INTERNATIONAL

Designation: ~~E2141 – 14~~ E2141 – 21

Standard Test Method for Accelerated Aging of Electrochromic Devices in Sealed Insulating Glass Units[1]

This standard is issued under the fixed designation E2141; 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 test method covers the accelerated aging of electrochromic devices (ECD) integrated in insulating glass units.

1.2 The test method is applicable for any electrochromic device incorporated into sealed insulating glass units (IGUs) fabricated for vision glass (superstrate and substrate) areas for use in buildings, such as sliding doors, windows, skylights, and exterior wall systems. The layers used for constructing the EC device and electrochromically changing the optical properties may be inorganic or organic materials.

1.3 The electrochromic (EC) glazings used in this test method are exposed ~~under use conditions to solar radiation and are deployed~~to environmental conditions, including solar radiation. They are employed to control the amount of transmitted radiation by absorption and reflection and, thus, limit the solar heat gain and amount of solar radiation that is transmitted into the building.

1.4 The test method is not applicable to other chromogenic devices, such as, photochromic and thermochromic devices which do not respond to electrical stimulus.

1.5 The test method is not applicable to electrochromic (EC) glazings that are constructed from superstrate or substrate materials other than glass.

1.6 The test method referenced herein is a laboratory test conducted under specified conditions. The test is intended to simulate and, in some cases, to also accelerate actual in-service use of the electrochromic ~~windows.~~glazing. Results from these tests cannot be used to predict the performance with time of in-service units unless actual corresponding in-service tests have been conducted and appropriate analyses have been conducted to show how performance can be predicted from the accelerated aging tests.

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

~~1.7.1 *Exception*—Inch-pound units are used 7.6.2.~~

1.8 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.22 on Durability Performance of Building Constructions.

Current edition approved ~~Dec. 1, 2014~~Oct. 15, 2021. Published ~~February 2015~~December 2021. Originally approved in 2001. Last previous edition approved in ~~2012~~2014 as ~~E2141 – 12.~~E2141 – 14. DOI: ~~10.1520/E2141-14.~~10.1520/E2141-21.

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E631 Terminology of Building Constructions
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2953 Specification for Evaluating Accelerated Aging Performance of Electrochromic Devices in Sealed Insulating Glass Units
G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
G155 Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials
G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

2.2 *ISO Standard:*[3]

ISO 9050 Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this test method related to building construction, thermal insulating materials and natural and artificial weathering tests for nonmetallic materials, refer to Terminologies E631, C168 and G113, respectively.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accelerated aging test, n*—a test in which the rate of degradation of building components or materials is intentionally increased from that expected in actual service.

3.2.2 *electrochromic device (ECD), n*—a combination of materials that include materials in which the transmittance, reflectance, and absorptance properties can be ~~altered, and other layers, such as transparent conducting oxide (TCO) layers for altering the optical properties (for example, transmittance, reflectance, absorptance) of the device,~~ altered in response to an applied electrical voltage or current.

3.2.3 *electrochromic (EC) glazing, n*—~~in a prepared opening of a building, the material installed which~~ glazing installed in a building that consists of an ECD with layer(s) of materials in which the optical properties can change in response to an applied electrical ~~field, attendant materials, and one or more lites of glass.~~field.

3.2.4 *electrochromic layer(s), n*—in an ECD, the layer(s) of material(s) in which the optical properties can change in response to application of an electrical voltage ~~and/or current.~~or current, or both.

3.2.5 *electro-optic cycling, n*—the process of applying repetitive ~~positive and negative voltages and/or currents~~ voltages or currents, or both, to an ECD for the purpose of reversibly changing the optical properties of the EC glazing from the highest to the lowest transmittance state.

3.2.6 *highest transmittance state, n*—also referred to as the clear state or bleached state, a descriptor for an EC glazing when it is in the transmittance state with the highest photopic specular light transmittance.

3.2.7 *lateral uniformity, n*—the degree of variation in the amount of irradiance in the x and y directions in the test plane used for exposing an EC glazing.

[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~~standard's Document Summary page on the ASTM website.

[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.~~ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

3.2.8 *lowest transmittance state, n*—also referred to as the tinted state, dark state or colored state, a descriptor for an EC glazing when it is in the transmittance state with the lowest photopic specular light transmittance.

3.2.9 *photopic transmittance ratio (PTR), n*—photopic transmittance ratio or PTR = τ_H/τ_L. The photopic transmittances (τ_H, τ_L) are obtained by integrating the spectra in the wavelength range of 380 to 780 nm using the spectral photopic efficiency Ip (CIE, 1924) as the weighting factor.

3.2.10 *room temperature, n*—ca ~~22°C~~22 °C.

3.2.11 *serviceability, n*—the capability of a building product, component, assembly, or construction to perform the function(s) for which it was designed and constructed.

3.2.12 *solar irradiance, n*—as related to natural weathering of materials, the irradiance of the sun incident on the earth's surface, having wavelengths between 295 nm and 4050 nm.

3.2.13 *specular (regular) transmittance, n*—the optical transmittance that does not include light with a diffuse component.

3.2.14 *switching cycle, n*—a transition in visible light transmittance through the whole or part of the EC-IGU's visible light transmittance range starting at one end of the range (at τ_H or τ_L) and ending back at the same point. For example, one switching cycle can be a transition from the highest transmittance state to the lowest transmittance state and back to the highest transmittance state, or a transition from the lowest transmittance state to the highest transmittance state and back to the lowest transmittance state.

3.2.15 *switching times T_H and T_L, n*—switching time, T_H, is the time it takes for the EC glazing to transition from its highest transmittance state over 80 % of its initial dynamic range (where dynamic range is τ_H-τ_L). Switching time (T_L) is the time it takes for the EC glazing to transition from its lowest transmittance state across 80 % of its dynamic range (where dynamic range is τ_H-τ_L).

3.3 ~~*Acronyms:*~~*Abbreviations:*

3.3.1 *AM*—air mass

3.3.2 *AWU*—accelerated weathering unit

3.3.3 *DBT*—dry-bulb temperature

3.3.4 *DPM*—digital panel meters

3.3.5 *ECD*—~~Electrochromic~~electrochromic device

3.3.6 *IG*—insulating glass

3.3.7 *IGU(s)*—insulating glass unit(s)

3.3.8 *NIR*—near-infrared (radiation)

3.3.9 *PTR*—photopic transmittance ratio

3.3.10 τ_H—specular (regular) transmittance in the *highest transmittance state*

3.3.11 τ_L—specular (regular) transmittance in the *lowest transmittance state*

3.3.12 T_H—time to switch from the highest transmittance state to a transmittance of $\tau_H - 0.8\ (\tau_H$-$\tau_L)$

3.3.13 T_L—time to switch from the lowest transmittance state to a transmittance of $\tau_L + 0.8\ (\tau_H - \tau_L)$

~~3.3.14 *TCO*—transparent conducting oxide~~

3.3.14 *UV*—ultraviolet (radiation)

4. Significance and Use

4.1 EC glazings perform a number of important functions in a building envelope including: minimizing the solar energy heat gain; providing for passive solar energy gain; controlling a variable visual connection with the outside world; enhancing human comfort (heat gain), ~~security, ventilation,~~ illumination, and glare control; and providing for architectural ~~expression, and (possibly) improving acoustical performance.~~ expression. It is therefore important to understand the relative serviceability of these glazings.

4.2 This test method is intended to provide a means for evaluating the relative serviceability of EC Glazings as described in Section 1.

4.3 The procedures in this test method include (*a*) rapid but realistic current-voltage cycling tests emphasizing the electrical properties, and (*b*) environmental test parameters that are typically used in weatherability tests by standards organizations and are realistic for the intended use of large-area EC IGUs.

5. Apparatus (See Figs. 1 and 2)

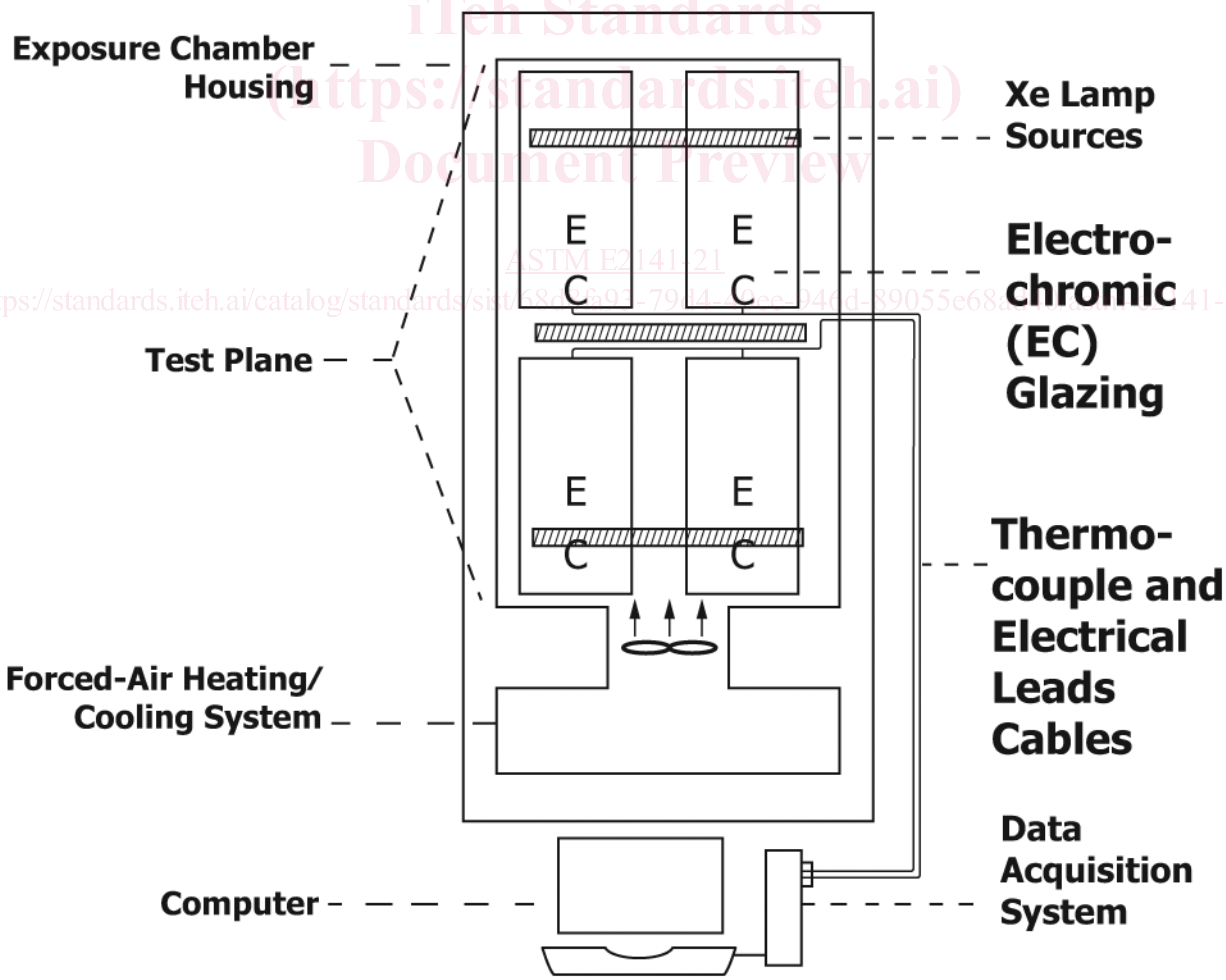

FIG. 1 Top-View Schematic Diagram of the (Essential) Components of an Environmental Test Chamber and Computer-Controlled Electrical Cycling and Data Acquisition System for Accelerated Aging of Electrochromic Glazings

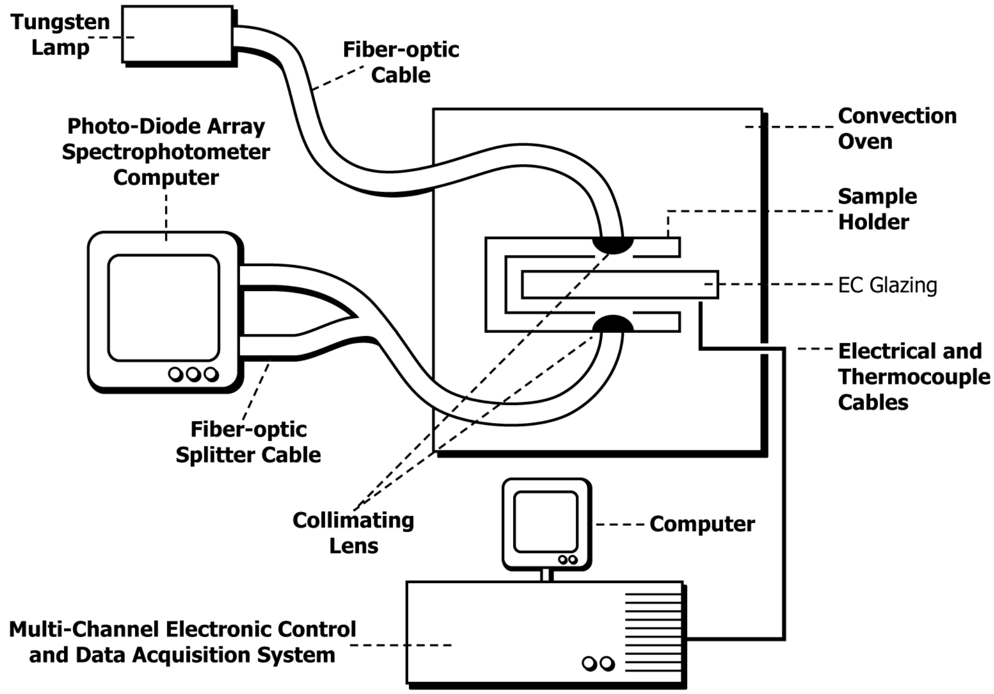

FIG. 2 Schematic of the (Essential) Elements of the Optical Measurement System Used for Recording ~~300~~300 nm to 780 nm Transmittance Spectra for a Switching Cycle of EC Glazings at Controlled Temperatures

5.1 *Accelerated Weathering Unit (AWU),* consisting of a temperature controlled chamber with properly filtered xenon-arc lamps to simulate the spectral power distribution of solar radiation over the UV/visible and NIR wavelength regions ~~(~~(Tables for Reference G173~~).~~) operated in accordance with Practice G155.

5.1.1 Fig. 1 shows a top-view schematic diagram of the essential features of the environmental test chamber including the layout of the EC IGUs on a ~~1220 by 1830 mm test plane,~~ test plane of sufficient size to accommodate testing of at least four specimens simultaneously, the location of ~~four~~sufficient xenon-arc lamps above the test ~~plane,~~ plane to deliver the specified radiation intensity, and the necessary connecting thermocouples and cables from the EC IGUs to the computer-controlled cycling and data acquisition system. Chamber dimension shall be large enough to accommodate all specimens. ~~It has been found that a chamber of size of 2400 mm high by 2650 mm deep by 4480 mm wide has been useful.~~

NOTE 1—It has been found that a chamber of size of 2400 mm high by 2650 mm deep by 4480 mm wide has been useful.

5.1.2 The test plane shall be vertically adjustable and the user shall adjust the distance from the lamps to the specimens to obtain the desired light intensity and lateral uniformity within the guidelines of this document. Temperature control within the test chamber shall be provided. Conditions inside the closed space shall be controlled for air temperatures from ~~20 to 95°C.~~ 20 °C to 95 °C ± 0.5 °C. Humidity within the test chamber shall be monitored and shall not exceed 60 %.

5.1.3 Simulated solar radiation shall be provided by spectrally ~~filtered and water-cooled 6500-W,~~ filtered, long-arc xenon arc lamps housed within a reflector system in the ceiling of the test chamber. The lamps may be water cooled. The lamps shall be suitably filtered to provide a match of an AM 1.5 solar spectrum ~~from 300 to 900 nm~~ (see Note ~~1~~2). The ~~water-cooled~~ lamps ~~are~~ may be surrounded by an NIR-absorbing filter, which reduces the heat ~~load. The EC IGU specimens are located on the vertically moveable test plane beneath the xenon arc lamps. The AWU shall have a means for allowing electrical connections to pass from inside to outside the unit to allow temperature monitoring and electrical control of the EC IGUs.~~load in the chamber and allows appropriate temperature control.

NOTE 2—At longer wavelengths, the xenon arc emission is at variance with the AM 1.5 solar ~~spectrum~~ spectrum, Tables for Reference G173, because the intensities relative to those in the UV/visible region are higher than in solar radiation. However, this part of the spectrum does not cause photolytically induced degradation.

5.1.4 The EC IGU specimens are located on the vertically moveable test plane beneath the xenon arc lamps. The AWU shall have a means for allowing electrical connections to pass from inside to outside the unit to allow temperature monitoring and electrical control of the EC IGUs.

5.2 *EC Cycling Unit,* for imposing voltage ~~and/or current cycles~~ or current cycles, or both, to alternately and repeatedly change the transmittance of the EC IGUs.

5.3 *Electrical Leads,* from the EC cycling unit in 5.2 to each EC IGU in the AWU described in 5.1.

5.4 *Computer Controlled Spectrometer,* for obtaining and storing data from the optical characterization of the specimens.

5.4.1 *Spectrometer Light Source,* a tungsten lamp or other suitable lamp source that provides illumination from ~~380~~380 nm to 780 nm.

5.4.2 *Fiber Optic Cables,* which shall be routed from the lamp source into the EC IGU specimen holder and from the EC IGU specimen holder to the spectrometer. One optical fiber guides the incident light from the lamp source to one side of the specimen; another optical fiber guides the transmitted light to the spectrometer attached to a computer. The fibers shall be optically coupled by properly aligned collimating lens assemblies attached to both the illuminating and the collection fibers.

5.5 *Computer-Controlled, Multichannel Potentiostat,* for switching to and from highest and lowest transmittance states during spectrometer transmittance measurements.

5.6 *Temperature-Controlled Oven,* capable of heating the test specimens to the selected test temperature. The oven will be used to carry out optical measurements of the EC-IGUs at the selected test temperature. It shall be large enough for the largest EC IGU to be tested and shall be able to reach the EC IGU testing temperature. The oven must also be designed to permit using the equipment in 5.4 for optical measurements while the EC IGU is maintained at the temperature chosen for testing in the AWU described in 5.1.

5.7 *Digital ~~Camera.~~Camera,* for taking photographs of the specimens.

5.8 *Video Camera and ~~Recorder.~~Recorder,* for taking videos of the specimens.

5.9 *Verified and Calibrated Thermocouples,* for use to measure specimen and chamber temperatures in the AWU and the oven.

6. Test Specimens

6.1 Test specimen size, design, and construction shall be established and specified by the manufacturer, except that the specimens shall be at least ~~250~~250 mm ± 6 mm × ~~250~~250 mm ± 6 mm.

6.2 Refer to Specification E2953 for details on specimen quantity and size.

7. Procedure[4]

7.1 *Overview*—The EC IGUs are exposed to simulated solar radiation in a temperature controlled chamber at selected specimen temperatures ranging from 70 °C to ~~105°C~~105 °C while the EC IGUs are cyclically switched between low and high transmittance states with the ability to pause during the duty cycles (see Note ~~2~~3 for further information), depending on the control strategy prescribed by the manufacturer. Accept the prevailing relative humidity in the chamber but ensure that it does not exceed 60 %. The EC IGU specimens are initially characterized optically at room temperature to determine initial performance. Then they are

~~[4] The sole source of supply of the apparatus known to the committee at this time is Atlas Material Testing Technology LLC, 4114 North Ravenswood Avenue, Chicago, IL 60613, Phone: +1-773-327-4520 | Fax: +1-773-327-5787, Email: atlas.info@ametek.com. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.~~

[4] ~~The procedure is based in part on the paper by Czanderna, A., et al., in "Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XV," Lampert, C. M.. Granqvist, C., Grätzel, M., and Deb, S. K.. eds., SPIE Vol. 3138, 68 (1997).~~The procedure is based in part on the paper by Czanderna, A., et al., in "Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XV," Lampert, C. M.. Granqvist, C., Grätzel, M., and Deb, S. K.. eds., *SPIE*, Vol. 3138, 68 (1997).

optically characterized in an oven at the selected test temperature in order to determine the time during which the specimens will be in or switching to the lowest transmittance state and the time during which the specimens will be in or switching to the highest transmittance state. This is because some EC products have temperature dependent switching times. The same equipment is used for both room and high temperature optical characterization measurements. After exposure in the AWU, the specimens are again optically characterized at room temperature as they were initially to provide after-aging EC-IGU performance data.

NOTE 3—Control duty cycle refers to the fraction of the total cycle time over which the specimen has a voltage ~~and/or current applied which~~or current, or both, applied that reduces the transmittance of the specimen. A 50 % duty cycle means that a voltage ~~and/or current which~~ or current, or both, that causes a reduction in transmittance is applied for 50 % of the total cycle time. During the remaining 50 % of the cycle time, a voltage ~~and/or current which~~ or current, or both, that causes an increase in the transmittance is applied. The applied voltages ~~and/or currents~~ or currents, or both, to increase and decrease transmittance are as specified in 7.3.4.

7.2 When received, inspect the EC IGUs ~~visually,~~ visually at room temperature, take photographs of any obvious defects or aberrations of the EC specimens in the highest transmittance state or lowest transmittance state, whichever is the unpowered state, and note and record your observations.

7.3 Carry out the initial optical characterization of the EC IGUs at room temperature:

7.3.1 Measure the optical transmittance between ~~380~~380 nm and 780 nm of all EC IGUs at room temperature in the convection oven, as shown schematically in Fig. 2.

7.3.2 The convection oven shall be allowed to equilibrate with room temperature for measurements at ca. ~~22°C.~~22 °C. The temperature of the EC IGU shall be monitored with a thermocouple (or other appropriate surface temperature probe or device) attached to the lite that contains the EC layers. The placement should be located on every sample on the center of the outer surface of the glass containing the EC layers with a ~~highly reflective tape (for example, aluminum or silver)~~ tape having an emissivity close to that of glass.

7.3.3 Measure transmittances per the spectrometer manufacturer's instructions ensuring that reference spectra for 100 % and 0 % transmittance are taken before each measurement and using at least 5 nm increments. The sample should be positioned or marked at the center of the outer surface of the lite containing the EC device such that the same spot on the sample is measured before and after exposure.

7.3.4 The magnitudes of the voltages ~~and/or currents~~ or currents, or both, used for switching the EC glazing between transmittance states, shall be applied as specified by the EC glazing manufacturer.

7.3.5 Determine the highest (τ_H) and lowest (τ_L) transmittance and the switching speed of the EC-IGUs.

7.3.5.1 The optical transmittance of the specimen shall be measured over a spectral range covering at least ~~380~~380 nm to 780 nm in successive intervals during the process of cycling between highest and lowest transmittance states. A time interval of a fraction of the total cycle time for taking each spectrum should be adequate for recording the optical properties of each EC IGU.

7.3.5.2 The photopic transmittance of the devices shall be obtained by integrating the spectra in the wavelength range of ~~380~~380 nm to 780 nm using the spectral photopic efficiency Ip (λ) (CIE, 1924) as the weighting factor.[5] The procedure for integration can be found in ISO 9050.

7.3.5.3 Allow the samples to reach their lowest transmittance and highest transmittance states during these measurements. Wait for 30 min from the start of the transition for the specimens to reach their extreme states or until the rate of change of transmittance is less than 0.4 %T per min, whichever yields the shortest time.

7.3.5.4 Plot the transmittance spectra measured during switching as a function of wavelength. Typical transmittance spectra recorded during a full switching cycle are shown in Fig. 3, in which the optical spectra of the glazings are plotted as a function of wavelength.

7.4 Use the oven and spectrometer to measure the optical transmittance as a function of time of the specimens at the selected test temperature.

[5] ~~Kingslake, R., "Applied Optics and Optical Engineering," in Vol. 1, Light: Its Generation and Modification, Academic Press, New York, NY, 1965, Table II, Chapter 1.~~Kingslake, R., *Applied Optics and Optical Engineering: Volume 1 Light: Its Generation and Modification*, Table II, Chapter 1, Academic Press, New York, NY, 1965.