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Paul Arveson

Director of Research,
Solar Household Energy, Inc.

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A low-cost method for measuring solar irradiance using a lux meter

Paul Arveson

Abstract: This report considers the question whether it is feasible to measure solar irradiance (for solar cooker performance measurements) with a low-cost commercial lux meter, rather than a more expensive pyranometer. The conclusion, based on numerous physical measurements with both instruments, is that it is feasible provided proper calibrations and procedures are followed.

The ASABE S.580.1 standard for solar cooker power measurement (ref. 1) requires the measurement of direct normal irradiance (DNI) of solar radiation. The usual instrument for collecting these data is a pyranometer, which is calibrated to measure total solar radiation, or irradiance, in units of Watts/m^2. Commercial pyranometers are scientific instruments and cost $200 or more. Examples of several models of pyranometers are shown in Figure 1.

Figure 1. Examples of pyranometers at the US National Renewable Energy Laboratory.

A lux meter is an instrument for measuring illuminance from the sun or other light sources. Lux meters are calibrated to measure visible light as seen by the human eye, which is called illuminance. Units are lux, which are equivalent to lumens/m^2. Several low-cost (under $40) lux meters are available from Amazon. They are made in China, and sold under brand names Dr. Meter, MoonCity, LONN, FHX, TOOGOO, RZ, etc. but they are all have the same model number, LX1330B (Figure 2). They have a range up to 200,000 lux. It is important to have this high range in order to measure full sunlight illuminance. It is also necessary to have an instrument that has a sensor separated from the meter by a cable.

Figure 2. The LX1330B lux meter.

Both the lux meter and the pyranometer use a silicon photodiode sensor, so they both have the same spectral response (which has a peak in the near infrared at about 950 nanometers).   We wanted to know if a low-cost lux meter could be used as a reasonable substitute for a pyranometer for solar cooker performance tests.

The ratio of the lux meter readings to pyranometer readings, that is, illuminance / irradiance (in units of lumens/W) is called luminous efficacy (ref. 2). Substitution of a lux meter would be feasible if the ratio of readings between the two instruments (the luminous efficacy) is constant across a wide range of sun and sky conditions. Then the readings from the lux meter could be multiplied by this constant to estimate values of solar irradiance that would be measured by a pyranometer.

We compiled a table consisting of pairs of values measured at (approximately) the same times:

- the direct illuminance readings measured with the lux meter pointed in the sun direction;
- the irradiance values from a calibrated Apogee SP-230 pyranometer aimed vertically, the normal position for global horizontal irradiance (GHI) measurements, as seen in the photo.

The pyranometer has a directive response relative to the sun's altitude, namely the cosine of the zenith angle of the sun. Therefore an adjustment is needed to estimate the direct normal irradiance (DNI) that would be measured if the pyranometer were pointed directly at the sun. We adjusted the GHI values to convert them to estimated DNI values by the formula DNI = GHI / cos(z) where z is the zenith angle (90 - sun altitude). We obtained the local sun altitudes from the Naval Observatory calculator at http://aa.usno.navy.mil/data/docs/AltAz.php

This adjustment boosted the pyranometer GHI values to some extent.

We collected a data set of 79 pairs of samples from all of the experimental data recorded in the summer of 2016. We plotted these data (ratio vs. sample number) to see if there was a reasonably flat ratio (luminous efficacy) across all the data.

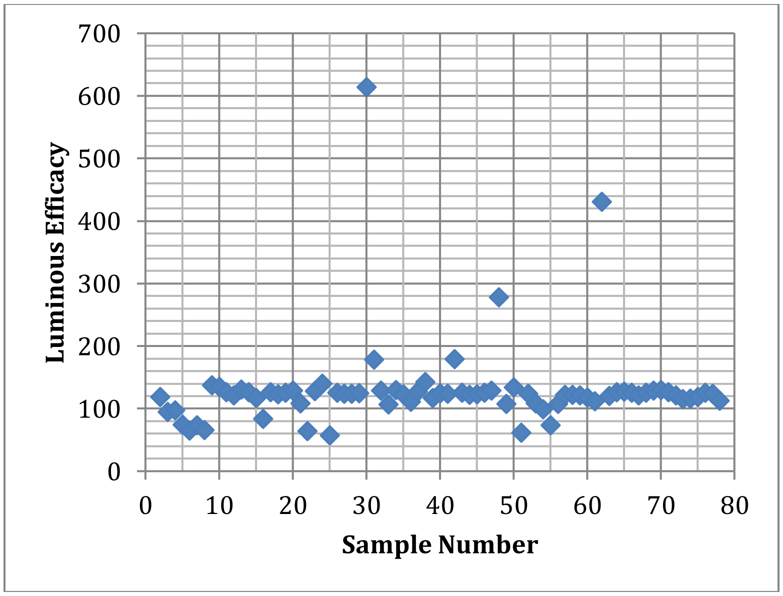

Figure 3. Direct luminous efficacy ratios in 79 pairs of measurements

The plot in Figure 3 clearly shows such a constant ratio (luminous efficacy) in most of the data, with the constant being around 120 (luminance in lux / irradiance in Watts/m^2). There were a few "outlier" points from measurements that were taken very late in the day, or due to variations in measurement times between the two instruments on partly cloudy days, when radiation was rapidly changing.

Perez *et al*. (ref. 3) shows values of direct luminous efficacy of about 110. The reason for the difference from our data probably has to do with the spectral response of the silicon photodiode in the lux meter and how it was calibrated. Hence it is recommended that individual lux meters should be calibrated in sunlight against a properly calibrated pyranometer before being used in the field. Provided such a calibration is done, we conclude that it is feasible to follow the ASABE S.580.1 protocol using a low-cost lux meter for solar DNI measurements.

The standard protocol requires measurements of direct normal irradiance and cooker pot temperatures every ten minutes. Without using data loggers, it will be necessary for the measurements to be done manually, which will be hot, repetitive work, and subject to more errors than by using data loggers. It is therefore recommended to use two or three technicians and a stop watch for recording readings. In this way, the cost of instrumentation can be reduced by a factor of more than ten.

Manual measurements in compliance with the standard protocol

Instrument requirements:

- Lux meter LX1330B $34
- Probe thermometers, such as Taylor Slow Cooker Digital Probe Thermometer $13 ea. (2 or more required)
- Stop watch or kitchen timer

So a minimal instrument setup would cost about $60.

Briefly, the procedure might have these steps:
1. Pot preparation: it is assumed that a hole will be drilled in each test pot for the thermometer wire, so that it does not pass over the lid of the pots. A minimum of two solar cookers should be measured at one time.
2. The measurements are to be performed only at times when the wind speed is low (less than 2.5 m/s).
3. Measurements may begin any time after 9 am.
Two technicians are required.
4. Technician A sets the stop watch or kitchen timer for 10 minute events.
5. Every 10 minutes, technician B reads aloud the thermometer values, in order, then reads the lux meter. To get a correct reading, the meter's sensor must be held toward the sun and slowly moved up and down, right and left, to find the maximum reading.
6. Technician A writes down the readings on a prepared form.
This work continues until the temperatures in all pots reach 95 degrees C, or until the local time goes past 3 pm.

References

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