Performance Silicones – High Performance Building

Photography credits for all cover images are listed on the last page of this presentation.

Structural Silicone Glazing:

50 Years of Performance Explained

Course #0DC011

By: Dow Performance Silicones
(formerly Dow Corning Corporation)

consumer.dow.com

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Copyright Materials

Course Description

- This course will review original and modern project applications of structural silicone glazing, a unique hyperelastic material that acts as a continuous flexible anchor for glass. It will discuss the history of structural silicone glazing, the basic engineering of systems for attaching the edge of glass and the advent of various system types.
- Performance aspects of silicone structural glazing will be reviewed in-depth with regard to building design, energy efficiency and safety performance through natural and manmade events.
- Current state-of-the-art systems will be highlighted, with reference to unitized curtainwalls and the use of finite element analysis to optimize the design. A review of current international standards for the application also will be presented.

Learning Objectives

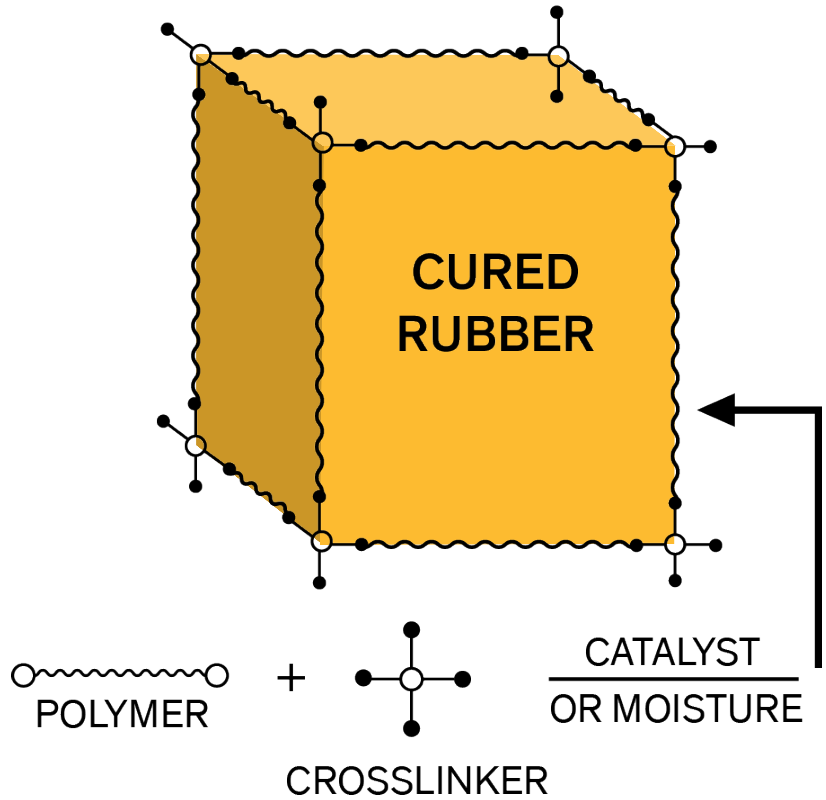
At the end of this course, participants should be able to:

- Map the basic load distribution on a piece of glass – and how that load is transferred to the edges of the panel
- Calculate the amount of structural silicone required to support the edge of glass
- Identify structural silicone as a thermal break in a glazing system
- Refer to standards and publications that document the science, engineering and performance of structural silicone glazing

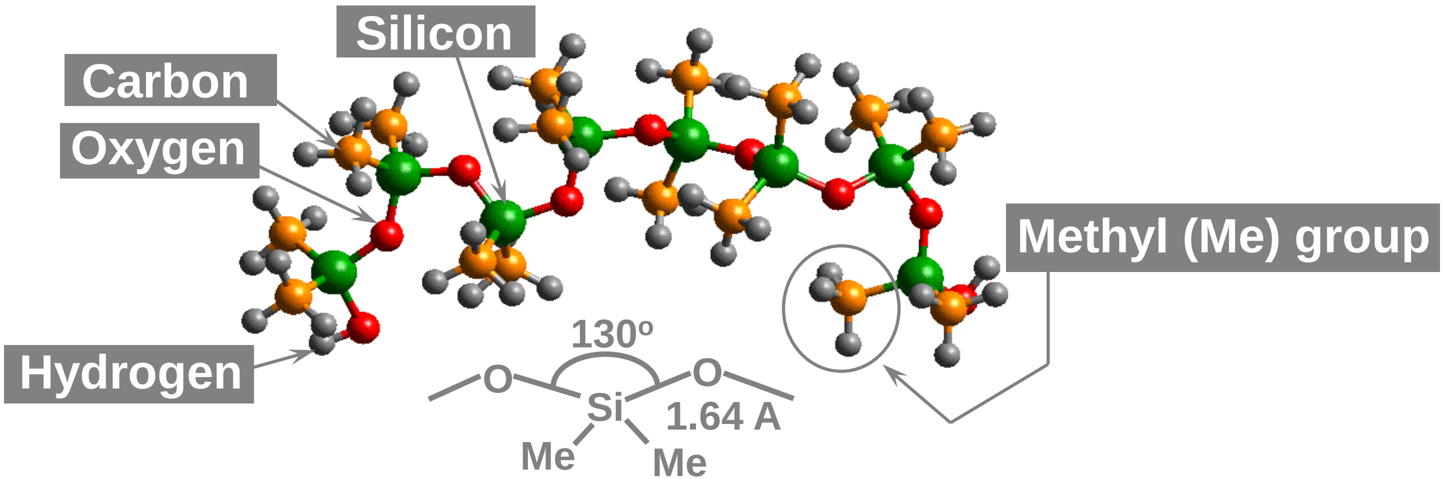
Agenda

- Why silicone?
  - Durability, adhesion to glass
  - Hyperelastic model
- Sizing structural silicone
- History of silicone structural glazing (SSG)
  - TVS, 2-sided, 4-sided, unitized
  - Thermal
- Checking historical projects
- Standards and important publications
- Next generation with FEA requires validation
- Innovations
- Quality control

Cure Process



Silicone as a Reliability Provider for the Construction Industry: What Is Silicone?



- Wide O-Si-O angle ⟶ Free Rotation, Low Tg, Tm, Low Modulus etc.
- Strong Si-O Bond ⟶ High Thermal Stability
- Low rotational energy: E(Si-O)=3.3 kJ/mole, E(C-C)=13.8 kJ/mole
- PDMS backbones covered by Methyl (CH3) groups ⟶ Hydrophobicity

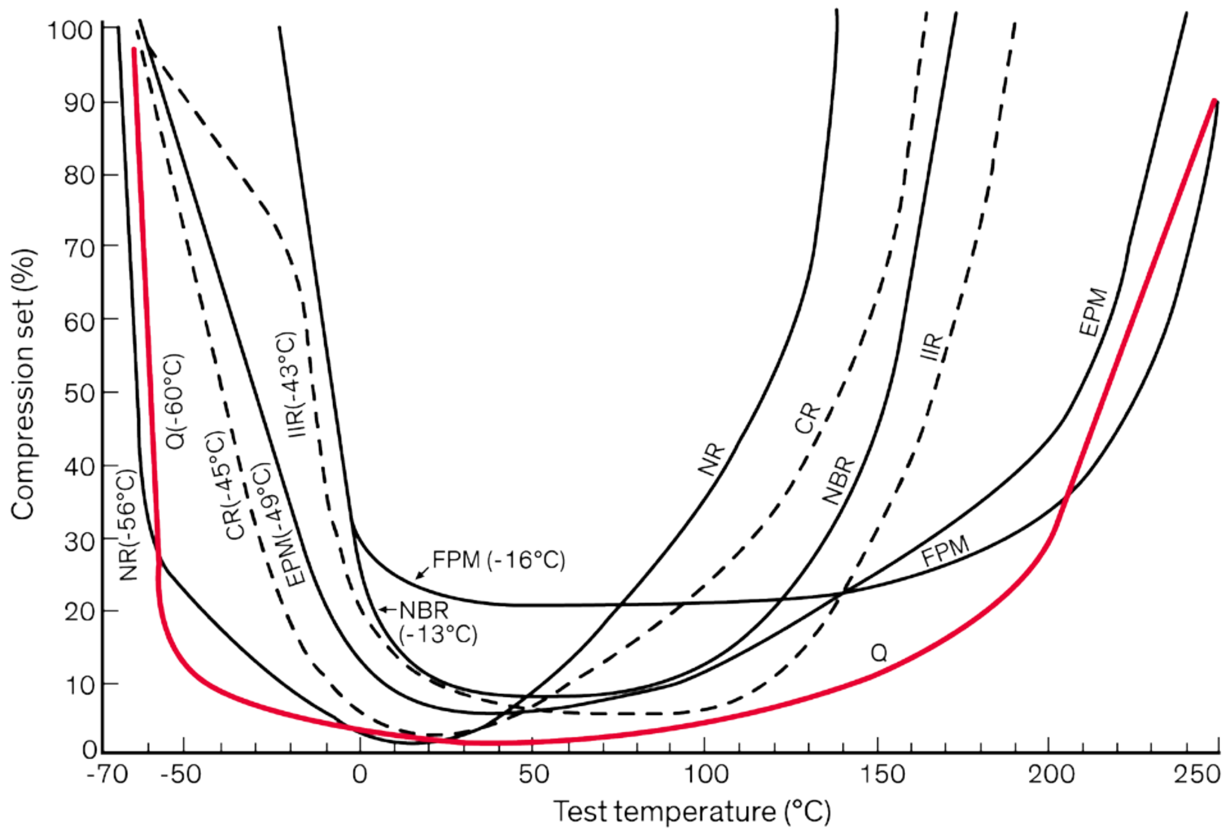
Key Properties of Silicone Sealant

- Superior durability and weatherability differentiates silicone from organic sealants
- Bond Type / Bond Energy

Bond Type	Bond Energy
Si-O	108
C-C	83
C-O	86

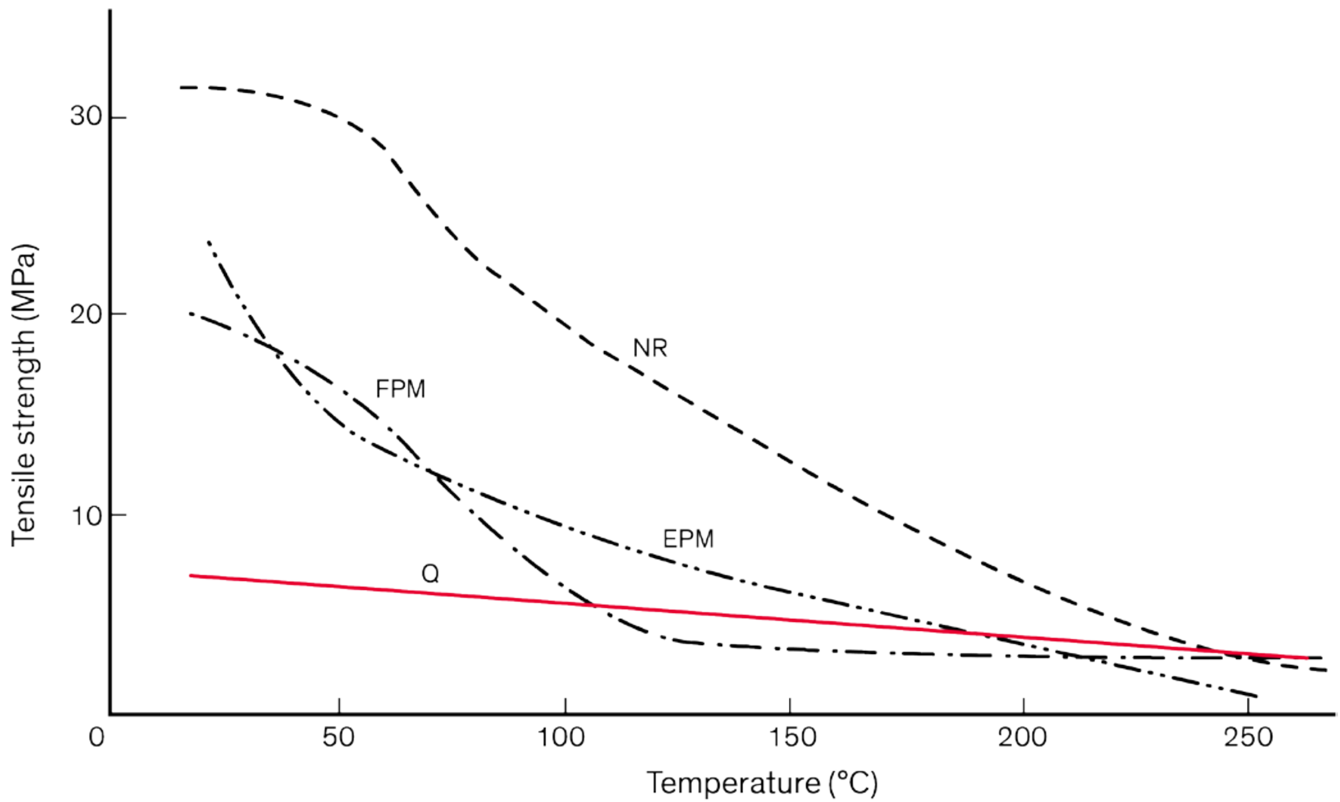
- Silicone sealants are stable in UV light and extreme temperatures

Excellent Compression Set at High and Low Temperatures



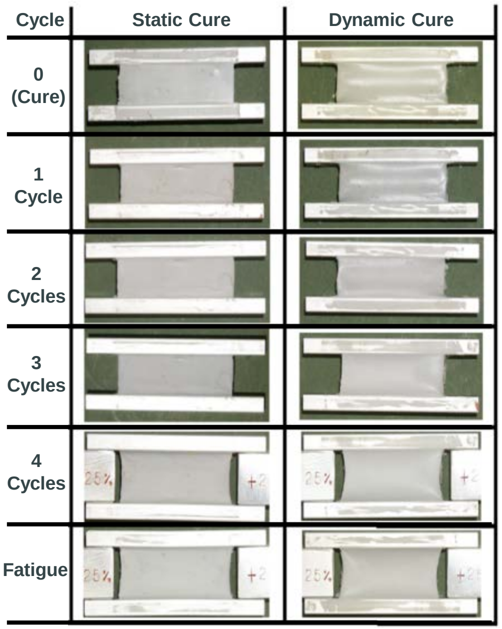
Blow (1964), Bunhill Publications

Consistent Properties Over a Wide Temperature Range

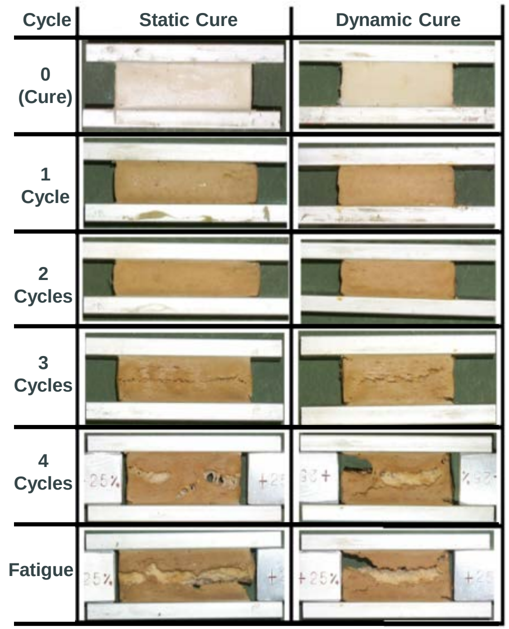


Blow (1964), Bunhill Publications

Example: Durability of Silicone Sealants Versus Organic Sealants



Silicone



Polyurethane

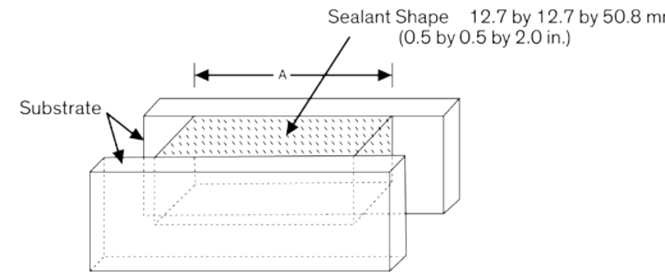
Cycle	Static Cure	Dynamic Cure
0 (Cure)		
1 Cycle		
2 Cycles		
3 Cycles		
4 Cycles		
Fatigue		

Polysulfide

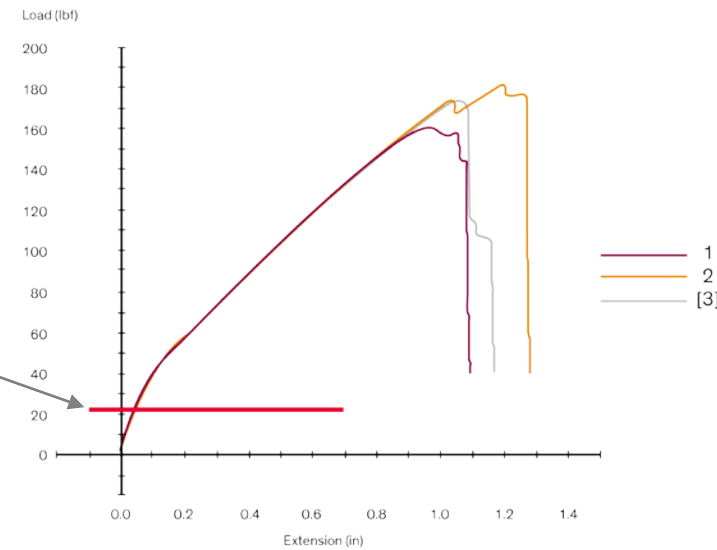
Jones, Hutchinson, Wolf; **Materials & Structures** ***34, 332-341 (2001)***

ASTM C1135 – Load Versus Displacement

- Determines stress-strain characteristics of structural silicone attached to parallel plates
- Useful to compare aged specimens to new specimens
- Basis for design stress
  - ASTM
  - ETAG
  - GB
  - ISO



20 psi live load design for return wind loads – industry standard



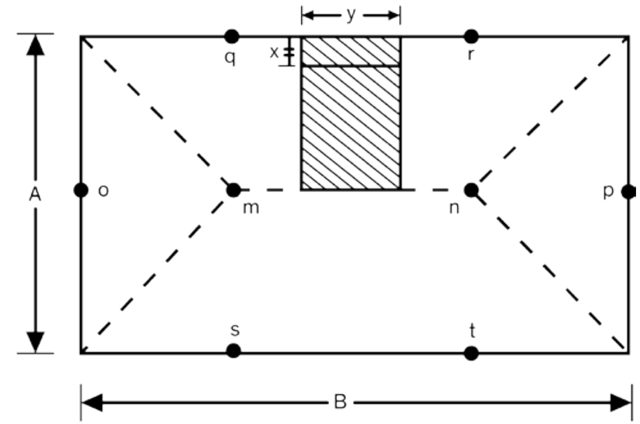
Nonlinear Hyperelastic Material

One must compare an FEA model to actual data to validate the model.

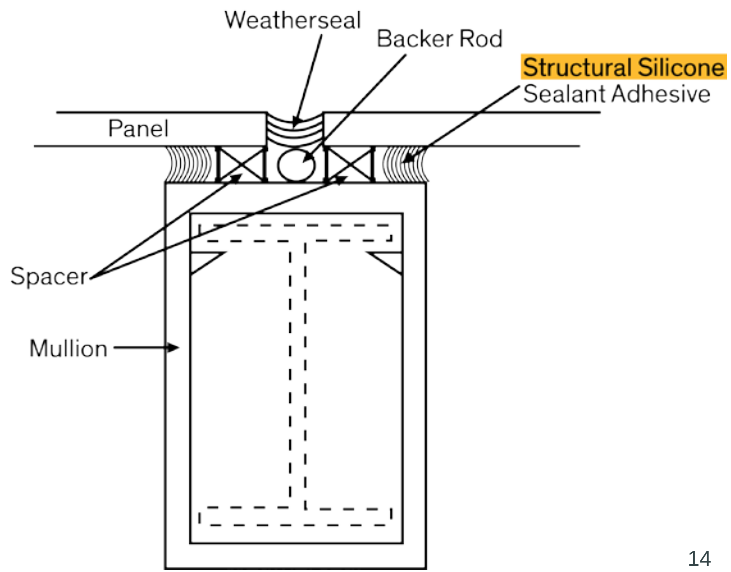
SSG – Yesterday and Today: Learning Points 1 and 2

- Basic design theory has remained the same
- Structural silicone is a method to firmly support the edge of glass
- Properly size structural joints:

$$\textbf{Bite} = \frac{\textbf{0.5 x short span length x wind load}}{\textbf{sealant design strength}}$$



Deflection patterns under trapezoidal load theory.



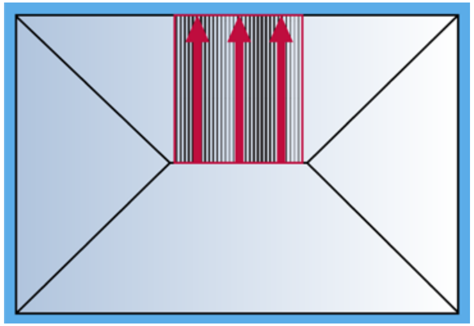
Mapping and Calculating Logic: Learning Point 2

- Draw the tributary of the rectangular plate
- Calculate the area where the load goes to the edge
- Calculate the bite needed:

$$\text{Bite (mm)} = \frac{\text{0.5 x short span length (mm) x wind load (kPa)}}{\text{sealant design strength (138 kPa)}}$$

$$\text{Bite (inches)} = \frac{\text{0.5 x short span length (ft) x wind load (psf)}}{\text{12 in/ft x sealant design strength (20 psi)}}$$

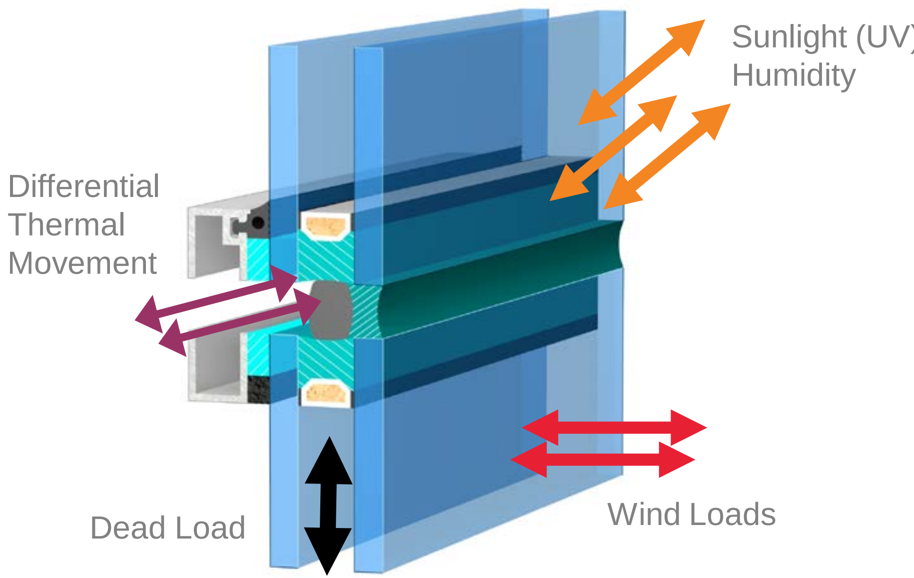
- Calculate the area of required silicone (bite x length):
  - 20 psi design
  - 138 kPa



4' x 8' panel
60 psf wind load
2 ft^2 area = 120 lb
12 linear inches of edge
6 in^2 of silicone required
1/2" bite needed

Structural Silicone Glazing (SSG): The Flexible Rubber Anchor

- Load-bearing bonding between glass and supporting metal frame using structural silicone sealant results in continuous thermal barrier and excellent air and water intrusion performance
- Bonding must be dimensioned according to load (thermal, live and dead) requirements
- SSG sealant carries loads and compensates for movements
- Higher performance requirements on IG edge seal regarding UV and heat resistance
- IG edge seal must fulfill live and dead load-bearing function

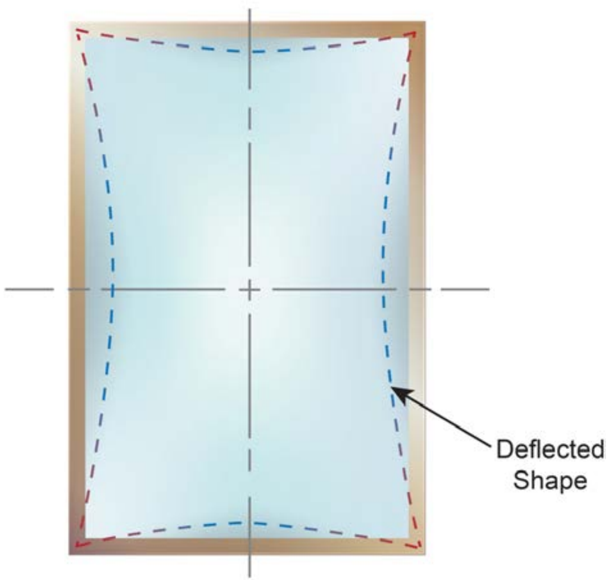


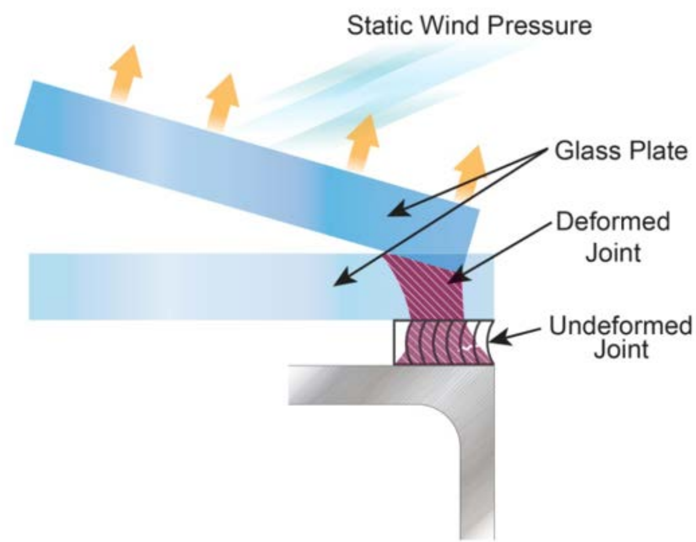
Organic-Sealed IG Unit, Structurally Glazed, After a Typhoon

- Where is the outboard lite?

Structural Seal Shape Deformation Under Wind Load

- Structural silicone acting in combination of shear and tension reduces glass deflection under wind load
- Advanced analysis of glass rotation and aluminum deflection is possible using finite element analysis





Haugsby, M. H., Schoenherr, W.J., Carbary, L.D., and Schmidt, C M., "Methods for Calculating Structural Silicone Joint Dimensions," Science and Technology of Glazing Systems*, ASTM STP 1054, C. J. Parise, Ed., ASTM International, West Conshocken, PA, 1989, pp. 46-57*

Trapezoidal Loading

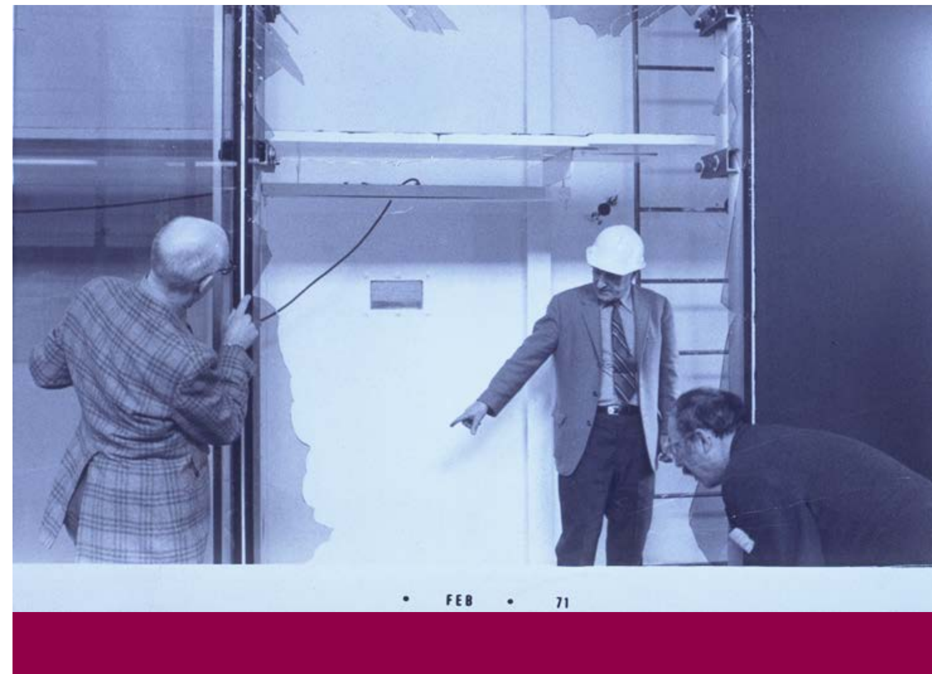
- Visual evidence of the loading pattern under negative wind load

Glass Stressed to Failure

- Visual evidence that the silicone is stronger than glass
- Notice the glass shards bonded to the vertical mullions

Glass Stressed to Failure

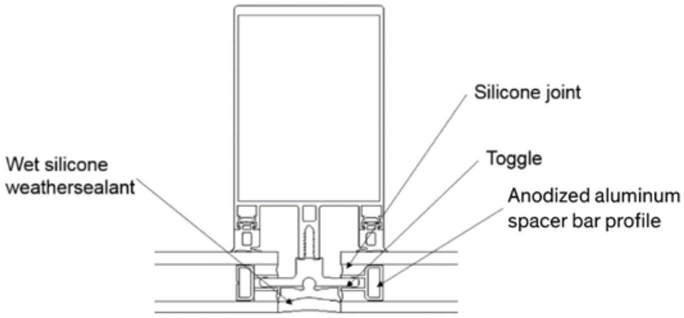
- First mockup of 4-sided SSG: February 1971
- Notice shards of glass held about the perimeter
- 455 W. Fort St. in Detroit, Michigan, USA

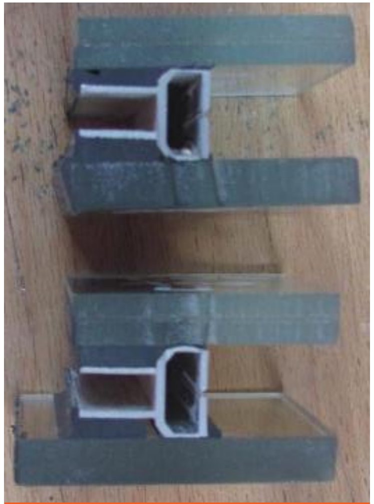


First 4-Sided SSG in 1971: SHG Inc. Building in Detroit – Still Performing!

Structural Silicone: A Method of Supporting Glass

- **TVS** – structural silicone in shear on verticals
- **2-sided** – typically vertical structural silicone in tension
- **4-sided** – typically both vertical and horizontal structural silicone in tension
- **Toggles** – outboard lite of IG is fully adhered
- **Unitized** – typically 4-sided for air, water, thermal and seismic performance
- **IG** – rigid 3-sided adhesion
- **Points** – designed on case-by-case basis
- **Impact resistance** – hurricane and blast
- **Finite element analysis**





SSG Toggles

Oaklawn Jockey Club, 1960s: 2-Sided SSG in Shear; Total Vision System

2-Sided and 4-Sided Examples

1987: Selb, Germany
4-sided SSG with safety devices

1985: Pleasanton, California, USA
Pleasanton Park; 2-sided

1986: Seattle, Washington, USA
3131 Elliot; 2-sided and 4-sided

1985: Rosenheim, Germany
ift Rosenheim; 4-sided insulating glass toggle system; no safety devices

Unitized Curtainwall

1982-83: Regents Square I, San Diego, California, USA
First unitized curtainwall system using 2-part structural silicone

1984: Exchange Square, Hong Kong
Unitized construction with 1-part silicone

Thermal Break Definitions – NFRC 100: Learning Point 3

- Thermal break: A material of low thermal conductivity that is inserted between members of high conductivity to reduce the heat transfer
  - Thermal barrier material conductivity shall not be more than 0.52 W/mK (3.60 Btu·in./h·ft^2·ºF)
- Thermally broken (TB) members: System members with a minimum of 5.30 mm (0.210") separation provided by a low-conductance material
  - Where thermal conductivity ≤ 0.5 W/mK (≤ 3.6 Btu·in./h·ft^2·ºF) or open air space between the interior and exterior surfaces
- Thermally improved (TI) members: System members with a separation ≥ 1.60 mm (0.062") separation provided by a material
  - Where thermal conductivity ≤ 0.5 W/mK (≤ 3.6 Btu·in./h·ft^2·ºF)] or open air space between the interior and exterior surfaces
- Structural silicone that has a thermal conductivity of 0.35 W/mK (2.42 Btu·in./h·ft^2·ºF) and a dimension of greater than 5.3 mm (7/32") between glass and aluminum is a **thermal break**

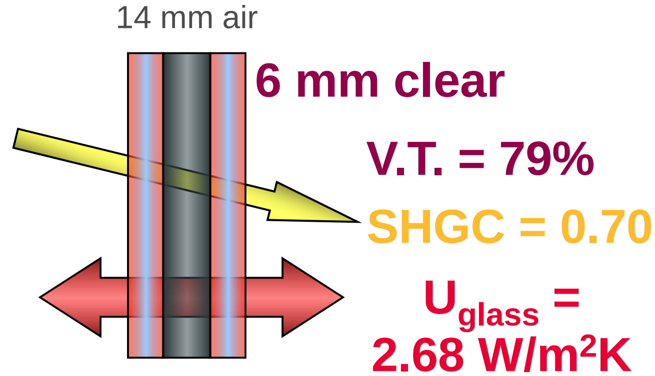
Glazing Systems

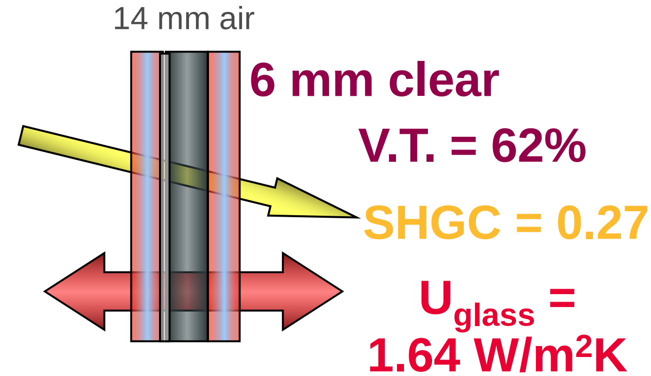
Calculate and compare performance with LBNL WINDOW software:

- Low performance
  - 6 mm clear
  - 14 mm air
  - 6 mm clear

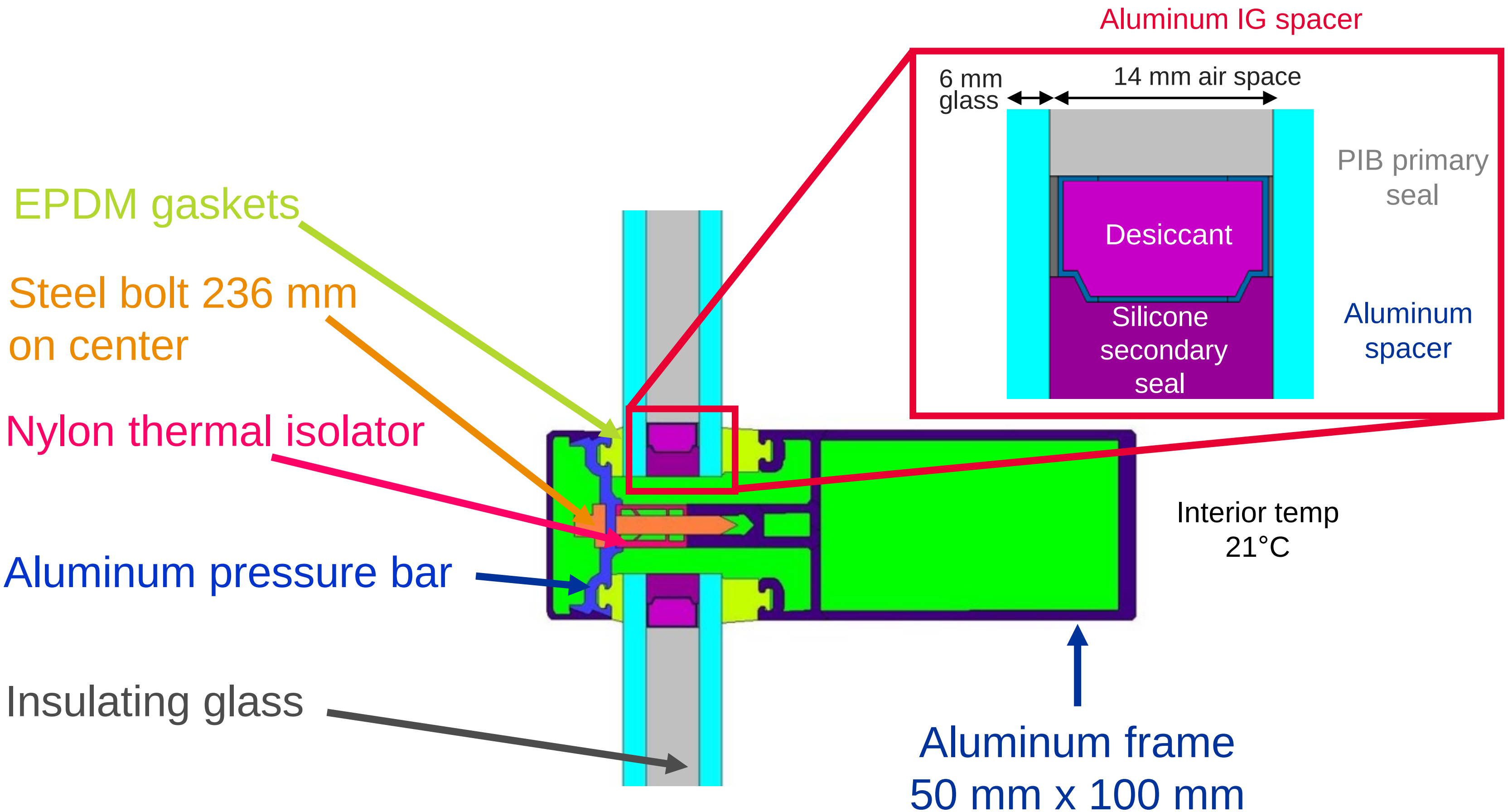
- **High performance**
  - 6 mm Low-E3 coating on Face 2
  - 14 mm air
  - 6 mm clear

→ increase IR reflection and absorption + maximize visible transmission



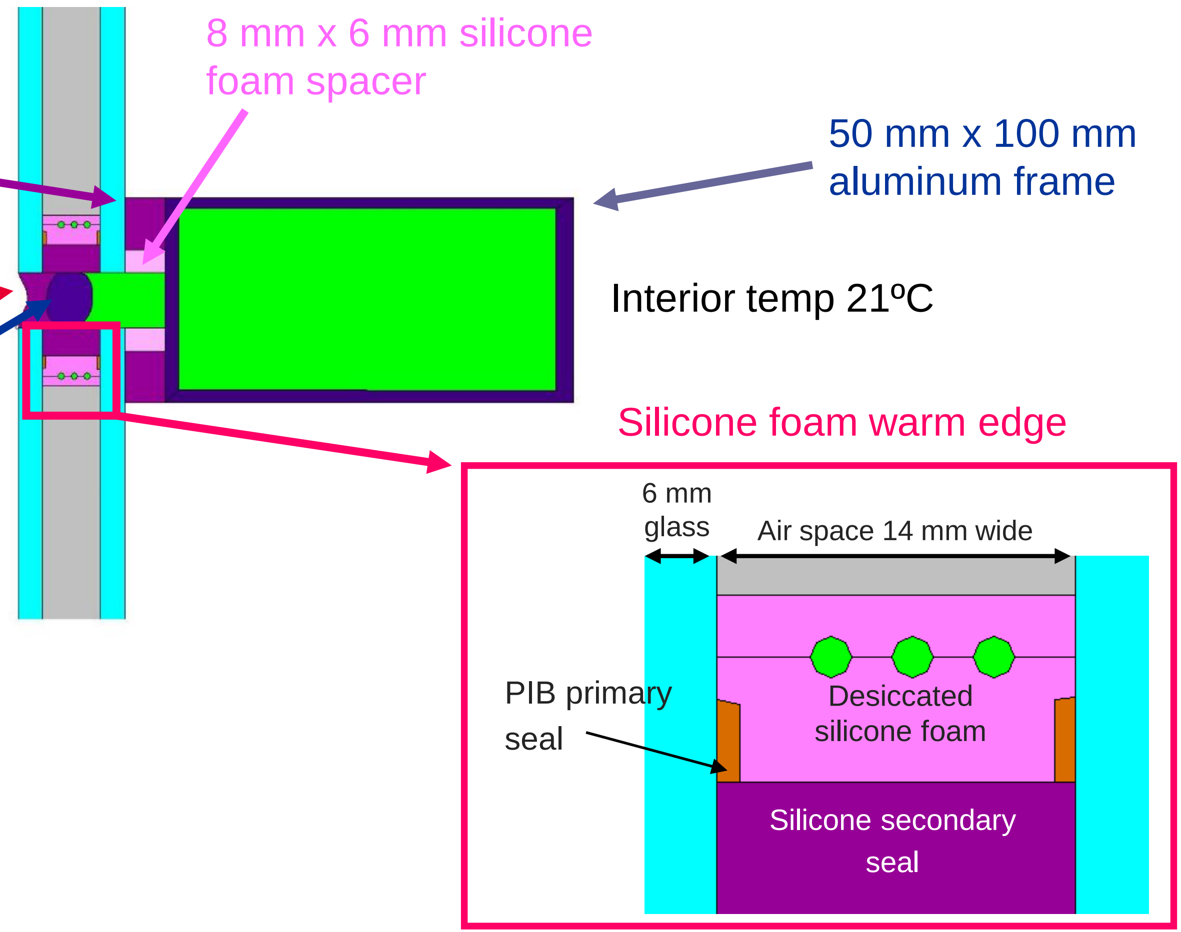


Dry Glaze Curtainwall

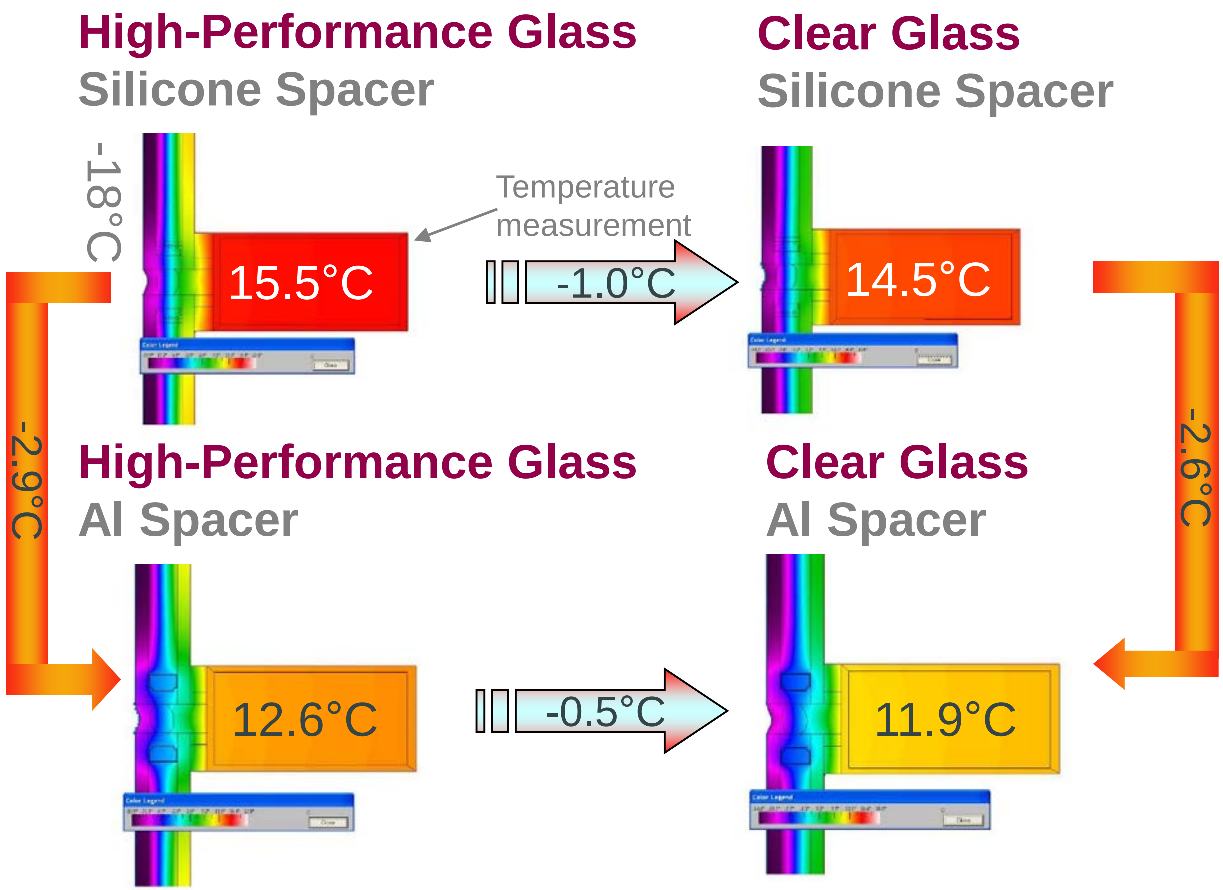


Structural Silicone Glazing Curtainwall

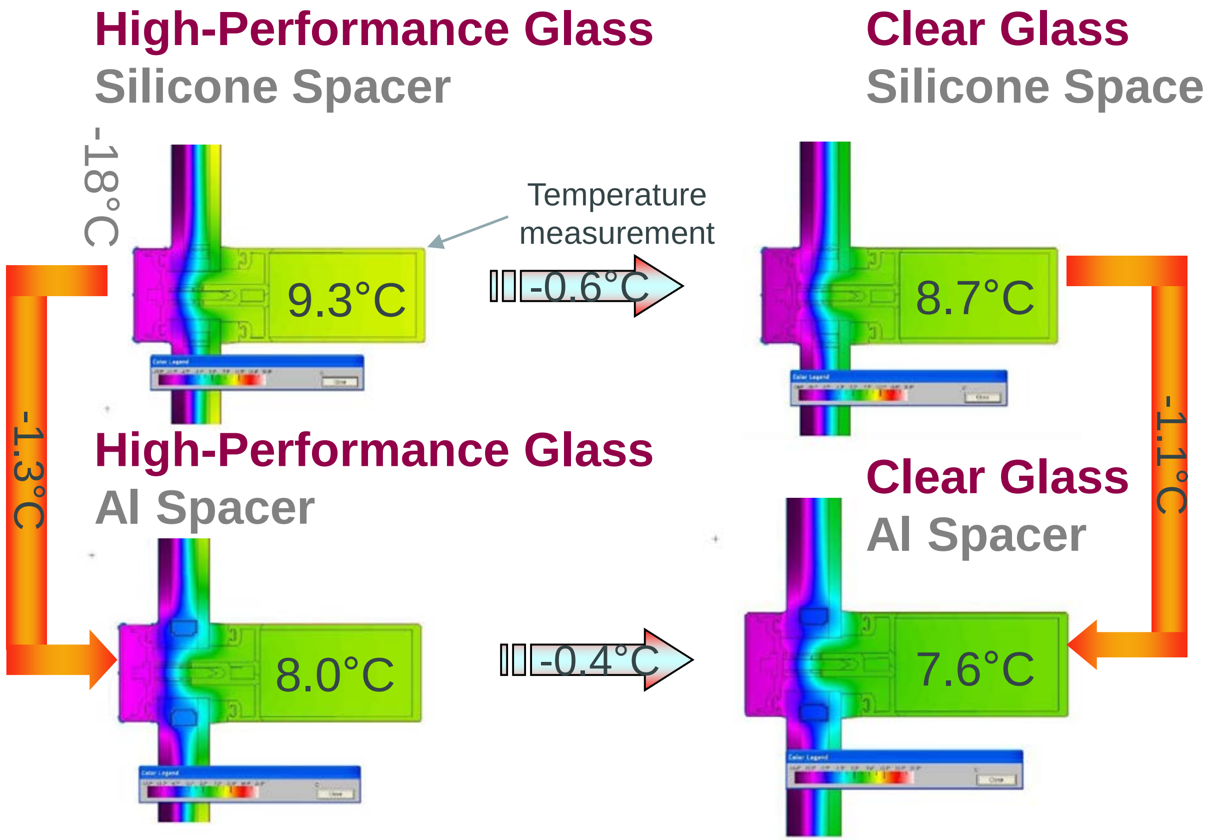
- 8 mm x 12 mm structural silicone joint
- 15 mm wide silicone weatherseal
- Foam backer rod



Temperature Evolution for SSG System at -18°C Cold



Temperature Evolution for Dry System at -18°C Cold

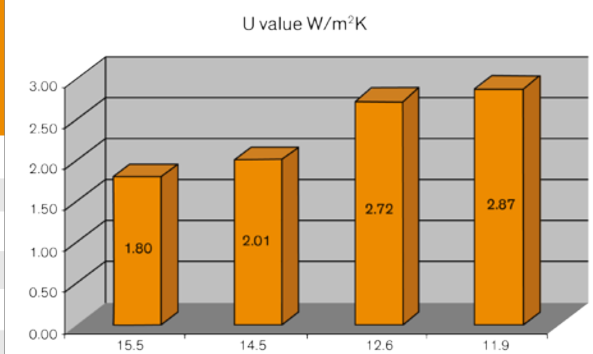


Comparisons: U-Value, SHGC and Temperature

- SSG gives better (lower) U-values than dry systems in all combinations
- SSG gives higher internal temperatures than dry in all combinations
- Silicone spacer provides a better (lower) U-value than aluminum spacer in all combinations

Decreasing performance

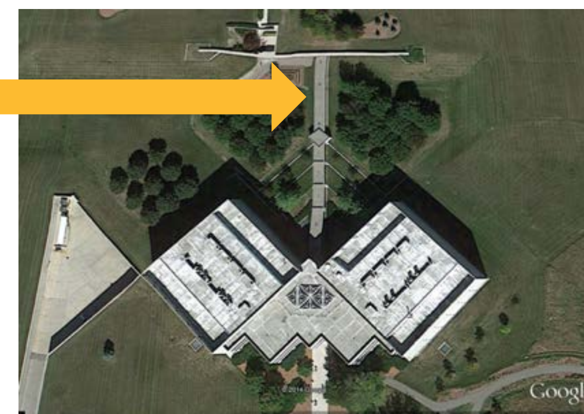
System	Spacer	Glass	U-value, w/m²K	SHGC	Visible Transmittance	Interior Mullion Temperature (exterior -16˚C)
SSG	Si	Low-E3/clear	1.80	0.28	0.59	15.5
SSG	Al	Low-E3/clear	2.01	0.30	0.59	14.5
SSG	Si	Clear/clear	2.72	0.68	0.74	12.6
SSG	Al	Clear/clear	2.87	0.69	0.74	11.9
Dry	Si	Low-E3/clear	2.19	0.27	0.58	9.3
Dry	Al	Low-E3/clear	2.30	0.27	0.58	8.7
Dry	Si	Clear/clear	3.07	0.67	0.74	8
Dry	Ai	Clear/clear	3.17	0.67	0.74	7.6



Structural Silicone Aging Data

West-facing SSG – 22-year exposure

- 2-sided SSG
- Field-applied in 1990
- IG
- West-facing in northern hemisphere
- Glass size 61" x 108"
- SSG size 1/4" x 5/8"
- Wind load 40 psf
- Broken glass 2012



Actual Aging Data

West-facing in Midland, Michigan, USA – 22-year exposure

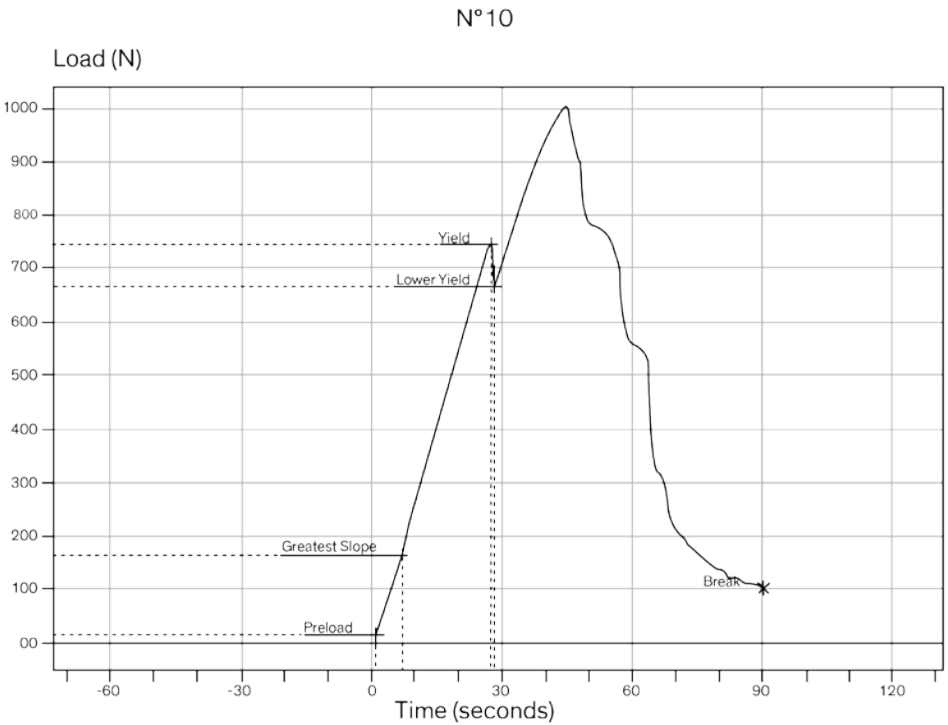
NO degradation!

6 x 15 mm Structural Silicone Joint in Service for 22 years – Tensile Testing								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Ave**
Peak Stress, MPa	59	0.6	0.45	0.64	0.57	0.5	0.55	**0.56**
Peak Strain, %	120.1	90.3	59.2	86.7	172.7	63.4	71.5	**94.8**
Elongation at Peak	7.6	5.7	3.8	5.5	11	4	4.5	**5.1**
25% MPa	0.38	0.42	0.39	0.37	0.23	0.36	0.37	**0.36**
50% MPa	0.53	0.56	0.45	0.59	0.42	0.47	0.52	**0.5**

12.5 mm x 12.5 mm as cured ASTM C1135	
Peak Stress, MPa	**0.55**
Peak Strain, %	**225**
Elongation at Peak	**27**
25% MPa	**0.3**
50% MPa	**0.41**

Monitoring Existing Projects:
European Parliament, Brussels – 1994-2009

Tensile Testing and Hardness Testing



Hardness Results, A scale		
Cadre nº 5	Cadre nº 38	Cadre nº 53
42	49	47
43	44	49
42	46	49

Monitoring Old SSG Projects

- Full monitoring during the lifetime of 25 years was done on an SSG project in Rosenheim, Germany: façade of the ift Testing Institute (Institut für Fenstertechnik)
- Units produced 1985 and installed 1986 using first generation of 2-part structural silicone
- Uninstalled in 2012; stored in a warehouse for 2 years before testing
- Samples cut by waterjet from glass units, then tested according ETAG 002
- Results from testing in tension and shear until rupture show sufficient remaining strength

1985: Rosenheim, Germany
4-sided insulating glass system; no safety devices; outer glass unsupported

Samples cut out from the units

Type of Test	Test Temperature	Average Breaking Stress X_{mean} (MPa)		Residual Strength Ratio	ETAG 002-1 Requirement
		ITT (New)	Natural Aging (23+2 Years)		
Tensile	+23ºC	0.95	0.75	0.79	≥ 0.75
	-20ºC	1.7	1.1	0.65	-
	+60ºC	0.81	0.73	0.90	-
Shear	+23ºC	0.94	0.67	0.71	-
	-20ºC	1.54	0.97	0.63	-
	+60ºC	0.71	0.67	0.94	-

Tensile and Shear Strength Values in Initial Type Testing (1985) and after 23+2 Years of Natural Aging and Corresponding Residual Strength Ratios

International Standards: Learning Point 4

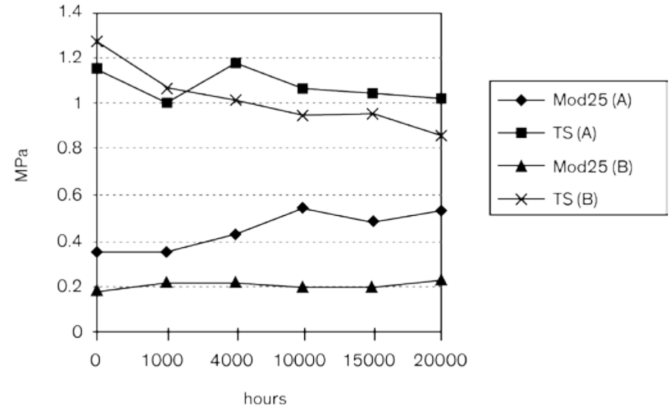
- ASTM International: C24 Building Seals and Sealants
  - C1135-15 Standard Test Method for Determining Tensile Adhesion Properties of Structural Sealants
  - C1184-14 Standard Specification for Structural Silicone Sealants
  - C1265-17 Standard Test Method for Determining the Tensile Properties of an Insulating Glass Edge Seal for Structural Glazing Applications
  - C1369-07(2014) Standard Specification for Secondary Edge Sealants for Structurally Glazed Insulating Glass Units
  - C1249-06a(2010) Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications
  - C1087-16 Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems
  - C1392-00(2014) Standard Guide for Evaluating Failure of Structural Sealant Glazing
  - C1394-03(2012) Standard Guide for In-Situ Structural Silicone Glazing Evaluation
  - C1487-02(2012) Standard Guide for Remedying Structural Silicone Glazing
  - C1564-15 Standard Guide for Use of Silicone Sealants for Protective Glazing Systems
  - C1401-14 Standard Guide for Structural Sealant Glazing
    - 50 references of state-of-the-art publications on structural silicone

International Standards: Learning Point 4 *(continued)*

- ASTM International: E06 Performance of Buildings
  - E2270-14 Standard Practice for Periodic Inspection of Building Facades for Unsafe Conditions
    - Reflects best practices for façade inspections and is intended for adoption by model building codes, local municipalities, or private owners of multiple buildings
  - E1825-17 Standard Guide for Evaluation of Exterior Building Wall Materials, Products, and Systems
  - E2841-11 Standard Guide for Conducting Inspections of Building Facades for Unsafe Conditions
- Publications
  - Glass Performance Days: www.gpd.fi
  - Challenging Glass TU Delft
  - ASTM Committee C24 Special Technical Publications
  - ASTM standards and technical articles relating to structural glazing

Additional Important Publications

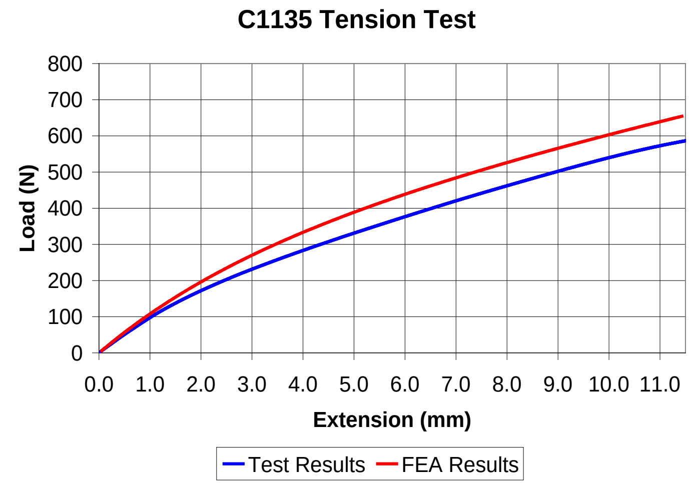
- ASTM STP 1200 (1992)
  - Usefulness of accelerated test methods for sealant weathering (Fedor)
    - Organic sealants showed ~2,000 hrs + 2 years in Florida
    - Silicones unaffected
  - Accelerated weathering and heat stability of various perimeter sealants (Carbary)
    - Organics showed major changes
    - Silicone showed stability
- Rilem State of the Art on Durability of Sealants (1999)
  - Durability of silicone with 20,000 hrs of weathering (Wolf)
- Rilem 3rd Symposium on Durability (2000)
  - Creep Resistance of Structural Sealants (Sugiyama)
  - Fatigue Resistance of Structural Sealants (Sugiyama)
- ASTM standards and technical articles related to structural glazing

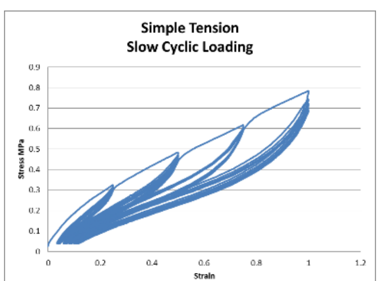


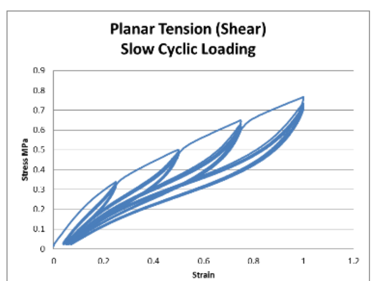
These publications provide data, guidance and direction to ensure the long-term success of SSG projects.

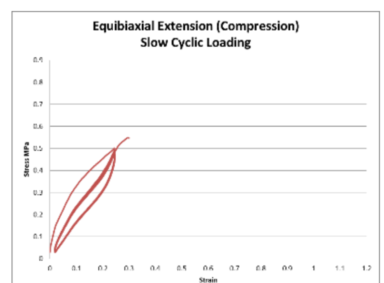
Creation and Validation of a Traditional SSG Configuration with a Model

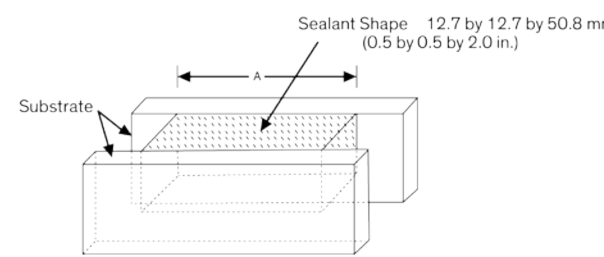
- Finite Element Analysis accommodates nonlinear hyperelastic behavior
- Hyperelastic data input into FEA program:
  - Tension
  - Shear
  - Biaxial extension
- Compare actual with model



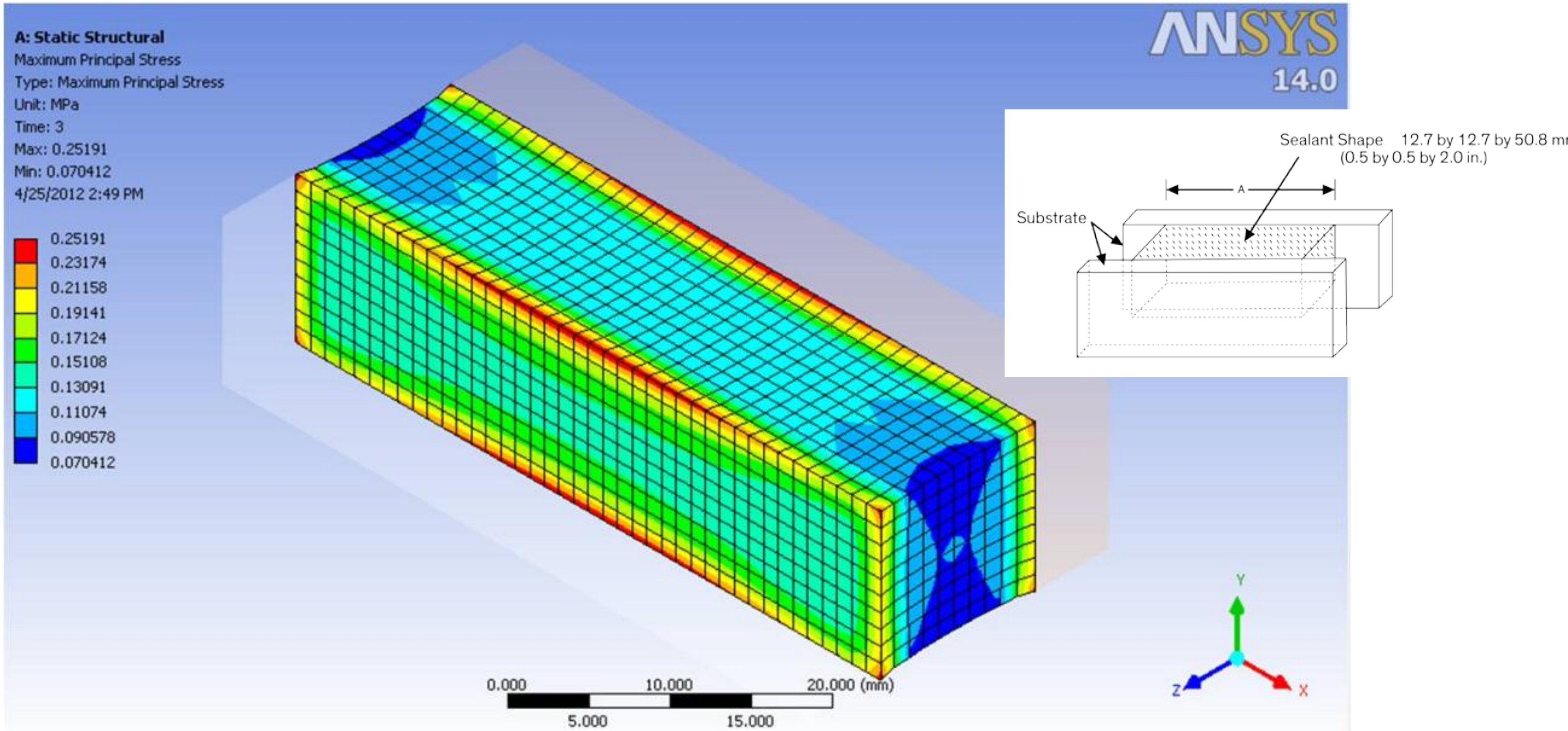




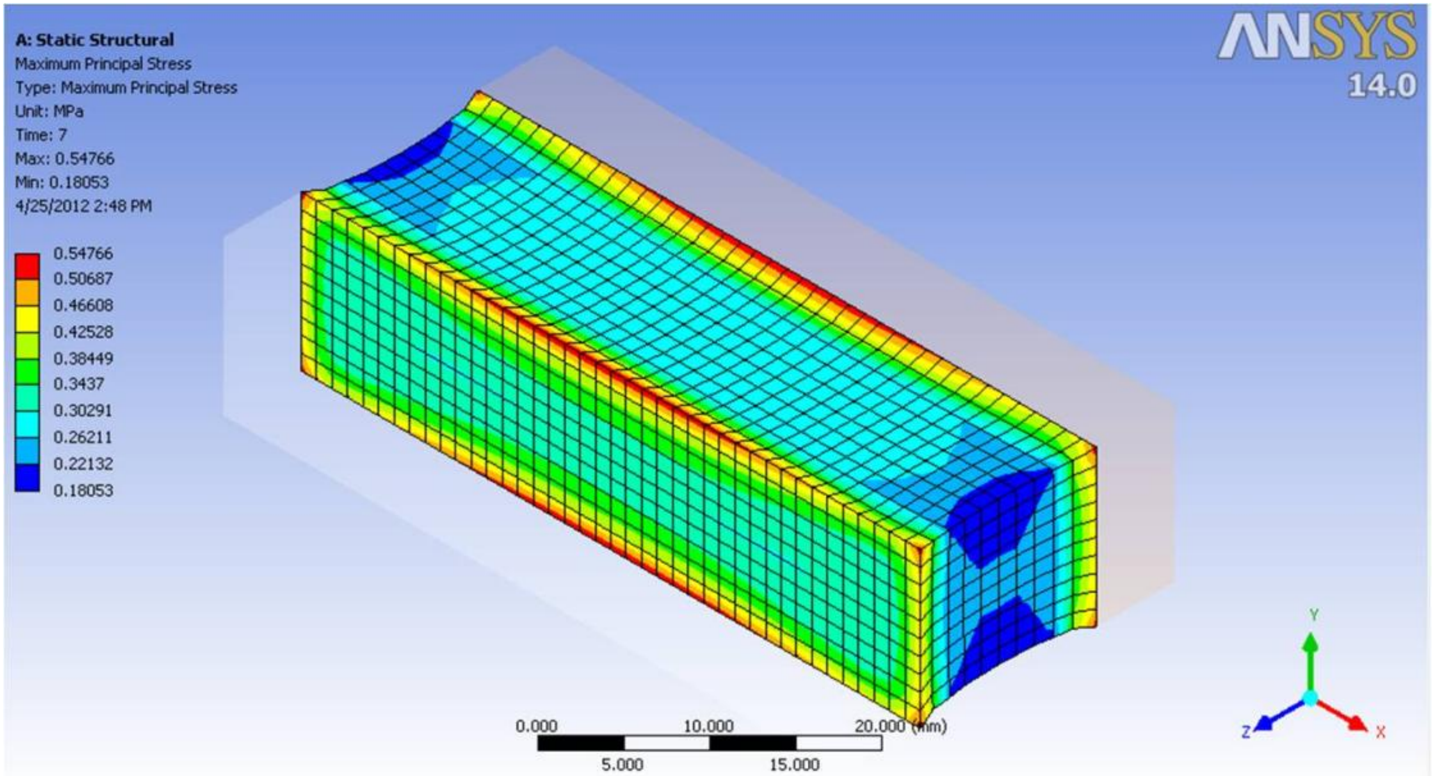




ASTM C1135 Testing: 20 psi, 0.14 MPa



ASTM C1135 Testing: 40 psi, 0.28 MPa



Validation of Models Through Validation Testing

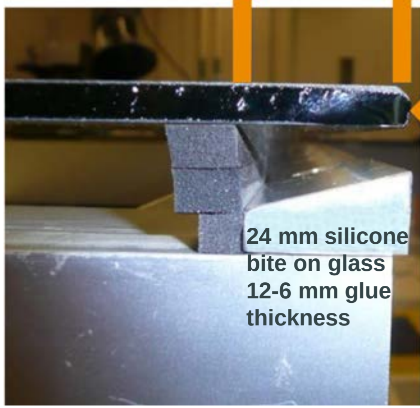
- Advanced models and designs need to be validated through designed mockups
- Account for glass deflection edges and center
- Correlate with model

Mockup Measurements of Joint Deflections

Gauges 3 and 4 positive
Travel direction

Gauges 2 and 5 positive
Travel direction

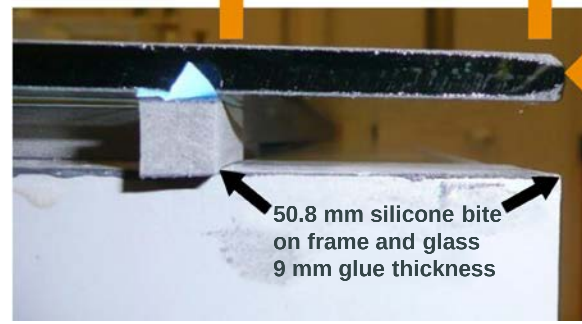
Gauges 1 and 6
positive
Travel direction

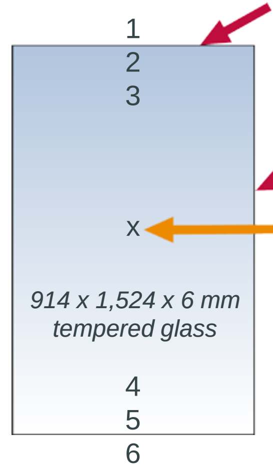


Gauges 3 and 4 positive
Travel direction

Gauges 2 and 5 positive
Travel direction

Gauges 1 and 6
positive
Travel direction





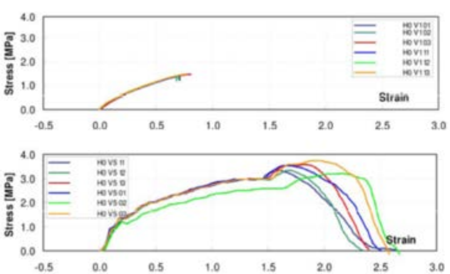
Structural silicone applied to
short span top and bottom

Long span unsupported

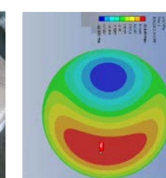
Center point deflection monitored

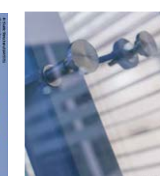
Innovations: Blast Mitigation, Impact Mitigation, Point Supports

Stress-strain curve for 2-part sealant
0.00083 m/s vs. 5.0 m/s movement rate
2"/minute vs. 11811"/minute



Loading Sequence	Loading Direction	Air Pressure Cycles	Number of Air Pressure Cycles
1	Positive	0.2P – 0.5P	3,500
2	Positive	0.0P – 0.6P	300
3	Positive	0.5P – 0.8P	600
4	Positive	0.3P – 1.0P	100
5	Negative	0.3P – 1.0P	50
6	Negative	0.5P – 0.8P	1,050
7	Negative	0.0P – 0.6P	50
8	Negative	0.2P – 0.5P	3,500





Quality Control

- Fears about adhesive attachment resulted in very specific contract language requiring the documentation of each step
- Façade engineers and consultants rely on QC data to validate materials are mixed, cured and adhered before they are put into service
- Contract documents require fabricators to perform QC tests, keep documentation and deliver it to the project
- Quality control is good for everybody because issues are discovered before the materials are installed

Summary

- Why silicone?
  - Durability, adhesion to glass
  - Hyperelastic model
- Sizing structural silicone
- History of SSG
  - TVS, 2-sided, 4-sided, unitized
  - Thermal
- Checking historical projects
- Standards and important publications
- Next generation with FEA requires validation
- Innovations
- Quality control

This concludes The American Institute of Architects Continuing Education Systems Course

For information about this course content, please contact:

Larry Carbary (l.carbary@dowcorning.com)

New brand name. Same trusted products.

- DOWSIL™ is the new product brand name for silicone-based building products from Dow Performance Silicones
- Products formerly branded *Dow Corning*® are now offered through the DOWSIL™ brand

DOWSIL™

silicones by DOW

- DOWSIL™ represents the combined power of Dow and Dow Corning
- New website: consumer.dow.com/construction

DOWSIL™ Structural Glazing Sealants

- **DOWSIL™ 795 Silicone Building Sealant –** 1-component industry standard for onsite glazing
- **DOWSIL™ 995 Silicone Structural Sealant –** 1-component, high-strength sealant for onsite and protective glazing
- **DOWSIL™ 983 Structural Glazing Sealant –** 2-component, fast-cure, in-shop sealant for unitized curtainwall and protective glazing

Torre Titanium La Portada in Santiago, Chile, survived an 8.8 earthquake without damage

DOWSIL™ 121 Structural Glazing Sealant: Two-Part Fast-Cure Sealant for Field Repairs

- Approved for structural and weatherseal applications
- Used for in-shop glazing or field repair/replacement
- Primerless adhesion to glass, alodine and anodized aluminum
- Adhesion to DOWSIL™ structural sealants for reglazing applications
- Adhesion and structural strength achieved in 24 to 48 hours
- Meets ASTM C719 Class 25 (G, A, O)
- Meets ASTM C1184 Structural Sealant Specification

Thank You

Cover Images:

Cornish College of the Arts Student Housing Photo credit: ©Ankrom Moisan Architects and Casey Braunger

ICE Krakow Photo credit: Courtesy of Wojciech Wandzel

Shenzhen Ping An Tower Photo credit: Ping An Insurance Group

Façade of the ICE Krakow Kongress Photo credit: Courtesy of G Ziemianski

Baku Towers Photo credit: Photography by Farid Khayrulin, Design HOK

Press Glass Photo credit: Press Glass

Form No. 63-7079-01