Pyranometer Calibration:
Leveling Errors and Cosine Effect*

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by

Philip D. Thacher and Ben J. Petterson
Sandia Laboratories
Albuquerque, N.M. 87115

The solar monitoring system for the Sandia Total Energy Systems Test Facility consists of a fixed, horizontal pyranometer and a tracking pyranometer and pyrheliometer. Readout uses a scanned A-D converter with recording via print-out, magnetic tape, or disk. The Eppley pyrheliometer is calibrated by direct comparison with a Kendall electrically-calibrated radiometer. The pyranometers, model PSP, also from Eppley, are calibrated against the pyrheliometer using shading techniques; and the parameters affecting that calibration are the subject of this summary.

Shading Technique In order to compare the pyranometer output with that of the calibrated pyrheliometer, a difference measurement is made: the pyranometer output when shaded from direct sunlight is subtracted from the output when light from the sun and sky are measured together. If the occulting disk blocks a field of view around the sun equal to that seen by the pyrheliometer, the difference in pyranometer readings should equal the pyrheliometer reading multiplied by the cosine of the angle between the sun and the normal to the pyranometer's detecting surface. On clear days, it is not

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really necessary to occult the same field of view. However, it is necessary that the same amount of background light reach the pyranometer in the shaded and unshaded conditions.

Present experiments were carried out on very clear days (diffuse sky contribution $<10\%$) using a blackened shading disk to prevent back reflections and standing such that the sun could not reflect off a shirt into the pyranometer. The occulting disk itself was a piece of cardboard 2.8 cm in diameter hand held 28 cm from the pyranometer. Shaded and unshaded readings were taken on about 1 minute intervals in order to ensure thermal equilibrium of the pyranometer's thermopile. Calibration is possible on hazy days, but is difficult. Calibration of a tracking pyranometer when incident light was equally split between direct and diffuse contributions showed $\leq 2\%$ disagreement with clear day calibrations.

Besides the parameters mentioned so far, the sun's azimuth can affect the output of a tilted pyranometer, and temperature modifies the output via a temperature coefficient of the device. Accordingly, a program was written to print out the pyranometer reading at a selectable interval, the pyrheliometer reading, that same reading multiplied by the sun's zenith angle, the solar azimuth, the temperature, and solar time. In order to make relative tests, three pyranometers can be recorded simultaneously and the ratio of two to the first computed. During the present tests, one of these pyranometer stations was shorted in order to provide a check on possible thermocouple effects in the lead wires as well as on the zero of the A-D converter.

Leveling Errors Leveling errors occur because the optical plane of the pyranometer's absorber disk does not lie in the horizontal plane indicated by the bubble level. If θ is the solar zenith angle, φ the solar azimuth, $\Delta\theta$ the sensor tilt, and φ_o the azimuth of the sensor's low point, then the pyranometer reading is proportional not to $\cos\theta$ but to

$$\cos\theta \cos\Delta\theta + \sin\theta \sin\Delta\theta \cos(\varphi-\varphi_o). \qquad (1)$$

If the pyranometer is rotated while holding the bubble level centered and for a constant solar orientation, the pyranometer reading will oscillate. The difference between maximum and minimum readings can be used to determine $\Delta\theta$ using Eq (1):

$$\tan \Delta\theta = (V_{max} - V_{min})/2V_{av} \tan \theta, \tag{2}$$

where V_{av} is the average of the maximum and minimum readings. For 5 pyranometers so far measured, $\Delta\theta \approx 0.7^{\circ}$; and for one, $\Delta\theta \approx 1^{\circ}$. For $\Delta\theta = 0.7^{\circ}$ and $\theta = 30^{\circ}$, the difference between V_{max} and V_{min} amounts to 1.5%.

The most readily visible effect of $\Delta\theta$ occurs when one pyranometer is calibrated against another over a period of several hours. A drift of 0.5%/hr has been observed in output ratios. This drift is eliminated by proper leveling. Such leveling is accomplished by recording V_{max} and V_{min} as before, and then tilting the pyranometer along the line joining the max and min points until the average reading is obtained. The bubble level can now be centered by shimming.

Cosine Effect Cosine effect refers to a variation of the pyranometer's calibration with θ. In order to test for the cosine effect, shading-technique calibrations of a leveled pyranometer were made for numerous solar zenith angles on clear days. Substantial decreases in calibration factor were found as θ increased: -1% at 30°, -2% at 50°, and -7% at 75%. At about 65° there is an anomaly in the calibration factor apparently arising from reflections in the glass hemispheres used to shield the absorber.

A difference in cosine effect was observed between morning and afternoon. Since this difference was not affected strongly by rotating the pyranometer, temperature increases, amounting to 15°C between morning and noon, may be responsible. However, the temperature coefficients of both the pyranometer and the reference pyrheliometer would have to add rather than cancel. These temperature coefficients remain to be studied.