Argonomics of Insulating Glass Units

The name of the game in today's window systems is energy performance. When you look back over the last few decades and track the evolution of energy efficient windows, the improvements are impressive. The overall R-values of dual pane insulating glass units have improved from less than R-2 to over double that value (>R-4). More recently, the development of triple pane windows improves this value to greater than R-9. The most recent developments in insulating glass technology using a vacuum space between glass plies (see *VacuMax*™ VIG units) can enhance the performance of any insulating glass unit by significantly improving thermal efficiency, delivering insulation performance that is two to four times better than conventional insulating glass and six to ten times better than standard monolithic glass. VIG units can deliver an impressive R-14 value, which is closer to the R-value of a traditional wall in a building. However, VIG units are beyond the scope of this technical document. Although the insulating property of glazing is important in all applications, the R-value of glazing is most important for northern climates and in residential use which is the primary focus of this technical document.

A major reason for the increased energy performance of glazing is due to advances made in the construction of insulating glass units, resulting in ever increasing R-values, or correspondingly decreasing U-values (R = 1 / U). The significant contributors to this improvement have come from:

- Low emissivity coatings
- Argon gas fills
- Warm-edge design
- Triple Vs Dual pane design

It is estimated that approximately 70% of insulating glass units include some type of low-E coated glass on one or more panes; approximately 30% use Argon gas fill; and in excess of 40% incorporate some type of warm-edge design. Triple pane design is relatively new and incorporation rates are still low. The FIGURE-1 performance pyramid illustrates the improvement resulting from these four factors.

Of these performance enhancements, the least understood and perhaps most controversial is the use of Argon (or other low thermal conducting gas such as Xeon or Krypton) in the "air space". What cannot be disputed, however, is the significance of a 15% performance improvement!

Argonomics of Insulating Glass Units

FIGURE-1 – Window Performance Improvement

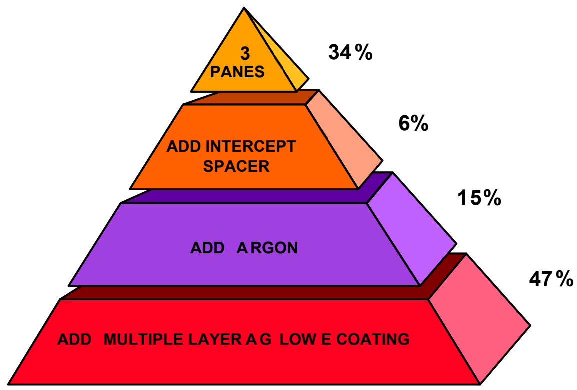


TABLE-1
CHANGES IN U-VALUE / LOW-E COATING VS. ARGON FILL

Insulating Glass Unit with Warm Edge Design
3mm Glass + 12mm Air Space + 3mm Low-E Coated Glass
For Center of Glass (COG) and Typical Wood Framed Window

IG UNIT CONFIGURATION	U-Value COG	ΔU COG	U-Value Window	ΔU Window
Coating emissivity = 0.10 - normal air fill	0.32		0.37	
Coating emissivity = 0.05 - normal air fill	0.30	**0.02**	0.36	**0.01**
Coating emissivity = 0.10 - Argon fill	0.27		0.34	
Coating emissivity = 0.05 - Argon fill	0.24	**0.03**	0.32	**0.02**
ΔU-value due to Argon gas fill	**0.05 0.06**		**0.03 0.04**	

As shown in Table-1 if we compare the effect of substituting a low-E coating with an emissivity of 0.05 for one with an emissivity of 0.10, the Center-of-Glass U-value improves from 0.32 to 0.30 or a ΔU COG of 0.02, which represents an improvement of approximately 6%. For the total window (ΔU Window), the improvement is 0.01 or approximately 3%. However, if we add Argon to the unit with the 0.10 emissivity coating, ΔU COG improves from 0.32 to 0.27 or by approximately 15% and ΔU Window improves from 0.37 to 0.34 or by approximately 8%. **The bottom line is that the improvement in total window U-value due to Argon filling is more than twice that of reducing the emissivity of the low-E coating by 50%.** This fact is more vital for residential glazing applications in northern climate zones.

Argonomics of Insulating Glass Units

Why Argon Works

The reason that Argon improves the R-value of an insulating glass unit is straightforward. Argon is a poorer conductor of heat than normal air. Or put in other words, it is a better insulator than air. That's really all there is to it - it's not "rocket science" and it is a fact confirmed by numerous tests. For a more complete discussion of the performance of various gas fills, you may wish to review Vitro's TD-101: *Gas Space Convection Effects on U-Values in Insulating Glass Units* and also TD-121: *Center of Glass U-Values for Double and Triple Glazed Insulating Glass Units with Solarban® 60 Low-e Glass with 100% Air, Argon, or Krypton or Mixtures of These Gases*.

There are better performers than Argon, as TABLE-2 shows. However, the benefits of Argon make it a good choice since Argon is:

- Inexpensive
- Colorless
- Odorless
- Safe
- Readily available

TABLE-2
THERMAL CONDUCTIVITY OF COMMON GASSES USED TO FILL INSULATING GLASS UNITS
Source: LBNL WINDOW Gas Library

GAS	THERMAL CONDUCTIVITY * (BTU/Hr-Ft-°F)
AIR	0.0139
ARGON	0.0094
CO2	0.0084
SF6	0.0075
KRYPTON	0.0050

* The lower the thermal conductivity, the better the gas insulates against heat loss

OK maybe there is some rocket science here -

The key to successfully manufacturing an Argon filled IG unit is of course to keep the Argon inside the unit. However, it is a known fact that all insulating glass units that are filled with Argon, or other Nobel gases, will lose some amount of gas over time due to the permeation of the gas

Argonomics of Insulating Glass Units

through the sealants even in a perfectly sealed IGU. So, what we are really talking about here is to not allow any additional gas leakage due to other factors such as:

- The type of sealant(s) used
- The design of the seal(s) and spacer
- Proper initial seal of the IGU
- Maintaining seal integrity over time

The long-standing accepted standard for gas retention in an IG unit, based on the German Standard DIN 1286, is a loss rate of 1% per year. This translates to a retention of 80% of the gas fill, Argon in our example, after 20 years of service. With the proper materials, design, and workmanship this is an achievable goal. Retention of less Argon fill will compromise the insulating performance capability and potentially the structure of the glazing unit especially if there is little to no retention of the Argon in the unit.

<u>Sealants</u>

The critical sealant physical property impacting gas retention is permeability. Permeability is the ease of movement of gases through a material. There is a wide range of permeability in the most commonly used IG sealants as shown in TABLE-3.

TABLE-3
SEALANT PERMEABILITY* TO ARGON
NORMALIZED TO POLYISOBUTYLENE(PIB)

SEALANT	RANK RELATIVE TO PIB
Polyisobutylene	1
Butyl Hot Melt	3
Polysulfide	40
Polyurethane	90
Silicone (two-part)	3000
** For specific products, consult the sealant manufacturer.*	

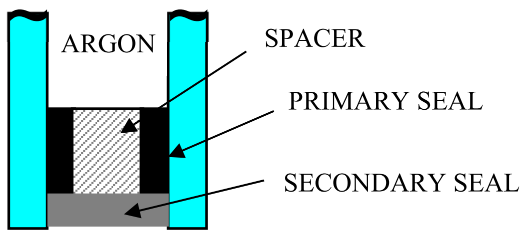
TABLE-3 illustrates that certain two-part silicones are 3,000 times more permeable than polyisobutylene. Or put another way, some two-part silicones will allow the Argon to escape 3,000 times faster than PIB under the same conditions. One-part silicone sealants, in general, have even higher permeability. Therefore, silicone sealants by themselves are generally not suitable for gas filled IG units unless they are specially formulated for Argon retention (i.e. high modulus silicone).

Argonomics of Insulating Glass Units

Seal Design

Let's focus on a typical dual seal IG unit as shown in FIGURE-2.

FIGURE-2 (not to scale)
TYPICAL DUAL SEAL IG UNIT EDGE CONSTRUCTION



The main barrier to gas retention is the primary seal which, in typical dual seal IG units, is PIB (polyisobutylene). From TABLE 3, we can see that PIB has the lowest permeability of any of the commonly used IG sealants. Properly constructed, such a unit could be expected to meet the acceptable Argon retention requirements **if the integrity of the primary seal is good to start with and is sustained throughout the IGU's life cycle.**

The flow of a gas through the sealant is calculated using the following formula:

$$Q = \frac{(\alpha)\,(\Delta P)\,(A)}{(L)}$$

Where Q - the flow
α - the material permeability
ΔP - the partial pressure difference (gas space to outdoors) of the gas involved
A - the cross-sectional area of the seal
L - the seal path length

In words, the formula says that the gas flow is equal to the product of the permeability of the seal (α), the partial pressure difference of the gas involved (ΔP), and the cross-sectional area of the seal (A), all divided by the seal path length (L). Given a partial pressure, the rate of gas flow (loss) can be reduced by:

- minimizing the cross-sectional area of the seal (A)
- minimizing the permeability of the seal (α)
- maximizing the seal path length (L)

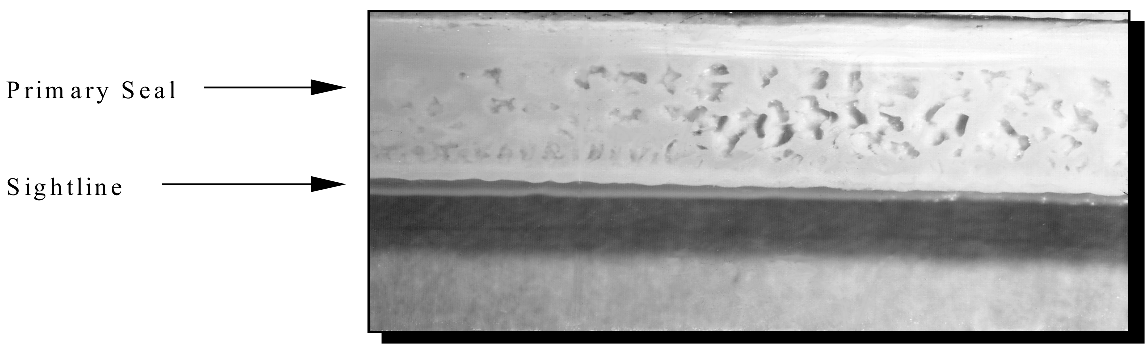
Argonomics of Insulating Glass Units

During service, the sealants are "worked" by a pumping action that is caused by temperature changes, barometric changes, wind loads, and thermal loads. Polyisobutylene has little resistance to such movement and can become deformed, where the cross-sectional area (A) is increased while simultaneously "necking down" its path length (L), resulting in increased rates of Argon loss. As can be seen from the above formula, both of these changes will increase the flow rate of gas through the sealant since (A) is becoming larger and (L) is becoming smaller.

To a certain extent, the deformation of the PIB is dependent on the ability of the secondary seal to resist the imposed movements. However, to a larger extent, the spacer type and configuration controls stresses in the PIB and the resultant deformation of the PIB sealant bead. During cycles of internal IG pressure change, the edges of the IG will tend to rotate. If the spacer is box shaped and relatively rigid, nearly all that motion will be translated into stress in the PIB and deformation of the PIB bead. This eventually leads to cavitation cells (voids) that form within the body of the PIB, similar to those shown in Figure-3.

FIGURE-3

PRIMARY SEAL CAVITATION



Gas entrapment in primary seal due to pumping of the seal during weather cycling (low modulus secondary seal)

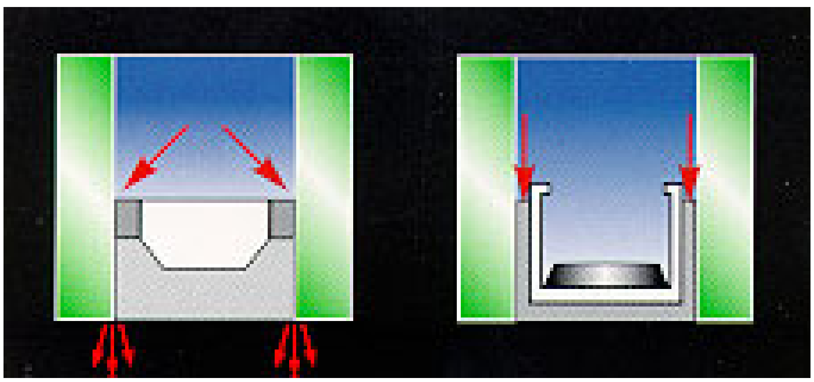
If the spacer is flexible, the glass edge rotations will be accommodated by the spacer with reduced deformation in the PIB bead. This fundamental difference greatly increases Argon retention in IG units with flexible spacers compared to IG units with rigid spacers. However due to the size, weight, and structural requirements of commercial windows, it is necessary to use a more rigid spacer (i.e., metal box spacer). With some types of rigid spacers, the use of relatively high modulus secondary sealants such as polysulfide, polyurethane, or high modulus silicone will reduce the deformation of the PIB and consequently retard gas loss. Lower modulus sealants such as low modulus silicone allow greater PIB deformation and, consequently, higher gas loss rates.

Argonomics of Insulating Glass Units

Since residential windows primarily use flexible spacers, this window design more readily lends itself for use of Argon fill. However, there are newer sealant and extrusion technologies available (i.e., thermoplastic spacer system) which replaces the PIB & metal spacer and overcomes these deformation concerns but with other potential concerns for gas leakage at the start/stop location.

Extensive Vitro research and development has gone into finding the proper insulating glass construction to retain Argon gas. The shape and flexibility of the Intercept™ spacer, as illustrated in FIGURE-4 below, combined with the use of low permeability sealants, provides one of the most effective designs available for keeping Argon gas inside the insulating glass unit.

FIGURE-4
ARGON ESCAPE ROUTES



Potential Sealant Fatigue | **Less Sealant Stress Due to Flexible Spacer**

If the secondary seal has high permeability in addition to low modulus (such as with low modulus silicone), there is **NO** second line of defense to retain the gas. TABLE-4 represents the results of tests measuring Argon retention in weathered and un-weathered IG units with different edge constructions.

Argonomics of Insulating Glass Units

TABLE-4
ARGON LOSS RATE TEST RESULTS*
TECHNICAL SEMINAR, INTER GLASS METAL, 1993
BASED ON DIN 1286 TEST METHOD

	LOSS RATE % PER YEAR	
SEALANT TYPE (PIB PRIMARY)	**UNAGED** (# of samples = n)	**AGED** (# of samples = n)
Polysulfide Dual Seal	0.4 (n = 122)	0.6 (n = 128)
Polyurethane Dual Seal	0.8 (n = 15)	0.9 (n = 13)
Low Modulus Silicone Dual Seal	6.5 (n = 30)	13.6 (n = 10)

* Presented by Morton International - "Performance of Gas Filled IG Units"

Similar testing of Intercept® insulating glass units was performed by the Institut fur Fenstertechnik e.V. under the direction of Professor Schmid. Testing was conducted using DIN 1286 part-2, which requires the evaluation of two samples. The results of the test are shown in Table-5.

TABLE-5
ARGON LOSS RATE TEST RESULTS
DUAL SEAL UNITS WITH POLYSULFIDE SECONDARY SEAL
BASED ON DIN 1286 TEST METHOD

SAMPLE NO.	GAS LOSS RATE % PER YEAR
Sample 1	0.14%
Sample 2	0.16%

**The long-standing accepted standard for gas retention is a loss rate of 1% per year.*

Argonomics of Insulating Glass Units

What Happens When the Argon Leaks Out?

As the Argon leaks out of an IG unit, oxygen, and nitrogen (which account for 99% of earth's atmosphere) do leak into the "airspace" **but at less than half the rate of Argon leaking out.** The end result is a pressure differential between the atmosphere and the sealed airspace. The lower pressure in the airspace than in the outside atmosphere causes the glass to deflect inward, otherwise known as a collapsed unit. FIGURE-5 and FIGURE-6 are real world examples of collapsed units caused by Argon loss.

FIGURE-5

NOTE THE DISTORTED REFLECTIONS OF THE VERTICAL MUNTINS CAUSED BY GLASS DEFLECTION AS A RESULT OF ARGON LOSS AND SUBSEQUENT UNIT COLLAPSE.

FIGURE-6

NOTE THE SEVERE DISTORTION IN THE UPPER GLASS LITES, AGAIN CAUSED BY GLASS DEFLECTION AS THE ARGON ESCAPES AND THE UNIT COLLAPSES.

Residential windows can be more prone to collapse due to the use of thinner glass (i.e., single strength glass, 2.5mm) which is more flexible. In these cases, a gas filled glazing unit may collapse just due to the naturally occurring Argon leakage even with a properly manufactured window. To understand why Argon leaks out faster than it can be replaced, we need to talk about partial pressures and the permeability of the sealant relative to the gases involved. The partial pressure is the driving force that causes a gas to go from point A inside the airspace to point B outside the airspace, while the permeability of a sealant describes how easy or hard it is for the gas to move through the material.

Argonomics of Insulating Glass Units

EXAMPLE – Partial pressure differences (∆P) in a unit filled with 100% Argon:

- Argon 14.7 psi - 0.1 psi = 14.6 psi (from gas space to the atmosphere)
- Oxygen 3.1 psi - 0.0 psi = 3.1 psi (from atmosphere to the gas space)
- Nitrogen 11.5 psi - 0.0 psi = 11.5 psi (from atmosphere to the gas space)

1) The IG unit has 100% Argon at atmospheric pressure of 14.7 psi; the outside atmosphere is <1% Argon @ 14.7 psi (14.7 x 0.01 = 0.1 psi) and the partial pressure difference is per above (14.7 - 0.1 = 14.6 psi) from the gas space to the atmosphere.

2) Seal permeability (α) normalized to Nitrogen and based on an average of published material permeabilities (Branrup, Immergut, Polymer Handbook, 2nd Edition, John Wiley & Sons, 1975).

- Argon 4.1 x Nitrogen
- Oxygen 4.2 x Nitrogen
- Nitrogen 1.0

What this means is that independent of the actual permeability of the sealant, both Argon and oxygen will permeate approximately four times faster than nitrogen through the same sealant.

If we substitute these values in the formula for gas flow (see page 5), we can establish the following ratios given the same seal path length and cross-sectional area.

- Argon (flow out) = 4.1 x 14.6 = 59.9
  gas permeability (α) times the partial pressure of Argon (∆P)
- Oxygen (flow in) = 4.2 x 3.1 = 13.0
- Nitrogen (flow in) = 1.0 x 11.5 = 11.5

If we add the Oxygen and Nitrogen "flow in" numbers we have a total inward impetus of 24.5. Given the 59.9 outward impetus of Argon, it is clear that the Argon will flow out of the unit at a rate of 59.9 divided by 24.5 or **2.4 times as fast as the oxygen and nitrogen will flow in to replace it.** This imbalance in flow rates may result in a net gas loss in the airspace that will cause reduced airspace pressure and eventually a collapsed unit constructed with glass that is thin and flexible. In collapsed units, the glass lites deflect inward toward each other with the following possible negative consequences:

- Optical distortion
- Reduced thermal performance
- Low-E coating rub/scratches where glass panes actually touch each other
- Seal failure
- Glass breakage

Argonomics of Insulating Glass Units

Conclusion

Let's summarize what we have discussed concerning the use of Argon in the manufacture of insulating glass units:

- **Argon is beneficial in many glazing applications** since it has significantly more influence on improving insulating glass R-value performance than some types of vacuum deposited low-e coatings.
- Argon loss and resultant collapsed insulating glass units with thinner glass components will likely occur with the use of some sealant types (i.e., low modulus silicone) and edge seal geometries (i.e., rigid box spacer).
- The energy conserving benefits of Argon can be realized, and Argon loss satisfactorily controlled with properly designed and manufactured insulating glass unit spacer and sealant systems.

The mechanisms involved with Argon loss in IG units are well known and understood as are the solutions to this problem. Therefore, **it is not necessary to avoid the manufacture or use of Argon filled units.** In fact, with the ever increasing demands of consumers, code requirements, and governmental regulations, the performance benefit of Argon fill is a necessity, cost effective, and the appropriate thing to do. Energy efficient Argon gas filled IG units with acceptable gas retention can be produced through the appropriate selection of a properly designed spacer and edge seal system along with proper workmanship during manufacture.

Argonomics of Insulating Glass Units

HISTORY TABLE		
ITEM	DATE	DESCRIPTION
Original Publication	March 1997	Technical Services Document
Post to Internet Site	5/8/2002	Argonomics – with minor changes.
Revision #1	10/04/2016	Updated to Vitro Logo and format
Revision #2	1/25/2019	Updated the Vitro Logo and format
Revision #3	2/21/2023	Revised to make current with newer IG designs such as triple pane and VIG; make some distinctions between residential & commercial and impact of regional climate
Revision #4	12/14/2023	Added qualifiers for silicone types, high modulus and low modulus.