An Employee Owned Company

Skye eGuides

Light Measurement Guidance Notes

Contents

1. Introduction

Light is a word which is generally used to describe the portion of the sun's radiation visible to the human eye. This portion is only a very small part of the sun's total radiation output, called the Electromagnetic Spectrum, some of which does not even reach the Earth's surface.

The electromagnetic spectrum also includes ultraviolet radiation (which gives us sunburn), infrared radiation (which keeps us warm) as well as X-rays, microwaves and radiowaves. If you would like to understand more about solar radiation and the electromagnetic spectrum, please read Appendix 1.

The part of the spectrum which can be measured using Skye Instruments light meters is in the ultraviolet, visible and near-infrared regions. These radiations directly affect the life of plants, humans and animals on the planet's surface.

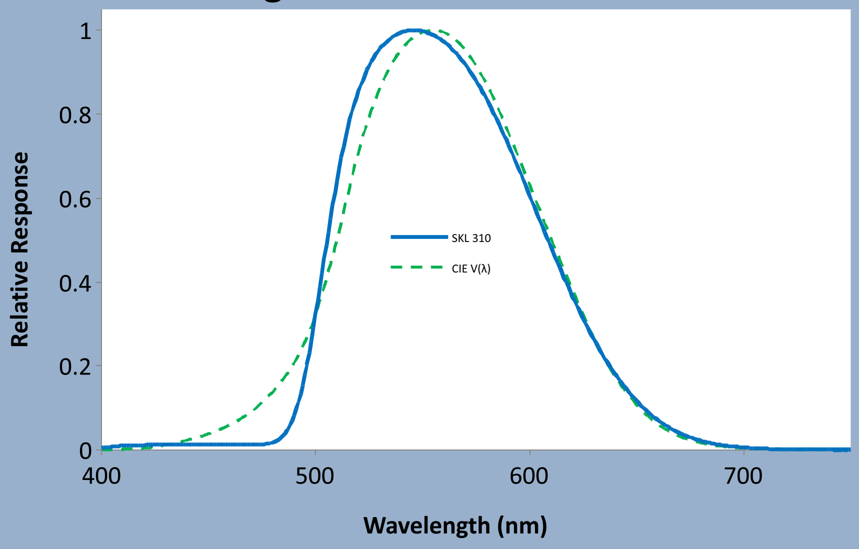
Radiation in the ultraviolet, visible and near-infrared regions are described as electromagnetic waves, and the distance between each wave is called the wavelength. In this part of the sun's spectrum, the wavelengths are very small, only 0.000000001m long, and are measured in nanometres (abbreviated as nm).

1.1 LIGHT AND HUMANS

Our eyes detect and see visible light radiation between 400 and 700nm. Our bodies can also detect infrared radiation (700 to 2000nm) which is invisible to our eyes but we feel as warmth, and are affected by ultraviolet radiation (280 to 400nm), also invisible but results in sunburn or, in extreme cases, skin cancer.

The seven colours of the rainbow appear between 400 and 700nm, but we do not see all colours equally as clearly. The colours we are most sensitive to, and so see best, are greens and yellows, which are around 500 to 600nm. We see a greater variety of shades of greens and yellows than we do any other colours, as our eyes have their peak response at 555nm.

Figure 1 - Lux Sensor SKL 310



Visible light, as seen by the human eye, is measured in lux units. The lux is carefully defined to include only the wavelengths seen by our eyes and in the same ratios. The shape of this response is called the CIE Photopic Curve, see Figure 1 (Lux Sensor SKL310).

Because we use visible light in order to see our way through the world, our eyes have become very sensitive to both very bright and very low light levels and are easily deceived when trying to assess the level or intensity of light. There can be 5 or more decades of light level between indoors and full sunshine, yet we are able to read a book equally well in both situations.
Lux Senors

1.2 LIGHT AND PLANTS

Plants also detect and use light radiation between 400 and 700nm, but with a wider sensitivity than is seen by the human eye. Plants can also benefit from infrared warming and be damaged by ultraviolet radiation, but the range 400 to 700nm is important for the photosynthesis process. This produces sugars and growth, and so is called the Photosynthetically Active Radiation or PAR region.

The shape of the wavelength response curve for plants shows that they are most sensitive to the red colour region, then blue and least of all to green colours. In fact, they reflect most of the green wavelengths, which is why they appear green to us. See the shape of a typical plant response curve in Figure 2 (PAR Special Sensor SKP 210) as formulated by Dr McCree in the early 1970's.

Photosynthesis converts the sun's radiation energy into sugar energy for the plant to use. This requires relatively strong radiation levels, and so in general, plants are not very sensitive to lower light levels. In full sunlight, plants will generally grow faster the more light they receive, while barely growing indoors.
PAR Quantum Sensors

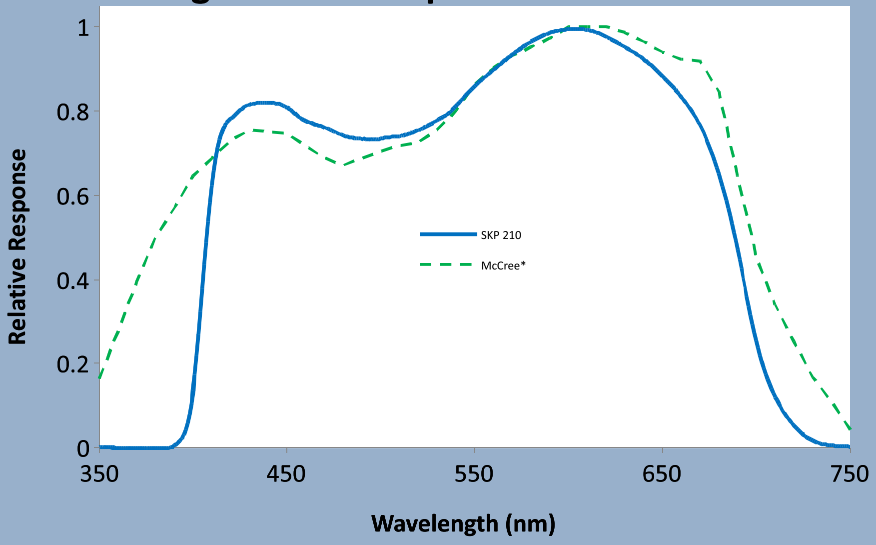


Figure 2 - PAR Special Sensor SKP 210

2. Light Measurement

Figure 1 - Lux Sensor SKL 310

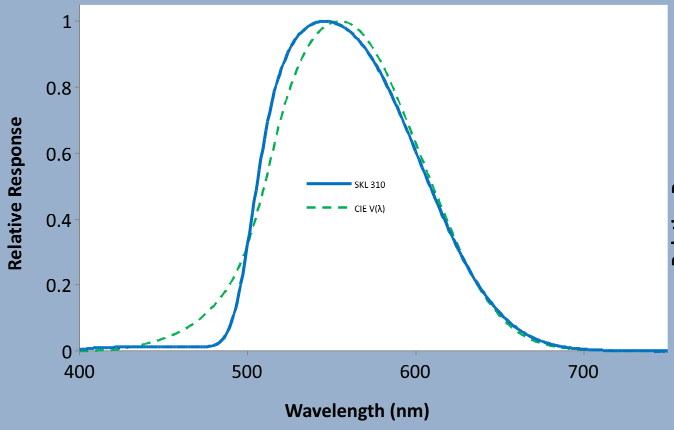
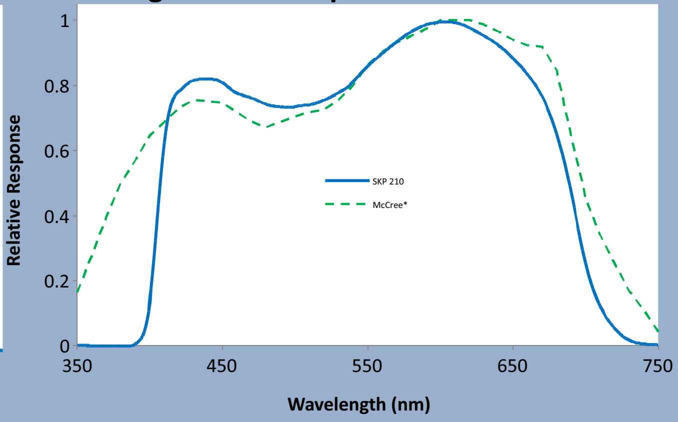


Figure 2 - PAR Special Sensor SKP 210



By comparing Figures 1 and 2, it is clear that plants and humans view the sun's radiation in very different ways. Also, we must remember that plants are not able to utilise the very low light levels which humans can easily see by.

It is important to measure light levels both accurately and differently, according to whether we are concerned with human comfort, or plant welfare.

2.1 LIGHT LEVELS FOR HUMANS & ANIMALS

Traditionally, we have measured light as the radiation that our eyes can see, assuming that the world around us 'sees' the same. Previously, readings were measured in foot candles (which were light levels as compared to the brightness of a candle). We now have a definition of exactly what we do see (the CIE Photopic Curve, Figure 1), and it is measured in lux units.

So to measure light levels in offices, buildings etc., a photopic or lux sensor and meter is used. These sensors can also be used for the automatic switching on of lights, for example in a car park when it gets dark, etc.

As animals have a very similar eye structure to our own, photopic or lux sensors can also be used for monitoring light levels in their living quarters, assessing artificial daylight levels etc.

See Figure 3 for examples of lux levels in daily situations.

2.2 LIGHT LEVELS FOR PLANTS

Solar radiation energy is often measured in watts per square metre (W m^{-2}). The watt is a unit of power.

Light bulb and lamp manufacturers sell their products rated sometimes in watts and sometimes in lux. This can be very confusing when relating different lamps to the energy a plant requires. As explained above, only the radiant energy between 400 and 700nm will result in photosynthesis, and affect the plant's health and growth rates. It is important to measure this PAR region preferably as an energy in W m^{-2}. (A measurement in lux will not give a true reading over the entire PAR region).

Plant science researchers prefer to measure the PAR energy in a more empirical unit of micro moles per square metre per second (µmol m^{-2} s^{-1}). The units of W m^{-2} and µmol m^{-2} s^{-1} are interchangeable for known light sources, and so either measurement is equally as valid. (See Appendix 3 for conversion factors).

So a PAR sensor and meter should be chosen as appropriate for plant measurements. The PAR Energy SKE 510 sensor will give readings in W m^{-2}, while the PAR Quantum SKP 215 or PAR Special SKP 210 sensors will give readings in µmol m^{-2} s^{-1}.

Figure 3 shows typical daily light levels in lux.
Figure 4 shows examples of PAR readings in different lighting situations.

Figure 3 - Typical Daily Light Levels in lux

Natural Light

Clear night, full moon	0.3 lux
Winter's day, overcast sky	900 - 2,000 lux
Summer's day, overcast sky	4,000 - 20,000 lux
Winter's day, clear sky	up to 9,000 lux
Summer's day, clear sky	up to 100,000 lux

Artificial Light

Candle at 1m distance	1 lux
Side roads	4 lux
Main roads	16 lux
Staircases	30 - 60 lux
Hallways	120 lux
Living rooms, offices	250 lux
Classrooms, shops, workshops	500 lux
Drawing offices, precision workshops	1,000 lux

Figure 4 - Typical Daily PAR Light Levels in W m^{-2}

Winter's day, overcast sky	20 - 40 W m^{-2}
Summer's day, overcast sky	40 - 60 W m^{-2}
Winter's day, clear sky	up to 200 W m^{-2}
Summer's day, clear sky	up to 400 W m^{-2}

2.3 LIGHT QUALITY FOR PLANTS

For an efficient photosynthesis process to take place, the quality of the light is just as important as the amount of light received by the plant. 'Good quality' light for plant germination and growth contains the correct ratios of the different colours and wavelengths between 400 and 700nm, such as appears on a bright, sunny summer afternoon.

If the light quality is poor when the plant is just emerging, it can grow tall and spindly as it tries to grow fast to 'reach' the light. To our eyes, it seems that there is simply a low light level, but the plant is actually seeing shortage of the red wavelengths in the light.

In contrast, if there is a surplus of the red wavelengths compared to other colours, the plant will growth thick and bushy, which in most cases will result in a healthy looking plant.

To measure the quality of light a plant is receiving, it is usual to measure the ratio between the red wavelength at 660nm and the far-red wavelength which is just outside the PAR range at 730nm. On a bright, sunny summer afternoon, the red to far-red ratio equals one.

At low sun angles such as early morning and early evening, the red / far-red ratio is often less than one, showing that even natural sunlight is not ideal for good plant growth throughout the whole day.

It is particularly important to measure light quality and the red / far-red ratio when giving plants supplementary lighting. Different lamp types give different colour ratio lighting, which can dramatically effect the red / far-red ratio. For example, quartz halogen lamps give out more blue wavelengths while tungsten lamps give out more red wavelengths.

A Red / Far-red SKR 110 sensor and SKR 100 Ratio meter can give measurements of the red wavelength or the far-red wavelength in µmol m^{-2} s^{-1}, but more importantly, it will read directly the Ratio between these two colours, and so quickly and easily will monitor light quality.

Red Far Red Sensor

3. Light Sensors and Meters

Solar radiation falls evenly over the whole Earth's surface. Ideally, a light sensor should act like a large flat surface, so that it measures the sun's radiation as if it were part of the planet surface.

In order to do this, Skye Instruments light sensors are 'cosine corrected', which means that they have a specially designed light acceptance geometry. Light can enter the sensor from a 180 degree hemisphere above it, according to Lambert's Cosine Law. This means that the sensor is more sensitive to light from directly overhead (just as mid-day sunshine is strongest) and gradually less sensitive to light from low angles (just as early morning and late evening sunshine is weakest).

A cosine corrected sensor does not measure any light which comes from below the 'horizon' of the hemisphere above it, as this could be stray, reflected light. It is therefore very important to ensure the sensor is levelled, so that the whole skyline is measured, without any ground reflections adding to the reading. The Skye Instruments levelling unit, which incorporates a level bubble, makes this procedure very simple.

The light sensitive sensors themselves require a readout device for viewing the light measurements. Usually, they are paired with a digital display meter for quick spot measurements. They can also be connected to our SpectroSense2 which allow the user to take readings from multiple sensors. If longer term measurements need to be made, the sensor can be connected to a larger datalogger along with other sensors for a complete microclimate study (for example, an automatic weather station).

DataHogs can also be linked up to supplementary lighting systems for automatic switching according to natural sunlight levels.

4. Appendices

Appendix 1 - Electromagnetic Radiation Spectrum

Light is simply a small part of a continuous spectrum of energy that ranges from radio waves to cosmic rays. This spectrum is all electromagnetic energy, just the wavelength is changing. The spectrum is commonly talked about in terms of wavelength or frequency. Both are different measures of the same thing in this case.

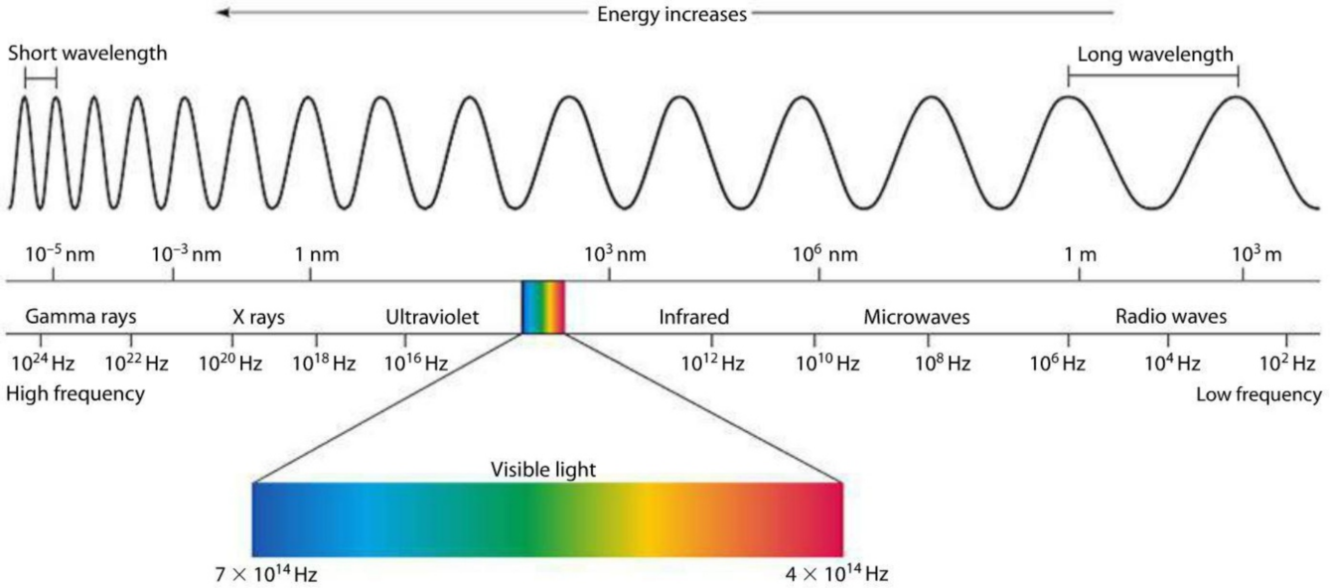
In the radio part of the spectrum both are used. The long wave 'Radio 4' is talked about as a frequency of 198KHz (or 198,000 waves per second) or a wavelength of 1500metres (where the distance between successive wave peaks is 1.5 kilometres).

With light, the frequency of the waves is so very high that it is an inconvenient measure. Even though their wavelength is very short, we have convenient numbers for it, and thus light is usually talked about as its wavelength. Green light for example has a wavelength of 555 nanometres (0.000000555metres) and its frequency is a number with 16 zeroes after it!

Human eyes have their peak sensitivity at 555nm, which is in the green part of the spectrum. (remember ROYGBIV - Richard of York gave battle in vain - gives the rainbow spectrum order of colour and decreasing wavelength, i.e. red / orange / yellow / green / blue / indigo / violet).

The sun produces a continuous spectrum received at the earth's surface from ultraviolet to radiowaves, the strongest and most significant being the visible and infrared regions. A tungsten light bulb will produce visible and infrared energies. A fluorescent tube will produce portions of the visible spectrum, but very little of the infrared region. Many other lamps are available, some giving you more useful energy (to plants) per watt of electricity required to power them than others.

See the Electromagnetic Spectrum below to see where our visible range fits into the complete picture.



APPENDIX 2 - Conversions of W m^{-2}

To begin, 1 watt = 1 joule per second

So, 1 W m^{-2} = 1 J m^{-2} s^{-1}

You need to include the time factor which is your logging interval to convert each W m^{-2} reading to J m^{-2}(time interval).

E.g. For a logging interval of 30 minutes = 1800 seconds

Y W m^{-2} = Y x 1800 J m^{-2} 30minutes

There are 48 x 30 minute readings in a 24 hour period, these should be added together to give a single reading of J m^{-2} day. To convert to MJ m^{-2} day then divide by 10^6 (or 1,000,000).

So in summary,

1. Multiply W m^{-2} reading by the logging periods in seconds
2. Add all readings for a 24 hour period
3. Divide the total by 106 to obtain MJ m^{-2} day

APPENDIX 3 - Conversion between µmol m^{-2} s^{-1}

Plant and other chemical processes use light radiation in ‘packets of energy’ or ‘quanta’. Simply, the process will add a carbon atom for example, to a chain of atoms with the energy from a quantum, and the remaining energy is wasted of there is not enough left from the quantum to add a second carbon atom.

A quantum of light contains a certain amount of energy depending on its wavelength. A quantum of red light has less energy than a quantum of blue light.

When dealing with plant efficiency and energetics, the Skye PAR Quantum or PAR Special meters are calibrated to read in quanta or micro mols per metre squared per second (µmol m^{-2} s^{-1}). A ‘mol’ is Avagadro’s (6.023 x 1023) number of quanta.

The formula for converting between W m^{-2} and µmol m^{-2} s^{-1} is:

$$\frac{119.708}{\text{Wavelength (nm)}} \qquad \frac{x\ (\mathrm{W\ m^{-2}})}{y\ (\mu\mathrm{mol\ m^{-2}\ s^{-1}})}$$

This is a precise formula for individual wavelengths.

For an **approximate** value over the waveband 400-700nm (PAR) under natural daylight conditions:

$$\frac{119.708}{\text{wavelength (nm)}} \qquad \frac{1}{4.6}$$

So to convert a reading of X µmol m^{-2} s^{-1} to W m^{-2} simply divide by 4.6
Or convert a daylight reading of Y W m^{-2} to µmol m^{-2} s^{-1} simply multiply by 4.6

However, other light sources have different ratios of colour energies within the 400-700nm band, resulting in slightly different conversion factors as shown below:

Light Source	To convert W m^{-2} to µmol m^{-2} s^{-1} multiply by:	To convert µmol m^{-2} s^{-1} to W m^{-2} divide by:
Daylight	4.6	4.6
Metal Halide	4.6	4.6
High pressure sodium (SON/T)	5.0	5.0
Mercury	4.7	4.7
White Fluorescence	4.6	4.6
Incandescent	5.0	5.0

(Taken from K.J. McCree. Photsynthetically Active Radiation. Envyvlopedia of Plant Physiology. New Series, Volume 12A. Physiological Plant Ecology I. Springer-Verlag Berlin Heidelberg. 1981.)

APPENDIX 4 - Conversion between lux and µmol m^{-2} s^{-1} or W m^{-2}

As can be seen in the previous pages, measurements in Lux and measurements made in the PAR region in µmol m^{-2} s^{-1} or W m^{-2}, are not exactly compatible due to the range of the response of these sensors.

However, it is possible to make an **approximate** conversion between these units as many lighting installations are quoted in Lux by the manufacturers.

Again, different types of lights have different conversion factors as below. Remember, this is only for measurements in the 400-700nm PAR region, not for total solar radiation sensors.

Light Source	To convert lux to µmol m^{-2} s^{-1} multiply by:	To convert µmol m^{-2} s^{-1} to lux divide by:
Daylight	0.0185	0.0185
Metal Halide	0.0141	0.0141
High Pressure Sodium (SON/T)	0.0122	0.0122
Mercury	0.0119	0.0119
Incandescent	0.0200	0.0200

Light Source	To convert lux to W m^{-2} multiply by:	To convert W m^{-2} to lux divide by:
Daylight	0.00402	0.00402
Metal Halide	0.00305	0.00305
High Pressure Sodium (SON/T)	0.00245	0.00245
Mercury	0.00262	0.00262
Incandescent	0.00397	0.00397

Taken from Thimijan and Heins, 1985, HortScience, 18 pp 818-822.

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