apogee INSTRUMENTS

OWNER'S MANUAL

QUANTUM SENSOR

Models JSQ-100 and JSQ-300 Series

(including SS models)

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CERTIFICATE OF COMPLIANCE

EU Declaration of Conformity

for the following product(s):

Models: JSQ-110, JSQ-120, JSQ-301, JSQ-303, JSQ-306, JSQ-321, JSQ-323, JSQ-326
Type: Quantum Sensor

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/30/EU	Electromagnetic Compatibility (EMC) Directive
2011/65/EU	Restriction of Hazardous Substances (RoHS 2) Directive

Standards referenced during compliance assessment:

EN 61326-1:2013	Electrical equipment for measurement, control and laboratory use – EMC requirements
EN 50581:2012	Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

Please be advised that based on the information available to us from our raw material suppliers, the products manufactured by us do not contain, as intentional additives, any of the restricted materials including cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls (PBB), polybrominated diphenyls (PBDE).

Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but rely on the information provided to us by our material suppliers.

INTRODUCTION

Radiation that drives photosynthesis is called photosynthetically active radiation (PAR) and is typically defined as total radiation across a range of 400 to 700 nm. PAR is often expressed as photosynthetic photon flux density (PPFD): photon flux in units of micromoles per square meter per second (µmol m^{-2} s^{-1}, equal to microEinsteins per square meter per second) summed from 400 to 700 nm (total number of photons from 400 to 700 nm). While Einsteins and micromoles are equal (one Einstein = one mole of photons), the Einstein is not an SI unit, so expressing PPFD as µmol m^{-2} s^{-1} is preferred.

The acronym PPF is also widely used and refers to the photosynthetic photon flux. The acronyms PPF and PPFD refer to the same parameter. The two terms have co-evolved because there is not a universal definition of the term “flux”. Some physicists define flux as per unit area per unit time. Others define flux only as per unit time. We have used PPFD in this manual because we feel that it is better to be more complete and possibly redundant.

Sensors that measure PPFD are often called quantum sensors due to the quantized nature of radiation. A quantum refers to the minimum quantity of radiation, one photon, involved in physical interactions (e.g., absorption by photosynthetic pigments). In other words, one photon is a single quantum of radiation.

Typical applications of quantum sensors include incoming PPFD measurement over plant canopies in outdoor environments or in greenhouses and growth chambers, and reflected or under-canopy (transmitted) PPFD measurement in the same environments.

Apogee Instruments JSQ series quantum sensors consist of a cast acrylic diffuser (filter), photodiode, and signal processing circuitry mounted in an anodized aluminum housing, and a cable to connect the sensor to a measurement device. Sensors are potted solid with no internal air space, and are designed for continuous PPFD measurement in indoor or outdoor environments. JSQ series sensors output an analog voltage that is directly proportional to PPFD under sunlight (e.g., model JSQ-110) or electric lights (e.g., model JSQ-120). The voltage signal from the sensor is directly proportional to radiation incident on a planar surface (does not have to be horizontal), where the radiation emanates from all angles of a hemisphere.

SENSOR MODELS

This manual covers the unamplified models JSQ-100 series and JSQ-300 series. Additional models are covered in their respective manuals.

Model	Signal	Calibration
JSQ-110	**Self-powered**	**Sunlight**
JSQ-120	**Self-powered**	**Electric light**
JSQ-311	**Self-powered**	**Sunlight**
JSQ-321	**Self-powered**	**Electric light**
JSQ-313	**Self-powered**	**Sunlight**
JSQ-323	**Self-powered**	**Electric light**
JSQ-316	**Self-powered**	**Sunlight**
JSQ-326	**Self-powered**	**Electric light**
JSQ-212	0-2.5 V	Sunlight
JSQ-222	0-2.5 V	Electric light
JSQ-214	4-20 mA	Sunlight
JSQ-224	4-20 mA	Electric light
JSQ-215	0-5 V	Sunlight
JSQ-225	0-5 V	Electric light
JSQ-420	USB	Sunlight and Electric light
JSQ-421	SDI-12	Sunlight and Electric light
JSQ-422	Modbus	Sunlight and Electric light

Line quantum sensors, JSQ-300 series, provide spatially averaged PPFD measurements. All sensors along the length of the line are connected in parallel, and as a result, Apogee line quantum sensors output a single voltage signal that is directly proportional to PPFD averaged from the location of the individual sensors.

Sensor model number and serial number are located near the pigtail leads on the sensor cable. If you need the manufacturing date of your sensor, please contact Apogee Instruments with the serial number of your sensor.

JSQ-110/JSQ-120

JSQ-313-323

JSQ-316/326

JSQ-311/321

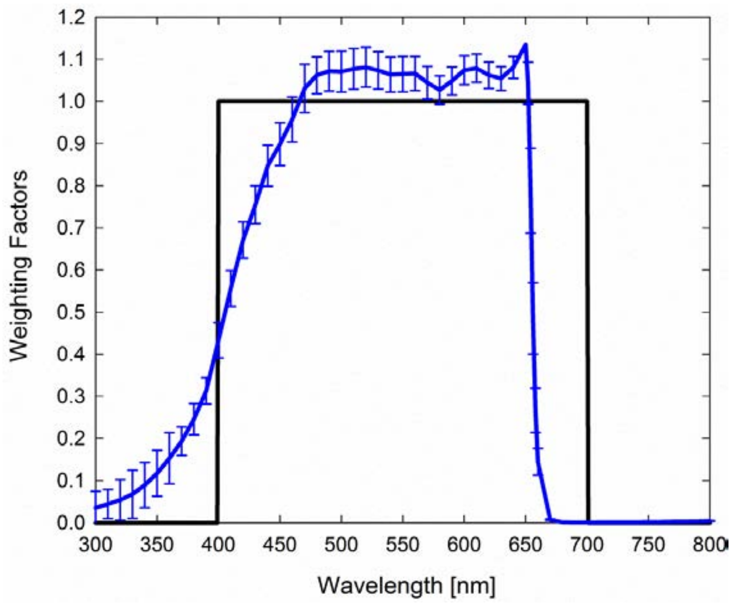
SPECIFICATIONS

	JSQ-100 Series	JSQ-313, JSQ-316, JSQ-323, JSQ-326	JSQ-311, JSQ-321
Power Supply	Self-powered		
Sensitivity	0.2 mV per µmol m^{-2} s^{-1}		
Calibration Factor (Reciprocal of Sensitivity)	5.0 µmol m^{-2} s^{-1} per mV		
Calibration Uncertainty	± 5 % (see Calibration Traceability below)		
Calibrated Output Range	0 to 800 mV		
Measurement Repeatability	Less than 0.5 %		
Long-term Drift (Non-stability)	Less than 2 % per year		
Non-linearity	Less than 1 % (up to 4000 µmol m^{-2} s^{-1})		
Response Time	Less than 1 ms		
Field of View	180º		
Spectral Range	410 to 655 nm (wavelengths where response is greater than 50% of maximum; see Spectral Response below)		
Spectral Selectivity	Less than 10 % from 469 to 653 nm		
Directional (Cosine) Response	± 5 % at 75º zenith angle (see Cosine Response below)		
Temperature Response	0.06 ± 0.06 % per C (see Temperature Response below)		
Operating Environment	-40 to 70 C; 0 to 100 % relative humidity; can be submerged in water up to depths of 30 m		
Dimensions	24 mm diameter; 28 mm height	500 mm length; 15 mm width; 15 mm height	700 mm length; 15 mm width; 15 mm height
Mass	90 g (with 5m of lead wire)	275 g	375 g
Cable	5 m of two conductor, shielded, twisted-pair wire; additional cable available in multiples of 5m; santoprene rubber jacket (high water resistance, high UV stability, flexibility in cold conditions); pigtail lead wires		

Calibration Traceability

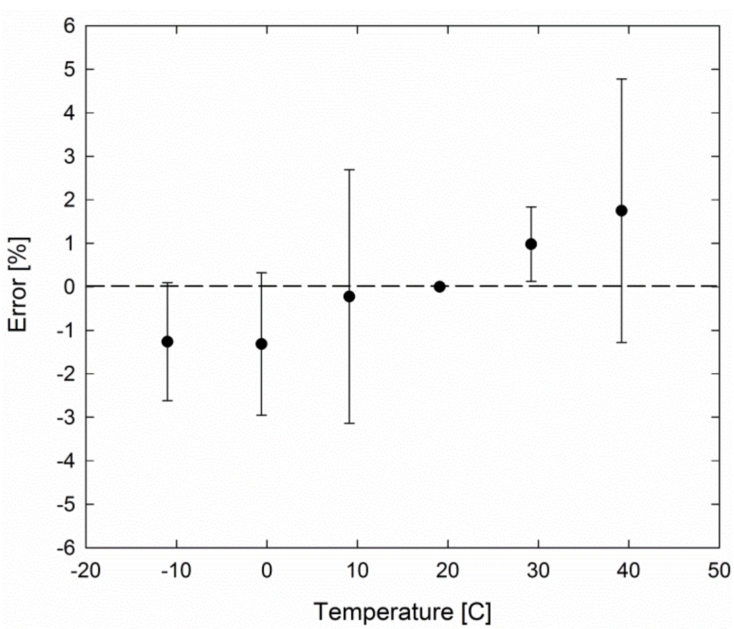
Apogee JSQ series quantum sensors are calibrated through side-by-side comparison to the mean of four Apogee model JSQ-110 or JSQ-120 transfer standard quantum sensors under high output T5 cool white fluorescent lamps. The transfer standard quantum sensors are calibrated through side-by-side comparison to the mean of at least three LI-COR model LI-190R reference quantum sensors under high output T5 cool white fluorescent lamps. The reference quantum sensors are recalibrated on a biannual schedule with a LI-COR model 1800-02 Optical Radiation Calibrator using a 200 W quartz halogen lamp. The 1800-02 and quartz halogen lamp are traceable to the National Institute of Standards and Technology (NIST).

Spectral Response



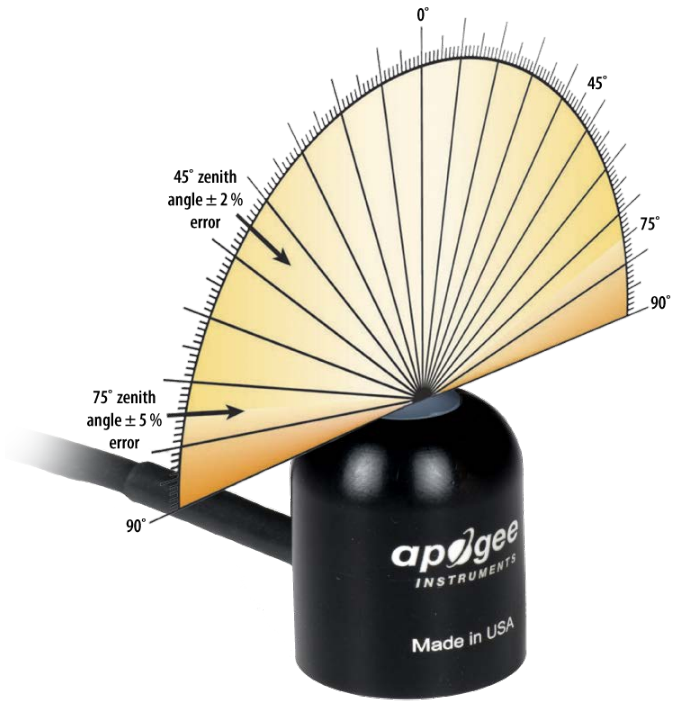
Mean spectral response of six JSQ series quantum sensors (***error bars represent two standard deviations above and below mean***) compared to PPFD weighting function. Spectral response measurements were made at 10 nm increments across a wavelength range of 300 to 800 nm in a monochromator with an attached electric light source. Measured spectral data from each quantum sensor were normalized by the measured spectral response of the monochromator/electric light combination, which was measured with a spectroradiometer.

Temperature Response

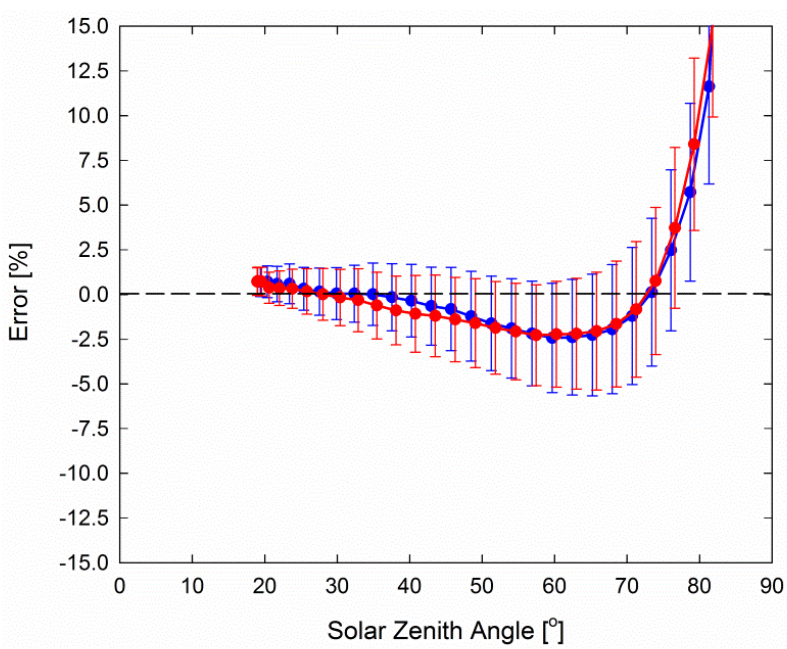


Mean temperature response of eight JSQ series quantum sensors (***errors bars represent two standard deviations above and below mean***). Temperature response measurements were made at 10 C intervals across a temperature range of approximately -10 to 40 C in a temperature controlled chamber under a fixed, broad spectrum, electric lamp. At each temperature set point, a spectroradiometer was used to measure light intensity from the lamp and all quantum sensors were compared to the spectroradiometer. The spectroradiometer was mounted external to the temperature control chamber and remained at room temperature during the experiment.

Cosine Response



Directional, or cosine, response is defined as the measurement error at a specific angle of radiation incidence. Error for Apogee JSQ series quantum sensors is approximately ± 2 % and ± 5 % at solar zenith angles of 45° and 75°, respectively.

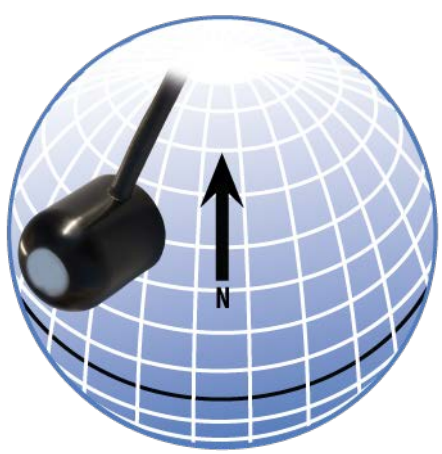


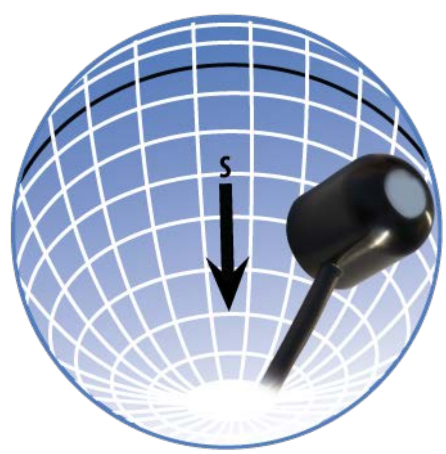
Mean cosine response of twenty-three JSQ series quantum sensors (***error bars represent two standard deviations above and below mean***). Cosine response measurements were made by direct side-by-side comparison to the mean of four reference thermopile pyranometers, with solar zenith angle-dependent factors applied to convert total shortwave radiation to PPFD. Blue points represent the AM response and red points represent the PM response.

DEPLOYMENT AND INSTALLATION

Mount the sensor to a solid surface with the nylon mounting screw provided. To accurately measure PPFD incident on a horizontal surface, the sensor must be level. An Apogee Instruments model AL-100 Leveling Plate is recommended to level the sensor when used on a flat surface or being mounted to surfaces such as wood. To facilitate mounting on a mast or pipe, the Apogee Instruments model AL-120 Solar Mounting Bracket with Leveling Plate is recommended.

To minimize azimuth error, the sensor should be mounted with the cable pointing toward true north in the northern hemisphere or true south in the southern hemisphere. Azimuth error is typically less than 1 %, but it is easy to minimize by proper cable orientation.





In addition to orienting the cable to point toward the nearest pole, the sensor should also be mounted such that obstructions (e.g., weather station tripod/tower or other instrumentation) do not shade the sensor. **Once mounted, the green cap should be removed from the sensor.** The green cap can be used as a protective covering for the sensor when it is not in use.

Cable Connectors

Apogee started offering in-line cable connectors on some bare-lead sensors in March 2018 to simplify the process of removing sensors from weather stations for calibration by not requiring the full cable to be uninstalled back to the data logger.

The ruggedized M8 connectors are rated IP67, made of corrosion-resistant marine-grade stainless-steel, and designed for extended use in harsh environmental conditions.

Inline cable connectors are installed 30 cm from the head (pyranometer pictured)

Instructions

Pins and Wiring Colors: All Apogee connectors have six pins, but not all pins are used for every sensor. There may also be unused wire colors inside the cable. To simplify data logger connection, we remove the unused pigtail lead colors at the data logger end of the cable.

If you ever need a replacement cable, please contact us directly to ensure ordering the proper pigtail configuration.

Alignment: When reconnecting your sensor, arrows on the connector jacket and an aligning notch ensure proper orientation.

A reference notch inside the connector ensures proper alignment before tightening.

Disconnection for extended periods: When disconnecting the sensor for an extended period of time from a station, protect the remaining half of the connector still on the station from water and dirt with electrical tape or other method.

When sending sensors in for calibration, only send the short end of the cable and half the connector.

Tightening: Connectors are designed to be firmly finger-tightened only. There is an o-ring inside the connector that can be overly compressed if a wrench is used. Pay attention to thread alignment to avoid cross-threading. When fully tightened, 1-2 threads may still be visible.

Finger-tighten firmly

OPERATION AND MEASUREMENT

Connect the sensor to a measurement device (meter, datalogger, controller) capable of measuring and displaying or recording a millivolt signal (an input measurement range of approximately 0-500 mV is required to cover the entire range of PPFD from the sun). In order to maximize measurement resolution and signal-to-noise ratio, the input range of the measurement device should closely match the output range of the quantum sensor. **DO NOT connect the sensor to a power source. The sensor is self-powered and applying voltage will damage the sensor.**

VERY IMPORTANT: Apogee changed all wiring colors of our bare-lead sensors in March 2018 in conjunction with the release of inline cable connectors on some sensors. To ensure proper connection to your data device, please note your serial number or if your sensor has a stainless-steel connector 30 cm from the sensor head then use the appropriate wiring configuration below.

Wiring for: JSQ-110 and JSQ-120 Serial Numbers range 0-25369

JSQ-313, JSQ-323, JSQ-316, JSQ-326, JSQ-311, JSQ-311 Serial Numbers range 0-3204

Red: Positive (signal from sensor)

Black: Negative (signal from sensor)

Clear: Shield/Ground

Wiring for: JSQ-110 and JSQ-120 Serial Numbers 25370 and above

JSQ-313, JSQ-323, JSQ-316, JSQ-326, JSQ-311, JSQ-311 Serial Number 3205 and above or with a connector

Black: Negative (signal from sensor)

Clear: Shield/Ground

White: Positive (signal from sensor)

Sensor Calibration

All Apogee un-amplified quantum sensor models (JSQ-100 and JSQ-300 series) have a standard PPFD calibration factor of exactly:

5.0 µmol m^{-2} s^{-1} per mV

Multiply this calibration factor by the measured mV signal to convert sensor output to PPFD in units of µmol m^{-2} s^{-1}:

Calibration Factor (5.0 µmol m^{-2} s^{-1} per mV) * Sensor Output Signal (mV) = PPFD (µmol m^{-2} s^{-1})

5.0 * 400 = 2000

Sensor Output
400 mV

Example of PPFD measurement with an Apogee quantum sensor. Full sunlight yields a PPFD on a horizontal plane at the Earth's surface of approximately 2000 µmol m^{-2} s^{-1}. This yields an output signal of 400 mV. The signal is converted to PPFD by multiplying by the calibration factor of 5.00 µmol m^{-2} s^{-1} per mV.

Spectral Errors and Yield Photon Flux Measurements

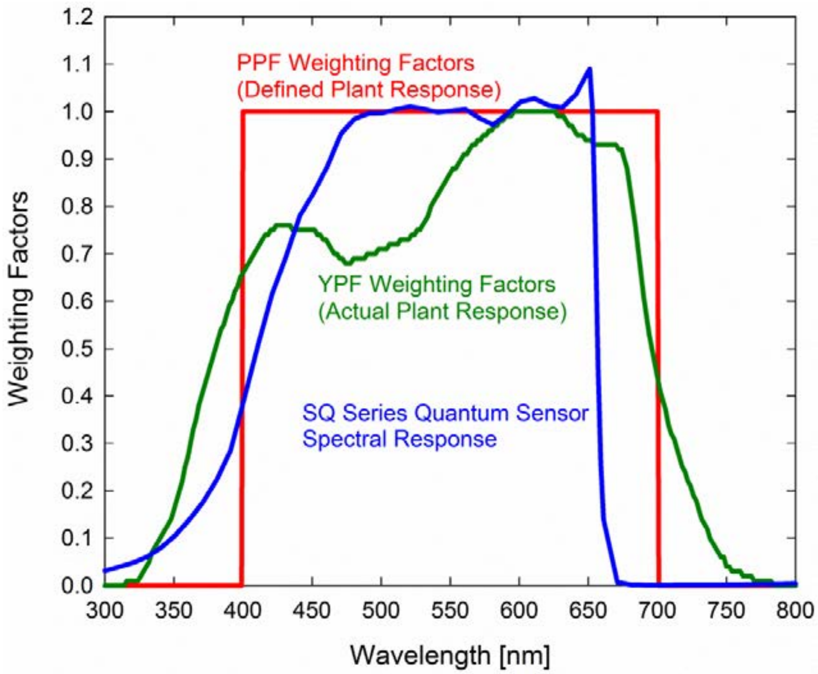
Apogee quantum sensors are calibrated to measure PPFD for either sunlight or electric light. The difference between the calibrations is 12 %. A sensor calibrated for electric lights (calibration source is T5 cool white fluorescent lamps) will read approximately 12 % low in sunlight.

In addition to PPFD measurements, Apogee JSQ series quantum sensors can also be used to measure yield photon flux density (YPFD): photon flux density weighted according to plant photosynthetic efficiency (McCree, 1972) and summed. YPFD is also expressed in units of µmol m^{-2} s^{-1}, and is similar to PPFD, but has been reported to be more closely correlated to photosynthesis than PPFD in some studies. PPFD is usually measured and reported because the PPFD spectral weighting function (equal weight given to all photons between 400 and 700 nm; no weight given to photons outside this range) is easier to define and measure, and as a result, PPFD is widely accepted. The calibration factor for YPFD is 4.50 and 4.45 µmol m^{-2} s^{-1} per mV for sunlight and electric light measurements, respectively.

The weighting functions for PPFD and YPFD are shown in the graph below, along with the spectral response of Apogee JSQ series quantum sensors. The closer the spectral response matches the defined PPFD or YPFD spectral weighting functions, the smaller spectral errors will be. The table below provides spectral error estimates for PPFD and YPFD measurements from light sources different than the calibration source. The method of Federer and Tanner (1966) was used to determine spectral errors based on the PPFD and YPFD spectral weighting functions, measured sensor spectral response, and radiation source spectral outputs (measured with a spectroradiometer). This method calculates spectral error and does not consider calibration, cosine, and temperature errors.

Federer, C. A., and C. B. Tanner, 1966. Sensors for measuring light available for photosynthesis. Ecology 47:654-657.

McCree, K. J., 1972. The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural Meteorology 9:191-216.



Radiation weighting factors for PPFD (defined plant response to radiation), YPFD (measured plant response to radiation), and Apogee JSQ Series quantum sensors (sensor sensitivity to different wavelengths of radiation).

Spectral Errors for PPFD and YPFD Measurements with Apogee JSQ Series Quantum Sensors

Radiation Source (Error Calculated Relative to Sun, Clear Sky)	PPFD Error [%]	YPFD Error [%]
Sun (Clear Sky)	0.0	0.0
Sun (Cloudy Sky)	1.4	1.6
Reflected from Grass Canopy	5.7	-6.3
Reflected from Deciduous Canopy	4.9	-7.0
Reflected from Conifer Canopy	5.5	-6.8
Transmitted below Grass Canopy	6.4	-4.5
Transmitted below Deciduous Canopy	6.8	-5.4
Transmitted below Conifer Canopy	5.3	2.6
Radiation Source (Error Calculated Relative to Cool White Fluorescent, T5)		
Cool White Fluorescent (T5)	0.0	0.0
Cool White Fluorescent (T8)	-0.3	-1.2
Cool White Fluorescent (T12)	-1.4	-2.0
Compact Fluorescent	-0.5	-5.3
Metal Halide	-3.7	-3.7
Ceramic Metal Halide	-6.0	-6.4
High Pressure Sodium	0.8	-7.2
Blue LED (448 nm peak, 20 nm full-width half-maximum)	-12.7	8.0
Green LED (524 nm peak, 30 nm full-width half-maximum)	8.0	26.2
Red LED (635 nm peak, 20 nm full-width half-maximum)	4.8	-6.2
Red, Blue LED Mixture (85 % Red, 15 % Blue)	2.4	-4.4
Red, Green, Blue LED Mixture (72 % Red, 16 % Green, 12 % Blue)	3.4	0.2
Cool White Fluorescent LED	-4.6	-0.6
Neutral White Fluorescent LED	-6.7	-5.2
Warm White Fluorescent LED	-10.9	-13.0

Quantum sensors can be a very practical means of measuring PPFD and YPFD from multiple radiation sources, but spectral errors must be considered. The spectral errors in the table above can be used as correction factors for individual radiation sources.

Underwater Measurements and Immersion Effect

When a quantum sensor that was calibrated in air is used to make underwater measurements, the sensor reads low. This phenomenon is called the immersion effect and happens because the refractive index of water (1.33) is greater than air (1.00). The higher refractive index of water causes more light to be backscattered (or reflected) out of the sensor in water than in air (Smith,1969; Tyler and Smith,1970). As more light is reflected, less light is transmitted through the diffuser to the detector, which causes the sensor to read low. Without correcting for this effect, underwater measurements are only relative, which makes it difficult to compare light in different environments.

The JSQ-100 and JSQ-300 series sensors have an immersion effect correction factor of 1.08. This correction factor should be multiplied to measurements made underwater.