

ABSTRACT

This technical paper outlines the core physics, spectral optical integrals, edge thermal bridging equations, and annual energy load algorithms used by the Architectural Vacuum Insulated Glass (VIG) Configurator. The modeling engine evaluates dynamic solar radiation, multi-coat Low-E optics, and micro-pillar conduction to deliver whole-window fenestration metrics across ASHRAE climate zones.

1. Boundary Conditions & Standard Rating Frameworks

Fenestration calculations align with NFRC 100/200 and ISO 15099 baseline environmental conditions to establish standardized thermal and solar performance comparisons.

Rating Standard	Outdoor Temp (T _{out})	Indoor Temp (T _{in})	Wind Speed	Solar Irradiance (E _s)
NFRC Winter Night	0.0°F (-17.8°C)	70.0°F (21.1°C)	12.3 mph (5.5 m/s)	0 W/m²
NFRC Summer Day	89.0°F (31.7°C)	75.0°F (23.9°C)	6.2 mph (2.75 m/s)	783 W/m²
ISO 15099 / EN 673	32.0°F (0.0°C)	68.0°F (20.0°C)	9.0 mph (4.0 m/s)	0 W/m²

2. Center-of-Glass Thermal Transmittance (U_{cg})

Heat transfer across an evacuated micro-cavity (<0.1 Pa) is modeled via parallel heat pathways: radiative exchange between Low-E coatings, solid conduction through micro-pillars, and residual gas conduction.

EQ 1. VACUUM CAVITY HEAT FLUX & PILLAR CONDUCTION

$q_{cg} = q_{rad} + q_{pillar} + q_{gas} \text{ [W/m}^2\text{]}$

$q_{rad} = \sigma \cdot [1 / (1/\epsilon_{h,1} + 1/\epsilon_{h,2} - 1)] \cdot (T_{s1}^4 - T_{s2}^4)$

$q_{pillar} = [(2 \cdot \lambda_p \cdot r_p) / S^2] \cdot (T_{s1} - T_{s2})$

Center-of-Glass Performance Matrix

Glazing Specification	Cavity Details	U _{cg} (Btu/h·ft²·°F)	U _{cg} (W/m²·K)
Dual-Pane Monolithic VIG (8.3mm)	0.3mm Vacuum (0.1 Pa) + Low-E	0.060 – 0.080	0.34 – 0.45
Hybrid VIG IGU (24mm)	VIG + 12mm Argon 90%	0.035 – 0.048	0.20 – 0.27
Standard Double IGU (24mm)	12mm Air + Single Low-E	0.280 – 0.320	1.59 – 1.82
Standard Triple IGU (36mm)	2x 12mm Argon + 2x Low-E	0.140 – 0.170	0.80 – 0.97

3. Optical Physics & Solar Heat Gain Modeling

Solar radiation dynamics are computed by integrating spectral optical properties from the LBNL International Glazing Database (IGDB) across the ASTM G173 solar spectrum.

EQ 2. SOLAR HEAT GAIN COEFFICIENT (SHGC) & INWARD FLOW

$$\text{SHGC} = \tau_s + \sum (N_{i,k} \cdot \alpha_{s,k})$$
$$N_i = U_{cg} / (h_{out} + h_{in})$$
$$\text{VLT} = \int [\tau(\lambda) \cdot V(\lambda) \cdot D_{65}(\lambda)] d\lambda / \int [V(\lambda) \cdot D_{65}(\lambda)] d\lambda$$

Where τ_s is direct solar transmittance, $\alpha_{s,k}$ is absorbed solar energy in glass layer k , $N_{i,k}$ is the inward flowing fraction of absorbed solar heat, and **VLT** represents visible light transmittance weighted by the photopic curve $V(\lambda)$.

4. Whole-Unit Transmittance & Edge Thermal Bridging

Whole-window performance (U_w) integrates center-of-glass (U_{cg}), frame transmittance (U_f), edge-of-glass conduction (U_{eg}), and perimeter solder/getter linear thermal bridging (Ψ_g) per NFRC 100.

EQ 3. NFRC 100 WHOLE-WINDOW ASSEMBLY EQUATION

$$U_w = [(A_{cg} \cdot U_{cg} + A_{eg} \cdot U_{eg} + A_f \cdot U_f) / A_w] + [(\Psi_g \cdot L_g) / A_w]$$

Thermal Bridge & Frame Interoperability Analysis

Framing System Type	Frame U_f (Btu/h·ft²·°F)	Edge Seal Ψ_g (W/m·K)	Whole-Unit U_w Impact
Thermally Broken Aluminum (Standard)	0.38 – 0.45	0.070 – 0.090	Dominates perimeter heat loss
High-Performance Fiberglass / Wood	0.18 – 0.24	0.035 – 0.050	Optimizes VIG thermal efficiency
Thermally Isolated Curtain Wall Grid	0.22 – 0.28	0.040 – 0.060	Ideal for large commercial facades
Uninsulated Structural Aluminum	0.85 – 1.10	0.120 – 0.150	Severely degrades net unit U-factor

5. Psychrometrics & Condensation Resistance Index

The Condensation Resistance (CR) rating is calculated per NFRC 500 to quantify immunity against indoor glass fogging or frosting under severe winter design conditions.

EQ 4. NFRC 500 CONDENSATION RESISTANCE INDEX

$$T_{si,min} = T_{in} - [U_{w,max} / h_{in}] \cdot (T_{in} - T_{out})$$

$$CR = 100 \cdot [1 - (T_{in} - T_{si,min}) / (T_{in} - T_{dp})]^{0.6}$$

6. Building Envelope Load & Carbon Offset Modeling

Annual thermal loads and operational grid carbon reduction are modeled using hourly bin weather data across standardized ASHRAE climate zones.

Annual Performance Offsets by ASHRAE Climate Zone

ASHRAE Climate Zone	Representative City	Heating Offset (Therms/kft²)	Cooling Offset (kWh/kft²)	CO ₂ Offset (MT/yr)
Zone 1A	Miami, FL	2.1	4,250	1.85
Zone 3A	Atlanta, GA	280.5	2,100	2.35
Zone 4A	New York, NY	610.0	1,450	3.82
Zone 5A	Chicago, IL	890.2	1,120	5.10
Zone 7	Minneapolis, MN	1,240.8	780	6.75

7. Regulatory Compliance Engine Mapping

ASHRAE 90.1-2022 Surpasses maximum prescribed fenestration U-factor requirements by 40–60%.	IECC 2024 Code Meets ultra-low energy commercial envelope targets for Climate Zones 4–8.	LEED v4.1 EA Contributes up to 12 points under Optimize Energy Performance credits.
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