Designation: G201 – 16

Standard Practice for Conducting Exposures in Outdoor Glass-Covered Exposure Apparatus with Air Circulation[1]

This standard is issued under the fixed designation G201; 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 practice covers the basic principles and operating procedures for using outdoor glass-covered exposure apparatus with air circulation. This practice is limited to the procedures for obtaining, measuring and controlling conditions of exposure. A number of exposure procedures are listed in Appendix X1; however, this practice does not specify the exposure conditions best suited for the material to be tested.

1.2 For direct weathering exposures, refer to Practice G7. For exposures behind glass without air circulation, refer to Practice G24.

1.3 Test specimens are exposed to solar radiation filtered through glass under partially controlled environmental test conditions. Different glass types and operating parameters are described.

1.4 Specimen preparation and evaluation of the results are covered in ASTM methods or specifications for specific materials. More specific information for determining the change in properties after exposure and reporting these results is described in Practices D5870, D2244 and Test Method D523.

1.5 The values stated in SI units are to be regarded as standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D523 Test Method for Specular Gloss

D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

D5870 Practice for Calculating Property Retention Index of Plastics

E903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres

E1084 Test Method for Solar Transmittance (Terrestrial) of Sheet Materials Using Sunlight

G7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

G24 Practice for Conducting Exposures to Daylight Filtered Through Glass

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

G141 Guide for Addressing Variability in Exposure Testing of Nonmetallic Materials

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

G177 Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface

G179 Specification for Metal Black Panel and White Panel Temperature Devices for Natural Weathering Tests

G183 Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers

2.2 *Other Document:*[3]

WMO No. 8 Guide to Meteorological Instruments and Methods of Observation, Fifth Edition

GM 9538P Weathering Exposure Tests for Interior Trims

2.3 *ISO Standard:*[4]

ISO 9060 Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

3. Terminology

3.1 The definitions given in Terminology G113 are applicable to this practice.

[1] This practice is under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.02 on Natural and Environmental Exposure Tests.

Current edition approved Feb. 1, 2016. Published February 2016. Originally approved in 2009. Last previous edition approved in 2009 as G201 – 09. DOI: 10.1520/G0201-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from World Meteorological Organization (WMO), 7bis, avenue de la Paix, Case postale 2300, CH-1211 Geneva 2, Switzerland, http://www.wmo.int.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

3.2 *Other Definitions:*

3.2.1 *limit temperature, n*—For enclosures operated in temperature control mode, the specified black panel temperature at which the circulating fan switches on in order to prevent or minimize black panel temperature readings above the set temperature.

4. Summary of Practices

4.1 Specimens are exposed to light, moisture (in the form of humidity) and heat in an outdoor glass-covered enclosure with air circulation.

4.2 The exposure conditions may be varied by selection of:

4.2.1 Glass Type:

4.2.2 Operation of the circulating fan (whether constantly on during daylight hours or only on when a specific limit temperature is reached).

4.2.3 Temperature level at which the fan operates.

4.2.4 Orientation of the test fixture.

5. Significance and Use

5.1 As with any accelerated test, the increase in rate of weathering compared to in-service exposure is material dependent. Results from exposures conducted to this practice may provide good rank correlation to results from actual use conditions for one type of material or product. It should not be assumed that this will be true for other materials or products. It is always best to verify the ability of an accelerated exposure test to properly rank the durability of materials with actual use conditions. Guide G141 provides information about using rank correlation.

5.2 Variation in results may be expected when operating conditions are varied within the accepted limits of this practice. Therefore, no reference shall be made to results from the use of this practice unless accompanied by a report detailing the specific operating conditions in conformance with Report Section 8.

5.3 The durability of materials in outdoor use can be very different depending on the location of the exposure because of differences in solar radiation, moisture, heat, pollutants, and other factors. Therefore, it cannot be assumed that results from exposure in a single location will be useful for determining durability ranking of materials in a different location.

5.4 It is strongly recommended that at least one control material be exposed with each test. The control material should be of similar composition and construction and be chosen so that its failure modes are the same as that of the material being tested. It is preferable to use two control materials, one with relatively good durability, and one with relatively poor durability. If control materials are included as part of the test, they shall be used for the purpose of comparing the performance of the test materials relative to the controls.

6. Apparatus

6.1 *Enclosure:*

6.1.1 Exposures shall be conducted in a glass-covered enclosure of any convenient size (see Fig. 1). The enclosure shall be constructed of a corrosion-resistant metal, such as anodized aluminum or stainless steel, and be designed to prevent outside air from circulating over specimens. Optionally, vents covered with air filter material may be installed in the bottom of the test fixture if required to limit the black panel temperature to a specified maximum. Typical enclosure sizes are about 1.8 m wide by 0.9 m high by 0.7 m deep (6 ft wide by 3 ft high by 2.3 ft deep). Other sizes may be used. Additional construction information can be found in GM 9538P.

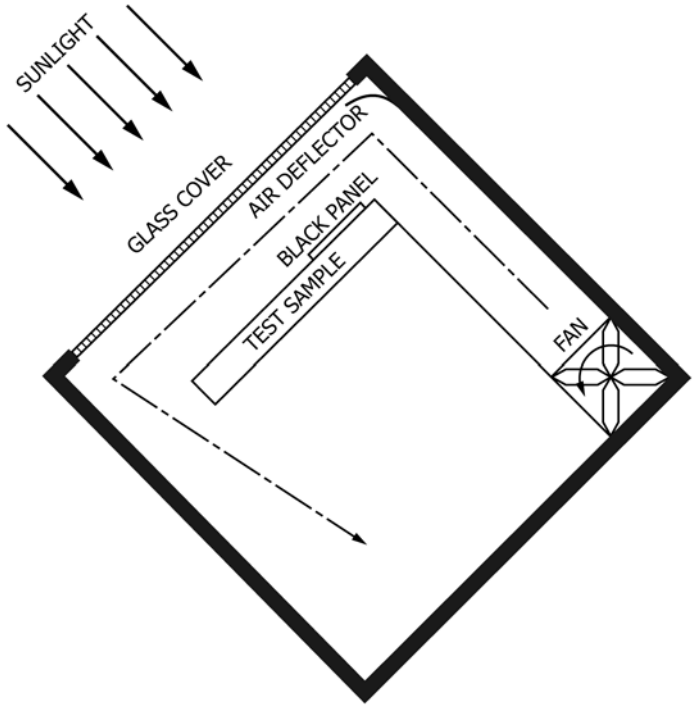
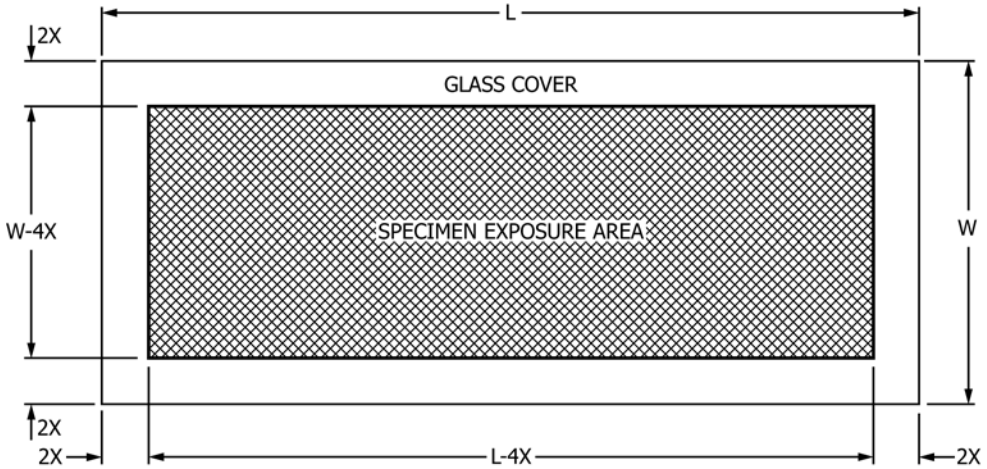


FIG. 1 Diagram of Typical Enclosure with Air Circulation

6.1.2 The enclosure shall be located where it will receive solar radiation throughout the day with no shadow on any specimen when the sun's angle of elevation is greater than 20 degrees. When the enclosure is installed over grass, the distance between the bottom of the enclosure and the ground shall be sufficient to prevent contact with plant growth, or to minimize damage that might occur during maintenance.

6.1.3 The enclosure shall be equipped with a rack which supports the specimens in a plane parallel to the glass. Alternately, the specimens can be mounted in an in-service position. Unless otherwise specified, the distance between the exposed surface of flat specimens shall be 75 ± 25 mm from the back surface of the glass cover.

6.1.4 Formed specimens with irregular dimensions may require custom mounting with varying distances from the glass cover. In such cases, mount the test specimen surface of major interest parallel to the glass cover at a distance of 75 ± 25 mm from the glass cover. The mounting frame or plate shall be constructed of a material that is compatible with the test specimens. In order to minimize shadowing from the top and sides of the enclosure, keep specimens away from each edge by a distance of at least twice the difference between specimens and glass as shown in Fig. 2. The effective width of the specimen mounting area is L-4X and the effective height of the



Legend: L = length of glass cover; W = width of glass cover; X = distance between glass cover and specimens

FIG. 2 Sample Exposure Area Diagram

mounting area is W-4X, where L is the width of the glass cover, W is the height of the glass cover, and X is the distance between the glass cover and the specimens. For example, if the specimens are 75 mm below the glass, then all specimens shall be at least 150 mm from the top, bottom, and sides.

6.1.5 The enclosure shall be capable of being oriented in a manner mutually agreed upon between interested parties. The test report shall contain the orientation used. Possible exposure orientations are:

6.1.5.1 Fixed tilt angle, typically in the range of 5 to 45 degrees, with cabinet facing equator.

6.1.5.2 Fixed tilt angle, typically 51 degrees, with tracking in rotation (azimuth).

6.1.5.3 Tracking azimuth and elevation in order to maintain the exposure plane normal to the sun's direct beam.

6.1.5.4 Any other angle that is mutually agreed on by all interested parties may be used. In some instances, exposures facing directly away from the equator or some other specific direction may be desired.

6.2 *Glass Cover:*

6.2.1 The glass cover shall be flat glass of one of the following types:

6.2.1.1 *Clear Tempered Glass*—The glass cover shall be non-laminated, tempered, clear flat glass having a nominal thickness of 3 to 4 mm. The glass thickness used shall be included in the test report.

6.2.1.2 *Clear Laminated Glass*—The glass cover shall be laminated, clear flat glass having a nominal thickness of 5.8 mm and containing a PVB (polyvinyl butyral) inner layer with an approximate thickness of 0.76 mm (0.030 in.). This type of glass is typically used in automotive applications.

6.2.1.3 Any other glass type as agreed upon between interested parties.

6.2.2 Wash the exterior and interior surfaces of the glass cover every month (or more frequently, if required) to remove dust particles and other undesirable material.

6.2.3 It is recommended that the spectral transmittance of representative glass samples be measured. If transmittance is measured, report the average for at least three representative pieces of the lot of glass being used. Follow the instructions of the UV-visible spectrophotometer used for measurement of the glass. If a spectrophotometer with an integrating sphere is used, the measurements shall be performed in accordance with Test Method E903.

6.3 *Black Panel Thermometer:*

6.3.1 For enclosures with a temperature-controlled circulating fan, one of the following black panel thermometer types shall be installed in the enclosure:

6.3.1.1 *Automotive Black Panel*—The black panel thermometer shall be constructed of 0.60 ± 0.06 mm (24 gauge) sheet steel with dimensions of approximately 100 by 125 mm (4 by 5 in.). The exposed surface of the black panel shall be primed and painted with black high heat spray paint.

6.3.1.2 *Specification G179 Black Panel*—The black panel thermometer shall be constructed in accordance with the requirements of Specification G179 with dimensions of approximately 100 by 125 mm (4 by 5 in.).

6.3.1.3 The type of black panel thermometer used shall be described in the test report. Regardless of which type of black panel is used, the black panel is exposed parallel to the glass at the same respective depth from the surface of the glass as the exposed surface of the test specimen. The panel must be mounted on 13 mm (½ in.) thick plywood, painted black, whose dimensions are at least 110 by 135 mm (4⅜ by 5⅜ in.) with a machined recess to allow space for the temperature sensor, thermocouple and their respective lead wires attached to the back of the black panel. The black panel must be fastened to the plywood with small screws near the corners of the panel. The black panel assembly shall be mounted in the plane of the test samples near the top edge of the sample mounting area no closer than 200 mm from the left or right edge of the glass cover as shown in Fig. 3.

6.4 *Circulating Fan:*

6.4.1 The test enclosure shall be equipped with a circulating fan which directs air between the top surface of specimens and the glass cover. This fan can be set to operate continuously during daylight hours, or based on the temperature reading

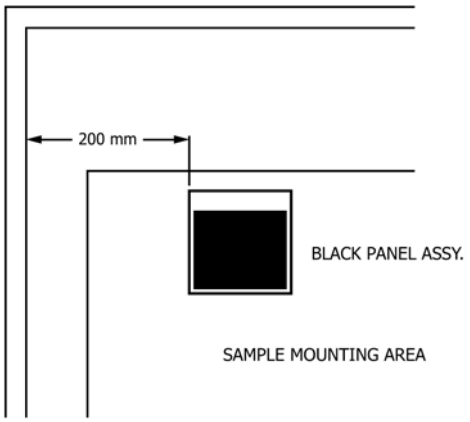


FIG. 3 Black Panel Location

from a black panel thermometer. The circulating fan shall be of sufficient air flow to maintain the desired black panel temperature. Unless otherwise specified, when the circulating fan is switched off and on based on the temperature of a black panel thermometer, set the controller to turn on at the desired limit temperature and off at a temperature that is 3°C less than the limit temperature.

6.5 *Over Temperature Protection:*

6.5.1 Unless otherwise specified, test enclosures shall be equipped with over temperature protection to prevent specimen overheating in the event of a fan failure. The over temperature protection shall be set to operate at a temperature no greater than 6°C above the limit temperature. The over temperature protection shall cover the test enclosure or change the enclosure orientation in order to prevent damage to specimens being exposed.

6.6 *Climatological Instruments:*

6.6.1 Within 1000 m of test enclosures shall be an area designated for measuring climatological conditions such as ambient temperature, relative humidity, and solar radiation.

6.6.2 Optionally, ambient air temperature and relative humidity can be measured in a shielded, elevated location.

6.6.3 *Solar Radiation:*

6.6.3.1 Instrumental means of measuring full-spectrum solar radiant exposure shall consist of a pyranometer connected to an integrating device to indicate the total energy received over a given period. The pyranometer shall be sensitive to solar radiation received at a geometry similar to that over which solar radiation is received by the test specimens. The pyranometer shall meet the requirements of an ISO 9060 Second Class instrument or better. The pyranometer shall be calibrated and operated in accordance with requirements in Practice G183.

6.6.3.2 Instrumental means of measuring solar radiant exposure in specific wavelength regions (such as all or a portion of the ultraviolet spectrum) shall consist of a wavelength-band specific global irradiance radiometer connected to an integrating device to indicate the energy received in a specified wavelength band over a given period (optional). The radiometer shall be calibrated and operated in accordance with requirements in Practice G183.

7. Procedure

7.1 Select the test conditions for exposure using conditions listed in Appendix X1, or any other condition agreed upon by interested parties.

7.2 If the enclosure is operated in temperature control mode, set the controller to the specified limit temperature.

7.3 Optionally, perform initial measurements on specimens prior to exposure using any agreed upon test method.

7.4 It is strongly recommended that at least three replicate specimens be used to allow for statistical evaluation of results. If only one specimen is available, it is recommended to make at least three measurements in different locations if possible. Mount test specimens in the test enclosure. For specimens that come in direct contact with plywood, it is recommended that plywood be covered with white card stock to shield specimens from exudation from plywood.

7.5 If test enclosures are used in tracking mode, set the enclosures to follow the sun between sunrise and sunset. If the circulating fan is set to non temperature control mode, the fan shall be switched on at sunrise and switched off at sunset. Other start and stop times may be used for daylight operations. If the circulating fan is set to a specified limit temperature, the control can be set to operate 24 hours per day, or while enclosures are following the sun.

7.6 Expose the test specimens and control specimens in the glass-covered test enclosure continuously 24 hours a day and remove from the cabinet only for inspection, return of specimens, or to protect specimens from possible damage during severe weather events.

7.7 For proper operation of the over temperature protection system and circulating fan, measure the black panel temperature in the test enclosure at least every 10 seconds. For calculation of TNR radiation, record black panel temperature at least every 5 minutes.

7.8 Optionally, measure and record daily the maximum, minimum, and average air temperature and relative humidity in the vicinity of the test enclosure.

7.9 Remove the test specimens and control specimens, if used, from the enclosure based on one of the following:

7.9.1 *Amount of Solar Radiant Exposure*—Expose the test specimens for a specified solar radiant exposure dose, either total (all wavelengths) or a selected wavelength band.

7.9.2 *Amount of Temperature Normalized Solar Radiant Exposure*—Expose the test specimens for a specified temperature normalized solar radiant exposure dose, measured using total solar radiation (all wavelengths) or solar radiation measured in a selected wavelength band.

7.9.3 *Predetermined Property Change*—Expose the test specimens (and any specified control specimen, if used) until a specified amount of property change has occurred in either the test materials or control specimens.

7.9.4 *Duration of Exposure*—Expose the test specimens for a specified time period.

7.9.5 *Any Other Specified Environmental Parameter.*

7.10 Two methods can be used to determine solar radiant exposure under glass. Only record solar radiation while the instruments are in operation.

7.10.1 *Under Glass Measurement Method*—Mounting the pyranometer under the glass produces a direct measurement of solar radiant exposure under glass, R_{UG}. The pyranometer or UV-radiometer shall be mounted under glass having the characteristics specified in 6.2.1. The glass shall be mounted parallel to the surface of the pyranometer or UV-radiometer sensor, 75 ± 10 mm above it, and at the same orientation (tilt angle) as the glass cover and test specimens as specified in 6.1.5. For fixed tilt exposures without rotation, the glass shall be at least 600 by 600 mm in size. For tracking exposures, the glass cover shall be at least 375 by 375 mm in size.

7.10.2 *Under Glass Calculation Method*—Mounting the pyranometer outside the enclosure produces a measurement of solar radiant exposure without glass (unfiltered), R_S. The transmission (τ) of the glass is applied after measurement to obtain R_{UG}. The pyranometer or UV-radiometer shall be mounted outside the enclosure at the same orientation as specimens being tested. The radiant exposure shall be calculated using the following equation:

$$R_{UG} = R_S \times \tau \quad (1)$$

where:

R_{UG} = solar radiant exposure under glass
R_S = solar radiant exposure outside the enclosure
τ = glass solar transmittance

The glass solar transmittance shall be determined using Test Methods E903 or E1084. Test Method E903 is a method for calculating the solar transmittance of the glass based on spectrophotometer measurements. Test Method E1084 is a method for directly measuring the solar transmittance of the glass using the sun as the source and a pyranometer as the sensor. Regardless of the method chosen, it shall be performed on at least three pieces of glass representative of the glass used in the exposure field. If Test Method E903 is used, the calculated solar transmittance for the above equation shall be based on the spectral irradiance distributions in TablesG177 for UV only or Tables G173 for total solar. If Test Method E1084 is used, the pyranometer or UV-radiometer used to determine the glass solar transmittance must be of the same type and wavelength sensitivity as the pyranometer or UV-radiometer used to determine radiant exposure. The glass used for glass solar transmittance measurements, whether the latter is based on Test Methods E903 or E1084, shall be pre-exposed for 3 months under the same conditions as the glass used for the exposures.

NOTE 1—The two methods of determining solar radiation under glass in 7.10.1 and 7.10.2, that is, by measurement and by calculation, may not provide identical results.

7.10.3 The transmittance of the glass can also be determined based on spectrophotometer measurements using Test Method E903 (1996). If spectrophotometer measurements are used, the measurements shall be performed on three representative pieces of glass. The calculated solar transmittance for Eq 1 shall be based on the spectral irradiance distributions in Tables G177 of UV only or in Tables G173 for total solar radiation.

7.11 *Determination of Temperature Normalized Radiation (TNR)*—This calculation is typically used in automotive applications. Determine temperature normalized radiation using the following equations:

$$TNR_i = R_{UGi} e^{13.643 - \left[\frac{5000}{T_i + 273.15}\right]} \quad (2)$$

$$TNR = \sum_{start}^{end} TNR_i \quad (3)$$

where:

TNR_i = Temperature Normalized Radiation calculated for a specific calculation period (expressed in TNR MJ/m^2) using measurements of irradiance and temperature. The calculation period used for determining TNR_i shall be one hour or less.
R_{UGi} = Solar radiant exposure under glass (MJ/m^2). Unless otherwise specified, R_{UGi} shall be the accumulated solar radiant exposure during the calculation period based on measurements performed at least every 5 min.
T_i = Temperature (°C) of the black panel placed in the enclosure. Unless otherwise specified, T_i shall be the average of temperature measurements during the calculation period, based on measurements performed at least every 5 min.
TNR = Temperature Normalized Radiation for the duration of the exposure test (expressed in TNR MJ/m^2). TNR is the summation of TNR_i over the time of the exposure test.
Start = beginning of the exposure test.
End = end of the exposure test.

NOTE 2—Langleys (g-cal/cm^2) is a non SI metric term for measuring radiant exposure. The preferred units for measuring solar radiant exposure are J/m^2.

7.12 *Sample Calculation for Temperature Normalized Radiation*—Table 1 presents data from a 1 hr. period to show the calculation of temperature normalized radiation based on TNR calculation interval of 5 min. The columns in this table are as follows:

(1) Date and Time

(2) Solar Radiant Exposure under glass for the incremental 5-min period

(3) Black panel temperature measured during the incremental 5-min period

(4) Calculated Temperature Normalized Radiation for the 5-min period using Eq 2 and 3 in 7.11

7.12.1 For the first line in this table, the following represents a calculation of the temperature-normalized radiation:

$$TNR_i = (0.0267) e^{13.643 - \left[\frac{5000}{100.3 + 273.15}\right]} \quad (4)$$

$$TNR_i = 0.344 \quad (5)$$

7.13 Optionally, perform final measurements using any agreed upon test method. It is recommended if only one specimen, take three measurements. Take measurements at the same location as initial measurements.

8. Report

8.1 The report shall include the following:

TABLE 1 Sample TNR Calculation Table

Date and Time (1)	R_i (MJ/m^2) (2)	T_i (°C) (3)	TNR_i (MJ/m^2 (4)
9/22/2008 1:05 pm	0.267	100.3	0.344
9/22/2008 1:10 pm	0.268	100.3	0.346
9/22/2008 1:15 pm	0.268	100.4	0.347
9/22/2008 1:20 pm	0.269	100.4	0.348
9/22/2008 1:25 pm	0.270	100.3	0.348
9/22/2008 1:30 pm	0.272	100.4	0.352
9/22/2008 1:35 pm	0.271	100.4	0.351
9/22/2008 1:40 pm	0.271	100.5	0.352
9/22/2008 1:45 pm	0.271	100.3	0.349
9/22/2008 1:50 pm	0.271	100.3	0.349
9/22/2008 1:55 pm	0.271	100.3	0.349
9/22/2008 2:00 pm	0.271	100.5	0.352
Total			4.187

8.1.1 Dates and location of exposure, including the latitude of the exposure site.

8.1.2 Type and thickness of glass used for the exposure.

8.1.3 Type of black panel thermometer used for the exposure.

8.1.4 Orientation of the enclosure during the test.

8.1.5 Orientation of the specimens within the test enclosure, such as parallel to glass, at an in-service orientation.

8.1.6 Duration of exposure in terms of solar radiant exposure, temperature normalized solar radiant exposure, or elapsed time.

8.2 The Report may optionally contain the following information:

8.2.1 Applicable physical property or appearance data for each specimen obtained prior to exposure and after each exposure increment, if measured. If replicate specimens are used, report the mean and standard deviation of each property measured.

8.2.2 Methods used for measuring physical or appearance properties of test and control specimens.

8.2.3 Solar radiant exposure data expressed in SI units, and the method of measurement (Under Glass Measurement Method or Under Glass Calculation Method), if measured.

8.2.4 Maximum, minimum, and average daily temperatures, as well as cabinet air and specimen temperatures, if recorded.

8.2.5 Maximum, minimum, and average daily relative humidity, as well as cabinet humidity, if recorded

8.2.6 Any other specified environmental parameter.

8.2.7 Any variations from the specified conditions.

9. Keywords

9.1 cumulative spectral sensitivity curve; degradation; durability; exposure; light exposure; ultraviolet radiation; weathering

APPENDIX

(Nonmandatory Information)

X1. EXPOSURE CONDITIONS

X1.1 Any exposure conditions may be used, as long as the exact conditions are detailed in the report. Following are some representative exposure conditions. These are not necessarily preferred and no recommendation is implied. These conditions are provided for reference only (see Table X1.1).

TABLE X1.1 Common Exposure Conditions

Cycle	Glass Type	Max. BPT °C	Orientation (Azimuth)	Orientation (Elevation)	Operation of Circulating Fan
1	clear tempered	N/A	facing equator	5°	during daylight hours
2	clear laminated	102°C	tracking	51°	when required to maintain BPT
3	clear tempered	102°C	tracking	51°	when required to maintain BPT
4	clear tempered	93°C	tracking	51°	when required to maintain BPT
5	clear tempered	85°C	tracking	51°	when required to maintain BPT