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G. R. Torok, W. Lichtenberger and J. C. Burgess

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Moisture Control and IG Unit Longevity

G.R. Torok[1], W. Lichtenberger[2], J.C. Burgess[3]

This paper presents a review of moisture-related causes of premature failure of insulating glass (IG) units. It is known that all IG units, hermetically sealed with one or more organic or inorganic sealants, with air spaces desiccated by adsorbents, will suffer moisture related failure. It is inherent in their composition. Moisture related failure is exacerbated by poor assembly of IG units and poor design of surrounding framing. This is not fully addressed by existing Canadian national standards for durability testing of IG units and performance testing of glazing systems (IG units plus surrounding framing), and only partly by proposed international standards. A criticism of existing and proposed standards with respect to IG unit assembly documentation requirements and performance testing, and performance and prescriptive requirements for glazing of IG units is given. A case study of widespread, premature failure of IG units is presented to illustrate premature failure of IG units due to prolonged wetting of the perimeter seal and the resulting need to glaze IG units to provide both exterior and interior seals. Drainage of the glazing cavity to the exterior is additionally recommended to remove water which may become trapped between the seals.

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[1] G.R. Torok is Project Manager with Gerald R. Genge (GRG) Building Consultants Inc., Sutton West, Ontario, Canada.

[2] W. Lichtenberger is Special Projects Manager, TruSeal Technologies Ltd., Hamilton, Ontario, Canada.

[3] J.C. Burgess is a scientist with the Building Research Association of New Zealand (BRANZ), Porirua City, Wellington, New Zealand.

Moisture Control and IG Unit Longevity

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The basic rules for long service life of materials are (a) to design so as to impose the least critical function upon a material, (b) to select a material that can perform the function and be durable in its service environment, or (c) to alter the environment to suit the proper-ties of the material that must be used.

Kirby Garden, 1969

It is probably safe to say that for most building enclosures and component materials, if the basic rules suggested by Kirby Garden [11] are followed, moisture related deterioration can be limited to local, minor repair (relative to the cost of replacement) from time to time. Roofing and waterproofing is an obvious exception, due in no small part to prolonged contact with water. Another exception, one not so obvious until considered thoughtfully, is insulating glass (IG) units. All IG units, hermetically sealed with one or more organic or inorganic sealants, with air spaces desiccated by adsorbents, will suffer moisture related failure. It is inherent in their composition. Moisture related failure is exacerbated by poor assembly of IG units and poor design of surrounding framing. This is not fully addressed by existing Canadian national standards for durability testing of IG units and performance testing of glazing systems (IG units plus surrounding framing), and only partly by proposed international standards. In this paper we will present recommended improvements in the construction of IG units and of window frames that should be considered by the prudent building designer to encourage the long life of IG units in windows.

Fundamentals of IG Unit Performance

Most IG units consist of two panes of glass, a perimeter spacer to separate the glass panes, desiccants (drying agents), and one or two sealants/adhesives to bind the spacer and glass panes together and to restrict the diffusion of water vapour into the IG unit air space.

The function of the desiccants (generally, a blend of desiccants is used) to remove water vapour from the interpane air space to prevent condensation on glass surfaces bounding the air space, when one side of the IG unit is exposed to temperatures colder than the dew point of the air. Typically, desiccants reduce the moisture content of the air considerably below that of the air outside of the IG unit. This creates a water vapour pressure gradient across the perimeter sealant(s). No sealant has an infinite resistance to water vapour diffusion and so, over time, water vapour diffuses into the interpane space. The desiccant adsorbs this “new” water vapour. However, desiccants have a finite capacity for adsorption of water vapour. As this capacity is used, the water vapour content of the air space increases. At some point, the water vapour content will be sufficiently high for condensation of water vapour to occur within the interpane space, on the glass panes. When this occurs consistently so that vision is obstructed, the IG unit is removed, discarded, and a new unit installed.

From this description, it can be seen that life span would be clearly dependent on:

- the resistance to diffusion of water vapour through the perimeter sealant(s) and
- the capacity of the desiccant(s) to adsorb water vapour.

In addition:

- Water vapour diffusion through sealant(s) is proportional to the water vapour pressure gradient across the perimeter sealants. The gradient is greatest when the unit is new and the air in the interpane space is driest. The gradient decreases with time as water vapour diffuses into the interpane space, the desiccant becomes saturated, and the moisture content of the air increases. The gradient is increased if the moisture content of the air in the framing surrounding the IG unit (glazing cavity) is increased. This might occur during humid summer weather, due to penetration of precipitation, or due to accumulation of condensate draining off the room-side surface of glazing in the winter [4, 6, 7, 16, 17].

- Water vapour diffusion through some materials may be adversely affected by relative humidity of the service environment [13, 26]. It is not known if this applies to IG unit sealants. For some other materials, it has been detected through comparison of ‘wet cup’ and ‘dry cup’ water vapour resistance test results in accordance with ASTM E96. IG unit sealants are typically tested to ASTM F1249 which is a ‘dry cup’ method and so such variations may not become evident during testing. Increased humidity of the air in the glazing cavity may be caused by ventilation to the outdoors during humid weather, penetration of rain water, or accumulation of condensation run-off.
- Water vapour resistance of sealant(s) depends on width and depth of the sealant, and consistency and continuity of application. Water vapour resistance is reduced at corners of dual seal IG units with spacers cut in sections and joined with mechanical connectors or ‘keys’. The joints between the keys and the adjacent spacers are only partly sealed by the innermost ‘primary’ sealant that is applied only between the spacer and the glass panes.
- Water accumulation in the framing and its prolonged contact with the IG unit perimeter seal detrimental to IG unit perimeter sealant(s). The ‘Field Correlation Study’ by the Sealed Insulating Glass Manufacturers Association (SIGMA) in the USA has shown that although well made IG units have a very low failure rate, most failures are due to prolonged wetting of the perimeter sealants [22, 23, 32, 33]. Potential sources for water include rain water penetration from the exterior due to failure of exterior glass/frame seals and penetration through framing joints, and drainage of condensation forming on room-side glass and framing surfaces [4, 6, 7, 16, 17].
- Manufacturing ‘errors’, in addition to discontinuity and inconsistency of sealants and bypassing of sealants through unsealed corners, such as insufficient sealant or compression of IG to ensure contact of sealants to glass (wet-out), poor glass washing and handling techniques that adversely affect bond of sealants to glass.

There are, then, a number of factors to be considered in the design and manufacture of both IG units and the frames into which they are installed, and also the manner of installation of the IG units in the framing. Unfortunately, this is not considered in Canadian and international standards for IG unit durability assessment and standards for overall glazing performance.

IG Unit Durability Test Standards

In Canada, the model National Building Code of Canada (NBCC) requires insulating glass units to meet the requirements of National Standard of Canada CGSB-12.8-97. Most provincial building codes are based on the NBCC and include the same requirement. The test method described in this standard, and almost all IG unit assessment standards world wide [4], was developed in the late 1950's by Wilson, Solvason et al, at the National Research Council of Canada (NRCC) Division of Building Research (DBR) [24, 25]. The test method attempts to simulate in a short period of time the forces that could be expected to act upon an IG unit and subsequently stress the sealant material and the sealant/glass bond, including:

- Changes in the volume of the interpane space due to temperature and barometric pressure changes, inside the units and in the air surrounding the units. The relatively positive or negative pressures created inside the interpane space, relative to the air surrounding the units, tends to force the glass panes against the sides of the spacer or pull it way, creating compressive and tensile stresses that must be resisted by the sealant(s).
- Differential thermal expansion and contraction of components, due to temperature differences from the inside to outside of the building, and due to unequal thermal expansion coefficients of the different materials used (glass panes, aluminum spacers, etc.).

This is done by installing IG units in a test rack, with one face exposed to constant, relatively "normal" interior conditions and the other to a cyclic regime of high temperatures with water spray, and low temperatures. Efficacy of the seal with respect to resistance to moisture gain is established by measuring the dew point of the gas fill in the interpane space by locally chilling one of the glass surfaces, at progressively colder steps until condensation forms on the glass, within the interpane space. The temperature at which condensation occurs is the dew point. The current CGSB-12.8-97 standard sets a maximum dew point temperature of -40ºC [27]. At warmer temperatures, the unit is considered to have failed.

With respect to water vapour resistance of IG units, one major change made since the development of the original test method was the addition of the high-humidity cycling test. It was recognized by Wilson and Solvason that although the amount of water vapour required to raise the dew point of IG units without desiccant(s) was very small, for units with desiccant(s), due to adsorption of water vapour by the desiccant(s), the amount of water vapour that would have to diffuse through the perimeter sealants must be very much larger, probably more than would diffuse into the units during the weather cycling test. The failures that did occur were ascribed to liquid water flow through openings in the perimeter seal [24]. Both weather cycling and high humidity cycling tests are included in the CGSB-12.8-97 standard.

The weather cycling test can be thought of as primarily a mechanical stress test for the sealants at temperatures similar to a severe Canadian service environment and the high humidity cycling test can be thought of as primarily a high humidity stress test for sealants.

Performance Testing vs. Reality

During development of the original test method, the performance of IG units in subject to the laboratory weather cycling test was compared against the performance of IG units exposed outside over a one year period. A good correlation was obtained between laboratory and field exposure, in the sense that if a high number of failures in the field then a high number of failures occurred in the lab, usually early in the weather cycling test. This suggested to the DBR researchers that the laboratory program was a reasonable acceleration of in-service conditions. Some units were left outdoors for longer periods of time [24] but the results of that weathering, as compared to the laboratory weather cycling test were not reported.

Correlation of the test method to actual IG unit performance installed in buildings does not appear to have been done at the time the original test method was developed. Nevertheless, it is generally considered that IG units passing the tests were capable of achieving at least 5 years of service, the length of the standard warranty offered by IG unit manufacturers when the basic test method was developed almost 40 years ago [4, 25] and typically, today as well. In North America, there has been one major study undertaken to correlate success in testing to success in actual in-service field performance. The recently reported 15 year results of SIGMA's 'Field Correlation Study', indicate a failure rate of 4.3% ± 1.6 % (20 year results have not yet been released). Failure is defined as 'moisture, fog or dirt collection' on the glass surfaces facing the interpane space [33], indicative of saturation of the desiccant or 'natural age death'. This suggests that it would be reasonable to expect the vast majority of well-made IG units – that is, those capable of passing the CGSB-12.8 test regime or ASTM E773 and ASTM E774 test regime (CBA level) - are capable of a attaining a service life of at least 15 years. This supports estimates published in various industry magazines and journals [7, 8, 16, 19, 22] and a specification manual that the service life of well-made IG units is at least 20 years [14].

Limitations of Performance Testing

It is reported that between 50% and 75% of the IG unit failures during the SIGMA 'Field Correlation Study' are due to prolonged wetting of the insulating glass unit seal [22]. Leaving this aside for the moment, 25% to 50% of the IG units failed for other reasons, although considering the definition of failure it is probably safe to say that the mode of failure was diffusion of water vapour through the perimeter sealant(s) and subsequent saturation of the desiccant. A number of probable causes were listed earlier in this paper. The IG units included in the survey came from different manufacturers and were made with different sealant materials and desiccants, and therefore different service lives could be expected. One would expect that if there was an inherent shortness of service life that could be attributed to materials alone, independent of service conditions, this would have become apparent and would have been reported, but it has not. It has been suggested elsewhere that because IG units are a product of human endeavours, some allowance for manufacturing error should be made [7, 8]. This seems to be a more likely cause, and it points to the following shortcomings in reliance on only performance-based testing as a tool for assessing quality of manufacture:

- Typically, IG unit performance test methods require test units of specific dimensions, typically 350mm x 500mm with a minimum12mm interpane space width and nominal 4mm thick glass. It is unlikely units with such specific dimensional requirements could be randomly selected from a manufacturer's daily production every time tests are performed, and thus it can be expected that the test units are specially made. CGSB-12.8-97, for example, attempts to offset this by requiring the specially made test units to be "fully representative of manufacturers standard production with regards to design and construction" [27]. In Canada, the Insulating Glass Manufacturers Association of Canada (IGMAC) also allows only the on-site auditor and manufacturer's personnel to be present in the plant during fabrication of the test IG units [31] to reduce the likelihood that the specially made test units receive any special attention during manufacture. Nevertheless, IG unit manufacturers sometimes become part of the process by providing audits of assembly or guidelines on the manufacture of IG units immediately prior to manufacture of test units [34, 35].

- The CGSB-12.8 standard does not mandate a frequency for testing. Neither does the model National Building Code of Canada or provincial building codes. Frequency of testing is mandated for IG unit manufacturers who are certified by IGMAC, but only on a four-year cycle unless there are changes in generic types of components used in manufacture or a change in the manufacturing facility location. Thus the number of units tested is very small.
- The CGSB-12.8 standard does not include requirements for reporting the construction of IG units. Reporting provided by test agencies authorized by IGMAC and the information subsequently contained in IGMAC's 'List of Certified Products' provides only a brief description of materials and no description of application. Thus quality of fabrication of IG units subsequently manufactured cannot be checked, either in the plant or in the field.
- Despite extra attention that may be provided during assembly, failure of 'special-run' sets of IG units does occur. Manufacturers can simply produce another batch of IG units for testing and try again. The number of times a manufacturer submits IG units for testing is not reported. Reporting of one or more failures to pass the test would be an important indicator of overall quality control by a subsequently certified manufacturer.

These shortcomings, together with only limited correlation of test method to service life, and considering that the cost of IG unit replacement can be substantial, a more detailed reporting of the construction of the test units would be beneficial to end users. The report should include a general description of sealant(s) application, including visible sealant bond-line dimensions (maximum, minimum, and variance), presence and extent of gaps in sealants, and for dual-sealed IG units constructed with tubular 'air spacers' and corner keys, whether the corners have been filled with primary sealant. This would enable end users to review construction of units in the plant, or as delivered to the job site, to confirm that the same quality of construction employed to pass the test method has been used on the units provided for their project.

In the meantime, in the absence of mandated reporting of IG unit construction details, for guidance for reviewing manufacture of IG units or subsequently in the field one can refer to sealant dimension guidelines published by IGMAC [29] and SIGMA [23], for other than conventional sealant materials such as polyisobutylene, polysulfide, and silicone. Construction guidelines are also occasionally published in industry media and other technical publications based on the results of independent testing [12, 22]. Upon request, sealant manufacturers will usually provide similar guidelines, although typically they tend to downplay inconsistencies and continuity issues.

Limitations of Frame Design

As noted, between 50% and 75% of the IG units that failed during the SIGMA 'Field Correlation Study' [22, 23] were found to have suffered prolonged contact with water. This finding, that the primary mode of failure of well-made IG units is prolonged water contact with the perimeter sealant(s), has been echoed recently in the glazing media [7, 8, 14, 16, 18, 19], and is noted in the 'User's Guide', Appendix D of CGSB-12.8-97 [27]. Water-related premature failure of IG units is not a new discovery, however, having been identified in the early 1960s by Wilson and Solvason in their second paper describing the development of the IG unit test method [24], in NRCC Canadian Building Digests 46 and 55 [10, 21], and in the seminal report "Aging Behavior .of Multiple Pane Insulated Glass Systems" by Feldmeier et al. at IFT Rosenheim, Germany [6].

In Canada, there is one omnibus window performance standard, CSA-A440, "Windows". As the name implies, this standard deals more with individual glazing units that form part of a building enclosure rather than glazing systems that form the entire enclosure - in other words, 'windows' rather than 'curtain wall'. Curtain wall design and construction is not subject to a specific design standard in Canada. With respect to glazing of IG units, CSA-A440-98 requires IG units to be "glazed in a manner which precludes accumulation of water in the glazing cavity" [28]. If a 'dry' seal (ie. a preformed gasket) is used as the exterior seal between the exterior face of the IG units and the surrounding framing, the standard requires drainage of the glazing cavity and an air and water seal is required between the interior face of the IG units and the surrounding framing. These requirements are consistent with the knowledge that prolonged water contact is detrimental to the perimeter seal of an IG unit.

Principles of design to promote drainage in walls and windows have been identified [1, 9, 15, 20]. Since 1993, the Scottish laboratory of the Building Research Establishment (BRE) in the UK has been running a research project that is examining the drainage of water and the ventilation of water vapour from within the glazing cavity surrounding IG units. A partner research project was started in New Zealand in1998 [3] in which common IG framing systems were installed in a laboratory building subject to a temperate climate, with the glazing cavity temperature, moisture content, and time of wetness measured and recorded. This work is gathering data on the effective removal of water and water vapour from the glazing cavity which would enable appropriate design decisions to be made to reduce the quantity of water that may penetrate seals.

Not stated by implied by the requirements of CSA-A440-98 is that if a ‘wet’ exterior seal (ie. a butyl glazing tape) is used, drainage of the glazing cavity is not required. The requirement for precluding water from the glazing cavity still applies, however, giving rise to windows with ‘wet’ exterior seals between IG units and framing, ‘dry’ interior IG/frame seals (typically), and undrained glazing cavities. In the event of failure of either seal, or incomplete application of one or both seals, water may accumulate in the glazing cavity and so wet the perimeter seal of the IG units, inducing premature failure. It is contradictory that CSA-A440-98 recognizes that water leakage around exterior ‘dry’ seals may occur and so requires drainage of the glazing cavity, yet it implicitly assumes that ‘wet’ seals will be perfect and no leakage will occur. This same contradiction has been incorporated into the proposed North American Fenestration Standard (NAFS) which has adopted the requirements of CSA-A440-98 with respect to glazing of IG units [36]. In the past, the CSA-A440 committee has justified the omission of drainage of the glazing cavities of exterior ‘wet’ sealed IG units on the basis of successful past performance [5]. As the following case study will show, past performance has not always been successful.

It is our view, supported by experience and research, that good design of framing (‘windows’, curtain wall, sloped glazing, etc.) includes for both complete exterior and interior seals between IG units and framing *and* drainage of the glazing cavity. This view is consistent with glazing recommendations by the insulating glass unit industry [30].

Case Study

In the early 1990s in the Toronto, following a ‘boom’ in construction in the mid to late 1980s, high rates of premature failure of IG units occurred in many high-rise residential apartment buildings. Investigations revealed the following contributing factors:

- Extensive condensation on the room-side surfaces of IG units and surrounding framing, caused by a variety of factors including incorrect operation of building make-up air supply, inadequate ventilation by residents, use of window coverings that thermally isolate the windows from warm room air, etc.

- A wet/dry, face-sealed, compression glazing system for the IG units, with the exterior wet seal being a pre-formed, unshimmed butyl compound glazing tape and the inside 'seal' being the edge of a removable, vinyl glazing stop. In some cases the edge of the interior stop is hard and inflexible, in others the edge had one or two rows of a softer, co-extruded vinyl. Over time, the glazing tape thickness was reduced due to compressive forces of the interior stop, wind action, volume changes of the IG unit interpane space, and differential thermal movements between IG unit(s) and frame. Reduction in glazing tape thickness resulted in a decrease in the efficacy of the seal between the interior face of the IG units and the interior removable stops, allowing condensation to drain into the glazing cavity.
- In some cases, the glazing tape material was defective in that under heat and UV radiation, it broke down and exuded from IG unit/frame joints. This made worse the decrease in seal between the interior removable glazing stops and the IG units, making it easier for condensation to drain into the glazing cavity.
- The use of an interior, removable vinyl stop with a horizontal leg that extends below and in contact with the perimeter seal of the IG units. Water bypassing the stop/IG seal collects on the horizontal leg directly against the perimeter seal of the IG units, resulting in prolonged wetting of the perimeter sealants.

Repairs undertaken in two sets of buildings in 1994 and 1996. In the first set of buildings, twin towers in a condominium complex, the work included:

- Replacement of failed IG units 'wet' glazed at the exterior with a glazing tape with an integral, continuous EPDM cord shim.
- Application of a clear silicone sealant between the interior face of IG units and the interior vinyl stops, and at joints in the vinyl stops. These seals were applied at both the remaining, original IG units and the new, replacement IG units.

The primary goal was to prevent drainage of condensation into and accumulation within the glazing cavity, especially on the horizontal leg of the interior glazing stops that held water directly against the IG unit seals. At the remaining, original IG units this was accomplished by the sealants added at the interior. At the new, replacement IG units this was accomplished by the use of a shimmed glazing tape subject to much less loss in thickness and application of sealants at the interior. In these buildings, in which between CDN$40,000 - $60,000 of IG units were replaced in 1994 and an unknown amount by the window manufacturer prior to expiry of the warranty, only about a dozen failures of remaining, original IG units were reported in the two years following repair. This confirmed the benefit of providing an interior seal to manage condensation drainage.

The potential weakness of the repair method is that seals were created at the exterior and interior faces but drainage of the glazing cavity was not provided. This was a limitation of the window frame design. Thus the seals had to be perfect. The exterior seals were well applied but the interior seals were found to be faulty in the majority of apartments and had to be augmented with new material. The low number of failures subsequently experienced indicate that the seals were done well enough the second time around to provide the required protection.

Incidences of widespread failure in newer high-rise residential buildings with similar windows have not been encountered. This coincides with changes in glazing practice, including:

- Exterior 'wet' seals of shimmed glazing tape.
- Interior removable vinyl stops that do not extend under the IG units.
- Interior removable stops that have softer, co-extruded vinyl bulb at the edge contacting the IG units (so-called 'dual-durometer'stops).

These features provide improved, longer-lasting seals at the exterior and interior faces of the IG units and appear to be sufficient to control the penetration of rain water and condensation run-off into the glazing cavity. The short-term results are good although with a typical absence of drainage of the glazing cavity, long-term performance may not be as good.

Summary

Returning to the quote from Kirby Garden that started this paper, requirements to ensure the long service life of IG units with respect moisture control may be summarized as follows:

Design so as to impose the least critical function upon a material. All IG units, hermetically sealed with organic or inorganic sealants, with air spaces desiccated by adsorbents, will suffer moisture related failure. It is inherent in their composition. While this cannot be changed, the time to failure can be improved by using good materials and proper assembly techniques for IG units and by improved glazing practices.

Select a material that can perform the function and be durable in its service environment. Premature failure is known to occur due to manufacturing related errors that result in discontinuities or inconsistencies in sealants. Such errors, if they exist in test IG units, are not reported. A more detailed description of sealant application is required, including visible bond-line dimensions (maximum, minimum, and variance), presence and extent of gaps in sealants, and filling of corner keys with primary sealant. This would enable purchasers to review construction of units in the plant, or as delivered to the job site, to confirm that the same quality of construction employed to pass the test method has been used to assemble their units. In the absence of such reporting, purchasers should insist on visible continuity and contact of sealants, visible consistency in sealant bond widths, and injection, wrapping or packing of corner keys or spacers with continuous, bent corners.

Alter the environment to suit the proper-ties of the material that must be used. The principle cause of premature failure of well-made IG units is prolonged water contact with the perimeter sealant(s). This is recognized by CSA-A440-98 and the proposed North American Fenestration Standard by requiring glazing to preclude the accumulation of water in the glazing cavity, and by requiring drainage to the exterior if the exterior IG unit/frame seal is a 'dry' type. The requirement for drainage should be extended to include windows with exterior 'wet' IG/frame seals. Purchasers of window systems should insist on exterior and interior seals *and* drainage to the exterior, irrespective of the type of exterior seal provided.

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