# Evaluation of Methods to Correct for IR Loss in Eppley PSP Diffuse Measurements

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## ABSTRACT

The IR loss in diffuse measurements made by thermopile pyranometers is examined. Diffuse measurements are used for the study of IR losses because diffuse irradiance is much smaller than the total irradiance and hence the IR effects can be more clearly seen. Specifically, diffuse measurements of an Eppley PSP pyranometer are compared to those made with a Schenk Star pyranometer. Pyranometers with black and white or star type junctions suffer minimal IR loss because the reference and receiving junctions of the thermopile are at the same thermal level. The difference between diffuse values can be attributed to calibration and cosine response errors as well as IR loss. This is a preliminary study over one month when pyrgeometer data are available. Examination of the differences at various times of the year and at more than one location is necessary to generalize the findings in this report. Several methods of correcting for IR loss are examined. First subtracting out the average nighttime offset during the day is tested. Next an extrapolation between early morning and late evening offsets is tested. This should help eliminate the IR offset in both the morning and evening hours, but underestimate the IR losses during the rest of the day. Next, correlations of IR losses calculated using pyrgeometer measurements with temperature, relative humidity, and irradiance are evaluated. Initial results show that it should be possible to use more commonly available measurements rather than prygeometer data to estimate IR loss for Eppley PSP pyranometers.

**KEYWORDS:** Pyranometer, pyrgeometer, irradiance, IR, modeling, global, diffuse, PSP, B&W, Schenk

## INTRODUCTION

Problems with measuring the diffuse irradiance were uncovered by the Atmospheric Radiation Measurement (ARM) Program during comparisons between theoretical and measured diffuse values. Pyranometers emit IR radiation during both the day and night and this IR radiation reduces the readings of the pyranometers during the day and yields negative readings at night. This IR loss is enhanced with black thermopile based pyranometers that produce a voltage by comparing the temperature of a central disk to the body of the pyranometer. Since there is no incident solar radiation during the night, the IR radiation loss produces negative readings that are characteristic of Eppley PSPs and other similar pyranometers. Pyranometer data reported by the University of Oregon Solar Radiation Monitoring Laboratory (UO SRML) are adjusted by subtracting the average negative values at night from the pyranometer readings during the day. However, this methodology only partially corrects the problem because the IR radiation during the day is larger due to the higher temperature reached by the central disk of the pyranometer.

Starting around 2000, high quality solar monitoring sites with diffuse measurements started using black and white or star type pyranometers. These instruments measure the temperature difference between black and white surfaces and the voltage generated by the temperature difference is proportional to the incident solar radiation. Since both the black and white surfaces radiate approximately the same amount of IR, the measured solar radiation does not significantly suffer from the IR radiation loss effect. The black and white (B&W) type pyranometers typically have nighttime irradiance values on the order of ±1 W/m$^2$. While these instruments are classified as Class II type pyranometers by the World Meteorological Organization (WMO) because of their large zenith and azimuthal angle dependence, they provide a much better measurement of the diffuse irradiance than most Class I pyranometers because their IR radiation offset is so small. On a clear day, the diffuse irradiance typically is about 100 W/m$^2$ while pyranometers with a single black detector might have an IR loss on the order of 10 W/m$^2$. Therefore an instrument that does not have much IR loss eliminates a possible 10% systematic error.

A method that can reasonably estimate the IR loss would be useful for compatibility with current measurements and to obtain more accurate comparisons for the long-term irradiance records. If such a method is developed, the historical record of global data gathered by high quality pyranometers can be corrected by accounting for the IR loss. Even more importantly, diffuse measurements can be corrected for this IR loss. When this is done, then the historical data can be compared with current high quality global and diffuse measurements that account for the IR loss.

In this paper, various methods for correcting for the IR radiation are examined. After discussing the experimental data, the IR radiation effect is examined. Initially, diffuse data from an Eppley PSP and a Schenk Star pyranometer will be used to evaluate methods of correcting for the IR loss. The improvement in the PSP diffuse data utilizing nighttime values will be tested first. Next a model developed by the ARM program [1] will be used to correct the diffuse data from the PSP and this will be compared with the Schenk data. Then correlations between other measured irradiance and meteorological values and IR loss correction values will be determined from pyrgeometer, solar, and meteorological values. A summary of the finding will then be presented along with a brief discussion of some of the issues related to the IR radiation of pyranometers. It is important to note that this is a feasibility study and parameters determined in this study were developed from only one month of data from one site.

## ABOUT THE DATA

The data used in this study come from the solar radiation monitoring site in Eugene, Oregon operated by the University of Oregon Solar Radiation Monitoring Laboratory (UO SMRL). Some of the parameters measured at this site are global, beam, and diffuse irradiance along with irradiance on tilted surfaces. In addition, ambient temperature, wind speed, relative humidity, and pressure are measured on a one-minute basis. The diffuse data are obtained from a Schenk Star pyranometer that is mounted on a ventilator and shaded by a shade ball on an automatic tracker and from an AC-ventilated shaded Eppley Precision Spectral Pyranometer (PSP) mounted on the same tracker. Most of these data values were sampled every two seconds and one-minute averages were gathered. The diffuse data

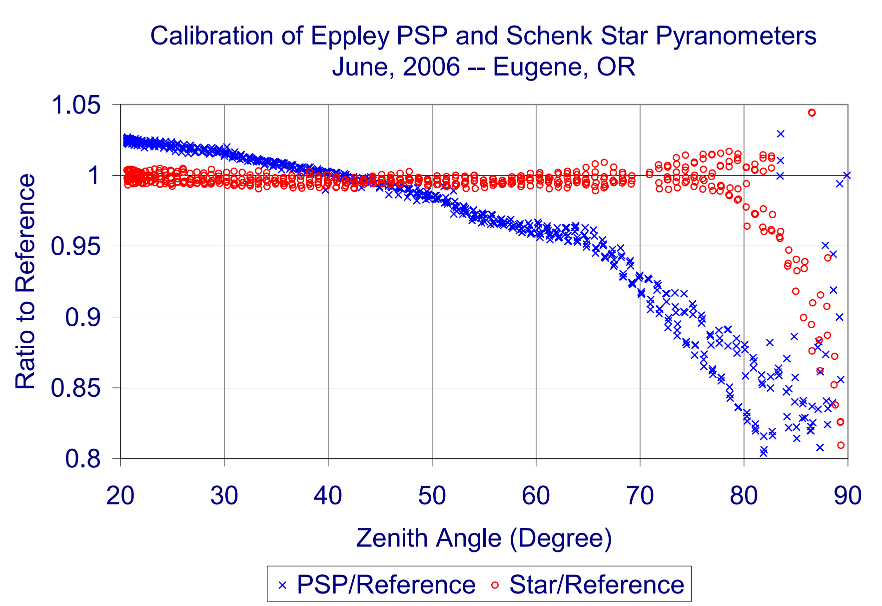


Fig. 1: Calibration of the Eppley PSP and Schenk Star pyranometers used for diffuse measurements. The “reference” global value is the beam irradiance projected onto a horizontal surface plus the diffuse irradiance. Three clear days were used to derive each calibration value.

from the Eppley PSP were recorded in 5-minute averages. Further information about the data from the Eugene site can be found at http://solardata.uoregon.edu/SolarData.html.

Fig. 1 shows the calibration of the Schenk Star pyranometer and the Eppley PSP. The "reference" global value is the beam irradiance, measured by an Eppley Normal Incident Pyrheliometer (NIP), projected onto a horizontal surface plus the diffuse irradiance. For the PSP calibration, the diffuse values from the Schenk pyranometer was used. For the Schenk calibration, the PSP diffuse values were used after being adjusted to match the Schenk diffuse values. The small adjustment to the PSP diffuse data (~5 to 10 W/m$^2$) accounted for the IR radiative loss from the PSP. Both pyranometers were mounted on automatic trackers on top of ventilators, just as with the diffuse measurements, except that the shade balls were removed. By calibrating the instruments on the tracker, azimuthal deviations are significantly reduced because at any given time the orientation of the pyranometers with respect to the sun is always the same. This is especially important for black and white or star type pyranometers. Note that calibrations are normalized to 45º.

A study by the ARM program [2] found that their Schenk pyranometer had greater than a 3 W/m$^2$ Root Mean Square error (RMS) (thus 2 sigma standard deviation of >6W/m$^2$), and a bias error of about 2 W/m$^2$ compared to the reference group of instruments. All these participating radiometers were freshly calibrated for the experiment, and studiously operated every day of the experiment, so are about as well run as can be. Consequently the use of the Schenk as a reference instrument has to be understood with the above information in mind. Thus, some of the disagreement in the plots comes from the Schenk itself and some of the disagreement comes from the uncertainties in the PSP and some of the disagreement comes from the IR loss of the PSP.

In May 2007, Chuck Long of Pacific Northwest National Laboratories set up a pyrgeometer at the Eugene site with temperature sensors for the dome and body of the instrument. The pyrgeometer was also mounted on the automatic tracker and a shade ball shaded the dome from direct sunlight. In addition, an Eppley PSP was set up at the site along with relative humidity and ambient temperature sensors. These data were measured every second and one-minute data averages and standard deviations were recorded. A Delta-T Devices model SPN-1 pyranometer was used to obtain global, diffuse, and beam irradiance values to check for sky cover.

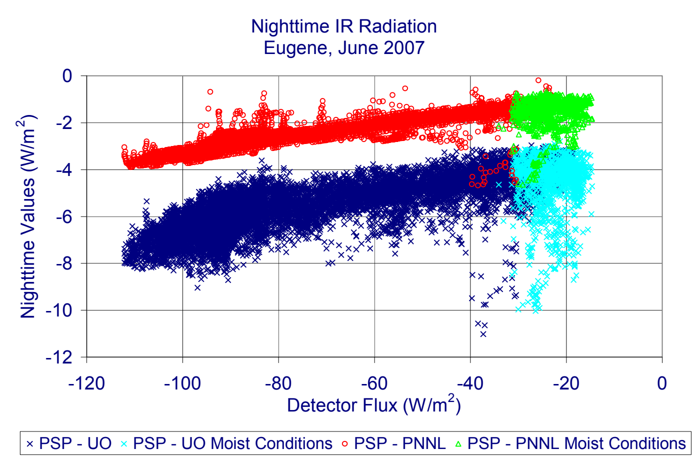


Fig. 2: Plot of nighttime pyranometer values plotted against the detector flux – see reference 1. The correlation during moist periods is different than during non-moist periods. See reference [1] for definitions.

The absolute accuracy of the Eppley PSP measurements is roughly ±4%, the Schenk Star measurements have an absolute uncertainty of ±5%, the Eppley NIP has an uncertainty of ±3%, and the pyrgeometer measurements have an uncertainty of ±4%.

The data from the first 28 days of June 2007 are used in this study. There were a limited number of clear days during June, but there were many clear periods. The majority of days were either cloudy or partially cloudy.

## PYRANOMETER IR RADIATION CHARACTERISTICS

One can look at nighttime negative readings to clearly see the pyranometer IR radiation. These values vary from pyranometer to pyranometer and depend on the sky temperature, the type of ventilator used to keep dust and frost off the pyranometer, relative humidity, and other factors. Figure 2 shows the nighttime IR radiation from two pyranometers. One pyranometer is mounted on a DC-powered ventilator and the other is mounted on an AC-powered ventilator. The two modes shown in Fig. 2 are discussed in reference [1].

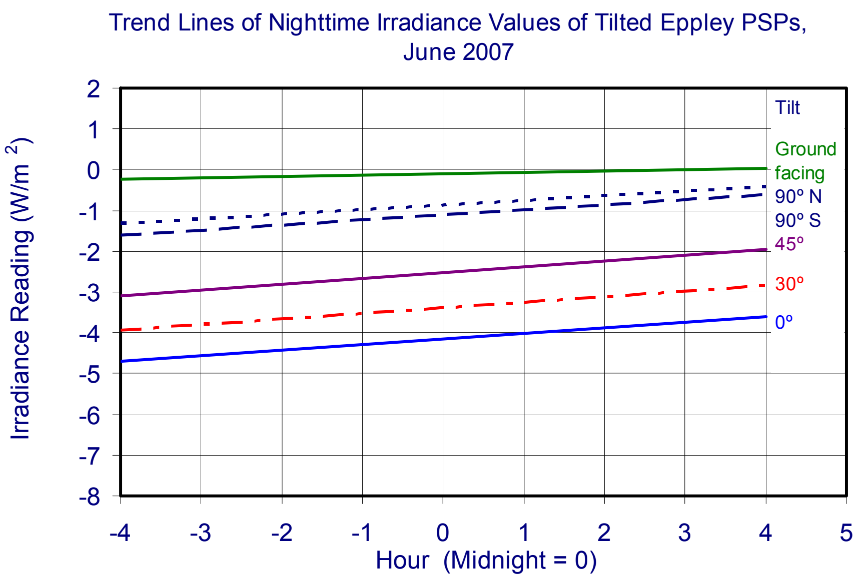


Fig. 3: Trend lines of nighttime values for tilted PSPs for June 2007. Note that as the pyranometer is tilted more, the nighttime values get smaller. This means that the IR loss becomes less as the pyranometer "sees" more of the ground.

One interesting feature of the PSP nighttime readings is that as the pyranometer is tilted from the horizontal, the portion of the sky "seen" by the pyranometer decreases and so does the nighttime IR loss (Fig. 3). None of the tilted pyranometers have ventilators. The spread of the data points is similar to that shown in Fig. 2, and the data points were left out for clarity. While there is considerable variation in nighttime IR losses from pyranometer to pyranometer, the tilted pyranometers showed a greater IR loss at night when they were set on a horizontal surface for calibration.

1. **Diffuse comparisons**

The IR loss values show up most clearly in the diffuse radiation data because the IR loss values are a much larger fraction of the diffuse values, especially during clear periods. Figure 4 shows the difference between the diffuse values measured by a Schenk Star pyranometer and an Eppley PSP. The Eppley PSP uses an AC-powered ventilator as does the Schenk Star. There is even a small heating element in the Schenk ventilator to help keep the dome ice-free. Since this heats both the black and white elements in the detector equally, the heater does not seem to significantly affect the reading of the Schenk. In Fig. 4, there appears to be a bimodal difference between the diffuse values from the Schenk and the PSP. The difference is greatest during the afternoon and least in the morning hours. Earlier studies [2] showed some examples of the Schenk having a morning and afternoon bias from the reference instruments as well.

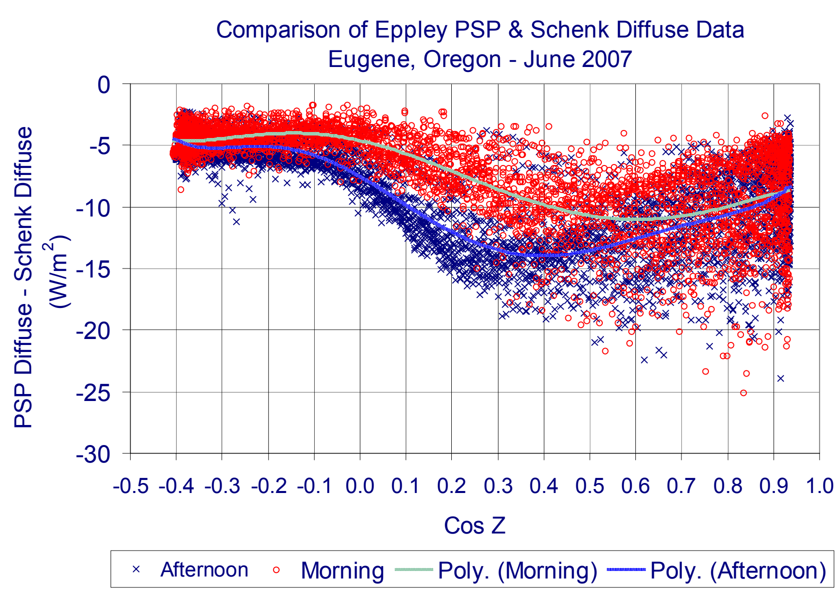


Fig. 4: Difference between the diffuse values from a Schenk Star pyranometer and an Eppley PSP. Not all the difference is related to the IR loss from the PSP. The morning values are plotted as o's and the afternoon values are plotted as x's. Trend lines are included to demonstrate the difference between morning and evening values.

The standard method used by the UO SRML in their analysis procedure is to subtract the average nighttime values from the values during the day. While this is helpful in accounting for some of the IR loss, this can lead to underestimation of the IR losses during the day when the

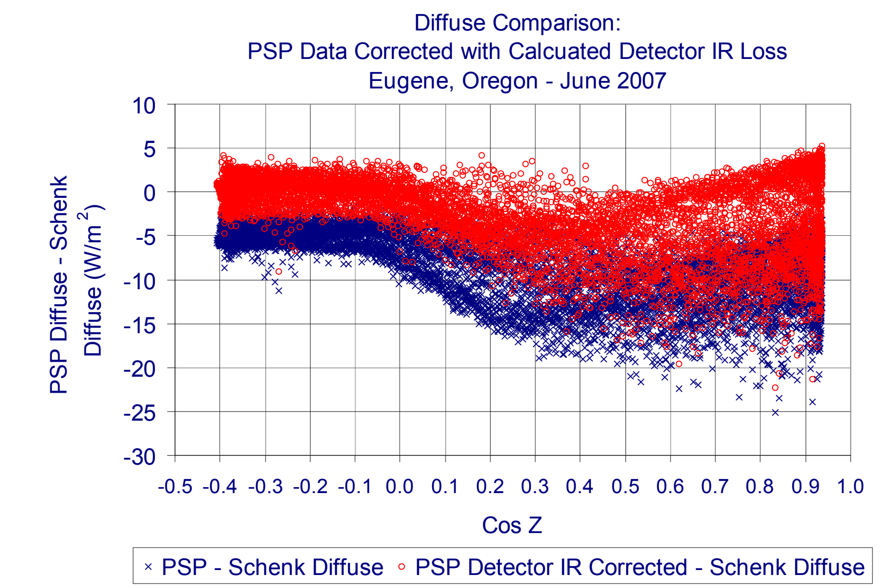


Fig. 5: Comparison of Schenk diffuse values with PSP diffuse values corrected for the detector IR losses. The x's are the differences without correction and the o's are the differences with detector IR losses included.

solar radiation is heating the pyranometer.

Work from [1] separates the IR losses into two categories, the detector losses and a full mode correction that takes temperature fluxes and other factors into account.

If only the detector IR losses are considered, the nighttime irradiance values are accounted for fairly well. Figure 5 plots the difference between the Schenk Star and PSP diffuse values when corrections for the detector IR losses are added to the PSP values.

Adding the detector IR losses to the PSP values removes the bimodal nature of the difference between the Schenk Star and corrected PSP diffuse values. In other words, the difference between the diffuse values is the same during the morning and afternoon hours when corrections are made for the IR losses. Therefore, in addition to reducing the differences between the two methods of measuring diffuse irradiance in an amount similar to subtracting the nighttime values during the day, the calculated detector IR losses also eliminates the differences between the two diffuse dataset previously observed for the morning and afternoon diffuse values.

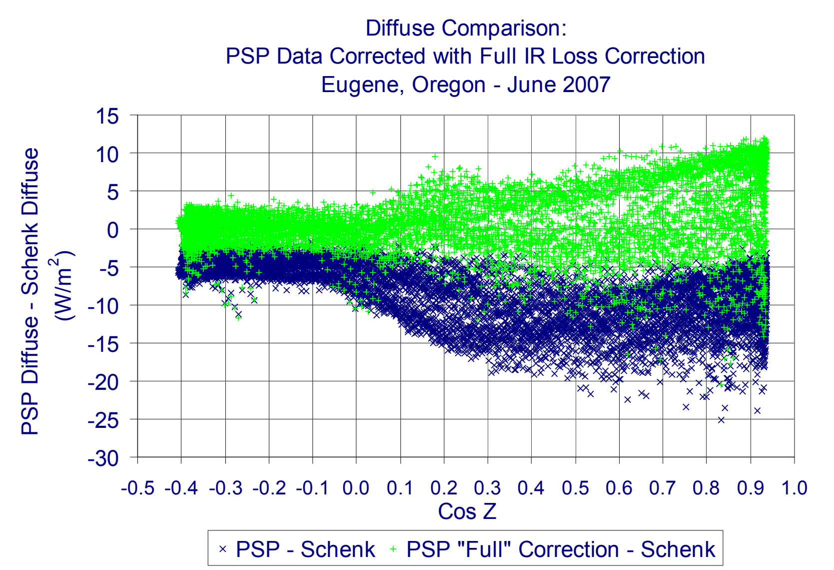


Fig. 6: Comparison of the fully corrected PSP diffuse data and the Schenk diffuse values. The bias in the corrected PSP diffuse data is greatly reduced.

**ACCOUNTING FOR IR LOSSES WITHOUT PYRGEOMETER DATA**

The next step is to make the full IR correction to the data. Since there is only one month worth of data and there are only a limited number of data points to make this correction, this comparison is only preliminary. Fig. 6 is shown to indicate what the full correction can do. A longer time period of study should help in determining the proper parameters for a full correction.

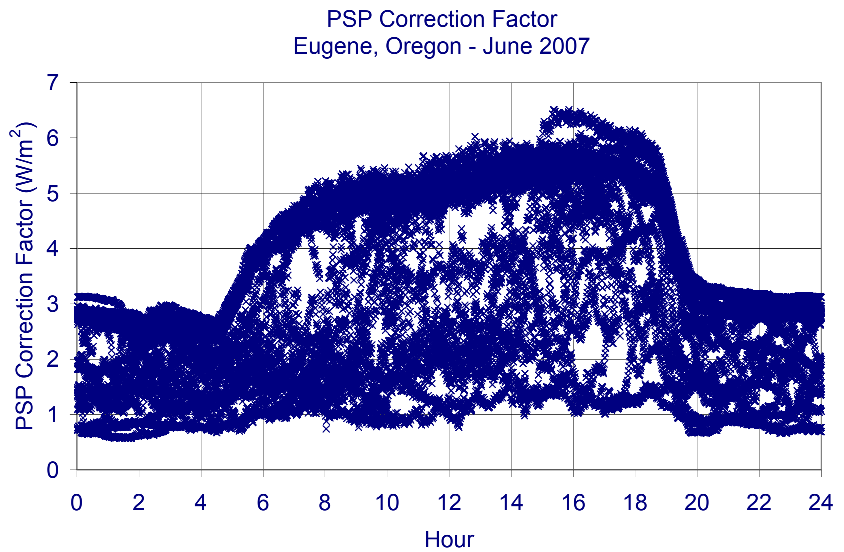


Fig. 7: PSP correction factor plotted against time of day. Data are from Eugene, Oregon in June 2007.

The analysis in the previous section indicates that much of the systematic difference between the Schenk Star and PSP diffuse values is related to IR losses. It is important to note that there is still a considerable amount of variation that is likely attributable to sources other than IR loss. However, the IR loss is a systematic error that reduces the measured diffuse and global values and data values can be improved if this loss is taken into account. This section will examine what can be done to correct the IR losses if one does not have a pyrgeometer co-located to help correct the PSP measurements, as is often the case.

Three methods can be used to correct the PSP data for the IR losses: One way is to average the nighttime IR losses and subtract the values out over the day as has been done with the UO SRML network data. The full PSP correction factors as calculated by the model in [1] and as a function of time of day are plotted in Fig. 7. As expected, the PSP correction factor is often larger during the day than at night. Therefore using the average nighttime values often systematically underestimates the IR losses during the day, especially during clear periods (See Fig. 8).

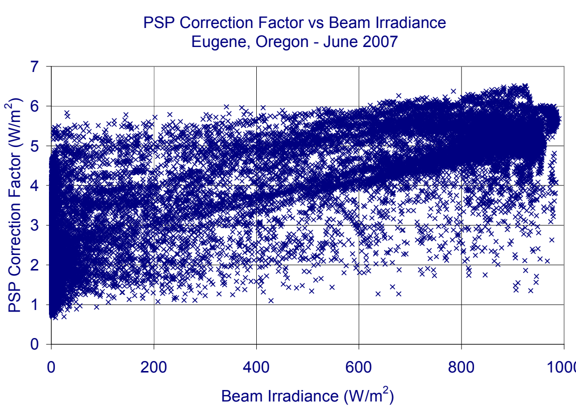


Fig. 8: Plot of IR Correction Factor verses Beam Irradiance. Data are from Eugene, OR in June 2007.

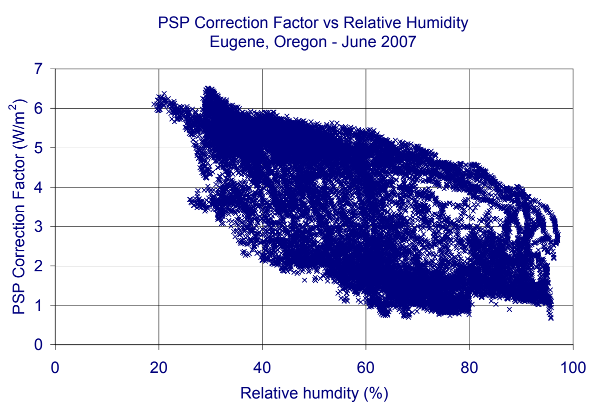


Fig. 9: Plot of IR Correction Factor verses Relative Humidity. Data are from Eugene, OR in June 2007.

A second method is to use just the times before sunrise and after sunset to determine the correction factor and to adjust the correction factor over the day so that increase in IR loss values over the day can be better assessed and the corrections around sunrise and sunset time are more accurate because the corrections are determined nearer to the data

Table 1: Fit to values in Eqn. 1.

| Parameter | Symbol | Parameter | Value | % Standard Deviation |
|---|---|---|---|---|
| Intercept | a1 | a1 | 5.789559 | 0.41% |
| Cos(Zenith Angle) | CosZ | a2 | -1.15049 | -1.41% |
| Clearness Index | $k_t$ | a3 | -1.25602 | -3.19% |
| Beam Irradiance | B | a4 | 0.00351 | 0.67% |
| Relative Humidity | RH | a5 | -0.03992 | -0.67% |

used to estimate the IR loss. While this is a slight improvement over the nighttime averaging method, it still an underestimates the IR losses during the day.

A third method is to develop corrections factors using a correlation between measured values and the estimated or modeled IR losses. Figures. 8 and 9 show plots of calculated IR losses verses incident beam radiation and relative humidity. Clearly there is a rough correlation between calculated IR losses and beam irradiance and relative humidity. The clearness index $k_t$ and the cosine of the incident zenith angle also correlate with the calculated IR Correction Factor.

A regression fit between the variables and the calculated PSP correction factor can then be run. The formula is given in Eqn 1.

Correction Factor = a1 + a2*CosZ + a3*$k_t$ + a4*B + a5*RH (Eqn. 1)

The results of the regression fit are given in Table 1. Overall the standard error is 0.62 W/m$^2$ out of 25,000 one-minute data points for June 2007 in Eugene Oregon. Another perspective of the fit is shown in Fig. 10 where the residuals are plotted against the calculated IR correction values. Equation 1 is the a first attempt at the correlation and a much longer time period with a broader a variety of conditions is needed before a valid correlation can be deduced.

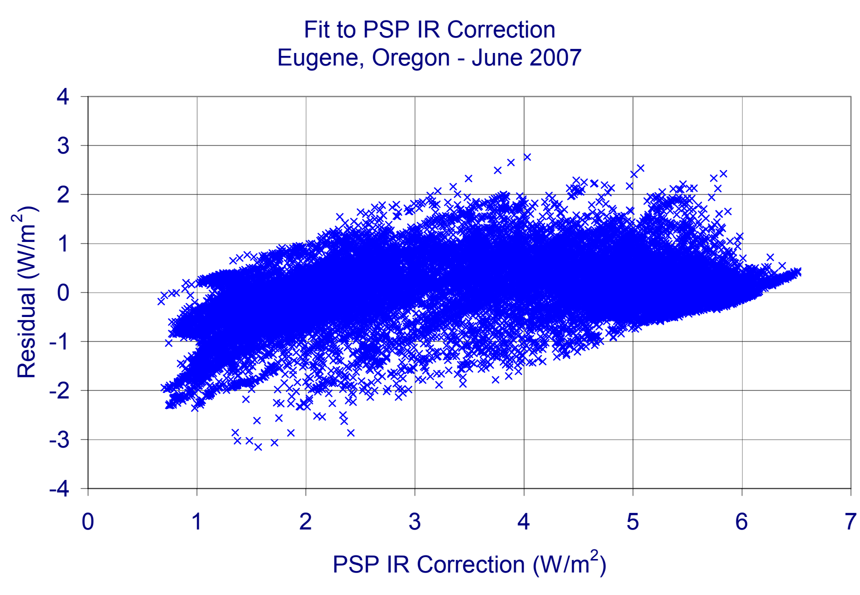


Fig. 10: Plot of residuals against calculated IR correction values for June 2007 in Eugene, OR.

**DISCUSSION & SUMMARY**

This is a limited study of the IR loss by Eppley PSP pyranometers at the Eugene station in June, 2007. However, even in this limited study, several features of the IR loss have been demonstrated. The IR loss increases during the day and tends to be highest in the afternoon when the relative humidity is lowest. In addition, the IR loss decreases as the pyranometer is tilted to face more of the ground and less of the sky. This helps confirm what has been learned elsewhere[1,2] about the IR losses.

The IR loss correction model, using pyrgeometer and meteorological data, developed by Younkin and Long [1] has been tested against diffuse measurements made by a Schenk Star pyranometer and an Eppley PSP. IR loss effects are more easily evaluated in diffuse measurements because the effects of beam irradiance and therefore much of the cosine response error influences are eliminated. Eppley B&W and Schenk Star type pyranometers suffer minimal IR loss because the reference and receiving junctions of the thermopile are at the same thermal level. Application of the calculated IR loss corrections was shown to bring the Schenk and PSP diffuse measurements into closer agreement. It is still necessary to look at the differences over a much longer time period to assess other systematic errors that could affect the relationship and help to separate out the various sources of error. Similar data from other sites are also needed for a more thorough evaluation.

Several methods of correcting for IR loss were examined. First, subtracting out the average nighttime offset during the day was examined. This method systematically underestimates the IR losses during the day. Extrapolation of the IR loss trends between the pre-sunrise and after-sunset hours would improve the estimate of IR losses, but this method would still significantly underestimate the IR losses during the day. Correlations of the remaining IR losses with temperature, relative humidity, and irradiance were evaluated. Because of the uncertainty in the diffuse measurements, IR correction values determined from an existing model [1] were utilized. It was found that for the period studied, that a correlation could be developed that would significantly account for the IR losses during the day. Again a much longer time period along with data from a variety of sites and instruments is needed to better develop and validate any model. While this study is preliminary in many respects, it does point to directions that can be taken to better correct for IR losses when pyrgeometer data are not available.

**ACKNOWLEDGEMENTS**

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