Designation: E2431 – 12

Standard Practice for Determining the Resistance of Single Glazed Annealed Architectural Flat Glass to Thermal Loadings[1]

This standard is issued under the fixed designation E2431; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers a procedure to determine the resistance of annealed architectural flat glass to thermally induced stresses caused by exposure to sun and shadows for a specified probability of breakage (P_b). Proper use of this procedure is intended to reduce the possibility of thermal breakage of annealed glass in buildings.

1.2 This practice applies to vertical or sloped glazing in buildings.

1.3 This practice applies to monolithic and laminated glass of rectangular shape and assumes that all glass edges are simply supported.

1.4 This practice applies only to annealed flat soda-lime silica glass with clean cut, seamed, flat ground, or ground and polished edges that are free from damage. The glass may be clear or tinted as well as coated (not including coatings that reduce emissivity of the glass).

1.5 This practice does not apply to any form of wired, patterned, etched, sandblasted, drilled, notched, or grooved glass or glass with surface and edge treatments, other than those described in 1.4, that alter the glass strength.

1.6 This practice does not address uniform loads such as wind and snow loads, safety requirements, fire, or impact resistance.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard. For conversion of quantities in various systems of measurements to SI units refer to IEEE/ASTM SI-10.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Documents:*[2]

C162 Terminology of Glass and Glass Products

E631 Terminology of Building Constructions

IEEE/ASTM SI-10 Use of the International System of Units (SI) (the Modernized Metric System)

2.2 *Other Documents:*[3]

2005 ASHRAE Handbook Fundamentals

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method refer to Terminology E631, and for general terms related to glass and glass products, refer to Terminology C162.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *edge bite, n*—the width of the glass edge (measured perpendicular to the cut edge, in the plane of the glass) that is protected from direct exposure to solar irradiance by the window frame edge conditions expressed in mm (in.) [see Table 1].

3.2.2 *edge thermal stress factor* (TSF_{edge})*, n*—the ratio of induced thermal stress to the solar load, SL, as the result of the edge bite condition expressed in MPa/(W/m^2).

3.2.3 *frame type, n*—the manner in which the edges of the glass are supported in the window frame [see Table 1].

3.2.4 *glass dimensions, n*—the rectangular dimensions of the glass (not the daylight opening), with the width being the smaller dimension and the length being the larger dimension both expressed in mm.

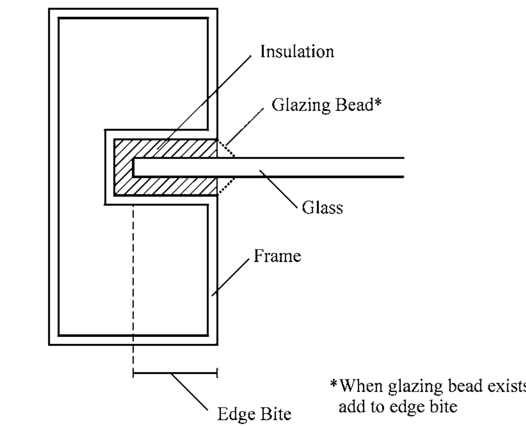
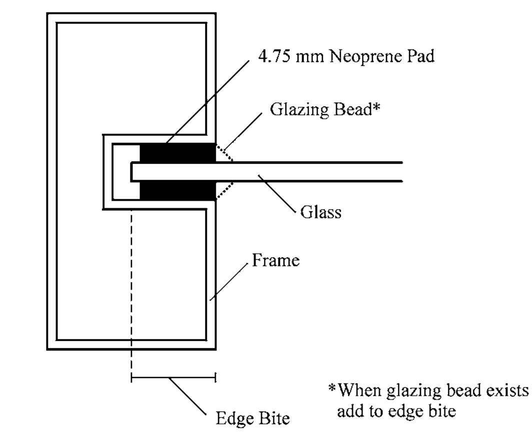
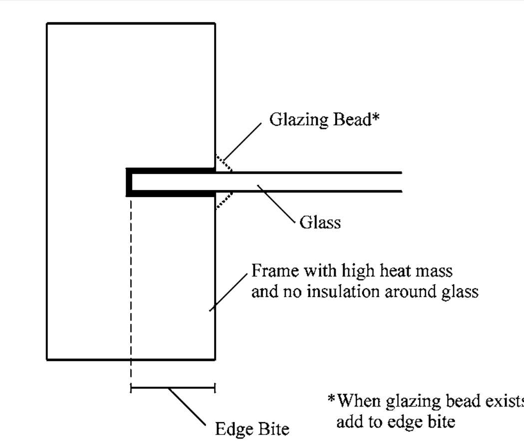
[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.51 on Performance of Windows, Doors, Skylights and Curtain Walls.

Current edition approved April 1, 2012. Published May 2012. Originally approved in 2006. Last previous edition approved in 2011 as E2431 – 06 (2011). DOI: 10.1520/E2431-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

TABLE 1 Frame Types

Frame Type	Sketch
Insulated edge -- This condition should only be used in the analysis if it can reasonably be assumed that the heat loss from the glass to the glazing pocket is negligible.	
Conventional edge -- This condition should be used in the analysis only when the glazing pocket is fabricated with thin walled members and the glass is cushioned with gasket materials as shown.	
High heat mass edge -- This condition should be used in the analysis when the glazing is encapsulated in a material with a high heat mass such as concrete, heavy metal, and so forth.	

3.2.5 *incident solar irradiance* (Insolation), (I_s), *n*—amount of solar energy per unit time per unit area normal to glass, to which the glass is exposed expressed in W/m^2.

3.2.6 *probability of breakage* (P_b), *n*—the number of lites per 1000 that would be predicted to break when exposed to the specified thermal loading conditions.

3.2.7 *shadow thermal stress factor* (TSF_{shadow}), *n*—the ratio of induced thermal stress to the solar load, SL, as the result of shadow condition expressed in $MPa/(W/m^2)$ ($psi/Btu/hr{\cdot}ft^2$).

3.2.8 *solar load* (SL), *n*—the total amount of solar irradiance absorbed by the glass expressed in W/m^2.

3.2.9 *solar load adjustment factor for interior shading devices* (SLA), *n*—nondimensional factor that is used to account for the increase in thermal stress caused by the reflection of solar irradiance from an interior shading device.

3.2.10 *solar reflectance of shading device* (R_s), *n*—decimal fraction of incident solar irradiation reflected from the device used as an interior shade.

3.2.11 *solar transmittance* (T_s), *n*—the amount of solar irradiance transmitted by the glass expressed as a fraction that ranges between 0.00 and 1.00.

3.2.12 *thermal stress, n*—edge tensile stress (MPa) induced in glass by solar irradiance.

3.2.13 *total solar absorptance* (A_s) , *n*—the amount of solar irradiance absorbed by the glass expressed as a fraction that ranges between 0.00 and 1.00.

3.2.14 *total thermal stress factor* (TSF_{tot}), *n*—the ratio of total thermal stress induced in the glass by the combination of edge conditions and shadow conditions to the solar load expressed in MPa/(W/m^2).

4. Summary of Practice

4.1 The specifying authority shall provide the glass width, length, and nominal thickness; solar absorption of the glass construction (can be obtained from manufacturer's data); incident solar irradiance (can be determined from 2005 ASHRAE Handbook Fundamentals or other documented source); the frame type and edge bite; description of exterior shading conditions; and interior shading devices.[4]

4.2 The procedure described in this practice shall be used to determine if the glass can resist the calculated thermal stresses for a specified probability of breakage.

5. Significance and Use

5.1 Use of this practice assumes:

5.1.1 the glass edges shall be free from damage,

5.1.2 the glass shall be properly glazed,

5.1.3 the glass shall not have been subjected to abuse, and

5.1.4 the glass edge support allows in-plane movement of the glass due to thermal expansion and contraction.

5.2 This practice does not address all factors that cause thermally induced stresses in annealed glass. Factors that are not addressed include: transient thermal stresses, HVAC registers, thermally insulating window coverings, drop ceilings and other heat traps, increased solar irradiance caused by exterior reflections, variations in heat transfer coefficients other than those assumed for the steady state analysis described herein, and stresses induced by thermal sources other than the sun. Factors other than those listed above may also induce thermal stress.

5.3 Many other factors shall be considered in glass selection. These factors include, but are not limited to, mechanically induced stresses, wind effects, windborne debris impacts, excessive deflections, seismic effects, heat flow, noise abatement, potential post-breakage consequences, and so forth. In addition, considerations set forth in building codes along with criteria presented in safety glazing standards and site specific concerns may control the ultimate glass type and thickness selection.

5.4 The proper use of this practice is intended to reduce the risk of thermally induced breakage of annealed window glass in buildings.

6. Procedure

6.1 Obtain the following information from the data supplied by the specifier:

6.1.1 The edge bite condition that most closely represents the project conditions from Table 1;

6.1.2 The total solar transmittance (T_s) of the specified glass;

6.1.3 The total solar absorptance (A_s) of the specified glass:

$$A_s = 1.00 - T_s - R_s \tag{1}$$

where:

R_s = total solar reflectance

6.1.4 The solar reflectance of the shading device (RSD), if used;

6.1.5 The incident solar irradiance (I_s) for this analysis; and

6.1.6 The specified acceptable probability of glass breakage (P_b) for this analysis.

6.2 Multiply the incident solar irradiance (I_s) by the solar absorptance (A_S) to determine the solar load (SL).

6.3 Determine the edge thermal stress factor (TSF_{edge}) from Fig. 1, given the edge bite and edge bite condition.

6.4 Determine the shadow thermal stress factor (TSF_{shadow}) using the common shadow patterns shown in Fig. 2 and the factors listed in Table 2.

6.5 Determine the total thermal stress factor (TSF_{total}) by summing the individual thermal stress factors given in 6.3 and 6.4.

6.5.1 If the calculated total thermal stress factor exceeds 39.4 kPa/(W/m^2) when the angular shadow pattern is assumed, that is, Fig. 2 b and d, then 39.4 kPa/(W/m^2) shall be used for the total thermal stress factor.

6.5.2 If the calculated total thermal stress factor exceeds 32.0 kPa/(W/m^2) when other shadow patterns, that is, Fig. 2 a and c, are assumed, then 32.0 kPa/(W/m^2) shall be used for the total thermal stress factor.

6.6 To determine the solar load adjustment factor (SLA) using Fig. 3, enter the vertical axis with the solar reflectance of the shading device (RSD) and the horizontal axis with total solar transmittance of the glass (T_S) to determine the solar load

[4] Beason, W.L., and Lingnell, A.W., "A Thermal Stress Evaluation Procedure for Monolithic Annealed Glass," *Use of Glass in Buildings*, ASTM STP 1434, V. Block, ed., ASTM International: West Conshohocken, PA, 2003.

TABLE 2 Shadow Thermal Stress Factors to be Used with Fig. 2

Shadow Condition	Maximum TSF_{shadow} kPa/(W/sq m)
Linear shadow	15.3
Angular shadow	31.9
L-Shaped shadow	20.8
Corner shadow	23.0

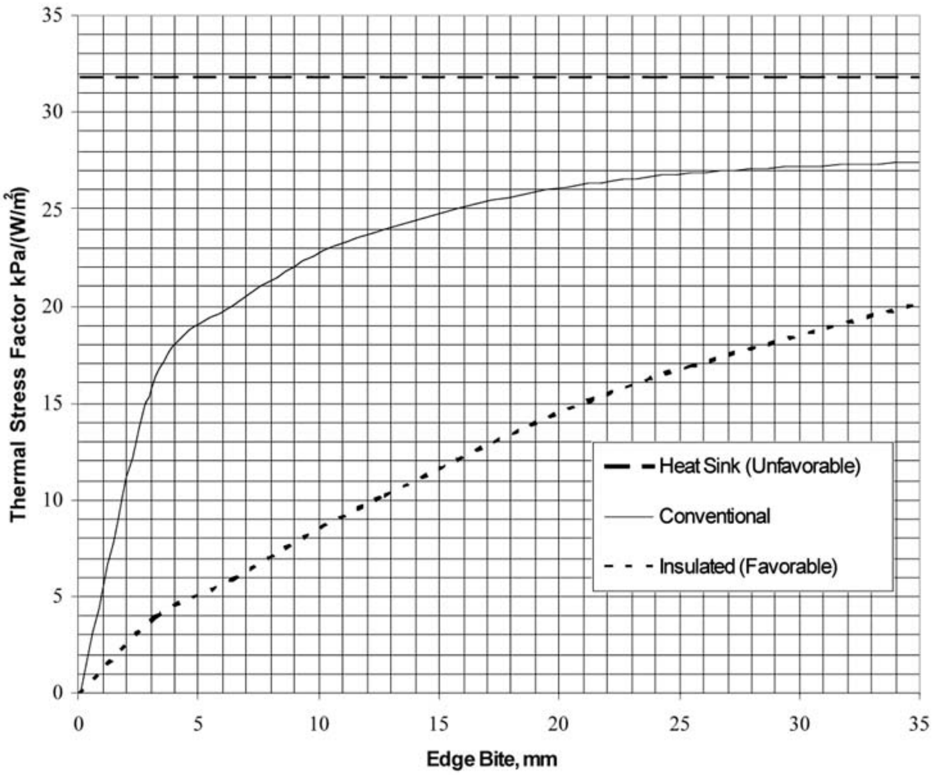


FIG. 1 Edge Thermal Stress Factor Chart

adjustment factor (SLA) for interior shading devices. If necessary use interpolation to estimate the solar load adjustment factor (SLA). If no shading device is used, the solar load adjustment factor (SLA) shall be taken to be 1.0.

6.7 Determine the calculated thermal stress, $\sigma_{calculated}$, by multiplying the total thermal stress factor (TSF_{total}) by the solar load (SL) and by the solar load adjustment factor (SLA).

6.8 Determine the perimeter of the glass lite by adding twice the width to twice the height.

6.9 Determine the allowable thermal stress, $\sigma_{allowable}$, from Fig. 4 using the glass perimeter and the specified acceptable P_b.

6.10 If $\sigma_{calculated} > \sigma_{allowable}$, P_b for the glass exceeds the specified probability of breakage for the thermal design conditions. If P_b for the glass exceeds the specified probability of breakage, the user shall consider using strengthened glass, modifying the controllable design conditions, or having a more comprehensive thermal stress analysis performed.

7. Report

7.1 The report shall consist of the design example worksheet presented in Fig. 5 or, as a minimum, shall include:

7.1.1 Project name,

7.1.2 Date,

7.1.3 Project location,

7.1.4 Glass type,

7.1.5 Glass dimensions,

7.1.6 Edge bite,

7.1.7 Frame type,

7.1.8 Solar absorptance (A_s),

7.1.9 Solar transmittance (T_s),

7.1.10 Total Solar Reflectance of Shade Device (RSD),

7.1.11 Incident solar irradiance (I_s),

7.1.12 Acceptable probability of breakage (P_b),

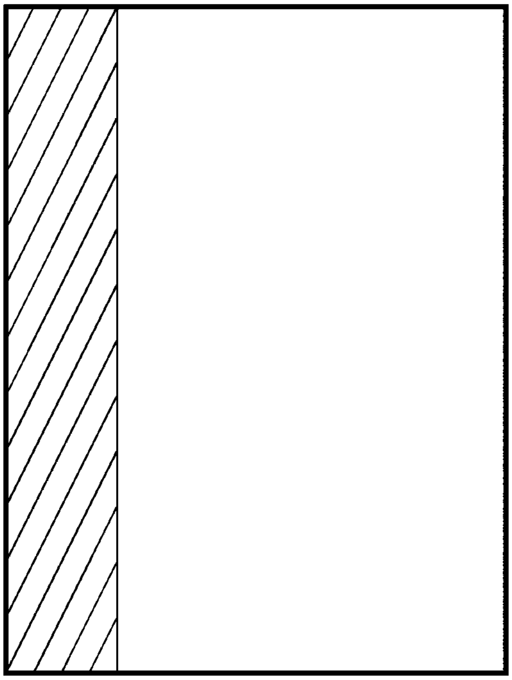
7.1.13 Allowable thermal stress ($\sigma_{allowable}$),

7.1.14 Calculated thermal stress ($\sigma_{calculated}$), and

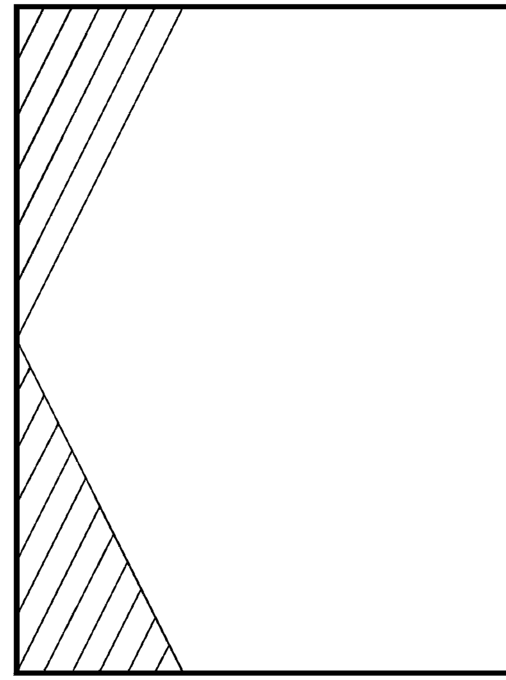
7.1.15 Conclusion.

8. Keywords

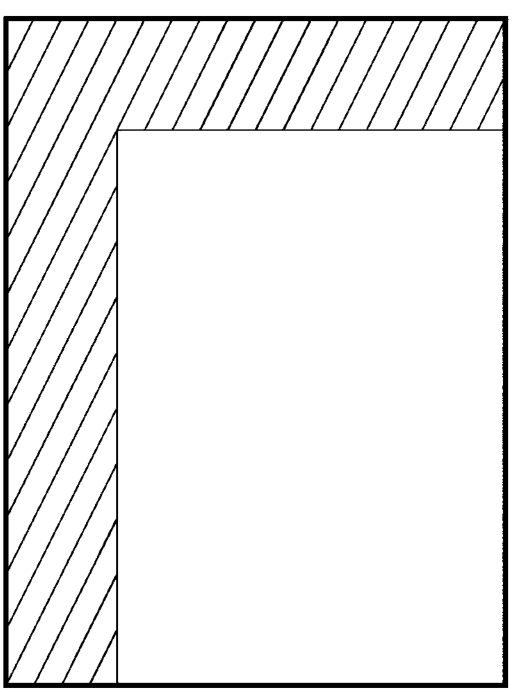
8.1 annealed glass; flat glass; glass; thermal breakage; thermal load; thermal stress; soda-lime silica glass



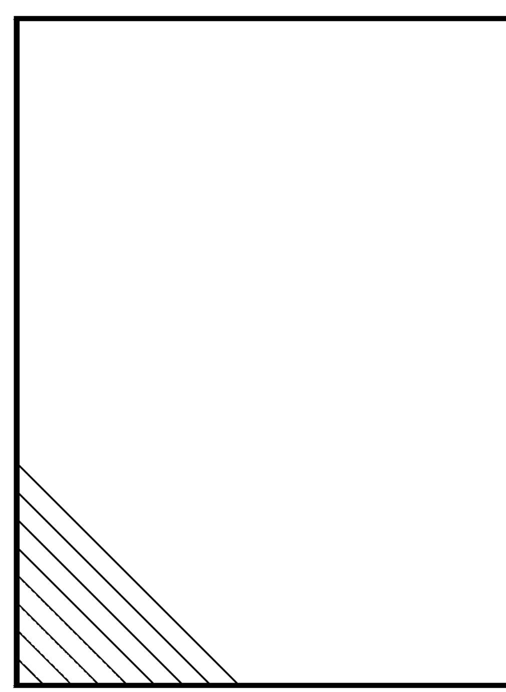
(a) Linear Shadow



(b) Angular Shadow



(c) L-Shaped Shadow



(d) Corner Shadow

FIG. 2 Shadow Conditions

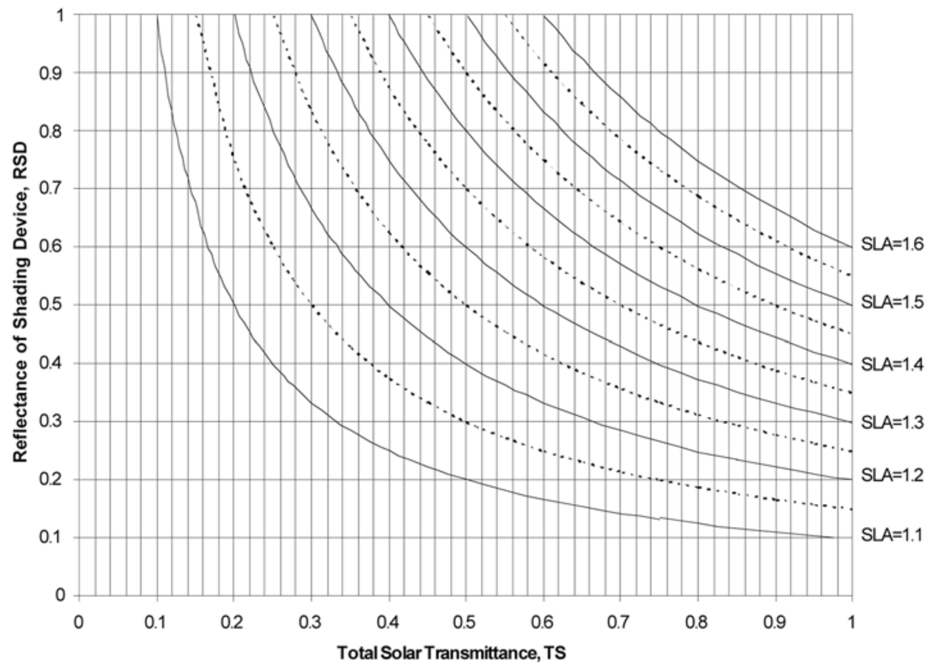


FIG. 3 Solar Load Adjustment Factor, SLA

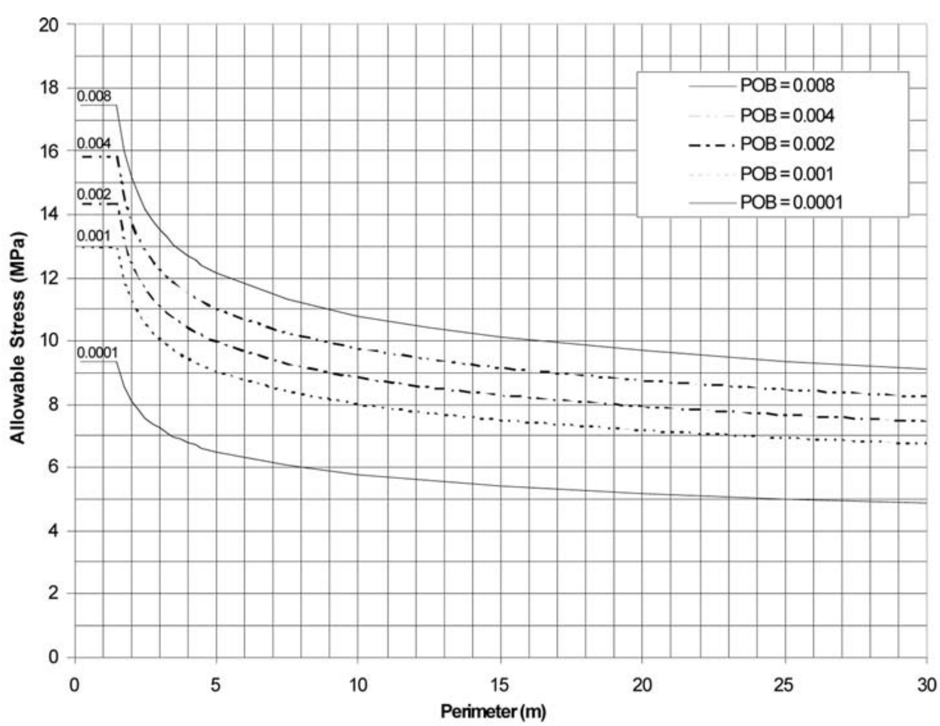


FIG. 4 Probability of Breakage (POB) Chart

DESIGN WORKSHEET FOR THERMAL STRESS EVALUATION

PROJECT: NAME: ______________________DATE:__________________

LOCATION: _______________________________________

Glass Type: _______________________

Glass Dimensions: width _________mm length ____________mm thickness____________mm

Perimeter _____________________m

Edge Bite: ______________________________mm

Frame Type: ___________________________

Solar Absorptance (A_s)__________________

Solar Transmittance (T_s)________________

Solar Reflectance of Shade Device (R_s)__________________

Incident solar irradiance (I_s)___________________W/m^2

Acceptable Probability of Breakage (P_b) _____________

Compute Solar Load (SL)

$SL = I_s \times A_s =$ _______ W/m^2

Determine Edge Thermal Stress Factor: Use Figure 1

$TSF_{edge}=$ ______________kPa/(W/m^2)

Shadow Thermal Stress Factor (TSF_{shadow})__________ kPa/(W/m^2) *(Use Figure 2 and Table 2)*

Determine Total Thermal Stress Factor (TSF_{total})

$TSF_{total} = TSF_{edge} + TSF_{shadow}$, but no greater than 39.4 kPa/(W/m^2) for angular shadows or 32.0 kPa/(W/m^2) for all other shadows.

$TSF_{total} =$ ________________ kPa/(W/m^2)

Solar Load Adjustment Factor (SLA)_____________ *(Use Figure 3)*

Determine the Calculated thermal stress, $\sigma_{calculated}$

$\sigma_{calculated} = (TSF_{total} \times SL \times SLA)/1000 =$ ______________MPa

Determine allowable thermal stress, $\sigma_{allowable}$*, from Figure 4*

$\sigma_{allowable} =$_______________MPa

Conclusion:

If $\sigma_{calculated} < \sigma_{allowable}$ OK

If $\sigma_{calculated} < \sigma_{allowable}$ NG

FIG. 5 Design Worksheet for Thermal Stress Evaluation

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF THE USE OF THIS STANDARD PRACTICE

X1.1 This appendix presents two examples of the use of this standard practice. The first example is typical of a commercial application and the second example is typical of a residential application.

X1.2 *Evaluation of the Thermal Stress Resistance of a Typical Commercial Window* (Example 1)—Determine the thermal stress resistance of a 1500 mm by 1800 mm by 6 mm, reflective bronze annealed glass plate that is to be installed in the Bright Athletic Complex located on the campus of Texas A&M University. This glass plate has a solar absorptance of 0.73 and a total solar transmittance of 0.20. This glass plate is subjected to a solar irradiance of 630 W/m^2 and will be subjected to linear shadows. The glass has an edge bite of 19 mm and is supported in a frame that can be classified as conventional. There are no interior reflective devices. It is desired that the probability of breakage (P_b) be less than or equal to 0.001.

X1.2.1 The above data are entered into the Example 1 design worksheet presented in Fig. X1.1.

X1.2.2 The solar load (SL) is calculated to be 460 W/m^2 by multiplying the specified incident solar irradiance (I_s) by the solar absorptance (A_s) as described in 6.2. This value is entered in design worksheet presented in Fig. X1.1.

X1.2.3 The thermal stress factor (TSF_{edge}) is determined to be 26 kPa/(W/m^2) using Fig. 1 as described in 6.3. This value is entered in the design worksheet presented in Fig. X1.1.

X1.2.4 The shadow thermal stress factor (TSF_{shadow}) is determined to be 15.3 kPa/(W/m^2) using Fig. 2 and Table 2 as described in 6.4. This value is entered in the design worksheet presented in Fig. X1.1.

X1.2.5 The addition of the thermal stress factor (TS_{Fedge}) and the shadow thermal stress factor (TSF_{shadow}) results in a value of 41.3 kPa/(W/m^2). Because this value is greater than 32.0 kPa/(W/m^2), the total thermal stress factor (TSF_{total}) is determined to be 32.0 kPa/(W/m^2) as described in 6.5.2. This value is entered in the design worksheet presented in Fig. X1.1.

X1.2.6 Because there is no shading device associated with the glass, the solar load adjustment factor (SLA) is taken to be 1.0 as described in 6.6. This value is entered in the design worksheet presented in Fig. X1.1.

X1.2.7 The calculated thermal stress, $\sigma_{calculated}$, is determined to be 14.7 MPa by multiplying the total thermal stress factor (TSF_{total}) by the solar load (SL) by the solar load adjustment factor (SLA) as described in 6.7. The result is converted from kPa to MPa by dividing by 1000. This value is entered in the design worksheet presented in Fig. X1.1.

X1.2.8 The perimeter of the glass plate is calculated to be 6.600 m using the methods presented in 6.8. This value is entered in design worksheet presented in Fig. X1.1.

X1.2.9 The allowable thermal stress, $\sigma_{allowable}$, corresponding to a glass perimeter of 6.600 m and a probability of failure 0.001 is found to be about 8.5 MPa using Fig. 4 as described in 6.9.

X1.2.10 The calculated thermal stress is greater than the allowable thermal stress, it is thus determined that the proposed glass application is not acceptable as described in 6.10.

X1.3 *Evaluation of the Thermal Stress Resistance of a Typical Residential Window* (Example 2)—Determine the thermal stress resistance of a 750 mm by 750 mm by 3 mm grey annealed glass plate that is to be installed in a residence located in Rockwall, Texas. This glass plate has a solar absorptance of 0.42 and a total solar transmittance of 0.53. This glass plate is subjected to a solar irradiance of 630 W/m^2 and it will be subjected to linear shadows. The glass has an edge bite of 10 mm and it is supported in a frame that can be classified as conventional. There is an interior reflective device with a reflectance of 0.50. It is desired that the probability of breakage be less than or equal to 0.008.

X1.3.1 The above data are entered into the Example 2 design worksheet presented in Fig. X1.2.

X1.3.2 The solar load (SL) is calculated to be 264.6 W/m^2 by multiplying the specified incident solar irradiance (I_s) by the solar absorptance (A_s) as described in 6.2. This value is entered in design worksheet presented in Fig. X1.2.

X1.3.3 The thermal stress factor (TSF_{edge}) is determined to be 22.8 kPa/(W/m^2) using Fig. 1 as described in 6.3. This value is entered in the design worksheet presented in Fig. X1.2.

X1.3.4 The shadow thermal stress factor (TSF_{shadow}) is determined to be 15.3 kPa/(W/m^2) using Fig. 2 and Table 2 as described in 6.4. This value is entered in the design worksheet presented in Fig. X1.2.

X1.3.5 The addition of the thermal stress factor (TSF_{edge}) and the shadow thermal stress factor (TSF_{shadow}) results in a value of 38.1 kPa/(W/m^2). Because this value is greater than 32.0 kPa/(W/m^2), the total thermal stress factor (TSF_{total}) is determined to be 32.0 kPa/(W/m^2) as described in 6.5.2. This value is entered in the design worksheet presented in Fig. X1.2.

X1.3.6 The reflectance associated with the interior shading device (RSD) is specified as 0.50. As stated previously, the specified value of the solar transmittance (TS) is 0.53. These values are used in conjunction with Fig. 3 to determine that the solar load adjustment factor (SLA) is 1.27. This value is entered in the design worksheet presented in Fig. X1.2.

X1.3.7 The calculated thermal stress, $\sigma_{calculated}$, is determined to be 10.8 MPa by multiplying the total thermal stress factor (TSF_{total}) by the solar load (SL) by the solar load adjustment factor (SLA) as described in 6.7. The result is

DESIGN WORKSHEET FOR THERMAL STRESS EVALUATION

PROJECT NAME:___Bright Athletic Complex______ DATE:__10/1/04_________

LOCATION:__ Texas A&M University ___________

Glass Type:_Annealed Reflective Bronze_________

Glass Dimensions: width__1500___mm length ___1800_____mm thickness__6_________mm

Perimeter______6.600__________m

Edge Bite:___________19_________________mm

Frame Type:_______Conventional________

Solar Absorptance (A_s) ______0.73________

Solar Transmittance (T_s)_____0.20_______

Solar Reflectance of Shade Device (R_s)______0___________

Incident solar irradiance (I_s)______630__________ W/m^2

Acceptable Probability of Breakage (P_b) ____0.001____

Compute Solar Load (SL)

$SL = I_s \times A_s =$ __460__ W/m^2

Determine Edge Thermal Stress Factor: Use Figure 1

$TSF_{edge}=$ ____26________kPa/(W/m^2)

Shadow Thermal Stress Factor (TSF_{shadow})__15.3____ kPa/(W/m^2) *(Use Figure 2 and Table 2)*

Determine Total Thermal Stress Factor (TSF_{total})

$TSF_{total} = TSF_{edge} + TSF_{shadow}$, but no greater than 39.4 kPa/(W/m^2) for angular shadows or 32.0 kPa/(W/m^2) for all other shadows.

$TSF_{total} =$ ____32.0________ kPa/(W/m^2)

Solar Load Adjustment Factor (SLA)_____1.0_____ *(Use Figure 3)*

Determine the Calculated thermal stress, $\sigma_{calculated}$

$\sigma_{calculated} = (TSF_{total} \times SL \times SLA)/1000 =$ _____14.7___MPa

Determine allowable thermal stress, $\sigma_{allowable}$, from Figure 4

$\sigma_{allowable}=$______8.5______MPa

Conclusion:

If $\sigma_{calculated} > \sigma_{allowable}$ NG

FIG. X1.1 Example 1, Typical Commercial Window

converted from kPa to MPa by dividing by 1000. This value is entered in the design worksheet presented in Fig. X1.2.

X1.3.8 The perimeter of the glass plate is calculated to be 3.000 m using the methods presented in 6.8. This value is entered in design worksheet presented in Fig. X1.2.

X1.3.9 The allowable thermal stress, $\sigma_{allowable}$, corresponding to a glass perimeter of 3.000 m and a probability of failure 0.008 is found to be about 13.0 MPa using Fig. 4 as described in 6.9. This value is entered in design worksheet presented in Fig. X1.2.

X1.3.10 The calculated thermal stress is less than the allowable thermal stress, it is thus determined that the proposed glass application is acceptable as described in 6.10.

DESIGN WORKSHEET FOR THERMAL STRESS EVALUATION

PROJECT NAME:____Residence_________DATE:____10/01/04______

LOCATION:____Rockwall, Texas___________________

Glass Type:___Grey____________

Glass Dimensions: width__750___mm length ___750_____mm thickness____3_______mm

Perimeter______________3______m

Edge Bite:____________________10________mm

Frame Type:________Conventional_______

Solar Absorptance (A_s) _____0.42_________

Solar Transmittance (T_s)______0.53______

Solar Reflectance of Shade Device (R_s)______0.50________

Incident solar irradiance (I_s)______630__________ W/m^2

Acceptable Probability of Breakage (P_b) _____0.008__

Compute Solar Load (SL)

$SL = I_s \times A_s$ = __264.6_____ W/m^2

Determine Edge Thermal Stress Factor: Use Figure 1

TSF_{edge}= _______22.8___kPa/(W/m^2)

Shadow Thermal Stress Factor (TSF_{shadow})___15.3__ kPa/(W/m^2) *(Use Figure 2 and Table 2)*

Determine Total Thermal Stress Factor (TSF_{total})

$TSF_{total} = TSF_{edge} + TSF_{shadow}$, but no greater than 39.4 kPa/(W/m^2) for angular shadows or 32.0 kPa/(W/m^2) for all other shadows.

TSF_{total} = ______32.0_______kPa/(W/m^2)

Solar Load Adjustment Factor (SLA)____1.27____ *(Use Figure 3)*

Determine the Calculated thermal stress, $\sigma_{calculated}$

$\sigma_{calculated} = (TSF_{total} \times SL \times SLA)/1000$ = ____10.8_________MPa

Determine allowable thermal stress, $\sigma_{allowable}$ *, from Figure 4*

$\sigma_{allowable}$ =______13.0_____MPa

Conclusion:

If $\sigma_{calculated} < \sigma_{allowable}$ OK

FIG. X1.2 Example 2, Typical Residential Window