What are pyranometer offsets?

Offsets in pyranometer signals are undesirable when accurate measurement of the global solar radiation is required. Users of pyranometers may therefore wish to have a basic understanding of the zero offsets. This white paper attempts to answer basic questions about zero offsets in pyranometer signals such as: What is their origin? How do I measure them? How important are they? And what does the ISO 9060 standard say about them?

Introduction

Zero offsets in pyranometer signals are values that persist even if the solar irradiance is zero. For modern pyranometers, the zero offsets are small. In most locations, during most of the day the offsets "hidden in the signal" will be negligible compared to the solar irradiance. Nonetheless, under certain low light conditions the zero offsets can become important.

Zero offsets in pyranometers can have several origins. Most of them can be traced back to thermal gradients, i.e. temperature differences inside the instrument. To understand this, one needs to look at the working principle of a pyranometer.[1] Simply put, a pyranometer functions as follows: the black sensor surface of a pyranometer absorbs solar radiation and converts it into heat. This heating leads to a temperature difference between the black surface and the pyranometer body which is measured with a thermopile. The thermopile output signal is in principle proportional to the irradiance. However, it is immediately clear that any temperature difference between the body and the black surface that can not be attributed to solar radiation leads to an offset in the measured irradiance.

There are various mechanisms that can lead to such temperature differences. In this white paper we will discuss the three most common ones: thermal radiation, rapid changes in ambient temperature, heat dissipation by pyranometer electronics and offsets of the electronics themselves.

Table 1 on the next pages shows the maximum allowable zero offsets per ISO 9060 pyranometer class. These offsets are a (infrared), b (temperature change) and c (total).

Offsets due to thermal radiation

The dome on a pyranometer acts as a radiation filter that blocks thermal radiation. This ensures that the pyranometer is sensitive to solar radiation with wavelengths between roughly 0.3 to 3 x 10^{-6} m. However, some sensitivity to thermal (longwave infrared) radiation with longer wavelengths remains, due to exchange of thermal radiation between the sky and the dome on one hand and between the dome and the black surface on the other hand, as illustrated in Figure 1. This leads to an offset in the measured solar irradiance.

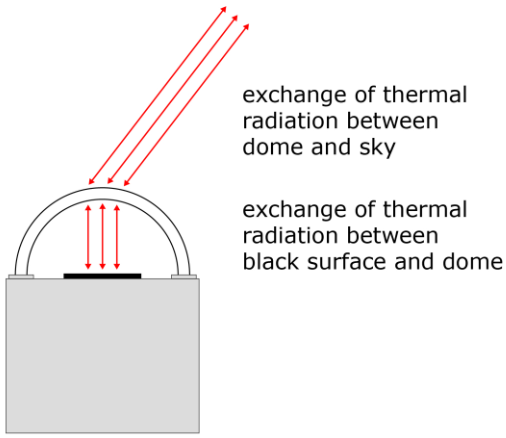

Figure 1 *an illustration of the exchange of thermal radiation between the sky and the dome of a pyranometer and between the dome and the black sensor surface*

The sensitivity of a pyranometer to thermal radiation can be determined either indoors in a lab environment or outdoors by comparing night-time pyranometer and pyrgeometer data. (The offset due to thermal radiation can also be determined in so called capping experiments, which will not be discussed in this white paper.) To measure the sensitivity to thermal radiation in a laboratory, the pyranometer is put in a dark environment where it is exposed to thermal radiation from a heated black body of known temperature. The net exchange of thermal radiation can be estimated from the temperature of the pyranometer and temperature of the black body. In this case, the offset in the pyranometer signal and the net exchange of thermal radiation

will have a positive value, because the black body will be warmer than the pyranometer.
Alternatively, the sensitivity to thermal radiation can be determined outdoors.
During the night the solar irradiance is zero, so sensitivity of the pyranometer to other factors such as net thermal radiation can be more easily studied. The net exchange of thermal radiation between the pyranometer and the sky can be estimated from pyrgeometer data. In an outdoors experiment, the offset and the net thermal radiation will be negative because the sky is colder than the pyranometer.
In both cases it is possible to plot the pyranometer signal as a function of the net thermal irradiance (Figure 2). The slope of this curve is the sensitivity of the pyranometer to a net exchange of thermal radiation.

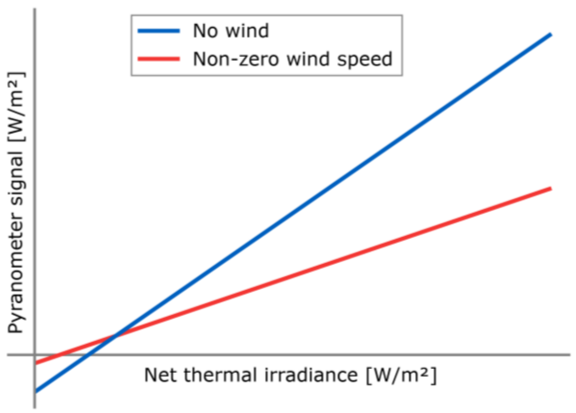

Figure 2 *a sketch of the pyranometer response to thermal infrared or longwave radiation. The slope is the sensitivity to thermal radiation, any offset is attributed to other factors. Note that the slope will also depend on other factors such as wind speed.*

The ISO 9060:1990 standard specifies the *zero-offset a* as the response to 200 W/m^2 net thermal radiation.[2] Note that the zero offset due to thermal radiation is not a fixed number: it changes with the actual exchange of thermal radiation. Furthermore other parameters such as wind speed can have strong influence.

Reduced offsets due to thermal radiation can be achieved in several ways. One common way is to add a second dome to the pyranometer, typically found on first class and secondary standard pyranometers.[3]
Another method involves using domes with an increased thermal conductivity to reduce the thermal gradients in the dome: a sapphire dome, as used in the SR25-D2 pyranometers.

Finally, ventilation can be used to reduce temperature differences between the dome and the body. Traditionally, external ventilation was used, for example by installing the pyranometer on an external ventilation unit, but an even better reduction of the zero offset can be achieved using internal ventilation (Figure 3).
SR30-D1 is a secondary standard pyranometer employing internal ventilation.

Figure 3 *ventilation can be used to reduce thermal gradients and thereby zero offsets. Left: an SR20-D2 pyranometer mounted on a VU01 ventilation unit for external ventilation. Right: an SR30-D1 pyranometer with internal ventilation.*

Offset due to temperature change

When a rapid change in ambient temperature occurs, some parts of the pyranometer may change temperature more quickly than other parts, which can cause temperature gradients inside the instrument and thus offsets in the pyranometer signal. Such rapid changes in ambient temperature can occur when a warm or cold wind picks up, or shortly after a sunrise or sunset.

The sensitivity of a pyranometer to changing ambient temperatures can be measured in a temperature-controlled climate chamber. The pyranometer should be placed inside a dark climate chamber which is set to create a certain rate of change in ambient temperature. A schematic of such a measurement is shown in Figure 4: initially the temperature is constant. At a certain moment the temperature starts to increase and an offset occurs in the pyranometer signal. Once temperature is constant again the offset disappears again. A similar effect occurs if the temperature decreases. Based on such measurements, the sensitivity to changes in ambient temperature can be calculated by dividing the change in the pyranometer output signal ΔE by the rate of change in ambient temperature $\mathrm{d}T/\mathrm{d}t$:

$$\text{Sensitivity to temperature change} = \frac{\Delta E}{\mathrm{d}T/\mathrm{d}t}$$

The ISO 9060:2018 standard specifies the *zero-offset b* as the response to 5 K/h change in ambient temperature. This rate of change is considered representative of common meteorological conditions. Annex A.2 mentions that the case of rapid changes in body temperature, possibly affected by cold rain showers, is exluded.

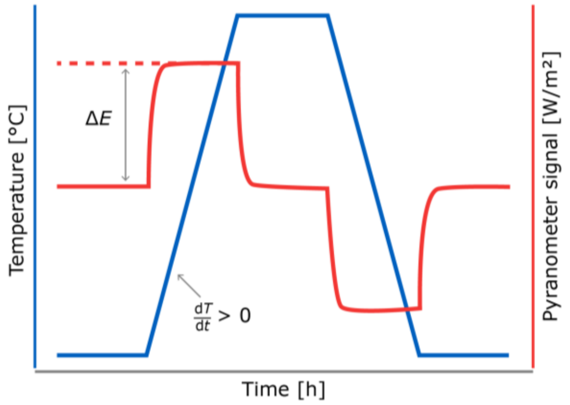

Figure 4 *a sketch of the offset* ΔE *in the pyranometer signal due to a change* dT/dt *in ambient temperature. The temperature is shown in blue. The red curve illustrates how the pyranometer signal responds to changing temperatures.*

Offsets due to pyranometer electronics or heating

Electronics inside a pyranometer can dissipate heat, which can cause temperature differences and thus offsets. Such effects are typically small, but can become significant if e.g. a heater is used to prevent dew or frost deposition.

These zero offsets can be measured easily by putting the pyranometer in a dark environment with a stable temperature. A non-zero signal can be attributed to electronic offsets. Such offsets were not mentioned in the ISO 9060:1990 standard.

Table 1 *the acceptable zero-offsets for pyranometers as specified by the ISO 9060:2018 standard*

a) Response to – 200 W/m2 net thermal radiation
b) Response to 5 K/h change in ambient temperature
c) Total zero offset including the effects a, b and other sources

Zero offset	Class A	Class B	Class C
a	± 7 W/m²	± 15 W/m²	± 30 W/m²
b	± 2 W/m²	± 4 W/m²	± 8 W/m²
c	± 10 W/m²	± 21 W/m²	± 41 W/m²

Conclusion

Historically the zero offsets, especially the offset due to thermal radiation, were significant. Frequently corrections were applied to raw pyranometer data in order to try to compensate for these offsets. However, such corrections are not trivial as the zero offsets not only depend on thermal radiation and temperature changes but also on additional factors like for example wind speed.

Modern pyranometers, like SR30-D1, are designed to reduce the zero offsets. For such pyranometers the zero offsets are well controlled and well within the acceptable limits of the ISO 9060 standard, making the need for complicated correction schemes largely obsolete. In most places, during most of the day solar irradiances are in the range of several hundreds up to about 1600 W/m² and relatively speaking the pyranometer offsets are negligible.

However, for specific low light conditions, such as those occurring around sunset or sunrise, those occurring near the polar regions or those occurring when measuring diffuse radiation with a shading band, the zero offsets can remain significant. In those cases it is important that users are aware of the zero offsets.

References

1. Hukseflux Thermal Sensors, (2018), application note, What is a pyranometer?
2. ISO (2018) ISO 9060:2018: Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
3. Hukseflux Thermal Sensors, (2018), application note, Pyranometer physics: why two domes?

About Hukseflux

Hukseflux Thermal Sensors makes sensors and measuring systems. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux products and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

Would you like more information?
E-mail us at: info@hukseflux.com