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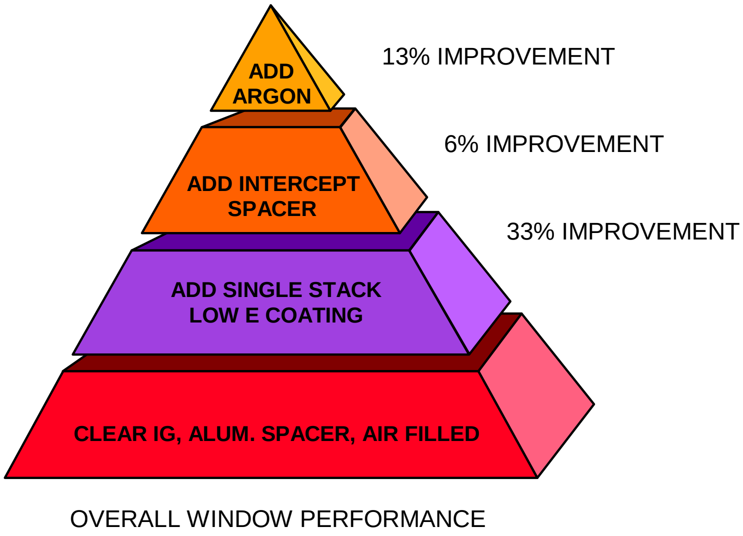
The name of the game in today's window systems is performance. When you look back only 10 to 15 years and track the evolution of energy efficient windows, the improvements are impressive. The overall R-values of dual pane insulating glass units have improved from less than 2 to 4 or more in a relatively short period of time. A major reason for this increased performance is advances made in the construction of insulating glass units, resulting in ever increasing R-values, or correspondingly decreasing U-values. The significant contributors to this improvement have come from:

- Low emissivity coatings
- Argon gas fills
- Warm edge design

It is estimated that approximately 30% of insulating glass units include some type of low-E coated glass; approximately 30% use argon gas fill; and in excess of 35% incorporate some type of warm edge design. The following performance pyramid illustrates the improvement resulting from these three factors.

FIGURE 1



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Of these three performance enhancements, the least understood and perhaps most controversial is the use of argon (or other low thermal conducting gas) in the "air space". What cannot be disputed, however, is the significance of a 13% performance improvement! As TABLE 1 demonstrates, the U-value improvement gained from using argon is two to three times as great as is realized from moving from a single stack MSVD low-E coating (typical emissivity of about 0.10) to a double stack MSVD low-E coating (typical emissivity of about 0.05).

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 for Typical Wood 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 Due to Argon gas fill	**0.05 0.06**		**0.03 0.04**	

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, we see that the Center-of-Glass U-value (U-value COG) 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 0.05, approximately 15% and ΔU Window improves from 0.37 to 0.34 or 0.03, 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 from 0.10 to 0.05.**

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Why Argon Works

The reason that argon improves the R-value of an insulating glass unit is straightforward: It 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 (formerly PPG Industries) TD-101: "Gas Space Convection Effects on U-Values in Insulating Glass Units" and 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 below shows; however, the benefits of argon make it a good choice. Argon is:

- Inexpensive
- Colorless
- Odorless
- Safe
- Readily available

TABLE 2
THERMAL CONDUCTIVITY OF COMMON GASSES USED TO FILL INSULATING GLASS UNITS FROM LBL WINDOW 4.1 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

O.K. maybe there is* some *rocket science

The "key" to successfully manufacturing an argon filled IG unit is, of course, to keep the argon in the unit, i.e., not let it leak out. If it does leak out, you not only lose the performance benefit, the unit may collapse.

Retaining the argon in the IG unit is dependent on several factors:

- The type of sealant(s) used
- The design of the seal(s) and spacer
- Maintaining seal integrity

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The accepted standard for gas retention in an IG unit, based on the German DIN 1286 Standard, is a maximum loss rate of 1% per year. This translates to a retention of 80% or more 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 than 80% of the Argon fill will seriously compromise the insulating performance capability and structure of the unit.

Sealants

The critical physical property of sealants that impacts 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.***	

What TABLE 3 illustrates, for example, is 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.

Seal Design

Let’s focus on a typical dual seal IG unit as shown in FIGURE 2

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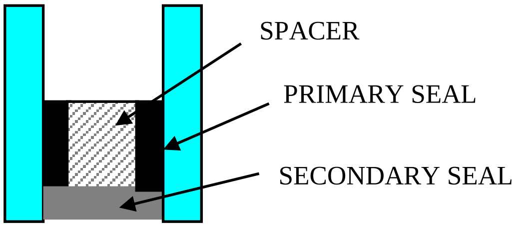
FIGURE 2
TYPICAL DUAL SEAL IG UNIT EDGE CONSTRUCTION



The main barrier to gas retention is the primary seal which, in 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 maintained.**

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

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

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

During service, the sealants are worked by 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 in the above formula) is increased while simultaneously “necking down” its path length (L in the above formula), which will lead to 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.

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To a certain extent, the deformation of the PIB is dependent on the ability of the secondary seal to resist the imposed movements. To a larger extent however, the spacer 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 of that motion will be translated into stress in the PIB and deformation of the PIB bead, eventually leading to cavitation cells (voids) forming 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. With rigid spacers, the use of relatively high modulus secondary sealants such as polysulfide or polyurethane will reduce the deformation of the PIB and consequently retard gas loss, while lower modulus sealants such as silicone allow greater PIB deformation and, consequently, higher gas loss rates.

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 low permeability sealants, provide one of the most effective designs available for keeping argon gas inside the insulating glass unit.

FIGURE 4
ARGON ESCAPE ROUTES

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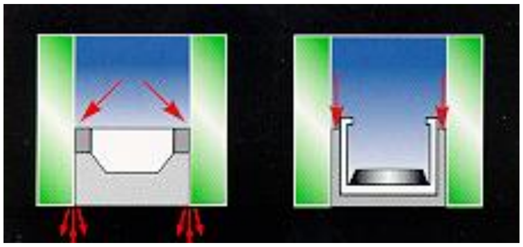

Potential Sealant Fatigue

Less Sealant Stress Due to Flexible Spacers

If, in addition to low modulus, the secondary seal has high permeability, such as with silicone, there is no second line of defense to retain the gas. TABLE 4 represents the results of tests to measure argon retention in weathered and unweathered IG units with different edge constructions.

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)
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.

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TABLE 4
ARGON LOSS RATE TEST RESULTS
DUAL SEAL UNITS WITH POLYSULFIDE SECONDARY SEAL
BASED ON DIN 1286 TEST METHOD

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

What Happens When the Argon Leaks Out?

As the argon leaks out of an IG unit, oxygen and nitrogen (which account for 99% of our atmosphere) do leak into the "airspace", **but less than half as fast as the argon is leaking out.** The end result is a pressure differential between the atmosphere and the sealed airspace (lower pressure in the airspace than the outside atmosphere) that causes the glass to deflect inward, otherwise known as a collapsed unit. FIGURES 4 and 5 are real world examples of collapsed units caused by argon loss due to the type and geometry of the sealants used in the insulating glass units.

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.

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To understand why the argon leaks out faster than it can be replaced, we need to talk about (A) partial pressures and (B) 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.

(A) Partial pressure differences (ΔP) 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)

For example: The IG unit has 100% argon at atmospheric pressure = 14.7 psi; the outside atmosphere is <1% argon @ 14.7 psi or 14.7 x 0.01 = 0.1 psi and the partial pressure difference is, as above, 14.7 - 0.1 = 14.6 psi from the gas space to the atmosphere.

(B) 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 4 times faster than nitrogen through the same sealant.

If we substitute these values in the formula (for gas flow) from 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

In words, the gas permeability (α) times the partial pressure of argon (ΔP)

- 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 the Argon, it is clear that the argon will flow out of the unit 59.9/24.5 or **2.4 times as fast as the oxygen and nitrogen will flow in and replace it.** This imbalance in flow rates may result in a net gas loss in the air space that will cause reduced airspace pressure and, eventually, collapsed units. In collapsed units, the glass lites deflect inward toward each other with the following possible consequences:

- Optical distortion
- Reduced thermal performance
- Low-E film rub at center

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- Seal failure
- Glass breakage

Conclusion

First, let's summarize what we have discussed concerning the use of argon in the manufacture of insulating glass units.

- Argon **is beneficial** - it has significantly more influence on improved insulating glass performance than some types of vacuum deposited low-e coatings.
- Argon loss and resultant collapsed insulating glass units can occur with the use of some sealant types and edge seal geometries.
- 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 the problem. **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 the government, the performance benefit of argon is necessary, cost effective, and the right thing to do. Energy efficient argon gas filled IG units, with acceptable gas retention, can be produced through the appropriate selection of a low permeability sealant, a properly designed spacer and the correct sealant application.

There are technologies on the market which have addressed and solved the problem of argon loss and resultant insulating glass unit collapse. Those technologies are widely available today and there will be new technologies available in the future. To eliminate argon, or avoid its use, would be a step backward. Let's keep what we have gained, and then all go out and look for the next good low cost alternative that can beat it.

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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	2016-10-04	Updated to Vitro Logo and format