6 UNDERSTANDING the VACUUM INSULATED GLAZING (VIG)

VIG is a double glazing unit where the air between the two panes of glass has been extracted, creating a partial vacuum. A vacuum provides excellent thermal efficiency because when the pressure is low enough, it will eliminate the conductive and convective heat exchange between the two panes of glass.

In a standard double glazed unit with a low-e coating, the conduction/convection component can result in 70% of the heat lost; so eliminating this loss is significant. The radiative heat loss can than be reduced by use of a low-e coating inside the VIG, producing an even lower U-factor.

For efficiency of a vacuum in reducing heat loss, typical distance between the two panes of glass is 0.2 mm. This is significantly less than a conventional IGU (air space 12 mm). As a result, VIG units can have thickness of 6.2 mm, comparable to a monolithic piece of glass but with the performance of a triple glazed insulated glass unit. Currently U-factor for a commercially available 6.2 mm thick VIG is 1.0 W/m2 K

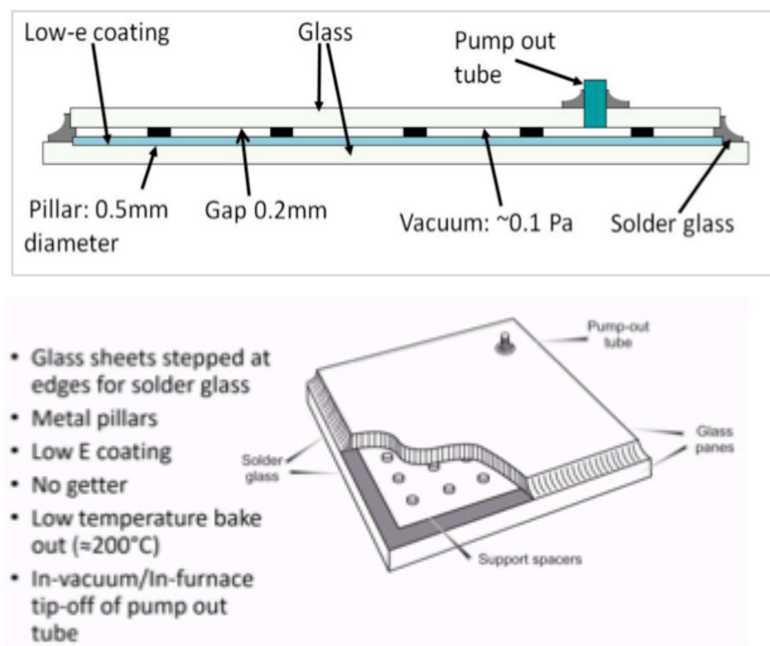

Figure: Schematic diagram of a VIG unit
Source: McSporran,.N (Top), University of Sydney (Bottom)

In a VIG unit, a hermetic seal is essential to maintaining the vacuum and energy efficiency of the unit, so such failures cannot be tolerated. Use of a glass seal in a VIG ensures that—providing the seal is manufactured correctly—ingress due to moisture is eliminated (glass has a moisture vapour transport rate of < 10e–6 g/m2 / day). Matching the thermal expansion coefficient of the soda lime glass with the glass seal is important to ensure that thermal mismatches do not occur that could cause seal failure. A specially designed glass solder that meets the above requirements is used. This type of solder glass has been used in the electric industries for many years with products like vacuum tubes, CRT displays, and plasma display panels. The pump out tube is also sealed using glass.

UNDERSTANDING the HIGH PERFORMANCE GLAZING SYSTEM

KEYWORDS: Energy Efficiency, High performance glazing, Vacuum Insulated G1lazing (VIG), tVIG (Tempered Vacuum Insulated Glass), SHGC (Solar Heat Gain Coefficient), U factor

For a smart, sustainable, and inclusive growth**,** the federal Government Bill C-12 (if approved) would see Canada to set greenhouse gas reduction (net Zero buildings) targets every five years starting in 2030-2050 (Foot note: 1). However, as energy codes become more stringent, maximizing the energy efficiency of the glazing used in buildings would becomes of greater importance. Glass building envelopes are appreciated for public buildings and commonly associated with contemporary architecture. While, curtain walls are often criticized for their limited insulation properties, the architectural need is to maximize glass surfaces for functional and aesthetic reasons challenges the poor thermal transmittance of glass in comparison with opaque components.

There are many solutions to reduce heat transfer through glazing and curtain wall framing. One such technology that is currently growing in prominence is **vacuum insulated glazing (VIG).**

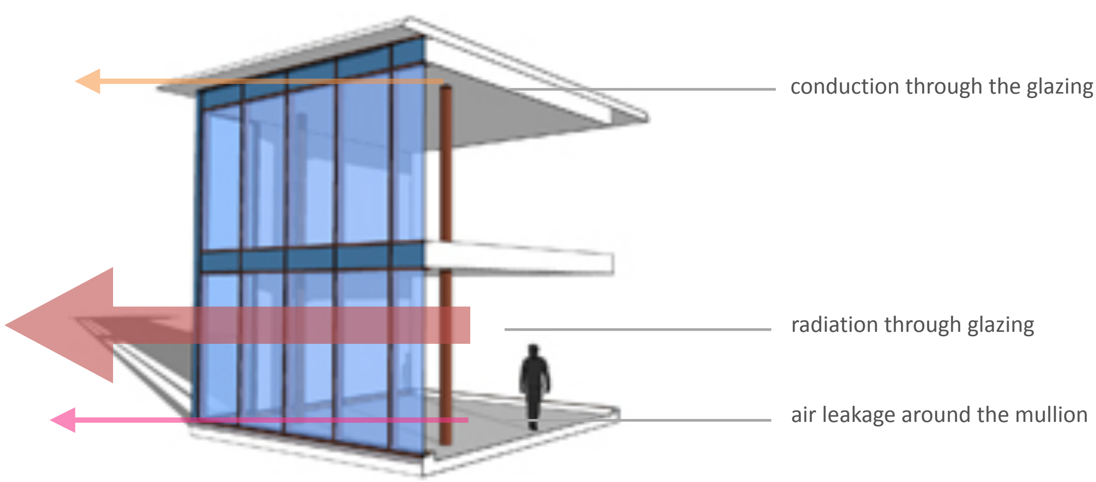

Figure: 3% of World's energy is wasted due to the thermal inefficiency of today's glazing system.
Source: Hybrid Curtain wall system

Designing Glazing

Architects must balance two important factors while designing glazing in building: its **aesthetics and performance**- for occupant's well-being and productivity. Aesthetics refer to the appearance of the glazing — how it matches other materials and complements. Performance is the HVAC needs of the building, occupant comfort, and always by energy and safety codes. The energy usage of a building is heavily influenced by the use of windows. So understanding some of the important parameters in glazing design is very important.

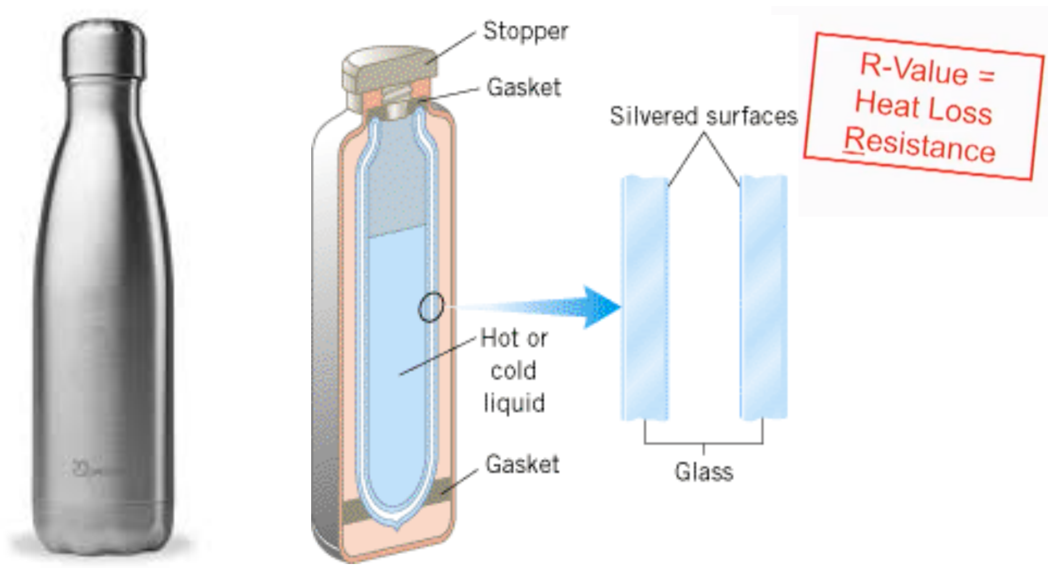

Figure: VIG Glasses are like a thermos Bottle when it is flat and transparent.

Understanding SHGC and U factor

The thermal performance characteristics of glazing described by two attributes: Solar Heat Gain Coefficient (SHGC) and U-Factor.

- **SHGC** is the ratio of solar heat gain through the glass relative to the incident solar radiation on the glazing. i.e., how much heat from the sun is transmitted into the building. SHGC is a decimal quantity from 0.0 to 1.0. **Higher SHGC numbers representing a larger amount of solar gain**.

- SHGC includes the solar energy that directly transmitted through the glazing plus the solar energy absorbed by the glazing and subsequently convected and thermally radiated inward. It is beneficial to incorporate a higher SHGC glazing (with a coated glass) when the heating costs of a simple building exceed its cooling costs.

- **U-Factor** describes the thermal conductivity or the heat flow through the glazing from the warm side to the cooler side. U-factor is the rate of heat loss per square metre, under steady state conditions, for a temperature difference of one kelvin and is expressed in **W/m2 K.** As for SHGC, there are number glazing options that used to control U-factor. **Higher U value represents worse thermal performance of the building envelope**.

- **R- Value**: Heat loss can be quantified in terms of thermal resistance, abbreviated to R value. This is the inverse of the U-factor.

Heat Transfer Mechanisms

Heat flows from hot to cold area and heat transfer takes place via conduction, convection and radiation
Three defined stages of heat loss in glass products (Foot note02):

1. Heat loss to the internal glass surface: When the glass is at a lower temperature than the room temperature. This Radiative heat loss dominates unless the glass surface has a low emissivity coating (emissivity typically from 0.02 to 0.2).

2. Heal Loss through the glazing: Glass has a high thermal conductivity. This is why single glazing is a poor insulator. Heat loss can be reduced by adding an additional pane and air space, i.e., an insulated glass unit (IGU). The low thermal conductivity of air reduces conductive loss and the second pane gives additional resistance loss by radiation. Performance can be further improved by using a lower thermal conductivity gas such as Argon or Krypton. Use of a low-e coating in the air gap will reduce the long wave radiation exchange between the panes by more than 75% and lower U-factor by approximately 25% to 40%.

3. Heat loss from outer glass surface: Here conduction and convection dominate due to the influence of wind. Radiation exchange depends on the weather condition, and temperature of the surrounding surfaces.

Reduced Heat Transfer Options

Building codes require **lower U-factors to reduce heat loss** from windows. To meet code requirements, some solutions are:

- Use of **lower thermal conductivity gas** than Argon, e.g., **Krypton**. It **lowers U-factor**. However, it is costly and not widely used, as over time gas inevitably leaked from the IGU and, reduces energy efficiency.

- **Low-e coating** on surface #4 of a double-glazed IGU (i.e., the outside surface of the internal pane of glass). This coating typically complements a low-e coating on surface #2 of the unit and **reduces U-factor by around 20%.** This can increases **risk of condensation** formation, due to the temperature of the internal pane of glass being reduced. Double Glazed Unit DGU with a *U*-value of 1 W/sqm·K and thickness around 28–32 mm.

- Use of a **second air space and third pane of glass,** giving **a triple glazed unit** (popular in North Ameria and Europe) **-** It requires redesign of fabrication facilities and increases both cost and weight of the glazing unit significantly. Triple Glazed Unit (TGU) with a *U*-value of 0.5 and W/sqm·K and a thickness of 40–44 mm

- Use of **Vacuum insulated glazing (VIG)** as high performance glazing with reduces U-factor. Excellent energy efficiency whilst maintaining an ultra-thin form factor—6.2 mm being the thinnest VIG aims at achieving a *U*-value of 0.3 W/sqm·K with a thickness of 18 mm.

Foot note 01: Trudeau unveils Canada's net-zero by 2050 plans https://www.bbc.com/news/world-us-canada-55006702
What do Canada's net-zero targets mean for Albertans? https://globalnews.ca/news/7473772/canada-net-zero-targets-alberta-environment/
Foot Note:02 D Pracucci, A.; Magnani, S.; Casadei, O. (2020) The Integration of Vacuum Insulated Glass in Unitized Façade for the Development of Innovative Lightweight and Highly Insulating Energy Efficient Building Envelope—The Results of Eensulate Façade System Design. *Designs*, *4*, 40. Pages 1-15

Vacuum Insulated Glazing (VIG)

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A vacuum provides **excellent thermal efficiency** because if the **pressure is low enough**, it will **eliminate the conductive and convective heat exchange** between the two panes of glass.

In a standard double glazed unit with a **low-e coating, the conduction/convection** component can result in **70% of the heat lost; so eliminating this loss is significant.** The radiative heat loss can than be reduced by use of a low-e coating inside the VIG, producing an even lower U-factor.

For efficiency of a vacuum in reducing heat loss, typical distance between the two panes of glass is **0.2 mm**. This is significantly less than a conventional IGU (air space 12 mm).
As a result, VIG units can have **thickness of 6.2 mm**, comparable to a monolithic piece of glass but with the performance of a triple glazed insulated glass unit. Currently U-**factor for a commercially available 6.2 mm thick VIG is 1.0 W/m2 K** (Table 1).

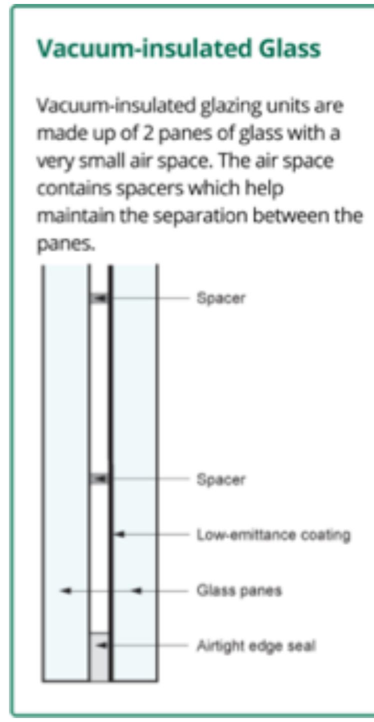


Figure: VIG. Source: McSporran (2014)

Glazing unit	Thickness (mm)	U-factor: winter (W/m2K)	U-factor: winter (Btu/hft2F)	SHGC
IGU: Low-e	24.1	1.9	0.47	0.62
IGU: Solar control low-e	24.1	1.7	0.29	0.39
NSG Spacia™	**6.2**	**1.4**	**0.25**	**0.66**
NSG Spacia™ Cool	**6.2**	**1.0**	**0.18**	**0.49**

Table 01: Performance figures of VIG versus conventional Glazing Source: McSporran,.N (2014).

Condensation Resistance:

The reduced thermal conductivity of VIG also provides increased condensation resistance. Condensation can be a major issue in buildings, both from an aesthetic standpoint and due to the damage it can cause to window frames and other building materials. For a **6.2 mm VIG with a U-factor of 1.4 W/m2 K**, installed in a room with **internal conditions of 20 °C and 60% relative humidity**, **no internal condensation** will form at **external temperatures down to –21 °C**. Identical tests using a conventional 12 mm IGU with low-e resulted in condensation forming at temperatures around 0 °C.

Sound Reduction:

A further advantage of VIG is its sound reduction performance relative to a conventional IGU. Due to the use of a vacuum between the panes, the attenuation of noise is improved over all frequency ranges relative to an IGU, but particularly in the mid-frequency range where noise from traffic and public transport is prevalent.

Design of VIG

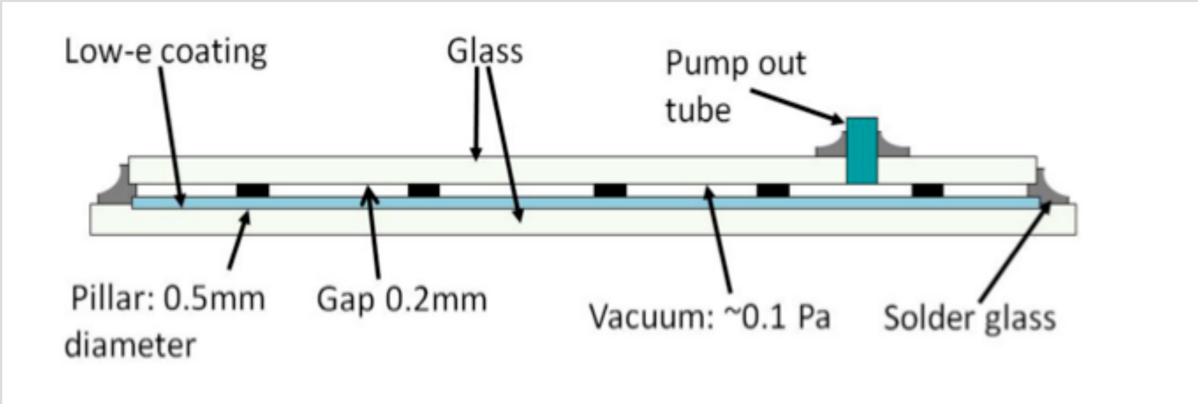


Figure: Schematic diagram of a VIG unit Source: McSporran,.N

VIG design is simple in design, consists of two sheets of glass that are hermetically sealed around the edge and separated by a narrow evacuated space. **The pressure** in the evacuated cavity is typically on the order of **0.1 Pa** and the **hermetic seal** is provided by a low melting point solder glass with a coefficient of thermal expansion that matches that of soda lime glass.

- In order for the VIG to replace single paned glazing, thickness is minimized using two sheets of **3 mm** glass; however, if greater strength is required—for example against the wind load— a thicker unit is designed. This can be achieved either by increasing the thickness of the external pane or the thickness of both panes. In order **to reduce radiative heat loss**, a **low-e coating** is used on one of the **internal surfaces of the VIG**, typically surface #2.

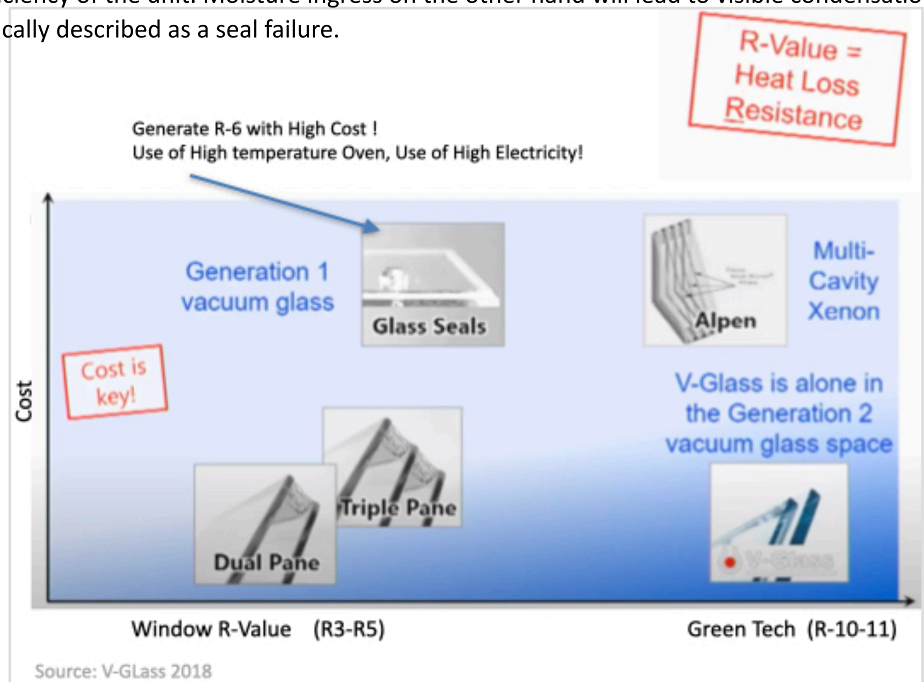
- One final unique design feature of a VIG unit is its small glass **pump out tube**, through which the internal volume of the unit is evacuated. This pump out tube is melted and closed near the end of the manufacturing process in order to ensure a hermetic seal and is then covered by a protection cap.

- To maintain separation of the glass panes under atmospheric pressure, a **pillar array** is used that maintains a distance of approximately **0.2 mm** between the two panes of glass. The design of the **pillar array** that separates the glass panes is sensitive. Number of variables (the size and shape of the support pillars, the type of the material used, and the spacing and pattern of the array) must be considered. All of these parameters are critical, as the pillar array influences both the strength and its thermal insulation properties of the units.

- The significant compressive stress acting on the pillars due to atmospheric pressure means the choice of a material with suitable compressive strength is critical. As heat will flow through the pillars, their thermal conductivity should be minimised as much as possible. Balancing pillar diameter and spacing is also important to ensure that conical indentation fracture will not occur in the glass sheet. (In the case of the **NSG Spacia™ product**, pillar diameter **is 0.5 mm** and the separation between pillars is **20 mm.**)Finally, the material used should not degrade in vacuum.

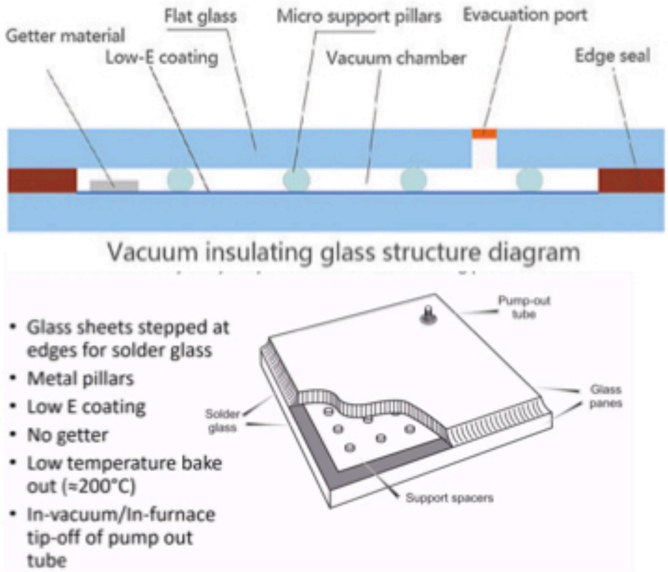
Difference between vacuum glazing (VIG) and a standard insulating glass unit (IGU)

The Difference is in the design of the seal between the two panes of glass.
In a standard insulated glass unit, two sealant materials are typically used—one organic and one inorganic. Although these seals are reliable, some leakage into and out of the unit is inevitable over time. In the case of a unit, which uses a low thermal conductivity gas such as Argon, this leakage will lead to a reduction in the energy efficiency of the unit. Moisture ingress on the other hand will lead to visible condensation, a condition that is typically described as a seal failure.



In a VIG unit, a hermetic seal is essential to maintaining the vacuum and energy efficiency of the unit, so such failures cannot be tolerated. Use of a glass seal in a VIG ensures that—providing the seal is manufactured correctly—ingress due to moisture is eliminated (glass has a moisture vapour transport rate of < 10e–6 g/m2 / day). Matching the thermal expansion coefficient of the soda lime glass with the glass seal is important to ensure that thermal mismatches do not occur that could cause seal failure. A specially designed glass solder that meets the above requirements is used. This type of solder glass has been used in the electric industries for many years with products like vacuum tubes, CRT displays, and plasma display panels. The pump out tube is also sealed using glass.

A unique consideration is outgassing from the internal surface of the glass, which can raise the pressure inside the unit and reduce thermal efficiency. Accelerated aging of vacuum units has been carried out by both NSG and Lenzen et al., and based on the above work, the likely pressure increase after 25 years at 30 °C was studied and found to be 0.04 Pa. The result of such a pressure increase in a VIG with a starting U-factor of 1.40 W/m2 K would be a degradation of 0.01 W/m2 K, giving a U-factor of 1.41 W/m2 K, a very small increase. The level of diffusion-related degradation is heavily influenced by the manufacturing conditions, so optimising these conditions is important in negating the effects of outgassing. Various durability tests have been developed and passed successfully for VIG, giving confidence in the durability of the construction. Furthermore, it is tentative that, long-term degradation of any of the key components of the unit is unlikely, as they are all based on glass.



Source: Building Green R-10 (Top) University of Sydney, Dr. Cenk Kocer2019

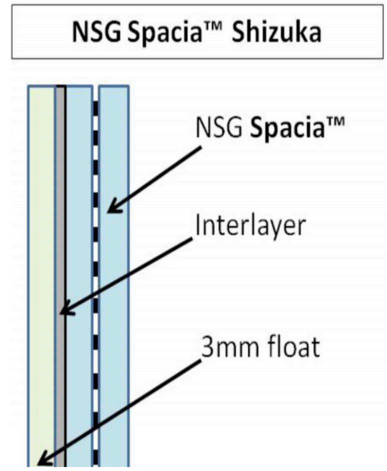


Figure: Schematic diagram of laminated NSG Spacia. Source: McSporran,.N (2014)

Performance of VIG

Standard VIG Units

Architects typically have to balance many parameters to select the optimum glazing option. One consistent design feature is that the side of the VIG unit incorporating the pump out tube is always intended to face into the building interior.

For 6.2 mm unit's (Table 2) performance can be optimised using different low-e coatings, typically on surface #2. In situations where **passive solar gain is useful, low-e coatings offering a higher SHGC** are typically used. These could be either pyrolytic or sputtered coatings. **NSG Spacia™ uses a pyrolytic coating resulting in a VIG with a U-factor of 1.4 W/m2 K and SHGC of 0.66**.

In situations, where a lower SHGC value is desirable, can be achieved through the use of an optimised single silver coating, a double silver coating, or even triple silver coatings. NSG Spacia™ Cool offers this functionality, giving a reduced SHGC of 0.49 with a U-factor of 1.0 W/m2 K in a 6.2 mm thickness

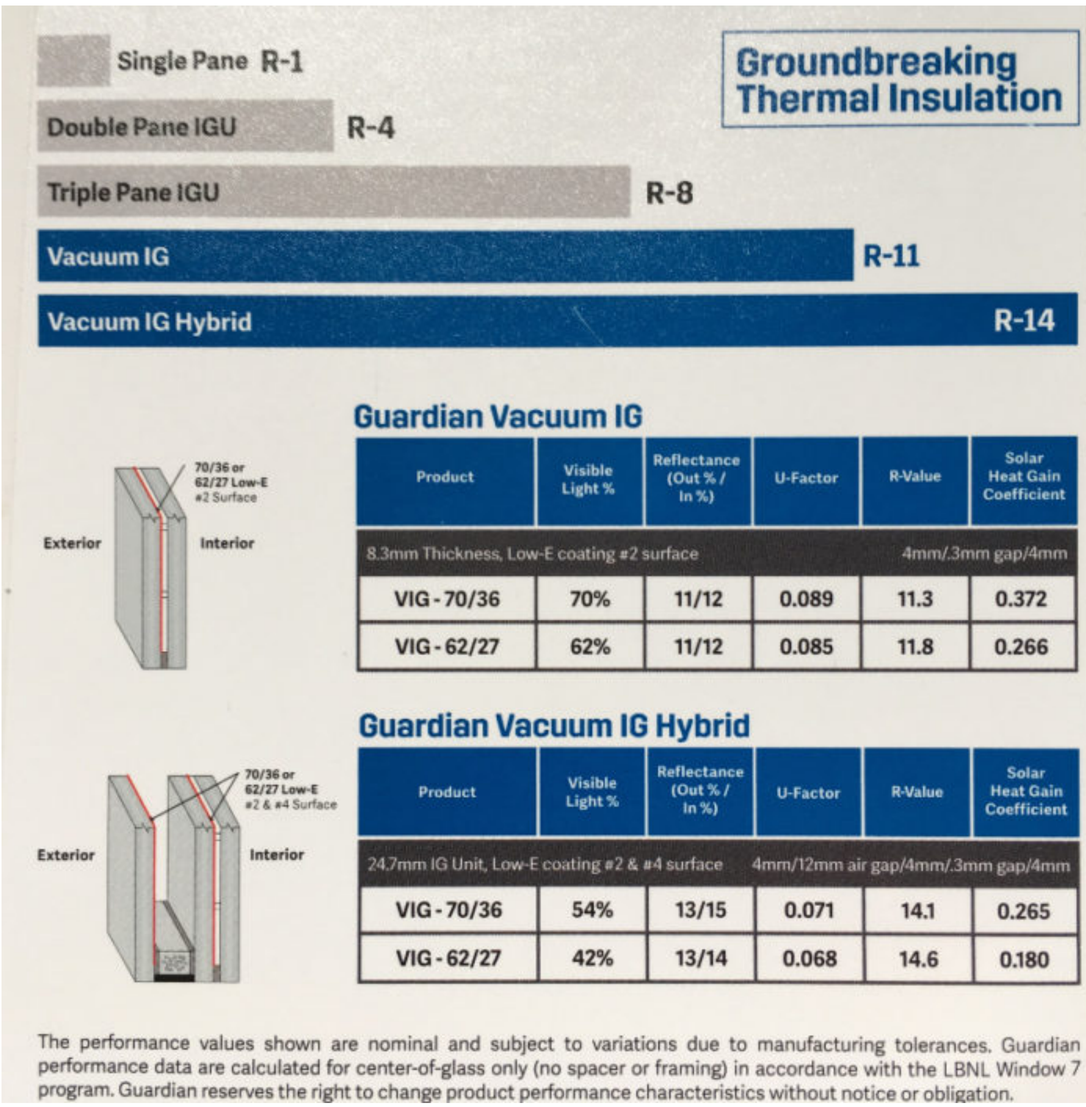
Glazing unit	Thickness (mm)	Tvis (%)	Rvis (%)	Tsol (%)	Rsol (%)	U-factor: winter		SHGC
						W/m2K	Btu/hft2F	
NSG Spacia™	6.2	76	16	61	15	1.4	0.25	0.66
NSG Spacia™ Cool	6.2	70	23	46	36	1.0	0.18	0.49
NSG Spacia™ Cool	10.2	68	23	43	33	1.0	0.18	0.48
NSG Spacia™ Shizuka	9.2	73	15	56	13	1.4	0.25	0.61
NSG Spacia™ Cool Shizuka	9.2	68	22	42	29	1.0	0.18	0.46
NSG Spacia™ 21	18.2	66	19	42	26	0.9	0.16	0.51
NSG Spacia™ 21 Solar Control	18.2	58	19	29	40	0.8	0.15	0.34
NSG Spacia™ 21 Solar Control	21.2	58	19	29	40	0.7	0.14	0.34

Figure: Detailed specification of selected VIG designs Source: McSporran,.N (2014).

Safety Glazing for VIG

The use of an additional glass pane laminated to the exterior pane of the VIG unit. This pane is typically **between 2.5 mm to 5 mm thick**. Use of such a laminate construction provides additional safety performance in addition to improved sound reduction and almost 100% absorption of UV.

This is provided by NSG Spacia™ Shizuka which is shown in Figure. If further burglar or vandal protection is required, an additional polycarbonate sheet can be laminated between the exterior pane and the VIG unit.


Groundbreaking Thermal Insulation

Single Pane R-1
Double Pane IGU R-4
Triple Pane IGU R-8
Vacuum IG R-11
Vacuum IG Hybrid R-14

Guardian Vacuum IG

70/36 or 62/27 Low-E #2 Surface
Exterior
Interior

Product	Visible Light %	Reflectance (Out % / In %)	U-Factor	R-Value	Solar Heat Gain Coefficient
8.3mm Thickness, Low-E coating #2 surface				4mm/.3mm gap/4mm	
VIG - 70/36	70%	11/12	0.089	11.3	0.372
VIG - 62/27	62%	11/12	0.085	11.8	0.266

Guardian Vacuum IG Hybrid

70/36 or 62/27 Low-E #2 & #4 Surface
Exterior
Interior

Product	Visible Light %	Reflectance (Out % / In %)	U-Factor	R-Value	Solar Heat Gain Coefficient
24.7mm IG Unit, Low-E coating #2 & #4 surface		4mm/12mm air gap/4mm/.3mm gap/4mm			
VIG - 70/36	54%	13/15	0.071	14.1	0.265
VIG - 62/27	42%	13/14	0.068	14.6	0.180

The performance values shown are nominal and subject to variations due to manufacturing tolerances. Guardian performance data are calculated for center-of-glass only (no spacer or framing) in accordance with the LBNL Window 7 program. Guardian reserves the right to change product performance characteristics without notice or obligation.

Figure: This chart shows the two IGU configurations that lead to R-10+ thermal performance for a VIG, in this case from Guardian Glass. Note how incredibly thin the units are (with a gap between the panes of glass just .03mm and very think tempered glass). Image Guardian Glass

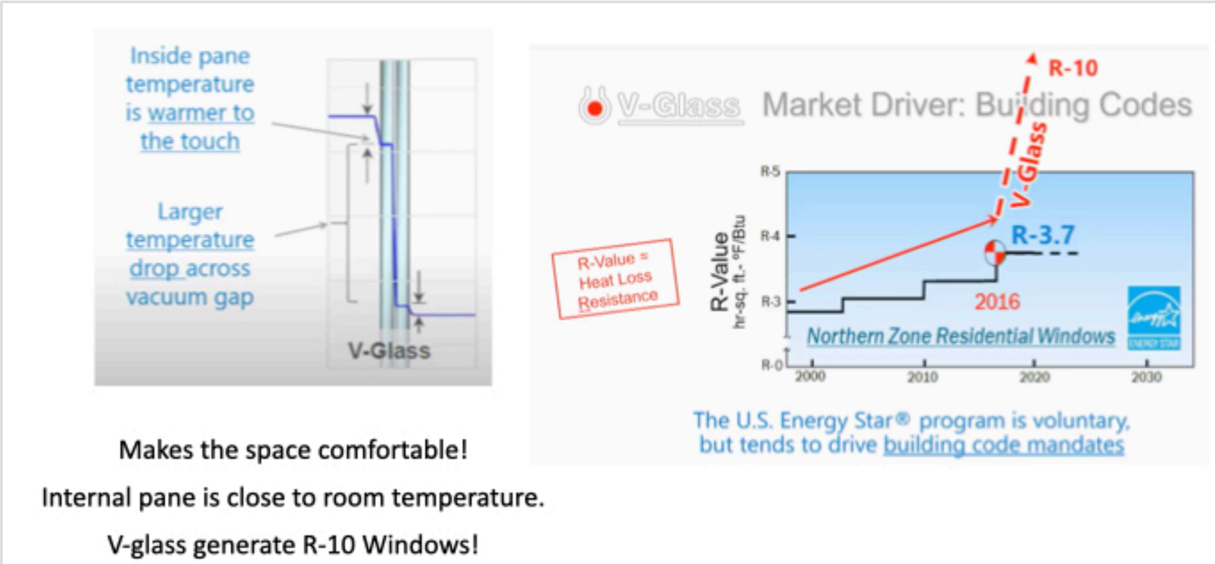


Figure: VIG structure to generate R10 Windows

VIG Manufacturers

- There are Chinese companies that are producing VIG in the R-10+ range (center-of-glass) and in the U.S. (by Michigan-based Guardian Glass) and Florida-based VIG Technologies (a company that uses LandGlass VIG from China).
- Popular commercial VIG products from China are: Beijing Synergy Vacuum Glazing and Qingdao Hengda Glass NSG.
- Some other prominent names are: VKR HOLDING AS, AGC GLASS EURO; AGC INC; AGC FLAT GLASS NORTH AMERICA INC.
- Operating in VIG market for building & construction include Vishvesh Glasses Private Limited, Panasonic Corporation, LandGlass Technologies Co., Ltd., V-Glass LLC, Nippon Sheet Glass Co Ltd, QINHUANGDAO YIWO GLASS CO., LTD, ICESUN VACUUM GLASS Ltd., T&I Sealed Units Limited, and Taiwan Glass Ind. Corp

New Development in VIGs

As a number of companies are developing VIG technology, many new designs are being proposed.

- **Use of more than one VIG unit** (double or triple VIGs) for low u-factors. It is challenging for its high cost (not commercial)
- **VIG utilising flexible edge seals** to replace the soldered glass seals currently in use. The advantage remains in thermal growth and contraction of the panes in extreme temperatures. However, this kind challenged to ensure long term vacuum stability, as very few materials have the exceptionally low moisture vapour transport rate of glass
- **Use of tempered glass** in the VIG unit- improvements to the U-factor of the units by new pillar array designs and new pillar materials are also in development. Challenges would be the use of more energy efficient pillar arrays typically increases the probability of glass breakage due to stress concentration on the pillars.

Size

- For 6.2 mm units the maximum available size currently is 1,350 × 2,400 mm. When the thickness of the unit is increased to 10 mm through the use of two 5 mm panes, this size can be increased to 3,000 × 2,000 mm.
- Current Maximum size is 60" x 96" (1500mm x 2438mm)with an expanding capability of 78 x 120 (1980x 3050mm)(Upcoming). Minimum and maximum thickness of tempered vacuum insulated glass units ranges from 0.26" (6.7mm) 0.33" (8.3mm) 0.41" (10.3mm) and 0.48 (12.3mm)

Cost

Chinese VIG producers gave manufacturing costs of up to 1,500 Yuan/m². Using $1 = 6.7 yuan and roughly 10 sf/m², that equates to $22 per square foot. In the U.S., it's typical to multiply manufacturing cost by three to get the consumer price (glazing installed in a window), which would mean $66/sf for a consumer buying windows with VIG. For comparison purposes, standard double-glazed IGU in the U.S. is about $10/sf retail, with Passive House triple-glazed windows in the range of $30–$70/sf.

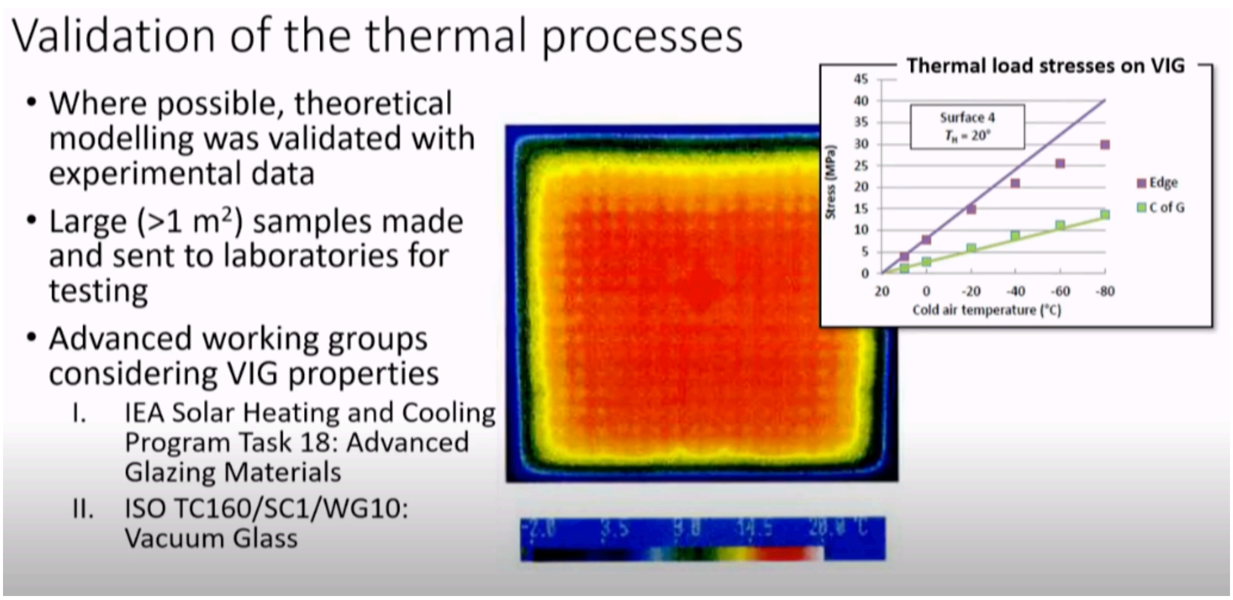


Figure: Validation of the Thermal Processes.Source: University of Sydney, Dr. Cenk Kocer 2019

VIG in Façade +Components

VIG design and testing have gradually changed the façade module and consequently, façade components have been progressively designed to achieve the expected target of 0.641 W/sqm·K for thermal transmittance. The results demonstrate that the target can be achieved by aluminum profiles, Ethylene Propylene Diene Monomer (EPDM) thermal bridge, and additional insulating components, obtaining a new product for unitized façades able to reduce energy consumption in buildings with large glass surfaces.

tVIG (Tempered Vacuum Insulated Glass) (SGCC certified)

tVIG™ Tempered vacuum insulated glass is the upgraded vacuum IG, which combines all the features of vacuum insulated glass and safety. The tempered glass within the tVIG™ is also SGCC certified adding that extra layer of reliability and performance.
A stand alone tVIGs has reached the average value of an **R15.4.**
A tVIG™ hybrid reach higher R Value. Acoustical performance reaching **STC 33/OITC 32.** Comfort Plus.

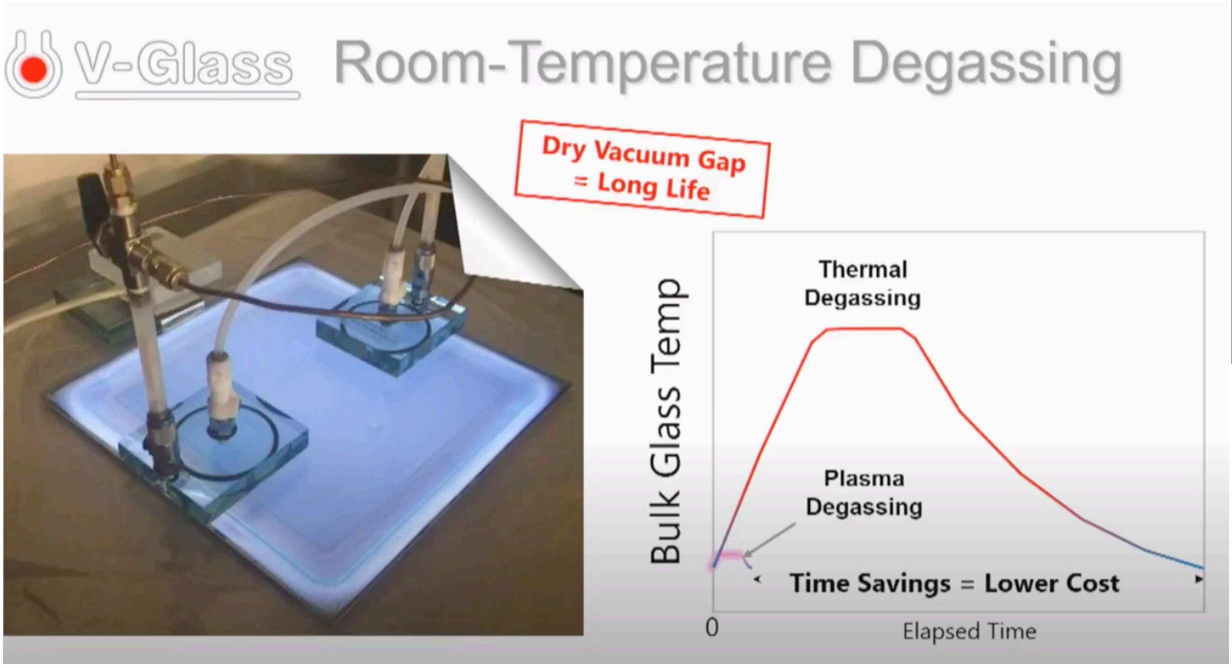


Figure: DeGassing: Vacuum Gap need to be dry, in order to deliver a long life. Source: V-GLass 2018

Performance of tVIG

The thermal insulation performance of tVIG™ is 2 to 4 times better than insulated glass. tVIG™ has a high vacuum interspace that eliminates any gas heat transfer. By using high-performance Low-E coating, it also considerably suppresses radiation heat transfer and reduces the U-value of tVIG™ to 0.48 W/(m2•K). The thermal insulation performance of tVIG™ is 2 to 4 times better than insulated glass and 6 to 10 times than single pane glass. tVIG™ meets all international passive house heat transfer requirements on windows and doors in stand-alone applications.

Thinner tVIG™

It has a structure thinner and lighter than insulated glass. In comparison with triple-pane insulated glass, tVIG™ has merely one sixth of its thickness and weighs 10 kg less per square meter while managing a much better U-value.**Taking out the Condensation.** tVIG™ effectively eliminates dew condensation between glass layers (even outside is -40 deg C). Dew condensation is caused by the temperature difference between the inner and outer surfaces of insulated glass.

Length of life

The life expectancy of tVIG™ exceeds 25 years. The flexible edge sealing materials wakens the shear forces around the seams, avoiding the sealing failure caused by the brittle edge sealing material especially in the environment with big temperature difference between indoor and outdoor. With the assistance of built-in high efficiency getter material, tVIG™ can sustain its superior performance against harsh environments and material aging for a long time.

VIG Challenges

1. Limited window/glazing industry has seen any third-party-certified laboratory testing of the new VIG product using the industry standard, ASTM E2190 "Standard Specification for Insulating Glass Unit Performance and Evaluation." This testing includes temperature extremes and accelerated aging/weathering testing. (For more information on this standard, including descriptions of specific tests, see "Certification & Testing for Insulating Glass Units.")

2. Maintaining the vacuum of the unit is essential throughout its lifetime. If the vacuum seal on these IGUs lose, the thermal performance does not fade—it crashes. There is a new standard being developed specifically for stress-testing VIG: ISO/DIS 19916-1, "Glass in building—vacuum insulating glass—Part 1: Basic specification of products and evaluation methods for thermal and sound insulating performance."

3. Evacuated window assemblies present a number of engineering problems. However, one major issue is the structural requirement to resist normal air pressure and variable pressures caused by wind and vibration. There can be large thermal stresses between large, window-sized panes of glass. A thermos bottle resists these forces easily because of its strong curved shape, but the large, flat surfaces of a window tend to bow and flex with changing pressures. Small pillars or spacers are used to maintain the separation between the panes. The pillars are very small but are somewhat visible, reducing the window clarity.

4. Like all sealed unites, maintenance of an airtight seal around the unit edge could be an issue. The seal must be maintained to eliminate gaseous conduction by keeping the air density within the unit to less than one millionth of normal atmospheric pressure; an air density of only ten times this amount is sufficient to re-establish conduction to its normal value. This vacuum seal must remain intact for the life of the window, through manufacture, transportation, installation, and normal operation, wear, and weathering.