



**A deep building
science dive on
windows: new
opportunities
and
technologies.**

Spring Camp 2022

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WESTLab Canada

April 25, 2022

Windows

- Fenestration Heat Transfer
 - U-factor
 - Solar Heat Gain Coefficient (SHGC)
 - Total Product Results
- Labels don't tell the whole story
- HOT 2000 Input
- New Technologies

Windows

○ U-factor

- National Fenestration Rating Council (NFRC) definition
- The heat transfer per time per area and per degree of temperature difference.
- The U-factor multiplied by the interior-exterior temperature difference and by the projected fenestration product area yields the total heat transfer through the fenestration product due to conduction, convection, and long-wave infra-red radiation.

Windows

- Solar Heat Gain Coefficient (SHGC)
 - National Fenestration Rating Council (NFRC) definition
 - The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. NFRC rates SHGC at normal incidence.
 - The SHGC includes both the directly transmitted energy, and the absorbed energy that is transmitted through the product.

Windows

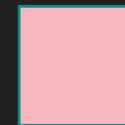
- For heat transfer analysis the window is broken into three regions
- Frame
- Edge-of-Glass
- Centre-of Glass



Frame Area



Edge-of-Glass
Area



Center-of- Glass
Area

Windows

○ U-factor

- Choice of Low-emissivity coating
 - Lower emissivity of the coating results in a lower center-of-glass U-factor
- Gas fill
 - Argon gas is the most common fill gas used
 - Krypton has been used but the cost increase of krypton has taken it out of reach for the window market
 - Air is used when the glass unit can not be filled with a gas

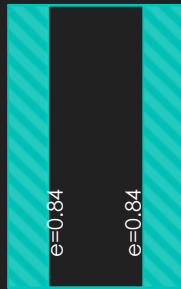
○ SHGC

- Choice of Low-emissivity coating
 - There are two types of low-emissivity or low-e coatings available on the market
- Pyrolytic
 - Hard coating resulting in a high solar gain coating
- Sputter – multiple types
 - High Solar Gain or Single Silver
 - Medium Solar Gain or Double Silver
 - Low Solar Gain or Triple Silver

Windows

- U-factors – center-of-glass for double-glazed glass units with argon fill

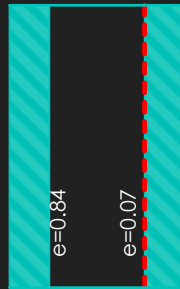
Clear-Air-Clear



$U=2.73 \text{ W/m}^2\text{K}$

$U=0.48 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

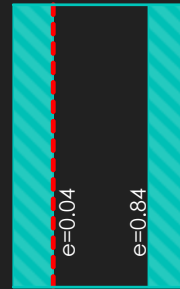
Clear- Argon-High Solar Gain



$U=1.47 \text{ W/m}^2\text{K}$

$U=0.26 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

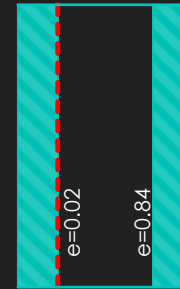
Medium Solar Gain-Argon-Clear



$U=1.39 \text{ W/m}^2\text{K}$

$U=0.25 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

Low Solar Gain-Argon-Clear



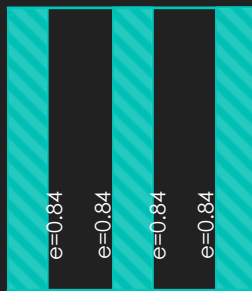
$U=1.36 \text{ W/m}^2\text{K}$

$U=0.24 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

Windows

- U-factors – center-of-glass for triple-glazed glass units with argon fill

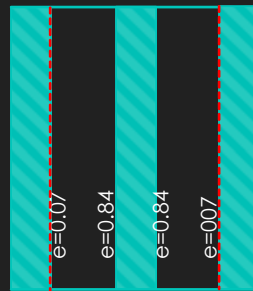
Clear-Air-Clear-Air-Clear



$U=1.77 \text{ W/m}^2\text{K}$

$U=0.31 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

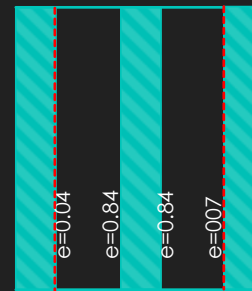
High SG-Arg-Clr-Arg-High SG



$U=0.75 \text{ W/m}^2\text{K}$

$U=0.13 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

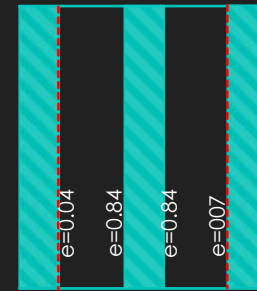
Medium SG-Arg-Clr-Arg-High SG



$U=0.73 \text{ W/m}^2\text{K}$

$U=0.13 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

Low SG-Arg-Clr-Arg-High SG



$U=0.72 \text{ W/m}^2\text{K}$

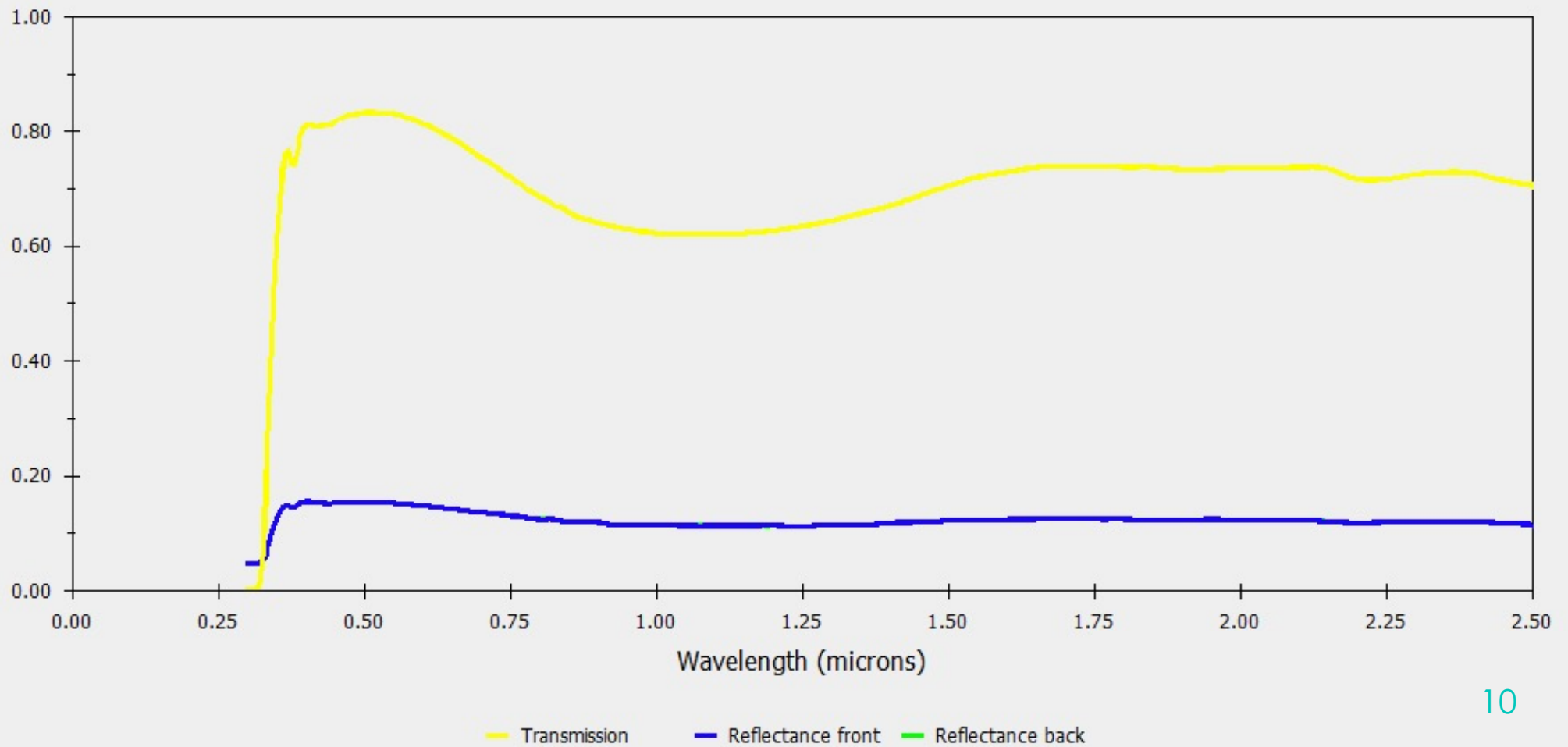
$U=0.13 \text{ BTU/hr}\cdot\text{ft}^2\cdot\text{F}$

Windows

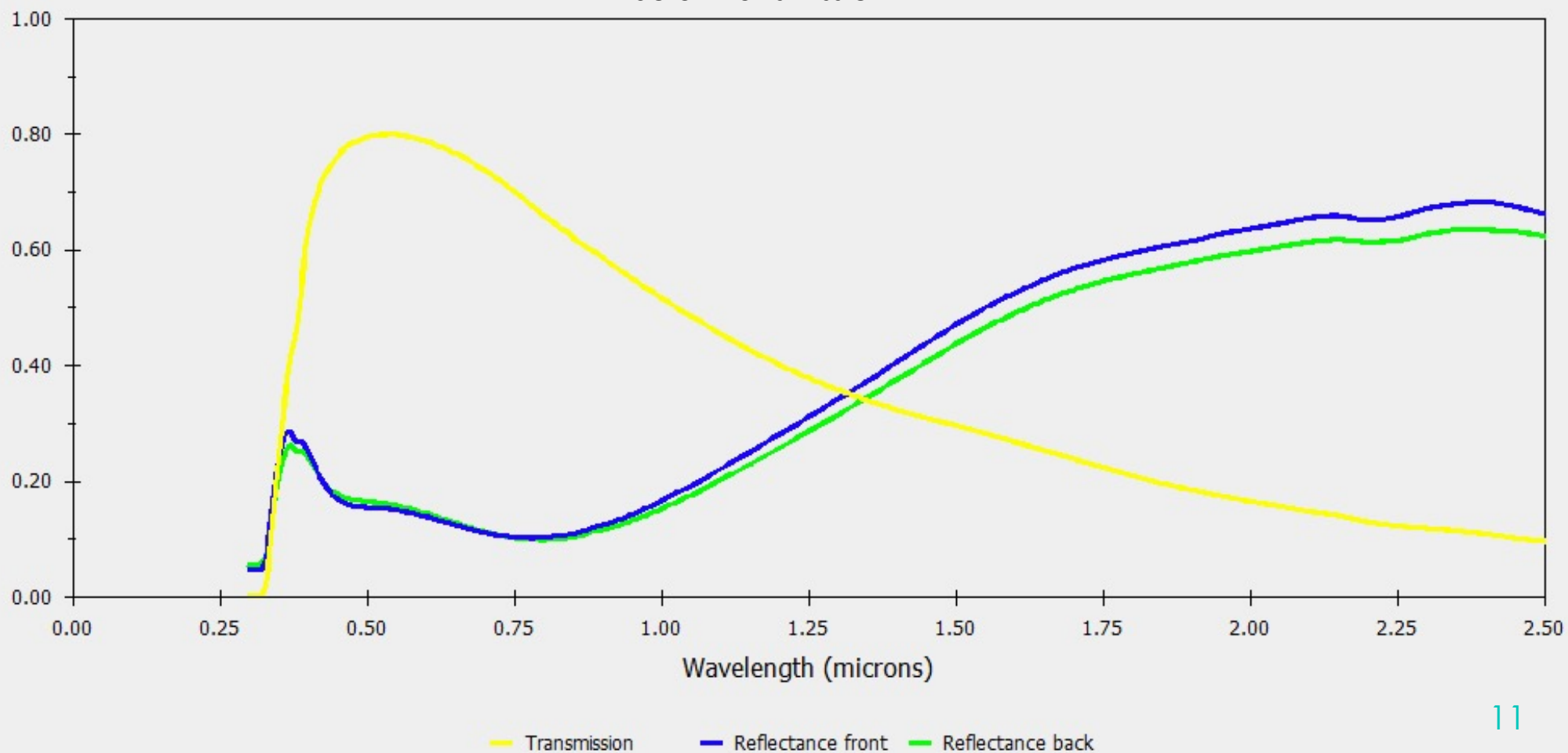
○ SHGC

- Low-e coatings are designed to control the amount of solar gain that will pass through the coating
- Sputter coatings
 - High-Solar Gain or single-silver coatings
 - Medium-Solar Gain or double-silver coatings
 - Low-Solar Gain or triple-silver coatings

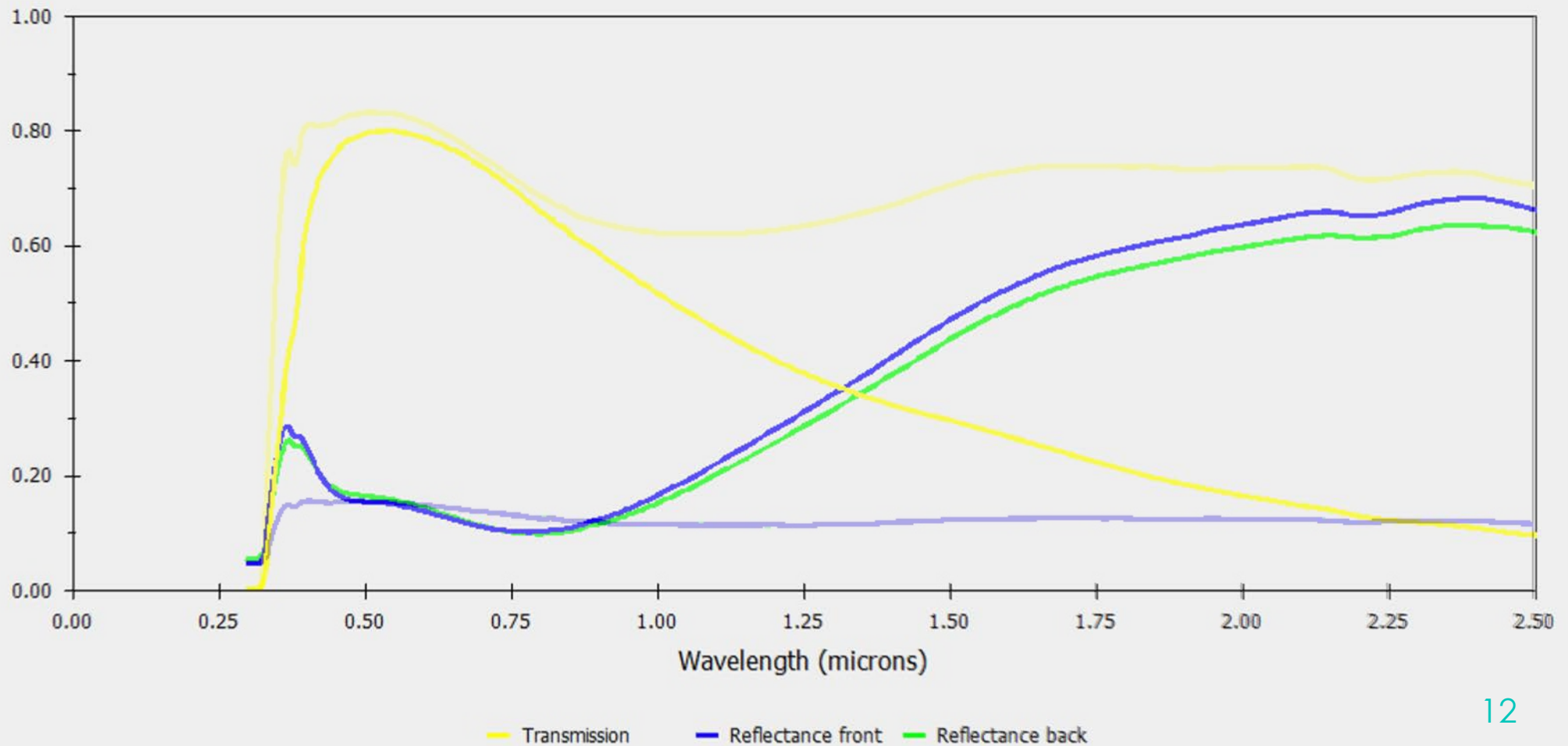
Double Glazed – Clear – Clear Solar Transmission



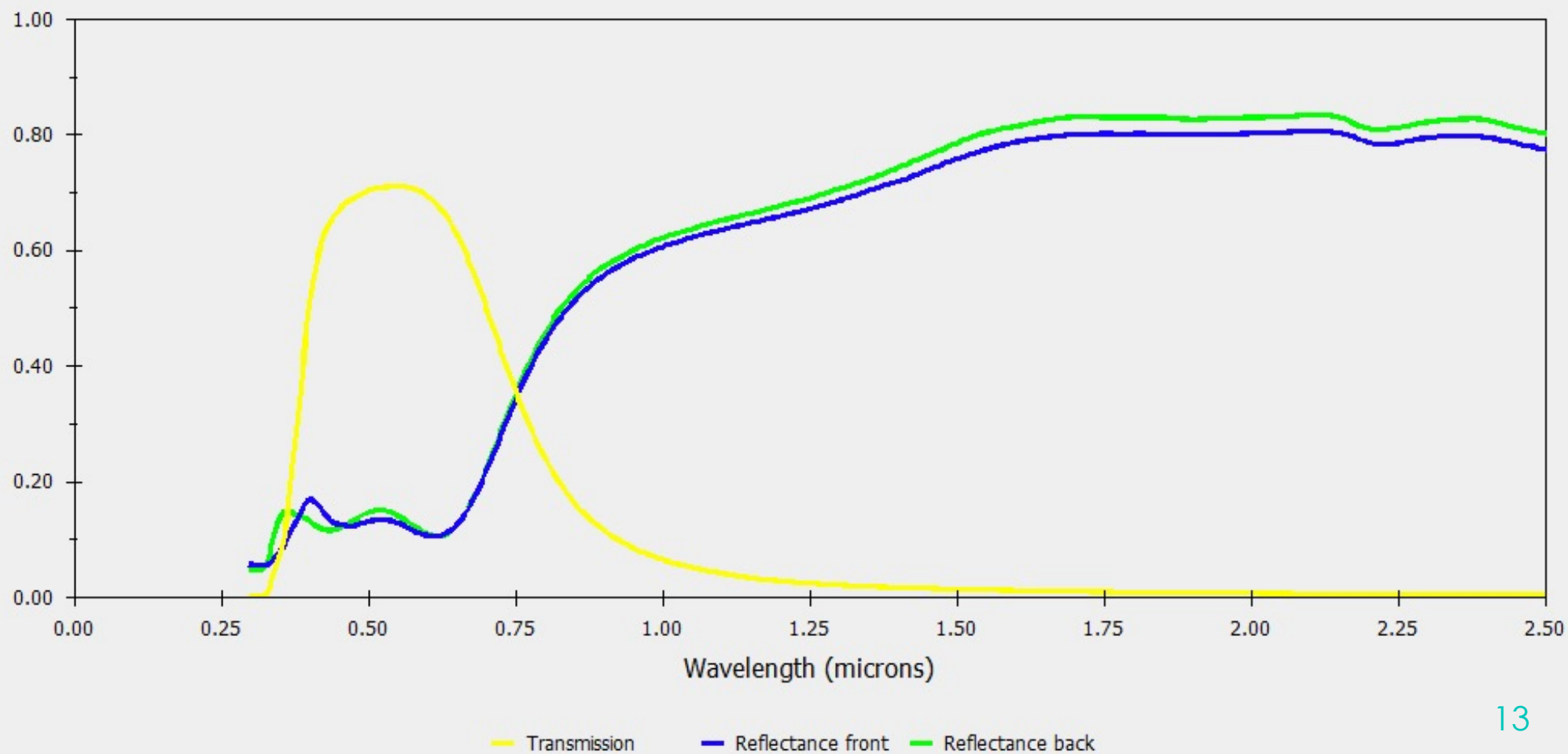
Double Glazed – High Solar Low-e – Clear Solar Transmission



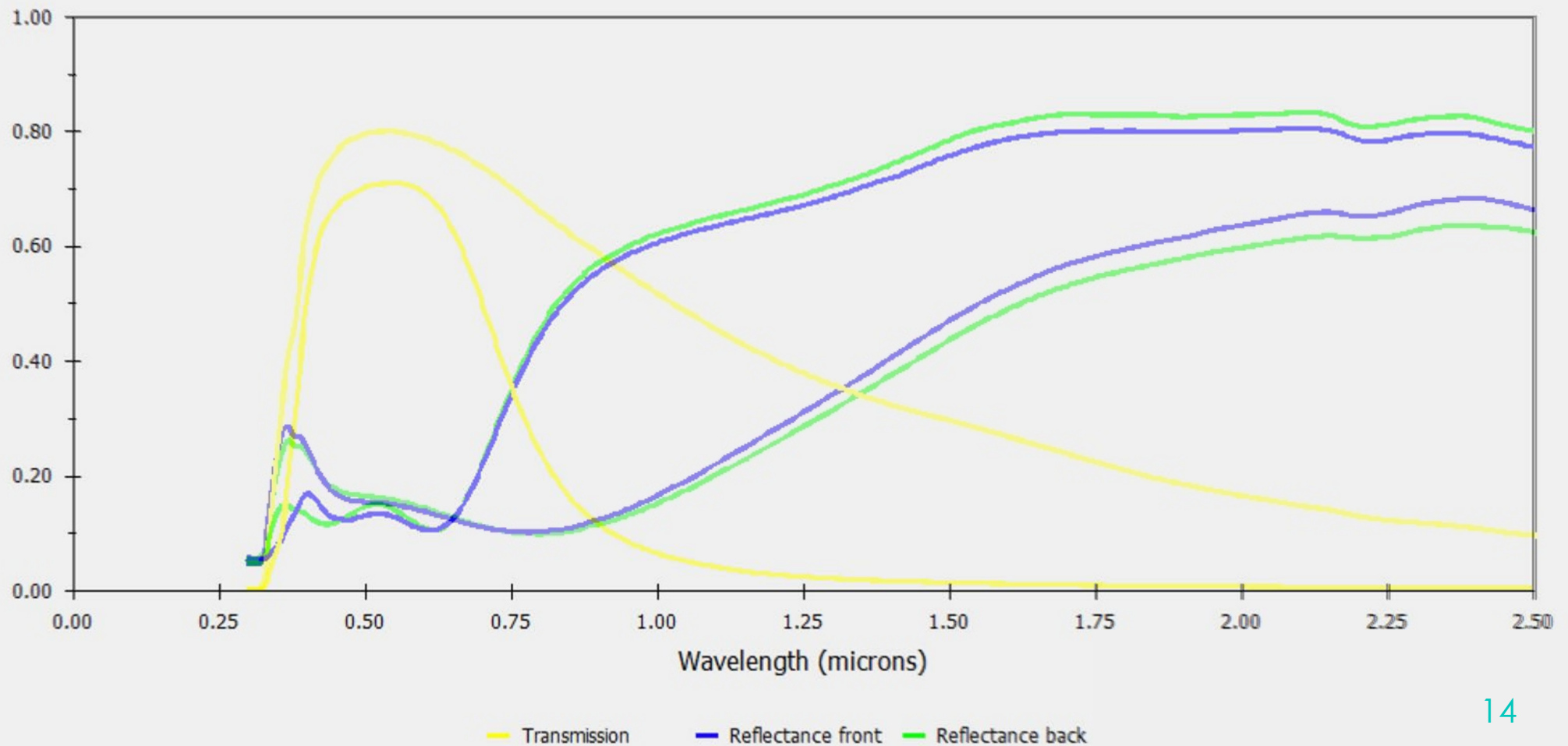
Double Glazed – High Solar Low-e – Clear compared to Clear – Clear
Solar Transmission



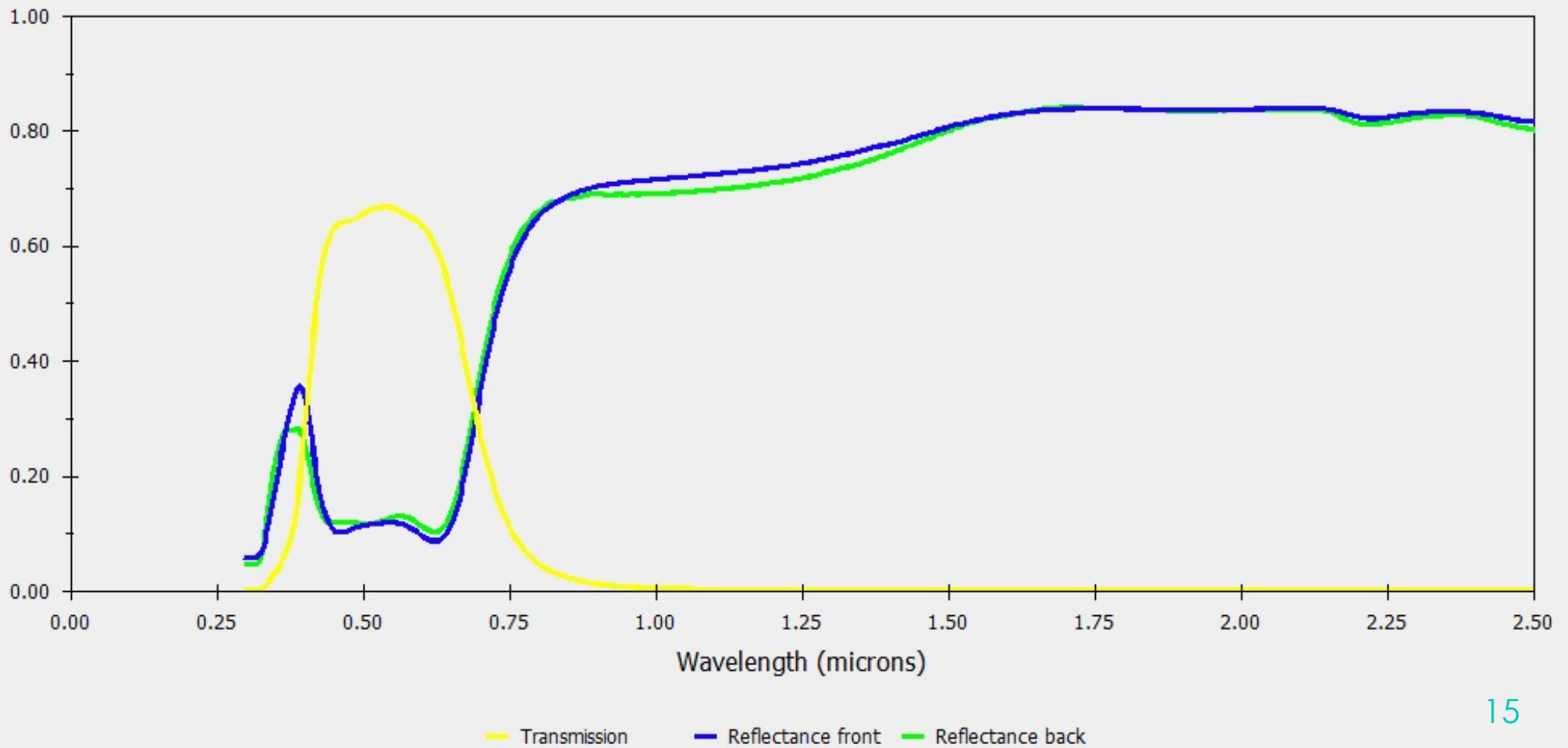
Double Glazed – Medium Solar Low-e – Clear
Solar Transmission



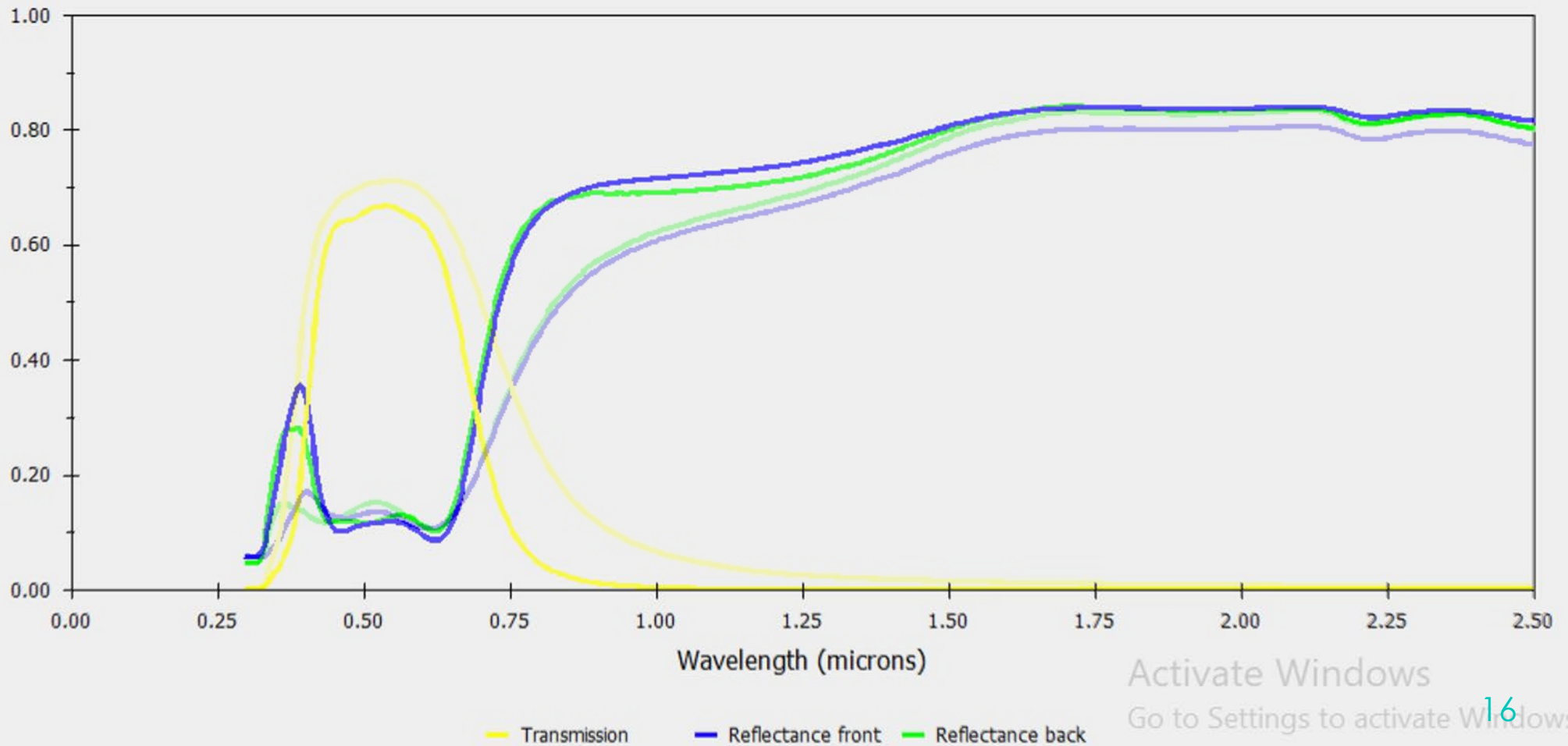
Double Glazed – Medium Solar Low-e – Clear compared to High Solar Low-e – Clear
Solar Transmission



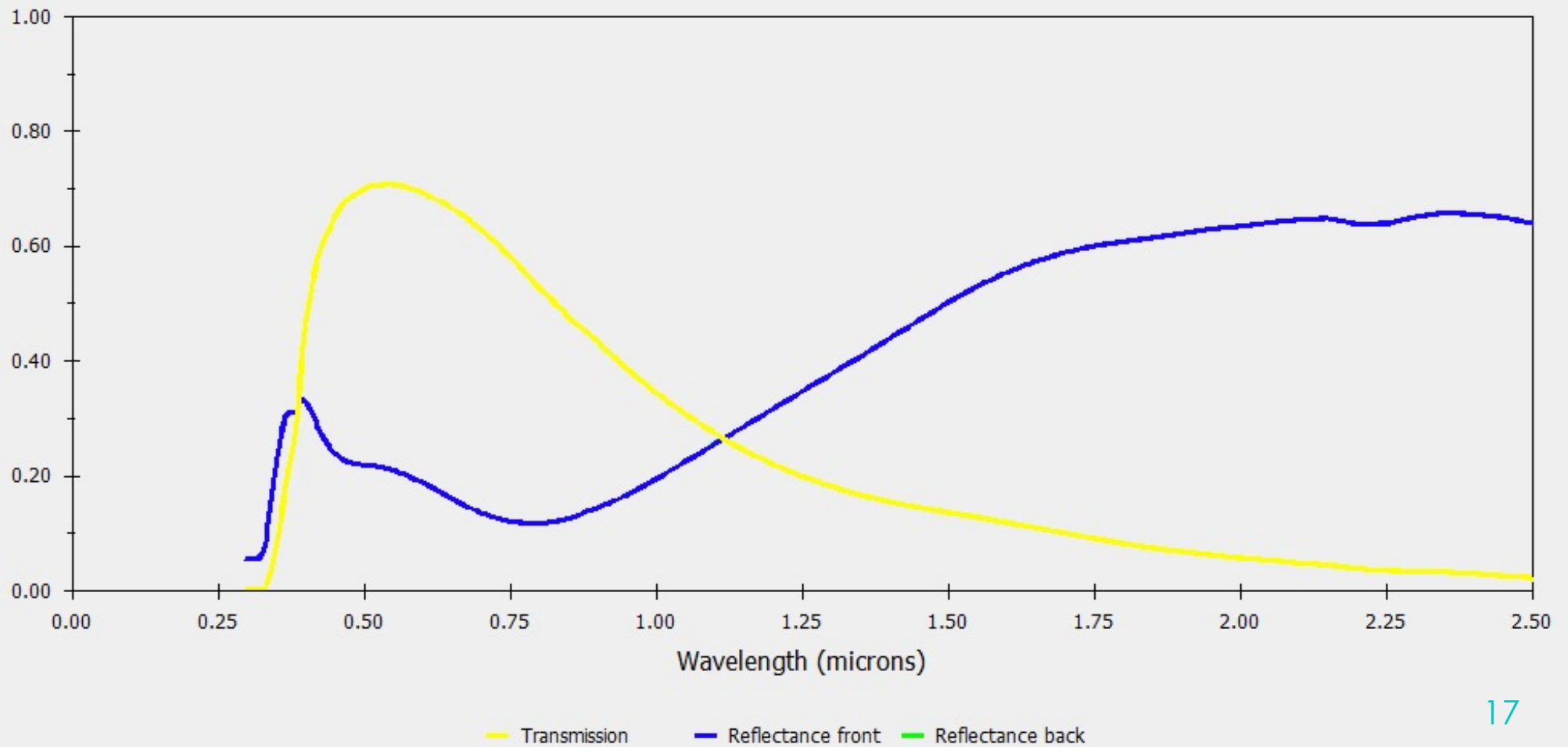
Double Glazed – Low Solar Low-e – Clear Solar Transmission



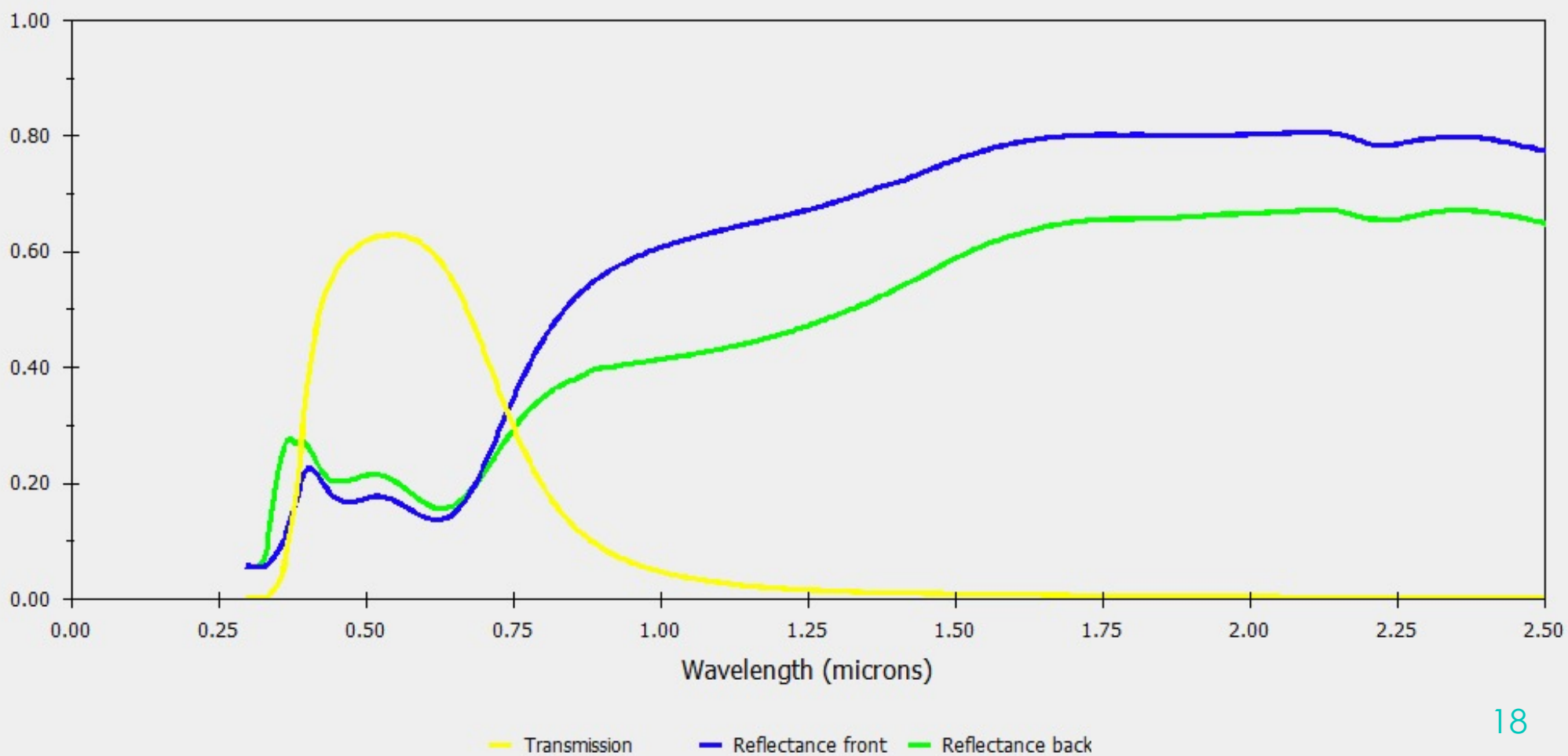
Double Glazed – Low Solar Low-e – Clear compared to Medium Solar Low-e – Clear
Solar Transmission



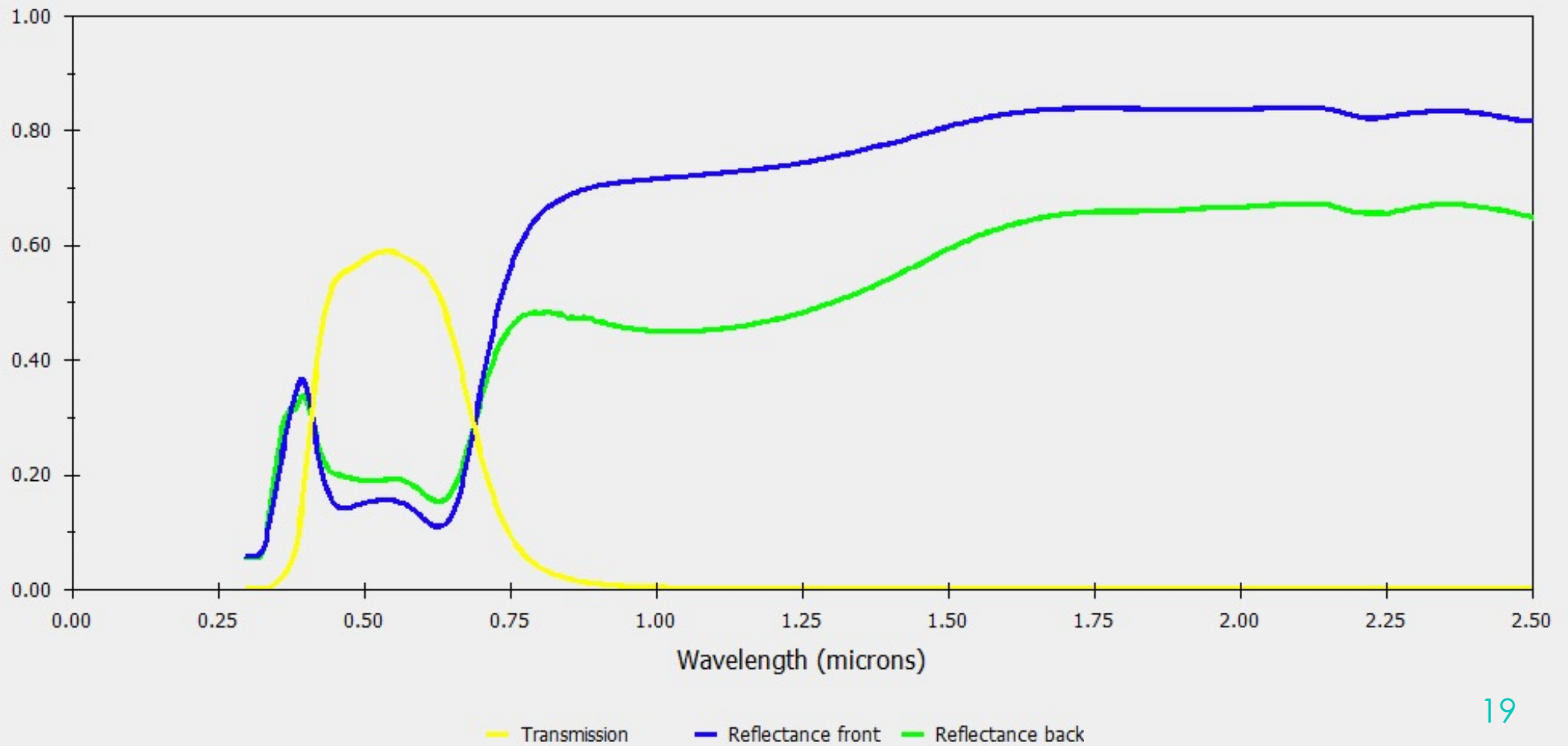
Triple Glazed – High Solar Low-e – Clear – High Solar Low-e
Solar Transmission



Triple Glazed – Medium Solar Low-e – Clear – High Solar Low-e
Solar Transmission



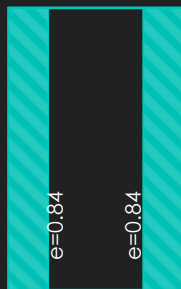
Triple Glazed – Low Solar Low-e – Clear – High Solar Low-e
Solar Transmission



Windows

○ SHGC – center-of-glass for double-glazed glass units with argon fill

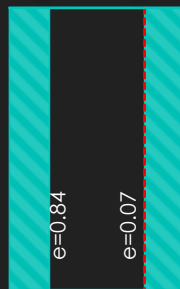
Clear-Air-Clear



SHGC=0.78

VT=0.82

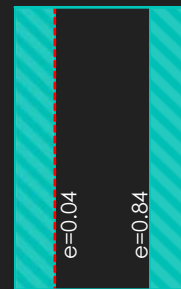
Clear- Argon-High Solar Gain



SHGC=0.69

VT=0.79

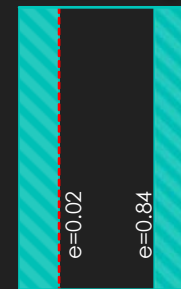
Medium Solar Gain-Argon-Clear



SHGC=0.37

VT=0.70

Low Solar Gain-Argon-Clear



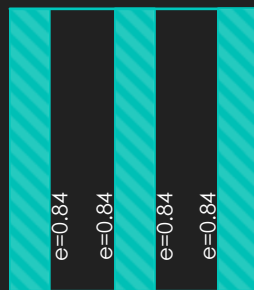
SHGC=0.27

VT=0.65

Windows

- SHGC – center-of-glass for triple-glazed glass units with argon fill

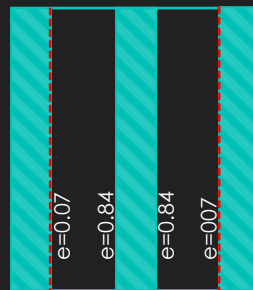
Clear-Air-Clear-Air-Clear



SHGC=0.70

VT=0.75

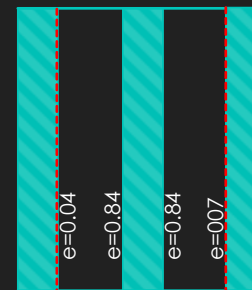
High SG-Arg-Clr-Arg-High SG



SHGC=0.56

VT=0.70

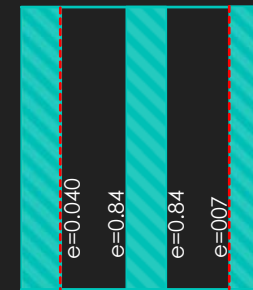
Medium SG-Arg-Clr-Arg-High SG



SHGC=0.33

VT=0.62

Low SG-Arg-Clr-Arg-High SG



SHGC=0.24

VT=0.57

Windows

- Edge-of-Glass Heat Transfer
 - U-factor
 - Low-e coating
 - Gas fill
 - Spacer system
 - Thermally improved spacer or warm edge spacers
- SHGC
 - Equal to the center-of-glass SHGC

Windows

- Frame Heat Transfer

- U-factor

- Frame Material

- Wood, PVC, Fiberglass, Thermally-Broken Aluminum

- Frame Design

- Material choices, Frame Height

- Spacer system

- Thermally improved spacer or warm edge spacers

- SHGC

- Very small and is a function of the frame U-factor

Windows

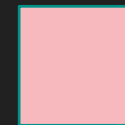
- Putting it all together
 - Frame
 - Edge-of-Glass
 - Centre-of Glass
- Total product U-factor
- Total product SHGC



Frame Area



Edge-of-Glass
Area



Center-of- Glass
Area

Windows

- Labels Don't Tell the Whole Story
- Windows are rated at a model size
- Example model sizes
 - Casement 600 x 1500 mm
 - Horizontal Slider 1500 x 1200 mm
 - Vertical Slider 1200 x 1500 mm
 - Fixed 1200 x 1500 mm

 National Fenestration Rating Council® CERTIFIED	World's Best Window Co. Series "2000" Casement Vinyl Clad Wood Frame Double Glazing•Argon Fill•Low E ABC-X-1-00001-00001		
ENERGY PERFORMANCE RATINGS			
U-Factor		Solar Heat Gain Coefficient	
0.35	1.99	0.32	
(U.S./I-P)	(Metric/SI)		
ADDITIONAL PERFORMANCE RATINGS			
Visible Transmittance		Air Leakage	
0.51		0.2	1.0
		(U.S./I-P)	(Metric/SI)
Condensation Resistance			
51		—	
<small>Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. www.nfrc.org</small>			

Windows – Total Product Results Model

Size Casement

Option	U-factor (W/m ² K)	SHGC
Double Glazed - Clear- Argon-High Solar Gain, warm edge spacer	1.51	0.51
Double Glazed - Medium Solar Gain-Argon-Clear, warm edge spacer	1.47	0.27
Double Glazed - Low Solar Gain-Argon-Clear, warm edge spacer	1.43	0.20
Triple Glazed - High Solar Gain-Argon-Clear-Argon-High Solar Gain, warm edge spacer	0.94	0.42
Triple Glazed - Medium Solar Gain-Argon-Clear-Argon-High Solar Gain, warm edge spacer	0.92	0.25
Triple Glazed - Low Solar Gain-Argon-Clear-Argon-High Solar Gain, warm edge spacer	0.91	0.18

Windows – Size Specific U-factor

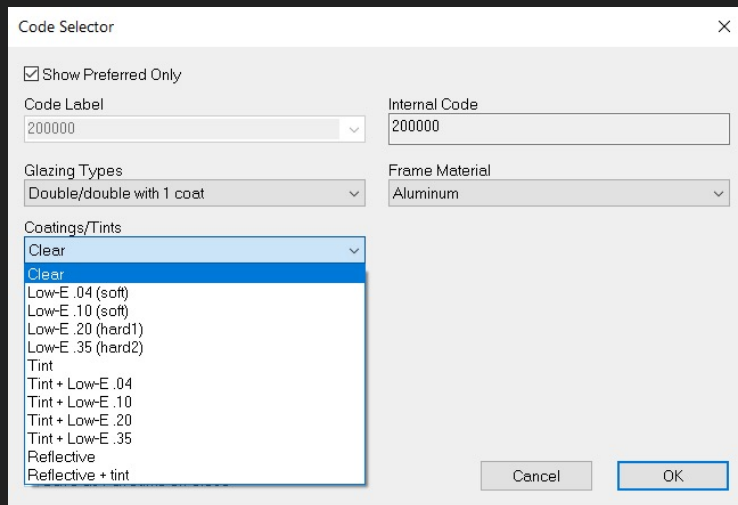
U-factor	Window Width (mm)						
Window Height (mm)	300	450	600	750	900	1050	1200
600	1.520	1.513	1.509	1.507	1.505	1.504	1.503
750	1.525	1.514	1.508	1.505	1.502	1.501	1.500
900	1.528	1.514	1.508	1.503	1.501	1.499	1.497
1050	1.530	1.515	1.507	1.503	1.499	1.497	1.496
1200	1.532	1.515	1.507	1.502	1.499	1.496	1.494
1350	1.533	1.515	1.507	1.501	1.498	1.495	1.493
1500	1.534	1.516	1.506	1.501	1.497	1.495	1.493
1650	1.535	1.516	1.506	1.501	1.497	1.494	1.492
1800	1.536	1.516	1.506	1.500	1.496	1.494	1.491
SHGC	Window Width (mm)						
Window Height (mm)	300	450	600	750	900	1050	1200
600	0.336	0.407	0.443	0.465	0.479	0.489	0.497
750	0.352	0.427	0.465	0.487	0.502	0.513	0.521
900	0.362	0.440	0.479	0.502	0.518	0.529	0.537
1050	0.370	0.450	0.489	0.513	0.529	0.540	0.549
1200	0.376	0.457	0.497	0.521	0.537	0.549	0.558
1350	0.380	0.462	0.503	0.528	0.544	0.556	0.564
1500	0.384	0.467	0.508	0.533	0.549	0.561	0.570
1650	0.387	0.470	0.512	0.537	0.553	0.565	0.574
1800	0.389	0.473	0.515	0.540	0.557	0.569	0.578

Windows – Size Matters

Casement Window	U-factor			SHGC		
Example	Small	Medium	Large	Small	Medium	Large
	300x600 mm	600x1500 mm	1200x1800 mm	300x600m m	600x1500 mm	1200x1800 mm
Double – High Solar	1.52	1.51	1.49	0.34	0.51	0.58
Double – Medium Solar	1.51	1.47	1.44	0.18	0.27	0.31
Double – Low Solar	1.51	1.43	1.42	0.14	0.20	0.23
Triple – High Solar	1.09	0.94	0.87	0.28	0.42	0.47
Triple – Medium Solar	1.08	0.92	0.85	0.16	0.25	0.28
Triple – Low Solar	1.07	0.91	0.84	0.12	0.18	0.21

Windows – HOT2000 Input

Code Editor



Code Selector

☒ Show Preferred Only

Code Label: 200000 Internal Code: 200000

Glazing Types: Double/double with 1 coat Frame Material: Aluminum

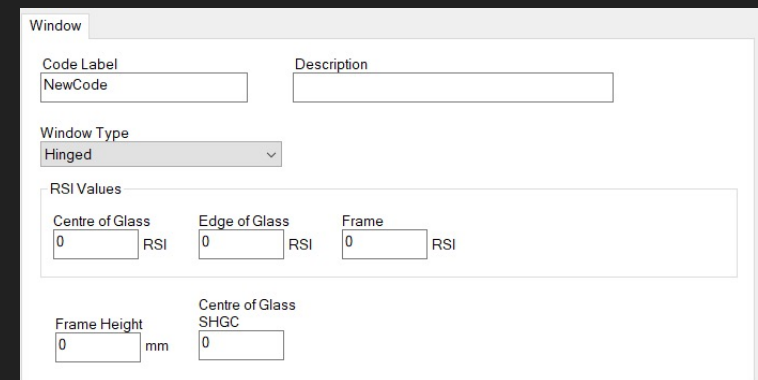
Coatings/Tints:

- Clear
- Low-E .04 (soft)
- Low-E .10 (soft)
- Low-E .20 (hard1)
- Low-E .35 (hard2)
- Tint
- Tint + Low-E .04
- Tint + Low-E .10
- Tint + Low-E .20
- Tint + Low-E .35
- Reflective
- Reflective + tint

Cancel OK

Legacy
User
Defined
Code

Overall
Window
Characteristics
Code



Window

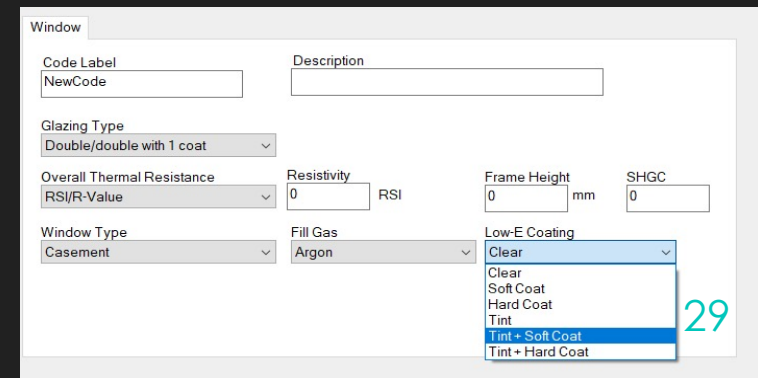
Code Label: NewCode Description:

Window Type: Hinged

RSI Values:

Centre of Glass: 0 RSI Edge of Glass: 0 RSI Frame: 0 RSI

Frame Height: 0 mm Centre of Glass SHGC: 0



Window

Code Label: NewCode Description:

Glazing Type: Double/double with 1 coat

Overall Thermal Resistance: RSI/R-Value Resistivity: 0 RSI Frame Height: 0 mm SHGC: 0

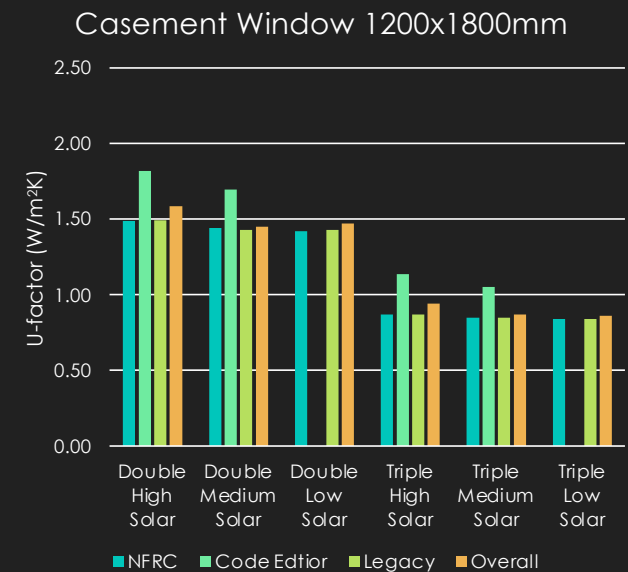
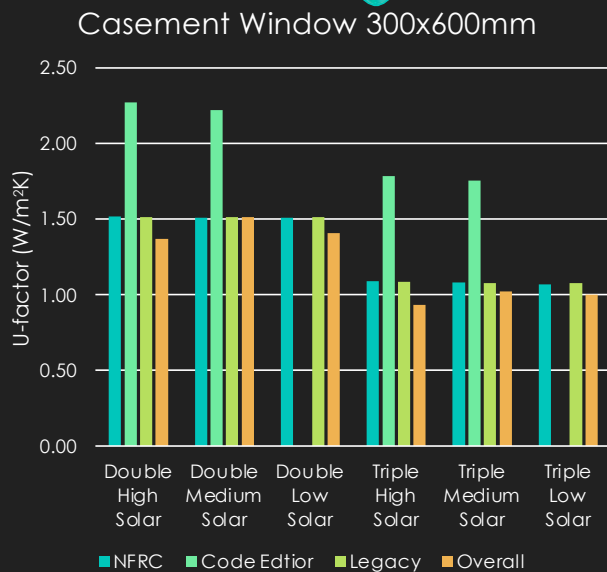
Window Type: Casement Fill Gas: Argon Low-E Coating:

- Clear
- Soft Coat
- Hard Coat
- Tint
- Tint + Soft Coat
- Tint + Hard Coat

Windows – HOT2000 vs. NFRC U-factors and SHGC

- U-Factors and SHGC values
 - Calculated at three sizes from NFRC and the three HOT2000 window codes
 - Casement Window
 - 300 x 600 mm
 - 600 x 1500 mm (NFRC model size)
 - 1200 x 1800 mm

Windows – HOT2000 vs. NFRC U-factors



- Code Editor can not handle low solar gain low-e, over predicts U-factor for high and medium solar gain low-e
- Legacy predicts U-factor very well, but the input data is not readily available
- Overall, under predicts U-factor slightly, but the input data is more readily available

Windows – HOT2000 vs. NFRC SHGC



- Code Editor can not handle low solar gain low-e, under predicts SHGC for high and medium solar gain low-e
- Legacy predicts SHGC very well, but again the input data is not readily available
- Overall predicts the SHGC well especially for triple glazed windows and the data is readily available.

Windows – HOT2000 vs. NFRC SHGC

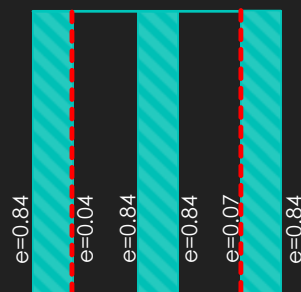
- Consider abandoning the window code editor as the prediction of the current low-e glass options is not handled very well
- Consider using the Overall Window Characteristic code for creating window codes in HOT2000
- Push the window industry to provide access to the data for the Legacy User Defined code
- NRCan could work with the fenestration industry to develop a better means of getting window performance input data

Windows – New Technology

- New technology being considered by the fenestration industry
 - Ultra triples – three low-e coating
 - Vacuum glazing and hybrid vacuum
 - Aerogel in glass units
 - Frame Design

Windows – New Technology

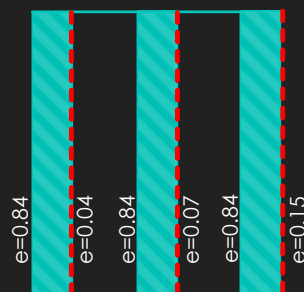
- New technology being considered by the fenestration industry
 - Ultra triples – three low-e coating



$$U_{cg} = 0.72 \text{ W/m}^2\text{K}$$

$$\text{SHGC} = 0.24$$

$$\text{VT} = 0.57$$



$$U_{cg} = 0.64 \text{ W/m}^2\text{K}$$

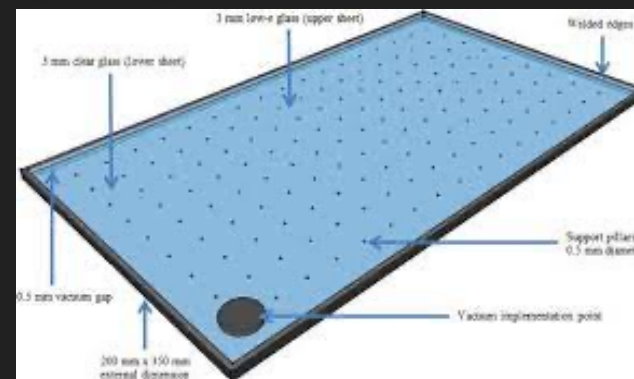
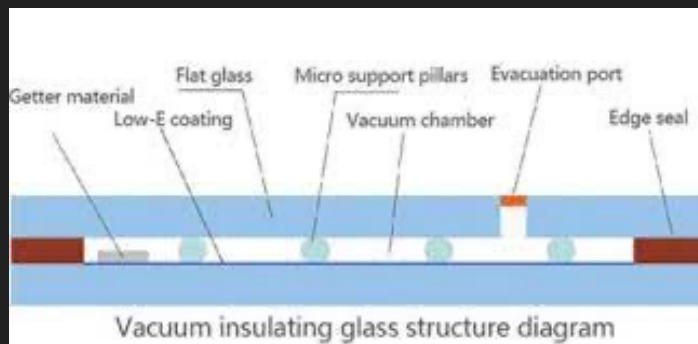
$$\text{SHGC} = 0.24$$

$$\text{VT} = 0.56$$

- Window modeling techniques are available now, but Legacy input would be the only option in HOT2000

Windows – New Technology

- New technology being considered by the fenestration industry
 - Vacuum glazing and hybrid vacuum glazing
 - Claims of U-factor center-of-glass under $0.60 \text{ W/m}^2\text{K}$ even lower in a hybrid
 - NFRC working on a rating for vacuum glazing



Windows – New Technology

- New technology being considered by the fenestration industry
 - Aerogel in glass units



- Potential for very low center-of-glass U-factors
- No modelling approach at this time
- NFRC will need to work on the modeling when these products become available

Windows – New Technology

- New Frame Design – NRCan Research Project

- Window design elements reviewed in this study

- Frame Material (new or additional materials)
 - Percent Frame Area (less frame area)
 - Number of Glass Layers (minimum triple glazed IGU)
 - Gas Fill (preferably argon, but krypton if required)
 - Overall IG Unit Thickness (optimized for spacer and gas choice)
 - Spacer System Type (lower conductance spacers)

Design Elements Needed to Achieve U-factor performance

U-factor Range (W/m ² K)	Window Design Elements Needed
1.05-0.95	3 to 4 elements
0.94-0.83	4 to 5 elements
0.82-0.65	5 to 6 elements

Windows – New Technology

- Fenestration Ratings vs Fenestration Performance
 - Ratings are for labels to compare one product to another
 - Fenestration performance data will be needed on any new technology to allow for the full energy efficiency improvements to be modelled in the building

Questions

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