Thermal Stress Update

INTRODUCTION

Vitro Architectural Glass (formerly PPG Industries) has for many years recommended that early design considerations regarding the use of glass on commercial projects include evaluation of potential thermal stress breakage. Thermally induced glass breakage is recognized and well understood in the glass industry. Procedures to help design influentials evaluate these risks have long been offered by Vitro. The basis and methodology included in previous versions of this document, such as TSR's 130 and 230 for monolithic and insulating glass respectively, remain valid and applicable and are continued in this document.

Completely satisfactory performance can be and has been achieved when attention is given to the thermal stress performance of the glass in the design stage of the project. Performing a thermal stress analysis, using the appropriate design factors, will lead architects and design professionals to the proper glass recommendation to ensure that the glass performs under the expected thermal loads. When installations experience thermal stress breakage problems, glass damage, improper glazing practice, inappropriate thermal stress analysis, or the complete absence of a thermal stress analysis are invariably involved.

The purpose of this document is to provide:

- An overview and perspective on thermal stress.
- Thermal Stress Factors for Vitro's 6mm (1/4") thick glass products, including new coated and tinted products.
- Clarification of the use of the thermal stress procedures and interpretation of the results.
- Updated product specific guidelines.

What's New in This Document?

The following additions and changes have been made to this version of the Thermal Stress Update:

- Vitro Optiblue® tinted glass and Solarban® z50 coated glass have been added
- Procedures to perform a thermal stress analysis for insulating glass units incorporating selected coatings on both the outdoor and indoor glass lites have been added.
- Selected 3mm (1/8") thick products have been removed.

The number of Vitro glass product combinations available when combining different glass substrates and coatings makes it impractical to address them all in this document. Users are encouraged to use Vitro's Thermal Stress Analysis computer program, which is available on Vitro's website and can be used to perform a thermal stress analysis for virtually any of Vitro glass products. Additional information about this valuable tool, including a link to the program, can be found on page 35 of this document.

Thermal Stress Update

OTHER IMPORTANT DESIGN ISSUES

Thermal stress is only one glass design consideration. Other important issues, not addressed in this document, include:

- Aesthetics
- Wind and Snow Loads
  - ASTM E 1300 – *Standard Practice for Determining Load Resistance of Glass in Buildings* can be used to evaluate specified glass products subjected to uniform wind and snow loads.
- Thermal and Optical Performance
  - Vitro publishes thermal and optical properties for its glass products based on simulations using the LBNL Window program. This program can be downloaded freely from the LBNL Window and Daylighting web site, which can be accessed using the following link: LBNL Window Program
  - Vitro invites you to use its web based Glass Performance Calculator to simulate the thermal and optical properties of many of its glass products, including monolithic, insulating glass, fritted glass and laminated glass applications. The program can be accessed using the following link:
- Glazing Systems
- Energy and Safety Glazing Codes

It is the design professional's responsibility to ensure compliance with all of these requirements. Vitro has long provided technical guidelines and offered specific assistance on these and other glass related issues. Consult your Vitro representative for assistance.

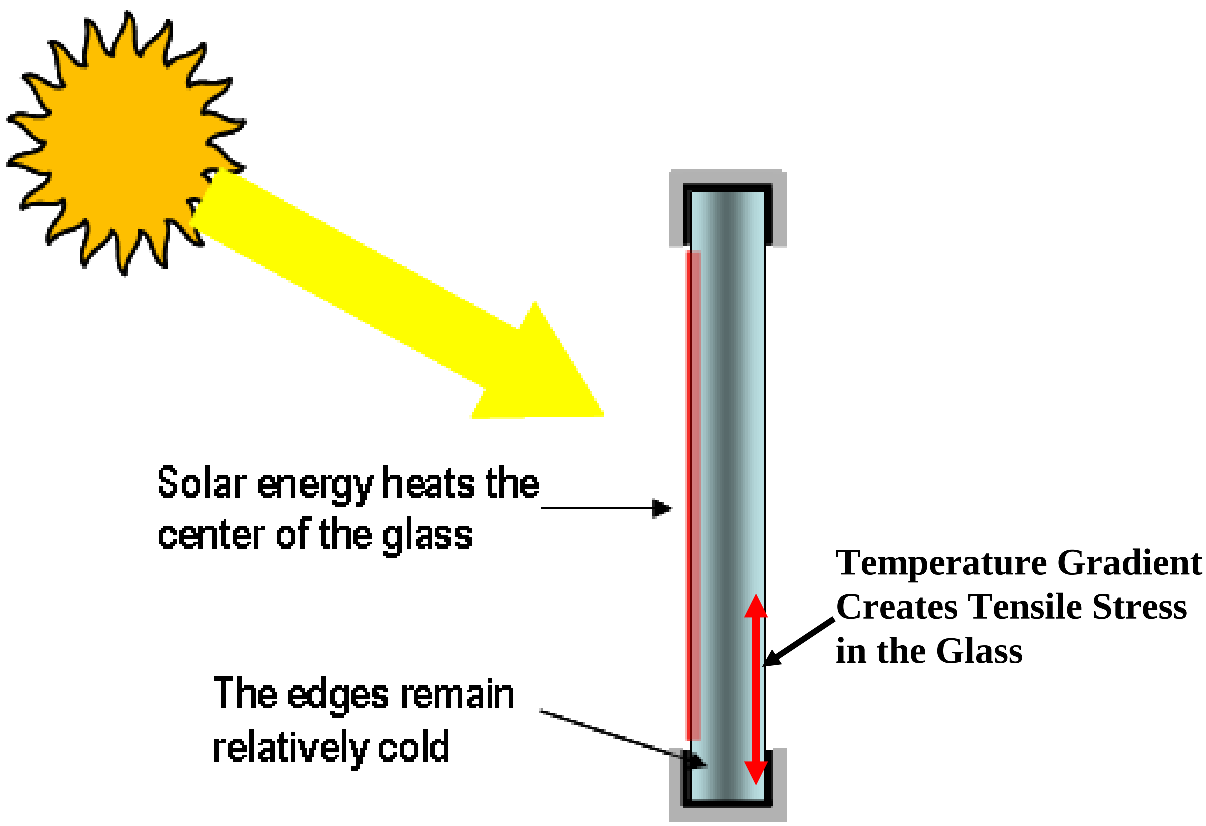
On going efforts by ASTM have resulted in a new Standard Practice for Determining the Resistance of Single Glazed Annealed Architectural Flat Glass to Thermal Loadings (E2431-06). Vitro fully supports and participates in the ASTM effort to develop a comprehensive practice for the evaluation of thermal stresses in glass, in which this first version of E2431 is the initial step.

Thermal Stress Update

THERMAL STRESS

Thermally induced stresses in glass are caused by a positive temperature difference between the center and edge of the glass lite (see Figure 1), meaning that the center of the glass is hotter than the edge. The expansion of the heated glass center results in tensile stress at the edge of the glass. If the thermally induced stress exceeds the edge strength of the glass, breakage will occur. The structural performance of glass is such that the risk of breakage can only be predicted statistically and will depend on several variables, including stress, edge strength, area under stress, and time duration of the stress. A critical fact to consider is that thermal stress breakage originates at the edge of the glass where, especially in commercial applications, damage can occur during handling, fabrication, and installation. Such damage can significantly reduce the glass edge strength. Accordingly, even a rigorous thermal stress analysis that is based on reasonable assumptions for edge strength will not be able to account for weakened edges due to handling and installation damage. **Prudence, logic, and the reality of damaged glass edges all suggest that heat strengthened glass be seriously considered when the analysis indicates that annealed glass is marginal for the application.**

FIGURE 1
THERMAL STRESS IN GLASS CAUSED BY TEMPERATURE GRADIENT



Thermal Stress Update

Glass thermal stresses are influenced by a number of product and environmental factors. The most significant contributors to thermal stresses are:

- Glass Type
- Coating Type and Coating Location
- Exterior Shading Patterns
- Interior Solar Control Applications (drapes, venetian blinds)
- Heating Register Location and Orientation

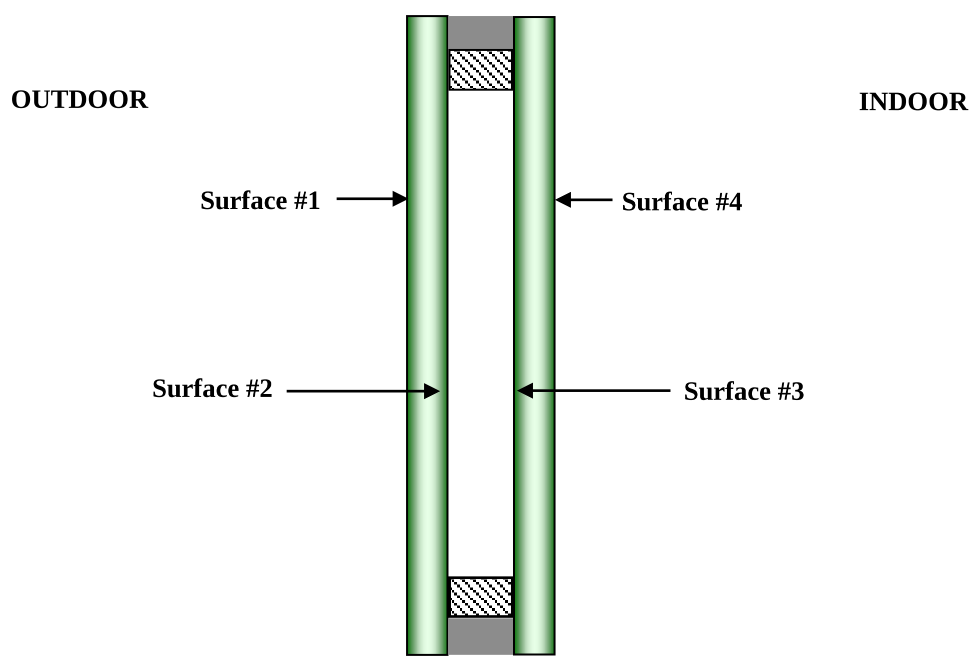
Glass Type

For purposes of this discussion, three types of glass are considered: clear glass, tinted glass, and spectrally selective glass. The temperature gradient that causes thermal stress typically arises when the sun heats the exposed area of cool or cold glass. The speed and amount of the temperature increase is directly related to the absorption of the glass. Because tinted glass, and especially spectrally selective glass, derive their improved solar performance by absorbing solar radiation, they are much more susceptible to thermal stress problems than clear glass.

Coating Type and Coating Location

Reflective and low emissivity coatings improve solar performance by both reflecting and absorbing solar radiation. As discussed, increased absorption will lead to increased glass temperatures. The effect of reflectivity will depend on both the reflectance of the coating and the location. Table 1, which applies to both clear and tinted substrates, shows the gross effect of both these factors. Use Figure 2 to locate the coating surface.

FIGURE 2
SURFACE DESIGNATION ON A TYPICAL INSULATING GLASS UNIT



Thermal Stress Update

TABLE 1 EFFECT OF COATING TYPE & LOCATION ON THERMAL STRESSES IN GLASS		
	EFFECT ON THERMAL STRESSES	
COATING TYPE & LOCATION	OUTDOOR LITE	INDOOR LITE
SOLARCOOL® on #1 Surface[1]	Decrease	Decrease
SOLARCOOL or VISTACOOL™ on #2 Surface[1]	Increase	Decrease
SOLARCOOL or VISTACOOL on #3 Surface	Increase	Decrease
SOLARCOOL on #1 combined with SOLARBAN or SUNGATE® on #3 Surface	Increase	Increase
SOLARCOOL or VISTACOOL on the #2 surface combined with SOLARBAN or SUNGATE on the #3 Surface	Increase	Increase
SOLARBAN or SUNGATE on #2 Surface[1, 2]	Increase	Decrease
SOLARBAN or SUNGATE on #3 Surface	Increase	Increase

Footnotes:

[1] For monolithic (single glazing) applications use OUTDOOR LITE for effect

[2] Only SUNGATE 500 coated glass can be glazed monolithically and only with the coating in the #2 position - never in the #1 position.

OUTDOOR SHADING PATTERNS

Shade patterns on the outdoor lite of glass increase thermal stresses by increasing the thermal gradient between the shaded and unshaded area of the glass. Outdoor shading patterns can be caused by any combination of design features, such as overhangs, fins and curtain wall members. They can also be caused by elements of the surrounding environment including adjacent buildings and trees. The effect of outdoor shading patterns on thermal stresses depends on the type of pattern and percentage of glass area shaded.

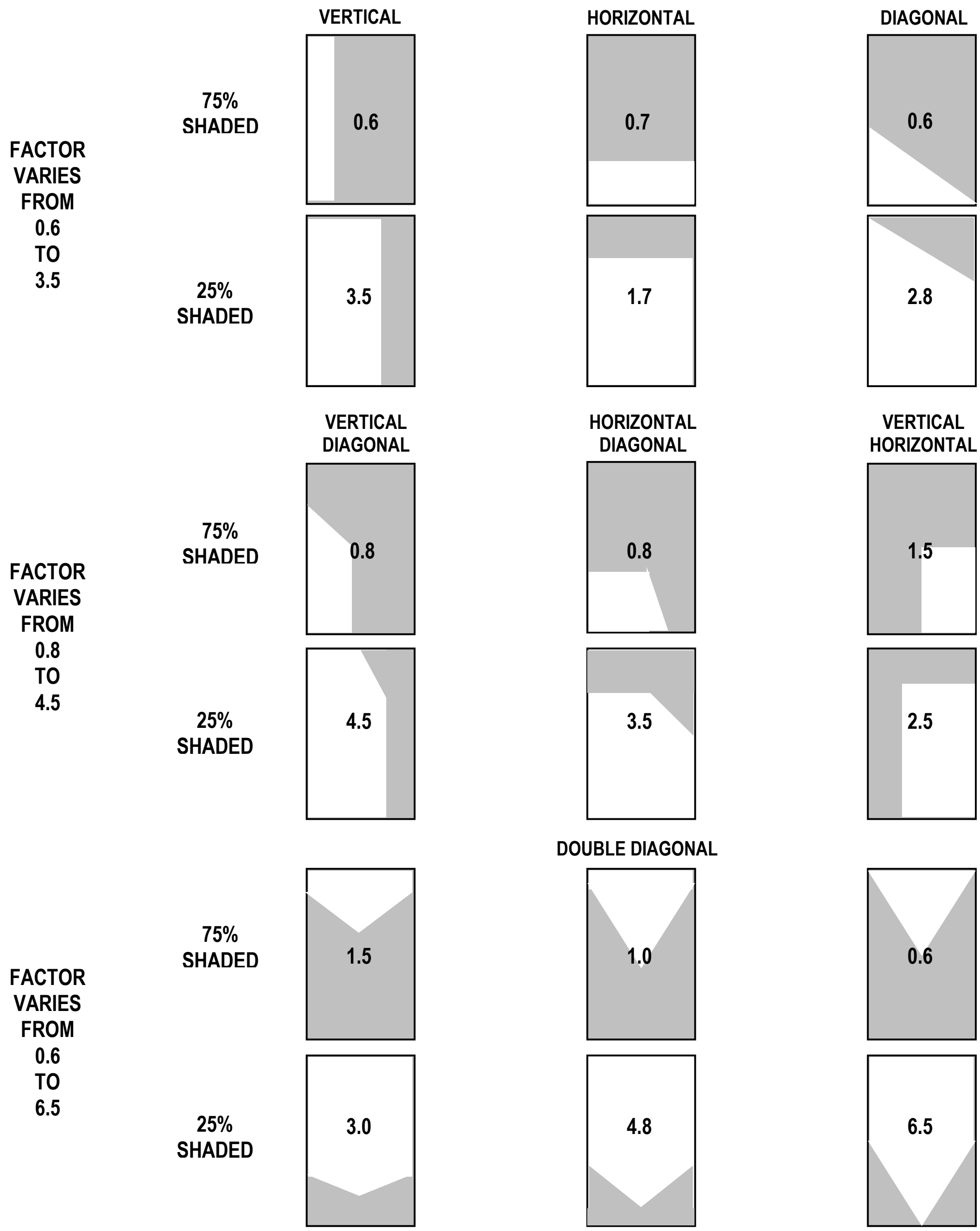
It should be emphasized that outdoor shading is a dynamic design element, varying seasonally due to changes in the incident angle of solar radiation. In addition, an important consideration is that shading and reflection patterns can be altered long after construction is completed, with the addition of new adjacent structures. Generally, shading patterns with 50% or less coverage of the glass is most unfavorable because they cause the highest temperature gradients. The shade patterns shown in Figures 3 and 4 are common in building applications and the range of effect for both monolithic and insulating glass applications are given for reference.

It is very unusual for situations to exist in building projects where there is no shading of the glass. In addition, as stated previously, shade patterns are dynamic and can change after the project is completed. For these reasons, Vitro recommends that all thermal stress analyses assume some level of outdoor glass shading using the patterns shown in Figures 3 and 4.

Thermal Stress Update

FIGURE 3

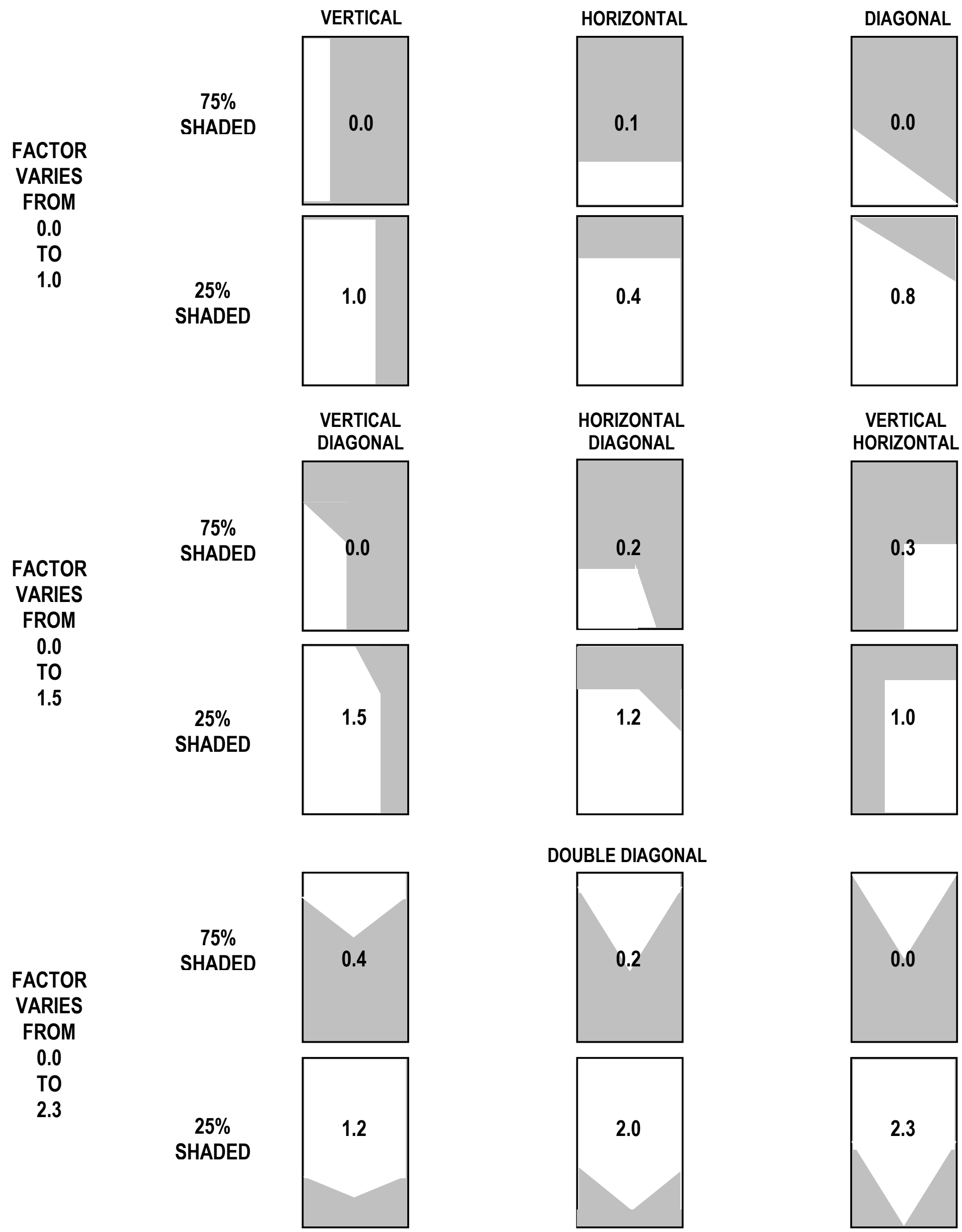
Outdoor Shading Patterns and Associated Approximate Thermal Stress Factors for Insulating Glass Units



Select the shading pattern which most closely approximates project conditions. Thermal stress increases as percent shaded area decreases. Thermal stress increases going down the table.

Thermal Stress Update

FIGURE 4
Outdoor Shading Patterns and Associated Approximate Thermal Stress Factors for Monolithic (Single)



Select the shading pattern which most closely approximates project conditions. Thermal stress increases as percent shaded area decreases. Thermal stress increases going down the table.

Thermal Stress Update

INDOOR SHADING DEVICES

The widespread use of insulating glass makes it important to consider the elements of interior design and their potential effect on the INDOOR lite of the insulating glass unit. The known or likely use of a variety of common interior window treatments is a critical design element.

Indoor shading devices increase the temperature of the central area of the glass in two ways:

- By reflecting solar radiation back through the glass
- By reducing the convection and conduction of heat through the glass

The effect of the indoor shading device is dependent on the type and color of device used and the amount of ventilation that exists within the air space between the shading device and the glass. Ventilating the air space will help to reduce edge stresses. The glass to shade space should be at least two inches and vented; a vented glass to shade space of six inches is preferable. Natural ventilation can be provided by leaving at least an inch between shading devices and surrounding construction at the sill and two inches at the head. As glass to shade spacing is decreased, edge stress increases. The following indoor shading devices are listed in order of increasing glass stress.

TABLE 2

RELATIVE EFFECT OF INTERIOR SHADING DEVICE ON GLASS STRESS

INTERIOR SHADING DEVICE	EFFECT ON GLASS STRESS
None	Least Stress
Dark open weave draperies	↓
Light open-weave draperies	↓
Dark closed-weave draperies	↓
Light closed-weave draperies	↓
Dark venetian blinds	↓
Light venetian blinds	Maximum Stress

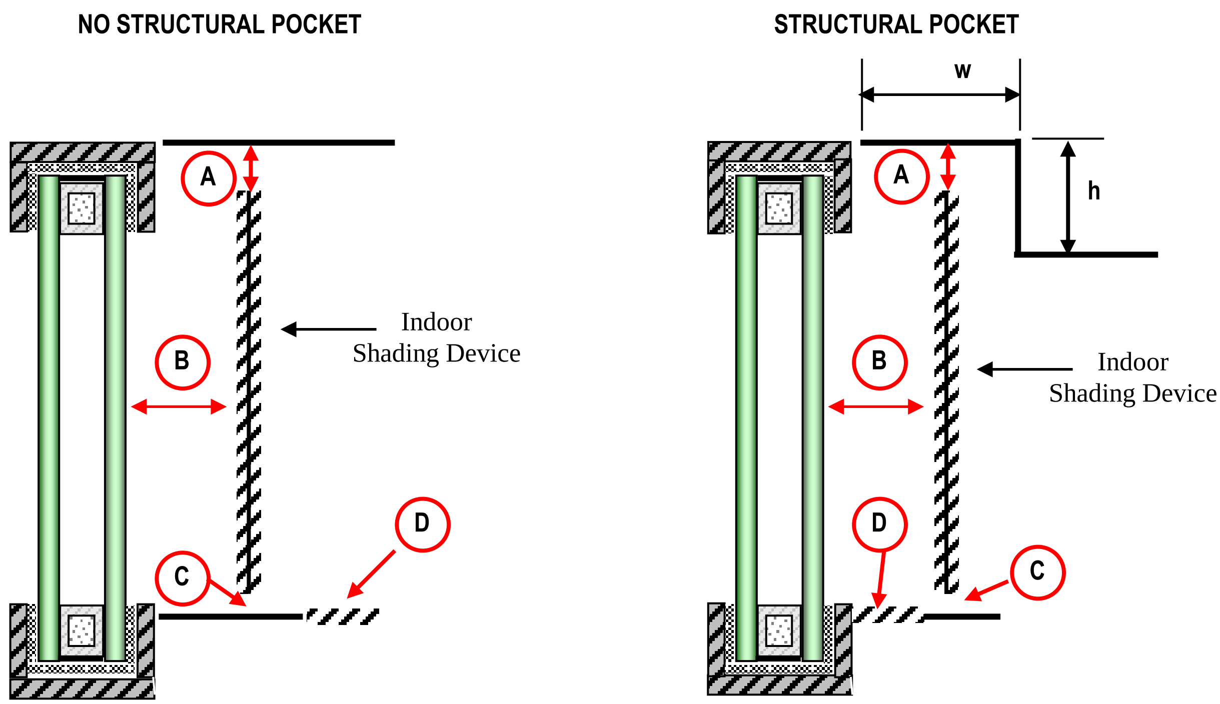
HEATING REGISTER LOCATION AND ORIENTATION

Heating registers that direct warm air against cold glass can induce thermal breakage. Also, if the heating register is located between the interior shading device and the glass, the trapped heat can cause the center of the glass to become excessively warm and lead to glass breakage. Accordingly, heating registers should be located on the room side of the interior shading, never between the interior shading and the glass. Register vanes should direct warm air away from the glass.

Figure 5 on page 9 may offer some guidance in determining indoor shading and heating register design elements that minimize thermal stresses in the glass.

Thermal Stress Update

FIGURE 5
INDOOR SHADING DESIGN CONSIDERATIONS



INDOOR SHADING DESIGN CONSIDERATIONS THAT INFLUENCE THERMAL STRESS IN GLASS			
Reference from Sketches Above	INFLUENCE ON THERMAL STRESS IN GLASS		
	Preferable	Favorable	Unfavorable
A	Minimum of 2" between Shading and Surrounding Construction	Minimum of 2" between Shading and Surrounding Construction	Less than 2" between Shading and Surrounding Construction
B	Ventilated Air Space, 6" or more	Ventilated Air Space, 2" to 6"	Non-ventilated Air Space
C	Minimum 1" Gap at Sill for Ventilation	Minimum 1" Gap at Sill for Ventilation	Less than 1" Gap at Sill for Ventilation
D	Heating Register on Roomside of Shading	Heating Register on Roomside of Shading	Heating Register Between Glass and Shading
Structural Pocket	None	**h** less than or equal to **w**	**h** greater than **w**

Thermal Stress Update

FRAMING SYSTEM

Framing with low heat capacity tends to minimize thermal stresses. For example, lock-strip gaskets tend to reduce thermal stresses because they are black and somewhat insulating. Metal glazing rabbets and frames, together with rubber gaskets, is the most typically used framing system. Thermal stresses will tend to increase as the thickness of the metal increases. Metal framing systems that include integral thermal barriers may reduce thermal stresses in the indoor glass of the insulating glass unit; conversely, this type of framing may increase thermal stress in the outdoor glass of the insulating glass unit.

Massive concrete or metal frames in thermal contact with glazing rabbets have great heat capacity and will result in increased thermal stress in the glass when the concrete or metal becomes cold and does not warm up as fast as the central area of the glass unit when exposed to solar energy.

Framing systems that are designed to make glazing easy will reduce the possibility of edge or impact damage to the glass unit during installation. Increasing the rabbet width and depth reduces tolerance problems and facilitates the glazing of the units, thus reducing the likelihood of glass edge damage.

Framing systems that require glass units to be joggle set increase the possibility of edge damage, unless each unit is cushioned adequately against impact, pressure and abrasion.

Figure 6 on page 11 is offered for guidance in evaluating the relative effects of the framing system on the expected thermal stresses in the glass.

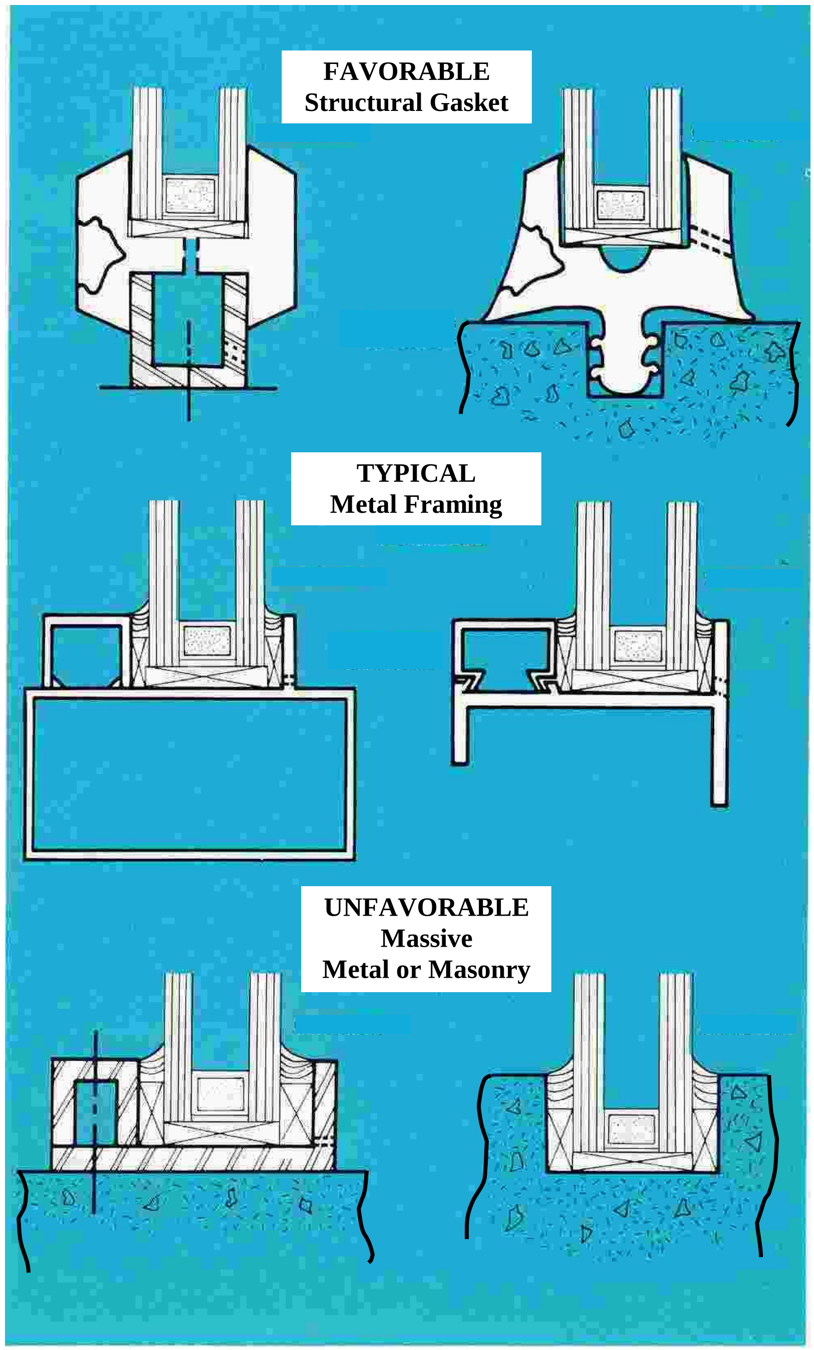
Very Important:

- **Glass edge damage will significantly reduce the glass edge strength, possibly by 50% or more depending on the severity of the damage.**
- **Damaged glass edges will lead to an increased probability of glass breakage due to thermal stresses, as well as due to other possible sources of glass stress.**
- **Vitro's recommendations to resist thermal stress breakage are based on clean-cut, undamaged glass edges.**

Thermal Stress Update

FIGURE 6

FRAMING SYSTEM CONSIDERATIONS



Thermal Stress Update

THERMAL STRESS ANALYSIS

Vitro's methodology (examples given later in this document) for estimating thermal stresses, which has been widely used in the glass industry for years, is based on determining the effect of the various design and environmental factors. This cumulative stress factor is then multiplied by the glass thermal stress factor to arrive at the estimated in-service thermal stress. Finally, the estimated thermal stress is used to calculate the predicted probability of glass breakage that is used to make the glass treatment recommendation, based on the design professional's acceptable level of glass breakage for the project.

Typically, Charts 1 & 2 for insulating and monolithic glass respectively, are used to determine whether glass strengthening is required. Charts 1 & 2 are a "go, no-go" tool based on a probability of breakage of 8 per 1000 and are appropriate if this level of predicted breakage is acceptable to the responsible design professional. Vitro can calculate the numeric probability of glass breakage based on the expected thermal stress, if required.

Obviously, the recommendation resulting from the analysis is valid only if the conditions assumed to make the analysis are representative or more severe than the actual in-service conditions. The reality is that in-service conditions are often different than the assumptions. Some of these differences are beyond the designer's control or even his or her ability to anticipate them; other changes can and should reasonably be anticipated and considered in reaching a final decision. For example, if the intended design does not include interior shading and a thermal stress analysis is performed based on this assumption, the results may indicate that annealed glass is adequate. If the decision is later made to install indoor shading devices, the consequent increased thermal stress may lead to unexpected glass breakage. A more conservative approach in the design stage is to assume some type of indoor shading, which could prevent this type of situation. ***In situations where reliable design conditions are unavailable, good engineering judgment is to assume the most conservative (i.e., severe) design conditions that could be reasonably expected.***

GUIDELINES

Over the years Vitro has provided guidelines for various Vitro glass products to assist our customers make quick, first level judgments concerning the need to provide additional fabrication to meet thermal stress requirements. Such guidelines can only be prepared based on assumed glazing and installation conditions and must be used with care and good judgment. Updated guidelines are offered in Table 18, together with the assumptions given in Table 17 that were used to prepare them.

Very Important:

- **The guidelines in Table 18 are offered with the expectation that they will be used with good judgment and caution.**
- **They are offered as a point of departure to make an initial assessment of potential thermal stress problems.**
- **They are NOT a substitute for an in depth thermal stress analysis.**

Thermal Stress Update

Tables 3 – 16, and Tables Tf, Tg, and Th are used to determine the various values required in the thermal stress analysis procedure. Tables 3 – 16 contain the stress factors for the various Vitro glass products, both coated and uncoated. Tables 3 and 4 apply to monolithic glass applications, and Tables 5 -16 apply to insulating glass unit applications. In addition to the glass stress factors, Tables 5 – 16 include the appropriate Installation Condition Table reference (Tf, Tg, or Th) to use based on the specified glass. Tables Tf, Tg, and Th contain the Installation Conditions and associated factors.

TABLE 3
STRESS FACTORS FOR *MONOLITHIC* APPLICATIONS WITH *CLEAR AND TINTED* GLASS

GLASS DESCRIPTION	GLASS THICKNESS		ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)
	INCHES	MM		
CLEAR	¼	6.0	220	110
ATLANTICA®	¼	6.0	800	370
AZURIA®	¼	6.0	790	370
CARIBIA®	¼	6.0	820	380
GRAYLITE®	¼	6.0	900	420
OPTIBLUE®	¼	6.0	410	200
SOLARBRONZE®	¼	6.0	590	280
SOLARGRAY®	⅛	3.0	480	230
	¼	6.0	690	320
OPTIGRAY®	¼	6.0	990	460
SOLEXIA®	¼	6.0	620	290
STARPHIRE®	¼	6.0	60	40

Thermal Stress Update

TABLE 4 STRESS FACTORS FOR *MONOLITHIC* APPLICATIONS WITH *SOLARCOOL AND VISTACOOL COATED* TINTED GLASS				
	GLASS THICKNESS		ALL OTHER	NORTH
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)
SOLARCOOL AZURIA(1)	¼	6.0	730	340
SOLARCOOL AZURIA(2)	¼	6.0	960	450
SOLARCOOL SOLARBRONZE(1)	¼	6.0	570	270
SOLARCOOL SOLARBRONZE(2)	¼	6.0	770	360
SOLARCOOL CARIBIA(1)	¼	6.0	740	350
SOLARCOOL CARIBIA(2)	¼	6.0	1000	460
SOLARCOOL SOLARGRAY(1)	¼	6.0	630	300
SOLARCOOL SOLARGRAY(2)	¼	6.0	890	410
SOLARCOOL GRAYLITE(1)	¼	6.0	720	340
SOLARCOOL GRAYLITE(2)	¼	6.0	1010	470
VISTACOOL AZURIA(2)	¼	6.0	850	400
VISTACOOL CARIBIA(2)	¼	6.0	850	400
VISTACOOL SOLARGRAY(2)	¼	6.0	730	340

(1) Indicates coating is on surface 1 (see Figure 2, p. 4)
(2) Indicates coating is on surface 2 (see Figure 2, p. 4)

Thermal Stress Update

TABLE 5 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *CLEAR AND TINTED* GLASS					
GLASS DESCRIPTION	GLASS THICKNESS		ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
	INCHES	MM			
CLEAR INDOOR LITE	¼	6.0	220	110	Tf
OUTDOOR LITE					
CLEAR	¼	6.0	240	120	Tf
ATLANTICA	¼	6.0	810	380	Tf
AZURIA	¼	6.0	810	380	Tf
CARIBIA	¼	6.0	840	390	Tf
GRAYLITE	¼	6.0	920	430	Tf
OPTIBLUE	¼	6.0	430	210	Tf
SOLARBRONZE	¼	6.0	610	290	Tf
SOLARGRAY	¼	6.0	710	330	Tf
OPTIGRAY	¼	6.0	1000	460	Tf
SOLEXIA	¼	6.0	640	300	Tf
STARPHIRE	¼	6.0	60	40	Tf

Thermal Stress Update

TABLE 6 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARCOOL AND VISTACOOL COATED* TINTED GLASS					
	GLASS THICKNESS		ALL OTHER	NORTH	FOR IG -
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)	USE TABLE
CLEAR INDOOR LITE	¼	6.0	220	110	Tf
OUTDOOR LITE					
SOLARCOOL COATED GLASS					
SOLARCOOL AZURIA(1)	¼	6.0	740	350	Tf
SOLARCOOL AZURIA(2)	¼	6.0	990	460	Tf
SOLARCOOL BRONZE(1)	¼	6.0	580	270	Tf
SOLARCOOL BRONZE(2)	¼	6.0	780	360	Tf
SOLARCOOL CARIBIA(1)	¼	6.0	740	350	Tf
SOLARCOOL CARIBIA(2)	¼	6.0	1010	470	Tf
SOLARCOOL GRAY(1)	¼	6.0	640	300	Tf
SOLARCOOL GRAY(2)	¼	6.0	900	420	Tf
SOLARCOOL GRAYLITE(1)	¼	6.0	730	350	Tf
SOLARCOOL GRAYLITE(2)	¼	6.0	1020	470	Tf
SOLARCOOL SOLEXIA(1)	¼	6.0	630	300	Tf
SOLARCOOL SOLEXIA(2)	¼	6.0	860	400	Tf
VISTACOOL COATED GLASS					
VISTACOOL AZURIA(2)	¼	6.0	860	400	Tf
VISTACOOL CARIBIA(2)	¼	6.0	860	400	Tf
VISTACOOL GRAY(2)	¼	6.0	760	350	Tf

Thermal Stress Update

TABLE 7 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SUNGATE 500* COATING ON SURFACE #2 OR #3					
GLASS DESCRIPTION	GLASS THICKNESS INCHES	GLASS THICKNESS MM	ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
OUTDOOR LITE: CLEAR GLASS WITH SUNGATE 500 ON THE # 2 SURFACE INDOOR LITE: CLEAR					
SUNGATE 500(2)CLEAR	¼	6.0	350	170	Tg
CLEAR	¼	6.0	220	110	Tg
SUNGATE 500 ON THE # 3 SURFACE					
INDOOR LITE					
CLEAR GLASS WITH SUNGATE 500 COATING ON #3 SURFACE	3/32	2.5	200	100	Tf
	⅛	3.0	240	120	Tf
	¼	6.0	290	140	Tf
OUTDOOR LITE					
CLEAR	3/32	2.5	100	60	Tf
	⅛	3.0	160	80	Tf
	¼	6.0	240	120	Tf
ATLANTICA	¼	6.0	830	390	Tf
AZURIA	⅛	3.0	720	340	Tf
	¼	6.0	820	380	Tf
CARIBIA	¼	6.0	850	400	Tf
GRAYLITE	¼	6.0	930	430	Tf
OPTIBLUE	¼	6.0	440	210	Tf
SOLARBRONZE	¼	6.0	630	300	Tf
SOLARGRAY	¼	6.0	730	340	Tf
OPTIGRAY	¼	6.0	1010	470	Tf
SOLEXIA	¼	6.0	660	310	Tf
STARPHIRE	¼	6.0	70	50	Tf

Thermal Stress Update

TABLE 8 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SUNGATE 100* COATING ON SURFACE #2 0R #3					
GLASS DESCRIPTION	GLASS THICKNESS INCHES	MM	ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
OUTDOOR LITE: CLEAR GLASS WITH SUNGATE 100 ON THE # 2 SURFACE INDOOR LITE: CLEAR					
SUNGATE 100(2)CLEAR	¼	6.0	400	190	Tg
CLEAR	¼	6.0	220	110	Tg
SUNGATE 100 ON THE #3 SURFACE					
INDOOR LITE					
SUNGATE 100(3)CLEAR	¼	6.0	270	130	As shown for OUTDOOR lite
OUTDOOR LITE					
CLEAR	¼	6.0	270	130	Tg
ATLANTICA	¼	6.0	870	400	Th
AZURIA	¼	6.0	860	400	Th
CARIBIA	¼	6.0	890	410	Th
GRAYLITE	¼	6.0	970	450	Th
OPTIBLUE	¼	6.0	480	230	Th
SOLARBRONZE	¼	6.0	670	310	Th
SOLARGRAY	¼	6.0	770	360	Th
OPTIGRAY	¼	6.0	1040	480	Th
SOLEXIA	¼	6.0	700	330	Th
STARPHIRE	¼	6.0	80	50	Tg

Thermal Stress Update

TABLE 9
STRESS FACTORS FOR *CLEAR INSULATING* GLASS
WITH *SOLARBAN 60* COATING ON SURFACE #2

GLASS DESCRIPTION	GLASS THICKNESS INCHES	GLASS THICKNESS MM	ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
OUTDOOR LITE					
SOLARBAN 60(2) CLEAR	⅛	3.0	210	100	Tg
	¼	6.0	490	230	Tg
SOLARBAN 60(2) STARPHIRE	⅛	3.0	120	60	Tg
	¼	6.0	300	140	Tg
SOLARBAN 60 ON TINTED GLASS SUBSTRATES*					
SOLARBAN 60(2)ATLANTICA	¼	6.0	940	440	Th
SOLARBAN 60(2)AZURIA	¼	6.0	940	440	Th
SOLARBAN 60(2)CARIBIA	¼	6.0	940	440	Th
SOLARBAN 60(2)BRONZE	¼	6.0	810	380	Th
SOLARBAN 60(2)GRAY	⅛	3.0	710	330	Th
	¼	6.0	830	390	Th
INDOOR LITE					
CLEAR	⅛	3.0	170	90	As shown for OUTDOOR Lite
	¼	6.0	220	110	

*** Solarban 60 coated tinted glass availability is on a project basis only. It is recommended that availability be confirmed prior to specifying or bidding the product for projects.**

Thermal Stress Update

TABLE 10 STRESS FACTORS FOR *INSULATING* GLASS WITH *SOLARBAN 60* COATING ON SURFACE #3					
	GLASS THICKNESS		ALL OTHER	NORTH	FOR IG -
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)	USE TABLE
INDOOR LITE					
SOLARBAN 60(3)CLEAR	⅛	3.0	210	100	As shown for OUTDOOR lite
	¼	6.0	230	110	
OUTDOOR LITE					
CLEAR	⅛	3.0	190	90	Tg
	¼	6.0	290	140	Tg
ATLANTICA	¼	6.0	910	420	Th
AZURIA	⅛	3.0	800	370	Th
	¼	6.0	900	420	Th
CARIBIA	¼	6.0	930	430	Th
GRAYLITE	¼	6.0	1000	460	Th
OPTIBLUE	¼	6.0	540	250	Th
SOLARBRONZE	¼	6.0	710	330	Th
SOLARGRAY	¼	6.0	820	380	Th
OPTIGRAY	¼	6.0	1070	500	Th
SOLEXIA	¼	6.0	750	350	Th
STARPHIRE	¼	6.0	80	40	Tg

Thermal Stress Update

TABLE 11 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARBAN 70XL* COATING ON SURFACE #2 OR #3					
	GLASS THICKNESS		ALL OTHER	NORTH	FOR IG -
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)	USE TABLE
OUTDOOR LITE: STARPHIRE GLASS WITH SOLARBAN 70XL ON THE # 2 SURFACE INDOOR LITE: CLEAR					
SOLARBAN 70XL(2) STARPHIRE OUTDOOR LITE	¼	6.0	340	160	Tg
CLEAR INDOOR LITE	¼	6.0	220	110	Tg
SOLARBAN 70XL ON THE #3 SURFACE					
INDOOR LITE					
SOLARBAN 70XL(3) STARPHIRE	¼	6.0	230	110	As shown for OUTDOOR lite
OUTDOOR LITE					
CLEAR	¼	6.0	310	150	Tg
ATLANTICA	¼	6.0	940	440	Th
AZURIA	¼	6.0	960	450	Th
CARIBIA	¼	6.0	960	450	Th
GRAYLITE	¼	6.0	1040	480	Th
OPTIBLUE	¼	6.0	560	270	Th
SOLARBRONZE	¼	6.0	750	350	Th
SOLARGRAY	¼	6.0	850	400	Th
OPTIGRAY	¼	6.0	1090	510	Th
SOLEXIA	¼	6.0	780	370	Th
STARPHIRE	¼	6.0	80	50	Tg

Thermal Stress Update

TABLE 12 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARBAN 80* COATING ON SURFACE #2 OR #3					
	GLASS THICKNESS		ALL OTHER	NORTH	FOR IG -
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)	USE TABLE
OUTDOOR LITE: CLEAR GLASS WITH SOLARBAN 80 ON THE # 2 SURFACE INDOOR LITE: CLEAR					
SOLARBAN 80(2) CLEAR	¼	6.0	430	200	Tg
CLEAR (Indoor Lite)	¼	6.0	220	110	Tg
OPTIBLUE (Indoor Lite)	¼	6.0	420	200	Tg
SOLARBAN 80 ON THE #3 SURFACE					
INDOOR LITE					
SOLARBAN 80(3)CLEAR	¼	6.0	170	90	As shown for OUTDOOR lite
OUTDOOR LITE					
CLEAR	¼	6.0	330	160	Tg
ATLANTICA	¼	6.0	970	450	Th
AZURIA	¼	6.0	990	460	Th
CARIBIA	¼	6.0	990	460	Th
GRAYLITE	¼	6.0	1060	490	Th
OPTIBLUE	¼	6.0	590	280	Th
SOLARBRONZE	¼	6.0	780	360	Th
SOLARGRAY	¼	6.0	880	410	Th
OPTIGRAY	¼	6.0	1110	520	Th
SOLEXIA	¼	6.0	810	380	Th
STARPHIRE	¼	6.0	80	50	Tg

Thermal Stress Update

TABLE 13 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARBAN z50* COATING ON SURFACE #2 OR #3					
GLASS DESCRIPTION	GLASS THICKNESS INCHES	GLASS THICKNESS MM	ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
OUTDOOR LITE: SOLARBAN z50 GLASS - COATING ON THE # 2 SURFACE INDOOR LITE: CLEAR					
SOLARBAN z50(2) GLASS	¼	6.0	650	300	Tg
CLEAR	¼	6.0	220	110	Tg
SOLARBAN z50 GLASS - COATING ON THE #3 SURFACE					
INDOOR LITE					
SOLARBAN z50(3)GLASS	¼	6.0	340	160	As shown for OUTDOOR lite
OUTDOOR LITE					
CLEAR	¼	6.0	300	150	Tg
ATLANTICA	¼	6.0	930	430	Th
AZURIA	¼	6.0	930	430	Th
CARIBIA	¼	6.0	930	430	Th
GRAYLITE	¼	6.0	1020	480	Th
OPTIBLUE	¼	6.0	530	250	Th
SOLARBRONZE	¼	6.0	730	340	Th
SOLARGRAY	¼	6.0	840	390	Th
OPTIGRAY	¼	6.0	1080	500	Th
SOLEXIA	¼	6.0	760	360	Th
STARPHIRE	¼	6.0	80	40	Tg

Thermal Stress Update

TABLE 14 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARCOOL OR VISTACOOL COATED OUTDOOR GLASS AND SUNGATE 500 COATING ON #3 SURFACE*					
	GLASS THICKNESS		ALL OTHER	NORTH	FOR IG -
GLASS DESCRIPTION	INCHES	MM	STRESS (PSI)	STRESS (PSI)	USE TABLE
OUTDOOR LITE: SOLARCOOL OR VISTACOOL COATED GLASS INDOOR LITE: SUNGATE 500 CLEAR – COATING ON #3 SURFACE					
INDOOR LITE					
SUNGATE 500(3)CLEAR	¼	6.0	350	170	As shown for OUTDOOR lite
OUTDOOR LITE					
SOLARCOOL AZURIA(1)	¼	6.0	760	360	Th
SOLARCOOL AZURIA(2)	¼	6.0	1010	470	Th
SOLARCOOL BRONZE(1)	¼	6.0	590	280	Th
SOLARCOOL BRONZE(2)	¼	6.0	820	390	Th
SOLARCOOL CARIBIA(1)	¼	6.0	760	360	Th
SOLARCOOL CARIBIA(2)	¼	6.0	1010	470	Th
SOLARCOOL GRAY(1)	¼	6.0	650	310	Th
SOLARCOOL GRAY(2)	¼	6.0	900	420	Th
SOLARCOOL GRAYLITE(1)	¼	6.0	740	350	Th
SOLARCOOL GRAYLITE(2)	¼	6.0	1030	480	Th
SOLARCOOL SOLEXIA(1)	¼	6.0	640	300	Th
SOLARCOOL SOLEXIA(2)	¼	6.0	870	410	Th
VISTACOOL AZURIA(2)	¼	6.0	870	410	Th
VISTACOOL CARIBIA(2)	¼	6.0	870	410	Th
VISTACOOL GRAY(2)	¼	6.0	770	360	Th

Thermal Stress Update

TABLE 15 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARCOOL OR VISTACOOL COATED OUTDOOR GLASS AND SOLARBAN 60 COATING ON #3 SURFACE*					
GLASS DESCRIPTION	GLASS THICKNESS INCHES	GLASS THICKNESS MM	ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
OUTDOOR LITE: SOLARCOOL OR VISTACOOL COATED GLASS INDOOR LITE: SOLARBAN 60 CLEAR – COATING ON #3 SURFACE					
INDOOR LITE					
SOLARBAN 60(3)CLEAR	¼	6.0	300	160	As shown for OUTDOOR lite
OUTDOOR LITE					
SOLARCOOL AZURIA(1)	¼	6.0	800	380	Th
SOLARCOOL AZURIA(2)	¼	6.0	1040	480	Th
SOLARCOOL BRONZE(1)	¼	6.0	660	310	Th
SOLARCOOL BRONZE(2)	¼	6.0	870	400	Th
SOLARCOOL CARIBIA(1)	¼	6.0	800	380	Th
SOLARCOOL CARIBIA(2)	¼	6.0	1040	480	Th
SOLARCOOL GRAY(1)	¼	6.0	710	330	Th
SOLARCOOL GRAY(2)	¼	6.0	950	440	Th
SOLARCOOL GRAYLITE(1)	¼	6.0	780	370	Th
SOLARCOOL GRAYLITE(2)	¼	6.0	1060	490	Th
SOLARCOOL SOLEXIA(1)	¼	6.0	700	330	Th
SOLARCOOL SOLEXIA(2)	¼	6.0	910	420	Th
VISTACOOL AZURIA(2)	¼	6.0	920	430	Th
VISTACOOL CARIBIA(2)	¼	6.0	920	430	Th
VISTACOOL GRAY(2)	¼	6.0	830	380	Th

Thermal Stress Update

TABLE 16 STRESS FACTORS FOR *INSULATING* GLASS UNITS WITH *SOLARCOOL OR VISTACOOL COATED OUTDOOR GLASS AND SOLARBAN 70 COATING ON #3 SURFACE*					
GLASS DESCRIPTION	GLASS THICKNESS		ALL OTHER STRESS (PSI)	NORTH STRESS (PSI)	FOR IG - USE TABLE
	INCHES	MM			
OUTDOOR LITE: SOLARCOOL OR VISTACOOL COATED GLASS INDOOR LITE: SOLARBAN 70 STARPHIRE – COATING ON #3 SURFACE					
INDOOR LITE					
SOLARBAN 70(3)CLEAR	¼	6.0	290	140	As shown for OUTDOOR lite
OUTDOOR LITE					
SOLARCOOL AZURIA(1)	¼	6.0	820	390	Th
SOLARCOOL AZURIA(2)	¼	6.0	1050	490	Th
SOLARCOOL BRONZE(1)	¼	6.0	690	320	Th
SOLARCOOL BRONZE(2)	¼	6.0	890	410	Th
SOLARCOOL CARIBIA(1)	¼	6.0	820	390	Th
SOLARCOOL CARIBIA(2)	¼	6.0	1050	490	Th
SOLARCOOL GRAY(1)	¼	6.0	740	350	Th
SOLARCOOL GRAY(2)	¼	6.0	960	450	Th
SOLARCOOL GRAYLITE(1)	¼	6.0	800	380	Th
SOLARCOOL GRAYLITE(2)	¼	6.0	1070	500	Th
SOLARCOOL SOLEXIA(1)	¼	6.0	730	340	Th
SOLARCOOL SOLEXIA(2)	¼	6.0	930	430	Th
VISTACOOL AZURIA(2)	¼	6.0	940	440	Th
VISTACOOL CARIBIA(2)	¼	6.0	940	440	Th
VISTACOOL GRAY(2)	¼	6.0	850	390	Th

Thermal Stress Update

TABLE - Tf
FOR USE WHEN REFERENCED BY APPROPRIATE STRESS FACTOR TABLE

Installation Condition			Factor Outdoors	Factor Indoors
1. Outdoor (Not Spandrels)			0.8	1.0
2. Type of Window (Insulating Glass Unit)			0.2	1.4
3. Framing System	Structural Rubber Gaskets		-0.2	-0.5
	Wood Sash		-0.1	-0.3
	Aluminum or Steel (Tubular)	- Thin	0.0	0.0
		- Thick (>⅛")	0.5	1.0
	Masonry or Metal (Solid)	- Massive	1.0	3.0
4. Outdoor Glazing Stop Color	Black		-0.2	-0.2
	Dark		-0.1	-0.1
	Light		0.0	0.0
5. Heating Register Location	Roomside of Indoor Shading	Heat Directed Away from Glass	0.0	0.0
		Heat Directed Toward Glass	0.0	0.1
	No Indoor Shading	Heat Directed Away from Glass	0.1	0.5
		Heat Directed Toward Glass	0.2	2.0
	Between Glass and Indoor Shading	Heat Directed Away from Glass	0.3	2.0
		Heat Directed Toward Glass	0.5	3.0
6. Design Winter Temperature (from ASHRAE Handbook)		Below -10° F. [1]	0.5	3.5
		-10° to +10° F. [1]	0.5	3.0
		+10° to +30° F.	0.5	3.0
		Above 30° F.	0.5	2.5
7. Altitude	Below 5,000 ft.		0.0	0.0
	Above 5,000 ft.		0.3	0.5
8. Adjacent Reflecting Surface	None		0.0	0.0
	Dark (Smooth)		0.2	0.2
	Medium		0.3	0.4
	White (Snow)		0.5	0.6
9. Outdoor Shading [2]	Vertical, Horizontal, or Diagonal Shadows		0.4 to 2.3	1.0 to 1.5
	Vertical & Horizontal			
	Vertical & Diagonal			
	Horizontal & Diagonal Shadows		0.4 to 2.5	1.0 to 1.8
	Double Diagonal Shadows		1.0 to 3.0	1.0 to 2.5

10. Indoor Shading	**Outdoor Glass**				**Indoor Glass**			
	Space Between Indoor Glass & Shading							
	Ventilated		Non-Ventilated		Ventilated		Non-Ventilated	
Drapes	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less
None	0	0	0	0	0	0	0	0
Dark Open Weave	0	0.2	0.3	0.4	0.2	0.2	1.0	2.0
Light Open Weave	0.2	0.4	0.5	0.6	0.8	1.0	1.5	2.5
Dark Closed Weave	0.2	0.5	0.7	0.8	1.0	1.2	2.0	3.0
Light Closed Weave	0.3	0.6	0.8	1.0	1.2	1.4	2.5	3.5
Venetian Blinds Dark	0.3	0.6	0.8	1.0	1.2	1.4	2.5	4.0
Light	0.4	0.8	0.9	1.4	1.6	1.8	3.0	4.0
11. Adjacent Indoor Structural Pocket	0	0	1.0	1.4	0.8	1.0	1.5	2.5

1. **When temperature is zero & below, Vitro recommends that the indoor glass lite be heat strengthened.**
2. See Figure 3, Page 6 to select closest expected shade pattern.

Thermal Stress Update

TABLE Tg
FOR USE WHEN REFERENCED BY APPROPRIATE STRESS FACTOR TABLE

Installation Condition			Factor Outdoors	Factor Indoors
1. Outdoor (Not Spandrels)			0.8	1.0
2. Type of Window (Insulating Glass Unit)			1.8	0.2
3. Framing System	Structural Rubber Gaskets		-.4	-0.2
	Wood Sash		-0.4	-0.0
	Aluminum or Steel (Tubular)	- Thin	0.5	0.2
		- Thick (>⅛")	2.0	0.4
	Masonry or Metal (Solid)	- Massive	3.5	0.9
4. Outdoor Glazing Stop Color	Black		-0.4	-0.2
	Dark		-0.2	-0.1
	Light		0.0	0.0
5. Heating Register Location	Roomside of Indoor Shading	Heat Directed Away from Glass	0.0	0.0
		Heat Directed Toward Glass	0.0	0.1
	No Indoor Shading	Heat Directed Away from Glass	0.0	0.1
		Heat Directed Toward Glass	0.4	0.5
	Between Glass and Indoor Shading	Heat Directed Away from Glass	0.5	0.3
		Heat Directed Toward Glass	0.6	0.6
6. Design Winter Temperature (from ASHRAE Handbook)		Below -10° F. [1]	1.5	1.0
		-10° to +10° F. [1]	1.5	0.8
		+10° to +30° F.	1.5	0.5
		Above 30° F.	1.5	0.2
7. Altitude	Below 5,000 ft.		0.1	0.1
	Above 5,000 ft.		0.3	0.3
8. Adjacent Reflecting Surface	None		0.0	0.0
	Dark (Smooth)		0.3	0.2
	Medium		0.5	0.3
	White (Snow)		0.6	0.4
9. Outdoor Shading [2]	Vertical, Horizontal, or Diagonal Shadows		0.8 to 3.5	0.4 to 2.0
	Vertical & Horizontal			
	Vertical & Diagonal			
	Horizontal & Diagonal Shadows		0.8 to 4.5	0.4 to 2.5
	Double Diagonal Shadows		0.8 to 5.5	0.4 to 3.0

10. Indoor Shading	**Outdoor Glass**				**Indoor Glass**			
	Space Between Indoor Glass & Shading							
	Ventilated		Non-Ventilated		Ventilated		Non-Ventilated	
Drapes	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less
None	0	0	0	0	0	0	0	0
Dark Open Weave	0	0.3	0.4	0.5	0	0.3	0.4	0.5
Light Open Weave	0	0.3	0.4	0.5	0.1	0.3	0.5	0.6
Dark Closed Weave	0	0.3	0.4	0.7	0.2	0.4	0.6	0.8
Light Closed Weave	0	0.3	0.4	0.7	0.3	0.4	0.7	1.0
Venetian Blinds Dark	0	0.3	0.4	0.9	0.3	0.5	0.8	1.2
Light	0.2	0.5	0.5	0.9	0.4	0.5	0.9	1.4
11. Adjacent Indoor Structural Pocket	0	0	0	0.4	0	0.3	0.4	0.8

1. **When temperature is zero & below, Vitro recommends that the indoor glass lite be heat strengthened.**
2. See Figure 3, Page 6 to select closest expected shade pattern.

Thermal Stress Update

TABLE - Th
FOR USE WHEN REFERENCED BY APPROPRIATE STRESS FACTOR TABLE

Installation Condition		**Factor** Outdoors	**Factor** Indoors
1. Outdoor (Not Spandrels)		0.8	0.8
2. Type of Window (Insulating Glass Unit)		0. 4	0.2
3. Framing System	Structural Rubber Gaskets	-0.2	-0.2
	Wood Sash	-0.1	0.0
	Aluminum or Steel (Tubular) - Thin	0.0	0.3
	- Thick (>⅛”)	0.8	0.6
	Masonry or Metal (Solid) - Massive	1.4	1.1
4. Outdoor Glazing Stop Color	Black	-0.2	-0.1
	Dark	-0.1	0.0
	Light	0.0	0.1
5. Heating Register Location	Roomside of Indoor Shading — Heat Directed Away from Glass	0.0	0.0
	Heat Directed Toward Glass	0.1	0.1
	No Indoor Shading — Heat Directed Away from Glass	0.2	0.2
	Heat Directed Toward Glass	0.3	0.6
	Between Glass and Indoor Shading — Heat Directed Away from Glass	0.4	0.4
	Heat Directed Toward Glass	0.6	0.8
6. Design Winter Temperature (from ASHRAE Handbook)	Below -10° F. [1]	0.6	1.0
	-10° to +10° F. [1]	0.6	0.8
	+10° to +30° F.	0.6	0.7
	Above 30° F.	0.6	0.6
7. Altitude	Below 5,000 ft.	0.1	0.0
	Above 5,000 ft.	0.4	0.2
8. Adjacent Reflecting Surface	None	0.0	0.0
	Dark (Smooth)	0.3	0.2
	Medium	0.5	0.3
	White (Snow)	0.7	0.4
9. Outdoor Shading [2]	Vertical, Horizontal, or Diagonal Shadows		
	Vertical & Horizontal	0.6 to 3.0	0.4 to 2.5
	Vertical & Diagonal		
	Horizontal & Diagonal Shadows	0.6 to 3.3	0.4 to 3.0
	Double Diagonal Shadows	0.6 to 3.8	0.4 to 3.5

10. Indoor Shading	**Outdoor Glass**				**Indoor Glass**			
	Space Between Indoor Glass & Shading							
	Ventilated		Non-Ventilated		Ventilated		Non-Ventilated	
Drapes	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less	6 in. plus	6 in. less
None	0	0	0	0	0	0	0	0
Dark Open Weave	0	0.3	0.4	0.9	0.1	0.3	0.6	0.9
Light Open Weave	0.3	0.5	0.7	1.2	0.2	0.4	0.7	1.0
Dark Closed Weave	0.3	0.6	0.9	1.7	0.3	0.4	1.0	1.4
Light Closed Weave	0.4	0.7	1.0	2.0	0.4	0.6	1.2	1.6
Venetian Blinds Dark	0.4	0.7	1.0	2.0	0.4	0.6	1.3	1.7
Light	0.5	0.9	1.1	2.0	0.6	0.8	1.5	2.0
11. Adjacent Indoor Structural Pocket	0	0	1.0 to 1.6	1.0 to 1.6	0.6 to 0.8	0.6 to 0.8	1.0 to 2.0	1.0 to 2.0

1. **When temperature is zero & below, Vitro recommends that the indoor glass lite be heat strengthened.**
2. See Figure 3, Page 6 to select closest expected shade pattern.

Thermal Stress Update

THERMAL STRESS GUIDELINES

The guidelines in Table 18 are general and have been prepared based on the assumed glazing and installation conditions in Table 17. The assumptions used may or may not be representative of your specific project. The guidelines presented are not a substitute for a rigorous thermal stress analysis and are offered only as a quick, first-step evaluation tool. The actual design conditions for your project must be compared to those assumed for the guidelines. If the assumptions used are representative or more severe than those for your project, then the guidelines may be appropriate; if the assumptions are less severe, then a thermal stress analysis must be done.

All of the analyses that were performed to develop the guidelines in Table 18 assumed good quality clean cut edges. Even slightly damaged edges can significantly weaken the glass edge strength and lead to increased thermal stress breakage.

TABLE 17

**ASSUMED DESIGN AND INSTALLATION CONDITIONS
USED TO DEVELOP GLASS AREA GUIDELINES IN TABLE 18**

1. **FRAMING:** Thin aluminum or structural rubber gaskets
2. **OUTDOOR GLAZING STOP COLOR:** Dark
3. **HEATING REGISTERS:** Indoors of the shading devices and directed away from the glass
4. **DESIGN WINTER TEMPERATURE:** +10° F. to + 30° F.
5. **ALTITUDE:** Below 5,000 feet
6. **ADJACENT REFLECTING SURFACES:** None
7. **OUTDOOR SHADING:** outdoor lite shaded 50%
8. **INDOOR SHADING:** 6” or more from the glass and ventilated
9. **ADJACENT INDOOR STRUCTURAL POCKET:** None
10. **ACCEPTABLE PROBABILITY OF GLASS BREAKAGE:** 8 lites/1000 lites.
11. **GOOD QUALITY CLEAN CUT EDGES**
12. **APPLICABLE ONLY TO VISION GLASS UNITS.**

Thermal Stress Update

TABLE 18
GUIDELINES TO REDUCE THERMAL STRESS BREAKAGE IN ¼" (6MM) THICK ANNEALED GLASS (ASSUMES GOOD QUALITY CLEAN CUT UNDAMAGED EDGES)

OUTDOOR LITE VITRO GLASS PRODUCT	MAXIMUM RECOMMENDED GLASS AREA SQ. FT. (SQ. M.) MONOLITHIC	INSULATING GLASS UNITS – INDOOR LITE AS SHOWN: UNCOATED	SUNGATE 500(3)	SUNGATE 100(3)	SOLARBAN 60(3) SOLARBAN 70(3) SOLARBAN 80(3)
AZURIA, CARIBIA, ATLANTICA	35 (3.2)	20 (1.8)	20 (1.8)	20 (1.8)	18 (1.7)
GRAYLITE	35 (3.2)	18 (1.8)	18 (1.7)	18 (1.7)	15 (1.4)
OPTIBLUE	55 (5.0)	40 (3.7)	40 (3.7)	35 (3.2)	27 (2.5)
SOLARBRONZE and SOLEXIA	50 (4.6)	35 (3.2)	35 (3.2)	30 (2.8)	22 (2.1)
SOLARGRAY	45 (4.2)	30 (2.8)	30 (2.8)	25 (2.3)	20 (1.8)
OPTIGRAY	30 (2.8)	15 (1.4)	15 (1.4)	15 (1.4)	15 (1.4)

	MONOLITHIC	INSULATING GLASS UNITS (CLEAR INDOOR LITE ASSUMED)
SOLARBAN 60/70/80(2) CLEAR	NA	35 (3.2)
SOLARBAN 60/70(2) STARPHIRE	NA	50 (4.6)
SOLARBAN 60(2) TINTED	NA	MUST BE HEAT TREATED
SOLARBAN z50 GLASS	NA	25 (2.3)
SOLARCOOL *Coated* AZURIA (1)	40 (3.7)	20 (1.8)
SOLARCOOL *Coated* AZURIA (2)	35 (3.2)	18 (1.7)
SOLARCOOL *Coated* CARIBIA (1)	40 (3.7)	20 (1.8)
SOLARCOOL *Coated* CARIBIA (2)	35 (3.2)	18(1.7)
SOLARCOOL *Coated* BRONZE (1)	45 (4.2)	30 (2.8)
SOLARCOOL *Coated* BRONZE (2)	45 (4.2)	25 (2.3)
SOLARCOOL *Coated* GRAY (1)	45 (4.2)	25 (1.8)
SOLARCOOL *Coated* GRAY (2)	40 (3.7)	20 (1.8)
SOLARCOOL *Coated* GRAYLITE (1)	40 (3.7)	20 (1.8)
SOLARCOOL *Coated* GRAYLITE (2)	35 (3.2)	15 (1.4)
VISTACOOL AZURIA(2)	40 (3.7)	20 (1.8)
VISTACOOL CARIBIA(2)	40 (3.7)	20 (1.8)
VISTACOOL GRAY(2)	45 (4.2)	22 (2.1)

CAUTION! These guidelines applicable only if design and installation conditions for the intended application are equal or less severe than those assumed in Table 17.

Thermal Stress Update

FORM 7265-IG (INSULATING GLASS UNIT)
(REVISED 4-98)

To: ________________________ Project: ________________________

From: ________________________ Location: ________________________

Location: ________________________ Architect: ________________________

Date: ________________________ General Contractor: ________________________

Project Status: ____________________ Glazing Contractor: ________________________

Product Description: ____

Size: ____________________ (inches) Glass Area: _________________ (sq. ft.)

Edge Area: _______________ (sq. in.) Total Quantity: ______________

Quantity by Elevation: North ______ East ______ South ______ West ______

DESIGN & INSTALLATION CONDITIONS **FACTORS**

Thermal Stress Factors from Table T____

Condition	Description	Outdoor Glass	Indoor Glass
1. Outdoor Wall	Yes - Not Spandrels		
2. Insulating Glass Unit			
3. Framing			
4. Outdoor Glazing Stop			
5. Heating Register			
6. Winter Temperature			
7. Altitude (atmosphere)			
8. Adjacent Reflecting Surfaces			
9. Outdoor Shading			
10. Indoor Shading			
11. Adjacent Indoor Pocket			
		Total	Total__________

CALCULATED EXPECTED EDGE STRESS

OUTDOOR GLASS: _________ **X** _________________ = ***Approximately*** ___________ psi
(total) (stress factor)

INDOOR GLASS: _________ **X** _________________ = ***Approximately*** ___________ psi
(total) (stress factor)

Thermal Stress Update

TABLE 19
(FOR USE WITH FORM 7265-M)

Condition				Factor
1. **Outdoor** (Not Spandrels)				1.0
2. **Type of Application**				
Single glazed				0.0
Double (including storm sash, not sealed insulating glass unit)				0.8
3. **Framing System**				
Structural lockstrip gaskets				-0.1
Wood				0.1
Aluminum or Steel				0.2
Concrete				1.0
4. **Outdoor Glazing Stop Color**				
Black				-0.2
Dark				-0.1
Light				0.0
5. **Heating Register Location**				
Room side of indoor shading; no indoor shading				
Heat directed away from glass				0.0
Heat directed toward glass				0.2
Between glass and indoor shading				
Heat directed away from glass				0.2
Heat directed toward glass				0.3
6. **Design Winter Temperature** (from ASHRAE Handbook)				
Below 0° F.				0.0
From 0° F. to 40° F.				-0.1
Above 40° F.				-0.2
7. **Altitude**				
Below 5,000 feet				0.0
Above 5,000 feet				0.1
8. **Adjacent Reflecting Surface**				
None				0.0
Dark				0.2
Medium				0.3
White (Snow)				0.4
9. **Outdoor Shading**[1]				
Vertical, Horizontal, or Diagonal Shadows				0.0 to 1.0
Vertical & Horizontal				0.3 to 1.0
Vertical & Diagonal				0.0 to 1.5
Horizontal & Diagonal				0.2 to 1.2
Double Diagonal				0.0 to 2.3
10. **Indoor Shading**				
	Space Between Glass & Shading			
	Ventilated		Non-Ventilated	
	6 in. plus	6 in. less	6 in. plus	6 in. less
None	0.0	0.0	0.0	0.0
Dark open-weave drapes	0.1	0.2	0.4	0.5
Light open-weave drapes	0.2	0.3	0.5	0.6
Dark closed-weave drapes	0.2	0.3	0.5	0.6
Light closed-weave drapes	0.3	0.4	0.6	0.7
Dark venetian blinds	0.3	0.4	0.6	0.7
Light venetian blinds	0.4	0.5	0.7	0.8
11. **Adjacent Indoor Structural Pocket**				

1. See Figure 4, Page 6 to select closest expected shade pattern.

Thermal Stress Update

FORM 7265-M (MONOLITHIC GLASS)
(REVISED 4-98)

To: ________________________ Project: ________________________

From: ________________________ Location: ________________________

Location: ________________________ Architect: ________________________

Date: ________________________ General Contractor: ________________________

Project Status: ____________________ Glazing Contractor: ________________________

Glass Thickness & Type: ____

Size: ____________________ (inches) Glass Area: _________________ (sq. ft.)

Edge Area: _______________ (sq. in.) Total Quantity: ______________

Quantity by Elevation: North ______ East ______ South ______ West ______

DESIGN & INSTALLATION CONDITIONS

Condition	Description	Thermal Stress Factors From Table 19
1. Outdoor Wall	Yes - Not Spandrels	1.0
2. Framing		
3. Outdoor Glazing Stop		
4. Heating Register		
5. Winter Temperature		
6. Altitude (atmosphere)		
7. Adjacent Reflecting Surfaces		
8. Outdoor Shading		
9. Indoor Shading		
10. Adjacent Indoor Structural Pocket		
		Total _________

CALCULATED EXPECTED EDGE STRESS

OUTDOOR GLASS: _________ (total) **X** ____________ (stress factor) = ***Approximately*** ___________ psi

Thermal Stress Update

How to Use Vitro's Thermal Stress Analysis Procedure

1. Early in the project design stage, review project architectural and shop drawings focusing on plan, elevations and sections through elevations. Note compass orientation of the project elevations: Windows facing between N 60° and N 45° E (non-sunny elevations in the Northern hemisphere) will most likely require normal glazing practice. All other orientations require detailed thermal stress analysis to determine the recommended glass types to reduce thermal stress breakage to acceptable levels.
2. With the appropriate information in hand, including this document, consult with the responsible project architect or decision maker for assistance in choosing the installation and design condition factors required to complete the thermal stress analysis.
3. Complete Form 7265-IG or 7265-M in detail, including project description, glass thickness and type, quantities and sizes and by referencing the appropriate Charts and Tables in this document to complete each of the required "Installation/Design Conditions" and to select the corresponding Factors.

   Note: For Solarcool coated glass, whether monolithic or in insulating units, it is important to correctly identify the coating surface location and then use the appropriate factors from the tables. This is also true for Solarban and Sungate coated glass that, except for Sungate 500 coated glass, are always used in insulating glass units, never as monolithic glass.
4. Calculate the expected thermal stress (for both the INDOOR and OUTDOOR glass in an insulating glass unit) and use Chart 1 or Chart 2 to determine the glass fabrication requirement.

   Note: If you wish, Vitro will be pleased to calculate the expected in-service thermal stress and provide the recommended glass type based on your completed Form 7265. Send the completed 7265-IG or 7265-M form to:

   Vitro Architectural Glass
   Technical Services
   Performance Glazings
   400 Guys Run Road
   Cheswick, PA 15024

On-Line Thermal Stress Analysis Tool

A Thermal Stress Analysis computer program, based on the procedures included in this document, is available on Vitro's website. The program allows users to either select default design conditions, or to specify appropriate design conditions for their specific project. The program will then perform the analysis and display the recommended glass treatment. In addition, the program will display the calculated probability of glass breakage for both the outdoor and indoor glass lites for both annealed and heat strengthened glass. The program may be accessed via the following link:

Thermal Stress Analysis

Thermal Stress Update

Thermal Stress Completed Example

For this example, let's consider the following product properties:

- A 1" Insulating Glass Unit (1/4" *GRAYLITE* + 1/2" Airspace + 1/4" Clear)
- Size - 48" x 72"

The completed Form 7265-IG on the following page was prepared as follows:

1. Refer to Table 5 "Stress Factors for *Clear and Tinted Insulating* Glass Units" to determine the appropriate **STRESS FACTORS** and Table to use to determine the **DESIGN FACTORS.**
   - ✓ As shown in Table 5, the Stress Factors for *GRAYLITE* are 920 (South, East, and West elevations and 430 for the North elevation. Table Tf is indicated for determining the Design Factors.
   - ✓ The Stress Factors for the Clear INDOOR lite are 220 (South, East, and West and 110 for the North elevation.
2. Calculate the Glass Edge Area by multiplying the 2 x (width + height) x thickness (in inches). For the completed example this would be 2 x (48 + 72) x 0.25 = 60 square inches.
3. Using Table Tf, choose the appropriate Design Factors for each Installation Condition.
   - ✓ In the completed example, the assumed Framing system was *Tubular Aluminum or Steel - Thin* and from Table Tf the associated Design Factors for both the Outdoor and Indoor Glass Lite are 0.0.
   - ✓ Note that for Installation Condition 9 "*Outdoor Shading",* you must refer to Figure 3 on Page 6 to help determine the appropriate shading pattern nomenclature and apply that to the appropriate table (Tf, Tg, Th) to determine the Design Factor. In the completed example, Horizontal Outdoor Shading was assumed with 50% shade coverage. Interpolating between the 75% shade coverage factor of 0.4 and the 25% shade factor of 2.3 for the outdoor lite yields a factor of 1.4. The same procedure applies for the indoor lite.
4. Arithmetically sum all of the factors for the outdoor and indoor glass lites.
5. Calculate the estimated thermal stress for each lite by multiplying the appropriate design factor total by the stress factor.
6. Determine the recommended glass treatment for each glass lite by using Chart 1.
   - ✓ Project lines from the calculated edge area (horizontal axis) and from the estimated thermal stress (vertical axis) until they intersect.
   - ✓ If the intersection point is on or above the curve, then the glass must be heat strengthened; if the intersection point is below the curve, annealed glass is adequate to meet the estimated thermal stress based on the assumed design conditions.

NOTES:

a) Heat strengthened or Tempered glass may still be required to meet safety, wind load, or other design considerations.

b) Careful consideration should be given to heat strengthening the glass if the analysis reveals that the estimated thermal stress is approaching the limits of adequate performance for annealed glass.

c) This example considers the non-North facing elevations, which are more severe for thermal stress than the North elevation. A similar analysis can obviously be done for the North elevation

Thermal Stress Update

EXAMPLE
COMPLETED FORM 7265-IG

To: Mr. Good Customer

From: Reliable Supplier

Location: Somewhere, USA

Date: 3 June 1998

Project: Test Case

Location: Anywhere, USA

Architect: Creative Designs

General Contractor: Big Builders

Glazing Contractor: ABC Glass

Project Status: Design

Product Description: 1" Graylite IG Unit

Size: 48" x 72" (inches)

Glass Area: 24.0 sq. ft.

Edge Area: 60 (sq. in.)

Total Quantity: 350

Quantity by Elevation: North 50 East 75 South 150 West 75

DESIGN & INSTALLATION CONDITIONS **FACTORS**

Thermal Stress Factors From Table Tf

Condition	Description	Outdoor Glass	Indoor Glass
1. Outdoor Wall	*Yes - Not Spandrels*	*0.8*	*1.0*
2. Insulating Glass Unit	*With 1/2" Airspace*	*0.2*	*1.4*
3. Framing	*Tubular Aluminum or Steel - Thin*	*0.0*	*0.0*
4. Outdoor Glazing Stop	*Black*	*-0.2*	*-0.2*
5. Heating Register	*Roomside - Directed Away from Glass*	*0.0*	*0.0*
6. Winter Temperature	*+10 to +30 degrees F.*	*0.5*	*3.0*
7. Altitude (atmosphere)	*Above 5,000 ft.*	*0.3*	*0.5*
8. Adjacent Reflecting Surfaces	*Medium*	*0.3*	*0.4*
9. Outdoor Shading	*Horizontal - 50% Shade Coverage*	*1.4*	*1.3*
10. Indoor Shading	*Dark Open Weave, Ventilated, 6 in. Plus*	*0.0*	*0.2*
11. Adjacent Indoor Pocket	*No*	*0.0*	*0.0*
		Total ***3.3***	*Total* ***7.6***

CALCULATED EXPECTED EDGE STRESS

OUTDOOR GLASS: ***3.3*** (total) X ***920*** (stress factor) **= *Approximately*** ***3,036*** psi

INDOOR GLASS: *7.6* (total) X *220* (stress factor) = *Approximately* *1,672* psi

Based on the analysis, the calculated edge stress of the outdoor glass, when plotted on Chart 1, requires that the outdoor glass be heat strengthened. Similarly, the indoor glass can be annealed for thermal stress purposes.

Thermal Stress Update

CHART 1 – INSULATING GLASS UNITS

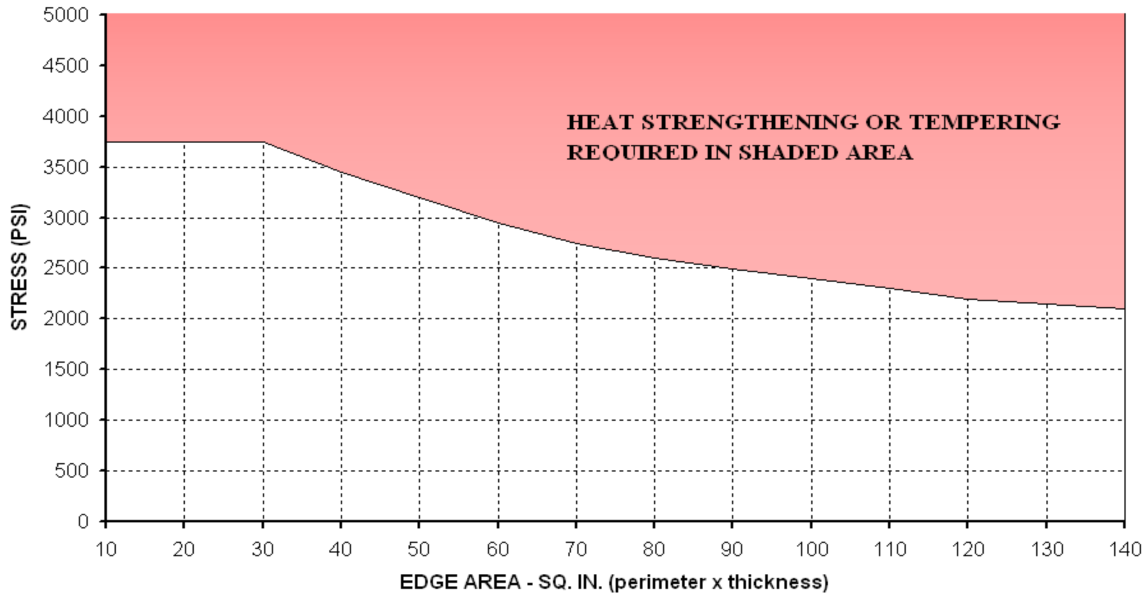
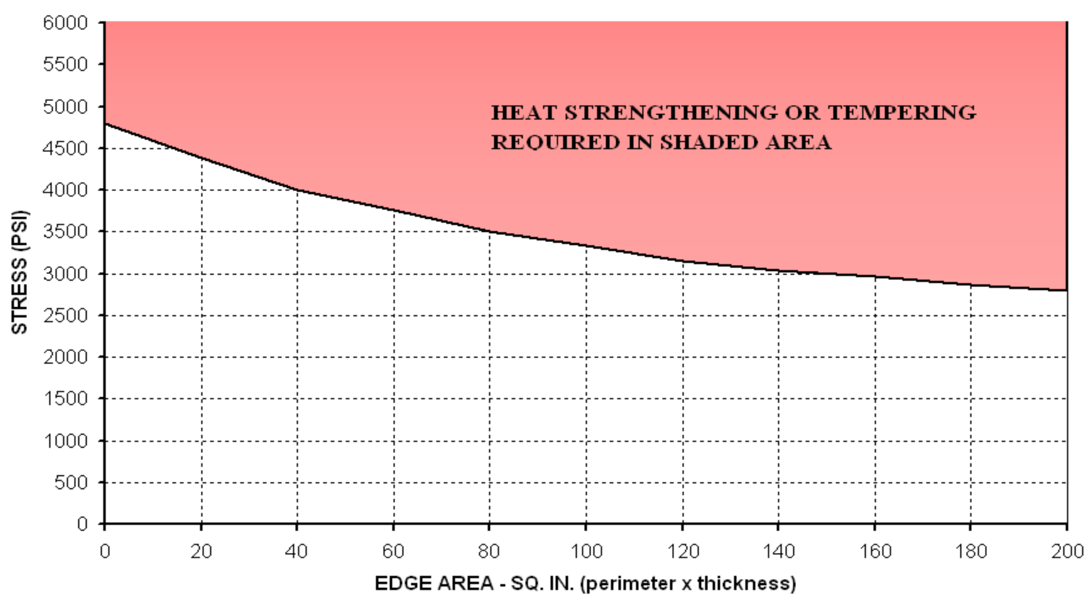


CHART 2 – MONOLITHIC GLASS



Thermal Stress Update

HISTORY TABLE		
ITEM	**DATE**	**DESCRIPTION**
Original Publication	6/3/1998	Thermal Stress Analysis
Revision 1	1/8/2002	Transferred to TD-109; Added Solarban 80
Revision 2	11/11/2004	Added new products; additional text on guidelines Miscellaneous formatting and error corrections
Revision 3	4/18/2006	Added new products; miscellaneous formatting
Revision 4	6/28/2006	Added new products, thermal stress diagram (Figure 1), new shading pattern sketches (Figures 3 & 4); Figure 5 – Indoor Shading; Figure 6 – Framing Systems; Formatting changes - Charts 1 and 2; editorial changes related to shading and framing
Revision 5	2/21/2008	Added new products (Solarban z50 and Optiblue), added analysis for having coatings on both inboard surfaces, added tables for new combinations of dual coatings, general updating of tables
Revision 6	6/13/2008	Corrected table reference on form 7265-M, clarified outdoor shading design factor determination in completed example explanation.
Revision 7	2016-10-04	Updated to Vitro Logo and format