Very High Performance Glazing In Traditional Framing

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ABSTRACT

For many centuries the benefits of daylight and vision through a single pane of residential clear glass far outweighed any discomfort from winter heat loss, condensation (or even icing), and any excessive summer heat gain from direct sunshine.

At the beginning of the 20th century larger sizes of glass became more readily available and so the above thermal issues became more apparent. Unwanted solar heat gain was reduced by using dark, solar IR absorbing bronze and grey tints. The negligible insulation value of single glazing was overcome by using multiple layers (2 or 3) with an optimum 0.5 inch air gap between each one. The insulation value could be further improved by the use of appropriate gasses in the sealed gap. It was not long before the idea arose of using a vacuum (as in a Thermos bottle) in the sealed space. First attempts to do this soon showed the problems from the approximate 10 tonne per square meter (1 ton per square foot) load that such a vacuum creates on the glass. At the time few realized the greater issue that heat transfer across the air space of double glazing is about 2/3 by radiation and only 1/3 by convection/conduction. Thus a vacuum insulating glass (VIG), even if it could have been made, would have offered little benefit compared to plain glass unless it included a then non-existent radiation barrier.

The advent of low emissivity (Low-E) coatings (reducing the emissivity of glass from 0.8 down to about 0.1) controlled this major heat transfer mode and caused the vacuum unit to be re-invented to further reduce the overall heat transfer of double glazing.

It is not widely recognized that two types of Low-E coating are available: high solar IR transmitting; and solar IR blocking (by reflection or absorption). Residences from Seattle to NYC and north, including Denver and Salt Lake City, can typically achieve a net annual energy benefit from the free passive solar heating of high solar IR transmitting windows. Residences to the south of that line, and most large commercial buildings throughout North America have greater air conditioning loads than heating loads and so benefit from solar IR blocking glass.

Today's VIG (composed of 2 plies of 3 mm (1/8 in.) glass, with Low-E coating(s) and a 0.7 mm (0.03 in.) gap supported by spacers on 25 mm (1 in.) centers) with high or low solar IR transmission, addresses all these heat gain and heat loss issues with a single piece of 6.5 mm (1/4 in.) thick glazing. Vacuum insulating glass can provide better

insulation than plain, sealed triple glazing. A vacuum unit has a fraction of the weight of multi-layer sealed units, fits into existing historic frames and sashes, and has the clear, non-reflective appearance of original traditional glass.

Safety glazing requirements are met with VIG by autoclave laminating an annealed glass ply to the VIG unit. Tempered glass cannot be used because of the high temperatures of the solder glass edge seal process. Work remains to be done incorporating solar control heat absorbing lights and accommodating their relative expansion differences at the edge seal.

INTRODUCTION

The design requirements for windows are many:

- Thermal insulation
- Solar Control
  - Daylighting
  - Glare prevention
  - Beneficial passive solar heating
  - Control of unwanted summer solar heat gain
  - UV transmission control
- Aesthetic appearance:
  - Privacy/transparency
  - color,
  - optical quality of transmitted images,
  - optical quality of reflected images
- Acoustic insulation
- Radio Frequency and Infra Red Electromagnetic insulation/transmission
- Security
- Protection against forced entry
- Wind load resistance
- Impact resistance
- Fire protection
- Emergency exit/entry

A single sheet of clear glass only keeps out wind, rain, and the birds and the bees. It has negligible insulation, or solar and glare control properties.

Not all of the design characteristics of an effective window require fixed performance values:

Residential windows are typically required to give unobstructed views by daytime but usually need to provide privacy for occupants at night.

By day, when the sun is shining directly on a window, there is usually too much light coming through a high transmission clear glass. But the reduced light through a dark glass is not valued on a cloudy day for most residential applications and in commercial applications the potential energy savings of natural daylighting can be lost.

A continental climate typically has unwanted heat loss through windows and walls in winter, and excessive unwanted heat gain through sunlit windows in summer.

The seasonal change in solar altitude angles allows fixed exterior shades and overhangs to control some of these quantities appropriately. Interior adjustable blinds, louvers and drapes can effectively control daylighting and glare, but do little to control heat gains and losses unless they can be well fitted to the window opening and tightly closed when needed.

There are dynamic “Chromogenic” glasses now becoming available which can be varied to control solar heat gains. They are switched from clear to dark by electrical or thermal means but at this stage they are more expensive and complex than static glass combinations with simple manually controlled interior blinds.

This paper discusses recent advances made in improving only the energy conservation performance aspects of windows using only static or fixed properties.

THERMAL CONTROL

This section considers only heat flow quantities driven by air temperature differences, without direct solar heating effects.

Windows always need to have good thermal insulation values, as measured by the U-Factor or thermal conductivity. (In this paper the use of “R Value” is avoided because it only measures the thermal resistance from surface to surface of a material. The U-Factor measures the thermal conductivity from air to air of a glazing system. U-Factors are needed in the calculation of overall building heat transfer).

Only in a warm, temperate, island climate, where seasonal temperature changes are minimal, like Hawaii, is there little need for good thermal insulation. It is interesting to note that there is an equal need for a good (low) U-Factor in hot climates (Dubai for example) where there can be a 29°C (50°F) air temperature difference driving unwanted heat gain inwards as during a cold Boston winter where there is an equal but opposite 29°C (50°F) air temperature difference driving unwanted heat loss outwards.

The relatively high thermal conductivity of glass compared to the insulating effect of the boundary layers of still air on either side of it means that the U-Factor is almost independent of glass thickness: doubling the thickness of 3 mm (1/8 in.) glass to 6 mm (1/4 in.) only improves (lowers) the U-Factor by 1.5%. Even laminating two plies of 3 mm (1/8 in.) glass with a 0.7 mm (0.03 in.) vinyl interlayer only improves the U-Factor by 4%. This is because the vinyl, while being thermally non-conductive, is not thick enough to be an effective insulator. Note that the North American summertime U-Factor for 3 mm (1/8 in.) clear glass is 10% better than the winter value because summer winds, on average, blow with less velocity according to ASHRAE North American standards. Higher wind speeds reduce the thickness and effectiveness of the insulating boundary layer of air. (Air temperature, plus its density and viscosity properties, are also factors in the U-Factor calculation). Note: European and some other countries ignore these differences in their U-Factor calculations and only use a single U-Factor. This can cause significant differences in the final heat flow calculations. Thus U-Factors of different glasses should be compared by only using values calculated according to the same measurement standards.

Thus it is seen that to improve the U-Factor more stationary boundary layers of air are needed. Hence we are lead to double, triple, quadruple or even more glass layers with gaps between.

Adding multiple glass plies quickly leads to 2 issues:

1. The total gas space in a symmetrical (both outer glass layers of the same thickness) sealed unit should not exceed 25 mm (1 in.) or there will be a risk of glass breakage from air pressure changes caused by normal climatic temperature and barometric variations. The optimum width of the air or argon gas space is just over 13 mm (1/2 in.). This restricts sealed units to about 25 mm (1 in.) overall thickness. Krypton gas has a lesser optimum gap width, around 8 mm (3/8 in.) but is significantly more expensive.
2. Each plain glass/air interface incurs a 4% reflection, so triple glazing can have an almost 24%, generally unwanted, visible reflection masking the transmitted view.

The solution to these problems is to use Vacuum Insulating Glass (VIG). This product has been successfully sold and installed in Asia by more than one manufacturer for over ten years. Using 2 plies of 3 mm (1/8 in.) clear glass, with small, 0.7 mm (0.03 in.) dia pillars spaced on 25 mm (1 in.) centers between the lights to resist the atmospheric pressure, a hard vacuum is sealed in the gap with a low melting temperature solder glass around the edges. The resulting glass, with no gas conduction/convection heat transfer, is just less than 7 mm (9/32 in.) thick. A hard vacuum is needed to eliminate heat transfer by gas. Over time residual out-gassing of water vapor and other volatiles is seen from glass surfaces. Some VIG units use ‘Getter’ material inside the unit to adsorb those gases. Another method is to bake the unit at relatively high temperature, up to 380°C (715°F) for a few hours, before final sealing.

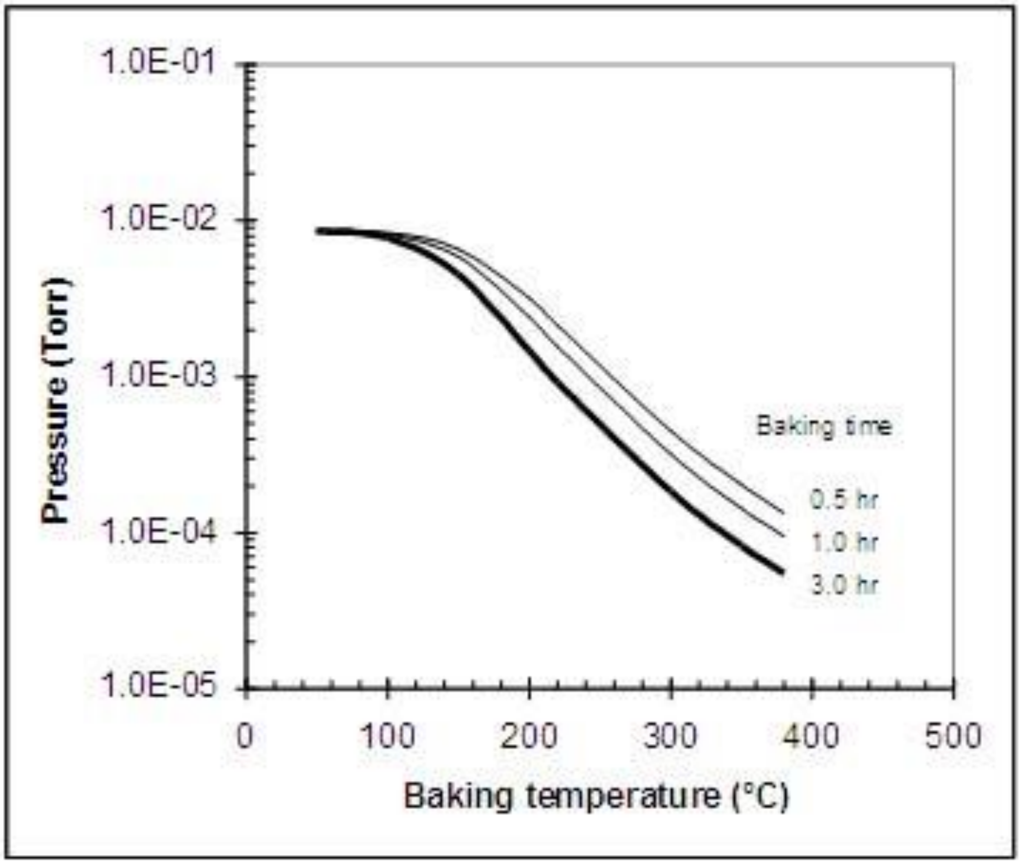

Fig. 1 Prediction of likely pressure increase after thirty years

This baking method has been shown to effectively retain the hard vacuum and hold the low thermal conductivity to within 3% of its original value even after almost 5 years of accelerated ageing at 150°C (300°F).

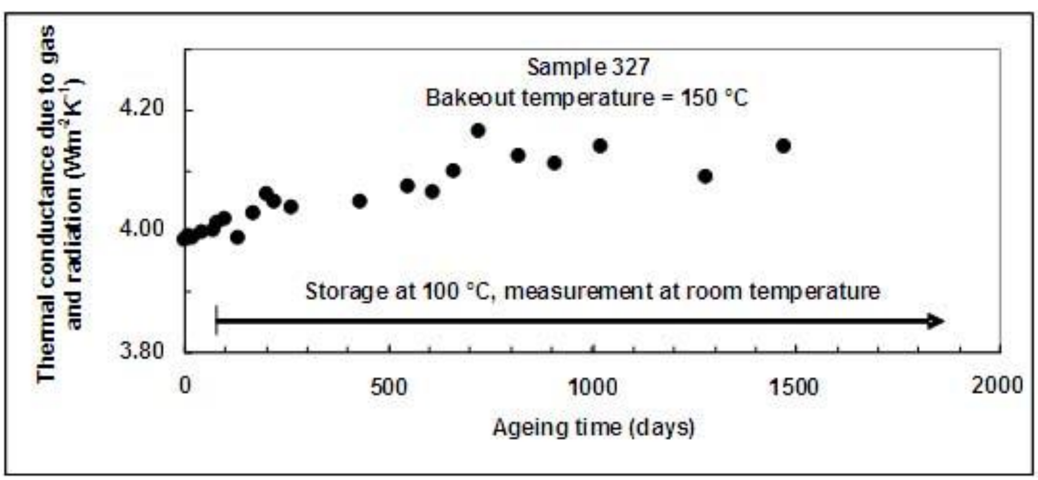

Fig. 2 Ageing test results of 150C baked VIG after long term storage at 100C

One advantage of small thickness of VIG is its ability to fit into existing frames, especially those of operating doors and windows. In consideration of the potential brittleness of the rigid VIG edge seal the following test of 50,000 cycles of door operation was made with impact loads of 10G (10 times the force of gravity) between the door frame and window frame. No change was seen or measured in the thermal insulation of the VIG unit after the testing.

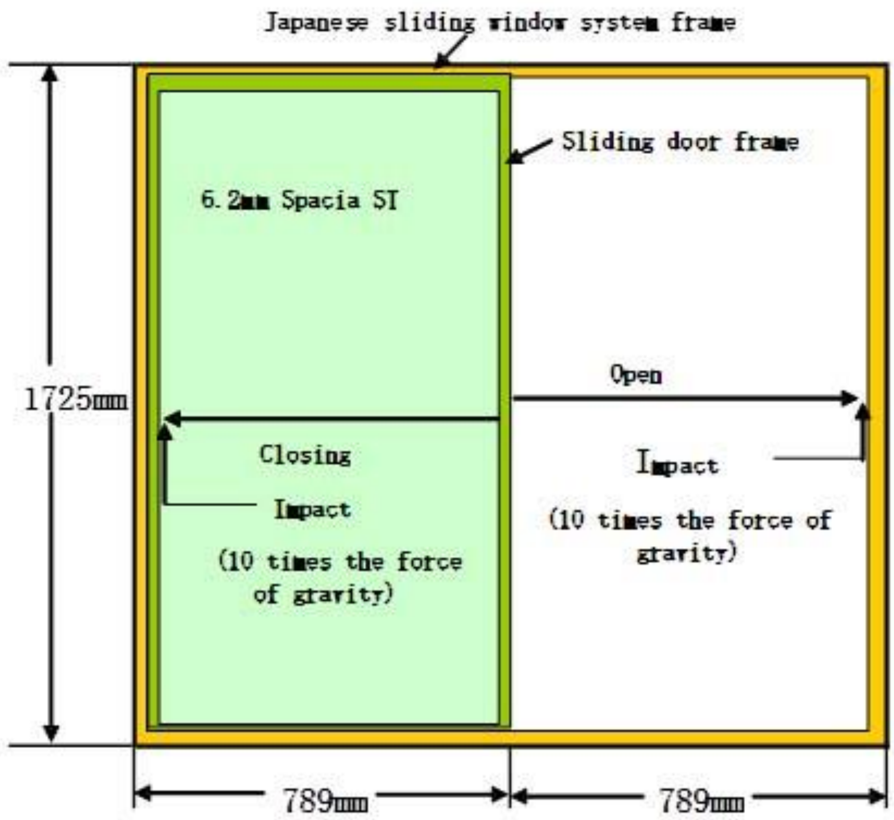

Fig. 3 Mechanical cycling test of VIG sliding door

But there is also a radiant heat transfer component between glass layers and between glass and the surroundings. This component is surprisingly large between the two layers of glass in a double glazed unit. Under winter conditions, about 70% of the heat flowing outwards from the warmer inner light to the cooler outer light of clear double glazing, is by radiation. The remaining 30% is by convection/conduction within the air/gas space. This immediately shows the need for visibly transparent low emissivity coatings.

The effective emittance between two surfaces is Eeff = (E1 x E2) / (E1 + E2). Plain glass has a very high emissivity value of 0.84 so the addition of a low-e coating

(typically in the range 0.04 to 0.20) to only one of the two layers will greatly reduce the radiant heat transfer between the layers
.

Effective Emittance

E1 \ E2	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	0.05	0.07	0.08	0.08	0.08	0.09	0.09	0.09
0.2	0.07	0.10	0.12	0.13	0.14	0.15	0.16	0.16
0.3	0.08	0.12	0.15	0.17	0.19	0.20	0.21	0.22
0.4	0.08	0.13	0.17	0.20	0.22	0.24	0.25	0.27
0.5	0.08	0.14	0.19	0.22	0.25	0.27	0.29	0.31
0.6	0.09	0.15	0.20	0.24	0.27	0.30	0.32	0.34
0.7	0.09	0.16	0.21	0.25	0.29	0.32	0.35	0.37
0.8	0.09	0.16	0.22	0.27	0.31	0.34	0.37	0.40

Fig. 4 Effective Emittance table for two low-e coatings facing each other

Thus the addition of a single low emissivity coating to either one of the inner layers (either surface #2 or #3 gives an equal radiant heat transfer reduction) turns the VIG into a very high performance product.

A significant recent development has been the addition of a ‘hard’ pyrolytic Low-E coating to the room-side surface of an insulating glass unit, which already had a Low-E coating on one of the two air space surfaces. This improves the U-Factor by over 20%. Note, this is only effective on the room side surface (#4 of 4 for double glazing) where the air is still. On the exterior surface (#1) the greater part of the heat transfer process takes place by forced convection from the assumed wind. (Those people who leave their residential window insect screens in place all year round realize a measurable winter thermal benefit).

The second issue of multiple reflections with multiple glass layers can be addressed by the application of the newly available, hard and durable, Anti-Reflection coatings.

Careful reading of coated glass suppliers literature will reveal that some ‘soft’ silver sputtered low-e coatings also have low visible reflection, and a common ‘hard’ pyrolytic Anti-Reflective coating also has a reduced emittance value.

Thus very high insulation values can be achieved with judicial combinations of VIG, Anti-Reflective coated glass, Low-E coated glass and ‘hard coated’ Low-E coatings. Free computer programs such as DOE’s LBNL Window 6 will easily evaluate the thermal performance of any combination of glass and coating.

In simple terms, lower U-Factors are always better, and Low-E coatings always help improve this thermal performance (insulation).

An extreme example of a common clear glass triple glazed unit with a U-Factor of (0.31 Btu/hr.sq.ft.F), 76% Tvis, 21% Vis Reflection, could be theoretically improved by:

1. Replace the center light with a VIG (Vacuum Double Glazed) unit
2. Put an Anti-Reflective coating on #1 surface of clear glass
3. Put Silver low-e coating on #2 surface
4. Put Silver low-e coating on #7 surface
5. Use Krypton gas filling
6. Put a hard pyrolytic low-e coating on #8 surface

This would give a U-Factor of (0.07 Btu/hr.sq.ft.F), 50% Tvis, 13% Vis Reflection. The insulation value would be 4 times better than clear triple glazing or 15 times better than single clear glass.

VIG INSTALLATIONS

Over 1,000,000 VIG units have been Installed in Japan over the last 10 years with no reported service failures.

Single glazed waiting rooms in subway stations have added insulating glass to existing metal frames thus allowing the interiors to be heated. Sizes available up to 4 ft. x 8 ft.

Fig. 5 Heated subway shelter

Fast food stores have had energy efficient VIG retroglazing to existing structures.

Fig. 6 Convenience food stores retroglazed with VIG

The thin section of single glazing framework is an ideal opportunity for high performance VIG units.

Fig. 7 VIG retroglazed into existing framework

In Europe the valuable architectural structures of old can be retained, while adding VIG units supplies current energy efficiency.

Hermitage Amsterdam

Library of Amsterdam University

Fig. 8 European VIG installations

In North America the MIT buildings in Boston MA, originally built in 1913-1915 must have operable windows as with original system while retaining high transparency and maintaining the original architectural integrity

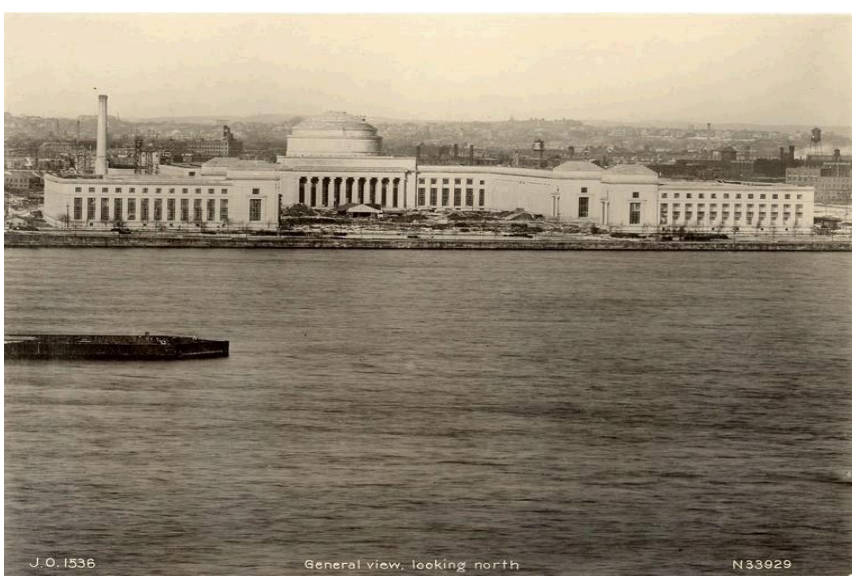

Fig. 9 MIT Boston

Fig. 10 MIT Boston. Exterior detail

This is being achieved with VIG units while preserving the full operational functions of the original frames and sashes. Fifty seven separate VIG units are in each bay. The only visible difference is one small black vacuum seal button near the corner of each unit.

Fig.11 MIT Boston. Vacuum seal buttons

The alternative structure would have been to add internal storm windows with separate operating mechanisms. This was attempted but proved to be impractical.

Fig. 12 MIT Boston. Interior storm window option

SOLAR CONTROL

Solar control is slightly more difficult to optimize. From an energy perspective we are interested only in the visible and Solar IR regions of the electro-magnetic spectrum. Although UV radiation is the most damaging to organic materials and paints, it only represents about 3% of the sun's energy and so will be ignored here, other than noting that the plastic interlayer of laminated glass absorbs almost all the Solar UV between 300 and 380 nm (Note: This does not block all the fading potential of sunlight for organic materials).

VISIBLE DAYLIGHT

Visible light from the sun is invariably desired but it must be appreciated that about 47% of the sun's energy is in the visible spectrum, so controlling light will also control a significant part of the solar heat gain, and likewise, controlling solar heat gain can affect light transmission.

A significant option in recent glass supply has been made by offering glass with a reduced Iron Oxide content. This has virtually eliminated the light green tint seen on standard clear glass, especially at greater thicknesses. “Low-iron” glass, 19 mm (3/4 in.) thick, has 10% greater light transmission than standard clear glass.

Durable Anti-Reflection coatings are now available to reduce the reflection from 8% for 6 mm (1/4”) clear glass to 2% or less. The classic explanation is that the coating causes destructive interference between light waves reflected of both sides of the thin coating. For this process to work a coating material is chosen so that the total reflection of both sides of the coating is less than half that of a non-coated glass surface. This has the result of increasing transmitted daylight by about 4% points when Anti-Reflective coatings are used.

These developments allow the daylight transmission and consequent energy savings to be increased where effective daylight controls and practices are implemented.

SOLAR TRANSMISSION

Big gains in passive solar heating can be had even with clear glass. The Solar Transmission of 19 mm (3/4”) Low-Iron glass is 28% points greater than standard clear glass.

In winter we want the sun’s free warmth. In fact a well designed window is the only item in the building envelope which can be net energy positive. So if we want to increase passive solar gains, while having minimal effect on visible daylight transmission and appearance compared to standard clear glass, we use Low-Iron glass, possibly with Anti-Reflective coatings.

But in summer we usually want to block the sun’s heat. Grey tints are available which reduce solar transmission, both in the Visible and Solar IR parts of the spectrum. Grey is the most color neutral. Different tints and thicknesses of glass can reduce the direct solar transmission down to less than 10% for 6 mm (1/4 in.) glass.

Spectrally selective tints and coatings are available to absorb or reflect the IR portion of the solar spectrum, while minimizing any reduction in the visible spectrum. The incentive to have optimum night time vision through car windows while blocking as much as possible of total solar heat gains (for air conditioning equipment reductions) prompted intensive work which developed the spectrally very selective Green, Blue and Blue-Green tinted automotive glasses. These tints are readily available for the Building industry.

Buildings, with double glazed units, can readily accommodate the wide variety of relatively fragile solar control coatings that have been developed but of these coatings have yet made the reverse trip back to automotive applications, though double glazing and some coatings are starting to appear in advanced car designs.

Current VIG units, with rigid edge seals, cannot, by themselves resist the differential thermal expansion of solar control glasses.

Fig. 13 Corner detail of rigid solder glass seal

One solution is to make a triple glazed unit with conventional solar control outer light and a VIG unit as the inner light of a normal sealed double glazed construction.

Meanwhile, in Germany, an extensive effort is being made to bond shaped flexible metal strips to the glass edges. These strips could be joined at their outer edges to give a flexible seal which would be vacuum tight, but would allow differential thermal expansion, as seen in the schematic section below.

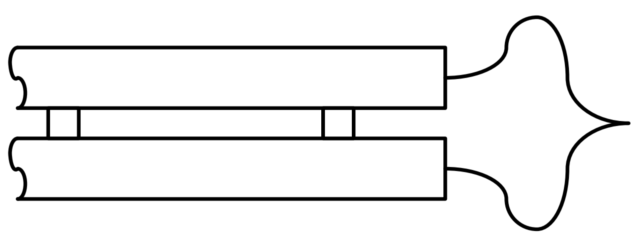

Fig. 14 Cross section of proposed flexible metal vacuum seal

COLOR
Bronze, blue, green, grey tinted glasses appear dark from the outside in daylight until a silver reflective coating or very light color blind is applied behind. Silver, copper, gold and other metallic color coatings are usually on clear glass. All deliver constantly changing aesthetic properties as hourly changes in the brightness of the light on either side of the glass changes the relative values of visible transmitted and reflected images. These glasses also provide solar heat gain reduction, primarily by solar and visible absorption. When the coated glass becomes hot it is even more important to have a low emissivity coating on the room side of the coating to either reduce the inward emitted long wave IR heat, or to reflect it back outwards.

In terms of range of choice, today you can select an outside (#1 surface) coating of up to 70% visible reflection (silver color), or down to 1% reflection with negligible transmitted light (an Anti-Reflective coating on the outside of a very dark grey tint). This latter glass has an eerie disappearing quality when viewed from outside in daylight.

DISCUSSION

The above words show the many, though sometimes perhaps conflicting, options available to the window designer today.

Perhaps what is needed now are suitable computer simulation programs to readily model the dynamic energy flows, in conjunction with appropriate operating programs to dynamically control solar and visible window properties, whether by operable blinds and louvers or by chromogenic glasses.

CONCLUSIONS

In simple terms, all Low-E coatings will always improve the thermal performance of all windows.

Appropriate selection of Low-E coatings whether for passive solar gain, or for solar heat blocking, and glass tints can have huge effects on annual energy consumption from energy and daylighting savings.

Vacuum insulating glazing is an added high performance option for energy efficient windows.

Free computer programs such as DOE’s LBNL Window 6, ComFen, ResFen and Energy Plus can readily evaluate the energy performance of any combination of glass and coating.