INTERNATIONAL STANDARD

ISO 18543

First edition
2017-10

Glass in building — Electrochromic glazings — Accelerated ageing test and requirements

Verre dans la construction — Vitrages électrochromes — Essai de vieillissement accéléré et exigences

Reference number
ISO 18543:2017(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 160, *Glass in building*, Subcommittee SC 1, *Product considerations*.

Introduction

Electrochromic (EC) glazings perform several 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 thermal comfort (controlling heat gain), energy efficiency performance, illumination, and glare control, and

— providing for architectural expression.

Therefore, it is important to understand the relative serviceability of these glazings.

This document is intended to provide a means for evaluating the durability of electrochromic glazings.

The test procedures covered in this document includes:

a) rapid but realistic cycling between high and low light transmission states;

b) environmental parameters that are typically used in weatherability tests such as simulated solar exposure and high temperature, which are realistic for the intended use of electrochromic glazings.

Glass in building — Electrochromic glazings — Accelerated ageing test and requirements

1 Scope

This document specifies the accelerated ageing test and requirements for electrochromic (EC) glazings.

The test method described in this document is only applicable to chromogenic glazings that can be switched using an electrical stimulus from high to low transmission states and vice versa. This test method is not applicable to other chromogenic glazings such as photochromic and thermochromic glazings, which do not respond to electrical stimulus.

This test method is applicable to any electrochromic glazing fabricated for vision glass (e.g. insulating glass unit, laminated glass) for use in buildings such as doors, windows, skylights and exterior wall systems and glazing exposed to solar radiation. The layers used for constructing the EC glazing and for electrochromically changing the optical properties can be inorganic or organic materials.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9050:2003, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

ISO 12543 (all parts), *Glass in building — Laminated glass and laminated safety glass*

ISO 20492 (all parts), *Glass in buildings — Insulating glass*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
chromogenic glazing
glazing that has the ability to change its visible and/or solar transmittance in response to an external stimulus such as electrical voltage or current, sunlight or temperature

3.2
electrochromic
EC
combination of materials through which visible and/or solar transmittance characteristics can be altered in response to an applied voltage or current

3.3
electrochromic glazing
EC glazing
glazing comprised of one or more panes of glass containing materials with *electrochromic* (3.2) properties

3.4
highest transmittance state
electrochromic glazing (3.3) when it is in the transmission state with the highest visible light transmittance

Note 1 to entry: This is also referred to as the clear state or bleached state.

3.5
lowest transmittance state
electrochromic glazing (3.3) when it is in the transmission state with the lowest visible light transmittance

Note 1 to entry: This is also referred to as the tinted state, dark state or coloured state.

3.6
lateral uniformity
degree of variation in the amount of irradiance in the x and y directions in the test plane used for exposing *electrochromic glazing* (3.3)

3.7
switching time
time it takes for *electrochromic glazing* (3.3) to transition from one transmittance state to another

Note 1 to entry: The time to go from a lower transmittance state to a higher transmittance state can be different from the time needed for the reverse transition.

3.8
switching cycle
transition in light transmittance through the whole or part of the *electrochromic glazing's* (3.3) visible light transmittance range starting at one end of the range (at τ_H or τ_L) and ending back at the same point

4 Symbols and abbreviated terms

EC	electrochromic
IGU	insulating glass unit(s)
NIR	near infrared (radiation)
PTR	photopic transmittance ratio
T	transmission
$\tau_{H,i}$	visible light transmittance[a] in the highest transmission state prior to accelerated ageing
$\tau_{L,i}$	visible light transmittance[a] in the lowest transmission state prior to accelerated ageing
$\tau_{H,f}$	visible light transmittance[a] in the highest transmission state after accelerated ageing
$\tau_{L,f}$	visible light transmittance[a] in the lowest transmission state after to accelerated ageing
t_L	time during which the transmittance of the glazing is reducing
t_H	time during which the transmittance of the glazing is increasing

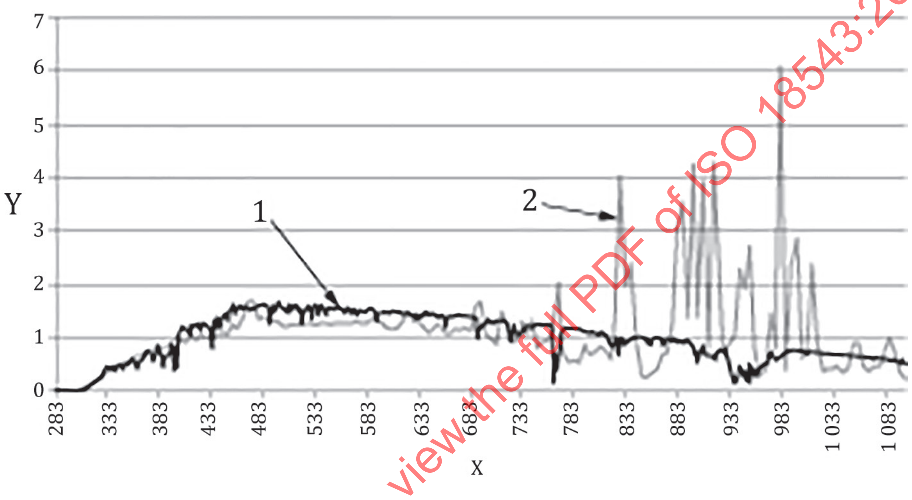
t_{cycle} total cycle time; the sum of t_L and t_H.

UV ultraviolet (radiation)

[a] See ISO 9050.

5 Test equipment

5.1 Test chamber, temperature-controlled and contains xenon arc lamps that have been filtered appropriately in order to simulate the spectral power distribution of solar radiation over the ultraviolet (UV), visible and near infrared (NIR) wavelength regions. Figure 1 shows the spectral irradiance of an appropriately filtered xenon arc source compared to the global AM 1,5 spectrum.



Key

X wavelength of the radiation in nm

Y irradiance in W/m²/nm

1 spectral power distribution of AM 1,5 solar irradiation

2 irradiance of an appropriately filtered xenon arc lamp which is used to simulate the spectral power distribution of solar radiation

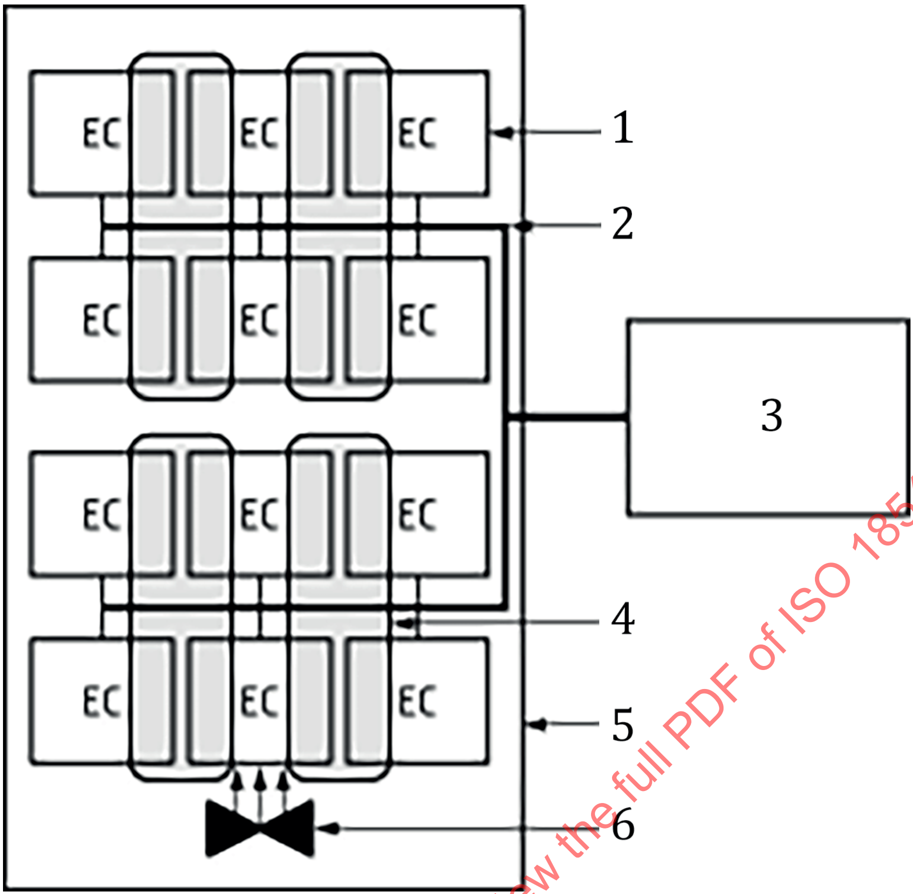
Figure 1 — Irradiance of an appropriately filtered xenon arc lamp compared to the spectral power distribution of AM 1,5 solar irradiation

NOTE 1 At longer wavelengths, the xenon arc emission is at variance with the air mass 1,5 solar spectrum 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 photolytic-induced degradation.

Figure 2 shows an example top-view of the essential features of the test chamber, including the layout of the EC glazings on a test plane, the location of the xenon arc lamps above the test plane and the necessary connecting cables from the EC glazings to the computer-controlled cycling and data acquisition system. Chamber dimension shall be large enough to accommodate all specimens.

The intensity of the irradiance at the specimens shall be adjustable to obtain the desired light intensity and lateral uniformity within the guidelines of this document.

NOTE 2 This can be achieved by adjusting the distance between the specimens and the lamps.



Key

1 EC glazings
2 electrical leads and thermocouples
3 EC cycling unit and data acquisition system
4 lamp sources
5 chamber enclosure
6 forced-air heating/cooling system

Figure 2 — Example top-view of the essential features of the environmental test chamber

Temperature control within the test chamber shall be provided. Conditions inside the closed space shall be controlled for air temperatures from 20 °C to 95 °C. The relative humidity within the test chamber shall not exceed 60 %.

Simulated solar irradiance shall be provided by the appropriate number of spectrally filtered and water-cooled 6 500 W, long-arc xenon arc lamps housed within a reflector system in the ceiling of the test chamber. The lamps shall be suitably filtered to provide a match of an air mass 1,5 solar spectrum from 300 nm to 900 nm (see Figure 1). The water-cooled lamps shall be surrounded by an NIR-absorbing filter, which reduces the heat load. The chamber shall be designed to achieve a radiation intensity over the spectral range of 300 nm to 3 000 nm of (1 000 ± 40) W/m^2 at the specimens. The lateral uniformity of irradiance across the test plane shall be no more than ±8 %. The EC glazing specimens shall be located on the test plane beneath the xenon arc lamps. The test chamber 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 glazings.

NOTE 3 A suitable lamp source and filter combination is a 3 500 W/6 500 W xenon burner (part number 20-6500-00) with an inner quartz filter (part number 20650600 and an outer filter of CIRA/Sodalime (Part Number 2065200) from Atlas®[1)].

1) CIRA and Sodalime are trade names of a product supplied by Atlas. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Thermocouples shall be used to measure specimen and chamber temperatures in the test chamber and the oven.

5.2 Electrochromic (EC) cycling unit, imposes voltage and/or current cycles to alternately and repeatedly change the transmittance of the EC glazings while in the test chamber.

NOTE The EC cycling unit can be provided by the EC glazing manufacturer.

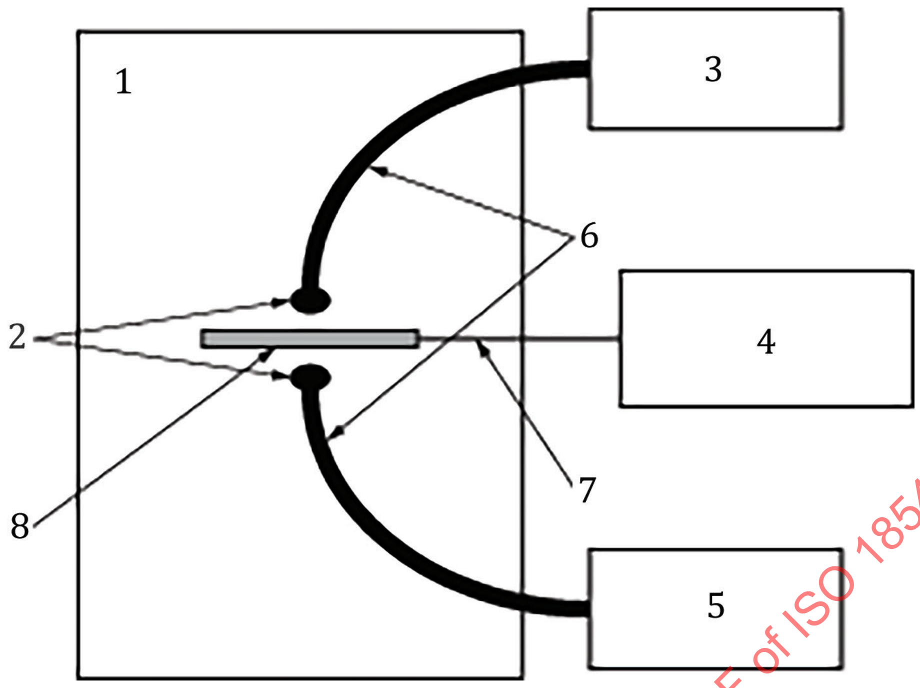
5.3 Spectrometer, used for obtaining and storing data from the optical characterization in the range 380 nm to 780 nm of the specimens in the highest and lowest transmission states.

5.3.1 Spectrometer lamp source, tungsten lamp or other lamp source that provides illumination from 380 nm to 780 nm.

5.3.2 Spectrometer fibre optic cables, routed from the lamp source into the EC glazing specimen holder and from the EC glazing specimen holder to the spectrometer. One optical fibre guides the incident light from the lamp source to one side of the specimen; another optical fibre guides the transmitted light to the spectrometer attached to a computer. The fibres shall be optically coupled by properly aligned collimating lens assemblies attached to both the illuminating and the collection fibres.

5.4 Switching control system, switching to and from highest and lowest transmission states during spectrophotometer transmittance measurements can be done by means of a computer controlled multichannel potentiostat or by manufacturer supplied control system.

5.5 Oven, capable of heating the test specimens to the selected test temperature (see Figure 3). The oven will be used to carry out optical measurements of the EC glazings at the selected test temperature. It shall be large enough for the largest EC glazing to be tested and shall be able to reach the EC glazing testing temperature. The oven shall also be designed to permit using the equipment in 5.2 and 5.3 for optical measurements while the EC glazing shall be maintained at the temperature chosen for testing in the test chamber (described in 5.1).



Key

1	convection oven	5	spectrometer
2	lens	6	spectrometer fibre optic cables
3	spectrometer lamp source	7	thermocouple and electrical leads
4	EC switching control system	8	EC sample

Figure 3 — Example of an oven used to determine the switching cycle for use in the test chamber

5.6 Image capturing equipment, digital camera and video camera for visual documentation.

6 Test specimen

The test specimen design and construction shall be established and specified by the manufacturer.

The minimum specimen size shall be (250 ± 5) mm × (250 ± 5) mm.

Five samples shall be submitted and four shall be tested together. The fifth sample shall be kept as a non-tested reference sample. See Clause 10 for reporting requirements.

NOTE 1 For samples in an insulating glass unit, capillary tubes can be used to provide edge pressure relief for the insulating glass units at the testing temperatures.

NOTE 2 The edge seals of the insulating glass unit (up to 16 mm from the edge of the glass) can be protected from radiation exposure by an appropriate material such as aluminium tape or foil.

NOTE 3 The edges or edge seals of laminated EC glazings can also be protected from radiation exposure by an appropriate material such as aluminium tape or foil during the test (up to 16 mm from the edge of the glass) provided that in the actual application the edge seals are also protected.

7 Test method

7.1 Overview

The EC glazings shall be exposed to simulated solar radiation in a temperature-controlled chamber at specific specimen temperatures and for a set number of switching cycles according to Table 1.

Table 1 — Test classification summary

Conditions of testing:	Class 1	Class 2
Specimen temperature	(85 ± 7) °C	(65 ± 7) °C
Number of switching cycles	50 000	30 000
Number of hours of exposure	≥5 000 h	≥5 000 h

The test temperature shall be the temperature of the EC containing lite in the lowest transmission state. The EC glazings shall be cyclically switched between low and high transmission states with the ability to pause during the duty cycles, depending on the control strategy prescribed by the manufacturer. The EC glazing specimens shall be initially characterized optically at room temperature to determine initial performance. Then they shall be 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 transmission state and the time during which the specimens will be in or transitioning to the highest transmission state.

NOTE 1 Some EC products have temperature-dependent switching times.

The same equipment shall be used for both room and high temperature optical characterization measurements. After exposure in the test chamber, the specimens shall be again optically characterized at room temperature, in the same way as they were initially, to provide after-ageing EC glazing performance data.

NOTE 2 The procedure is based in part on Reference [2].

Because the make-up of insulating glass units and the orientation of the EC containing lite relative to the light source (i.e. room side versus exterior) can affect the results, the orientation of the product relative to the light source, the test temperature and the tested make-up will determine for which installed applications and product configurations this test is relevant.

7.2 Sample preparation

Thermocouples (0,13 mm diameter) shall be taped to the centre surface of the EC containing lite in the specimens with 8 mm × 8 mm pieces of aluminium tape. If the thermocouple is on the lite furthest away from the radiation source, special care shall be taken to ensure it is appropriately shielded from the light source.

NOTE The thermocouple leads can also be taped away from the centre of the specimen using up to two additional 8 mm × 8 mm pieces of aluminium tape to provide strain relief to prevent the thermocouple from being pulled off the glass surface.

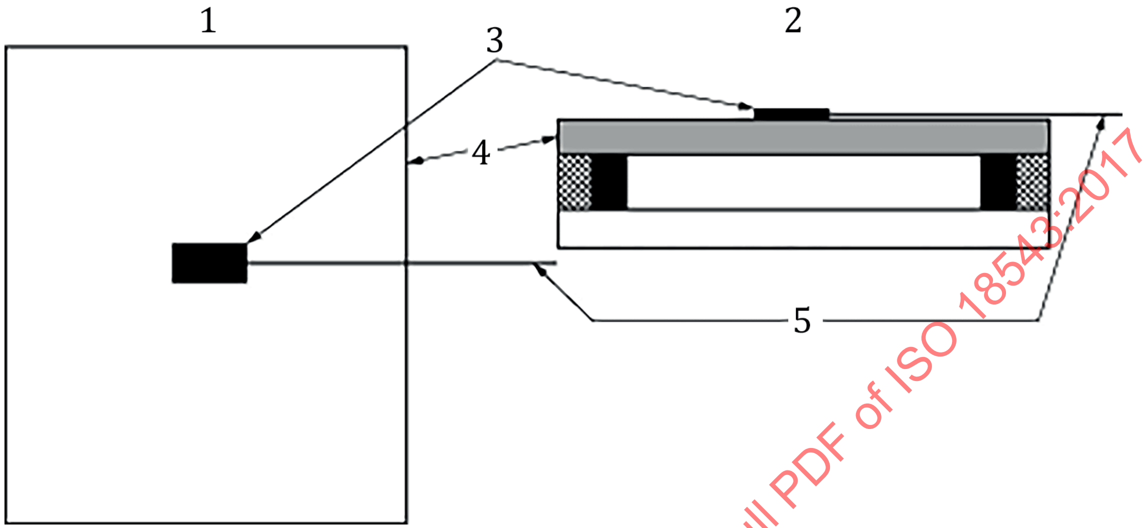
7.3 Procedure

7.3.1 General

When received, the EC glazings shall be inspected visually. Photographs of any obvious defects or aberrations of the EC specimens shall be taken in the highest transmission state or lowest transmission state (whichever is the unpowered state), and observations shall be recorded.

7.3.2 Initial optical characterization of the EC glazings at room temperature

The convection oven shown in Figure 3 shall be allowed to equilibrate with room temperature for measurements at approximately 22 °C. The temperature of the EC glazing shall be monitored by a thermocouple (or other appropriate surface temperature probe or device) attached to the pane that contains the EC layers (see Figure 4). In this case, Figure 4 shows an insulating glass unit, but a monolithic EC glazing can also be used.



Key

1 top view of the EC glazing sample

2 side view of the EC glazing sample

3 aluminium tape

4 lite containing the EC

5 thermocouple wire

Figure 4 — Placement of the thermocouple on an EC glazing sample

The highest (τ_H) and lowest (τ_L) transmittance and the switching speed of the EC glazings shall be determined as follows:

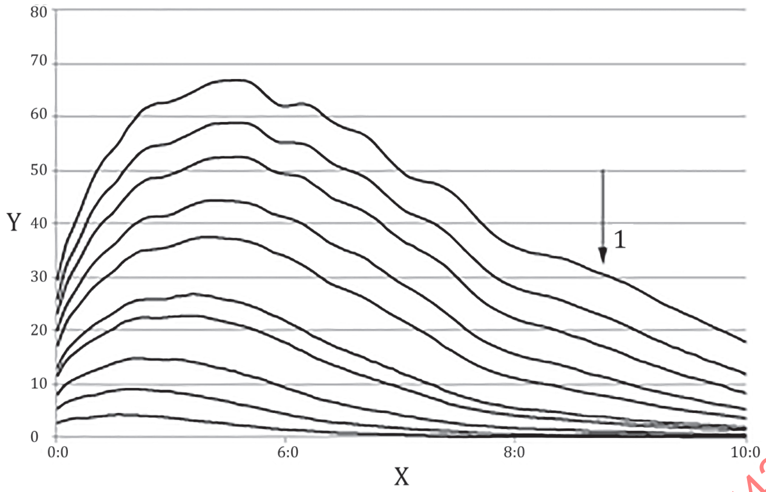
a) The optical transmittance of the specimen shall be measured at one point near the centre of glass over a spectral range covering at least 380 nm to 780 nm in successive intervals during the process of cycling between highest and lowest transmission states. Reference spectra for 100 % and 0 % transmittance shall be taken before each measurement and using at least 5 nm increments. Ensure that the measurement is away from the area that is covered by the thermocouple attachment or shielding.

NOTE 1 A time interval of a fraction of the total EC cycle time for taking each spectrum is adequate for recording the optical properties of each EC glazing.

b) The light transmittance of the glazings shall be obtained by integrating the spectra in the wavelength range of 380 nm to 780 nm using the spectral photopic efficiency Ip (λ) as the weighting factor[3]. The procedure for integration is found in ISO 9050.

c) The samples shall reach their lowest transmission and highest transmission states during these measurements. The control protocols used for switching the EC glazing between transmission states shall be applied as specified by the EC glazing manufacturer. 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 minute (whichever yields the shortest time).

NOTE 2 Typical transmittance spectra recorded during a full switching cycle are shown in Figure 5, in which the optical spectra of the glazings are plotted as a function of wavelength.



Key

X wavelength, in nm

Y light transmittance, in %

1 direction of reducing transmission

Figure 5 — Typical transmittance spectra recorded during a full switching cycle in which the optical spectra of the glazings are plotted as a function of wavelength

7.3.3 Optical transmittance measurement as a function of time at the test temperature

The magnitudes of the voltages used for switching the EC glazing between transmission states during the long-term cycling tests at the temperature of (85 ± 7) °C or (65 ± 7) °C, shall be applied as specified by the EC glazing manufacturer or using the manufacturer's control system.

Each EC glazing shall be heated in a convection oven at the specified specimen test temperature.

The switching times for obtaining a photopic transmittance ratio (PTR) of 5, starting from and returning to the highest transmission state shall be determined by measuring the transmittance as a function of time using the spectrometer as described in 7.3.1. The photopic transmittance ratio (PTR) is = τ_H/τ_L. The photopic transmittances (= τ_H, τ_L) are obtained by integrating the spectra in the wavelength range of 380 nm to 780 nm using the spectral photopic efficiency Ip as the weighting factor.

If the sample does not reach an initial PTR of 5, the sample should be cycled through 85 % of its dynamic range (where dynamic range is $\tau_H - \tau_L$). That is, the sample should be cycled starting from τ_H through to a transmittance of τ_H-0,85($\tau_H - \tau_L$).

Use these switching times to program the switching control system with specific voltage profiles for cyclic testing at the test temperature in the test chamber. The control duty cycle shall be 50 % with a voltage or current applied which causes an increase in transmittance or in the highest transmission state, and 50 % with a voltage or current applied which causes a decrease in transmittance or in the lowest transmission state. A control system provided by the manufacturer can be used as long as it generates a 50 % duty cycle and switching times to achieve a PTR of at least 5 (or 85 % of the dynamic range if the performance does not achieve a PTR of 5) in the samples during cycling in the test chamber. The applied voltages and/or currents to increase and decrease the transmittance shall be as specified in this subclause.

NOTE Control duty cycle refers to the fraction of the total cycle time (t_{cycle}) over which the specimen has a voltage or current applied which reduces the transmittance. A 50 % duty cycle means that a voltage or current which causes a reduction in transmittance is applied for 50 % of the total cycle time. During the remaining 50 % of the cycle time, a voltage which causes an increase in the transmittance is applied. Since $t_{cycle} = t_L + t_H$ where t_L is the time during which the transmittance is reducing and t_H is the time during which the transmittance is increasing, with a 50 % duty cycle, $t_L = 0{,}5 \times t_{cycle}$.

7.3.4 Setting up the test chamber

The radiation intensity over the spectral range 300 nm to 3 000 nm shall be 1 000 ± 40 W/m² to represent a 1 sun illumination. The variation of the illumination intensity at the test plane of the specimens shall be ≤8 %.

NOTE For the determination of the total irradiance level, pyranometers according to the specifications in ISO 9060[1] and the sensitivity to the spectral range from 300 nm to 3 000 nm can be used.

The chamber temperature shall be adjusted to obtain the desired surface temperature of the EC glazing in the lowest transmission state. The temperature of the EC glazing is the temperature measured at the centre of glass on the light with the EC properties when in the lowest transmission state, irrespective of the orientation of the sample relative to the radiation source.

EXAMPLE With a chamber air temperature of 60 °C, the centre of glass EC glazing surface temperature in the lowest transmission state reaches a steady-state temperature of about 85 °C depending on the specimen size, lowest transmission state reached during voltage cycling, location of the glazing in the test plane, and the EC glazing construction.

7.3.5 Mounting of the EC glazings in the test chamber

EC glazing specimens shall be placed horizontally onto the test plane. The surface of the glazing unit facing the light source shall be the surface facing the exterior when the glazing is installed in the building. Suitable electrical connections shall be made from the EC cycling unit and data acquisition system to the wires of each EC glazing.

NOTE The test plane can either be horizontal or vertical. The critical requirement is that the illumination and uniformity meet the requirements of this standard.

7.3.6 Cycling the EC glazings in the test chamber at elevated temperature and under simulated solar exposure

The testing temperature shall be that of the lite with the EC properties in the lowest transmission state.

NOTE The average EC glazing temperature will be less because of a typical decrease of about 5 °C when the EC glazing is in the high transmission state.

Before cycling at the test temperature, the EC glazing specimens shall be cycled in the test chamber at room temperature to verify the integrity of the electronic control and data acquisition system, as well as the continuity of the electrical and thermocouple connections.

With the specimen in the highest transmission state, the xenon arc lamps shall be activated. When the EC specimen approaches the desired testing temperature, the voltage cycling of the EC glazing shall be started, using the voltage or current profile at the specified test temperature obtained by earlier oven pretesting (see 7.3.3). Adjustments shall be made to the chamber air temperature to account for the inevitable rise in temperature of the specimens resulting from absorption in the lowest transmission state.

Specimen temperatures and cycling data shall be recorded using the data acquisition system and periodic monitoring shall be done to ensure proper operation of the test chamber and associated experimental apparatus.

7.3.7 Interim visual and optical characterizations

The cycling of the EC glazings and the functions of the test chamber may be shut down periodically at approximately every 2 000 h during the test. After shutting down the chamber, the thermocouple and electrical leads to the specimen from the cabling shall be disconnected, the specimens removed, and the optical transmittance in the highest and lowest transmission states re-measured at room temperature as in 7.3.2.

The EC glazing specimens shall be visually inspected and any detectable degradation shall be photographed with the digital camera. Any visually detectable degradation of the specimens in the highest and lowest transmission states shall be recorded.

The visual uniformity tests shall be made when the EC glazing is held at a constant transmittance. To establish a given transmittance state for assessing the uniformity of the EC glazing, the manufacturer shall be asked to provide control information (voltage, current, time) or a control system that will result in a constant transmittance of the EC glazing in the lowest and highest transmission states, and this information or equipment shall be used.

The optical measurements and other observations shall be recorded. The EC glazing specimens shall be remounted into the test chamber for the next series of cyclic testing, that is, another 2 000 h or until the test is complete as appropriate.

The procedure in 7.3.6 and 7.3.7 shall be repeated until

— Class 1 performance: a total of 50 000 switching cycles and at least 5 000 h under test conditions are achieved, or

— Class 2 performance: a total of 30 000 switching cycles and at least 5 000 h under test conditions are achieved.

7.3.8 Final characterization

7.3.8.1 Final optical characterization

After the specimens have amassed 50 000 switching cycles (for Class 1) or 30 000 cycles (for Class 2) and a minimum of 5 000 h under test conditions, the specimens shall be optically characterized at room temperature following the procedure in 7.3.2.

7.3.8.2 Video documentation

Each EC glazing that has been aged shall be mounted next to an un-aged witness specimen from the same batch of all of those tested. The dynamic response for five switching cycles between the highest and lowest transmission states shall be recorded using the video camera.

7.3.8.3 Final visual inspection

Final visual inspection shall be performed, taking photographs, and recording all evidence of visually detectable degradation.

8 Performance requirements

8.1 Visible light transmittance

The photopic transmittance of the lowest and highest transmission states shall be determined according to light transmittance (see 3.3) and ISO 9050:2003, Table 1 (weighting functions).

The visible light transmittance in the highest transmission state and the lowest transmission state shall change by no more than ± 5 % T absolute. That is:

$$|\tau_{H,i} - \tau_{H,f}| \leq 0{,}05$$

$$|\tau_{L,i} - \tau_{L,f}| \leq 0{,}05$$

All four tested samples shall be measured and reported, but at least three samples shall meet the abovementioned requirements.