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Standard Terminology of Solar Energy Conversion[1]

This standard is issued under the fixed designation E772; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This terminology pertains to the conversion of solar energy into other forms of energy by various means, including thermal absorption (i.e., solar thermal) and the photovoltaic effect (i.e., photovoltaics).

1.2 This terminology also pertains to instrumentation used to measure solar radiation.

1.3 This terminology also pertains to glass for solar energy applications.

1.4 Fundamental terms associated with electromagnetic radiation that are indicates as derived units in Standard SI 10 are not repeated in this terminology.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

~~1.1 ASTM Standards:~~

2.1 *ASTM Standards:*[2]

C162 Terminology of Glass and Glass Products

C859 ~~Terminology Relating to Nuclear Materials~~ 1048 Specification for Heat-Treated Flat Glass Kind HS, Kind FT Coated and Uncoated Glass

C1651 Test Method for Measurement of Roll Wave Optical Distortion in Heat-Treated Flat Glass

D93 ~~Test Methods for Flash Point by Pensky-Martens Closed Cup Tester~~ 1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics

D1245 Practice for Examination of Water-Formed Deposits by Chemical Microscopy

D4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems

D5544 Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water

D7236 Test Method for Flash Point by Small Scale Closed Cup Tester (Ramp Method)

E349 Terminology Relating to Space Simulation

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables

E491 Practice for Solar Simulation for Thermal Balance Testing of Spacecraft

E971 ~~Practice for Calculation of Photometric Transmittance and Reflectance of Materials to Solar Radiation~~

927 Specification for Solar Simulation for Photovoltaic Testing

E816 Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers

E1021 Test Method for Spectral Responsivity Measurements of Photovoltaic Devices

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum

E1171 Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments

E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells

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E1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules

E2236 Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction Photovoltaic Cells and Modules

E2527 Test Method for Electrical Performance of Concentrator Terrestrial Photovoltaic Modules and Systems Under Natural Sunlight

F1863 Test Method for Measuring the Night Vision Goggle-Weighted Transmissivity of Transparent Parts

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G130 Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer

G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance

G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37 ~~Tilted Surface~~

2. ~~Tilted Surface~~

G197 Table for Reference Solar Spectral Distributions: Direct and Diffuse on 20 Tilted and Vertical Surfaces

SI 10 IEEE/ASTM SI 10 American National Standard for Metric Practice

2.2 *ISO Standard:*[3]

ISO 9060 Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiaiton

2.3 *WMO Document:*[4]

WMO-No. 8 Guide to Meteorological Instruments and Methods of Observation, Seventh ed., 2008, World Meteorological Organization (WMO), Geneva

3. Adjectives for Electromagnetic Radiation

3.1 Properties and quantities associated with electromagnetic radiation vary with:

3.1.1 The direction and geometric extent (solid angle) over which the incident or exitant flux, or both, is evaluated, and

3.1.2 The relative spectral distribution of the incident flux and the spectral response of the detector for exitant flux.

3.2 Adjective modifiers can be used to indicate the geometric, spectral, and polarization conditions under which radiometric properties and quantities are evaluated. The adjectives defined in this Terminology are: **conical, diffuse, direct, directional, hemispherical, luminous, normal,** and **spectral**.

3.3 For reflectance and transmittance, the direction and geometric extent of both the incident beam and exitant beam must be specified.

3.4 For emittance, only the exitant beam need be specified, and for absorptance, only the incident beam need be specified.

3.5 Radiometric properties also vary with the polarization of the incident flux and the sensitivity to polarization of the collector-detector system for flux incident or exitant at angles greater than about 15° from normal.

3.6 An instrument used for solar energy measurements or a solar energy receiver will usually determine the directions and geometric extents, such as a pyranometer, a pyrheliometer, or a flat-plate solar thermal collector.

4. Terminology

ELECTROMAGNETIC RADIATION AND OPTICS

~~**absorber**—that part of a solar collector whose primary function is to absorb radiant energy and transform it into another form of energy.~~

~~Note 1—A thermal absorber usually possesses a solid surface through which energy is transmitted by thermal conduction to the transfer fluid; however, the transfer fluid itself can be the absorber in the case of an optically transparent container and a "black liquid". A photovoltaic absorber converts part of the incident solar flux into electrical energy, and part to thermal energy.~~ absorptance, *n*—ratio of the absorbed radiant or luminous flux to the incident flux.   **E349**

absorptance, α— ~~the ratio of the absorbed radiant or luminous flux to the incident flux. (Practice E491). See **radiometric properties and quantities**.~~ absorption, *n*—transformation of radiant energy to a different form of energy by interaction with matter.   **E349**

~~**absorption**—the process by which incident radiant energy is transformed into another form of energy by interaction with matter.~~ aerosol, *n*—any solid or liquid particles, with a nominal size range from 10 nm to 100 μm, suspended in a gas (usually air).   **D5544**

~~**air handling unit**—a device used for distributing conditioned air supply to a room, space, or area.~~ aerosol optical depth, *AOD*, *n*—a measure of the **extinction** caused by **aerosols** in the atmosphere relative to the **zenith** and modeled with Ångstrom's **turbidity** formula.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.
[4] Available from World Meteorological Organization, http://www.wmo.int.

DISCUSSION—Although it varies with wavelength, it is common to report aerosol optical depth at a single wavelength only, especially 0.5 µm.

air mass, AM—the ratio of the mass of atmosphere in the actual observer-sun path to the mass that would exist if the observer was at sea level, at standard barometric pressure, and the sun was directly overhead.

NOTE 2—(Sometimes called air mass ratio.) Air mass varies with the zenith angle of the sun and the local barometric pressure, which changes with altitude. For sun zenith angle, Z, of 62° or less and local atmospheric pressure, P, where P_o is standard atmospheric pressure, AM ≈ sec Z (*air mass, AM, n*—relative optical mass (see **optical mass, relative**) calculated using the density of air as a function of altitude.

(1) $AM \approx ls / lz = sec\theta z, for \theta z \leq 1$ rad (60°)

DISCUSSION—Eq 1 is a simple approximation of the **optical mass, relative** (see Eq 5) that uses the ratio of the path length along the sun vector (l_s) to the path length along the **zenith** (l_z) (see **sun vector, zenith**, and **zenith angle, solar**). Other solutions are more complicated and take factors such as refraction and local air pressure into account.

DISCUSSION—The abbreviation **AM** is also commonly used to refer to a particular standard solar spectral irradiance, such as those in Standard E490, Tables G173, and Table G197. Thus, **AM0** can indicate the extraterrestrial spectral irradiance table in Standard E490, and **AM1.5** the hemispherical spectral irradiance table in Tables G173. Using AM1.5 in this way is discouraged because air mass is but one of many variables that modify solar spectral irradiance such as clouds, aerosol scattering, and water vapor absorption; note that both Tables G173 and Table G197 use an air mass value of 1.5, but differ greatly. The distinction between a spectral irradiance and a path length ratio should be made clear whenever these abbreviations are used.

air mass one, *AM1, n*—a relative optical mass (see **optical mass, relative**) that is equal to one. Because of the way in which relative optical mass is defined, AM1 always denotes a vertical path at sea level.

air mass, optical—see **optical mass, relative**.

air mass, pressure corrected, *AM_p, n*—an approximation of **air mass** for locations above sea level that uses the ratio of the local barometric pressure P, to the standard sea level atmospheric pressure $P_0 = 101.325$ kPa (see Eq 2).

$$AMp \approx \frac{P}{P_0} AM$$ (2)

albedo—the use of the term *albedo* is discouraged in favor of the preferred term, **air mass ratio**—see **optical mass, relative**.

air mass, relative optical—see **optical mass, relative**.

air mass zero, *AM0, n*—the absence of atmospheric attenuation of the solar irradiance at one astronomical unit from the sun.
E491

albedo—discouraged in favor of the preferred term, **reflectance**.

altazimuthal mount—a supporting device that facilitates tracking of the sun and allows rotation about horizontal and vertical axes. It can be used to aim equipment such as heliostats, concentrating collectors, exposure specimens, or radiometers. angle of incidence, rad or °, *n*—the angle between a ray and the normal vector to the plane on which the ray is incident; especially the angle between the sun vector and the normal vector.

angle of incidence—the angle between a ray and the normal to the plane on which it is incident. (The plane of incidence may be the aperture plane, the collector, or any other plane of interest.) angle of reflection, rad or °, *n*—the angle between the direction of propagation of a reflected ray and the normal vector to the surface of interest at the point of reflection.

angle of reflection—the angle between the direction of propagation of a reflected ray and the normal to the surface at the point of reflection.

angle of refraction—the angle between the direction of propagation of a refracted ray and the normal to the interface at the point of refraction. angle of refraction, rad or °, *n*—the angle between the direction of propagation of a refracted ray and the normal vector to the interface of interest at the point of refraction.

aperture area—see **area, aperture** altitude angle, solar—see **elevation angle, solar**.

attenuation—see **extinction**.

apparent solar time, apt—the hours of the day as computed from the position of the sun using the equation of time. (See ASHRAE *Handbook of Applications,* 1982, Chapter 57.) azimuth angle, solar, ψ[rad or °], *n*—the angle between the line of longitude (or geographical meridian) at the location of interest and the horizontal component of the **sun vector**. By convention, the azimuth angle is positive when the sun is east of the line of longitude and negative when it is west of the line of longitude.

area, absorber—the total uninsulated heat transfer surface area of the absorber, including unirradiated as well as irradiated portions. beam, *n*—*of radiant energy*, a collection of rays confined to a specific path.

area, aperture—of a flat plate collector, (*1*) the maximum projected area of a solar collector through which the unconcentrated solar radiant energy may be admitted to the absorber. (*2*) *effective aperture area*—the area as defined above projected normal to the sun's rays and corrected for any shading. Units: square metres (m^2) [square feet (ft^2)]. blackbody, Planckian radiator, *n*—a thermal radiator which completely absorbs all incident radiation, whatever the wavelength, the direction of incidence, or the polarization. This radiator has, for any wavelength, the maximum spectral concentration of radiant exitance at a given temperature.
E491

area, collector panel—the total area of the panel assembly (with its containing box, if present), projected on the aperture plane. Bouguer's Law, *n*—an expression of the **extinction** of radiation in a medium that states the intensity exponentially decreases due to both scattering and absorption as it passes through the medium (see Eq 3), where τ_λ is the wavelength-dependent **extinction optical thickness**. The ratio of I to I_0 is equal to the atmospheric transmittance, T, and τ_λ is equal to the summation of the extinction optical thicknesses associated with each individual scattering or absorption process $\tau_{i\lambda}$.

(3) $I = I0\ exp(-\tau\lambda) = I0\ exp(-i=1n\ \tau i\lambda)$

DISCUSSION—Bouguer's Law is also known as Lambert's Law or Beer's Law.

circumsolar diffuse radiation—**see radiant energy, circumsolar**.

conical, *adj*—describing a solid angle larger than an infinitesimal element and less than a hemisphere (2π sr); the geometry of the solid angle must be described in context.

diffuse, *adj*—*describing radiometric quantities*, indicates flux propagating in many directions, as opposed to a collimated beam.

diffuse, *adj*—*describing solar irradiance*, the global hemispherical irradiance minus the direct beam irradiance.

diffuse, *adj*—*describing reflectance*, the directional hemispherical reflectance minus the specular reflectance.

DISCUSSION—**Diffuse** has been used in the past to refer to hemispherical collection (including the specular component) or irradiation, with equal radiance for all directions over a hemisphere. This use is deprecated in favor of the more precise term **hemispherical**.

diffusion, *n*—change of the spatial distribution of a beam of radiation when it is deviated in many directions by a surface or a medium.   **E349**

direct, *adj*—*describing solar radiation*, a collimated beam.

directional, *adj*—of or relating to a direction in space.

DISCUSSION—For optical properties, over an infinitesimal solid angle, the property is assumed constant. The variation in optical property with respect to changing azimuth (counter-clockwise) and incidence angle (from the surface normal), with respect to a reference mark on a sample, is the directional response.

elevation angle, solar, α [rad or °]**,** *n*—the complement of the solar zenith angle, i.e. $\pi/2 - \theta_z$ radians. See **zenith angle, solar**.

emission, *n*—release of radiant energy.   **E349**

emissive power—discouraged in favor of the preferred term **radiant exitance**.

emittance, ε**,** *n*— for a sample at a given temperature, ratio of the radiant flux emitted by a sample to that emitted by a blackbody radiator at the same temperature, under the same spectral and geometric conditions of measurement.

extinction, *n*—the attenuation of radiant energy from an incident beam by the processes of molecular absorption and scattering caused by atmospheric constituents.

DISCUSSION—Scattering by air molecules can be modeled with **Rayleigh scattering**, and scattering by **aerosols** with Ångstrom's **turbidity** formula. Absorption processes are modeled with tables of measured absorption coefficients versus wavelength.

extinction coefficient, monochromatic, $k_{i\lambda}$ *[dimensionless]***,** *n*—a measure of the **extinction** caused by a particular atmospheric constituent (see **Bouguer's Law** and **extinction optical thickness, monochromatic**).

extinction optical depth, monochromatic, [dimensionless]**,** *n*—the product of the **extinction coefficient** $k_{i\lambda}$ for a particular atmospheric constituent times the path length to the top of the atmosphere, m_r, see **extinction optical thickness, monochromatic** and **optical mass, relative**.

DISCUSSION—Optical depth is sometimes used synonymously with optical thickness, but the preferred distinction between the two is that optical thickness refers to the extinction along the entire path through the atmosphere rather than the vertical path.

extinction optical thickness, monochromatic, $\tau_{i\lambda}$[dimensionless]**,** *n*—the product of the **extinction coefficient** $k_{i\lambda}$ for a particular atmospheric constituent times the path length through atmosphere, see **Bouguer's Law** and Eq 4, in which m_{act} is the **optical mass, actual**.

$$\tau_{i\lambda} = k_{i\lambda}\cdot m_{act} \tag{4}$$

hemispherical, *adj*—describing half of a sphere, i.e. a 2π sr solid angle.

~~*charge capacity*~~**incident angle**—see ~~**thermal capacity**~~angle of incidence.

index of refraction, *n*—the numerical expression of the ratio of the velocity of light in a vacuum to the velocity of light in a substance.   **D1245**

infrared radiation, *n*—radiation for which the wavelengths of the monochromatic components are greater than those for visible radiation, and less than about 1 mm.   **E349**

irradiance, E [W·m^{-2}]**,** *n*—*at a point on a surface*, radiant flux incident per unit area of the surface; the derived unit **heat flux density, irradiance** in Standard SI 10.

~~**cloud cover**—that portion of the sky which is covered by clouds, usually expressed in tenths of sky covered.~~ irradiance, spectral, E_λ *or* $E(\lambda)$[W·m^{-2}·nm^{-1} or W·m^{-2}·μm^{-1}]**,** *n*—the irradiation at a specific wavelength over a narow bandwidth, or as a function of wavelength; also, the derivative with respect to wavelength of irradiance.

DISCUSSION—Spectral irradiance is commonly reported in tabular form as pairs of wavelength and irradiance values, as in Standard E490, Tables G173, and Table G197; see **spectral**.

DISCUSSION—Following the normal SI rules for compound units (see Standard SI 10), the units for spectral irradiance, the derivative of irradiance with respect to wavelength $dE/d\lambda$, would be W·m^{-3}. However, to avoid possible confusion with a volumetric power density unit and for convenience in numerical calculations, it is common practice to separate the wavelength with a compound unit. Compound units are used in Standard E490, Tables G173, and Table G197.

~~**collector, concentrating**—a solar collector that uses reflectors, lenses, or other optical elements to redirect and concentrate the~~

solar irradiance on the collector aperture onto an absorber of which the surface area is smaller than the collector aperture area. irradiance, total, E_T [W·m^{-2}], *n*—the integration over all wavelengths of spectral irradiance, or the solar irradiance measured with a pyranometer or a pyrheliometer.

irradiation, *n*—application of radiation to an object.   **E349**

collector efficiency **irradiation**—*at a point on a surface*, see **radiant exposure**.

isotropic radiant energy— see **efficiency, collector** radiant energy, isotropic.

local zenith—see **zenith**.

collector, evacuated tube—a solar collector made from transparent tubing (usually glass) with an evacuated space between the tube and the absorber. The absorber may consist of an inner tube or another shape, with means for removal of thermal energy and may be specially coated. luminous, *adj*—*referring to a radiometric quantity*, weighted according to the spectral luminous efficiency function V() of the CIE (1987).   **D1003**

collector, flat plate—a nonconcentrating solar collector in which the absorbing surface is essentially planar. monochromatic radiation, *n*—radiation charcterized by a single frequency. By extension, radiation of a very small range of frequency or wavelenght that can be described by stating a single frequency or wavelength.   **E349**

collector, line-focus—a concentrating solar collector that concentrates the solar flux in one dimension only. normal, *adj*—describing a direction that is perpendicular to a surface.

collector, point focus—a concentrating collector that focuses the solar flux to a point. normal vector, *n*—the upward-pointing vector normal to the plane of a receiver.

optical depth—see **extinction optical depth, monochromatic**.

collector, solar thermal—a device designed to absorb solar irradiance and to transfer the thermal energy to a fluid passing through it. optical mass, actual, m_{act} [dimensionless], *n*—the line integral along the **sun vector** of the density (ρ) of a substance as a function of altitude between a point in the atmosphere (0) and the vacuum of space (∞); in atmospheric transmittance calculations, the densities are normalized with units of (length)$^{-1}$(see Eq 5).

(5) $m_{act} = \int_0^\infty \rho \, ds$

    Discussion—The word "air" has been avoided in this definition because direct solar radiation is attenuated not only by air molecules but also by additional constituents such as aerosols and water vapor. Thus, it is possible to calculate water vapor mass as well as air mass using this equation. Optical masses are occasionally reported with units of km.

optical mass, relative, m_r [dimensionless], *n*—the ratio of the actual optical mass (see **optical mass, actual**, m_{act}) to the line integral along the **zenith** of the density of a substance as a function of altitude (ρ) between a point in the atmosphere (0) and the vacuum of space (∞) (see Eq 6).

$$m_r = m_{act} / \int_0^\infty \rho \, ds \qquad (6)$$

optical thickness—see **extinction optical thickness, monochromatic**.

collector, tracking—a solar collector that moves so as to follow the apparent motion of the sun during the day, rotating about one axis or two orthogonal axes. polarization, *n*— *with respect to optical radiation*, the restriction of the magnetic or electric field vector to a single plane.   **G138**

collector, trickle—a flat plate solar collector in which unpressurized liquid flows or "trickles" over the absorber.

collector cover (glazings)— see **cover plate, collector.** polarization, parallel, *n*—a plane of polarization parallel to the plane of incidence, reflectance, or transmittance.

combustible liquid—a liquid having a flash point at or above 37.8°C (100°F). The flash point of a liquid having a viscosity less than 45 SUS at 37.8°C (100°F) and a flash point below 93.4°C (200°F) shall be determined in accordance with Test Methods D93 polarization, perpendicular, *n*—a plane of polarization perpendicular to the plane of incidence, reflectance, or transmittance.

polarization, plane of, *n*—by convention, the plane containing an electromagnetic wave's electric vector.

radiance, W·m^{-2}·sr^{-1}, *n*—the SI derived unit **radiance** in Standard SI 10.

concentrating collector— see **collector, concentrating.** radiant emissive power—see **radiant exitance**.

concentration ratio, geometric—the ratio of the collector aperture area to the absorber area. radiant energy, *Q*[J], *n*—energy in the form of photons or electromagnetic waves.

concentrator—an optical device (lenses or mirrors) that, as part of a solar collector, receives the unconcentrated solar irradiance and redirects (concentrates) it to a smaller area (the receiver). radiant energy, atmospheric, *Q*[J], *n*—the portion of terrestrial radiation that is emitted by the atmosphere.

conical, ω— over a solid angle larger than an infinitesimal element of solid angle and less than a hemisphere. The geometry of the solid angle must be described in the text. For incident beams it is assumed that the radiance is constant over the entire solid angle. (See **Radiometric properties and quantities**) radiant energy, blackbody, J, *n*—radiant energy emitted by a (laboratory) blackbody, or radiant energy having that spectral distribution. See **Planck's law** in Practice E491.

containment material—in a solar energy system, a material that encloses the heat-transfer fluid or is in contact with the heat transfer or heat storage material, or both. radiant energy, circumsolar, J, *n*—radiation scattered by the atmosphere so that it appears to originate from an area of the sky immediately adjacent to the sun. Often referred to as the solar aureole, its angular extent is generally directly related to the aerosol optical depth.

~~convection~~—~~the transport of heat by fluid flow.~~ radiant energy, effective nocturnal, J , *n*—energy transfer required to maintain a horizontal upward-facing blackbody surface at the ambient air temperature, in the absence of solar irradiance.

radiant energy, infrared—see **infrared radiation**.

~~convection, forced~~—~~convection caused by mechanical forces such as fans and injectors.~~ radiant energy, isotropic, J, *n*—diffuse radiant energy that has the same radiance in all directions.

~~convection, natural~~—~~convection within a fluid, due to density differences caused by temperature differences.~~ radiant energy, terrestrial, J, *n*—radiant energy emitted by the earth, including its atmosphere.

~~cover plate, collector~~—~~a sheet of transparent (or translucent) glazing placed above the absorber in a solar collector, to provide thermal and environmental protection.~~ radiant exitance at a point on a surface, $M[\text{W·m}^{-2}]$, *n*—quotient of the radiant flux leaving an element of the surface containing the point, by the area of that element. **E349**

~~degree day~~ radiant exitance—see **radiant exitance at a point on a surface**.

radiant exitance, emitted—see **radiant exitance at a point on a surface**.

radiant exposure, $H[\text{J·m}^{-2}]$**,** *n*—*at a point on a surface*, time integral of irradiance.

radiant flux, $\Phi[\text{J/s}]$**,** *n*—the SI derived quantity **power, radiant flux** in Standard SI 10.

radiant flux, net, W, *n*—difference between downward and upward (total solar and terrestrial) radiant flux; net flux of all radiant energy across an imaginary horizontal surface.

radiant flux, net terrestrial, W, *n*—difference between downward and upward terrestrial radiant fluxes; net flux of terrestrial radiant energy.

radiant power—see **degree day, heating** and **degree day, cooling.** radiant flux.

~~degree-day, cooling,~~ ~~(DDC or DDF, Celsius or Fahrenheit respectively)~~—~~one cooling degree-day is counted for each degree that the daily mean temperature is higher than a base temperature; used to estimate energy requirements for air conditioning or refrigeration.~~ radiation, *n*—*(1)* emission or transfer of energy in the form of electromagnetic waves or particles. *(2)* the electromagnetic waves or particles. **E349**

~~degree-day, heating,~~ ~~(DDC or DDF, Celsius or Fahrenheit respectively)~~—~~one heating degree-day is counted for each degree that the daily mean temperature is lower than a base temperature; used to estimate energy requirements for heating.~~ radiation coefficient, *n*—the quotient of the net radiant exitance of a blackbody (full radiator), by the temperature difference between the blackbody and the surroundings with which it is exchanging radiation. **E349**

~~design life~~—~~the period of time during which a system or component is expected to perform its intended function, without significant degradation of performance and without requiring major maintenance or replacement.~~ Rayleigh scattering, *n*—a model of molecular scattering in the atmosphere in which the **monochromatic extinction coefficient** varies as the wavelength raised to the negative fourth power. Eq 7 is an approximation for dry air using wavelengths in μm.

(7) $\quad k\,r\lambda = 0.008735\lambda - 4.08$

reflectance, *n*—ratio of the reflected radiant or luminous flux to the incident flux. **E349**

reflection, *n*—return of radiation by a surface without change of frequency of the monochromatic components of which the radiation is composed. **E349**

reflection angle—See **angle of reflection**.

reflectivity, *n*—reflectance of a layer of material of such a thickness that there is no change of reflectance with increased thickness. **E349**

DISCUSSION—Reflectivity is a property of a material and reflectance is a property of a sample of the material, with no restriction on thickness or surface topography.

refraction, *n*—change in the direction of propagation of radiation determined by change in the velocity of propagation in passing from one medium to another medium with a different index of refraction.

refraction angle—see **angle of refraction.**

refraction index—see **index of refraction.**

reradiation, *n*—loss of energy by radiation from a surface previously heated by absorption.

spectral, *adj*—*referring to radiometric quantities*, for monochromatic radiation at a specified wavelength (or frequency), or, by extension, for radiation within a narrow wavelength band about a specified wavelength. **E349**

DISCUSSION—When applied to a property, spectral is indicated by the subscript λ following the symbol for the quantity, as $L_\lambda = dL/d\lambda$; at a specific wavelength, it is indicated by the subscript λ with the wavelength in parentheses, as L_λ (500 nm).

sun vector, *n*—the vector pointing from the location of interest (usually a point on the Earth's surface in solar energy applications) to the center of the sun's disk.

DISCUSSION—Because of the curvature of the Earth, and because of the refraction due to density variations with altitude, the sun vector varies along the path a beam of solar radiation follows from the top of atmosphere to the ground.

transmission, *n*—passage of radiation through a medium without change of frequency of the monochromatic components of which the radiation is composed. **E349**

transmission coefficient—see **extinction coefficient**.

transmittance, *T* [dimensionless]**,** *n*—ratio of the transmitted radiant or luminous flux to the incident flux. **E349**

turbidity, *n*—an empirical expression of **aerosol optical depth** that uses Ångstrom's wavelength-dependent formula (see Eq 8).

$$k_{\alpha\lambda} = \beta \cdot \lambda^{-\alpha} \tag{8}$$

DISCUSSION—In Eq 8, α and β are called the Ångstrom turbidity parameters and λ is the wavelength. The units of α and β are such that the units of k_α are dimensionless. With wavelength units of µm, β is commonly called the "turbidity" because it varies more than α, which tends to stay fairly constant.

ultraviolet radiation, *n*—radiation for which the wavelengths of the monochromatic components are smaller than those for visible radiation and more than about 1 nm.   **E349**

visible radiation, *n*—any radiation capable of causing a visual sensation.   **E349**

zenith, *n*—the upward-pointing vector normal to the Earth's surface at the location of interest (usually a point on the Earth's surface in solar energy applications).

zenith angle, solar, θ_z[rad or °]**,** *n*—the angle between the **zenith** and the **sun vector**.

INSTRUMENTATION

absolute cavity pyrheliometer—see **self-calibrating absolute cavity pyrheliometer**.

absolute cavity radiometer—see **self-calibrating absolute cavity pyrheliometer**.

~~equatorial mount—a sun-tracking mount, usually clock-driven, whose axis of rotation is parallel to that of the earth.~~ bolometer, *n*—instrument for measuring irradiance. Its principle is based on the variation of electrical resistance, with the incoming radiation of one or both of the resistance elements which comprise the instrument, as a result of temperature changes.

~~evacuated tube collector~~—~~see **collector, evacuated tube.**~~ cavity radiometer—see **self-calibrating absolute cavity pyrheliometer**.

~~exitance, radiant~~—~~see **radiant exitance.**~~

~~exposure racks, at-latitude—in solar energy applications, racks that hold specimens at an inclination angle equal to the latitude of the rack location, facing south.~~ edge-stress meter—see **polarimeter, edge-stress**.

~~**flammable liquid**—a liquid having a flash point below 37.8°C (100°F) and having a vapor pressure not exceeding 40 psi (absolute) at 37.8°C and shall be known as a Class I liquid.~~ field pyrheliometer, *n*—pyrheliometers that are designed and used for long-term field measurements of direct solar radiation. These pyrheliometers are weatherproof and therefore possess windows, usually quartz, at the field aperture that pass all solar radiation in the range from 0.3 to 4-µm wavelength.   **E816**

~~**flash point**—of a liquid, the minimum temperature at which it gives off vapor in sufficient concentration to form an ignitable mixture with air near the surface of the liquid within the vessel as specified by appropriate test procedure and apparatus.~~ full width at half maximum, *FWHM*[nm or µm], *n*—*in a bandpass filter*, FWHM is the interval between wavelengths at which transmittance is 50 % of the peak, frequently referred to as bandwidth.   **G130**

~~flux, radiant~~—~~see **radiant flux**~~ grazing-angle surface polarimeter—see **polarimeter, grazing-angle surface**.

~~forced convection~~ international pyrheliometric scale—see **World Radiometric Reference**.

net pyrgeometer—see ~~**convection, forced.**~~ pyranometer, net.

~~free convection~~ net pyrradiometer— see ~~**convection, natural.**~~ pyranometer, net.

~~**Fresnel lens, circular**—a sheet of transparent material into which concentric grooves have been formed in such a pattern that light will be focused as with a lens. (Focusing mirrors of similar design are also available.)~~ photometer, *n*—a device that measures luminous intensity or brightness by converting (weighing) the radiant intensity of an object using the relative sensitivity of the human visual system as defined by the photopic curve.   **F1863**

~~**Fresnel lens, linear**—a sheet of transparent material into which parallel grooves have been formed in such a pattern that light will be focused as by a cylindrical lens. (Focusing mirrors of similar design are also available.)~~ polarimeter, *n*—an instrument used to measure the rotation of the plane of polarization of polarized light passing through an optical structure or sample.

~~**Fresnel-reflector system**—flat mirrors arranged in an array such that they reflect onto a target, the illuminated area of which simulates the shape and size of the flat mirror. (Such an array simulates the ray-tracing of a parabolic trough of the same aperture angle.)~~ polarimeter, edge stress, *n*—a specialized **polarimeter** for measuring residual edge stress in annealed, heat-strengthened, or thermally tempered flat glass. Used as a non-destructive method of characterizing strength and relative frangibility of glass.

polarimeter, grazing-angle surface, *n*—a specialized **polarimeter** for measuring residual surface stress in annealed, heat-strengthened, or thermally tempered flat glass. Used as a non-destructive method of characterizing strength and relative frangibility of glass.

polarimeter, photoelastic, *n*—a **polariscope** adapted for quantitative measurement of optical retardation, birefringence, or stress and strain using photoelastic analysis techniques.

polariscope, *n*—an optical device consisting of a light source, mutually perpendicular polarizing elements, and generally equipped with one or more retardation plates for qualitative observations of relative optical retardation by color differentiation.   **C162**

primary standard pyrheliometers, *n*—pyrheliometers, selected from the group of absolute pyrheliometers (see **self-calibrating absolute cavity pyrheliometer**).   **E816**

pyranometer, *n*—a radiometer with a hemispherical field-of-view (i.e. a 2π sr solid angle) used to measure the total solar radiant energy incident upon a surface per unit time per unit area. This energy includes the direct radiant energy, diffuse radiant energy, and reflected radiant energy from the background.

pyranometer, field, *n*—a pyranometer meeting World Meteorological Organization (WMO) Second Class "moderate quality" or better (that is, "Good Quality" or "High Quality") First Class specifications, described in WMO-No. 8, appropriate to field use, and typically exposed continuously.

pyranometer, net, *n*—an instrument for measuring the difference between the irradiance falling on the top and bottom of a horizontal surface.

pyranometer, reference, *n*—a pyranometer (see also ISO 9060), used as a reference to calibrate other pyranometers, which is well-maintained and carefully selected to possess relatively high stability and has been calibrated using a pyrheliometer.
$\qquad\qquad$ **G167**

pyranometer, spherical, *n*—instrument for measuring the solar flux falling from a 4π sr solid angle onto a spherical surface.

pyrgeometer, *n*—an instrument for measuring infrared atmospheric irradiance at wavelengths greater than 3000 nm on a horizontal upward facing black surface at the ambient air temperature.

pyrheliometer, *n*—a radiometer used to measure the direct or beam solar irradiance incident on a surface normal to the sun's rays.

pyrheliometer, compensated, *n*—pyrheliometer based on the comparison of the heating of two identical metal strips, one exposed to a solar radiant energy, the other to a joule effect.

full radiator—see **blackbody.** pyrheliometer, field—see **field pyrheliometer**.

gross collector area— see **area, gross collector.**

heat-actuated cooling—the use of thermal energy to initiate a thermodynamic cycle which results in a local decrease in temperature. pyrheliometer, primary standard—see **primary standard pyrheliomers**.

heat capacity—see **thermal capacity.** pyrheliometer, reference—see **reference pyrheliometer**.

pyrheliometer, secondary standard—see **secondary standard pyrheliometer**.

pyrheliometer, self-calibrating absolute cavity—see **self-calibrating absolute cavity pyrheliometer**

heat loss rate—the rate at which heat is lost from a system or component of a system, per degree temperature difference between its average temperature and the average ambient air temperature. pyrheliometer, secondary reference, *n*—a pyrheliometer essentially meeting the World Meteorological Organization (WMO) "High Quality" specifications as described in WMO-No. 8, but not having self-calibrating capability.

heat transfer fluid—(*1*) *in solar energy systems*, a liquid or gas that passes through the solar collector and carries the absorbed thermal energy away from the collector. (*2*) any fluid that is used to transfer thermal energy between subsystems in solar energy systems. pyrradiometer, spherical, (*n*—instrument for measuring total flux incident from a 4π sr solid angle onto a spherical surface.

heliostat—a reflector that is mechanically moved so that solar flux is reflected in a constant direction to a stationary receiver or target. radiometer, *n*—a general class of instruments designed to detect and measure radiant energy. $\qquad$ **G113**

hemispherical, 2 π—over an entire hemisphere. It is assumed that the incident radiance is uniform in density over the hemisphere. radiometer, broad-band, *n*—a relative term generally applied to radiometers with interference filters or cut-on/cut-off filter pairs having a FWHM between 20 and 70 nm and with tolerances in center (peak) wavelength and FWHM no greater than ±2 nm.
$\qquad\qquad$ **G130**

illuminance—luminous irradiance. radiometer, narrow-band, *n*—a relative term generally applied to radiometers with interference filters with FWHM ≤ 20 nm and with tolerances in center (peak) wavelength and FWHM no greater than ±2 nm. $\quad$ **G130**

radiometer, wide-band, *n*—a relative term generally applied to radiometers with combinations of cut-off and cut-on filters with FWHM greater than 70 nm. $\qquad$ **G130**

radiometry, *n*—measurement of the quantities associated with radiation. $\qquad$ **E349**

reference pyrheliometer, *n*—pyrheliometers of any category serving as a reference in calibration transfer procedures. They are selected and well-tested instruments (see Table 2 of ISO 9060), that have a low rate of yearly change in responsivity. The reference pyrheliometer may be of the same type, class, and manufacturer as the field radiometers in which case it is specially chosen for calibration transfer purposes and is termed a secondary standard pyrheliometer (see ISO 9060), or it may be of the self-calibrating cavity type (see **self-calibrating absolute cavity pyrheliometer**). $\qquad$ **E816**

reflectometer, *n*—an instrument for the measurement of quantities pertaining to reflection. $\qquad$ **E349**

refractometer, *n*—an optical instrument used to measure the index of refraction of an unknown sample.

roll-wave gauge, *n*—instrument used to monitor and quantify roller wave surface distortion, typically present in thermally tempered flat glass processed in a horizontal roller-hearth tempering furnace. $\qquad$ **C1651**

secondary standard pyrheliometer, *n*—pyrheliometers of high precision and stability whose calibration factors are derived from primary standard pyrheliometers. This group comprises absolute cavity pyrheliometers that do not fulfill the requirements of a primary standard pyrheliometer.
$\qquad\qquad$ **E816**

self-calibrating absolute cavity pyrheliometer, *n*—a radiometer consisting of either a single- or dual-conical heated cavity that, during the self-calibration mode, displays the power required to produce a thermopile reference signal that is identical to the sampling signal obtained when viewing the sun with an open aperture. The reference signal is produced by the thermopile in response to the cavity irradiance resulting from heat supplied by a cavity heater with the aperture closed. $\qquad$ **E816**

spectrophotometer, *n*—instrument for measuring the ratio of two spectral radiometric qualities. $\qquad$ **E349**

spectroradiometer, *n*—an instrument for measuring the radiant energy of a light source at each wavelength throughout the

spectrum. **G138**

incident angle—see **angle of incidence.** strain viewer—see **polariscope**.

in-service conditions—the normal conditions to which a system and its components will be exposed during their operational lifetimes. This does not include stagnation conditions; see **stagnation conditions.** sunphotometer, *n*—a narrow-band radiometer (see **radiometer, narrow-band**) that measures relative direct solar intensity at a number of discrete wavelengths that are selected for determination of atmospheric optical depths due to constituents, especially aerosol scattering and molecular absorption by water vapor and ozone.

insolation—the use of the term *insolation* is discouraged in favor of the preferred term, **solar irradiance.** sun radiometer—see **sunphotometer**.

World Radiometric Reference, *WRR,* *n*—the mean of a selected group of at least four World Metrological Organization (WMO) self calibrating absolute cavity pyrheliometers maintained at the World Radiation Center, Physical Meteorological Organization, Davos (WRC/PMOD) at Davos, Switzerland. The WRR is accepted as representing the physical units of total solar irradiance with an uncertainty of 0.3 % and a confidence of 99 %.

DISCUSSION—As of 1970 the WRR replaced the "International Pyrheliometric Scale of 1956, IPS56", the "Smithsonian Pyrheliometric Scale of 1913, SI13" and the "Angstrom Scale of 1905, A05", as follows: WRR/IPS56 = 1.026, WRR/SI13 = 0.977, and WRR/A05 = 1.026. See WMO-No. 8, Section 7.1.2.2.

SOLAR ENERGY – GENERAL

absorber, *n*—that part of a solar collector whose primary function is to absorb radiant energy and transform it into another form of energy.

DISCUSSION—A thermal absorber usually possesses a solid surface through which energy is transmitted by thermal conduction to the transfer fluid; however, the transfer fluid itself can be the absorber in the case of an optically transparent container and a "black liquid". A photovoltaic absorber converts part of the incident solar flux into electrical energy, and part to thermal energy.

instantaneous collector efficiency—see **efficiency, instantaneous collector.** albedo—discouraged in favor of the preferred term, **reflectance**.

international phyrheliometric scale—pyrheliometric scale decreed as being in operation from July 1, 1957, in order to meet an urgent need for a single international scale. altazimuthal mount, *n*—a supporting device that facilitates tracking of the sun and allows rotation about horizontal and vertical axes. It can be used to aim equipment such as heliostats, concentrating collectors, exposure specimens, or radiometers.

irradiation—(*1*) process of exposing a surface or material to radiant flux; (*2*) at a point on surface, see **radiant exposure.** apparent solar time, *apt*[h], *n*—the hours of the day (i.e. time) as computed from the position of the sun (see **solar noon**).

isohel—curve on a map showing areas of equal sunshine duration during a given interval of time, normally a year. auxiliary energy subsystem, *n*—*in solar energy applications*, equipment using nonsolar energy sources to supplement or backup the output provided by a solar energy system.

isopleth—a line on a chart or graph connecting points having a specified constant value of a single variable as a function of two other specified variables. cloud cover, *n*—that portion of the sky which is covered by clouds, usually expressed in tenths of sky covered.

isotropic radiant energy—see **radiant energy, isotropic** collector cover (glazings)—see **cover plate, collector**.

collector, concentrating, *n*—a solar collector that uses reflectors, lenses, or other optical elements to redirect and focus the solar irradiance on the collector aperture onto an absorber of which the surface area is smaller than the collector aperture area.

collector, flat plate, *n*—a nonconcentrating solar collector in which the absorbing surface is essentially planar.

collector, line-focus, *n*—a concentrating solar collector that concentrates the solar flux in one dimension only.

collector, point focus, *n*—a concentrating collector that focuses the solar flux to a point, i.e. in two dimensions.

line-focus collection—see **collector, line-focus.** concentration ratio—see **concentration ratio, geometric** and **concentration ratio, photovoltaic**.

luminous (photometric) concentration ratio, geometric, *n*—*referring to a radiometric quantity*, indicates the weighted average of the spectral radiometric quantity, with the photopic spectral luminous efficiency function given in Annex A1 of Practice E971 being the weighting function. of a concentrating solar thermal collector, the ratio of the collector aperture area to the absorber area.

concentration ratio, photovoltaic, *n*—the total irradiance at the front surface of a concentrator cell divided by $1000\ W \cdot m^{-2}$.

natural convection—see **convection, natural.** concentrating collector—see **collector, concentrating**.

natural-type environment—in solar energy applications, the natural aspects of the outdoor exposure environment elements (or simulation), including changes with time, that may affect the thermal performance of a collector through degradation of collector materials or physical damage to the collector configuration. (Typical aspects include radiant exposure, ambient temperature, and rain impingement.) concentrator, *n*—an optical device (lenses or mirrors) that, as part of a solar collector, receives the unconcentrated solar irradiance over a large area aperture and redirects and focuses (concentrates) it to a smaller area (the receiver).

natural weathering—long-term exposure of materials to unconcentrated sunlight on fixed-angle (or seasonally adjusted) racks,

the purpose of which is to assess the effects of environmental factors in various functional and decorative parameters of interest. cover plate, collector, *n*—a sheet of transparent (or translucent) glazing placed above the absorber in a solar collector, to provide thermal and environmental protection.

nonoperational mode—the condition that exists when a solar collector has been filled, purged of heat transfer fluid (if a liquid), and capped (but not sealed) to prevent contamination by foreign substances prior to exposure. design life, *n*—the period of time during which a system or component is expected to perform its intended function, without significant degradation of performance and without requiring major maintenance or replacement.

nonselective surface—a surface for which the spectral optical properties reflectance, absorptance, transmittance, and emittance are essentially independent of wavelength over a particular wavelength range.

Note 9—For solar absorbers, the absorption of solar energy is largely confined to the wavelength range from 0.3 to 3.0 μm, but there is significant flux emitted at wavelengths out to about 30 μm. direct radiation, *n*—radiation received from a small solid angle centered on the sun's disk, on a given plane (see ISO 9060). That component of sunlight is the beam between an observer, or instrument, and the sun within a solid conical angle centered on the sun's disk and having a total included planar field angle of 5 to 6° (see also Test Method E816).

direct beam radiation—see **direct radiation**.

direct solar radiation—see **direct radiation**.

normal, ⊥—directional in a direction normal (perpendicular) to a surface. equatorial mount, *n*—a sun-tracking mount, usually clock-driven, whose axis of rotation is parallel to that of the earth's axis of rotation.

operating conditions, extreme—unusual physical conditions to which a component or system may be exposed and for which it is not designed or intended to withstand, nor is it required to withstand by a local regulatory agency. exposure racks, at-latitude, *n*—racks that hold specimens at an inclination angle equal to the latitude of the rack location, facing the equator.

operating conditions, normal—the usual range of physical conditions (for example, temperature, pressure, wear and tear, weather) for which the component or system was designed. Fresnel lens, circular, *n*—a sheet of transparent material into which concentric grooves have been formed in such a pattern that light will be focused as with a lens. (Focusing mirrors of similar design are also available.)

outgassing—the process by which materials expel gases. Fresnel lens, linear, *n*—a sheet of transparent material into which parallel grooves have been formed in such a pattern that light will be focused as by a cylindrical lens. (Focusing mirrors of similar design are also available.)

Fresnel-reflector system, *n*—flat mirrors arranged in an array such that they reflect onto a target, the illuminated area of which simulates the shape and size of the flat mirror. (Such an array simulates the ray-tracing of a parabolic trough of the same aperture angle.)

heliostat, *n*—a reflector that is mechanically positioned so that solar flux is reflected onto a stationary receiver or target.

in-service conditions, *n*—the normal conditions to which a system and its components will be exposed during their operational lifetimes. This does not include stagnation conditions; see **stagnation conditions.**

period system efficiency— see **efficiency, period system.** insolation—discouraged in favor of the preferred term, **solar irradiance.**

Discussion—Insolation is sometimes used as a synonym for **radiant exposure**, with units of J·m^{-2} or the non-SI equivlaent kWh·m^{-2}. This usage is also discouraged.

isohel, MJ·m^{-2}·year $^{-1}$**,** *n*—a line on a map connecting points that receive equal amounts of solar radiation over a period of one year.

isopleth, *n*—a line on a chart or graph connecting points having a specified constant value of a single variable as a function of two other specified variables.

point focus collector— see line-focus collector—see **collector, line-focus**.

natural-type environment, *n*—*in solar energy applications*, the natural aspects of the outdoor exposure elements (or simulation), including changes with time, that may affect the performance of a collector through degradation of collector materials or physical damage to the collector configuration. Typical aspects include radiant exposure, ambient temperature, and rain impingement.

natural weathering, *n*—outdoor exposure of materials to unconcentrated sunlight, the purpose of which is to assess the effects of environmental factors on various functional and decorative parameters of interest.   **G113**

operating conditions, extreme, *n*—unusual physical conditions to which a component or system may be exposed and for which it is not designed or intended to withstand, nor is it required to withstand by a local regulatory agency.

operating conditions, normal, *n*—the usual range of physical conditions (for example, temperature, pressure, wear and tear, weather) for which the component or system was designed.

point focus collector—see **collector, point focus**

receiver, *n*—*in solar energy systems*, that part of the solar collector to which solar irradiance is finally directed or redirected, and includes the absorber and any associated glazings through which the redirected energy must pass.

shading—see **shadowing**.

polarization—for plane polarized beams the plane of polarization is taken as the electric vector. For elliptically or partially polarized beams, polarization must be handled by use of the Stokes parameters, which is rather complex and must be handled in the text. The direction of polarization of a plane polarized beam is taken as the angle between the plane of polarization and the plane of incidence or of reflection or transmission. For other than parallel or perpendicular polarization, the subject is most