Glass Informational Bulletin **GANA (Doc. #)-XXXX**

Products for Energy Applications

Introduction
Insulating glass can play a significant role in the energy performance of a building. When installed in a fenestration system (such as a window, curtainwall, skylight or storefront), there are two characteristics which drive its contribution to energy performance of an IGU: U-factor (thermal transmittance) and solar heat gain coefficient (SHGC) (how much of the sun's radiative energy is transmitted through the window). The relative importance of SHGC and U-factor, and the specification for performance depend to a considerable extent on the specifics of the building design and type as well as the climate zone. Small to medium sized buildings in cold climates may be more heating dominated and thus have a higher emphasis on U-factor for energy performance. Large buildings (especially hospitals and office towers) tend to be internal load dominated, and as such have higher requirements for cooling load minimization than, say, heating loads even in cold climates.

With the increased emphasis on providing daylight and views for occupants, even large buildings are becoming narrower in order to increase daylight penetration. In these cases, the envelope becomes even more important to energy performance and the optimization of solar heat gain performance and U-factor is critical. It is also important to note that both SHGC and U-factor have a significant influence on thermal comfort of occupants near the façade and so when designers are making glazing product choices, thermal comfort as well as energy performance should be considered.

The following glazing products or components represent strategies that designers can use to improve the energy performance of their building envelopes based on their need to optimize U-factor or SHGC, or both.

<u>The performance data provided in this document is for center of glass values unless specifically stated otherwise.</u> Note that the whole fenestration U-factor is an area weighted average of the center of glass, edge of glass and frame U-factors. The whole unit SHGC is also an area weighted average of frame and center of glass values. All strategies discussed below affect the center of glass U-factor (and SHGC), except for the use of warm-edge spacer which impacts the overall U-factor (and to a small extent its SHGC) by improving the edge of glass U-factor. In this latter section, the U-factors quoted are whole fenestration U-factors. The data is_based on National Fenestration Rating Council (NFRC) procedures and calculated using Lawrence

Berkeley National Laboratory (LBNL) Window 7 software and the International Glazing Database (IGDB).

Glazing Products and Components

Dual IG

Conventional insulating glazing units (IGU) consist of two glass panes separated by a cavity filled with air. To improve the energy performance of a conventional IGU, the following additions can be made: type of low-e coating, cavity gas fill material (inert gas or vacuum), spacer material, number of cavities of an IGU, use of dynamic glazing and use of a ceramic frit pattern. In addition, external to the IGU, solar shading devices or window films may be used to improve the energy performance of the building façade. The following sections of this document will provide more details on each of these technologies.

Low-e Coatings

Low-e coatings have been developed to minimize the amount of ultraviolet and infrared light that can pass through glass without compromising the amount of visible light that is transmitted. There are two different types of low-e coatings: passive low-e coatings and solar control low-e coatings. Passive low-e coatings are designed to maximize solar heat gain into a home or building to create the effect of "passive" heating and reducing reliance on artificial heating. Solar control low-e coatings are designed to limit the amount of solar heat that passes into a home or building for the purpose of keeping buildings cooler and reducing energy consumption related to air conditioning.

Low-e coatings are applied to various surfaces of insulating glass units. Whether a low-e coating is considered passive or solar control, they offer improvements in performance values. Passive low-e coatings function best when on the third or fourth surface (furthest away from the sun) and are typically used in heating dominated climates, while solar control low-e coatings function best when on the lite closest to the sun, typically the second surface and are typically used in cooling dominated climates. The below table provides typical thermal and optical performance value ranges for different classifications of low-e coatings.

1" IGU (Low-e #2 on Clear + Air + Clear)	Typical U-Factor Range	Typical VLT Range	Typical SHGC Range
Pyrolytic "Hard Coat" & Single Silver - Low-e	0.32 - 0.37	54% - 74%	0.45 – 0.70
Double Silver Low-e	0.29 – 0.29	53% - 70%	0.28 – 0.39
Triple Silver Low-e	0.28 – 0.29	51% - 65%	0.23 – 0.30

*For more information on different coating application methods, reference the GANA *Glazing Manual*

There are a wide range of low-e coatings available on the market today that have different attributes. Solar control coatings can be combined with passive coatings on the 4^{th} surface to lower IGU U-factors. Multiple coatings can be added to triple pane IGU to lower the U-factor even more. In addition, tinted substrates can be combined with low-e coatings in a glazing construction to decrease SHGC and add desired aesthetics.

When thinking of window designs: size, substrate tint color and other aesthetic qualities come to mind. However, low-e coatings play an equally important role and significantly affect the overall performance of a window and the total heating, lighting, and cooling costs of a building.

Gas Fill

Traditionally, an IG unit is filled with plant air. Using inert gas as an alternative fill is a growing trend in order to improve the U-factor of the IG unit. The type of gas and the width of the airspace will determine the U-factor. Reference Glass Informational Bulletin *Performance Improvements in Insulating Glass Units: Cavity Gap and Insulating Gases* for more information on gas fill.

Effect of argon filling on U-factor

If an inert gas is used, Argon is the most common gas because of its availability and reasonable cost. A fabricator is targeting the passing criteria for initial fill to be a minimum of 90% according to ASTM E2190. Maintaining an 80% minimum fill is required after completing ASTM test protocol. The table below shows the % of Ar fill and the resulting U-factor for an IGU unit with double silver Low-e coating #2 surface and ½" air space.

Typical IGU with 1/2" airspace and low-e coating	**U-Factor (BTU/(hr-ft^2-°F))**
100% Air	0.295
90% argon	0.250
80% argon	0.255
70% argon	0.260
60% argon	0.265

Effect of Other Gases on U-factor

There are options available for other fill gases that lead to an improved U-factor. As a result of the lower conductivity of the gas there is an improvement in U-factor of the IGU. The table below shows typical U-factor for a dual IG unit, with double silver Low-e coating and ½" air space.

Gas Fill	**Formula**	**Conductivity (Btu/(hr-ft-°F))**	**U-Factor (Btu/(hr-ft^2- °F))**
Air	O_2N_2	0.0150	0.295
Argon	Ar (90%)	0.0100	0.250
Krypton	Kr (90%)	0.0053	0.236
Xenon	Xe(90%)	0.0032	0.221

Effect of Air Space Width on U-factor:

For each type of gas fill there is an optimal spacer width that would yield the lowest U-factor value. In general, as you move from air fill, to Argon fill, to Krypton fill, to Xenon fill you need to decrease the width of the spacer to achieve the optimum U-factor.

Gas Fill	**Formula (Fill %)**	**Optimum Spacer Width**	**U-Factor (Btu/(hr-ft^2-°F))**
Air	O_2N_2	½" (0.500")	0.293
Argon	Ar (90%)	7/16" (0.460")	0.245
Krypton	Kr (90%)	5/16'' (0.310")	0.218
Xenon	Xe (90%)	¼'' (0.221'')	0.201

Vacuum Glazing
In vacuum insulating glazing (VIG), two glass panes, typically 0.12 – 0.20 in. (3mm to 5mm) thick, are hermetically sealed together around the edges and separated by microspacers approximately .005 - .01 in. (0.15mm to 0.25mm) thick. The microspacers, which act as support pillars, are made of high strength material such as metal or ceramic and are spaced evenly across the surface of the glass. The air between the two panes is then extracted through a small pump out tube. Once a vacuum is made, the pump out tube is sealed with a glass frit on the inner surface of the unit to create a permanent vacuum. See Figure 1.

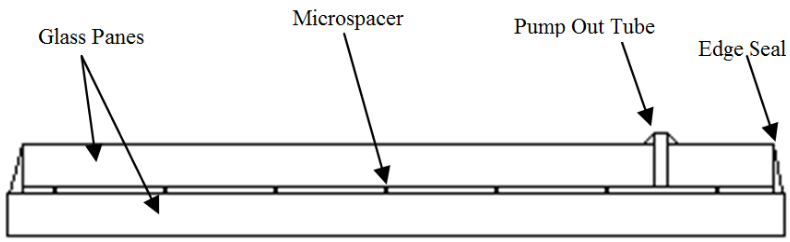

Figure 1

The vacuum is very effective at minimizing conduction and convection heat losses and is effective even at a very thin cavity depth. Therefore, VIG technology enables the lowest possible heat transfer from a cavity material selection standpoint and does so at a minimum cavity depth. This allows VIGs to offer the same performance as conventional double glazing in one quarter of the overall thickness and two thirds of the weight of a standard IGU. The lack of conductive or convective heat exchange between the panes of glass lowers the U-factor. Additionally, use of a low-e coating on surface 2 significantly reduces heat transfer due to radiation. Depending on the type of low-e coating, VIGs can have a U-factor of 0.25 or less while maintaining a high SHGC. Due to their thin configuration and high thermal performance, VIGs are suitable for many façade designs, including retrofits.

Warm Edge Spacers
Warm edge spacers are spacers that hold the glass panes apart in an insulating glass unit which have been specifically designed to reduce the thermal transmittance across the edge of glass. Standard metal box spacers, typically made from aluminum, create a thermal bridge across the edge of glass at the edge seal resulting in significant heat loss in winter (or gain in summer). Warm-edge spacers are generally comprised of materials that are of lower conductivity than aluminum (e.g. stainless steel, plastic with backer material, silicone-foam matrix with backer material, extruded butyl matrix) or are a hybrid of a non-metallic material and thin gauge metal (e.g. plastic hybrid stainless steel or PHSS).

The thermal conductance of a spacer depends on the shape and thickness of the material, not on the conductance of the bulk material itself. Also, the overall conductance of the edge is determined by the amount of sealant used (more sealant results in higher conductance, and higher U-factor), the amount and type of desiccant used (more desiccant results in higher conductance) and the extent to which the edge of glass is buried into the frame. The greater the

edge bite on the glass for captured framing systems, the lower the conductance (lower the U-factor). Thus, it is important when comparing spacers to compare their performance in the same insulating glass unit with the same sealant height (as needed for the design and for durability) and with the same frame bite. Figure 2 below shows the overall window U-factor as a function of four different spacer types: Aluminum, stainless steel, and two warm edge spacers, plastic hybrid stainless steel and foam. Warm edge spacers can, on average, provide a reduction in U-factor of 0.01-0.03 btu/°F.hr.ft^2, depending on the type.
Warm edge spacers can be used on their own or in conjunction with any of the strategies described in this document within an insulating glass unit.

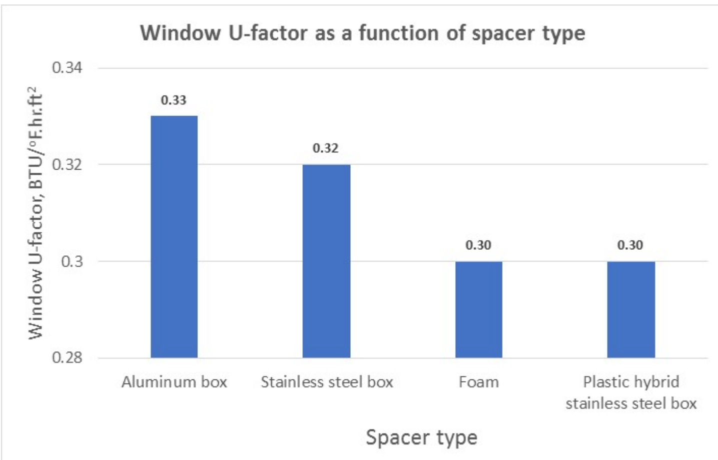

Figure 2
The variation of overall window U-factor as a function of spacer type. The window comprises an aluminum, thermally broken frame with dual pane, low-e glazing. U-factors are based on NFRC standard sizes and rounded to the second decimal place. *Figure courtesy of Technoform Glass Insulation.*

Triple IG
The distinguishing characteristic of a triple IG unit is two sealed air spaces. One example of a triple insulating glass unit consists of three lites of ¼" clear glass, each separated by ½" spacer incorporating a drying agent (desiccant) and hermetically sealed around the perimeter with polyisobutylene (PIB) as the primary seal and silicone as the secondary seal.

Triple IG units are normally specified in cold climates because of the increase in the insulating value or lowering of the U-factor of the unit as compared to a dual IG unit. For example, as shown in the table below, compared to a dual unit with a double silver low-e coating, the U-factor can be lowered from approximately 0.3 to 0.21 in a triple insulating unit. One or more low-e coatings can be added to multiple surfaces to achieve improved performance characteristics. In addition, argon or krypton mixtures can be used to fill the sealed air spaces to further improve the U-factor of the triple IG unit.

	U-Factor	VLT	SHGC
1" Dual IGU Double Silver[1] coating #2	0.29-0.30	68%-70%	0.38-0.39
1 ¾" Triple IGU Double silver coating #2	0.21-0.22	61%-63%	0.34-0.35
1 ¾" Triple IGU with Double silver coating #2 and single silver[2] coating #4	0.16-0.17	56%-60%	0.32-0.33
1 ¾" Triple IGU (same as unit above, coatings #2 and #4) with the addition of argon gas fill	0.13-0.14	56%-60%	0.32-0.33

[1] The double silver coating shown in table is a high light transmitting (≈ 70%) Low-e coating
[2] In the triple IGU make ups the coating on #4 surface is a high light transmitting single silver coating.

Ceramic Frit

One option to improve the energy performance of an IG unit is to add a silkscreen pattern of ceramic frit on the glass. The term ceramic frit is used interchangeably with ceramic enamel or ceramic paint. The ceramic frit is applied to the glass with either a silkscreen application or digital printer. It must then be processed through a furnace to permanently bond the ceramic frit to the glass surface.

The ceramic frit can be applied in an unlimited number of patterns depending on what the designer is trying to achieve. Common patterns consist of lines or dots that cover between 20% and 60% of the glass surface. In addition to pattern applied there is also a choice of many different colors with shades of white and gray being the most popular for both aesthetics and energy performance. The ceramic frit is typically applied to any glass surface except #1 because of concerns of weathering caused by exposure to the outside environment. The best improvement in energy performance occurs if the ceramic frit is applied to the #2 surface.

Ceramic frit patterns on glass are used to create a certain aesthetic look, to reduce glare, to make widows visible to birds and to improve the energy performance (SHGC) of the IG unit. Currently, the NFRC is developing a methodology to simulate the thermal and optical properties of diffusing glass products, such as ceramic frit. In the meantime, glass fabricators use different techniques to approximate the improved solar performance by taking into account the solar performance of the ceramic frit and amount of coverage on the glass. By changing the color and amount of coverage the designer is able to fine tune the energy performance of the IG unit. To further improve the performance of an IG unit ceramic frit can also be combined with low-e coatings.

A range of SHGC and VLT values can be obtained in a 1" IGU with a high light transmitting (70%) double silver Low-e coating with different combinations of ceramic frit coverage and color. The values for VLT and SHGC will change as the Low-e coating and ceramic frit patterns are put on different surfaces. The table below shows the range of values for the following configurations; ceramic frit and Low-e coating #2 surface, Low-e coating #2 and ceramic frit #3 and ceramic frit #2 and Low-e coating #3. Adding a ceramic frit pattern to the IGU does not change the U-Factor of the IGU.

	VLT	SHGC
No silkscreen	68%-70%	0.38-0.46
20% white	59%-60%	0.33-0.41
20% gray	57%-58%	0.33-0.39
60% white	37%-40%	0.23-0.39
60% gray	27%-31%	0.22-0.33

Dynamic Glazing

Dynamic glazing products can provide energy savings through optimized use of natural daylight and reduced need for air-conditioning, resulting in increased occupant comfort by controlling unwanted heat gain and glare. With the exception of PDLC (privacy glass), dynamic glazing can control daylighting without additional appendages to the façade, while also preserving the view to the exterior through the glazing.

A dynamic glazing product is a fenestration product that has the fully reversible ability to change its optical performance properties, such as visible light transmission, near infrared transmission and solar heat gain coefficient. These properties can change based on the exposure to different stimuli; some change in response to electrical stimuli (electrochromic), others change in response to absorbed sunlight (primarily UV (photochromic)), and some respond to ambient or product temperature (thermochromic). The ability to modulate these properties provides for a building envelope that adapts to the outside environmental conditions (or user requirements) and provides higher energy performance by capturing useful daylight while controlling glare and unwanted solar heat gain.

Dynamic Glazing products are discussed further in FB32-11 (2018) Dynamic Glazing for High Performance Buildings. The VLT range for electrochromic glazing can range from 1 to 60 percent and the SHGC can range from 0.09 to 0.42 in a dual pane insulating glass unit.

Energy Control Window Films

Window film used for energy control is a very thin, high performance polyester film which may be only 1.5 thousandths of an inch (0.038 mm) thick but contain as many as 14 different scientifically controlled layers. It is normally applied to the interior (room) side of a window, but many films are also available for external installation. Window films are normally used for application to an existing window to improve its energy performance and extend the physical use of that window in place.

All window films block 95-99% of all UV radiation from entering a building. Window films can be very dark in color or almost totally clear and modern clear films can save more energy than the darker films of the past.

Depending on the film selected and the type of window on which it is installed, solar heat gain can be reduced from 55-84%. All window films have slight insulation values (9-11%) but certain Low-e window films may retain up to 55% of a building's internal heat in winter. Each window film manufacturer publishes film-to-glass recommendation tables showing which of their films is recommended for each type of glass/window combination and most quality window films have NFRC- certification of their published energy performance specifications.

Window film can also be manufactured in safety/security versions or decorative versions, and the energy control parameters listed above can be incorporated into these versions also. Window film is a readily available, cost effective, technologically proven, and environmentally conscious choice to save energy. The film may change the solar absorption of the glass to which it is applied. The applicator should check with the glass fabricator to ensure the glass is sufficiently heat-treated to accept the film without potentially increasing the thermally-induced stress leading to breakage.

Solar Shading Devices
Solar shading devices are generally affixed to the exterior of the building in order to prevent direct sun penetration at certain times of the day and year. Stopping the penetration of the sun at or on the exterior of the window, before it enters the building, is the most effective way of minimizing heat gain. These shading devices are generally used as a method of solar control in combination with fenestration with solar control low-e insulating glazing. The type of solar shading and its effectiveness depends on the orientation of the façade. For example, horizontal shading above a window can work well in a southern orientation if made deep enough, yet for orientations with east and west components, vertical fins may be more applicable. Often solar shading devices are static, but some are operable, with components that change angle following the position of the sun in the sky in order to maintain optimum shading performance. For this reason, movable systems are more effective at controlling solar heat gain than static systems.

Horizontal shading can be as simple as a solid overhang or as complex as containing multiple airfoils angled to block the sun at particular solar positions. There are many other designs for horizontal shading systems that achieve different aesthetics. Vertical fins can also be solid or perforated, or more complex in shape as needed for the design performance and aesthetics.

It is important in envelope design to ensure that the façade has sufficient strength to support the weight of the solar shading devices and that an appropriate maintenance schedule is considered for operable systems.

The overall performance of the shading systems depends on its depth and position relative to the window (the portion of the window it shades) and whether it is static or dynamic (how much shading is achieved over the course of the day/year). These attributes contribute to the whole window solar heat gain coefficient. The model energy codes ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC) give credit for external horizontal fixed shading of windows. ASHRAE 90.1 has a list of multipliers based on the size of the horizontal projection over the window, and this multiplier is used to reduce the real SHGC of the window to provide an effective SHGC which is used for demonstrating code compliance. In the IECC, specific solar heat gain coefficients are given for each zone with three different ranges of projection factor. In addition, the green building codes ASHRAE 189.1/IgCC require solar shading of windows (or as alternative compliance path the use of dynamic glazing) as an energy saving and daylighting strategy.

Conclusion
This GIB provided information on several technologies commonly used to improve the energy performance of an IGU and the building façade. This is accomplished by optimizing how much of the sun's radiative energy is transmitted through the window (SHGC) and how much thermal energy is transmitted through the IGU (U-Factor). The table below shows which technologies contribute to controlling U-Factor and/or SHGC.

	SHGC	U-Factor
Low-e Coatings	X	X
Gas Fill		X
Vacuum Insulating Glazing	-	X

Warm Edge Spacer	-	X
Triple IGU	-	X
Ceramic Frit	X	
Dynamic Glazing	X	
Energy Control Window Films	X	-
Solar Shading Devices	X	

"X" denotes major contribution while "-" denotes minor contribution

References:

- GANA *Glazing Manual*
- Glass Information Bulletin: *Performance Improvements in Insulating Glass Units: Cavity Gap and Insulating Gases*
- Glass Informational Bulletin: *Dynamic Glazing for High Performance Buildings*
- Glass Informational Bulletin: *Describing Architectural Glass Constructions*
- FDR Design Inc. Why Gas Fill? - https://cdn.shopify.com/s/files/1/1525/9640/files/content_why_gas_fill_8.5_x_11_-_web.pdf
- Vacuum Glazing
  - http://www.commercialwindows.org/adv_glass.php
  - https://www.buildinggreen.com/blog/vacuum-insulated-windows
  - http://www.physics.usyd.edu.au/app/research/vacuumglazing/
  - https://www.pilkington.com/en/us/products/product-categories/thermal-insulation/pilkington-spacia
- Guardian Glass (https://www.guardianglass.com/commercial/ToolsandResources/EvaluationTools/GlassAnalytics/index.htm)
- Viracon (http://www.viracon.com/search-by-performance)
- Vitro Architectural Glass (http://construct.vitroglazings.com/default.aspx)
- International Window Film Association (www.iwfa.com)
- National Fenestration Rating Council (www.nfrc.org)
- U.S. Department of Energy (www.eere.doe.gov)

Consult the *Tech Center* section of glasswebsite.com for additional Glass Informational Bulletins and flat glass industry reference resources.

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