Design Considerations for IG Cavity Pressure Compensation
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1.0 Scope & Introduction

1.1 This technical manual provides generic design alternatives for cavity compensation for insulating glass units and determines conditions that impact the pressure in the IGU cavity.

1.2 Insulating Glass Units (IG or IGU) are dynamic assemblies in that the cavity can change dimensionally based on environmental factors (temperature and barometric pressure), dynamic load factors (wind load) and location (elevation). Since the cavity of a standard IG contains air, a fill gas or a mixture, the pressure and volume within the cavity are subject to these factors.

As the IG temperature increases, or the elevation is higher than point of manufacture, or lower barometric pressures, the volume of gas inside the IG increases relative to its original volume, causing outward deflection of the glass panes. Similarly, if the temperature decreases, or the elevation is lower than point of manufacture, or higher barometric pressures, the volume of gas inside the IG decreases relative to the conditions external to the IG, causing inward deflection of the glass panes. The amount of deflection is dependent upon the IG dimensional geometry, glass thickness, edge seal design and materials, glazing or framing design and materials and other factors.

Generally, IGUs are designed to withstand breakage or other effects from these dynamic and static forces. In some cases, the fenestration manufacturer or IG supplier will provide IG units to a location that will be permanently deflected, but well within the tolerance of breakage.

Some IG’s are manufactured with a compensation system based upon final location. There are several methods for compensating the IG cavity. This bulletin will describe some of the methods available. This document addresses compensation between point of manufacturing and final installation, but it does not cover daily fluctuations in cavity compensated with open capillary tubes (daily fluctuations are covered in TB-1601/95 (14) Guidelines for Capillary Tubes).

1.3 This document does not address uniform loads from wind load conditions. For symmetrical insulating glass units, the wind moves the inner and outer lites in concert and does not change the cavity space significantly.

This is a complex issue and there are many factors that will impact the functionality, specifically they may cause glass breakage and loss of seal integrity of the IGU. Some of these factors include but are not limited to size, aspect ratio, glass thickness, type of glass, sealant and spacer selection, spacer size and sightline. Contact your supplier for specific information. There are software programs commercially available that can address these factors as described in this document. A list of some of these software programs is included in Section 7.0 References.

1.4 Factors Affecting the Cavity Pressure

Glass thickness, glass area, aspect ratio, cavity width, altitude change, temperature, pressure (internal and external), are some of the factors that may affect the cavity...
pressure. Air, nitrogen, argon, krypton, xenon and other gas fills all respond in a similar manner to these factors (Ideal Gas Laws – see Item 1.5).

1.5 Mathematical models and explanation of theory for reference:

Gas Laws
The expansion of air (gas) due to pressure or temperature changes is predictable. The General Gas Law is the combination of Charles’ Law, Boyle’s Law and Gay-Lussac’s Law.

1.5.1 Ideal Gas Law states the following:

\[
\frac{(P_1 \times V_1)}{T_1} = \frac{(P_2 \times V_2)}{T_2}
\]

1.5.2 Charles’ Law states: \( \frac{V_1}{T_1} = \frac{V_2}{T_2} \)

Where: \( V \) = Volume and \( T \) = absolute temperature (\( ^\circ C +273 \ ( ^\circ F +460) \))

The volume of gas is proportional to the temperature.

The higher the temperature, the greater the volume if pressure is held constant. If the starting temperature is known, the average temperature of the gas in the IG when it was sealed is known and the temperature at the installation site is known then the effect temperature has on the volume of gas trapped in the IG can be calculated.

1.5.3 Boyle’s Law states \( P_1V_1 = P_2V_2 \)

The volume of fixed mass of gas at constant temperature is inversely proportional to the pressure. If pressure goes up, volume goes down. The value of pressure times volume becomes a constant.

\[ V_2 = \frac{(P_1 \times V_1)}{P_2} \]

If the starting elevation is known, \( P_1 \) (pressure one); destination elevation is known, \( P_2 \) (pressure 2) and the volume of air or gas in the IG is known, \( V_1 \) (the initial volume of gas) then \( V_2 \) (the volume of air or gas at the destination) can be calculated.

1.5.4 Gay Lussac’s Law states: \( \frac{P}{T} = k \)

The pressure of a fixed mass of gas varies directly with the temperature of the gas when the volume is constant.
Example:

An insulating glass unit sealed at 11°C (52°F) @ 305m (1000’) will be pressure neutral at 21°C (70°F) @ sea level. Conversely, an insulating glass unit sealed at 31°C (88°F) @ sea level will be pressure neutral at 21°C (70°F) @ 305m (1000’).

Unit size 610mm x 610mm x 6.4mm (24” x 24” x 0.250”) Cavity Volume = 2.36 liters (144ci)  
305m (1000’) = 0.98 bar (14.2 psi)  
0’ = 1.01 bar (14.7 psi)

A change in temperature from 11°C (52°F) to 21°C (70°F) will cause 2.36 liters (144ci) of gas to expand to 2.44 liters (149ci) (expansion of 0.08 liters [4.9 ci]).
A change in elevation from 305m (1000’) to 0.0m (0’) will cause 2.36 liters (144ci) of gas to be reduced to 2.28 liters (139ci) (reduction of 0.08 liters [4.9 ci])

This demonstrates that a temperature change of 7.8°C (18°F) is equal to 305m (1000’) of elevation change, or 1°C for 305m (1.8°F for 100’)

Computer Simulation:


2.0 Category Definitions

Tubes Inserted (TI): tubes inserted in units for pressure equalization at some point after fabrication.

Holes Resealed (HR): holes into the sealed cavity, created either in the field or at the factory, that are permanently sealed in the field for the purpose of cavity pressure compensation.

Pressure Adjusted (PA): Units initially made with a positive or negative preset.

Relief System (RS): Bladder or diaphragm

Post Fabrication (PF): Designs requiring a secondary fabrication process at or near the installed altitude (e.g. Closing of a valve).

3.0 Tubes Inserted (TI)

3.1 Capillary Tubes

General Description and Considerations
As defined in TB-1601/95 (14) Guidelines for Capillary Tubes, a capillary tube is a tube inserted in an IG unit to control unit internal pressure during shipping and/or during in-service use. Typically, they are either 0.81 mm (0.032 in) I.D. aluminum tubes or 0.53 mm (0.021 in) I.D. stainless steel tubes (both annealed and tempered) 300 mm long (12 in) long. They allow slow pressure equalization of the IG unit cavity. More details are covered in TB-1601/95(14).

Note: Capillary tubes may be left open or sealed closed according to the manufacturer’s instructions. This document only references tubes that are closed.

3.1.1 Advantages and Disadvantages

i. Advantages

- Relieve pressure caused by elevation changes from manufacturing point to job site that could cause glass breakage or severe visual distortion.
- Reduce pressure changes caused by elevation differences as a result of shipping that may cause glass breakage during transport (i.e. transport over a mountain).
- Assist in equalizing unit pressure during some types of unit fabrication processes.
- Minimizes reflective distortion due to glass deflection caused by barometric pressure and/or temperature changes.
- Ensure designed thermal performance by maintaining the intended cavity width.
- Reduced mechanical stress and damage to glass and/or spacer and/or sealant system during in-service use caused by cavity pressure changes. In extreme cases, the glass may break, or the edge system may be breached [a result is spacer blow out and/or seal loss and/or glass deflection.]
- Minimizes aesthetic concerns caused by glass contacting internal grids, especially with narrow cavity units.

ii. Disadvantages

- Added processing step during unit fabrication and the additional workmanship considerations.
- Not recommended for gas filled IG unit. (i.e. argon filled, krypton filled, etc.) Fill gas concentration will decrease, becoming equal to the surrounding air.
- Difficulty in closing tubes in the field.
- Inability to close tubes in window sash.
- Capillary tubes can get plugged during installation rendering their purpose ineffective.

3.1.2 Manufacturing Considerations and Guidelines

Fabricators utilizing capillary tubes shall have specific guidelines for the placement and installation of the tube in each type of IG unit manufactured based on the type of spacer system that is used, the sealant(s) for the perimeter
The IG perimeter sealant shall have and retain adhesion to the tube and shall completely seal the area around the tube where it penetrates the IG unit.

3.1.4 Storage and Handling

Special consideration with respect to storing units with open capillary tubes must be reviewed with the fabricator as improper storage conditions and open time can lead to the tubes allowing the accumulation of moisture, reducing the future capacity of the desiccant. This situation may be detrimental to the long-term performance of the units. Careful handling of the unit during the manufacturing process and placement into the shipping racks or cases is important so that the tube is protected and not damaged during the packaging and shipping process. Capillary tubes should be sealed once they have reached their final destination, once pressure equalization has been achieved and both glass lites are parallel to each other. IG with capillary tubes shall be protected from the weather and humidity at the job site. Handling units with capillary tubes carefully is critical so that the tube is not damaged or dislocated from the original position from the factory.

3.1.5 Glazing of IGU Utilizing a Capillary Tube

Glazing of IG units with capillary tubes should follow the fabricator’s instructions with regard to where the tube is to be placed in relation to the IG unit’s stop, sides or bottom of the installed IG Unit. It is normal to have the tube point down and positioned near the top of the unit. The tubes are generally sealed prior to the glazing operation. The capillary tubes should be glazed with the edge of the unit placed such that the tube has clearance so as to not be pressed against the glazing frame or accessories within the glazing system. Consideration shall be given to units that are pre-glazed and shipped to the final destination prior to sealing. The framing system should provide access to the capillary tube such that proper sealing of the tube can be accomplished.

3.1.6 IGU Consideration for Environmental Conditions

Environmental conditions that need to be considered for capillary tubes have been addressed in previous sections of the document regarding pressures, temperatures and volume changes that occur in insulating glass units. (See section one). It is important to understand the conditions that will be anticipated during the life of the units fitted with capillary tubes so that proper attention is...
given to the environmental conditions that can be expected from initial manufacturing to final installation. Variations in environmental conditions may occur during shipping, storage, extreme weather events, etc., many of which can be reviewed by the project team to make sure the conditions will not have an adverse effect on the installed units.

3.2. Breather Tubes

3.2.1. General Description and Considerations

As defined in TB-1601, Guidelines for Capillary Tubes, a breather tube is a tube inserted in an insulating glass (IG) unit to control unit internal pressure during shipping. They are generally 3 mm (0.12 in) in diameter and made of either aluminum, copper, polyethylene or other materials. These tubes must be closed at the job site or unit failure could result. They permit rapid pressure equalization of the IG unit cavity.

3.2.2. Advantages and Disadvantages

i. Advantages
   • Relieve pressure caused by elevation changes from manufacturing point to job site that could cause glass breakage or severe visual distortion.
   • Reduce pressure changes caused by elevation differences as a result of shipping that may cause glass breakage during transport.
   • Assist in equalizing unit pressure during some types of unit fabrication processes.
   • The breather tube can be inserted in either desiccated side or non-desiccated sides. When using the desiccated side, it is important that the desiccant does not block the tube during insertion.

ii. Disadvantages:
   • Added processing step during unit fabrication and the additional workmanship considerations.
   • Not recommended for gas filled units. Gas content will escape through the breather tube or capillary tube reducing the percent concentration of fill gas.
   • Difficulty in closing tubes in the field.
   • Inability to close tubes in window sash
   • Breather tubes should be covered temporarily with bags containing moisture adsorbent material (i.e. desiccant) during storage, handling and shipping, to be removed prior to installation.
   • Breather tubes can be closed by crimping the tube closed. Sealing or fusing the end of the tube can be done as additional insurance that the tube is completely closed and pressure tight. Reference TB-1601-95(16) Use of Capillary Tubes, Section 2.0 General Information and Consideration.
3.2.3. Manufacturing Considerations and Guidelines

Fabricators utilizing breather tubes will have specific guidelines for the placement and installation of the tube in each type of insulating glass unit manufactured based on the type of spacer system that is used, the sealant(s) for the perimeter sealing system or insertion method used to place the tube in the unit. The position and attachment will be determined by the fabricator such that the breather tube can be easily identified when shipped with the insulating glass unit. The fabricator should provide specific guidelines in writing relative to the proper handling and closing of the breather tubes when the units reach their destination. The breather tube is usually sealed as soon as the units reach the intended destination and not left open for any extended period of time.

3.2.4. Workmanship Considerations

The insulating glass perimeter sealant must have and retain adhesion to the access tube and must completely seal the area around the tube where it penetrates the unit.

3.2.5. Storage and Handling

Special consideration with respect to storing the units with breather tubes must be reviewed with the fabricator as improper storage conditions and unsealed time can lead to the tubes accumulating moisture situations that are detrimental to long term performance of the units. Storing in outdoor conditions without proper weather protection over extended periods are discouraged. Careful handling of units with breather tubes is critical so that the tube is not damaged or dislocated from the original position from the factory. Also, careful handling of the unit during the manufacturing process and placement into the shipping racks or cases is important so that the tube is protected and not damaged during the packaging and shipping process.

3.2.6. Glazing of IGU Utilizing a Breather Tube

Glazing IGU's with breather tubes should follow the instructions from the fabricator with regard to where the tube is to be placed with regard to the top, sides or bottom of the unit when installed. It is normal to have the tube point down and positioned near the top of the unit. The tubes are generally sealed prior to the glazing operation and within a time period as stipulated by the manufacturer. The breather tubes should be glazed with the edge of the unit placed such that the tube has clearance so as to not be pressed against the glazing frame or accessories within the glazing system. Consideration must be given to units that are pre-glazed and shipped to the final destination prior to sealing. The framing system should provide access to the breather tube such that proper sealing of the tube can be accomplished within the timeframe designated by the manufacturer.
3.2.7. IGU Design and Application Consideration for Environmental Conditions

Environmental conditions that need to be considered for breather tubes have been addressed in previous sections of the document regarding pressures, temperatures and volume changes that occur in insulating glass units. (See section one). It is important to understand the conditions that will be anticipated during the life of the units with breather tubes so that proper attention is given to the environmental situations that can be expected from initial manufacturing to final installation. The environmental conditions may occur during shipping, storage, extreme weather events, etc. many of which can be reviewed by the project team to make certain the conditions will not have an adverse effect on the installed units.

4.0 Post Fabrication (PF)

4.1 Valves

4.1.1. General Description and Considerations

IG Pressure compensation valves are intended to alleviate the pressure differential between the IGU gas space and atmospheric air caused by changes in altitude from the time of manufacture to installation. The most common mode is to specify a one-way valve designed to be mechanically depressed under a specific pressure differential load in order to adjust the pressure in the cavity relative to the atmospheric pressure at the time of manufacture. After venting the valve returns to a closed position, usually under the load of a spring. This method requires the valve remain uncovered during transport to the installation location for pressure adjustment after sealing of the IGU. For the technique to be possible, a valve must be installed into either the IGU spacer or one of the panes of glass before the time of filling. Although both are possible the former is recommended due to aesthetic and manufacturing advantages when sufficient area is available on the spacer.

Careful consideration of unit longevity needs to be taken when selecting a pressure compensation valve. This involves choosing a valve with a specific venting pressure at an identified altitude threshold such that the valve will only activate above that pressure threshold and remained sealed under pressures experienced during seasonal thermal cycles. Valves selected with low activation pressures may vent during high temperature conditions. This premature high temperature venting could cause a negative pressure within the IG and adversely affect IGU performance at low temperatures conditions, increased glass and sealant stresses and convex IG. Proper attachment and sealing of the valve to the spacer or glass could also influence the longevity of the IG. A method and materials resistant to gas and moisture permeation should be considered to not adversely affect the longevity of the IGU.

Two-way valves may be used when IGUs are shipped to both lower and higher elevations than the manufacturing location. Similar considerations as listed above
for one-way valves need to be made. However additional considerations need to be made to the venting pressure threshold when the atmospheric pressure is higher than the IGU cavity pressure. Desiccant capacity should be sufficiently high to absorb additional moisture that may enter the IG when venting ambient air into the IG.

Proper valve design must be done to prevent premature gas venting from the IGU. If an improper venting pressure is selected for the unit, the unit can bow inward excessively and potentially could cause seal failure or glass breakage. Depending on the pressure necessary to activate the valve, the glass may remain in a less bowed state after venting even in instances of proper valve design.

4.1.2. Advantages and Disadvantages:

i. Advantages:
   - Automatically adjusts to pressure, no secondary operations.
   - Can be integrated into the IG.
   - Immediate venting once activation pressure is achieved

ii. Disadvantages:
   - May be seen in the IGU cavity
   - May take too much pressure differential to activate the valve.
   - Two-way valves – pressure differential to activate too low and allows moisture / gas exchange
   - May need clearance in unit cavity
   - One-way valves may release pressure during hot seasons cause the IGU to be concave during cold seasons.

4.1.3. Workmanship Considerations

Care should be taken to ensure valves are properly mounted, secured, and sealed to the spacer or glass. A poor seal around the valve could negatively influence the longevity of the unit. Additionally, care should be taken in secondary sealant application to not cover the valve outlet when the value is mounted on the spacer. Covering the valve outlet could prevent the valve from venting and increase the stresses experienced by the IG seals and glass at the installed elevation.

4.1.4. Manufacturing Considerations and Guidelines

From a manufacturing perspective, the placement of the pressure compensation valve could change how the unit is assembled or gas filled. For IGU constructions using cold presses and chamber fill, installation of the valve into the spacer could be prior to gas filling but special care should be given to not cover the valve when applying the secondary sealant downstream.

Systems using hot presses and lance fill will likely want to install the valve after the IGU has moved through the oven and after lance filling to avoid pressure build up in the IGU and allow lance filling through the same hole the valve will be mounted
in. Properly designed valves may be able to move through the hot press if they can adequately vent the pressure build up in the IG, but only two-way valves would then be able to be gas filled through the valve after the oven and press. One-way valves would likely require an additional hole for gas filling if they were installed prior to being pressed. Material properties of the valve components need resistant to high temperatures when considering application before an oven.

Special considerations for glass handling should be made for any valves mounted in the glass surface. Rollers for glass transport may need to be designed to specifically handle glass with mounted valves. Assembled IGUs should be oriented with the glass pane containing the valve away from rollers whenever possible.

Post processing of assembled IGUs to add pressure compensation valves is another potential solution but runs the risk of gas dissipation during the process of mounting the valve and may require time constrained processes.

4.1.5. Storage and Handling

Pressure regulating valves should be kept free of debris during storage that may plug or restrict the airflow of the valve inlet/outlet or actuation of the valve disc.

4.1.6. Glazing of IGU Utilizing a Valve

When the IGU is glazed, the valve should remain uncovered to allow proper venting. Setting block placements and glazing sealant placements should be evaluated when locating the valve to avoid restricting airflow of the valve outlet. Additionally, mechanical loading of the valve by framing material could cause stress in the sealing & mounting method of the valve causing moisture or gas permeation around the valve.

4.1.7. Design and Application Consideration for Environmental Conditions

If an IGU is designed with a valve for cavity compensation at a lower installed elevation than manufactured, the IGU should be desiccated appropriately to compensate for additional moisture ingress during valve venting.

4.1.8. IGU Design Consideration

The IGU will need to be designed so that it has sufficient strength to perform under cyclical thermal loads, seasonal temperature changes and at the venting pressure of the valve. Calculations will need to be done to ensure the proper valve is used so the final internal pressure inside the IGU when installed fall within the design limits of the edge seal. Additionally, transportation temperature and altitudes should be considered when designing the unit. Cold temperatures and drops in elevation, especially after achieving elevation above the valve’s activation threshold, will add to the negative deflection of the unit, increasing the potential for glass breakage. Additional calculations need to be done for valve
specification taking into consideration the gas space volume and glass thickness, both of which will affect the gas space pressure.

It is common for multiple width spacers to be used in the industry depending on glazing cavity thicknesses and glass thicknesses. Dimensional constraints on narrow spacer widths will need to be considered when designing or specifying valves.

Manufacturers must also plan for the use of internal components (grids or blinds). Internal component connector locations and potential interferences will need to be identified before locating the valve in the IGU. Additional contributing factors to the placement of the valve may be influenced by the glazing cavity design. Setting block placements and glazing sealant placements should be evaluated when locating the valve to avoid restricting airflow of the valve inlet. Additionally, similar to internal component testing, the valve should be tested to ASTM E2189 for volatile fog performance.

5.0 Pressure Adjusted (PA)

5.1 Desiccant Adsorption / Desorption

5.1.1 General Description and Considerations:

The intent of desiccant adsorption / desorption techniques are to adjust the pressure inside of the IGU in order to compensate for changes in altitude from the time of manufacture to installation. The most typical mode is to adsorb a sacrificial gas from the cavity onto the desiccant in order to reduce the pressure in the cavity relative to the atmospheric pressure at the time of manufacture. This allows sealing at atmospheric pressure, without the need to puncture the spacer or glass for pressure adjustment after sealing. For the technique to be possible, a sacrificial gas must be mixed into the insulating gas at the time of filling and the IG must use a desiccant that will adsorb the sacrificial gas but not the insulating gas.

Take great care to pick a combination of desiccant and gas that will not compromise unit longevity. This includes choosing sacrificial gasses that are strongly held onto the desiccant and are not easily desorbed due to increases in temperature. When this occurs, this desorption will occur at high temperature and re-adsorption at cold temperature. This in turn will exaggerate the stress on the unit seals during daily temperature cycling reducing unit longevity.

Use of desiccant other than the 3 Angstrom desiccant will allow for more sacrificial gas choices for adsorption but may also cause nitrogen from the air to be weakly adsorbed. Potentially causing the above described exaggerated stress on the IG unit seals. Choose a sacrificial gas free of any hazardous properties like flammability, corrosiveness, color, odor, or toxicity. As workers may be exposed to these gases during production and in the event of glass breakage.

Proper gas mixing and design must be done to prevent excessive gas from being added to the IGU. If too high of a ratio of sacrificial gas is mixed into the IG unit,
the unit may bow inward excessively, and potentially could cause seal failure or glass breakage.

5.1.2. Advantages and Disadvantages:

i. Advantages:
   • Able to adjust for altitude without changes to the sealed system

ii. Disadvantages:
   • May require use of desiccant with pore size greater than 3 Angstrom
   • Requires knowledge of altitude of installation at time of manufacture
   • Requires additional gas beyond air and argon
   • Requires precise mixing / metering of gas to be adsorbed and pressures during manufacture.

5.1.3. Workmanship Considerations

The main advantage of using desiccant adsorption over other pressure compensation techniques is the IG seal design remains unchanged from typical design. It should be reiterated; glass breakage could occur if too much of the sacrificial gas is added to the IG unit. Additionally, as the seals of the IG unit cure, they may cure with the glass in a significantly bowed position. This may cause unusual stresses when the unit is parallel at its installed altitude. Testing should be done on to ensure this will not affect longevity.

5.1.4. Manufacturing Considerations and Guidelines

From a manufacturing perspective, the IGU will be produced as normal with the exception of the addition of the sacrificial gas. Premixed gas (standard insulating gas with a preset amount of sacrificial gas) could be ordered in premixed tanks, or mixed onsite at the time of manufacture. More or less sacrificial gas will need to be mixed to adjust the unit for the specific altitude of installation.

5.1.5. Storage and Handling

There is a time frame between storage and shipping where the unit may contract as sacrificial gas is removed from the cavity by the desiccant and could cause failure (i.e. seal failure, glass touching and damaging the low-e coating).

5.1.6. Glazing of IGU Utilizing Desiccant Adsorption / Desorption

The unit will likely be glazed with the glass bowed in negatively, when adding accessories like tape applied grills to the glass, this bow will need to be accounted for.
5.1.7. IGU Design and Application Consideration for Environmental Conditions

The IGU will need to be designed so that it has sufficient strength to overcome the negative bowing of the IGU during the time prior to installation at altitude. Calculations will need to be done to ensure the proper amount of sacrificial gas is added so the final internal pressure inside the IGU when installed fall within the design limits of the edge seal. Additionally, transportation temperature and altitudes should be considered when designing the unit. Cold temperatures and drops in elevation will add to the negative deflection of the unit, increase the potential for glass breakage.

Manufacturers also must plan for the use of internal components (grids or blinds). The negative bowing of the glass may cause crushing of the components and or scratching of the glass. Finally, packaging of the units should allow the units to expand during transportation uphill. No special considerations for environmental conditions.

5.2. Pre-Inflating / Pre-deflating

5.2.1. General Description and Considerations

Pre-inflating and pre-deflating can allow insulating glass to be manufactured at one elevation and adjusted to a desired cavity condition at its pre-determined destination. This method does have some limitations and may not work for certain IGU constructions, due to increased stress on the seal and glass. Pre-inflating/deflating can be done by removing or injecting gas to increase or decrease the volume by a specific amount to compensate for the expansion or contraction of the gas due to change in atmospheric pressure. This change in volume is usually accomplished by controlling the flow in or out of a unit. Using the example on page 4, a 610mm x 610mm x 6.4mm (24" x 24" x 0.250") IGU with a cavity volume of 2.36 liters at 1000’ would be reduced to 2.28 liters at 0.0m (0’), therefore you could pre-inflate this unit by adding 0.08 liters to compensate for it going from 305m to 0.0m (1000’ to 0’).

In many cases where the makeup of the unit is robust enough, it may be desirable to put the unit under the stress of inflating/deflating for a short period of time, but have an equalized unit at the destination elevation with the original unaltered seal it was manufactured with.

5.2.2. Advantages and Disadvantages:

i. Advantages:
   - Ship units with the correct volume of gas in them for their destination
   - Can be done very accurately with equipment available on the market
   - Can retain Argon / Krypton even while shipping to different elevations.
   - Can be used for temperature compensation as well.
Does not require any further processing after leaving the production plant therefore, there is no reliance on an installer or outside contractor.

- Can work with most spacer/sealant systems.
- This system can work with units going up or down in elevation or temperature.

ii. Disadvantages:

- Additional stress on IG seal until it arrives at the destination elevation.
- Typically done one unit at a time.
- Some unit sizes or constructions may not be able to handle the additional stress.
- Glass may contact the other lite of glass or internal grids when pre-deflating some units.
- May require specialized racking procedure/system for units.
- Some spacers and methods may require additional components (closures/seals) to be added to the IGU construction to help maintain the adjustment in the cavity.
- Can be very difficult to do without purchasing machinery to do it.

5.2.3. Workmanship Considerations

- Maintain the pre-inflation/deflation between adjustment and sealing.
- Final seal must be able to withstand stresses caused by adjustment.
- Operator must assure each unit is adjusted to the correct elevation setting.
- Must validate equipment periodically to assure flow meters and pressure readings are properly calibrated.
- Calculate volume adjustment based on the actual insulating gas being used (i.e. air, argon, krypton).
- Temperature in manufacturing and at the destination must be known.

5.2.4. Manufacturing Considerations and Guidelines

It is important to consider the manufacturing environment temperature and the average glass temperature at the destination elevation when calculating the adjustment volume.

5.2.5. Storage and Handling

Care also needs to be taken when handling, for example, larger convex IGU’s may not be able to be racked without space between the units to allow for the convexity.
5.2.6. Glazing of IGU Utilizing Pre-Inflating / Pre-deflating

Pre-inflating/deflating of IGU’s mean that they will have a convex or concave shape during glazing if they are glazed at the same elevation that the IGU was manufactured at. Glazing of convex or concave IGU’s can be done in most cases, however the manufacturer should pay close attention as the degree of concavity/convexity can vary a large amount depending on the size, aspect ratio and degree of adjustment.

Pre-inflated/deflated windows may be unable to operate until they reach the design elevation. This is especially true in sliding windows (horizontal and vertical) that are convex after adjustment. The convexity after pre-inflating can be enough in some applications to interfere with operation at the time of manufacturing.

Pre-inflated/deflated IGU’s can cause other challenges during window assembly related to installation of external muntin bars on convex/concave IGU’s.

5.2.7. IGU Design and Application Consideration for Environmental Conditions

Adjustment of IGU’s for change in elevation does induce additional stress on the edge seal from the time of manufacture until it reaches its final elevation. Many IGU constructions can handle this additional stress but the amount of stress, the size of the unit, the spacer, sealant and glass all need to be considered to determine when this type of adjustment is appropriate.

Pre-inflating/deflating is a method to adjust a unit for its elevation at the final destination in many cases, however, it does not compensate for changes in elevation during transit to the final location. Depending on the application pre-inflating/deflating may help lower the effect of elevation changes during transit or it may make them worse. For example, if a unit is manufactured at sea level and adjusted to go to 1524m (5000’) and during transit it goes over an 2538m (8000’) pass, the adjustment is lowering the effect of the 2538m (8000’) pass to be equivalent to 914m (3000’) different than the unit is made for. On the other hand, if an IGU is manufactured at 1219m (4000’) and adjusted for sea level but goes over a 3048m (10000’) pass on the way there, it will experience the full 3048m (10000’) difference. Whether or not the unit breaks or the seal fails will be dependent on the exact make up of that unit.

5.3. Temperature Manipulation

5.3.1. General Description and Considerations

Temperature manipulation is the process whereby the environment is controlled through heating or cooling the entire unit prior to sealing and / or gas filling. This impacts the gas volume as explained in Item 1.5.1.
Altering cavity volume using temperature manipulation at the time of fabrication is an easy way to implement the process and is predictable, but there are some drawbacks as well. Here are some pros and cons and mathematical models and explanation of theory for reference.

5.3.2. Advantages and Disadvantages:

i. Advantages:
   - The gas laws do not change so this method of volume manipulation is reproducible.
   - Controlling ambient conditions during gas filling and sealing not only results in the ability to alter the cavity volume but also results in a more consistent product being produced.
   - Simply air conditioning or heating a room or chamber to a predetermined temperature where the units are gas filled and sealed is all that is required.
   - Large batches become an easy task as the gas filling/sealing process remains the same and only the environment is altered.
   - Different sized units can go through the same temperature manipulation and may have the same results when installed at a different elevation.

5.3.3. Disadvantages:
   - Possibly inefficient to do small batches.
   - Construction of a climate-controlled room or apparatus may be difficult and interfere with other processes in the plant.
   - Increased cost to heat and cool the IG’s.
   - Temperature needed to compensate for installation elevation may not be reachable – too hot or too cold.

5.3.4. Workmanship Considerations

When batches of IGU’s are processed with this method, for example units in a climate-controlled air conditioned or heated room, then there are no workmanship considerations beyond typical (non-temperature manipulated) manufacturing.

5.3.5. Manufacturing Considerations and Guidelines

Refer to 1.5.1 and 1.5.2 for equations correlating elevation changes with the required equilibrium temperature of the IGU during the sealing process.

5.3.6. Storage and Handling

If the units are intentionally deflected at the time of fabrication, there may be special handling considerations when racking the units.

5.3.7. Glazing of IGU Utilizing Temperature Manipulation

Temperature manipulation will cause convex or concave conditions in the insulating glass unit. Refer to Section 1.3.
5.3.8. IGU Design and Application Consideration for Environment Conditions
Glass thickness, spacer, and sealant must be designed to withstand an atypical positive or negative pressure initially after construction as well as during transportation.

Construction of a separate climate-controlled room or the installation of something similar to a walk-in cooler may be necessary. The room would probably have large access doors so carts can be rolled in and out accommodating batches. Consultation with a heating / air conditioning professional would be advised to achieve the correct sized appliances.

6.0 Relief System (RS)

6.1. Bladders
While the benefits of using a bladder system are straightforward, there are numerous issues when considering their use including:

- Magnitude of elevation change to require use
- IGU pressurization due to temperature difference
- Use with air or insulating gases
- IGU sizes and aspect ratios
- Glass thickness, type and coatings
- Glazing space thickness
- Short term (in transit) vs. long term (installed) elevation and/or temperature changes
- Types of edge seal construction
- Multiple-cavity IGU’s (triples, quads, etc.)
- Proper IGU design and fabrication for use of capillary tubes

This document discusses each of these considerations for bladder systems and provides direction for proper design, application and advantages/disadvantages for their use in insulating glass.

6.1.1. Introduction
The use of a bladder system in insulating glass units is a means to accommodate for changes in elevation of an insulating glass unit (IGU) from the point of IGU manufacture to the point of installation. Such elevation change creates a pressure differential between the IGU glazing space and the exterior environment that, unless alleviated, can cause glass deflection, excessive edge sealant stress and/or glass breakage. These pressure changes can be exacerbated by internal heating of the IGU due to the radiant effects of the sun that are common at these elevations. A bladder system acts as a mechanism for relieving this pressure differential over a short period of time.
6.1.2. Terminology
Bladder System (Transport): A flexible container is attached to the IG cavity typically via a tube to control unit internal pressure during shipping. The flexible container (bladder, sometimes referred to as a balloon) is typically made of coated plastic or foil. The bladder is removed once the IG unit has reached the job site and sealed. The tube and bladder permit pressure equalization of the IG unit cavity during transport. Prior to final installation the access tube is sealed and the bladder removed.

Bladder System (Permanent): Similar to the transport system, however, this bladder system remains active throughout the life of the IGU. It can be used for a single IG unit or in parallel with multiple IG units. In the event of multiple IGUs the units are plumbed together. These systems can be plumbed to a compressed fill gas tank, to be actively replenished with fill gas. May have a bladder on the access tube for shipping.

6.1.3. General Description and Considerations
Bladder System Function
The bladder allows the IGU cavity to exhale and inhale as the unit is transported and as temperature and pressures change. If the unit is taken from a lower elevation to a higher elevation the bladder will inflate. If the unit is taken from a higher elevation to a lower elevation the bladder will deflate (needs to be pre-inflated at time of fabrication). These bladders are typically located outside of the sash for a transport system. This way they are accessible and can be removed and sealed at jobsite. If this is part of a larger permanent building wide system, then final plumbing of the units together will be required. During the transport of the units using a bladder system, the unit remains completely sealed, so there should no moisture uptake or gas loss.

Equalization Rate
The rate of equalization is dependent upon, access tube diameter, temperature, barometric pressure, altitude, IG unit dimension, glass thickness, cavity width, and the type of insulating glass spacer. Typically, the majority of pressure equalization will occur within 48 hours. As the unit equalizes in pressure, the pressure difference becomes less, and therefore the rate of pressure equalization is reduced.

6.1.4. Advantages and Disadvantages
i. Advantages:
   • Relieve pressure caused by elevation changes from manufacturing point to job site that could cause glass breakage or severe visual distortion.
   • Reduce pressure changes caused by elevation differences as a result of shipping that may cause glass breakage during transport.
   • Minimize reflective distortion due to glass deflection caused by barometric pressure and/or temperature changes.
   • Maintain thermal performance by maintaining the intended cavity width.
• Reduce the mechanical stress on glass and sealant during in-service use caused by glass deflection due to cavity pressure changes.
• Minimizes aesthetic concerns caused by glass contacting internal grids, especially with narrow cavity units.

ii. Disadvantages:
• Added processing step during unit fabrication and the additional workmanship considerations.
• Difficulty in removing and sealing access tube in the field.
• Inability to close bladder/access tubes in window sash.
• If used in a building wide system, can lead to unneeded complexity.

6.1.5. Workmanship Considerations

• The insulating glass perimeter sealant must have and retain adhesion to the access tube and must completely seal the area around the tube where it penetrates the unit.
• Inadvertently closing or plugging the tube during fabrication negates its value.
• Bladders must be securely placed over tube, no leaks.

6.1.6. Manufacturing Considerations and Guidelines

• IG Manufacturer should consider variables such as insulating glass unit construction, altitude, size, cavity thickness, glass type and thickness, shipped versus installation altitude when bladder systems should be used.
• The access tube can be inserted in a comer or through any leg.
• The tube should be inserted as per the spacer or sealant manufacturer’s recommendations.
• The tube can be inserted in either desiccated side or non-desiccated side of a box spacer. When using the desiccated side, it is important that the desiccant does not block the tube during insertion.
• It may be possible/conceivable to place bladder inside of non-desiccated spacer leg. This would be allowable for permanent bladder solutions, though pressure change must be known to so that spacer leg is large enough to accommodate bladder growth.
• A sufficient amount of the tube must extend beyond the unit to allow for access to place bladder over tube.
• It is important to protect the bladder from being prematurely damaged or destroyed.

6.1.7. Storage and Handling

Units manufactured with bladder systems should be stored to protect them from the elements. Care should be taken to prevent any physical damage to the bladder and tube.
6.1.8. **Glazing of IGU Utilizing a Bladder System**

- Units that are fabricated with a bladder systems that will remain permanently operating for the life of the IGU (building wide system) need to confirm all plumbing connections are without leak.
- Units that are fabricated with bladder systems where the bladder will be removed at installation must include the manufacturer’s (IG and/or bladder manufacturer) written instructions for removal. Proper removal of the bladder should ensure no damage occurs to the seal of the IGU.
- Properly sealing the access tube is of utmost importance.
- Units that are fabricated with bladder systems should be glazed in accordance with the bladder manufacturer’s written recommendations.
- The IG Manufacturer should be contacted regarding specific requirements for removing and sealing the bladder system or installing it into a building wide system in accordance with the IG Manufacturer’s written recommendations.

6.1.9. **IGU Design and Application Consideration for Environment Conditions**

1. **Altitude Changes and Duration**

   - IG units experiencing changes in altitude can fail from glass breakage, or pressure over loading of the edge seal. In addition, windows that employ sliding sash (vertical or horizontal sliders) may experience deflection from altitude changes that will not permit the window to operate properly. Check with the IG manufacturer for recommendations on when bladder systems should be used.

   - Multiple elevation changes: from the point of fabrication to the final place of installation an IGU may undergo multiple elevation changes during transport. In cases, such as shipment from US Midwestern States to the US or Canadian west coast through the US or Canadian Rocky Mountains there may be multiple elevations and, concurrently, short-term relative pressure changes between the IGU and ambient air. While these pressure intervals may be short in nature (several minutes to several hours) they may be quite extreme with elevation differences approaching 3,048 m (10,000 ft.).

   - Depending upon the relative difference in elevation change and time duration between changes, access tubes may not be of sufficient diameter to enable a pressure equalizing response over these short periods of extreme pressure change. IGU utilizing access tubes that experience such type of conditions should be treated as an IGU without access tubes and should be packaged to properly manage glass and edge seal stresses that will be experienced.
7.0 References


TB-1601-16, IGMA Guidelines for Use of Capillary Tubes
TM-3000-90(16), IGMA Glazing Guidelines for Sealed Insulating Glass Units for Commercial and Residential Use

“Gas Filling of IG Units”, Randi Emst, FDR Design, Inc

"PRESSURES AND STRESSES IN SEALED DOUBLE GLAZING UNITS" by K. R. Solvason, August 1974

Software:

1. W.R.Grace STRESS AND DEFLECTION APPROXIMATION PROGRAM, (NOTE: Only runs on DOS operating system).
2. FDR Pressures and Stresses calculator for Excel: https://fdrdesign.com/search?q=solvason+pressures+and+stresses
3. SDG Atmospheric Effects on Insulating Glass Units http://www.standardsdesign.com/AEIGU/AEIGUHome.htm
## Appendix A

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
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<tbody>
<tr>
<td><strong>System</strong></td>
<td><strong>System</strong></td>
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<tr>
<td>Passive Adjustment</td>
<td>May be visible in cavity</td>
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<tr>
<td>Integrated into IG units with correct volume of gas in them for their installation</td>
<td>May take too much pressure differential to activate</td>
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<tr>
<td>Can be done very accurately with equipment available on the market</td>
<td>Gas may not be able to activate too low and allows for condensation</td>
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<tr>
<td>Can retain Argon/Inert even while shipping to different elevations</td>
<td>Grill frame design needs to be considered</td>
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<tr>
<td>Can be used for temperature compensation as well</td>
<td>One way valves may release pressure during hot season, and become concave during cold season</td>
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<td>Does not require any further processing after leaving the production plant</td>
<td>May require use of desiccant with positive rate greater than 0.5</td>
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<tr>
<td>Works with most spacer/sealant systems</td>
<td>Requires knowledge of altitude of installation at time of manufacture</td>
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<tr>
<td>This system can work with units going up or down in elevation or temperature</td>
<td>Requires additional gas beyond air and argon</td>
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<tr>
<td>Volume manipulation uniform across a given set of sample depth designs</td>
<td>Requires plastic handling of gas to be absorbed and pressure during manufacture</td>
</tr>
<tr>
<td>Controlling ambient conditions during gas filling and sealing not only results in the ability to alter the cavity volume but also in a more consistent product being produced</td>
<td>Additional stress on IG seal until it arrives at destination elevation</td>
</tr>
<tr>
<td>Simply air conditioning or heating a room or chamber to a predetermined temperature where the units are gas filled and sealed is all that is required</td>
<td>Typically done one unit at a time</td>
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### Design Considerations for IG Cavity Compensation

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<th>Valves</th>
<th>Desiccant Actuation</th>
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<th>Temperature Manipulation</th>
<th>Molding</th>
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