Guidelines and Specifications for Enhanced Durability Evaluation of Insulating Glass and Vacuum Insulating Glass Units

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Foreword

The National Renewable Energy Laboratory (NREL) has conducted research into durability of advanced fenestration technologies for almost 30 years. In addition, NREL has recently begun to research potential methods to enhance durability evaluation of present market insulating glass units (IGU), which include vacuum insulated glass (VIG). This document outlines a proposed process flow for enhanced evaluation of durability of both IGU and VIG products. This proposed evaluation process is a topic of active research at NREL as well as with industry partners. NREL will periodically update this document based on research results, both internal and external to NREL, that may inform development of improved durability evaluation. This document is meant to serve as a guideline for interested parties who may wish to engage in enhanced durability evaluation of IGUs, either internally or with external testing laboratories. NREL will work to support adoption of the suggestions in this guideline in the hope that these practices become more broadly adopted by the industry. Further research in this area will continue to inform both adaptations of this guideline as well as development of improved durability evaluation standards.

It is important to note that this document is written by scientists and engineers researching fenestration durability for an audience of industry practitioners of the evaluation of fenestration durability. Hence, this document references present industry practices and standards that may not be immediately familiar to those who have not previously been active in this area. This document is not meant to give an exhaustive explanation of fenestration durability concerns; rather, it is intended to communicate proposed modifications and suggested research areas to those already experienced in this field. More detailed discussion on fenestration durability and suggested new procedures will be discussed elsewhere.

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Introduction

In the United States, more than 40% of primary energy and 70% of electricity is consumed in residential and commercial buildings, resulting in annual energy costs of more than $430 billion.[1] Approximately 35% of this consumption can be attributed to losses through the building envelope. Windows bring many desirable features to any dwelling including connection to the outside environment, effective use of daylighting, and improved ventilation. However, windows remain, thermally, the weakest link in the building envelope and are responsible for most thermal losses. Table 1 shows center-of-glass overall thermal resistance values (R-value) from the installed window base in single-family homes in the United States as well as those for an emerging high thermal performance technology, vacuum insulating glass (VIG). Based on comparison of these values to wall (R11–R19) and roof (R21–R30) insulation, it is clear that windows need considerable innovation to match other opaque envelope systems and drive necessary energy efficiency improvements.

Table 1. Installed Window Units in the United States Based on R-Value and Insulating Glass Unit (IGU) Configuration

Technology	R-Value (hr-ft^2-°F/Btu)	Percentage of Installed Base
Single Pane	0.9	41%
Double Pane/Low-E/Argon fill	3.2–4.4	58%
Triple Pane	5.0–7.5	1%
Vacuum Insulating Glass (VIG)	10+	N/A

It is also important to note that the values cited above are for “as specified” initial performance. It is not clear how long this level of performance is maintained over time in the field; however, performance is known to degrade. This degradation can result in performance reduction which may have substantial impact on overall building energy use. Failure of high-performance glazing—namely, triple pane and VIG—could reduce the energy performance of the window much more dramatically than present market technologies. Windows represent a significant investment for a building owner, whether in new construction or retrofit applications. The energy performance of the window must deliver cost savings over time to maximize the return on investment (ROI) and “lock in” reductions in energy use and carbon emissions. Therefore, it is crucial to the extend the lifetime of IGU products in the field.

The purpose of this report is to provide a guideline for enhanced durability evaluation protocols that focus on energy performance and resiliency considering all aspects of IGU degradation in the field as well as the emerging impacts of climate change. We seek to accomplish this goal by providing a route that leads to minimal disruption of present industry practices, hence the methods discussed are largely based on minor modifications to existing methods. Proposed modifications to stress factors presently used in existing industry protocols (ASTM E-2188/E-2190) include:

- Increased temperature exposure range based on observed increasing climate extremes
- Wind pressure testing based on increased frequency and intensity of storm systems

- Increased temperature ramp rates due to rapid environmental changes (i.e., polar vortex excursions).

The guideline also considers the evaluation of additional key performance metrics including:

- Thermal conductivity to ensure insulating performance is maintained over time
- Characterization of optical properties to determine degradation of energy saving glass coatings
- Characterization of desiccant moisture uptake compared to available desiccant capacity, which offers the potential to allow projection of a product lifetime.

Further optional evaluation practices may include:

- Evaluation of the impact of environmental pollutants on durability of IGUs
- Separate evaluation of as-received IGU edge seal component materials to ensure quality.

These additional stress factors and performance metrics enable a more robust evaluation of the durability of IGUs. Given additional stress factors and evaluation metrics, this guideline may provide a more direct tie between laboratory-based testing and energy performance in the field. Separate ongoing projects focused on field evaluation of installed IGUs will be compared to the results of evaluation using this guideline in an attempt to correlate lab testing to field performance.

Scope

This guideline provides specification of performance requirements and associated test methods for sealed IGU and VIG. The type of glass and the maximum dimensional tolerances for such units are also specified.

1. This guideline is applicable to preassembled, permanently sealed IGUs with multiple gas filled or vacuum spaces and preassembled IGUs with capillary tubes closed or intentionally left open.
2. This guideline is applicable only to sealed IGUs that are constructed with glass panes. This guideline does not apply to units incorporating panes made from material other than glass. The guideline is applicable for IGUs incorporating laminated glass pane(s).
3. The qualification of test specimens is based on frost/dew point and on the absence of fog after the specified test durations.
4. This guideline covers degradation of thermophysical properties, optical properties, and desiccant materials and systems.
5. Qualification under this guideline is intended to provide a basis for evaluating the durability of sealed IGUs.
6. This guideline is not applicable to sealed IGUs containing a spandrel glass coating.

The method referenced herein is a laboratory test conducted under specified conditions. It is intended to simulate and, potentially, to also accelerate degradation found for in-service use of IGUs. Currently, the results cannot be used to predict the performance over time of in-service units unless actual corresponding in-service tests and appropriate analyses have been conducted to show how performance can be predicted from this guideline.

Sealed IGUs qualified according to this guideline are not necessarily suitable for structurally glazed applications. Factors such as longevity when exposed to long-term weather, pollutants, and ultraviolet light as well as the structural properties of the sealant must be reviewed for these applications.

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

Referenced Standards

American Society for Testing and Materials (ASTM) C162 – Terminology of Glass and Glass Products

ASTM C518 – Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

ASTM C717 – Terminology of Building Seals and Sealants

ASTM C1036 – Specification for Flat Glass

ASTM C1249 – Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications

ASTM C1265 – Test Method for Determining the Tensile Properties of an Insulating Glass Edge Seal for Structural Glazing Applications

ASTM C1369 – Specification for Edge Sealants for Structurally Glazed Insulating Glass Units

ASTM D7897 - Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance

ASTM E546 – Test Methods for Frost Point of Sealed Insulating Glass Units

ASTM E631 – Terminology of Building Constructions

ASTM E2141 – Standard Test Method for Accelerated Aging of Electrochromic Devices in Sealed Insulating Glass Units

ASTM E2188 – Test Method for Insulating Glass Units Performance

ASTM E2189 – Test Method for Testing Resistance to Fogging in Insulating Glass Units

ASTM E2190 – Standard Specification for Insulating Glass Unit Performance and Evaluation

International Organization for Standardization (ISO) 760 – Determination of Water – Karl Fischer Method (General Method)

ISO Draft International Standard (DIS) 19916-1 – Glass in building – Vacuum insulating glass – Part 1: Basic specification of products and evaluation methods for thermal and sound insulating performance

ISO/DIS 20492-1 – Glass in Buildings – Insulating Glass – Part 1: Durability of Edge Seals by Climate Tests

EN 1279-2 2002 – Test method for moisture penetration

EN 1279-3 2002 – Gas leakage rate and tolerances

EN 1279-4 2002 – Physical attributes of edge seals

GB/T 11944-2012 – Insulating glass unit (Chinese standard)

Terminology

Definition of Terms:

1. For definitions of terms found in this specification, refer to Terminology ASTM C717, Terminology ASTM C162, and Terminology ASTM E631.
2. Definitions of terms specific to this guideline:
    A. Sealed insulating glass unit. Preassembled unit, comprising panes of glass, which are sealed at the edges and separated by dehydrated air or other gasses or evacuated space(s) intended for vision areas of buildings. The unit is normally used for windows, window walls, picture windows, sliding doors, patio doors, or other types of fenestrations.

    B. Symmetrically sealed insulating glass unit. A unit comprising two or more panes of glass of the same type and thickness.

    C. Asymmetrically sealed insulating glass unit. A unit comprising two or more panes of dissimilar glass and/or differing thickness.

    D. Spacer. The component used to control the space between the panes of glass in glazing units.

    E. Fracture. A crack in a glass component which penetrates through the thickness of the glass.

    F. Nominal thickness. The manufactured thickness within agreed tolerances as specified in ASTM C1036.

    G. Nominal thickness of the glazing unit. The sum of the nominal thicknesses of the panes of glass and the spacer. See ASTM C1036.

    H. Gas-Filling. An inert gas introduced into the IGU gap to improve thermal and/or acoustic insulation properties.

I. Pillar. A small structure placed between glass lites in a VIG unit. These prevent the opposing glass lites from contacting each other with the internal chamber under vacuum. They also provide direct thermal conduction between the two glass surfaces.

Sample Specimens

- Specimen design and construction techniques shall be established by Test Method ASTM E2188 unless specified differently here.
- The glass and airspace thickness(es) for qualification under this specification are 4 mm (5⁄32 in.) glass with 12 mm (1⁄2 in.) airspace or 5 mm (3⁄16 in.) glass with 6 mm (1⁄4 in.) airspace. An exception is made for the gap width of VIG where the gap is per manufacturer specification.
- Glass or airspace thickness(es), or both, may be increased (for example, using 6 mm glass with 12 mm airspace). This may result in a more rigorous test.
- For triple or more pane units, 4 mm (5⁄32 in.) glass with 6 mm (1⁄4 in.) airspaces are used.
- For vacuum glass units, actual glass thickness and vacuum gap(s) are used.
- All of the values specified above are nominal.
- Tolerance of glass thickness shall be in accordance with ASTM C1036.
- IGU gap tolerance(s) shall be 6 ± 0.8 mm (1⁄32 in.).
- Fifteen double-glazed units shall be submitted when testing to this guideline.
- Seventeen triple-glazed units shall be submitted when testing to this guideline.
- For vacuum glazing, two samples sized 14 inch by 40 inch and four samples sized 14 inch by 20 inch for a total of six samples shall be provided when testing to this guideline.

Evaluation Methods

Based on the combination of research on IGU durability at the National Renewable Energy Laboratory (NREL) as well as a survey of current industry practices and international standards, NREL is proposing an enhanced guideline for evaluation of IGU durability performance. This guideline is based on adaptation of the existing ASTM E2188/2189/2190 standards to disrupt present practice as little as possible with respect to test logistics, duration, and ultimately, cost. However, NREL does propose modified procedures to incorporate additional metrics as well as increase stress induced during evaluation.

The criterion for passing ASTM E2188/2189/2190 is presently a frost point measurement which determines the potential for condensation to form inside the IGU. This metric does not necessarily take relevant value-adding characteristics such as thermal properties and low-e performance over time into account. Based on this, NREL proposes to add both optical properties and thermal conductivity as metrics to determine performance after the weathering cycles.

We also recommend increasing the number of thermal cycles in the weathering process but propose changing the total cycle time to allow double the number of cycles to be accomplished in the same timeframe as the present ASTM protocols. This change is based on feedback from multiple partners who are currently running repeated ASTM E2188/2190 tests in an attempt to project longer lifetime. The increased ramping rate and number of cycles also exposes edge seal(s) to more rigorous cyclic gap pressure stresses.

Furthermore, we propose evaluation that will include characterization of moisture uptake in the desiccant. This will allow manufacturers more insight into performance and how it can be improved as compared to the present pass/fail evaluation. As mentioned, the proposed test flow is based on modification of the present ASTM E2188/2189/2190 protocols. These modifications are highlighted in blue text in the below process flow outline. Items in black or references to other standards are identical to current practice.

Proposed New Enhanced IGU Durability Evaluation Process Flow

(Text marked in blue are added enhanced requirements)

1. Collected samples shall be allowed to equilibrate to ambient laboratory conditions prior to testing.
2. Measure frost/dew point on all 15 specimens.
   A. Categorize specimens in order of increasing dew point values and assign each sample a number (see Table 2).
   B. From this sample matrix, select the two lowest and two highest dew point values to be used in accelerated cycling.
3. Perform initial thermal conductance measurements in accordance with ASTM C518 for all IGU samples as received.
4. Characterize optical properties of IGU samples using a spectrophotometer (range 300–1100 nm) as received (see Appendix D).

NOTE: Appropriate evaluation of Low-e performance will likely require evaluation at longer wavelengths. How to incorporate these measurements into this guideline is currently being evaluated by NREL and will be updated as appropriate. This initial wavelength range is intended to identify any changes in optical performance that may impact visual light and unit appearance.

5. Measure total moisture adsorption capacity of the desiccant collected from two samples (Specimen #3 and #13) as received (see Appendix B).

6. The initial moisture content of desiccant in as received samples will be measured on four specimens from the middle of the matrix (i.e., 6–9) (destructive testing). The appropriate moisture evaluation method used will be determined by the insulated glazing design as well as desiccant type (i.e., granular desiccant or desiccant incorporated within the sealant or within a matrix material [see Figure 1]).
   A. Granular desiccant (950°C drying method) (reference method EN1279-02)
      i. Desiccant is removed from the IGU spacer and added to a pre-weighed dish which is capable of being covered with a lid. The sample and dish should then be weighed to determine the mass of desiccant being evaluated.
      ii. The desiccant and dish are then heated at 950°C over the period of 60 ± 20 minutes and held at that temperature for 120 ± 5 minutes to drive off any moisture.
      iii. The sample shall be transferred to a dry, desiccated chamber and allowed to cool to room temperature.
      iv. The final mass of the dish and dried desiccant materials shall be determined, and moisture content is determined by the difference between the initial and final mass.

Note: To avoid any additional moisture gain, desiccant samples should be collected and stored in a dry container immediately after heating. Appropriate personal protective equipment such as face mask, thermally protective gloves, or alternate handling procedures that do not involve skin contact or breathing desiccant dust should be used to conduct this transfer.

   B. Desiccant incorporated in organic materials
      i. The initial and final moisture content is measured using the Karl Fischer method (ISO 760).
   C. For IGUs without desiccant or desiccant matrix
      i. The absorbed moisture content is determined by correlating the corresponding partial water vapor pressure as a function of temperature based on the earlier measured frost/dew point (Appendix B).

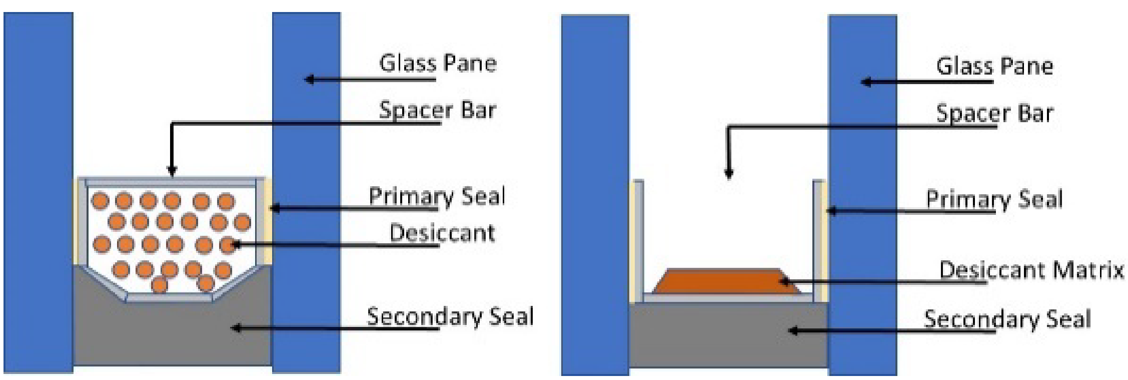

Figure 1. Desiccant-filled (left) and desiccant-based matrix (right) edge seal constructions.

7. Initial pressure testing (Appendix C) is performed on four specimens selected for the accelerated testing (IGUs 1, 2, 14, and 15).

Note: The addition of pressure as a stress factor for durability of IGU seals is an area of active research by NREL as well as industry partners. Currently, this guideline suggests pressure testing separately from the accelerated climate cycling steps. This is done to try and simplify adoption of this practice with minimal disruption to existing test chamber capabilities. However, this guidance may be modified to incorporate pressure directly into climate cycling pending on-going research as well as availability of suitable testing chambers.

8. Conduct the initial high humidity/high temperature exposure (ASTM E2188) on four test specimens (IGUs 1, 2, 14 and 15) to be used in the accelerated climate test.
9. Conduct accelerated climate exposure on the four samples (IGUs 1, 2, 14 and 15) carried out according to ASTM E2188, with the changes highlighted in blue text below:
    A. Increased temperature cycling range [70ºC to -40ºC] (instead of [60ºC to -29ºC]).
    B. Modification to the cycle period is 3 hours (instead of 6 hours as listed in ASTM E2188).
    C. The cycle temperature ramp down is changed from 23ºC to -40ºC in 30 minutes; temperature is held steady at -40ºC for 30 minutes; temperature is then ramped up from -40ºC to 70ºC in an hour; temperature is then held steady at 70ºC for 30 minutes and then ramp down to 23ºC in 30 minutes (see Figure 2).
    D. Ultraviolet illumination (UV) will be turned on during the ramp up the period from 23ºC to 70ºC, during the hold at 70ºC and from ramp down from 70ºC to 23ºC. UV is turned off during the ramp from 23ºC to -40ºC and the ramp back up to 23ºC. This is consistent with current practice (ASTM E-2188/E-2190)
    E. Test length total is 63 days to reach a total of 504 thermal cycles.

Note: NREL is aware that increasing the cooling ramp rate of the thermal cycling protocol may present challenges for some existing evaluation chambers. It is acceptable to use lower temperature ramping rates as is feasible within evaluation chamber design; however, the suggested 504 thermal cycles should still be completed and the suggested temperatures should be achieved in the evaluation. If evaluation chambers are not able to reach the proposed temperature ramping rates, the total time of the evaluation will increase beyond the present 63 days.

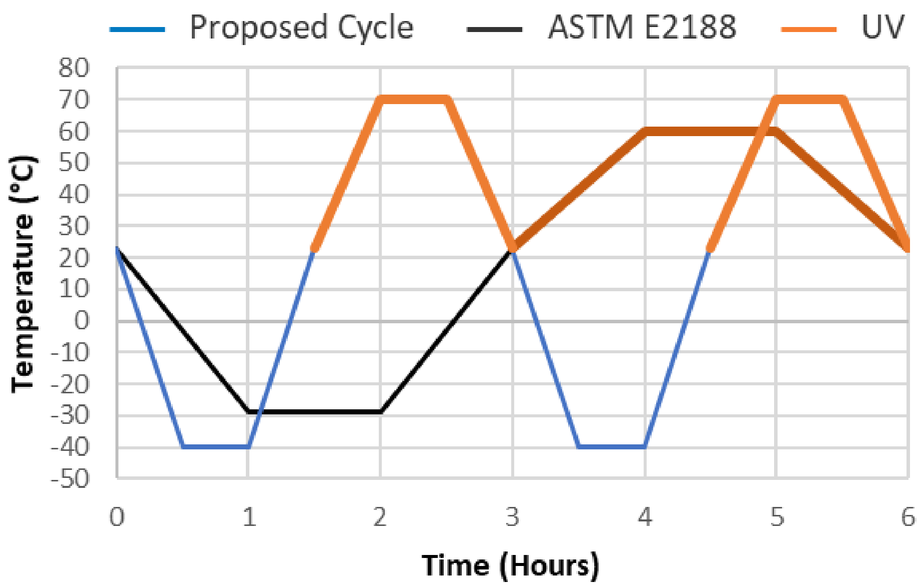

Figure 2. Graphical representation of the present industry accelerated climate test (ASTM E2188) compared to the process suggested in this guideline.

11. Conduct a second high humidity/high temperature exposure on the four specimens under accelerated evaluation (ASTM E2188).
12. Following the second high humidity/high temperature exposure, perform thermal conductance measurements (ASTM C 518) on all four specimens evaluated under accelerated climate cycling—thermal conductance shall not change more than 5% from that measured for the as received samples.
13. Characterize the optical properties of IGU samples using a spectrophotometer (range 300–1100 nm) after the accelerated climate cycling—no change in optical properties should be detected after testing in accordance with the test method described in Appendix D.
14. If specimens contain an inert gas fill, measure the final gas content (destructive test) in the IGU cavity. Use the syringe method discussed in Appendix A on two out of the four specimens tested under accelerated testing.
15. The four units which were exposed to pressure testing (Appendix C) and that complete the weather cycle and high humidity phases of Test Method ASTM E2188 unbroken shall have the frost/dew point determined and reported.
16. Measure final desiccant moisture content on the four specimens evaluated under accelerated testing. The moisture permeability index should not increase by more than 20% on average and should not exceed 25% on individual units (Appendix B).

17. Conduct volatile fog testing following ASTM E2189.
18. The remaining three samples are left as spare.

Table 2. Overview of Samples Identified for Varied Evaluation Processes as Defined by Categorization to Measured Frost/Dew Point of As-Received Specimens

Assigned Sample ID	Experiment
1, 2, 14, 15	Initial pressure testing Thermal conductance measurements Characterize optical properties Accelerated cycling Final moisture content
6, 7, 8, 9	Initial moisture content
3, 13	Moisture-absorption capacity
4, 5	Volatile fog testing following method
10, 11, 12	Spares

Guideline Protocol Specific to Vacuum Insulating Glass

1. Collected samples shall be allowed to equilibrate to ambient laboratory conditions prior to evaluation.
2. Specimens shall consist of two samples sized 40 inch by 14 inch and four samples sized 14 inch by 20 inch for a total of six samples.
3. Measure frost/dew point on all six specimens. Any dew formation would be considered failure of that sample. One sample sized 14 inch by 40 inch and two samples sized 14 inch by 20 inch which pass frost/dew point testing are selected for accelerated testing. The remaining three are to be considered spares.
4. Perform thermal conductance measurements on the two specimens sized 14 inch by 20 inch before accelerated climate testing (ASTM C518).

Note: If the larger sample can be tested in the ASTM C518 chamber, one should test that sample also.

5. Characterize the optical properties of the IGU samples using a spectrophotometer (range 300–1100 nm) before accelerated climate testing (see Appendix D).
6. Conduct initial pressure testing (Appendix C) on three specimens selected for the accelerated testing.
7. Conduct the initial high humidity/high temperature exposure on three test specimens to be used in the accelerated climate test (ASTM E2188).
8. Accelerated climate testing shall be conducted on the three samples according to ASTM E2188, with mentioned changes below:
    A. One sample sized 14 inch by 40 inch and two samples sized 14 inch by 20 inch which passes frost/dew point testing are selected for accelerated testing.

B. One thermocouple shall be placed on each IGU to be evaluated. This thermocouple shall be placed at the center of the IGU. Care should be taken to not place the thermocouple on a pillar but place it in a location equidistant between the pillars.

C. Increased temperature cycling range [70ºC to -40ºC] (instead of [60ºC to -29ºC]).

D. Modification to the cycle period is 3 hours (instead of 6 hours as listed in ASTM E2188).

E. The cycle temperature ramp down is changed from 23ºC to -40ºC in 30 minutes; temperature is held steady at -40ºC for 30 minutes; temperature is then ramped up from -40ºC to 70ºC in an hour; temperature is then held steady at 70ºC for 30 minutes and then ramp down to 23ºC in 30 minutes (See Figure 2).

F. Ultraviolet illumination (UV) will be turned on during the ramp up period from 23ºC to 70ºC and steady at 70ºC and from ramp down from 70ºC to 23ºC.

G. Test length total is 63 days to reach a total of 504 thermal cycles.

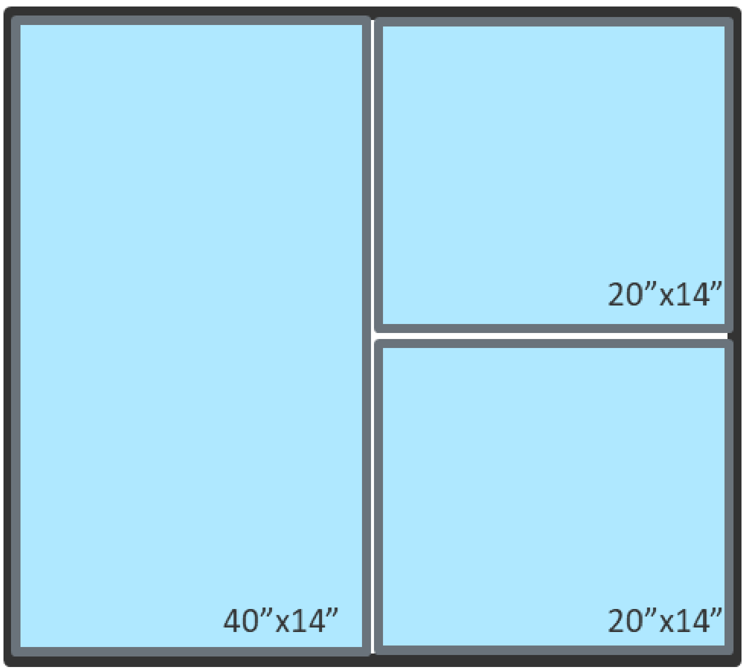

Figure 3. Orientation of VIGs mounted in the evaluation chamber

9. Conduct a second high humidity/high temperature exposure on the three specimens evaluated under accelerated testing (ASTM E2188).

10. Perform thermal conductance measurements on the two specimens sized 14 inch by 20 inch tested under accelerated testing (ASTM C518). Thermal conductance shall not change more than 5% tested in accordance with Test Method ASTM C518 after undergoing testing in accordance with this guideline.

Note: If the larger sample can be tested in the ASTM C518 chamber, one should test that sample also.

11. Characterize optical properties of IGU samples using a spectrophotometer (range 300–1100 nm). No change in optical properties should be detected after testing in accordance with the test method described in Appendix D.

Guideline Protocol for Optional Testing for IGU and VIG Units

These methods are optional and are currently being evaluated by NREL for appropriateness and ability to be implemented. They are listed here for reference and discussion.

1. Exposure to water, pollutants, and weather conditions listed in ASTM D7897 can be performed on an additional sample set with identical analytical metrics to those called out above (e.g., thermal conductivity, optical properties, desiccant moisture content). This method is presently being evaluated by NREL and will be further developed as appropriate.
2. Collection and quality control testing of edge seal components including sealants and desiccant materials
    A. Spacer, primary, and secondary sealants will be collected and analyzed for material consistency.

Note: The intent of item 2 is to attempt to separate performance issues generated by materials supplied as compared to work quality. This will help manufacturers determine appropriate actions to correct any observed failures. Specific quality control methods are not called out at this time and may be the focus of future research and development. This step was added due to industry interest based on interviews.

Performance Requirements

Insulating Glass Units

1. Initial, intermediate (after the weather cycle phase) and final (after final high humidity test) frost/dew points shall be determined. For triple pane units, the frost/dew point is determined for all airspaces. The final frost/dew points shall be -40°C or colder when measured in accordance with Test Method ASTM E546 or equivalent. Final frost/dew points shall be determined at least 24 hours after test completion but no later than 7 days.
2. Volatile Fog Testing (ASTM E2189): Two specimens shall be evaluated for double glazings, four specimens shall be evaluated for triple glazings. No fog shall be visible after testing in accordance with Test Method ASTM E2189.
3. Optical properties: No change in optical properties after testing in accordance with Appendix D.
4. Thermal Conductance: Thermal conductance shall not change more than 5% tested in accordance with Test Method C518 after undergoing testing in accordance with this guideline.
5. Desiccant moisture content: Shall be reported per (ISO 20492-1). The moisture permeability index should not increase by more than 20% on average and not exceed 25% on individual units. (see Appendix B)

6. Gas Content (Appendix A): Initial average gas fill concentration of ≥90% prior to testing and the final average gas fill concentration of the same four specimens after testing shall be ≥85% after testing.

Specimens shall also comply with the following performance requirements:

1. There shall be no evidence of contamination on the interior glass surfaces of the units after undergoing testing in accordance with this guideline.
2. The units shall show no indication of leakage at the seal when tested in accordance with this guideline.
3. The units shall show no evidence of frost or condensation on the interior glass surfaces when tested in accordance with this guideline.
4. The units shall show no evidence of fogging or contamination on the interior glass surfaces after being tested by UV exposure.
5. In the event IGUs are gas-filled, the amount of gas in the cavity must be a minimum of 90% by volume. The gas-filling requirements must comply with EN 1279 Part 3 and Part 4.

Vacuum Insulating Glass Units

1. Thermal conductance shall not change more than 5% tested in accordance with Test Method C518 after undergoing testing in accordance with this guideline.
2. No change in optical properties should be detected after testing in accordance with the test method described in Appendix D
3. Thermocouple temperature shall not change more than 5% when comparing any same points through the period of thermal cycling (if the vacuum is lost there will be a drastic change in surface temperature of the glass).

Qualification

1. When all test specimens have met the requirements as described in the guideline protocol, this set of test specimens shall be deemed to be qualified according to this guideline specification.
2. If a specimen fails to meet the requirements as described in guideline test protocol, this set of specimens shall not be qualified according to this specification.

Reports

Test Methods:

- Report all information as required in the Report Section of Test Method E2188.
- Report all information as required in the Report Section of Test Method E2189.
- Report all information as required in the Report Section of Test Method E2190.
- Report all information as required in the Report Section of Test Method C518.

- Report all information as required in the Report Section of Test Method ASTM E2141 – optical.
- Report whether the set of test specimens meets the qualifications of this specification.

Test Durations:

- Report the duration of the accelerated weathering test.
- Report the duration of the high humidity/high temperature testing.
- Report the duration of volatile fog testing.

Data Logging

A continuous temperature chart or data logging device must be maintained for equipment operation for both the high humidity/high temperature testing and the accelerated weathering testing. Charts or data logging must be digital with no greater than a five-minute interval and provide clear real time values for time and temperature, and to a level of accuracy that will allow determination that standard conditions were met. While continuous logging is recommended for the ASTM E2189 fog chamber(s), it is not required. A daily manual log is acceptable to verify real time values.

UV Bulbs

UV output of each bulb shall be measured at least every 2000 hours. With the specified range of UV light output established in ASTM E2188-2019, UV output shall be measured frequently, before the start of tests, or often enough to ensure testing in accordance with the requirements of the standard.

Accelerated Weathering Chamber

The film coefficient on the weather side shall be 15 W/m^2K (wind speed of 2.75 m/s) (ASHRAE Summer conditions), while the indoor side shall be Natural conditions, not to exceed 9.44 W/m^2K (wind speed of 1.36 m/s).

At least annually, the accelerated weathering chamber shall be checked for temperature uniformity. This shall be done by recording temperatures at several locations in the chamber, at a minimum: (1) upper right, (2) upper left, (3) center, (4) lower right, and (5) lower left, and ensuring these individual temperatures are within the tolerances ±3ºF.

Calibration

Calibration of all equipment used for measuring and recording devices shall be performed at least annually.

Guideline Document Maintenance

NREL and industry partners continue to perform research and development in enhanced durability evaluation of fenestration products related to this proposed guideline document. Some of the areas in this guideline are still the subject of active research and others may emerge or change based on ongoing efforts. NREL will periodically update this guidance as further information is developed.

Legal Disclaimer

Keywords

Insulating glass units; vacuum insulating glass; seal durability; sealed insulating glass units; unit performance and evaluation

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Appendix A. Gas Fill Procedure

A.1. Gas fill procedure (GB/T 11944-2012)

A.1.1 *Test Conditions*. The test shall be performed under temperature of 23ºC ± 2ºC, and relative humidity of 30% - 75%. Before the test, all the samples shall be placed under such environment for at least 24 h.

A.1.2 *Testing equipment.* Paramagnetic oxygen analyzer with analyzer resolution of 0.1% and the accuracy shall be ≤ ±1.0 % (V/V). Other instruments which meet requirements are also allowed to be used.

A.2 Test process

A2.1 *Instrument calibration*. Before the test, the oxygen analyzer's calibration shall be carried out using dry air of which the oxygen concentration has been confirmed, or argon or krypton with a purity of 99.99% or higher. Other instruments shall be calibrated before testing.

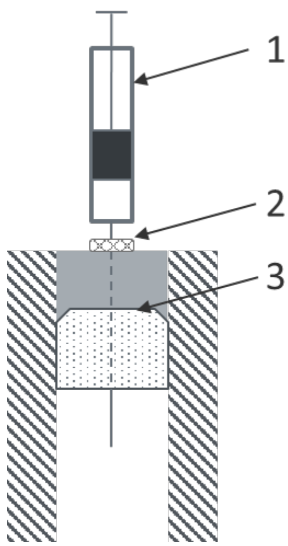

Figure A-1. (1) Gas-tight syringe; (2) Glue cushion; (3) IGU edge seal

A2.2 *Drawing gas*. Vertically place the sample and using an awl penetrate the spacing frame at the middle of the sample, then immediately insert the gas-tight syringe from which any gas has been completely discharged, (Figure A-1), through the glue cushion into the insulating glass unit. Extract gas into the syringe, then push the gas in syringe back into the hollow cavity, repeat twice, then extract a 20 ml gas sample into the syringe.

B2.2 *Measurement*. Insert the syringe that contains the gas sample into the analyzer inlet, and then slowly inject the gas into analyzer; the value showed after the display becomes stable shall be the measurement result.

Appendix B. Desiccant – Moisture Content

B1. Desiccant – Moisture content (ISO 20492-1)

B1.1 Measure the initial moisture content (*T*i) of the desiccant (if any) on the four selected test specimens in accordance with Appendix B.2. For sealed insulating glass units without desiccant, determine an equivalent value for initial moisture content (*T*i) using the dew point temperature.

B1.2 Calculate the average initial moisture content of the desiccant from the following equation:

$$T_{1,av} = \sum_{n=1}^{4} \frac{T_{i,n}}{4}$$

B1.3 Submit the four selected test specimens to accelerated cycling and run through the required number of cycles.

Note: For reasons of time saving and cost aspects of this test, the manufacturer or an agent of the manufacturer may decide whether the spare units are to be submitted to climate conditions from the beginning, or only when a unit under climate conditions breaks.

B1.4 After cycling the four test specimens, store them for a minimum of two weeks under standard laboratory conditions.

B1.5 Measure the final moisture content (*T*f) of the desiccant (if any) of the four test specimens in accordance with B.2.

B1.6 When the amount of desiccant in the test specimen differs from the sealed insulating glass units placed on the market, the final moisture content *T*f shall be corrected by the following:

$$k = \frac{Q_{desiccant\_as\_per\_system\_description}}{Q_{desiccant\_unit\_in\_test}}$$

here Q is the amount of desiccant in weight (g) or in volume (cm^3)

Note: When there are technical reasons that the quantity of desiccant in the test pieces cannot be representative of the system description, the test can be performed with a different quantity, however test results should be corrected in order to obtain a true value.

B1.7 For units without desiccant, measure the final dew point temperatures of the five test specimens. Using these dew point temperatures, determine an equivalent value for *T*f for each specimen in accordance with B.2.4.

B1.8 Establish the standard moisture adsorption capacity (*T*c) by measurement of desiccant samples from test specimens.

If a measurement of *T*c is required, use the measured values of the two specimens

$$T_{c,av} = \sum_{n=1}^{2} \frac{T_{c,n}}{2}$$

B1.9 Calculate the moisture penetration index, *I*, in fractions or in percentage, of each of the four selected or designated test specimens subjected to the climate conditions, from the following equation:

$$I = \frac{T_f - T_{i.av}}{T_{c,av} - T_{i,av}} \text{ or } I = 100\frac{T_f - T_{i.av}}{T_{c,av} - T_{i,av}} in\%$$

B1.10 Calculate the average moisture penetration index from the following equation:

$$I_{av} = \sum_{n=1}^{4} \frac{I_n}{4}$$

B1.11 Ensure that sealed insulating glass unit manufacturers are aware of the accuracy of the climate test, using the results from proficiency testing.

B2. Measurement of moisture content (ISO 20492-1)

B2.1 *General.* Use one of the moisture content measurement methods that corresponds to the appropriate insulating glass design (bulk desiccant, desiccant incorporated in sealant, or no desiccant). Ensure that moisture content values from different measurement methods are not mixed.

NOTE: Although the final outcome, the moisture penetration index *I*, is independent of the method used, the moisture content values are not.

B2.2 *Moisture content of desiccant in bulk.* When the desiccant in the test specimens is loose and not incorporated into a sealant, use the 950°C drying method to measure the initial moisture content *T*i, or the final moisture content *T*f.

B2.3 *Moisture content of desiccant incorporated in organic spacer*. When the desiccant in the test specimens is incorporated in an organic spacer, use the Karl Fischer method to measure the initial moisture content *T*i, or the final moisture content *T*f. Prepare and collect four samples of organic spacer material containing desiccant.

Note: The method directly determines the moisture contents: *T*i, *T*f.

B2.4 *Moisture content in insulating glass units without desiccant.* When the dew point temperature is measured in accordance with 20492-1:2007, Annex A, determine the corresponding water vapor partial pressure using the water vapor partial pressure table as function of the temperature (20492-1:2007, Table 2). Designate the value obtained as *T*i in the case of initial moisture content, and *T*f in the case of the final moisture content.

The value of the water vapor partial pressure obtained for the controlled limit environmental conditions (environment temperature of 10 °C with a dew-point temperature of -5 °C, giving a relative humidity of 32,8 %), shall be designated *T*c, and is equal to 402 Pa (dew point -5 °C).

Appendix C. Pressure Test Procedure

Pressure Test Procedure

C.1 Initial Pressure Exposure:

Long term performance of hermetically sealed spacer-edge-seal is the important part of determining the life expectancy of an insulating glass unit (IGU). Its long-term behavior is mainly defined by in-field exposure and climatic loads. Here, increasing stresses on the polymer sealants lead to can lead to polymer chain re-orientation. The stress and strain experienced in the field introduces changes in the physical properties of sealants inducing changes when measured in different directions, and causes macroscopic deformation of the spacer-edge-seal. Both affect the permeation rate of the edge seal, yet are not considered by the current established testing standards. Therefore, an attempt is made to specify a method to expose the test samples to wind loads experienced during wind gusts on a given day before conducting the accelerated weather exposure test.

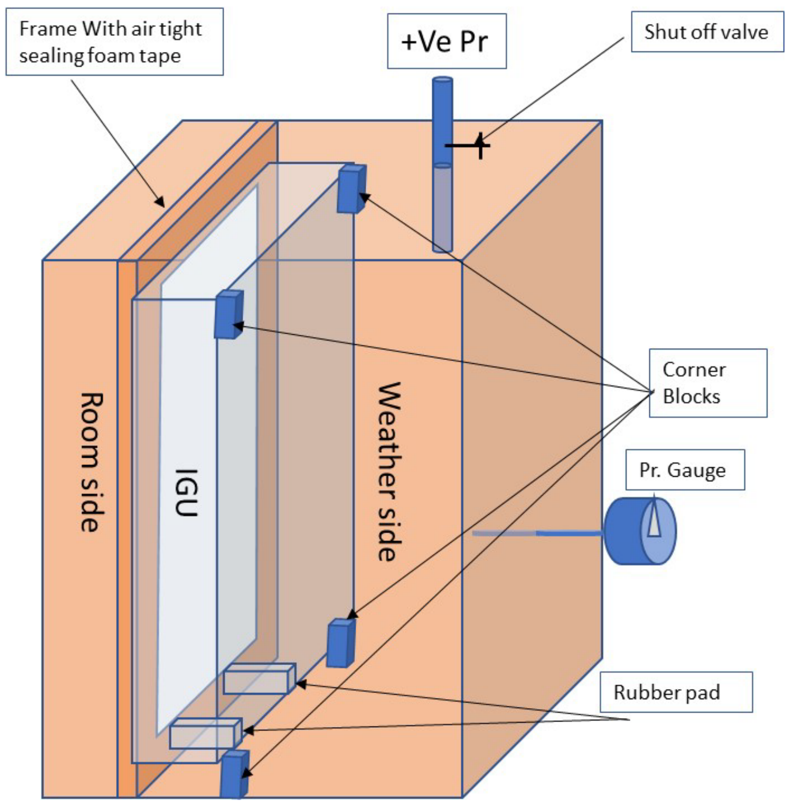

Figure C-1. Weather wind pressure exposure test

Chamber: The weather chamber represents the installation of an IGU in a building which has a weather side (out-door) and room side (in-door). The IGU is placed against a fixed frame which has a rubber gasket that seals the IGU and creates a hermetic seal preventing any leakage of air from the weather side to the room side. The IGU is held in place from the weather side using four corner clamps. The IGU bottom (sill) is placed on two rubber pads as it is installed in the window frame as shown in the figure.

The weather side chamber is pressurized to a level representing a given wind gust speed. Wind pressure is given by the equation $P = 0.00256 \times V^2$, where V is the speed of the wind in miles per hour (mph). The unit for wind pressure is pounds per square foot (psf). The IGU is exposed to five pressure cycles, i.e., the pressure is built in the chamber from atmospheric pressure to a specified pressure level and then held in place for five minutes and then released back to atmospheric pressure.

C.2 Procedure:

a) Select four samples from submitted units which will also be used for accelerated weather exposure testing and place them in the chamber. Mount each unit in a frame using the corner clamps.

b) Measure the glass and spacer-edge-seal thickness before commencing the tests.

e) After the sample is installed in the chamber, gradually pressurize the weather chamber to 25 psf.

f) Maintain the pressure chamber at the high pressure for 10 minutes, then release the pressure back to atmospheric pressure. Repeat the cycle five times.

g) Evaluate the IGU samples after the pressure testing as follows:

(1) Record the glass and spacer-edge-seal thickness before and after commencing the tests.

(2) Record any deformation in the spacer sealant.

Note: Breakage of the glass of any of the four specimen units tested shall not constitute a failure. If any units do fracture, they may be replaced by a spare unit after exposing to pressure test.

Appendix D. Optical Measurements

Optical Measurements

D.1 Apparatus

D.1.1 *Computer Controlled Spectrophotometer,* for obtaining and storing data from the optical characterization of the specimens.

D.1.2 *Spectrometer Light Source,* a tungsten lamp or other suitable lamp source that provides illumination from 300 to 1100 nm.

D.1.3 *Sample IGU holder,* Positions IGU for repeated optical measurements at the center of glass and the interior edge.

D.2 Procedure

D.2.1 Measure the optical transmittance between 300 nm to 1100 nm of all the IGUs following the procedure outlined in ASTM E-2141.

NOTE: The ASTM E-2141 procedure is intended for the evaluation of dynamic fenestration technologies. This requires optical characterization of IGU's in their tinted and clear states. This is not feasible with a non-dynamic technology. However, the same measurement procedure outlined in this method should be followed except for characterization in multiple states.

D.2.2 Measure transmittances per the spectrophotometer manufacturer's instructions ensuring that reference spectra for 100 % and 0 % transmittance are taken before each measurement and using at least 5 nm increments.

D.2.3 The sample should be positioned or marked 1.25 in from the spacer sight line of the lite such that the same spot on the sample is measured before and after exposure. See Figure D-1.

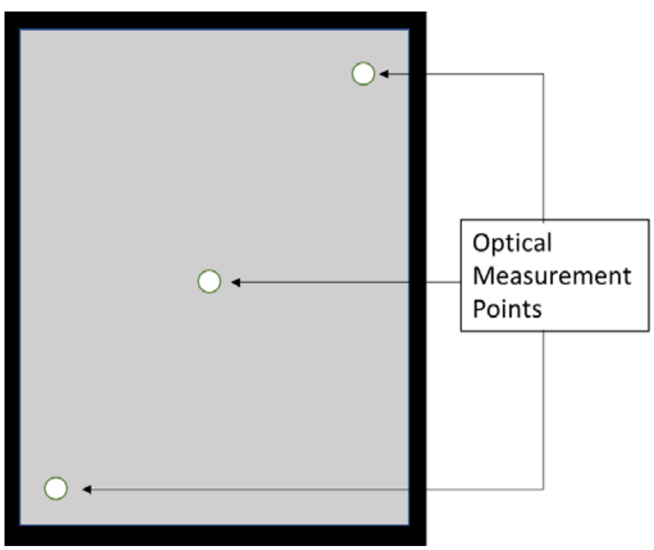

Figure D-1. Optical measurement points

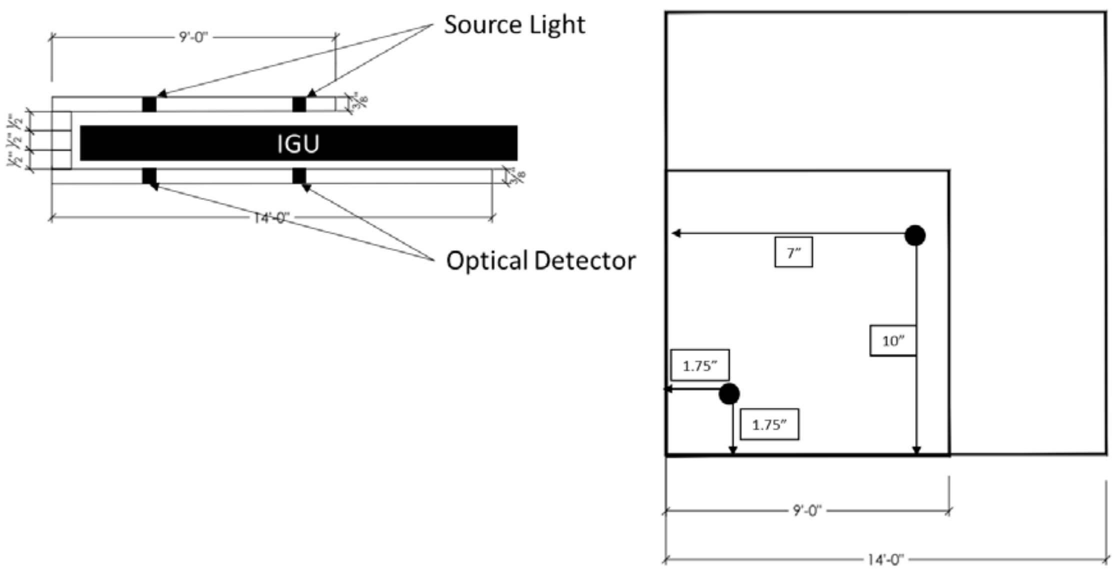

Figure D-2. Sample IGU holder for optical measurement