Lesson 3:
PYRANOMETER

Course: Laboratory of Atmospheric Remote Sensing
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What measures the pyranometer?

It is used to measure **solar irradiance** on the surface of the earth. In simple terms a pyranometer measures the amount of sunlight reaching the earth's horizontal plane.

The measurement of the sun's radiation on the earth is given by both the **direct and diffuse solar radiation** received from the hemisphere above the plane of the pyranometer. It is expressed as global solar radiation (or irradiance) [W/m^2].

Pyranometers measure a portion of the solar spectrum, not responding to long-wave radiation.

Range of solar radiation: 300-2800 nm.

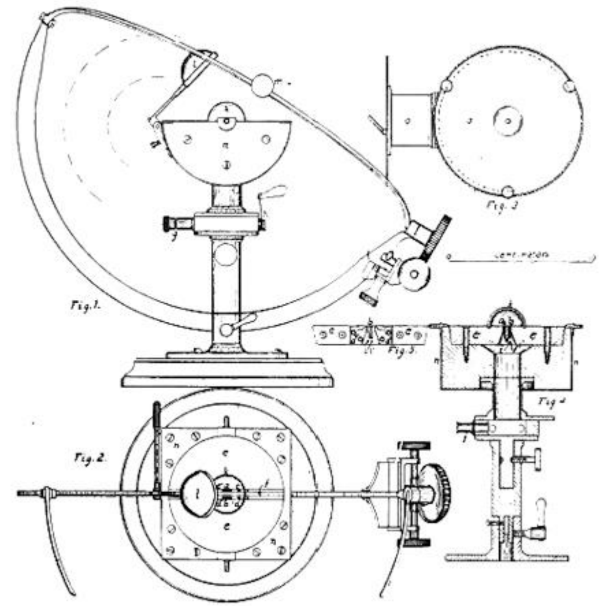
Applications and purposes

- Solar energy: to determine how **efficiently solar panels** are converting the sun's energy into electricity and when the panels need to be cleaned. Sensors used for this purpose usually measure radiation in the plane of the solar panel array.
- Utilities: to compute **gas** and **electricity energy usage**
- Research: to foresee or quantify **plant growth** or production
- Agriculture: to predict **plant water usage** and to schedule irrigation (as well as golf and park maintenance)
- Meteorology: in order to validate and improve **weather prediction models** and to identify which **climatic patterns** a given area can expect in the near future.

Hystory

“The Pyranometer - An Instrument for Measuring Sky Radiation” – 1912 by Abbot and Aldrich

The principle works on the difference in temperatures caused by radiation falling on two blackened manganin strips with the same area but a thickness ratio 10: 1, the thicker strip acting as a heat-sink.



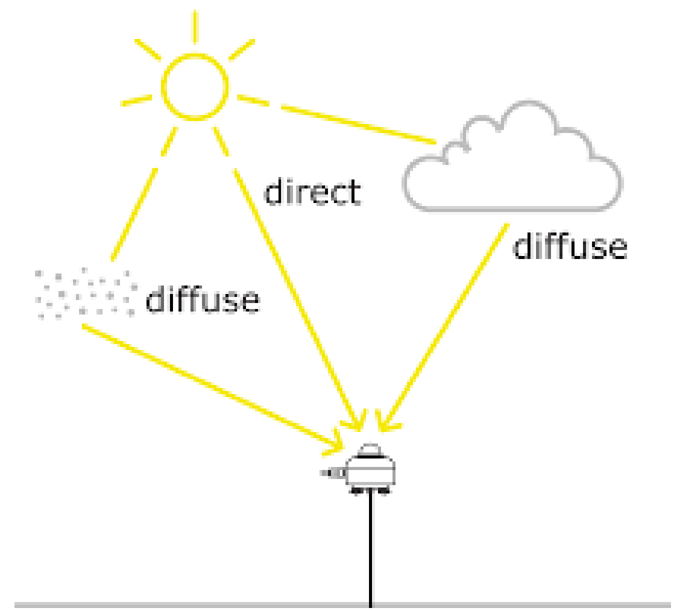
The temperatures are measured by two thermocouples and the difference voltage signal is shown by a galvanometer.
Electrical heating is then applied to balance out this signal to zero and the power required is proportional to the received radiation, self-compensating for the effects of changing instrument temperature.

Global irradiance

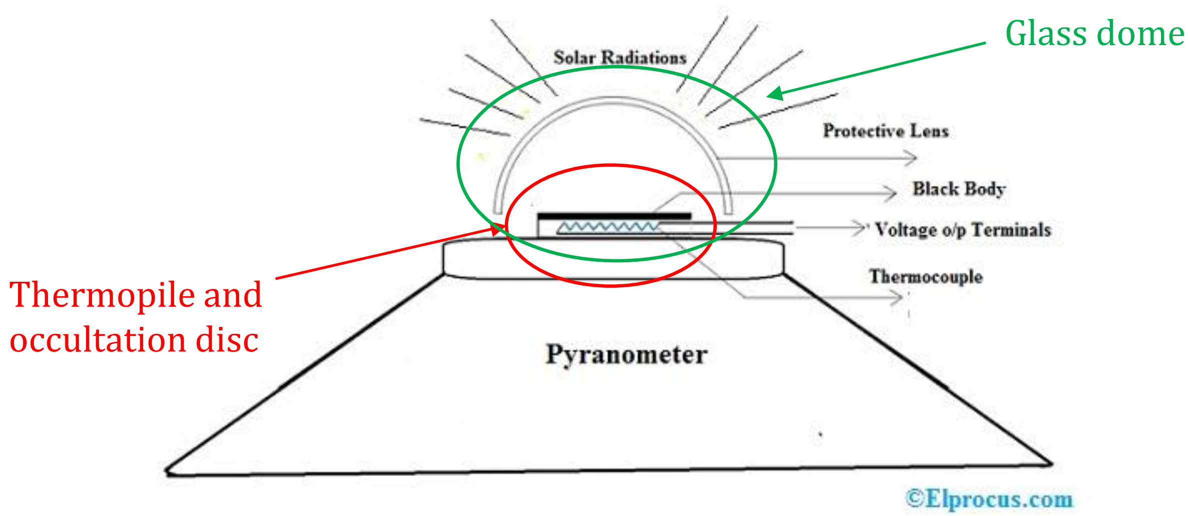
Global irradiance: the amount of solar energy per unit area per unit time incident on a surface of specific orientation emanating from a hemispherical field of view (2π sr), denoted Eg↓.

The global irradiance includes direct sunlight and diffuse sunlight. The contribution from direct sunlight is given by $E \cdot \cos(\theta)$ where θ is the angle between the surface normal and the position of the sun in the sky and E is the maximum amount of direct sunlight. The contribution of the diffuse sunlight is denoted Ed.

$$Eg\downarrow = E \cdot \cos(\theta) + Ed$$



Main components



Thermopile: it uses a thermocouple used to notice dissimilarity in temperature between two surfaces. These are hot (labeled active) and cold (reference) accordingly. The labeled active surface is a black surface in flat shape and it is exposed to the atmosphere. The reference surface depends on the difficulty of the pyranometer because it changes from a second control thermopile to the covering of the pyranometer itself.

Glass Dome: it limits the response of spectral from 300 nm to 2800 nm from 180 degrees of view. It also protects the thermopile sensor from rain, wind, etc.

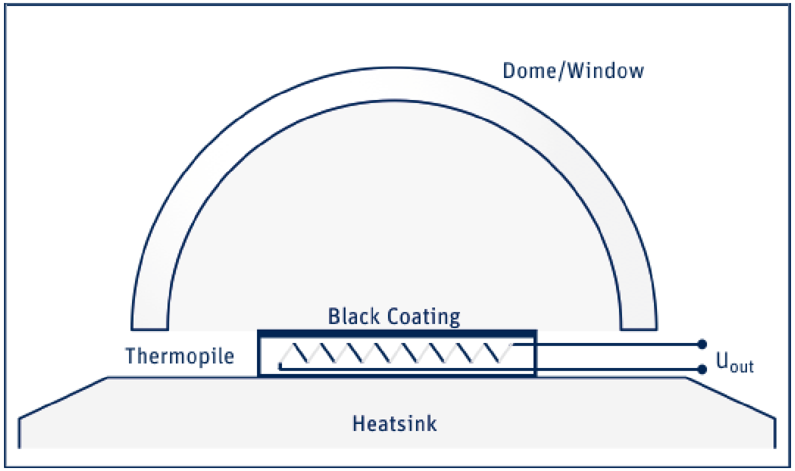
Occultation Disc: it disc is mainly used to measure the radiation of blocking beam & diffuse radiation from the panel surface.

Working principle (1)

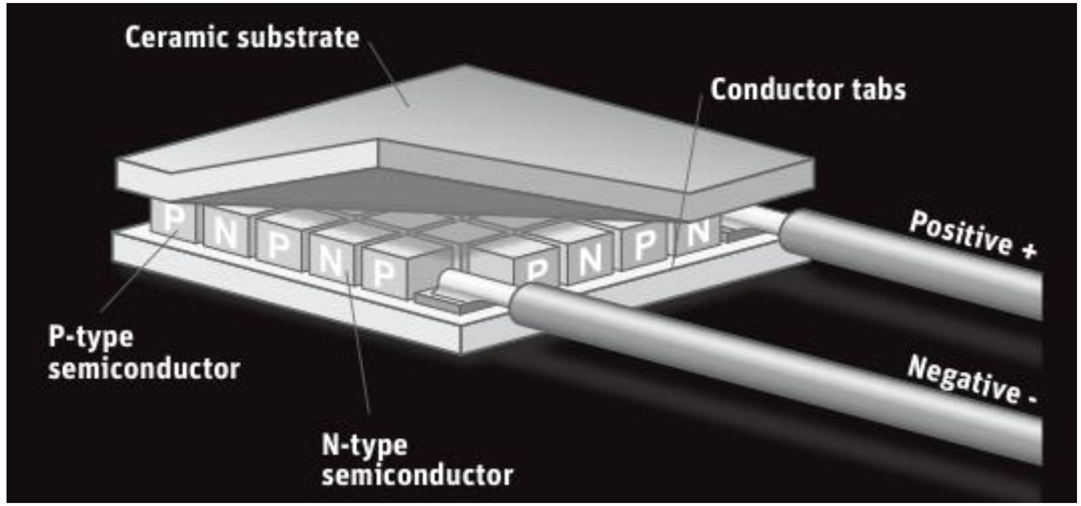
The working principle of the pyranometer mainly depends on the **difference in temperature measurement between two surfaces, like dark and clear**.

The **thermoelectric detection principle** is used: incoming radiation is almost completely absorbed by a horizontal blackened surface on the thermopile, over a very wide wavelength range, whereas the clear surface reproduces it, so less heat can be absorbed.

The resulting increase of temperature is measured via thermocouples connected in series or series-parallel to make a **thermopile**.



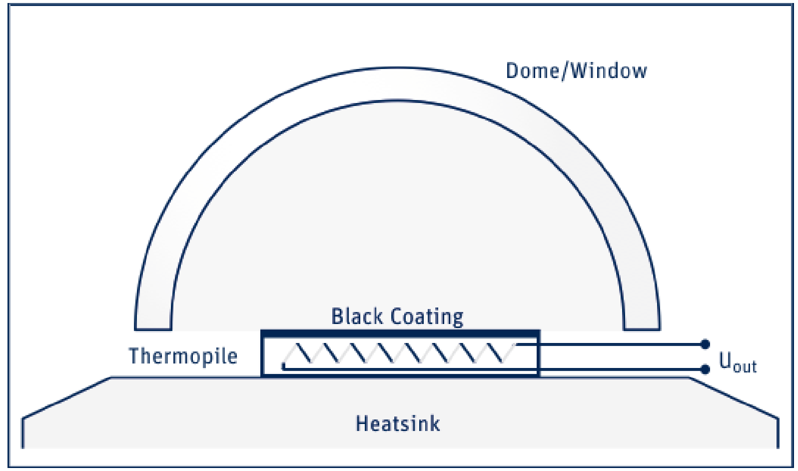
Working principle (2)



The **thermopile** plays a key role in measuring the difference in temperature. The potential difference formed within the thermopile is due to the gradient of temperature between the two surfaces. These are used to measure the sum of solar radiation.

The active (hot) junctions are located beneath the blackened receiver surface and are heated by the radiation absorbed in the black coating.
The passive (cold) junctions of the thermopile are in thermal contact with the pyranometer housing, which serves as a heat-sink.

Working principle (3)



It is necessary to protect the black detector coating against external influences which may affect the measurement (precipitation, dirt, wind).
Nearly all pyranometers use an optical quality glass for their hemispherical single or double domes.

Depending upon the glass, the transmission is from 300 nm or less to about 3000 nm. Double domes give better stability under dynamically changing conditions by further ‘insulating’ the sensor surface from environmental effects such as wind and rapid temperature fluctuations.

Working principle (4)

The shape of the dome, and the refractive index of the material, improves the response of the sensor when the sun is close to the horizon, 'bending' the incoming radiation beam.
The higher refractive index further improves the directional response and better thermal conductivity than glass provides other performance benefits.

The voltage which is generated from the thermopile is calculated with the help of a potentiometer.

Advantages and disadvantages

- ✓ The temperature coefficient is extremely small
- ✓ Standardized to ISO standards
- ✓ Measurements of performance ration & performance index are accurate.
- ✓ Response time is longer compare to PV cell

- ✗ its spectral sensitivity is imperfect, so it does not observe the complete spectrum of the sun.

  So errors in measurements can occur.

World Radiometric Reference by WMO (1)

The WMO has established the **World Radiometric Reference (WRR)** as a “collective standard.”

“The WRR is accepted as representing the physical units of total irradiance within 0.3 per cent (99 percent uncertainty of the measured value).”

All pyranometer calibrations trace back to the WRR.

Quality classification: established by the **WMO** and the International Organization for Standardization (**ISO**) for different applications.

The ISO categories named “secondary standard,” “first class,” and “second class” closely correspond to the WMO categories named “High quality,” “Good quality,” and “Moderate quality.”

Differences in WMO and ISO classification:

- spectral range: 0.35-1.5 μm for WMO; 0.30 to 3.0 μm for ISO
- spectral sensitivity: 2% for WMO; 3% for ISO
- WMO specifies “Resolution” and “Achievable uncertainty,” which are not mentioned by ISO

World Radiometric Reference by WMO (2)

Table 7.4. Characteristics of operational pyranometers

Characteristic	*High quality*[a]	*Good quality*[b]	*Moderate quality*[c]
Response time (95% response)	< 15 s	< 30 s	< 60 s
Zero offset:			
(a) Response to 200 W m^{-2} net thermal radiation (ventilated)	7 W m^{-2}	15 W m^{-2}	30 W m^{-2}
(b) Response to 5 K h^{-1} change in ambient temperature	2 W m^{-2}	4 W m^{-2}	8 W m^{-2}
Resolution (smallest detectable change)	1 W m^{-2}	5 W m^{-2}	10 W m^{-2}
Stability (change per year, percentage of full scale)	0.8	1.5	3.0
Directional response for beam radiation (the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring, from any direction, a beam radiation whose normal incidence irradiance is 1 000 W m^{-2})	10 W m^{-2}	20 W m^{-2}	30 W m^{-2}
Temperature response (percentage maximum error due to any change of ambient temperature within an interval of 50 K)	2	4	8
Non-linearity (percentage deviation from the responsivity at 500 W m^{-2} due to any change of irradiance within the range 100 to 1 000 W m^{-2})	0.5	1	3
Spectral sensitivity (percentage deviation of the product of spectral absorptance and spectral transmittance from the corresponding mean within the range 300 to 3 000 nm)	2	5	10
Tilt response (percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1 000 W m^{-2})	0.5	2	5
Achievable uncertainty (95% confidence level):			
Hourly totals	3%	8%	20%
Daily totals	2%	5%	10%

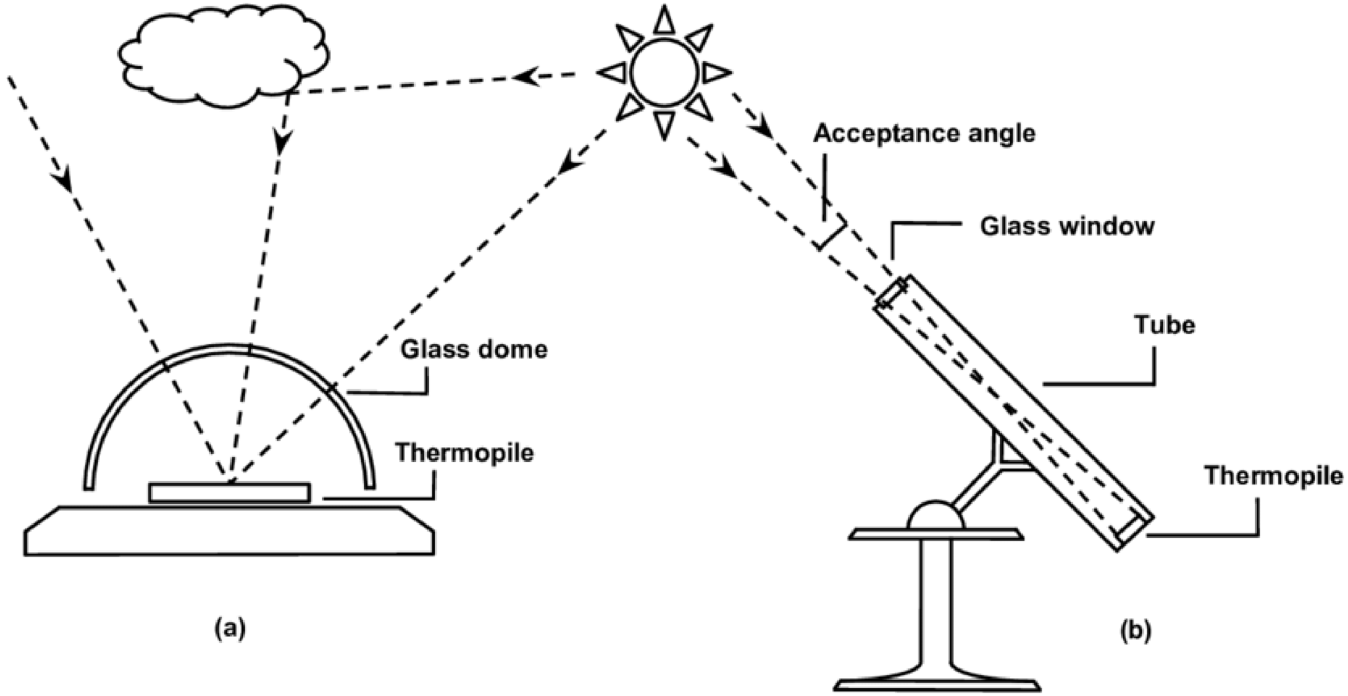
Notes:

a Near state of the art; suitable for use as a working standard; maintainable only at stations with special facilities and staff.

b Acceptable for network operations.

c Suitable for low-cost networks where moderate to low performance is acceptable.

Pyrheliometer



Pyranometer is used to measure diffused sun energy.
Pyrheliometer is used to measure the sun's energy directly.

Recap (1)

- The spectral response (light sensitivity) of a pyranometer depends on the type of pyranometer.
- Thermopile technology is able to convert thermal energy into electrical energy based on temperature difference. Thermopile pyranometers measure the flux density of solar radiation from a 180 degree angle of view. The temperature of the sun exposed area and shadow area are used to determine solar irradiance.
- A thermopile pyranometer has a sensor covered in a black coating that absorbs the solar radiation and a glass dome that limits the spectral response (light sensitivity).
- In a thermopile pyranometer the active junctions are located under the black coated sensor and radiation absorbed by the black coating heats the junctions.
- In a thermopile pyranometer the passive junctions are located in an area protected from solar radiation.
- The temperature difference between the active and passive junctions generates a small electrical voltage to provide the solar irradiance measurement.

Recap (2)

- Thermopile pyranometer technology is useful in a number of professional fields including climatology, research into climate change, photovoltaic systems, the physics of building engineering, and meteorology.
- Thermopile pyranometers are most often installed in meteorological stations horizontally.
- Manufacturers of thermopile pyranometers should follow the ISO 9060 standard which the World Meteorological Organization has adopted as standard. The best standard is labeled as secondary standard, while second is labeled as first class and third is labeled as second class.
- Pyranometers must be calibrated and calibration standards are determined by the type of pyranometer. Calibration of these tools is dependent on the intended use as well.
- The thermopile pyranometers are much more expensive than photovoltaic pyranometers.
- The less expensive pyranometers can be useful in farming and monitoring of the environment when absolute accuracy is not required.