



BUILDING SCIENCE LIVE
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Seeing Clearly Untangling Architectural Glass Selection

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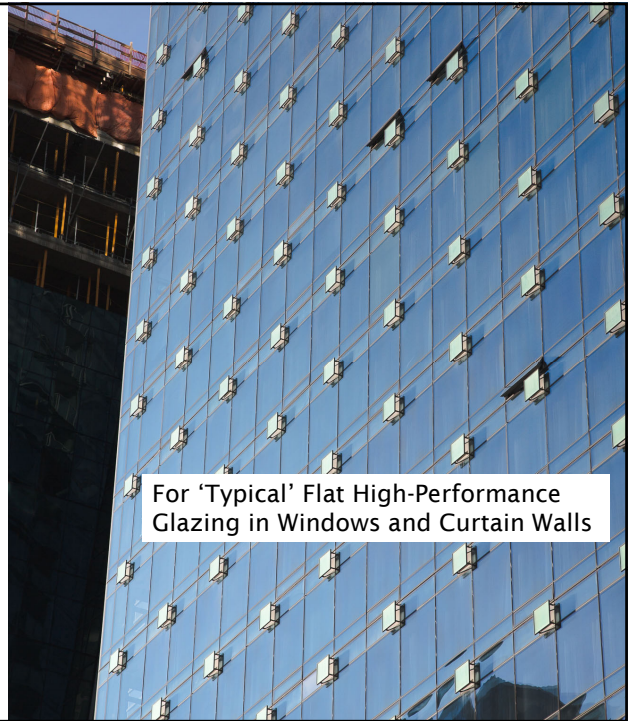
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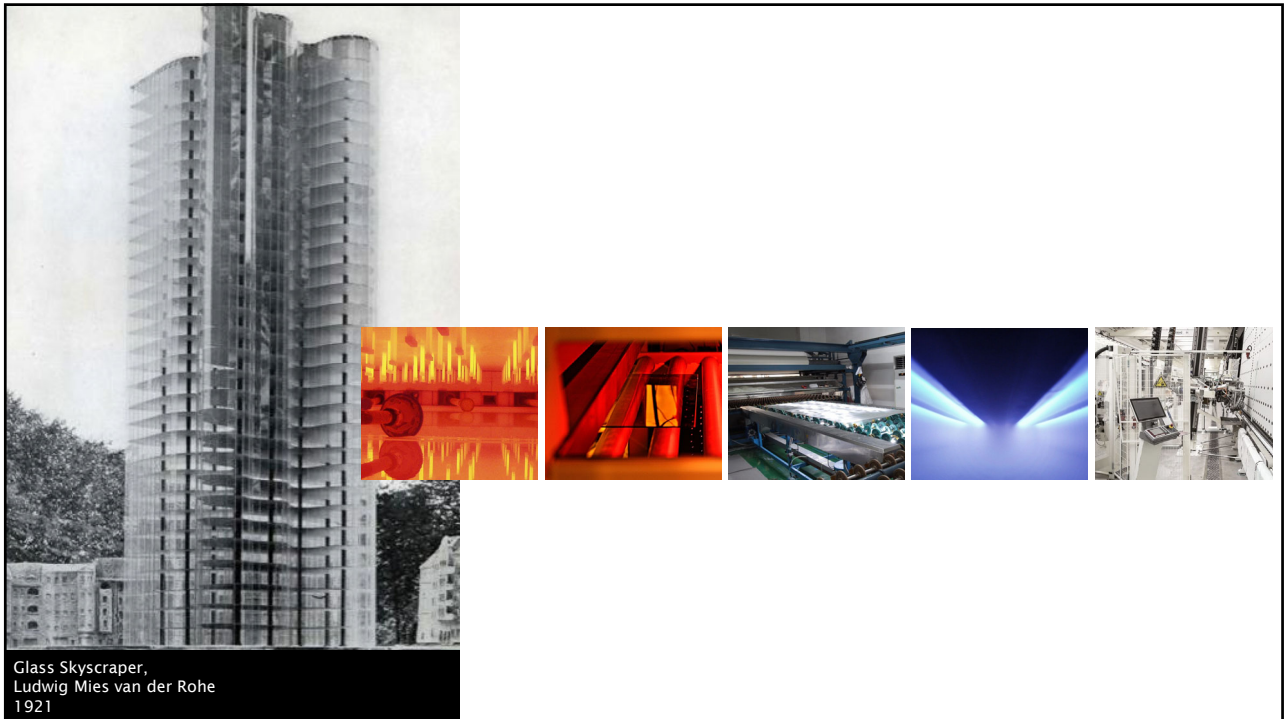
Learning Goals

1. Identify **key performance requirements** and standards for glass selection.
2. Recognize which **components** of insulated glass units affect their performance and how these interact.
3. Understand the **design process** and when critical decisions must be made around glass and glazing.
4. Apply a **framework** to compare options for insulated glass units across multiple requirements.



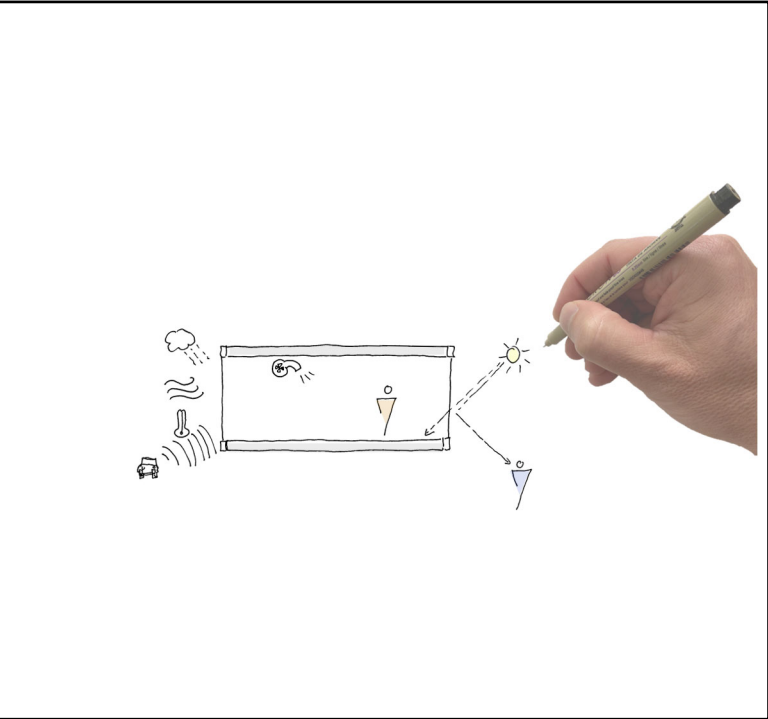
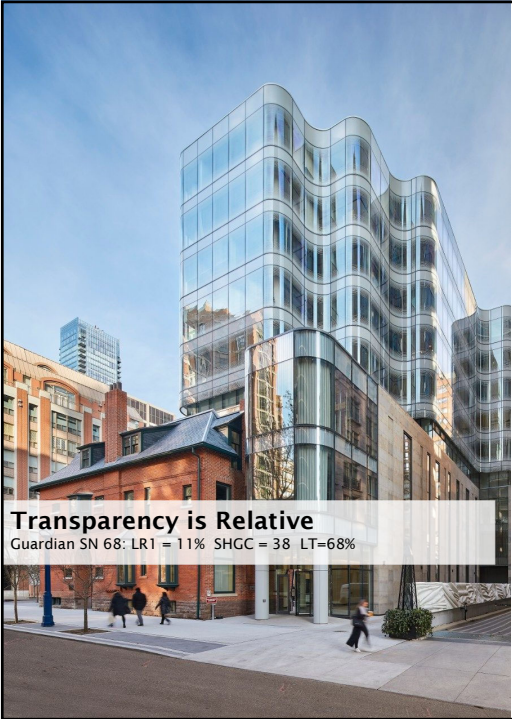
For 'Typical' Flat High-Performance Glazing in Windows and Curtain Walls

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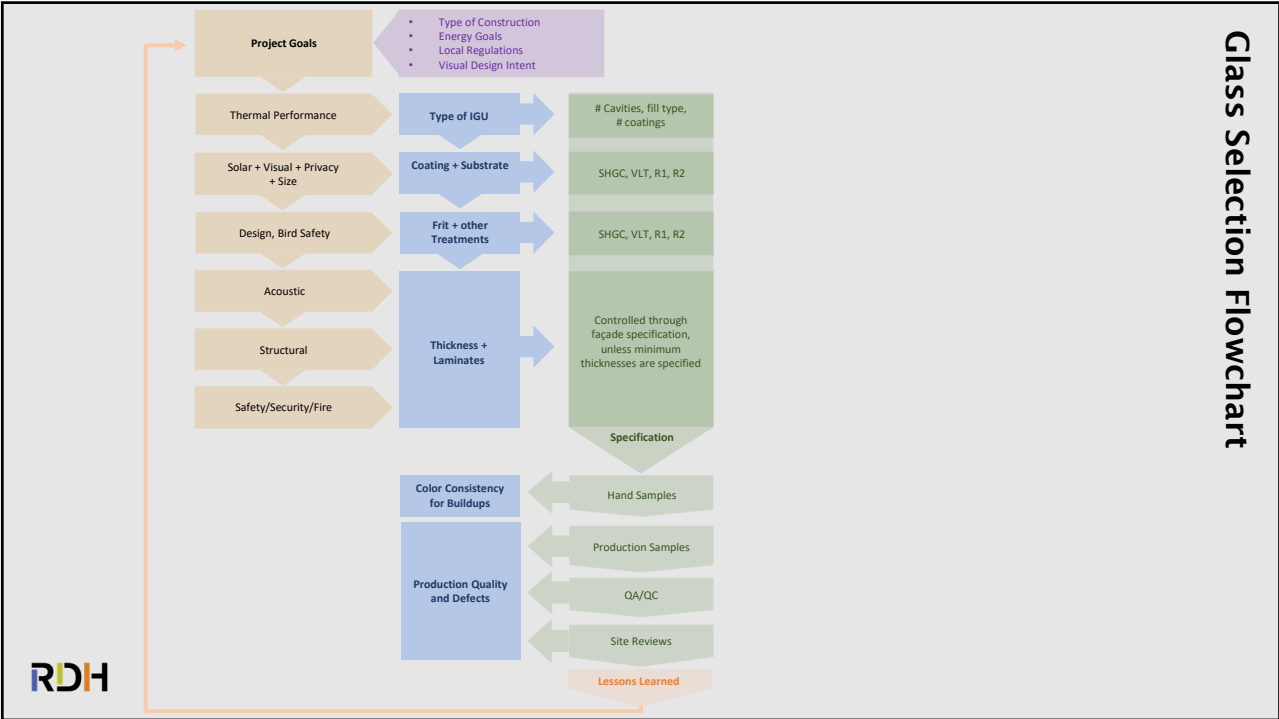


Glass Skyscraper,
Ludwig Mies van der Rohe
1921

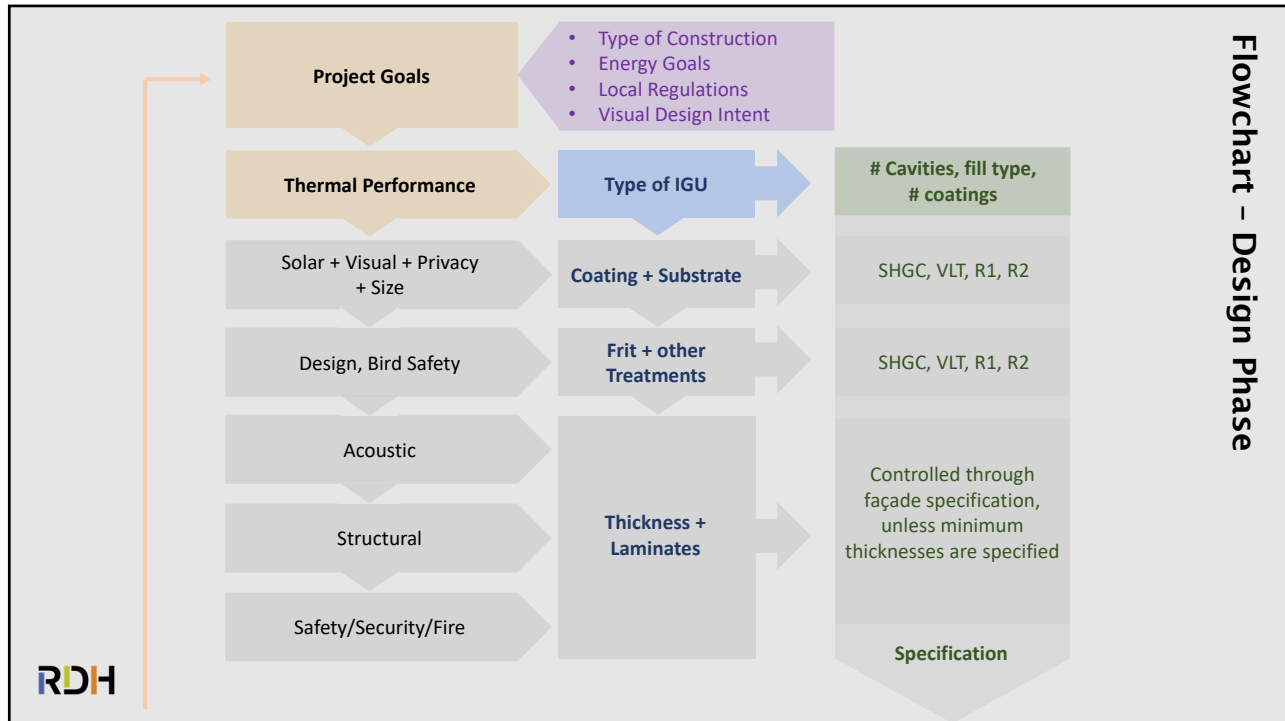
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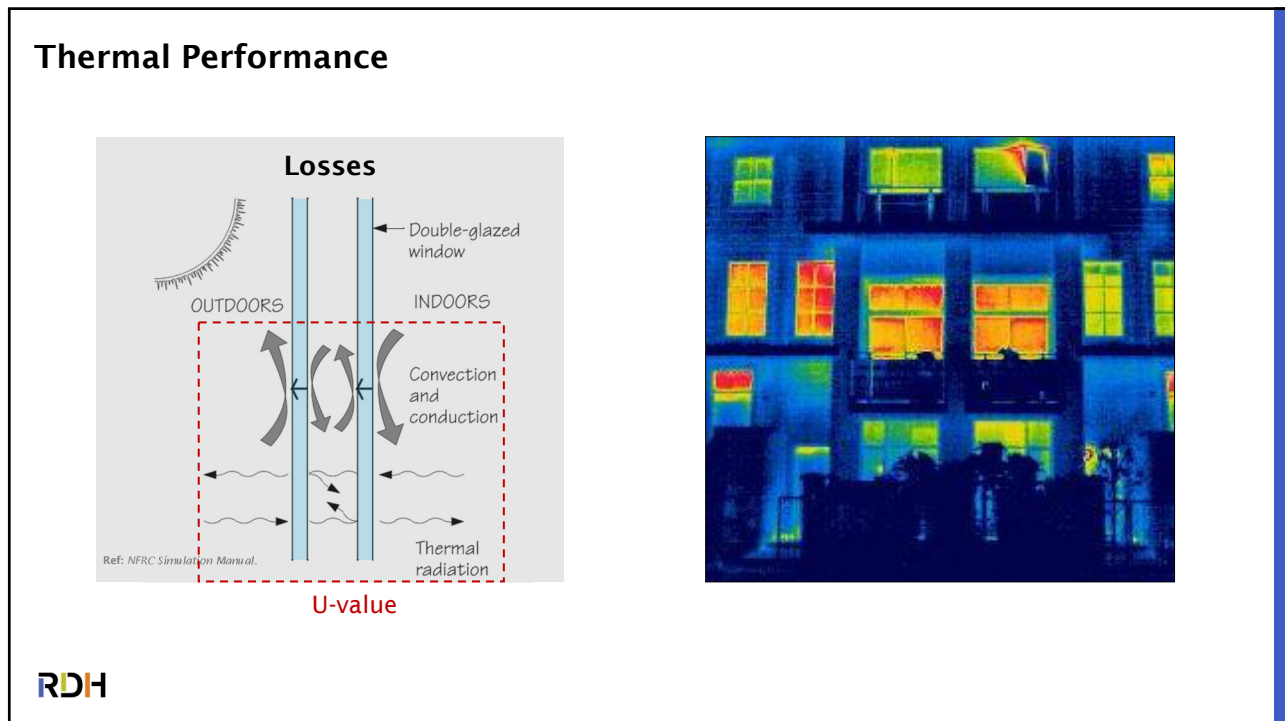
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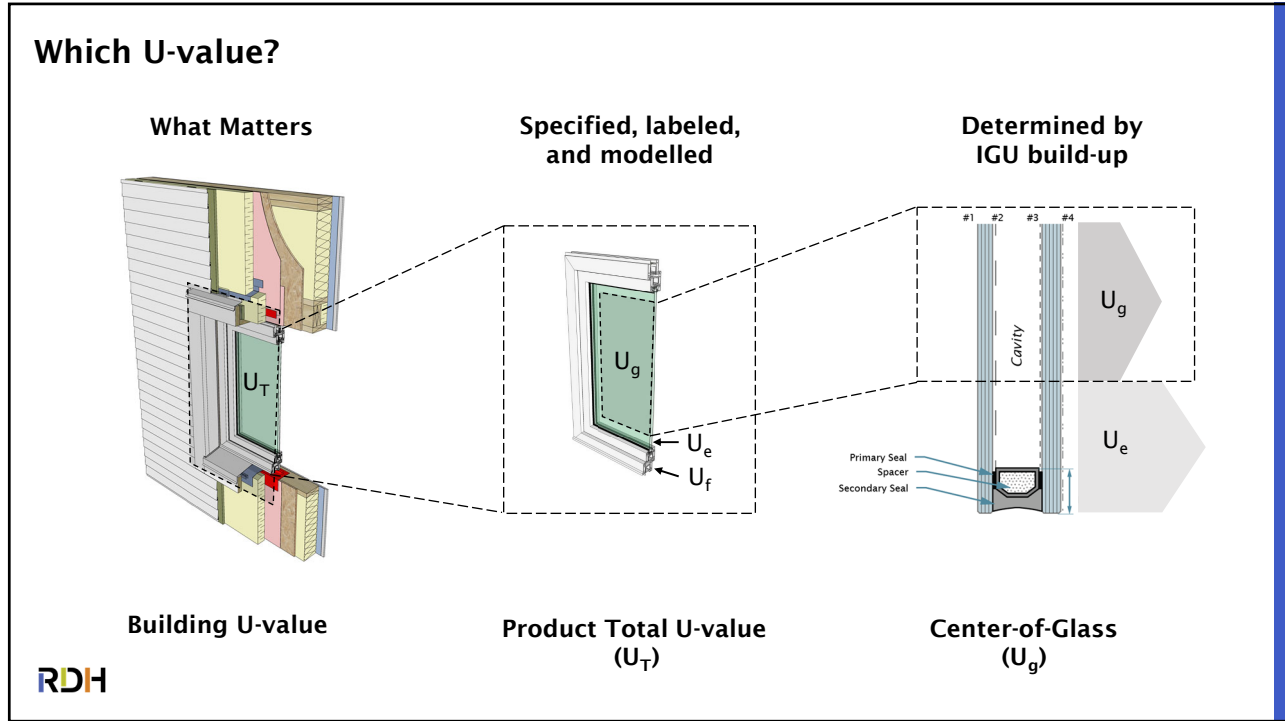
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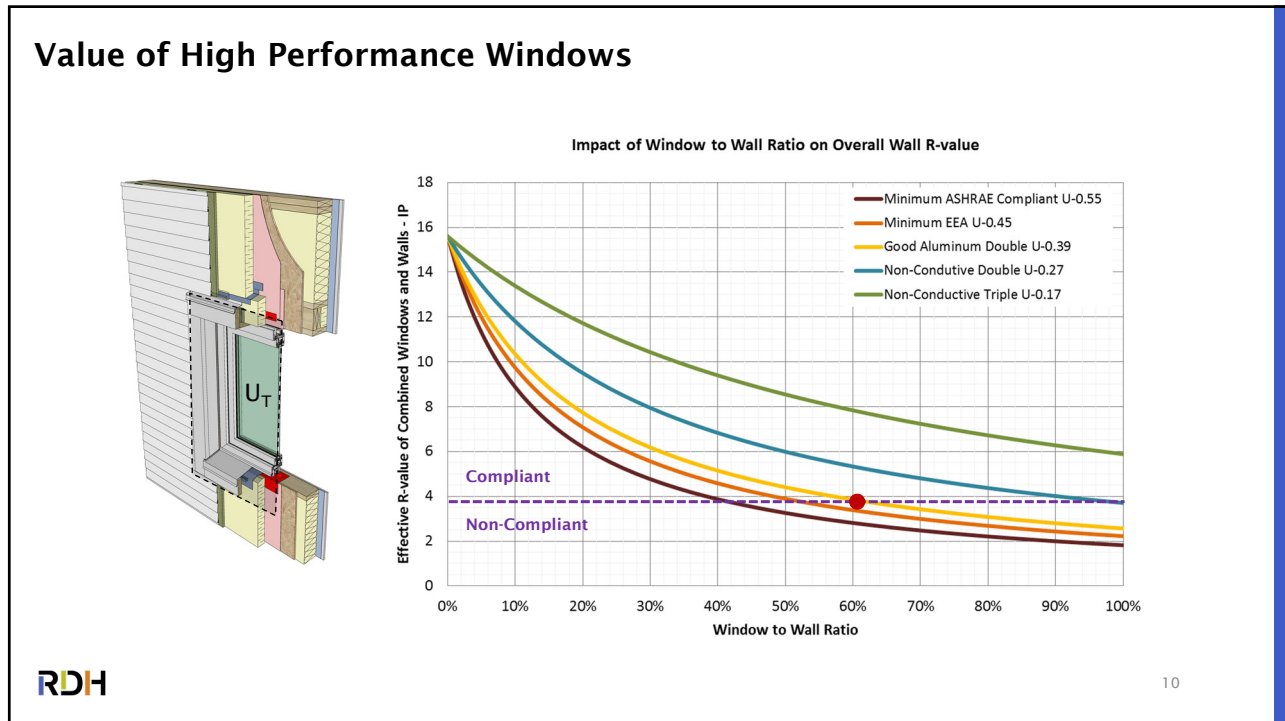
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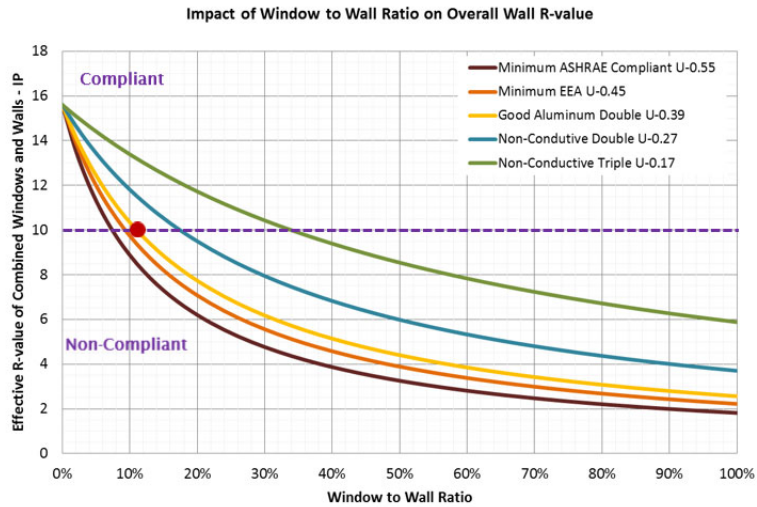
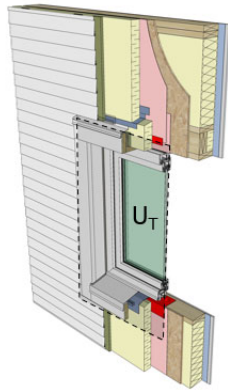


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Value of High Performance Windows

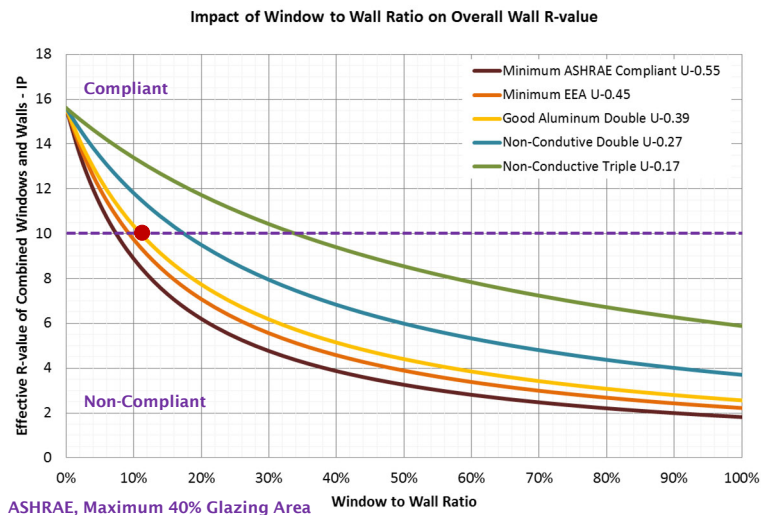


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Value of High Performance Windows

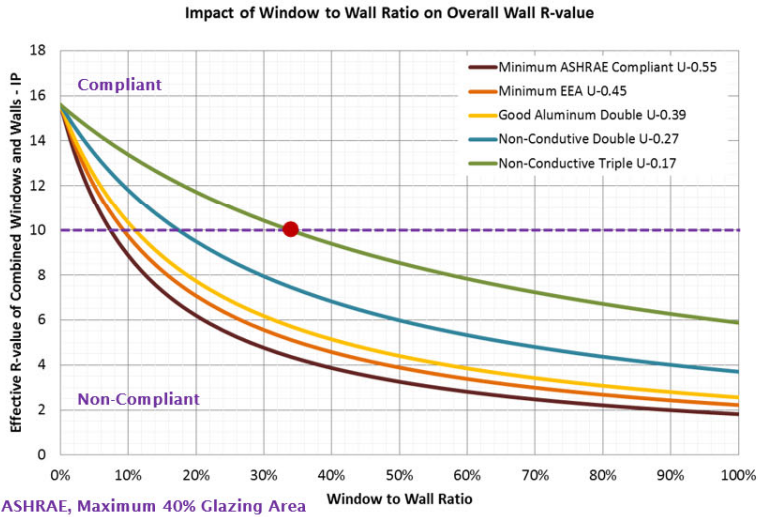


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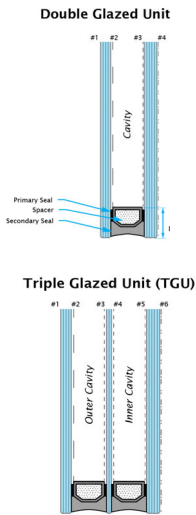
Value of High Performance Windows



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U-values



	Gas	Low-e	Ug (IP)	Ug (SI)
Double Glazing	Air	No coating	0.48	2.73
		1 low-e	0.30	1.70
		2 low-e	0.24	1.36
	Argon	No coating	0.45	2.56
		1 low-e	0.24	1.36
		2 low-e	0.20	1.14
Triple Glazing	Air	No coating	0.31	1.76
		One Coating	0.22	1.22
		Two Coatings	0.25	1.42
	Argon	Three Coatings	0.14	0.79
		No coating	0.29	1.65
		One Coating	0.18	1.02
		Two Coatings	0.12	0.70
		Three Coatings	0.10	0.57
		No coating	0.29	1.65

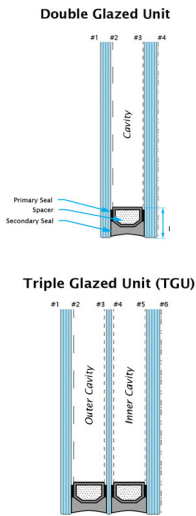
Watch-it: Coatings facing each other do not increase performance!

Note: For 1/2" (12.7 mm air spaces).



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U-values



		Gas	Low-e	Ug (IP)	Ug (SI)
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	Argon	No coating		0.29	1.65
		One Coating		0.18	1.02
		Two Coatings		0.12	0.70
		Three Coatings		0.10	0.57

Watch-it: Coatings facing each other do not increase performance!

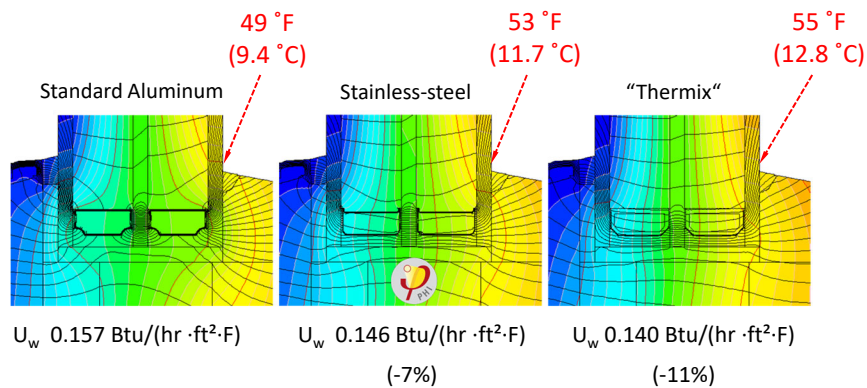
Note: For ½" (12.7 mm air spaces).



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Thermal performance of IGU edge spacers

Thermally improved spacers decrease the window U-value and raise internal surface temperature

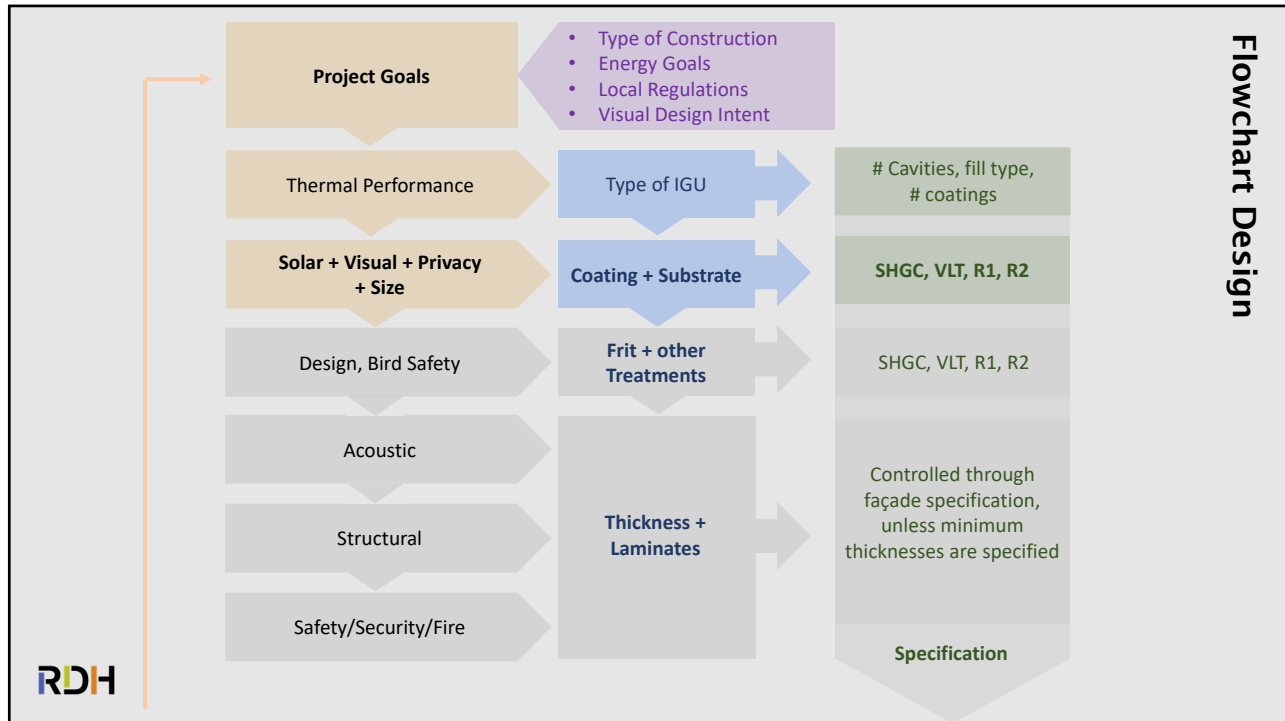


Calculation of the window U-value with:
 $U_g = 0.12 \text{ Btu}/(\text{hr} \cdot \text{ft}^2 \cdot \text{F})$
 $U_f = 0.13 \text{ Btu}/(\text{hr} \cdot \text{ft}^2 \cdot \text{F})$

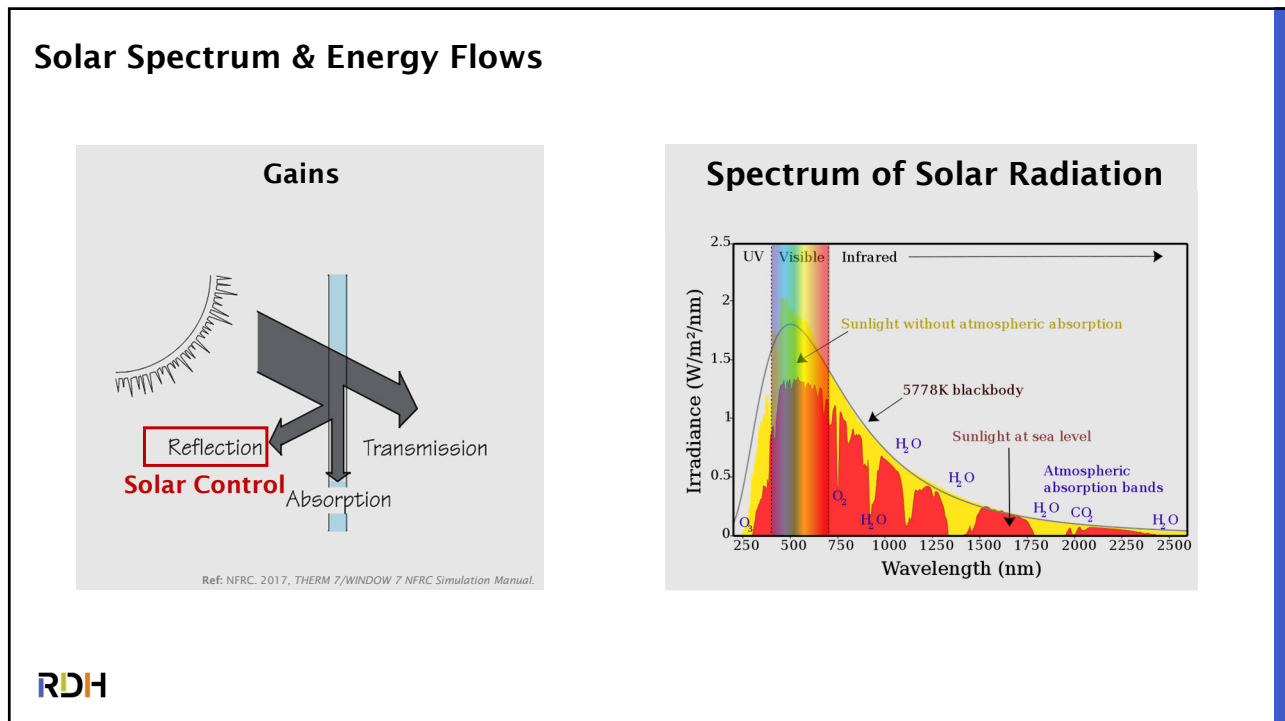
Source: PHI Berthold Kaufmann



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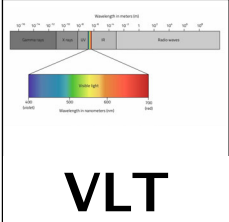


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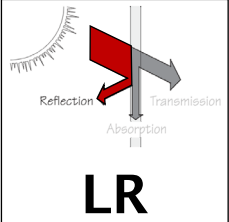
Solar Spectrum & Energy Flows

Visible Light Transmittance
The amount of **visible light transmitted** through the glass


Solar Heat Gain Coefficient
The amount of inward flowing **solar radiation** directly transmitted through and absorbed by the glass or IGU.



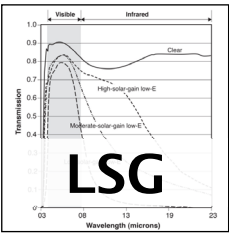
VLT



LR



SHGC



LSG

Reflectance (Outdoor)
The amount of **radiation** in the visible light or solar spectrum **reflected** to the exterior instead of being transmitted or absorbed

*Also consider indoor reflectance for nighttime conditions

Light to Solar Gain Ratio
Also known as the selectivity, the LSG is the **ratio** of VLT to SHGC.

- Low: $LSG < 1.5$
- Mid: $1.5 < LSG < 2.0$
- High: $2.0 < LSG$

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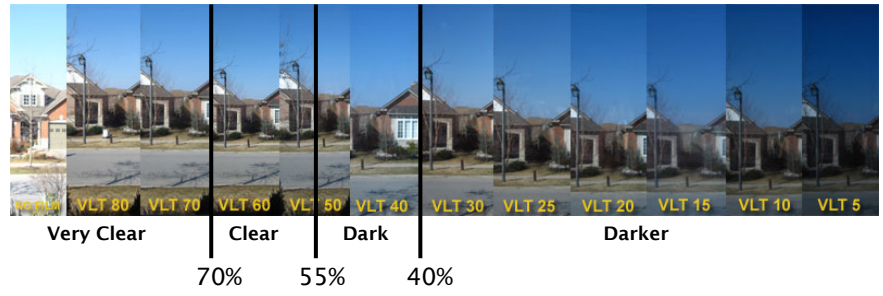
Visible Light Transmission

Low Daylight Autonomy

Typ. Office

Glare on a sunny day

Glare on a cloudy day



Very Clear Clear Dark Darker

70% 55% 40%

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Image Ref: <https://www.apexfilms.ca/about-visual-light-transmission-or-vlt>

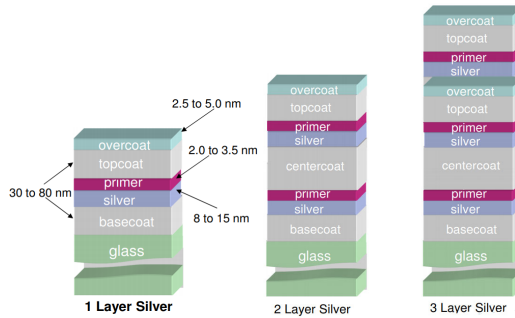
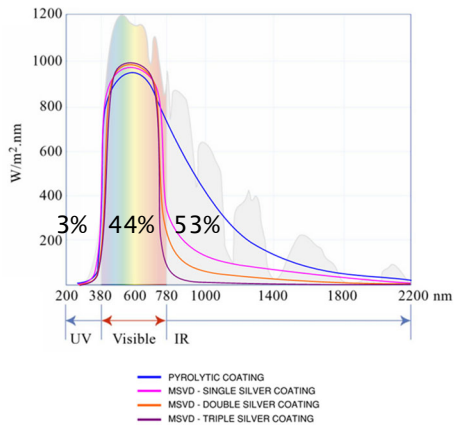
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Visible Light Transmittance

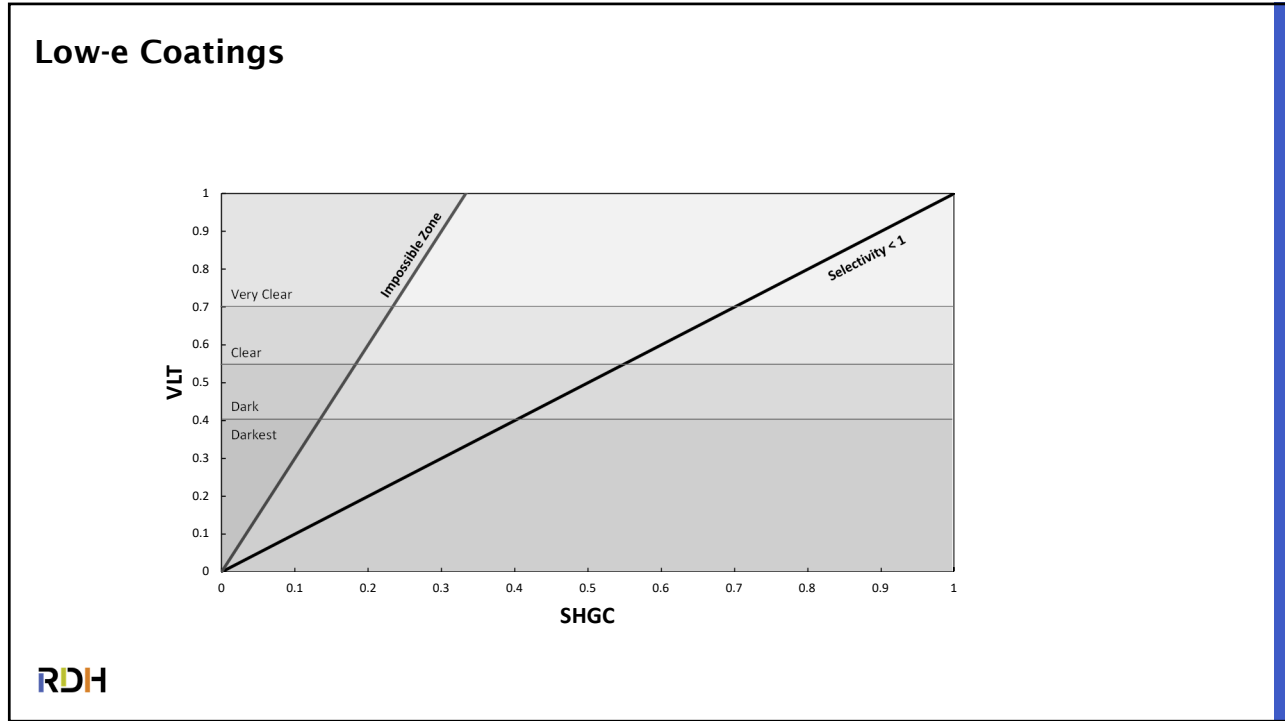


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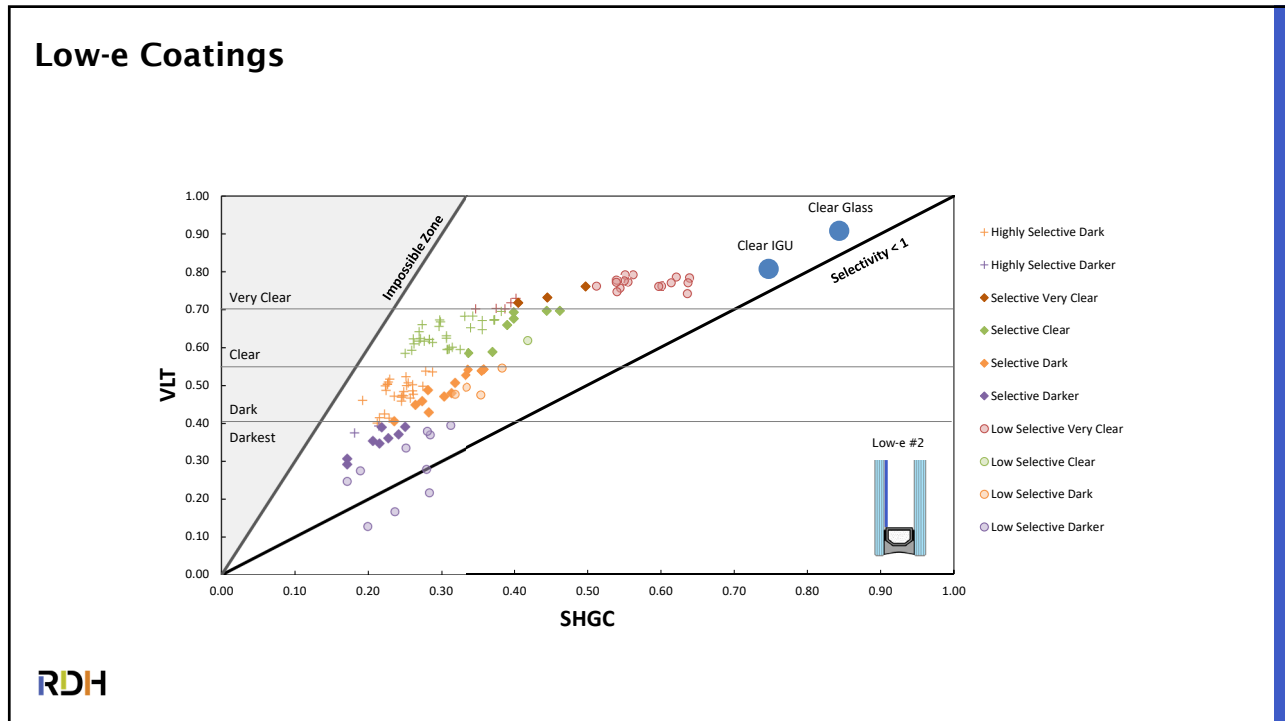
Solar Heat Gain Coefficient



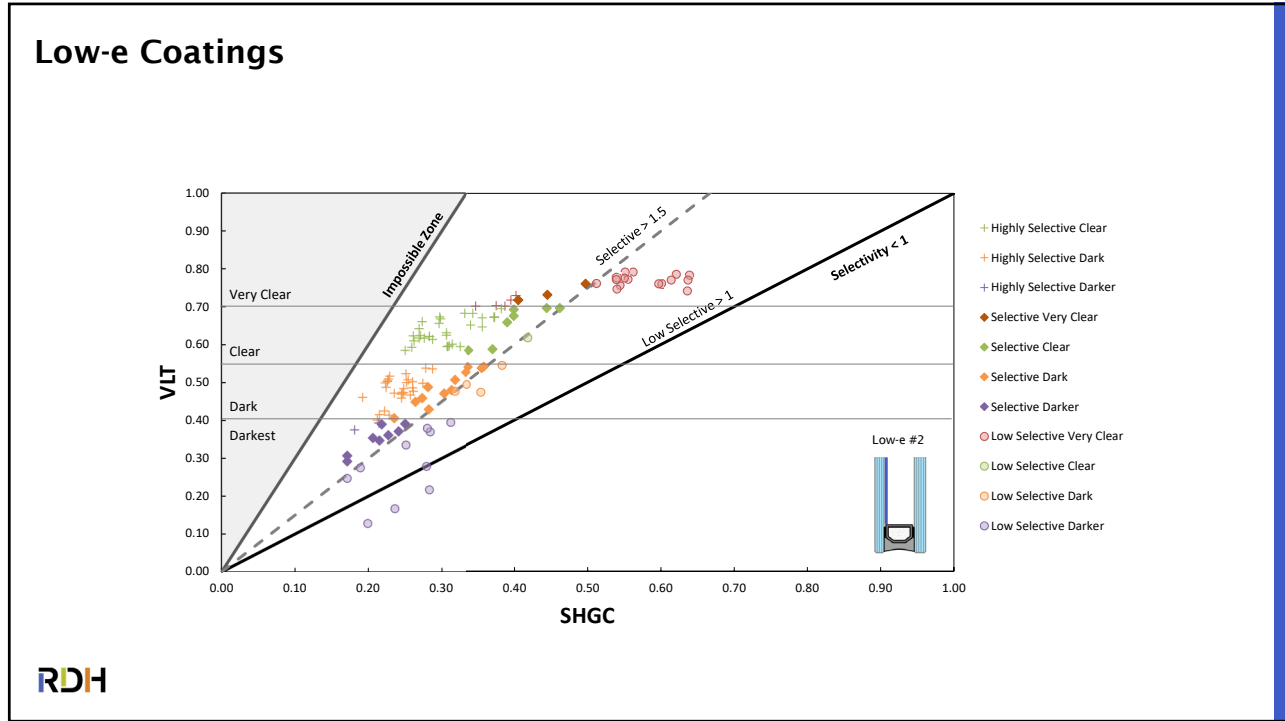
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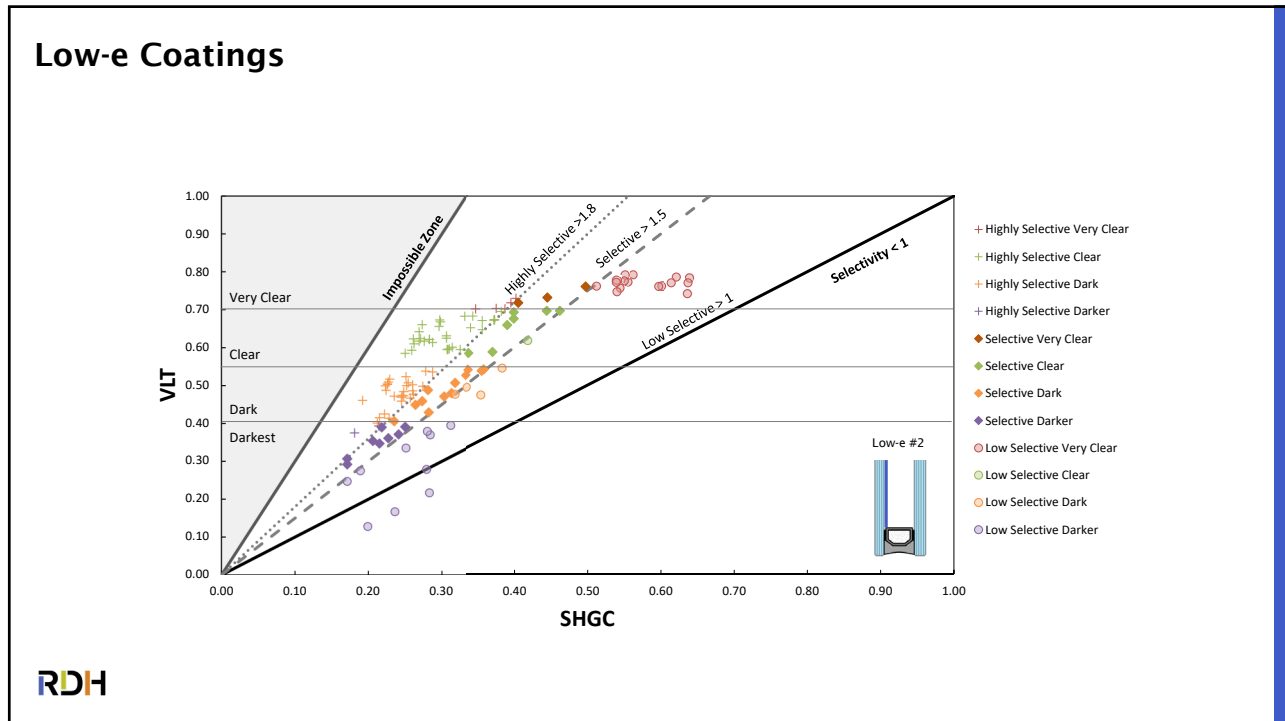
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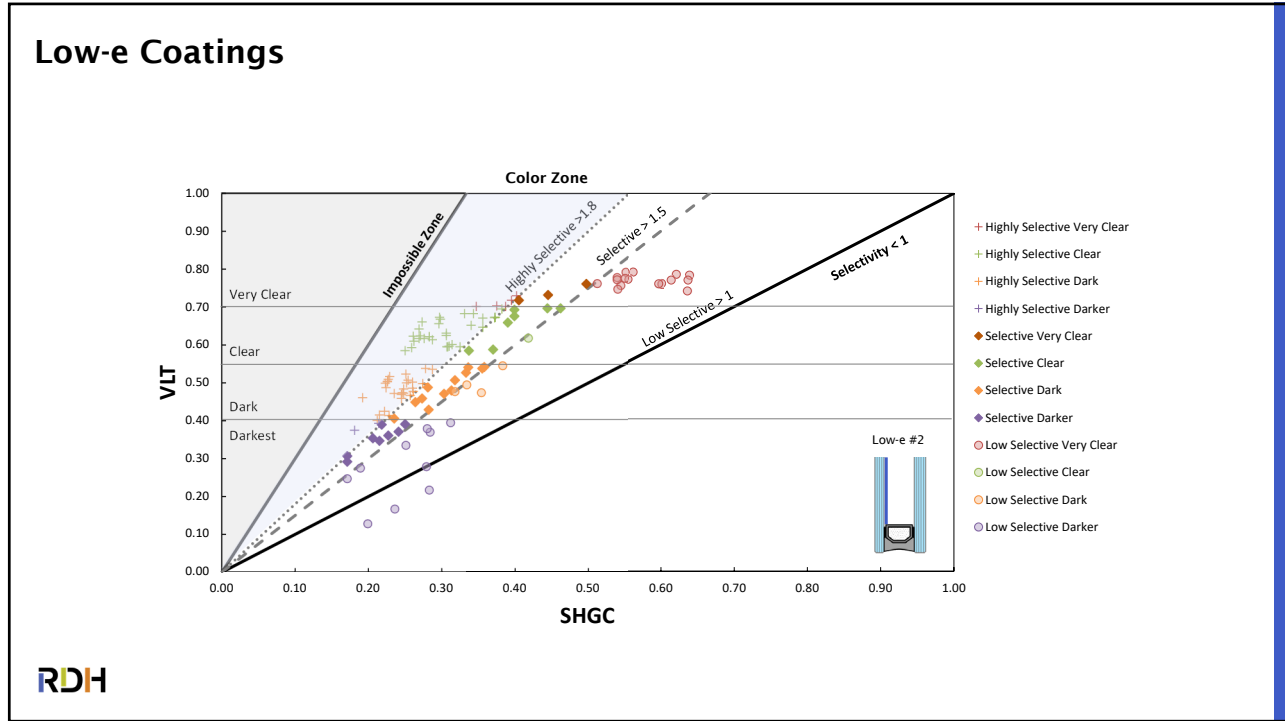
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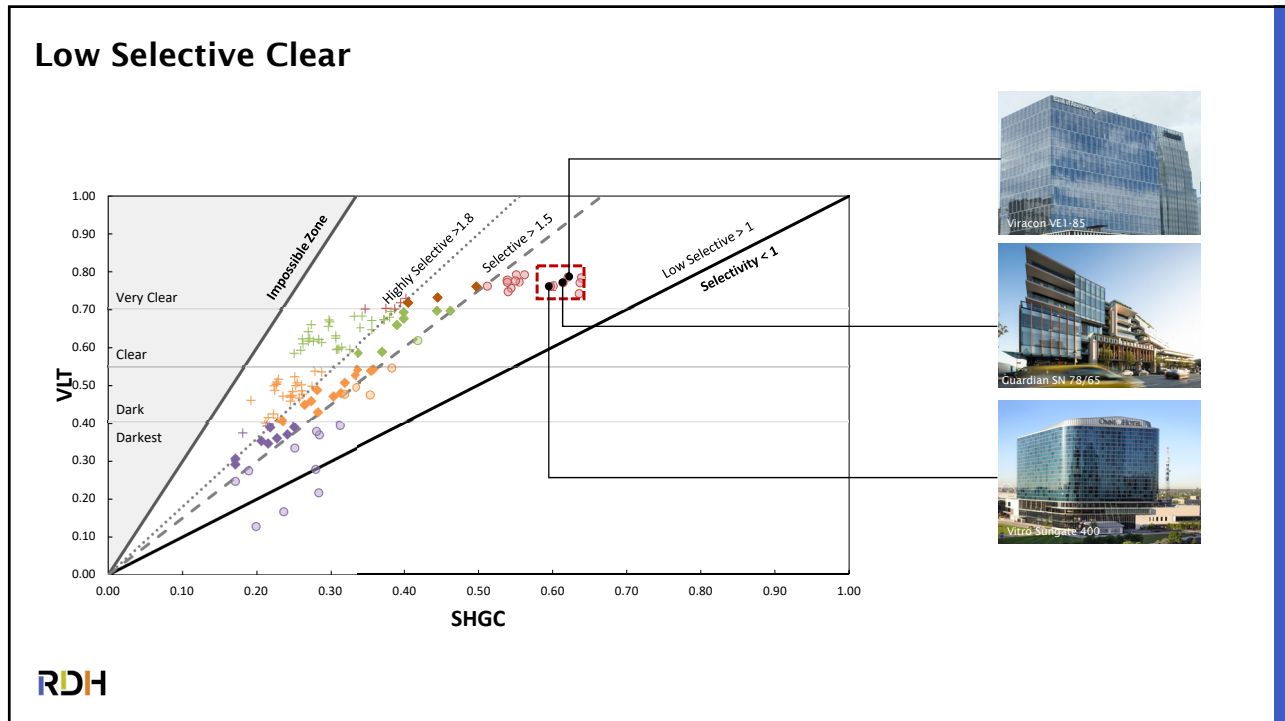
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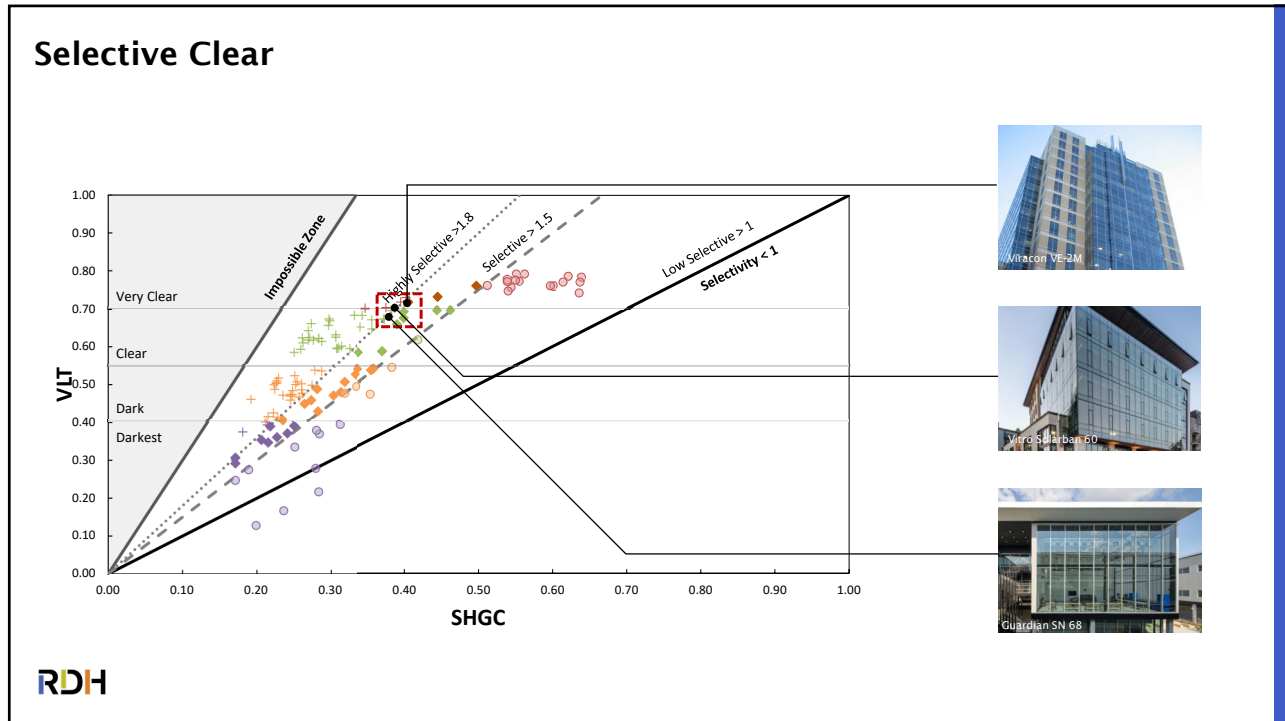
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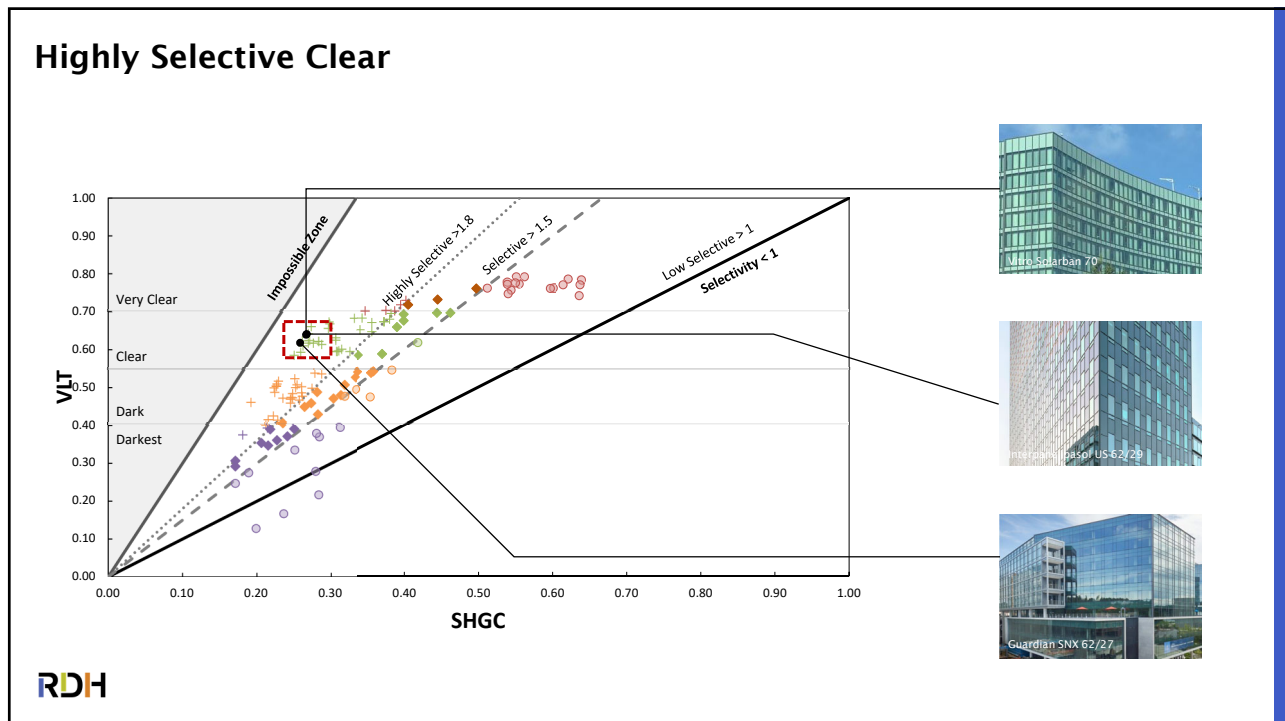
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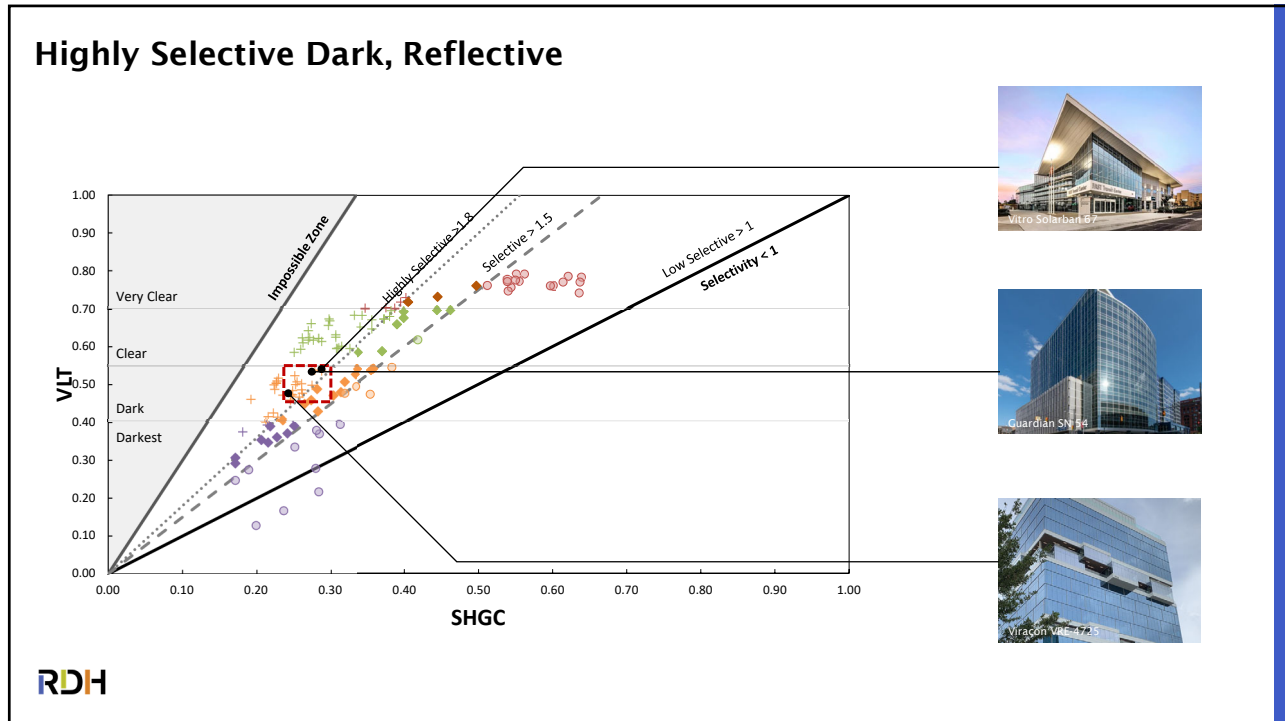
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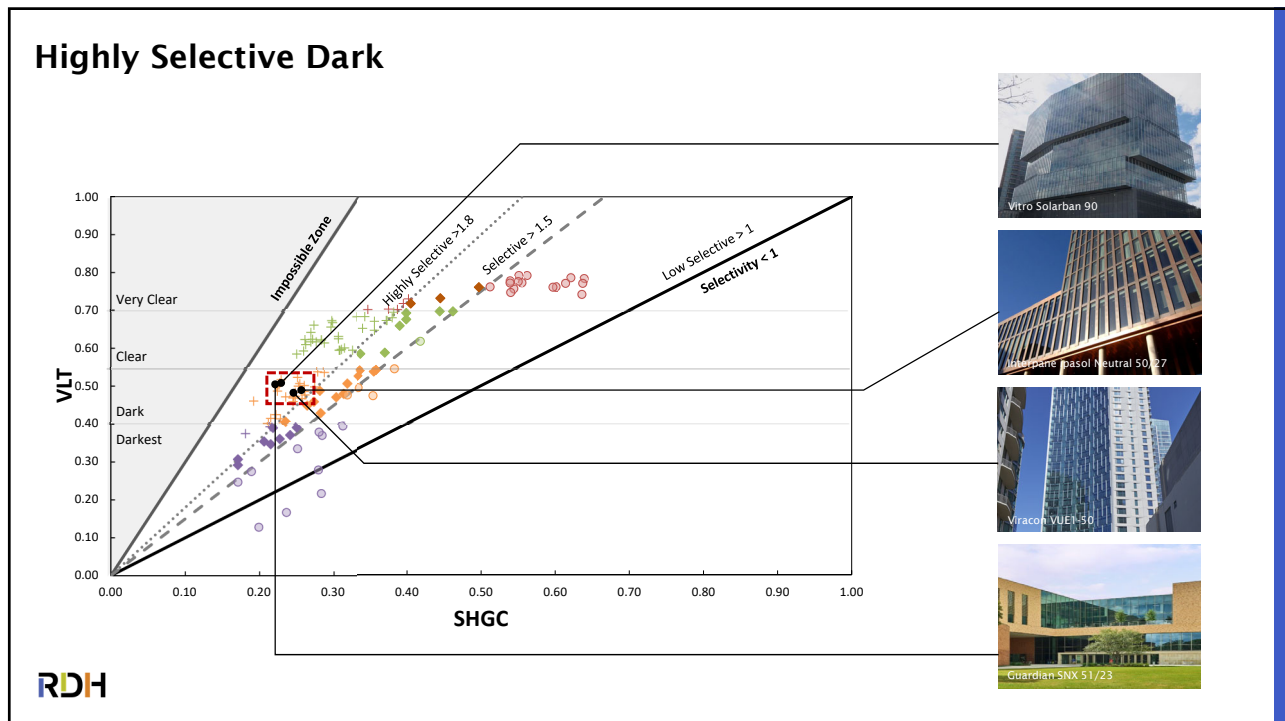
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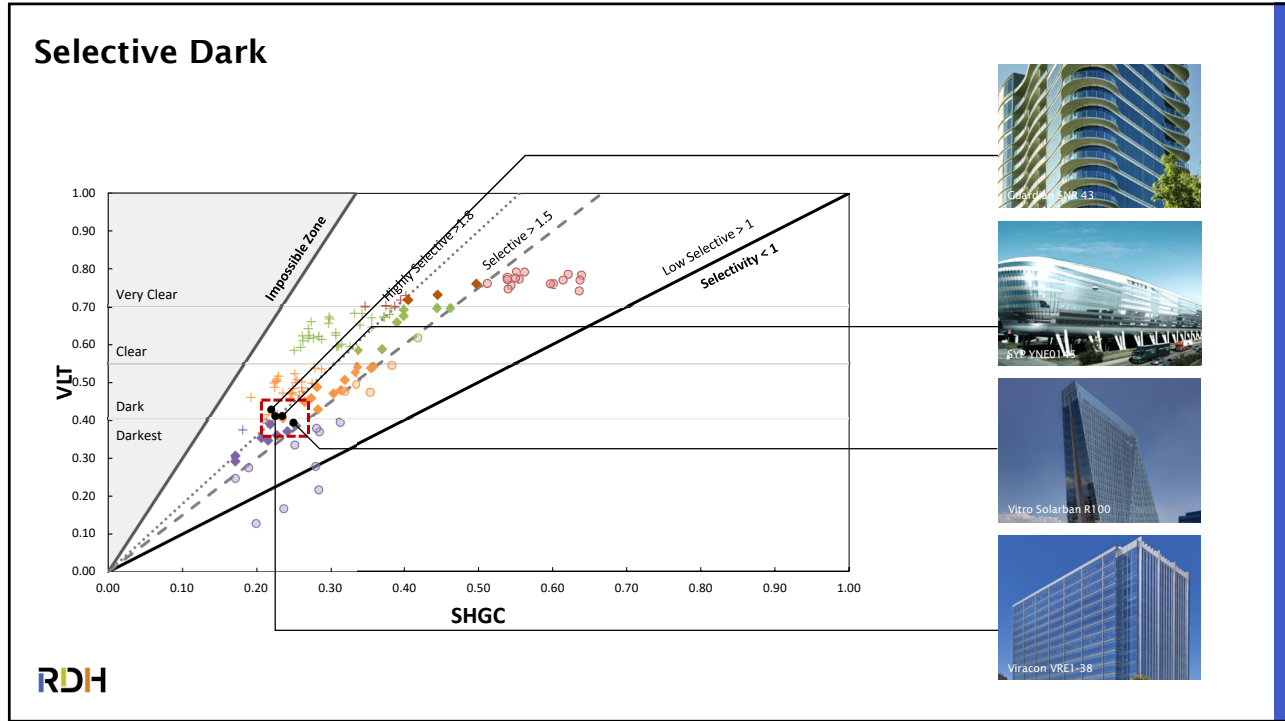
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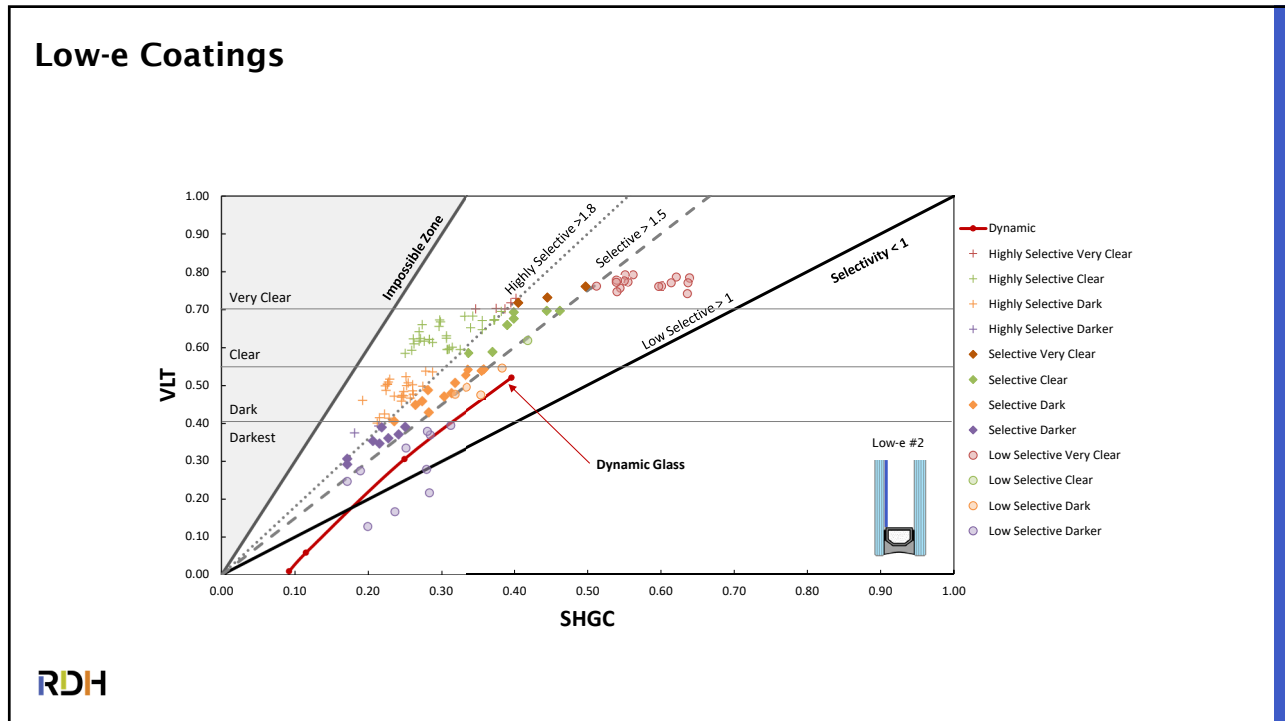
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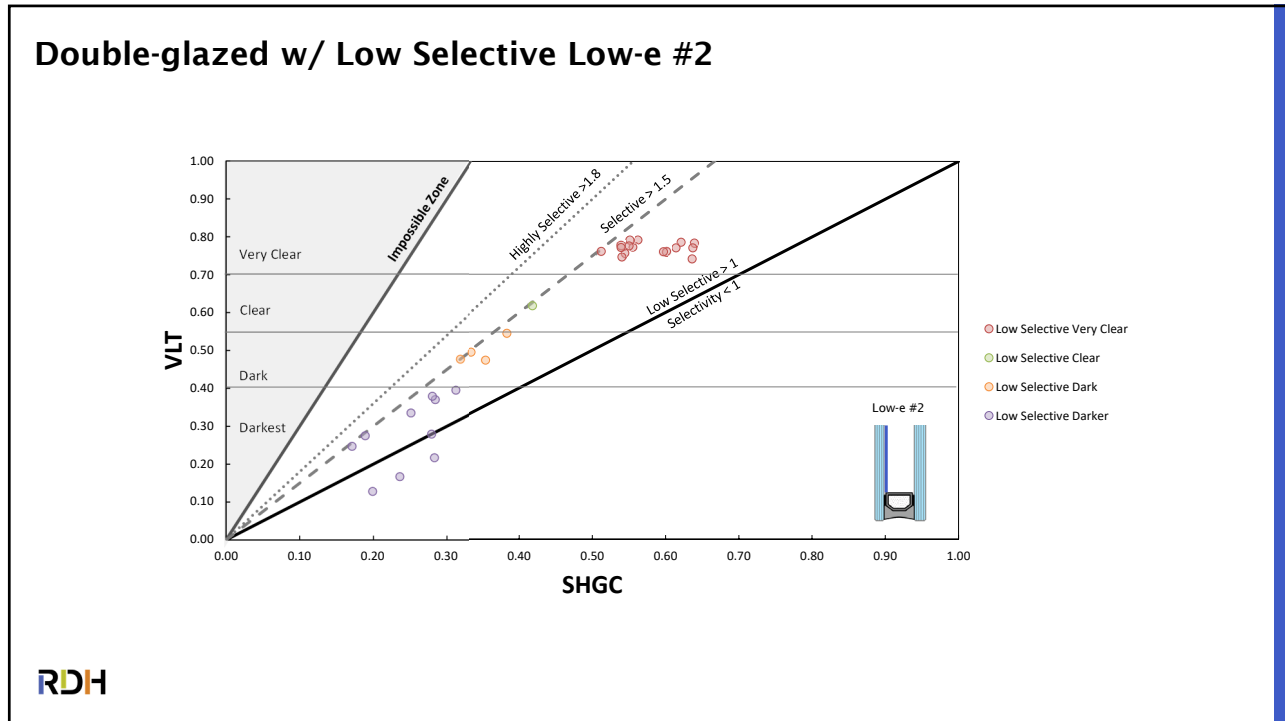
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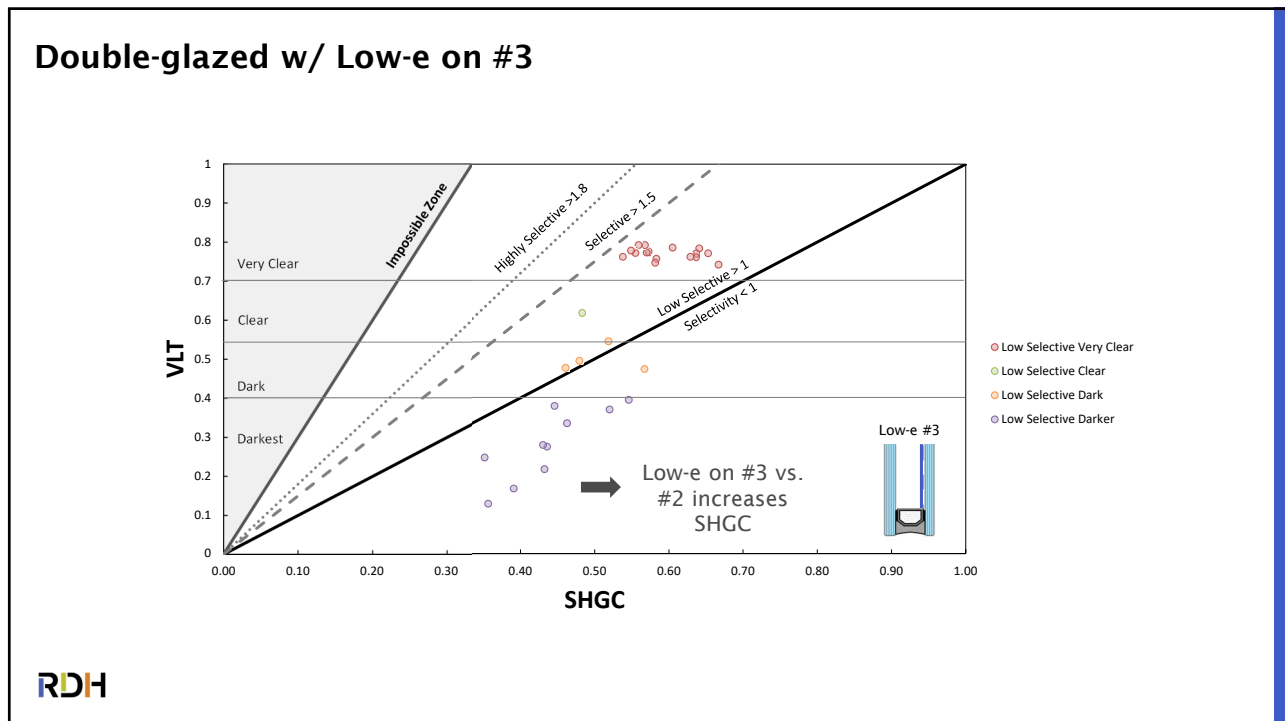
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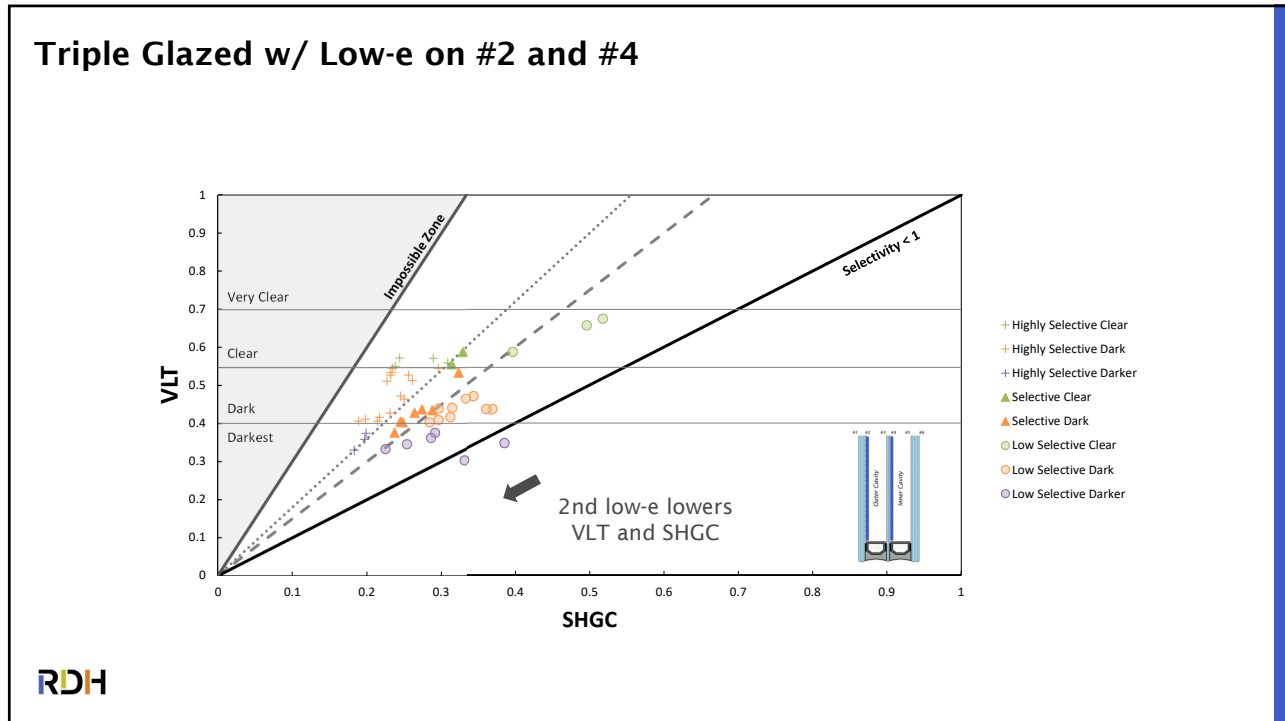
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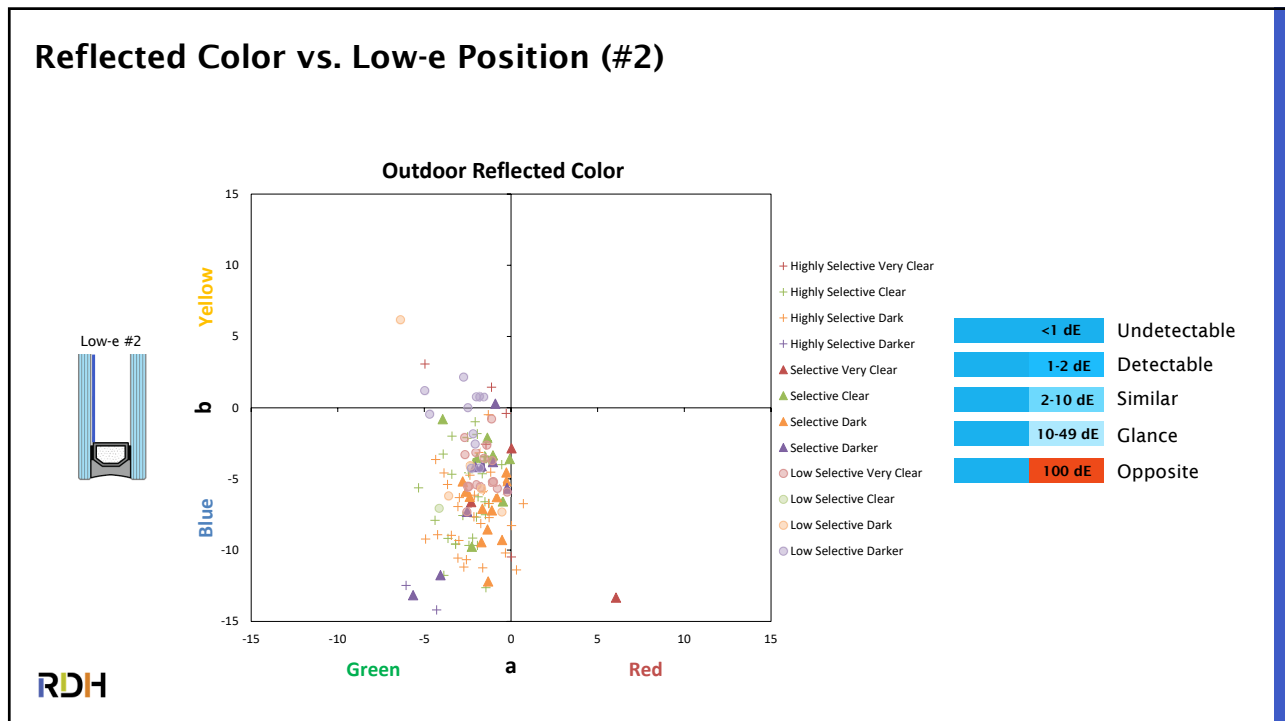
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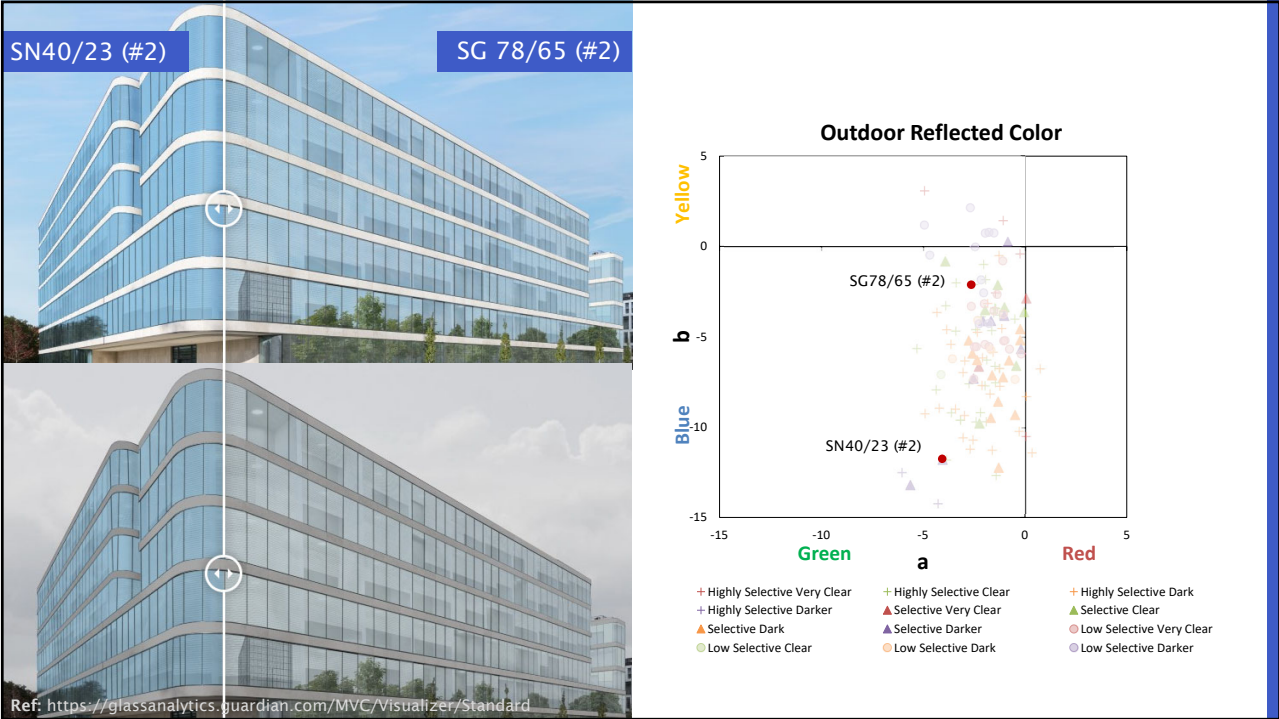
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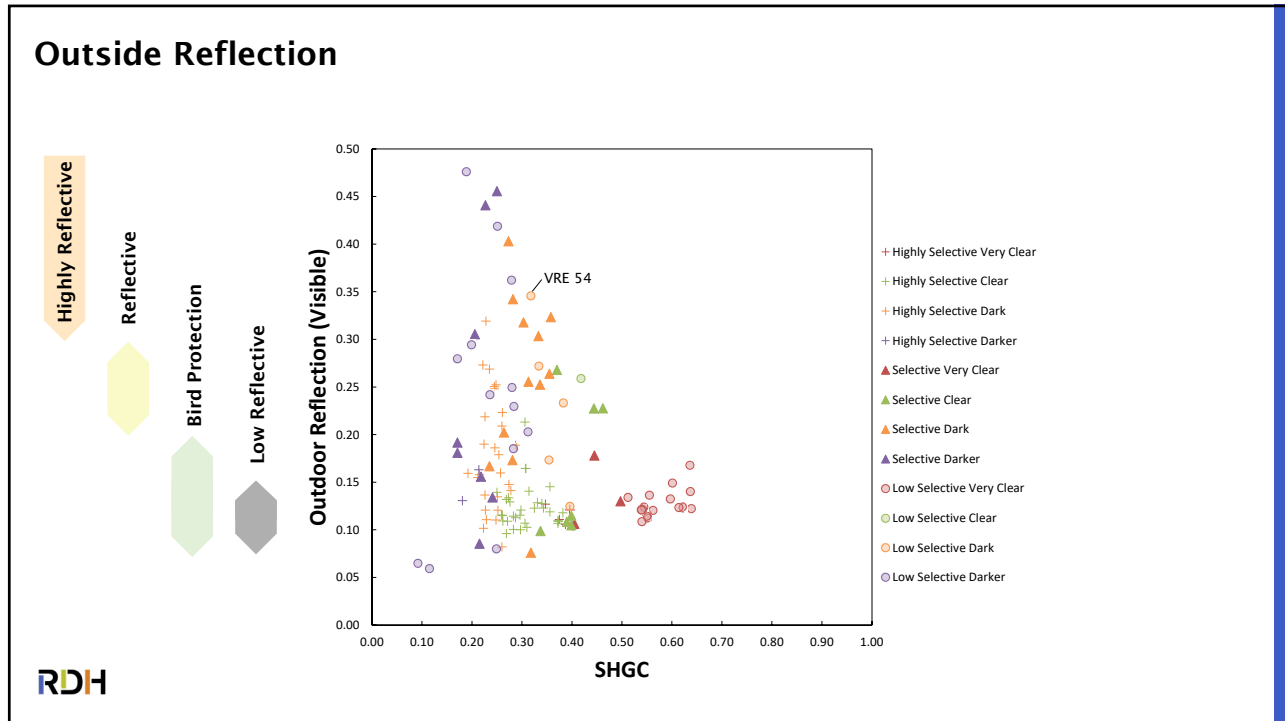
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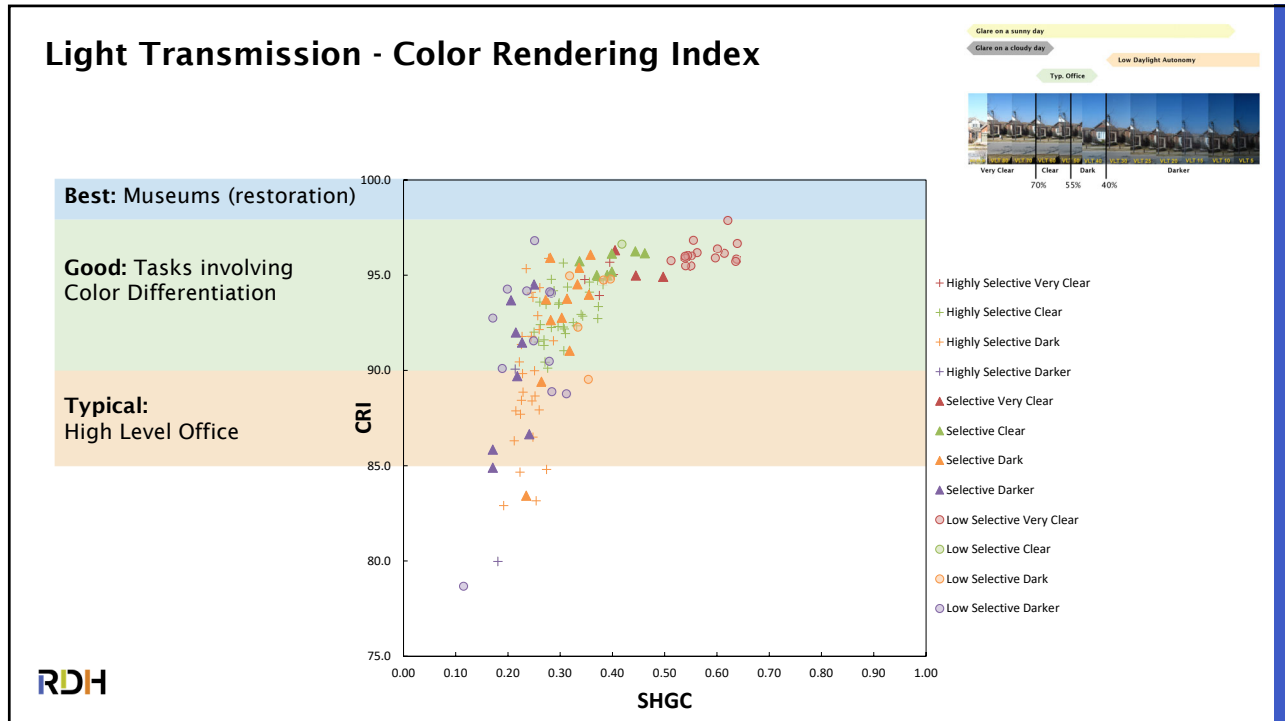
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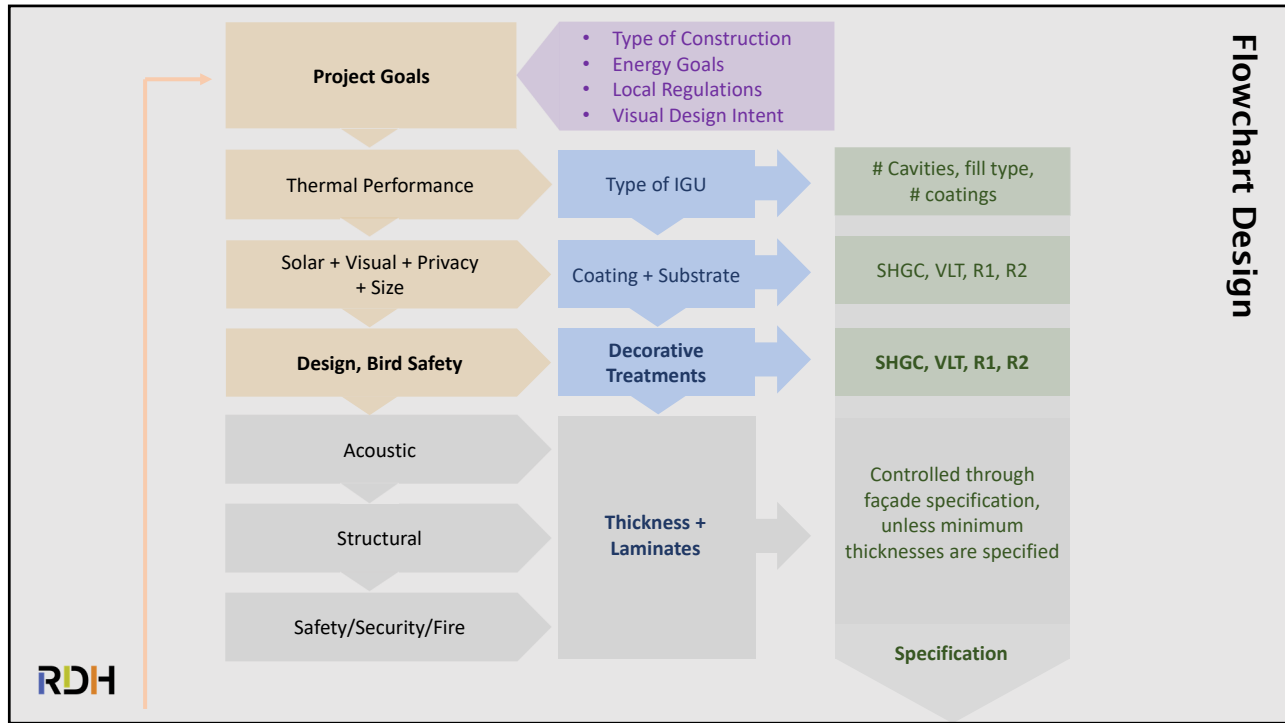
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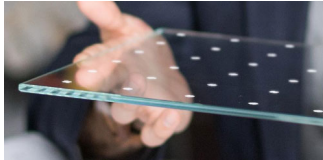




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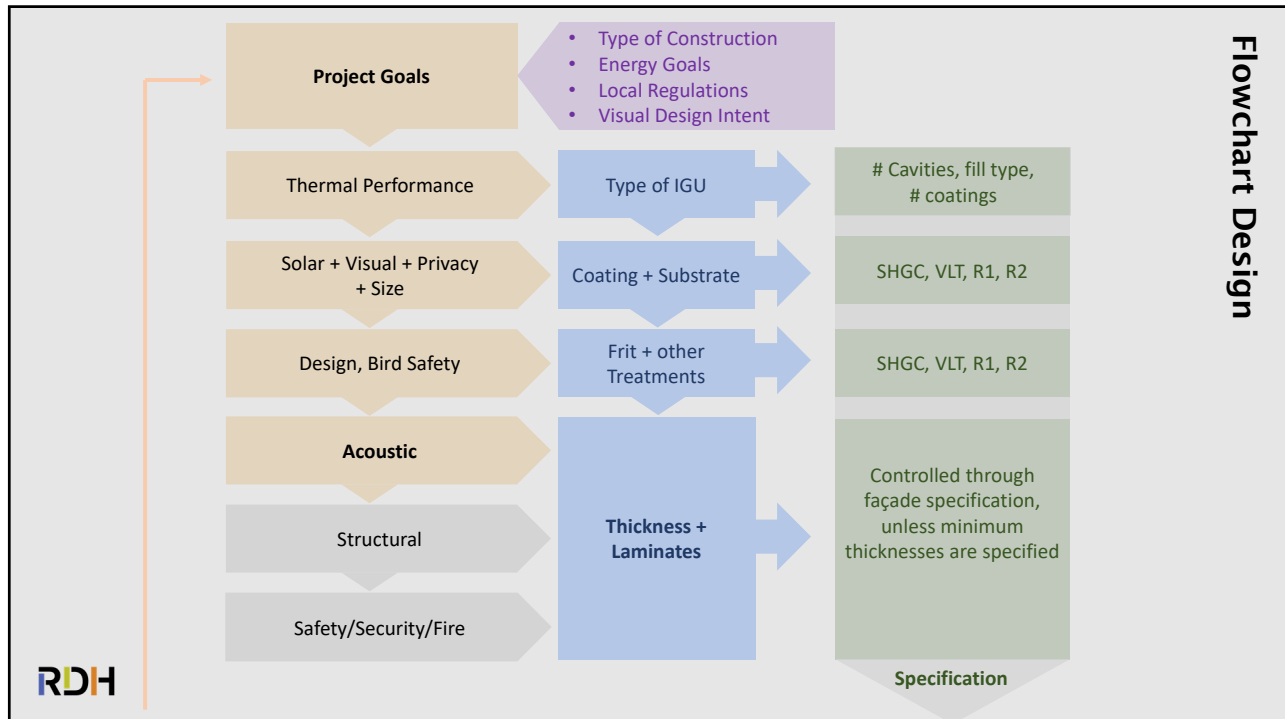
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Bird Safing Glazing Options

<p>Ceramic Frit</p>  <p>High Availability</p> <p>Low cost (~3-5 \$/ft²) for frit, more for the lamination</p> <p>Surface 2 typical</p> <p>Note: Not all suppliers allow frit and coating on same face, but laminated light instead</p>	<p>Acid Etch</p>  <p>Low Availability</p> <p>Medium cost (~15 \$/ft²)</p> <p>Surface 1 typical</p> <p>Note: Limited supply (Walker) may lead to extensive shipping and extended lead times</p>	<p>Transparent Coatings</p>  <p>Low Availability</p> <p>High cost (~20-40 \$/ft²)</p> <p>Surface 1 or 2, depending on product</p>
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See also <https://abcbirds.org/glass-collisions/products-database/>

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Acoustic

- Similar to light, sound is generated at varying wavelengths
- Glass will reduce the transmission of specific wavelengths into a space to higher or lower degrees
- Often reported/specified by a single point metric depending on the frequency range of interest:

STC - Sound Transmission Class
OITC - Outdoor/Indoor Transmission Class



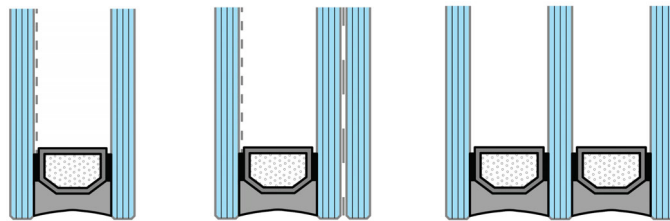
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Acoustic

The variables that impact sound transmission through glass include:

- Glass thickness
- Air space depth
- Gas fill
- Laminations
- Edge Damping
- Glass Size
- Construction (balanced vs. unbalanced)

Typical IGU Make-ups



STC	30 - 35	34 - 41	32 - 40
OITC	24 - 30	29 - 36	25 - 31



Triple glazing performs no better than double glazing if glass weight and total section depth remains the same



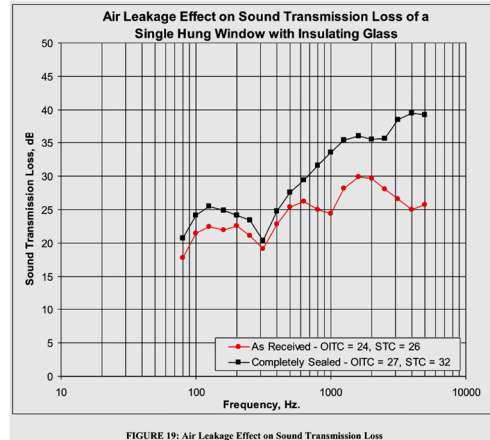
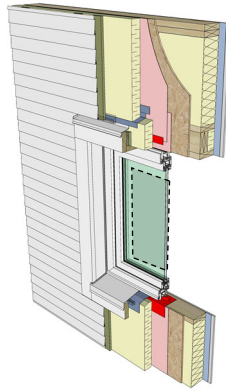
Ref: AAMA TIR-A1-2015. *Sound Control for Fenestration Products*
 Ref: Guardian Glass Analytics

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Acoustic

Additional variables that impact STC/OITC performance include:

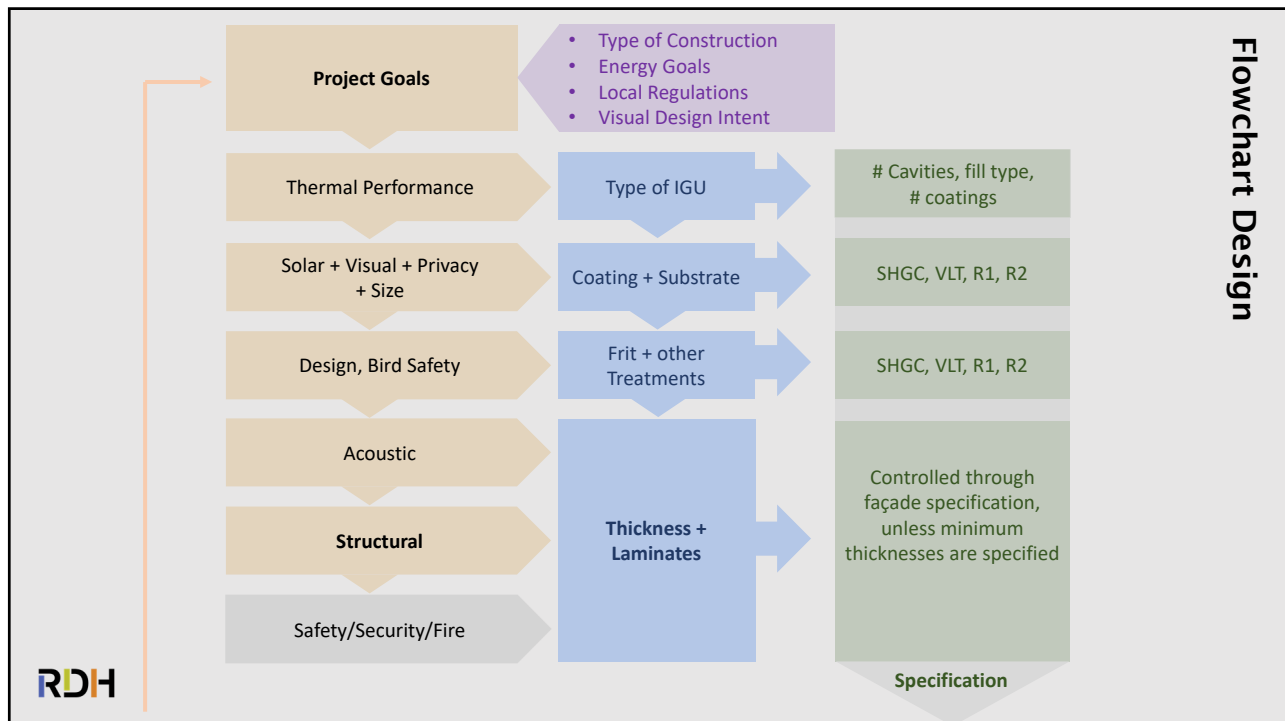
- Window frame
- Edge Seals
- Air leakage



Ref: AAMA TIR-A1-2015. Sound Control for Fenestration Products

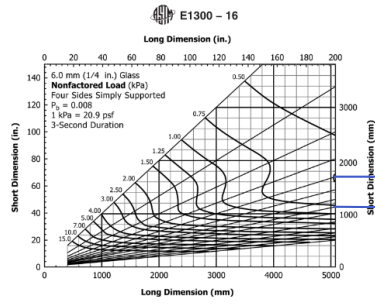


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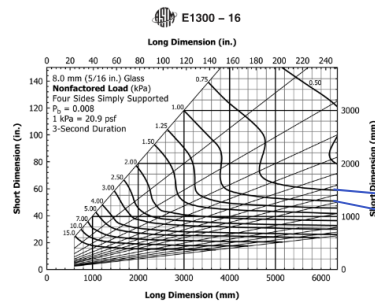
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Structural



Maximum Capacity of tall IGU

2x6mm 2x1/4"
 1.0kPa @ 1.60m 20psf @ 61"
 1.5kPa @ 1.10m 30psf @ 42"
 (pressure for short dimension)

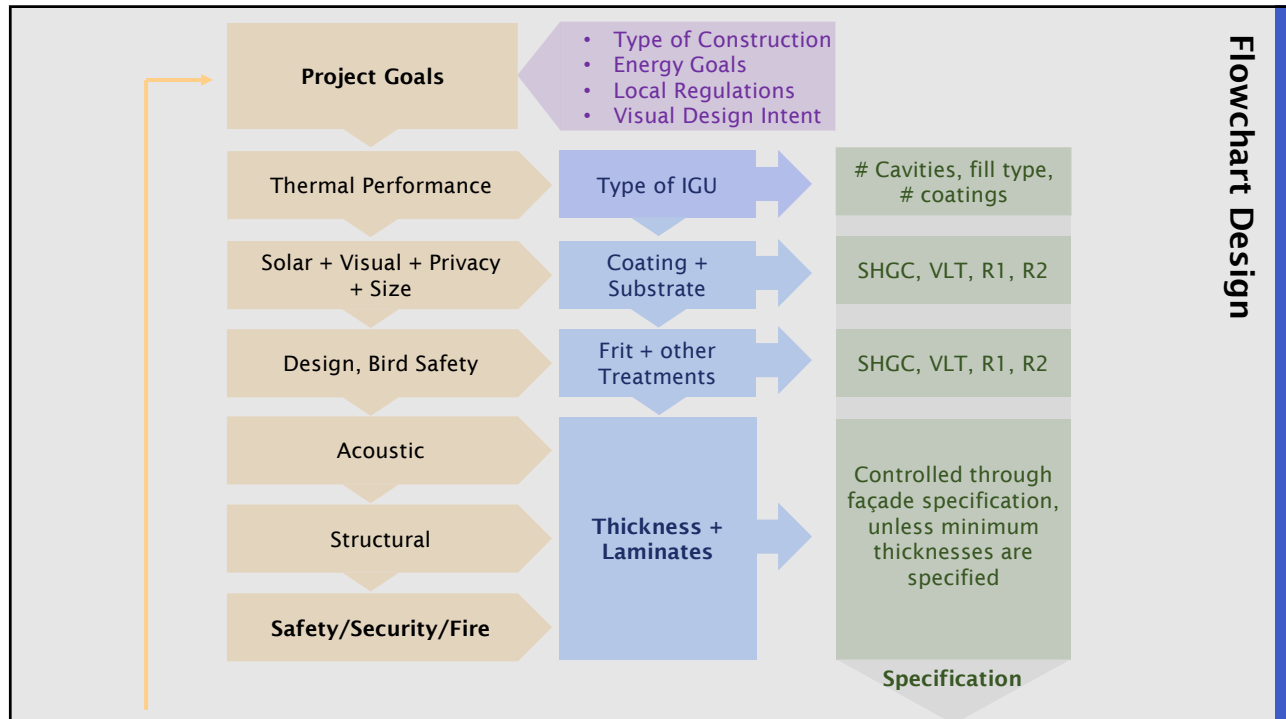


Maximum Capacity of tall IGU

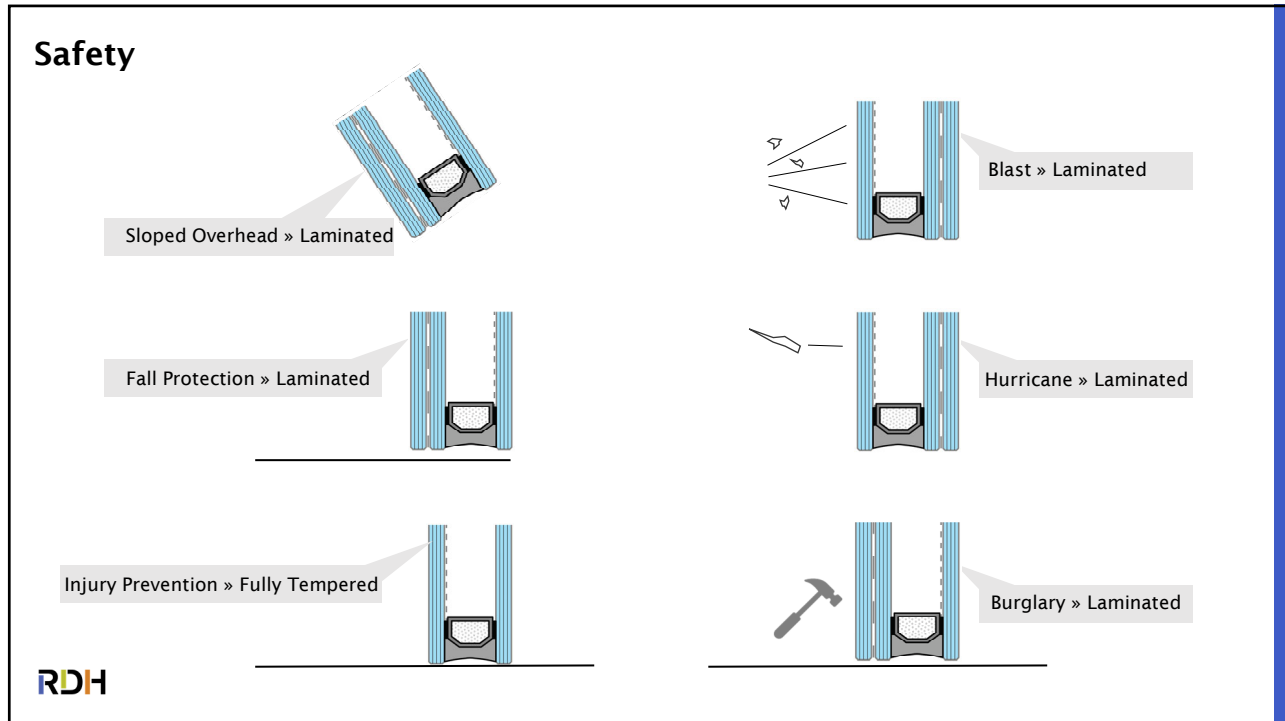
2x8mm 2x5/16"
 1.5kPa @ 1.50m 30psf @ 60"
 2.0kPa @ 1.20m 40psf @ 50"
 (pressure for short dimension)



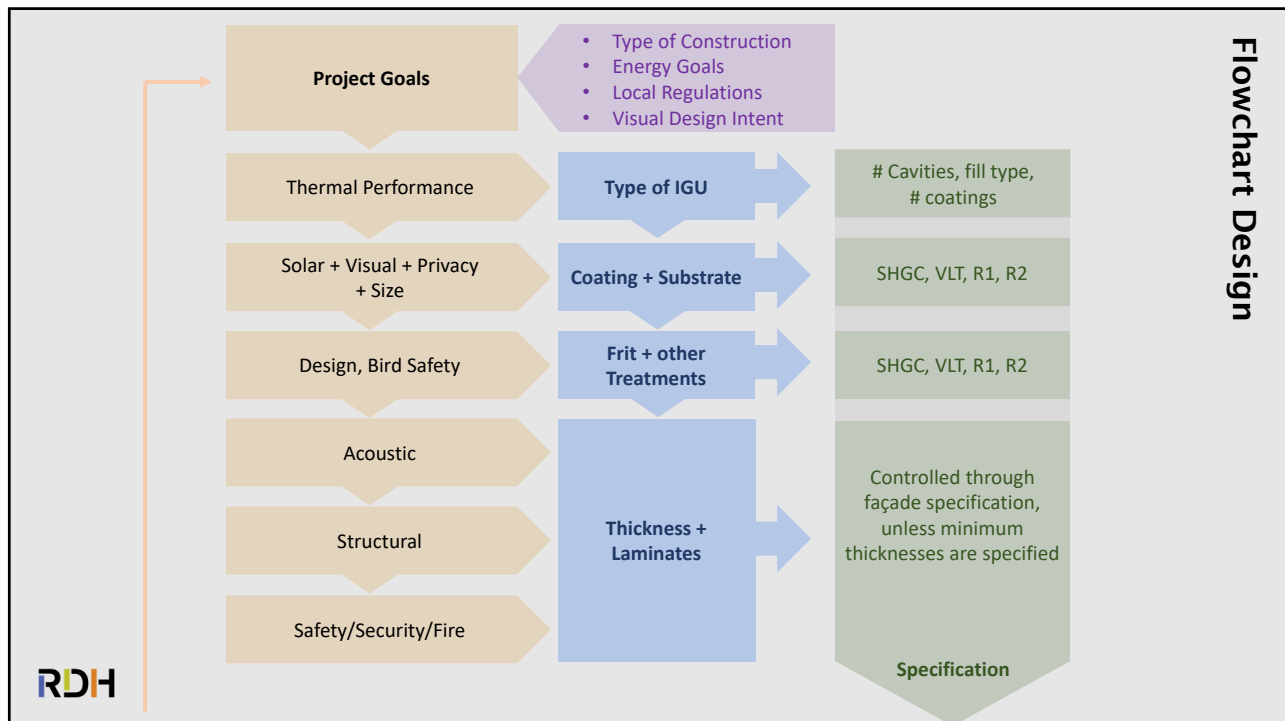
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Specification

Glass	Clear	Monolithic	Annealed
	Ultra Clear	Laminated - PVB	Heat Strengthened
Cavity Gas	Architectural	Laminated - SGP	Fully Tempered
	Air		Chem. Tempered
Spacer	Argon		
	Krypton		
Coating	Aluminum		
	Stainless Steel		
Position	Foam		
	Thermoplastic & Hybrid	"Warm Edge Spacer"	
FRP	FRP		
	Passive low-e	-----	
Coating	Selective low-e	- - - - -	
	Interior low-e	
Position	#2 (Low SHGC)		
	#3 (High SHGC)		
Position	#2 & #4 (Low SHGC)		
	#3 & #5 (High SHGC)		
Position	+ #4 or #6 (Interior low-e)		

Double Glazed Unit (DGU)

Triple Glazed Unit (TGU)

> 5,000,000 Combinations

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Specification

- Document design choices
- Identify unique applications
- Performance based specification allows for competitive tenders

Glass Type Name	GL-I, GL-I*	GL-I-A, GL-I-A*	GL-II, GL-II*	GL-II-A, GL-II-A*	GL-IV
Location	LOBBY + ATRIUM WALL GLASS	LOBBY + ATRIUM WALL GLASS - ACOUSTIC	ICU Glass	ACU Glass	BALUSTRADE GLASS
Sketch					
Glass Color	Low Iron	Low Iron	Float	Float	Low Iron
Glass Strength	HS, FT where Safety Glass	HS, FT where Safety Glass	Varies (see Glass Build-Up below)	Varies (see Glass Build-Up below)	Heat Strengthened
Glass Panel Shape	Flat	Flat	Flat	Flat	Flat
Coating (Basis of Design)	TBC	TBC	TBC	TBC	N/A
Glass Build-Up (Indicative)	Overall Unit Thickness: 1"	Overall Unit Thickness: 1"	Overall Unit Thickness: 1"	Overall Unit Thickness: 1"	Overall Unit Thickness: 1"
	Outdoor Lite: 1/4" Interspace Content: Air Indoor Lite: 1/4"	Outdoor Lite: 1/4" Interspace Content: Air Indoor Lite: 1/8"+1/8"	Outdoor Lite: 1/4" Interspace Content: Air Indoor Lite: 1/4"	Outdoor Lite: 1/4" Interspace Content: Air Indoor Lite: 1/8"+1/8"	Lite: 3/8" / SCP / 3/8"
Spacer Type	Aluminum	Aluminum	Aluminum	Aluminum	N/A
Interlayer Type	N/A	PVB	N/A	PVB	Ionoplast
Interlayer Color	N/A	Clear	N/A	Clear	Clear
Interlayer Thickness	N/A	0.03" (0.76mm)	N/A	0.03" (0.76mm)	0.035" (0.9mm)
Ceramic Coating Color	* Mid Grey Frit	* with Etch Frit	* with Etch Frit	* with Etch Frit	Etch Frit
Ceramic Coating Pattern	* with Bird Protection Pattern, tbc	* with Bird Protection Pattern, tbc	* with Bird Protection Pattern, tbc	* with Bird Protection Pattern, tbc	Bird Protection Pattern, tbc
U-Value (W/m²K) (Basis of Design)	<1.4	<1.4	<1.4	<1.4	N/A
Solar Heat Gain Coefficient (SHGC) (Basis of Design)	<28%	<28%	<28%	<28%	<28%
Visual Light Transmittance (%) (Basis of Design)	>65%	>65%	>65%	>65%	>65%
Outdoor Visible Reflectance (Basis of Design)	<12%	<12%	<12%	<12%	<5%

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(c) RDH Building Science except as noted

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Visual Mock-ups

Recommendations for effective VMUs

- Full sized
- Multiple lighting conditions & viewing angles
- Natural daylight
- Representative backdrop color
 - White backdrop will emphasize transmitted color
 - Dark backdrop will emphasize reflected color



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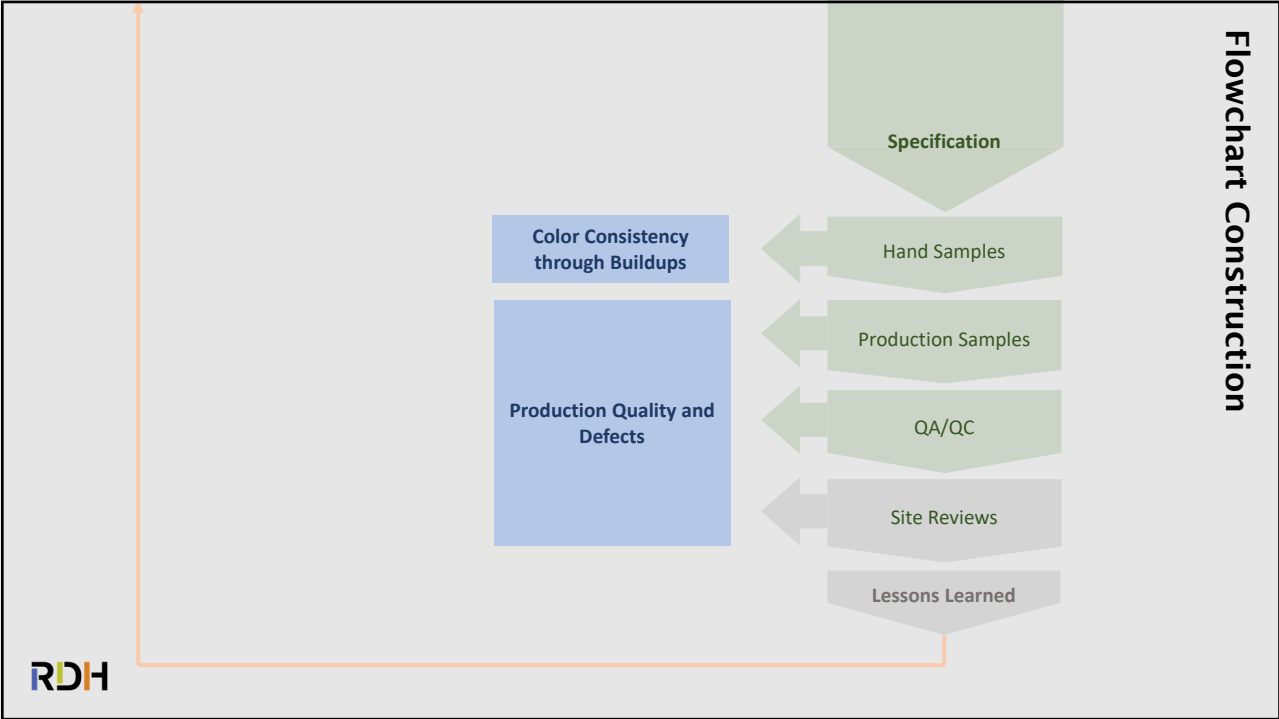
Visual Mock-ups

Recommendations for effective VMUs

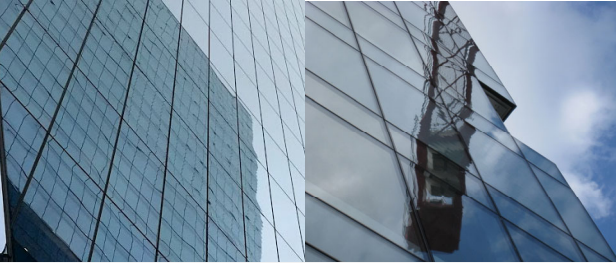
- Full sized
- Multiple lighting conditions & viewing angles
- Natural daylight
- Representative backdrop color
 - White backdrop will emphasize transmitted color
 - Dark backdrop will emphasize reflected color



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Rollerwave, Edge Dip, Warp

Rollerwave direction: horizontal (parallel to width)
(as long as width is < 126", and height is > 13")

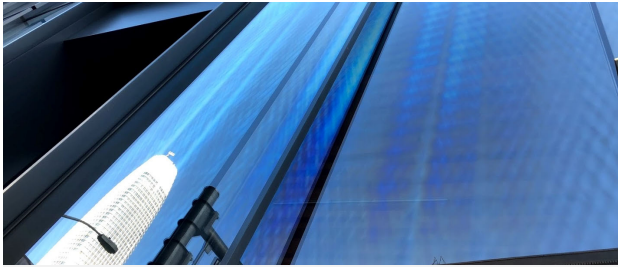
Rollerwave: 0.15 mm/300 mm (0.006") for glass thickness ≤ 6 mm (1/4")
0.08 mm/300 mm (0.003") for glass thickness ≥ 8 mm (5/16")

Edge dip: 0.25 mm/300 mm (0.008") for glass thickness ≤ 6 mm (1/4")
0.20 mm/300 mm (0.01") for glass thickness ≥ 8 mm (5/16")


General warp: 0.2% of edge length (2 mm/1000 mm)


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Anisotropy



ANISOTROPY - NAKED EYE



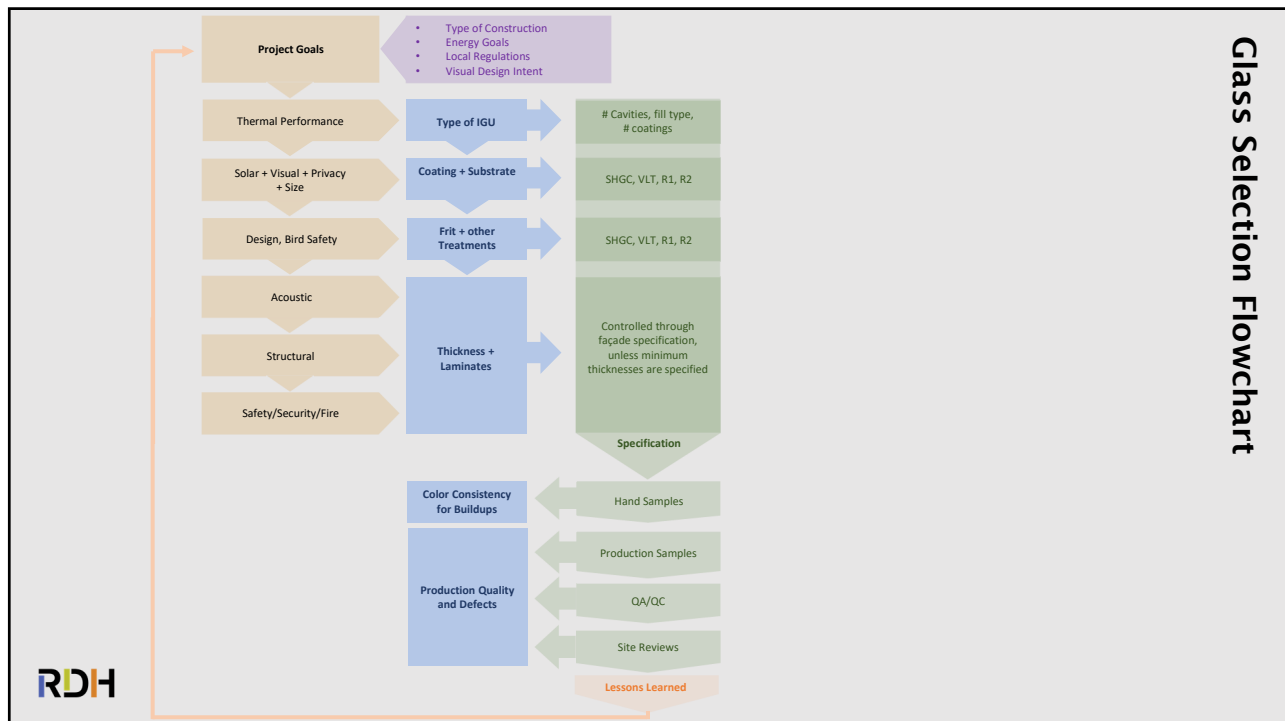
ANISOTROPY - VIA POLARIZED LENS

Scan only for single sheet, glass assemblies still to be approved through review.

ASTM C1901-21 Measurement

Retardation on 95% of Glass surface < 50nm

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