, natural light in a greenhouse is normally not measured directly, but is derived from a measurement outside on the meteorological station. Ideally, both light measurements would be done using a quantum sensor *(see further)*, but in reality, they are done using any type of sensor. In short, the two measurements are often not compatible, but need to be compared.

Many people still use a luxmeter, but that is totally unsuitable for horticulture. A luxmeter is based on the sensitivity of the human eye for certain colours, and is meant for measuring light in a work place or retail shop, etc. Lux has no relevance for plant photosynthesis. Comparing different light sources (the sun, HPS or SON-T, LEDs) with a luxmeter gives 'crook' outcomes. *(see Image 1a and 1b)*

1a.

1b.

These HPS lights (left) and LED lights (right) produce the same light intensity in micromol/m^2/s and have the same effect on plant photosynthesis, but they look different to the human eye and give different readings in a luxmeter.

Basic Principles

Before going into calculations with light, we must first have some basic principles clear.

1. *Radiation or rays* are an electro-magnetic phenomenon. Radiation can be light, but it can also be X-rays, radio waves, sound, ultra-violet (UV) and infra-red (IR).
2. *Wavelength* is a characteristic of radiation. In light, the wavelength determines the light colour. Wavelength is often expressed in nanometer (nm).

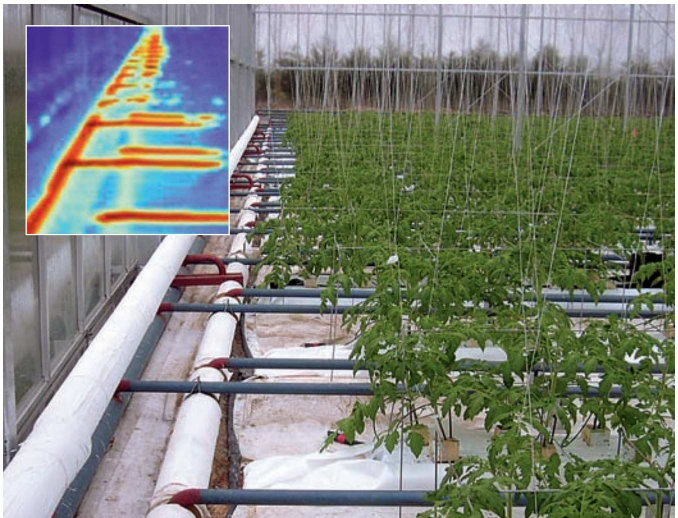
3. *Nanometer* (nm) is a millionth of a millimetre, and is used for wavelength.
4. ***Global radiation or solar radiation (radiation from the sun)*** consists for 45 to 50% of light and for the rest of heat radiation, plus a bit of UV. It covers wavelength range 300 to 1500 nm *(see Figure 1)*.
5. ***Solar radiation:*** see global radiation (radiation from the sun).
6. *Light* is radiation with a wavelength between 400 to 700 nm. This part of the spectrum is visible to the human eye and it also activates photosynthesis in plants.
7. *PAR (Photosynthetically Active Radiation)* is the scientific term for light, being radiation in waveband 400 - 700 nm. PAR indicates that this radiation activates photosynthesis.
8. ***Growlight*** also is radiation in waveband 400 - 700 nm. Growlight is a popular term for PAR, sometimes used in horticulture, to indicate that this radiation makes plants grow.
9. *Photosynthetic Photon Flux Density (PPFD)* is the scientific name for 'amount of PAR'. It is expressed in mol-units, or more precise, in micromol/m^2/s.
10. *Photons (or quanta)* are light particles that contain energy. The amount of energy in each photon depends on its wavelength (light colour). A blue photon contains much more energy than a red photon.
11. ***Quanta:*** see photons.
12. ***Quantum meter*** measures PAR as number of photons in micromol/m^2/s.
13. ***Mol*** is a measure for a certain enormously high number of particles (in this case photons). The number is 24 digits long. A micromol is a one millionth part of this, so an 18 digit number. 'Micro' is abbreviated by the Greek letter μ (mu), thus 1 μmol/m^2/s = 1 micromol/m^2/s.
14. *Heat radiation, IR, NIR* is radiation with a wavelengths beyond 700 nm. This radiation cannot be seen but can be felt as warmth. It contains energy (heat) and is important in greenhouses for temperature and for crop transpiration.
15. *Infra-red (IR)* is radiation with wavelengths beyond about 700 nm to far beyond 3000 nm.
16. *Near-infra-red (NIR)* is the first part of the infra-red, namely wavelength 700 to 1500 nm. IR and NIR are both called met heat radiation.
17. *Ultra-violet (UV)* is radiation with a wavelength under 400 nm. It is invisible and is very harmful for living organisms. UV with the lowest wavelength is most dangerous, but it is blocked by the atmosphere.
18. ***Measurement and units:*** radiation is measured in energy-units (joule or watt). Light is measured as number of photons, expressed in mol-units. Note that the unit lux is not suitable for horticulture, as mentioned before.
19. ***Joule*** is a unit for energy.
20. *Watt* is a unit for rate of energy use: 1 Watt = 1 Joule/second.
21. *Intensity* is the amount at a certain moment.
22. *Sum* is the amount accumulated over a longer period. Lightsum = light intensity x duration. Radiation sum = radiation intensity x duration.
23. *Morphogenic light or 'steerlight'* is light of particular wavelengths (especially a particular colour blue, red and far-red). A small amount of it can have a large effect on some plant processes such as flowering, setting and stretching. Steerlight is a popular term only.

Lighting is common practice in countries with dark winter conditions.

High pressure sodium lamps are the most common type of lamps for greenhouse lighting

LED light is being tested and compared with HPS light for lighting in greenhouses. Good light measurements are essential in such tests.

Radiation from the sun contains light (nearly 50% of the energy), heat (about 50%) and a bit of UV.



Heating pipes produce infra-red radiation (IR), which is heat radiation. It can't be seen - only a special IR camera can make it visible.

The best way to measure light is with a quantum meter, e.g. this LI-190 quantum sensor from LI-COR. (Photo: www.licor.com)

Solar or global radiation

Radiation is a bundle of rays, and each ray is characterised by its wavelength, expressed in nanometers. With light, the wavelength determines the light colour. Radiation from the sun, also known as solar radiation or global radiation, consists of rays with a wavelength varying from about 200 to over 1500 nm *(see Figure 1)*. The sun produces rays beyond that, but the extreme wavelengths are blocked out by the atmosphere.

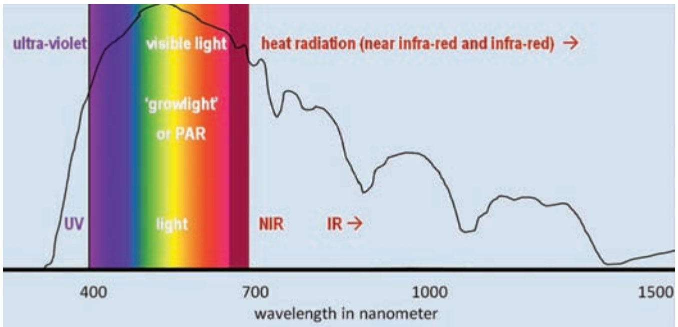


Figure 1.
Solar raditation as it arrives on earth (black curved line). About 45-50% of the energy is in the form of visible light, about 50% is heat radiation and a bit is UV. (Nederhoff, 2010)

About half the solar radiation is light, which is radiation with a wavelength between 400 and 700 nm. Light is visible to our eyes, and it also triggers plant photosynthesis and is, therefore, named PAR (Photosynthetically Active Radiation). Other terms are 'growlight' which is a popular word for PAR.

Light, growlight and PAR all refer to radiation in the waveband 400-700 nm. The term Photosynthetic Photon Flux Density (PPFD) is the scientific name for 'amount of PAR', which is expressed in mol-units (e.g. micromol/m^2/s).

While nearly half the solar radiation is light, the other half is heat, and a tiny bit is ultra-violet *(see Figure 1)*. All solar radiation with a wavelength higher than about 700 nm is heat. Radiation directly beyond 700 nm is near infra-red (NIR) and further to the right it becomes infra-red (IR). The terms NIR and IR can get mixed up, as they are both used to indicate radiation beyond 700 nm.

Measuring global radiation

All global radiation (visible light, UV, NIR and IR) contains energy, which warms up the greenhouse and activates crop transpiration. This energy can be measured by a solarimeter or pyranometer. These type of meters measure the energy of the whole spectrum of global radiation; that is, the energy in all rays present in the sunshine, including light, heat and UV. Results are given in energy units, such as Joules per second per m^2, which equals Watts per m^2 (because 1 Watt = 1 Joule/second). It is important to know the quantity of energy received from sunshine, as this energy influx is a factor in climate control and irrigation control.

Measuring PAR

For plants the Photosynthetically Active Radiation (PAR) is obviously very important, as it drives photosynthesis. There are two types of PAR meters, that both measure in the waveband 400-700 nm.

Generally, a PAR meter is a quantum meter. This measures the number of photons (quanta, or light particles) and presents the results in mol-units (e.g. micromol/m^2/s). A micromol is a certain number of particles (see Basic Principles).

But a PAR meter can also be a meter that measures energy in the 400-700 nm waveband, and produces results in energy units (Joules/s/m^2 or Watt/m^2). (For instance, *see* LI-191 on www.licor.com.)

If such an energy-based PAR meter is placed beside a solarimeter and both measure the energy in the natural radiation outside (in Joules/s/m^2 = Watt/m^2), then the solarimeter would measure about twice as much as the PAR meter.

Meteorological station

Most greenhouses are equipped with a meteorological station for measuring the conditions outside. Most meteorological stations contain one sensor for radiation or light. This can vary from a cheap sort of luxmeter to a state-of-the-art quantum meter. Growers using lighting in the greenhouse are particularly interested in light, and ideally, they would have a quantum meter on their meteorological station. Historically, however, meteorological stations are equipped with a solarimeter (global radiation meter). The reading of global radiation is often used as a rough indication for light. Below is an explanation of how a light measurement can be derived from global radiation measurement.

Estimating PAR in the greenhouse

Knowing how much energy arrives in the greenhouse is important for control of temperature and humidity. Knowing how much PAR arrives in the greenhouse is important for plant management and for advanced control of CO_2 and lighting. Natural light varies considerably, and very rarely is natural light measured in the greenhouse on a continuous basis. This is understandable as it is not easy to do: a light sensor in a greenhouse would frequently get shaded by a construction element, or would become overgrown or covered by dust. A solution to overcome shading is to use multiple sensors in a greenhouse. Another solution could be measuring outside, and calculating from that the light inside.

Winter light conditions can be very poor at higher latitudes, like here in Holland.

A meter for solar radiation (white, right/under), should not be shaded by other parts of the meteurological station.

These HPS lamps are mounted under the truss so that they cause minimal light loss due to light interception.

These high pressure sodium lamps will switch off automatically at a certain level of natural radiation, set by the grower.

In practice, however, PAR in the greenhouse is derived from a measurement by the solarimeter on the meteorological station outside. This method has some shortcomings. Firstly the measurement is done outside, whereas we want to know what happens in the greenhouse. Also it measures all radiation, whereas we are interested in waveband 400-700 nm only. Thirdly, a solarimeter measures the amount of energy (in Joules/s/cm^2 or in Watt/m^2), while for some purposes we want to know the number of photons (in micromol/m^2/s).

Despite these shortcomings, the solarimeter outside is often used to estimate the number of photons of natural light in the greenhouse. There are three steps in this calculation, namely:

1. light transmission of the greenhouse roof (for instance 70%)
2. the fact that light is about half of the global radiation (50%)
3. conversion from energy units (Joules) to number of photons (micromol).

This latter step is complicated and requires a conversion factor or conversion tables *(see further)*.

Light transmission

Light transmission of the greenhouse roof is assumed 70% as a good average. It is often much higher, even over 80%, especially in modern greenhouses used for vegetable production. It is often lower as well, such as in greenhouses for flower production. Moreover, light transmission is not constant, except under diffuse light conditions. With sunny or part-sunny weather the light transmission varies considerably during the day and over the season, depending on the position of the sun. For now, we ignore that variation, and simply assume a fixed light transmission of 70%. Hence this method is not accurate but just an estimate. *Table 1* is a conversion table showing the three conversion steps for a range of light levels, and light transmission is assumed 70%.

Radiation intensity and sum (in energy units)

At this point, we should distinguish between light intensity and light sum, and the same for radiation.

Intensity is the amount *in one second*, whereas *sum* is the amount over *a certain period*, longer than a second. Sum = intensity x time. This applies to radiation and light.

A radiation meter gives us the intensity in Joule per second per m^2 (J/s/m^2 = Watt/m^2 = W/m^2). To find the radiation sum over day, a multiplication is made of intensity and time. This can be done manually or can be programmed in the computer. Radiation intensity is given in Joule/m^2/second (equals W/m^2) and time is given for instance in hours per day. Since one is given in seconds and the other in hours, we need to bring them in line by multiplication (60 x 60). The result is a radiation sum per day in J/cm^2/day.

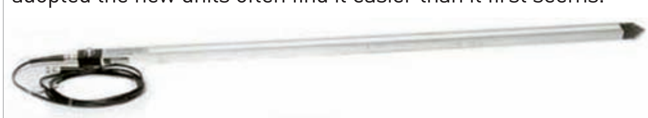
Here follows an example. If radiation intensity is 100 J/s/m^2 and duration is 3 hours per day, the radiation sum is 100 x 3 x 60 x 60 = 1080000 Joule/m^2/day. This large number is not handy and therefore we change from 'per m^2' to 'per cm^2' and drop four zeros (because 1 m^2 = 10,000 cm^2). So the radiation sum becomes 108 Joule per cm^2 over a day (108 J/cm^2/day).

Daily sums can be accumulated to find the radiation sum over a week, month or random period. It has to be stated clearly what period is covered (i.e. 'J/cm^2 over the month of January). The tables display the daily sums that were calculated using this method.

Intensity of lighting (PAR, in mol-units)

A supplier of a lighting installation will design the installation to get the required light intensity, and will then measure it after the lights are installed. Increasingly, these measurements are performed with a quantum sensor that gives results in 'mol', or more precisely, micromol/m^2/second. A mol is a certain huge number of particles (a 24-digit number), and a micromol is one millionth of that (an 18-digit number). 'Micro' is often abbreviated by the Greek letter µ (mu), so micromol/m^2/s becomes µmol/m^2/s. The light intensity of a lighting installation in a greenhouse typically supplies between 50 and 200 µmol/m^2/s PAR.

Photons and micromol are difficult concepts, but they are the best measure of light for photosynthesis. They are commonly used in many industries, so horticulture can't stay behind. Growers who adopted the new units often find it easier than it first seems.



The best sensor for measuring light in a greenhouse is a Li-cor line quantum sensor (LI-191), that measures the average light intensity over 1 m length. Photo: www.licor.com

Light sum of lighting (PAR, in mol-units)

If the intensity of a lighting installation is known (PAR in micromol/m^2/s) and if also the number of hours of lighting is recorded, then it is easy to calculate the light sum. Light sum = light intensity x time. Light sum is the number of photons (in mol or micromol) that lands on a surface over a certain period of time.

An example will illustrate how to calculate the light sum. The intensity is, for instance, 80 micromol/m^2/s and the duration is say, 8 hours. Multiplication by 60 x 60 is necessary to account for hours and seconds. Sum = 80 x 8 x 60 x 60 = 2,304,000 micromol/m^2/day. This large number is not handy. It can be reduced by six zeros by changing from micromol to mol (1 mol = 1,000,000 micromol). This means that the result is 2.3 mol/m^2/day.

One thing to consider is that some lighting installations are dimmable or can be partly switched off, so they operate on 25, 50, 75 or 100%. The lighting capacity percentage has to be recorded for every moment and has to be accounted for in the calculation. One last remark is that the intensity of lamps can decline due to ageing and hence one cannot rely on a one-off measurement of some years ago. The intensity has to be checked now and then.

Conversion from Joule to mol

As described earlier, some measurements are carried out in energy-units such as Joules or Watt, while other measurements are done in micromol photons. To enable comparison or accumulation of light data, they must have the same units. So we need to convert some data from Joule to micromol (or the other way round). This can only be done by a conversion factor. The conversion factor depends on the light colour and differs between light sources. Even different LEDs have different conversion factors. Daylight varies in composition (light colour), but under diffuse daylight conditions, often one average conversion factor for daylight is assumed, namely 1 joule = 4.6 micromol. The reverse conversion is: 1 micromol = 0.22 joule.

For various lamp types, often the following conversions factors are used:

- for SON-T: 1 joule = 4.95 micromol
- for red LEDs: 1 joule = 5.5 micromol
- for blue LEDs 1 joule = 3.9 micromol
- for 90% red plus 10% blue LEDs: 1 joule = 5.4 micromol.

The tables present conversion factors for light intensity and light sum for various types of light. Note that light data must always be presented with a description and proper units to make clear whether the figure is about radiation or light, intensity or sum, energy or photons, over which period, etc.

Summary

The current method of measuring light and radiation in practice makes it hard to compare the amount of natural light and the amount of lighting. Given the importance of light and the cost of lighting, it is desirable to find a better method of quantifying light and lighting in a greenhouse. By far the best method is using a quantum sensor that measures photons in (micro)mol, but in practice, a range of sensors is being used. Calculating light sums and radiation sums, and changing from one to another unit often requires several steps and sometimes a conversion factor. This article explains light measurements and light units, and the accompanying tables give examples of calculations and conversions.

Table 1.
Calculations on global radiation and natural light (sunlight)

Global radiation & natural light		number	units
1a global radiation outside	intensity	100	$W/m^2 = J/s/m^2$
2a global rad. in greenhouse	intensity	70	$W/m^2 = J/s/m^2$
3a ´growlight´ in greenhouse	intensity	35	$W/m^2 = J/s/m^2$
4a PAR in greenhouse	intensity	161	$micromol/m^2/s$
1b global radiation outside	rad. sum after 1 hour	36.0	J/cm^2
2b global rad. in greenhouse	rad. sum after 1 hour	25.2	J/cm^2
3b ´growlight´ in greenhouse	lightsum after 1 hour	12.6	J/cm^2
4b PAR in greenhouse	PAR-sum after 1 hour	0.58	$mol/m^2/d$

- Global radiation outside is assumed 100 Watt/m^2. Derived from this are the amount of radiation, light and PAR in greenhouse, as well as the sums of radiation, light and PAR after 1 hour.
- 2a is calculated from 1a: multiply by 70% for light transmission of greenhouse roof
- 3a is calculated from 2a: multiply by 50% for fraction of light in global radiation
- 4a is calculated from 3a: multiply by 4.6
  (conversion factor for Joule to micromol for global radiation)
- 1b comes from 1a; 2b comes from 2a; 3b comes from 3a, by multiplication:
  x 1 (number of hours) x 3600 (seconds per hour) x 0,0001 (m^2 per cm^2)
- 4b comes from 4a: x 1 (number of hours) x 3600 (seconds per hour)
  x 0,000001 (mol per micromol)

Table 2.
Calculations on HPS and LED light
(LED is ca 90% red and ca 10% blue)

Artifical light		HPS	LED-r/b	units
5a PAR in greenhouse	intensity	100	100	$micromol/m^2/s$
6a 'growlight' in greenhouse	intensity	20.20	18.50	$W/m^2 = J/s/m^2$
5b PAR in greenhouse	sum after 1 hour	0.36	0.36	mol/m^2
6b 'growlight' in greenhouse	sum after 1 hour	7.3	6.7	J/cm^2

- PAR intensity is assumed 100 micromol/m^2/s. Derived from this is 'growlight' intensity in W/m^2, and also the PAR-sum and 'growlight' sum after 1 hour of lighting.
- 6a is calculated from 5a: divide by conversion factor (or multiply with its reverse) The conversion factor is 4.95 for HPS and 5.4 for red/blue LEDs
- 5b is calculated from 5a; by multiplication by the number of hours (1 hour in this example) and by 3600 (number of seconds in one hour) and by 0,000001 (number of mol per micromol)
- 6b comes from 6a: by multiplication with the number of hours (1) and 3600 (number of seconds in an hour) and 0.0001 (number of m^2 per cm^2)

About the author
Elly Nederhoff is Associate Researcher and Leo Marcelis is Professor in Crop Production in Low-Energy Greenhouses at Wageningen University and team leader at Wageningen UR Greenhouse Horticulture, in the Netherlands.
Email: Elly.Nederhoff@wur.nl and Leo.marcelis@wur.nl

Disclaimer
This article was crafted with the greatest care, but the authors and the publisher accept no responsibility for any errors that may exist in the text or tables.

Table 3. *Solar radiation and natural light: calculated intensity and sums of radiation, growlight and PAR outside and in the greenhouse*

solar	intensity			sum		sum		sum		sum	
factor	70%	50%	4.6	3 hours/day	8 hours/day	3 hours/day	8 hours/day	3 hours/day	8 hours/day	3 hours/day	8 hours/day
global radiation outside	global radiation inside	''growlight' inside	PAR inside	global radiation outside	global radiation outside	global radiation inside	global radiation inside	''growlight' inside	''growlight' inside	PAR inside	PAR inside
watt/m^2 =J/s/m^2	W/m^2 = J/s/m^2	W/m^2 = J/s/m^2	micromol/m^2/s	J/cm^2/d	J/cm^2/d	J/cm^2/d	J/cm^2/d	J/cm^2/d	J/cm^2/d	mol/m^2/d	mol/m^2/d
10	7.0	3.5	16.1	10.8	28.8	7.6	20.2	3.8	10.1	0.17	0.46
30	21	11	48	32	86	23	60	11	30	0.52	1.39
50	35	18	81	54	144	38	101	19	50	0.87	2.3
80	56	28	129	86	230	60	161	30	81	1.4	3.7
100	70	35	161	108	288	76	202	38	101	1.7	4.6
130	91	46	209	140	374	98	262	49	131	2.3	6.0
160	112	56	258	173	461	121	323	60	161	2.8	7.4
200	140	70	322	216	576	151	403	76	202	3.5	9.3
250	175	88	403	270	720	189	504	95	252	4.3	11.6
300	210	105	483	324	864	227	605	113	302	5.2	13.9
350	245	123	564	378	1008	265	706	132	353	6.1	16.2
400	280	140	644	432	1152	302	806	151	403	7.0	18.5
500	350	175	805	540		378		189		8.7	
600	420	210	966	648		454		227		10.4	
700	490	245	1127	756		529		265		12.2	
800	560	280	1288	864		605		302		13.9	
900	630	315	1449	972		680		340		15.6	

Table 4. *Light from high pressure sodium (HPS) lamps: calculated intensity and sums of growlight and PAR in the greenhouse*

HPS	intensity	HPS	PAR sum inside greenhouse (mol/m^2/day)				HPS	''growlight' sum in greenhouse (Joule/cm^2/day)			
factor	0.20	hours/day	1 hours/day	8 hours/day	12 hours/day	20 hours/day	hours/day	1 hours/day	8 hours/day	12 hours/day	20 hours/day
PAR	growlight	intensity	sum	sum	sum	sum	intensity	sum	sum	sum	sum
micromol/m^2/s	W/m^2 = J/s/m^2	micromol/m^2/s	mol/m^2/d	mol/m^2/d	mol/m^2/d	mol/m^2/d	W/m^2 = J/s/m^2 PAR	J/cm^2/d	J/cm^2/d	J/cm^2/d	J/cm^2/d
10	2.0	10	0.04	0.3	0.4	0.7	2.0	0.7	5.8	8.6	14.4
20	4.0	20	0.07	0.6	0.9	1.4	4.0	1.4	12	17	29
30	6.0	30	0.11	0.9	1.3	2.2	6.1	2.2	17	26	43
50	10.0	50	0.18	1.4	2.2	3.6	10.1	3.6	29	43	72
80	16.0	80	0.29	2.3	3.5	5.8	16.2	5.8	46	69	115
100	20.0	100	0.36	2.9	4.3	7.2	20.2	7.2	58	86	144
130	26.0	130	0.47	3.7	5.6	9.4	26.3	9.4	75	112	187
160	32.0	160	0.58	4.6	6.9	11.5	32.3	11.5	92	138	230
200	40.0	200	0.72	5.8	8.6	14.4	40.4	14.4	115	173	288
250	50.0	250	0.90	7.2	10.8	18.0	50.5	18.0	144	216	360
300	60.0	300	1.08	8.6	13.0	21.6	60.6	21.6	173	259	432

Table 5. *Light from LEDs (90% red, 10% blue): calculated intensity and sums of growlight and PAR in the greenhouse*

LED-r/b	intensity	LED-r/b	PAR sum inside greenhouse (mol/m^2/day)				LED-r/b	''growlight' sum in greenhouse (Joule/cm^2/day)			
factor	0.185	hours/day	1 hours/day	8 hours/day	12 hours/day	20 hours/day	hours/day	1 hours/day	8 hours/day	12 hours/day	20 hours/day
intensity	intensity	intensity	sum	sum	sum	sum	intensity	sum	sum	sum	sum
micromol/m^2/s	W/m^2 = J/s/m^2 PAR	micromol/m^2/s	mol/m^2/d	mol/m^2/d	mol/m^2/d	mol/m^2/d	W/m^2 = J/s/m^2 PAR	J/cm^2/d	J/cm^2/d	J/cm^2/d	J/cm^2/d
10	1.9	10	0.04	0.3	0.4	0.7	1.9	0.7	5.3	8.0	13
20	3.7	20	0.07	0.6	0.9	1.4	3.7	1.3	11	16	27
30	5.6	30	0.11	0.9	1.3	2.2	5.6	2.0	16	24	40
50	9.3	50	0.18	1.4	2.2	3.6	9.3	3.3	27	40	67
80	14.8	80	0.29	2.3	3.5	5.8	14.8	5.3	43	64	107
100	18.5	100	0.36	2.9	4.3	7.2	18.5	6.7	53	80	133
130	24.1	130	0.47	3.7	5.6	9.4	24.1	8.7	69	104	173
160	29.6	160	0.58	4.6	6.9	11.5	29.6	10.7	85	128	213
200	37.0	200	0.72	5.8	8.6	14.4	37.0	13.3	107	160	266
250	46.3	250	0.90	7.2	10.8	18.0	46.3	16.7	133	200	333
300	55.5	300	1.08	8.6	13.0	21.6	55.5	20.0	160	240	400