How High-Performance Windows Can Help You:

updates from the industry and the field

Learning Objectives

- Key findings and builder experiences from using high-performance windows in pilot projects
- Overview of new window technologies and performance capabilities
- Value of high-performance windows in code and above-code programs
- Homeowner benefits and sales tools for high-performance windows

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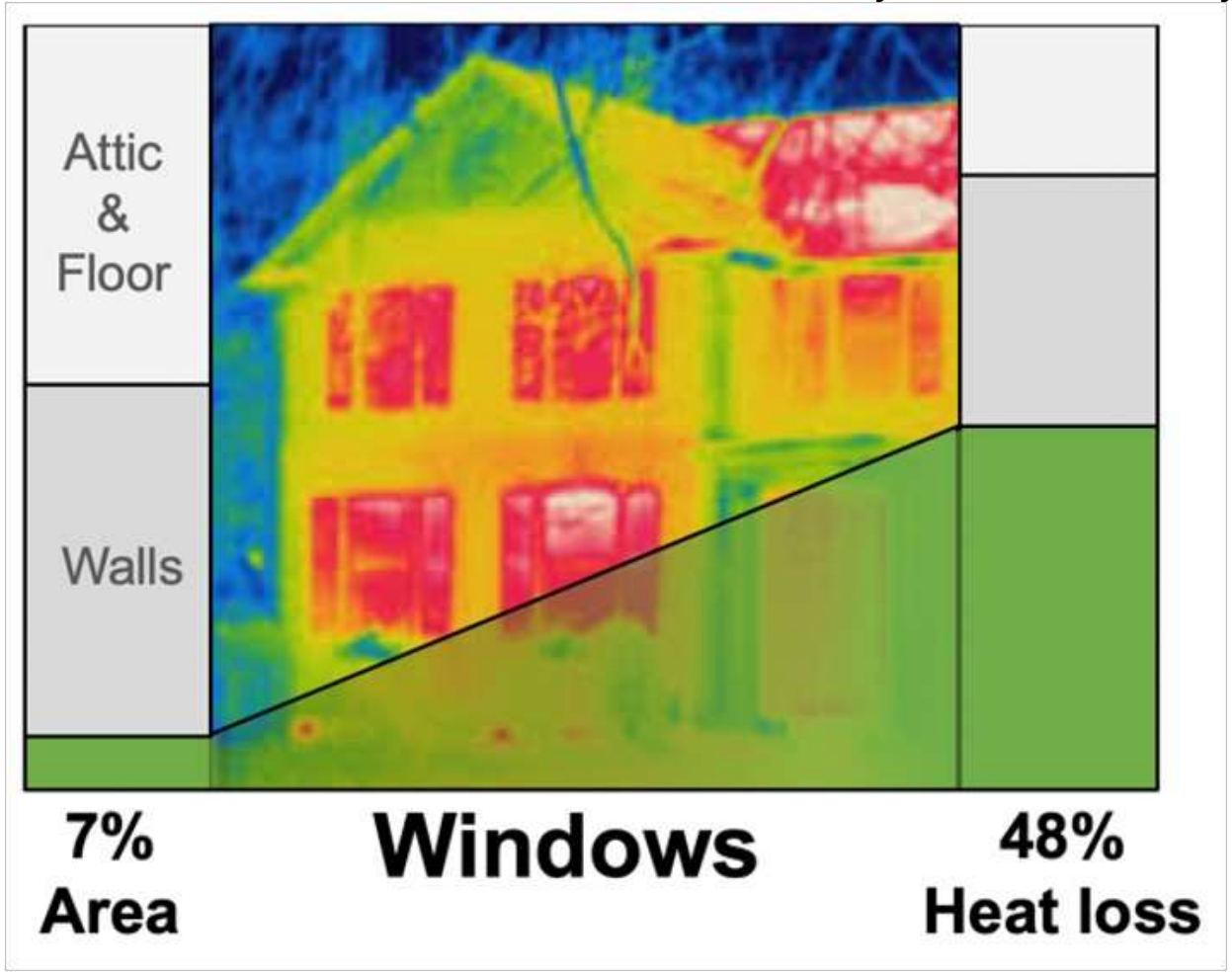
High-Performance Windows (HPW) - Background

The Large Impact of Windows

*Based on UA analysis of 2,000 SF 2-story house, 15% WWR, IECC 2015



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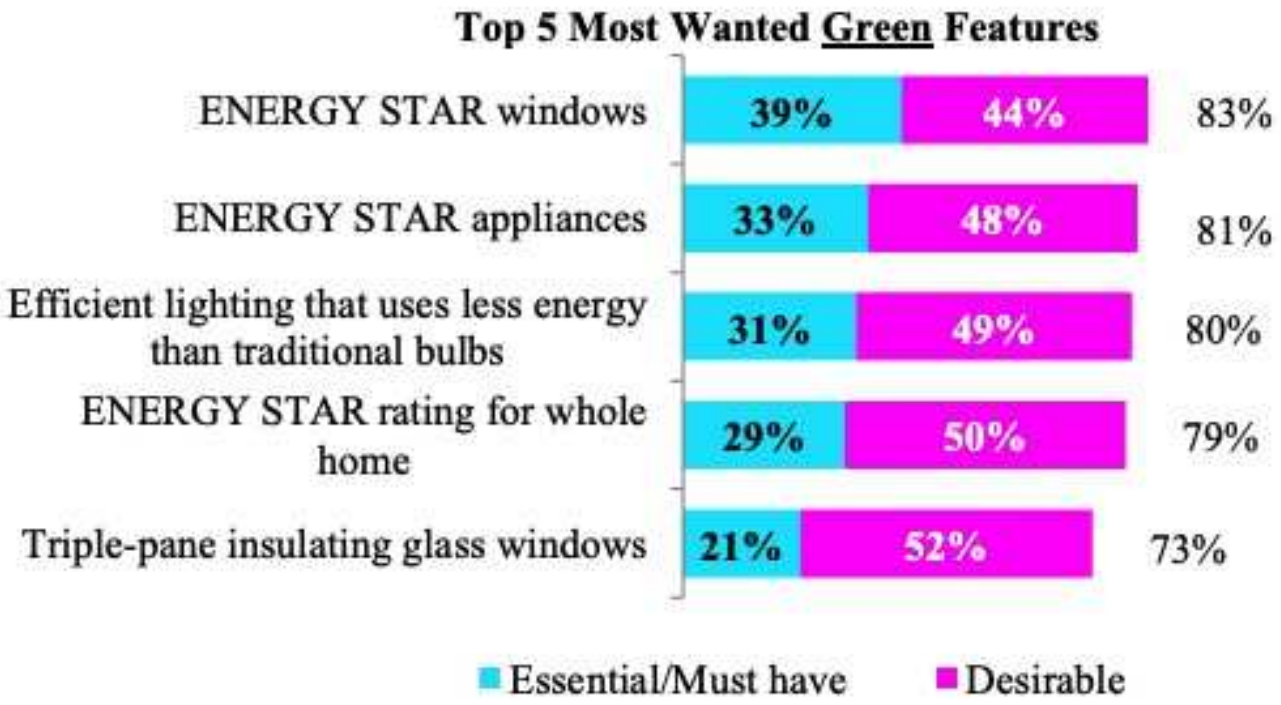
Envelope performance will only improve if windows get better or smaller.
The market needs to choose.

Consumers Want Better Windows

*Rose Quint. 2021. ***What Home Buyers Really Want,*** Special Study for Housing Economics. Economics and Housing Policy. National Association of Home Builders

National Association of Home Builders



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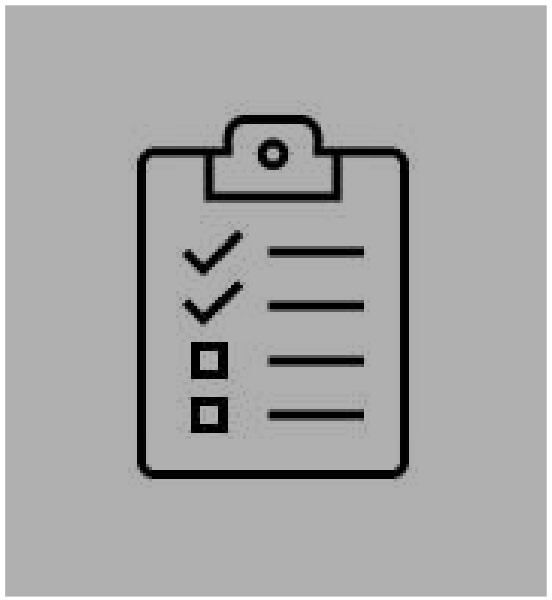
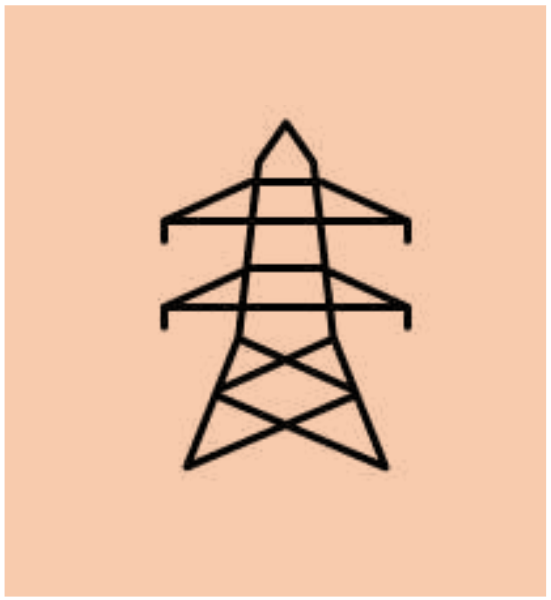


Codes & Standards

Above Code

Electrification/Decarb



Non-energy Benefits

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Codes and Standards

Climate Zone	2006		2009		2012		2015		2018		2021		2024*	
	U	SHGC	U	SHGC	U	SHGC	U	SHGC	U	SHGC	U	SHGC	U	SHGC
1	1.20	0.40	1.20	**0.30**	**NR**	**0.25**	NR	0.25	NR	0.25	0.50	0.25	0.50	0.25
2	0.75	0.40	**0.65**	**0.30**	**0.40**	**0.25**	0.40	0.25	0.40	0.25	0.40	0.25	0.40	0.25
3	0.65	0.40	**0.50**	**0.30**	**0.35**	**0.25**	0.35	0.25	**0.32**	0.25	**0.30**	0.25	0.30	0.25
4 except Marine	0.40	NR	**0.35**	NR	**0.32**	**0.40**	0.32	0.40	0.32	0.40	**0.30**	0.40	0.30	0.40
5 and Marine 4	0.35	NR	0.35	NR	**0.32**	NR	0.32	NR	**0.30**	NR	0.30	0.40	**0.28**	**NR**
6	0.35	NR	0.35	NR	**0.32**	NR	0.32	NR	**0.30**	NR	0.30	NR	**0.28**	NR
7 & 8	0.35	NR	0.35	NR	**0.32**	NR	0.32	NR	**0.30**	NR	0.30	NR	**0.27**	NR

*Numbers from the last public review. No further changes anticipated

- Windows have gotten better but remain low performance relative to everything else

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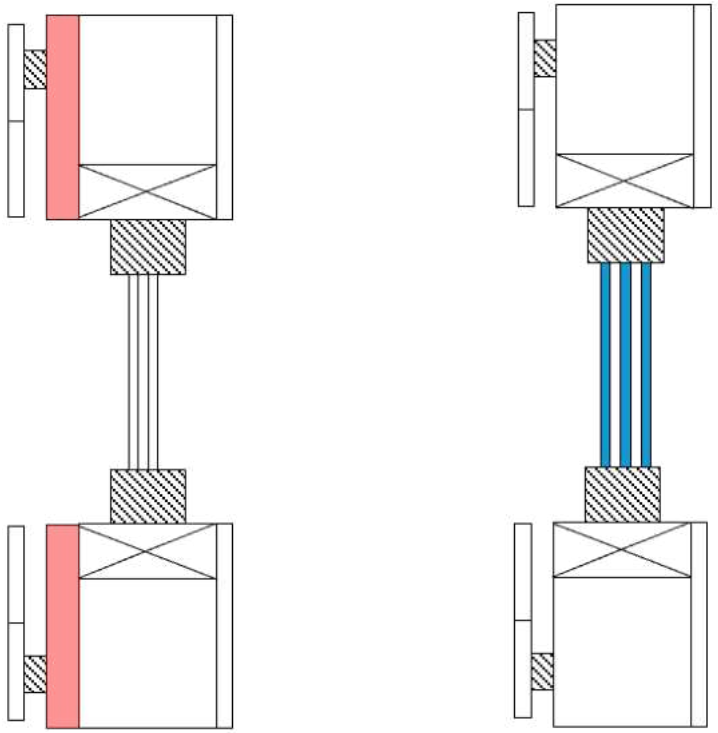
Insulation Trade-Off

2021 IECC & Ca T24



Prescriptive: 2000 sf R5 continuous insulation
or
Tradeoff: 300 sf high performance windows

- Demonstrated window wall-trade-off works in CZ-3 and above!

  Cort, Katherine, Louie Edward; Hart, Robert. 2022. Using Triple-Pane Windows to Meet IECC Envelope Requirements. ASHRAE Journal 64 (3), 50-58

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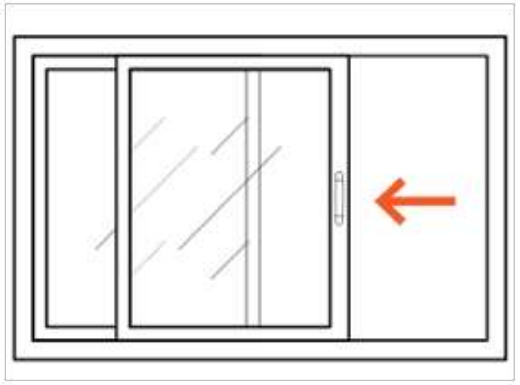
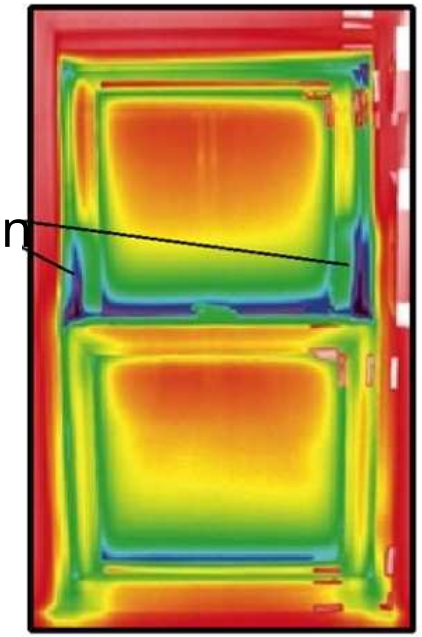
Infiltration





- Sliding windows still dominate, but hinged (casement, awning, tilt-and-turn) are gaining steadily

	2017	2019	2021
Sliding	76%	73%	70%
Hinged	15%	18%	21%

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ENERGY STAR for Windows Updated

Version 6

Climate Zone	U-Factor	SHGC	
Northern*	≤ 0.27	Any	Prescriptive
	= 0.28	≥ 0.32	Equivalent Energy Performance
	= 0.29	≥ 0.37	
	= 0.30	≥ 0.42	
North-Central	≤ 0.30	≤ 0.40	
South-Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

Version 7

Effective October 2023

Climate Zone	U-Factor[1]	SHGC[2]		Technology
Northern	≤ 0.22	≥ 0.17	Prescriptive	Triple-pane
	= 0.23	≥ 0.35	Equivalent Energy Performance	
	= 0.24			Double-pane HSG with s4 low-e
	= 0.25	≥ 0.40		
	= 0.26			
North-Central	≤ 0.25	≤ 0.40		Double-pane MSG with s4 low-e Triple-pane wood
South-Central	≤ 0.28	≤ 0.23		Double-pane LSG
Southern	≤ 0.32	≤ 0.23		Double-pane LSG

https://www.energystar.gov/products/res_windows_doors_skylights/partners

- **80% of triple-pane** and **25% of double-pane** product lines met requirements of North and North Central as of November 2022 (before the spec was announced).

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Above Code

U.S. DOE Zero Energy Ready Home
Single Family Homes National Program Requirements
Version 2 (Rev. 1)

Window Specs Required for DOE ZERH Projects	IECC CZ 1-2		IECC CZ 3,4A, 4B		IECC CZ 4C, 5 (SHGC values listed below may be paired with the U-value in the same row)		IECC CZ 6-8	
	U-Value	SHGC	U-value	SHGC	U-Value	SHGC	U-Value	SHGC
	≤ 0.40	≤ 0.23	[CZ 3] ≤ 0.30 [CZ 4] ≤ 0.30	[CZ 3] ≤ 0.25 [CZ 4] ≤ 0.40	≤ 0.27 = 0.28 = 0.29 = 0.30	Any ≥ 0.32 ≥ 0.37 ≥ 0.42	≤ 0.25	Any

- Moving to ES v7 in next update

- Based on ERI
  (Energy Rating Index)
- ES v6 basis

ENERGY STAR Single-Family New Homes
National Program Requirements, Version 3.2 (Rev. 13)

Climate Zone: [11]	1 - 2	3	4A & 4B	4C - 8
Window U-Value:	0.40	0.30	0.30	0.27
Window SHGC:	0.25	0.25	0.30	0.30

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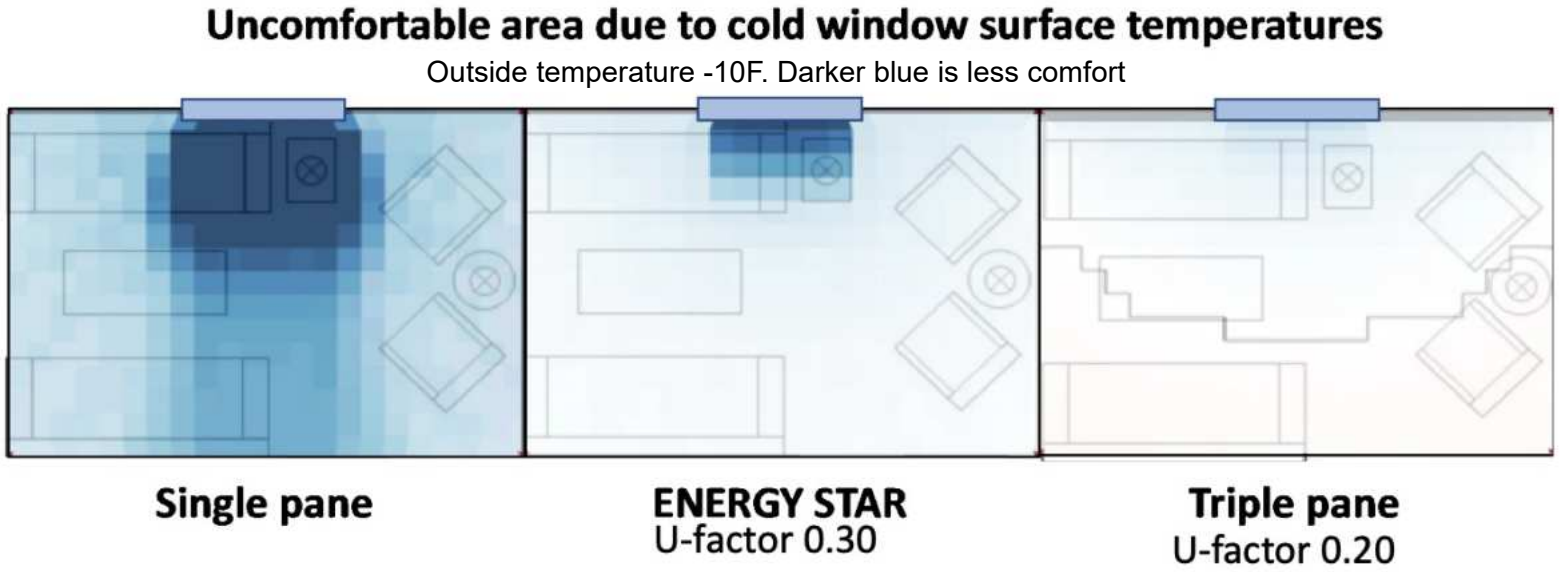
Non-Energy Benefits



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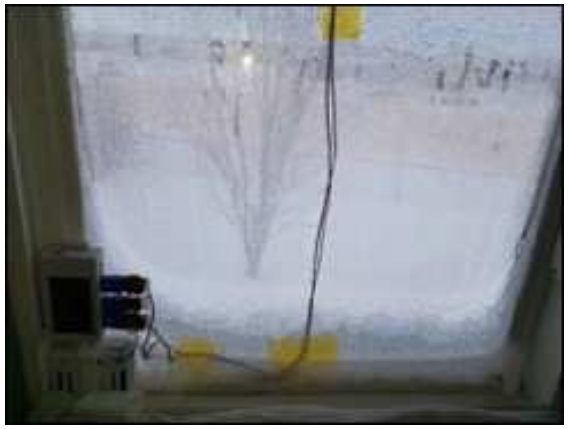
Example: Helena, MT



Condensation and ice buildup on existing double-pane

March 2021
PNNL led demonstration

Window replaced with Thin-triple

Thin-triple window reduced sound infiltration by ~10 dB
(6-10 dB reductions are typically perceived as reducing sound by half)

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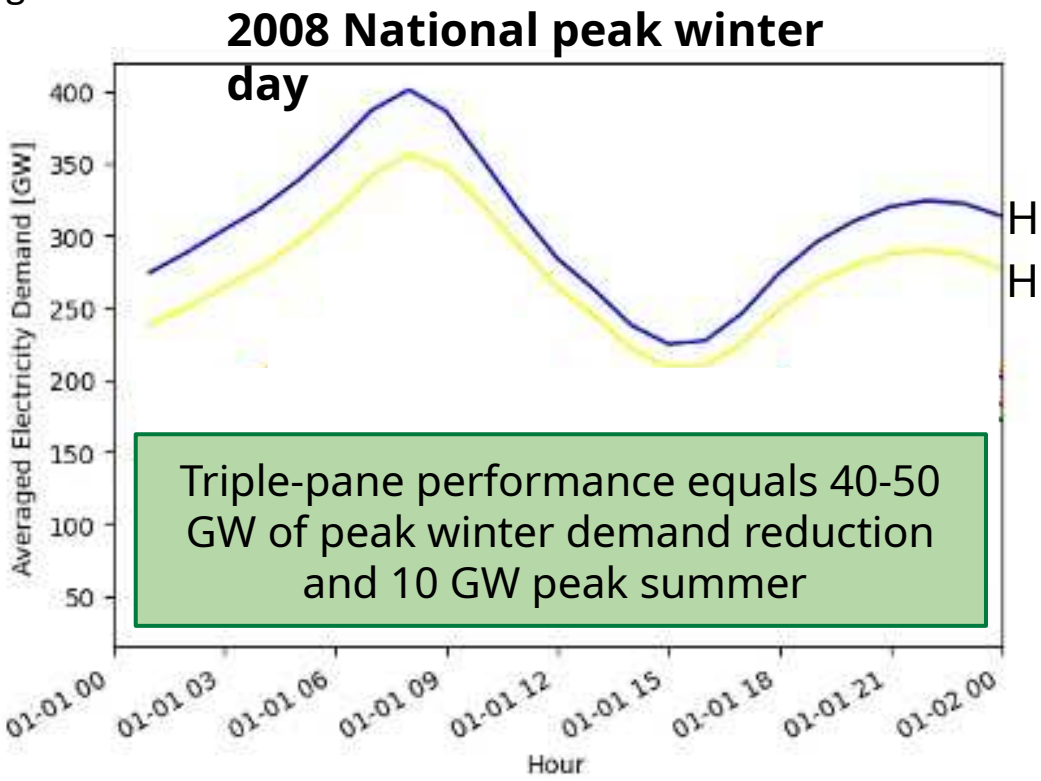
Electrification & Decarbonization

High performance windows are an enabler

- ❑ Peak Load reduction
- ❑ Backup heating reduction
- ❑ HVAC rightsizing



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The New High Potential Emerging Glass Technologies

We will cover the following:

- ***300 Years of US Window History in 5 Minutes***
- ***Last 5 Years of the US Window History in 5 Minutes***
- ***The future of the US Window Industry in 5 minutes***

History of Last 300 Years in US Window Technology

. . . in 5 Minutes

Hint: We Like What We Like In the US

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The History of Changes in Consumer Preferences in US Window Design

US Window Design
1700s

US Window Design
Today

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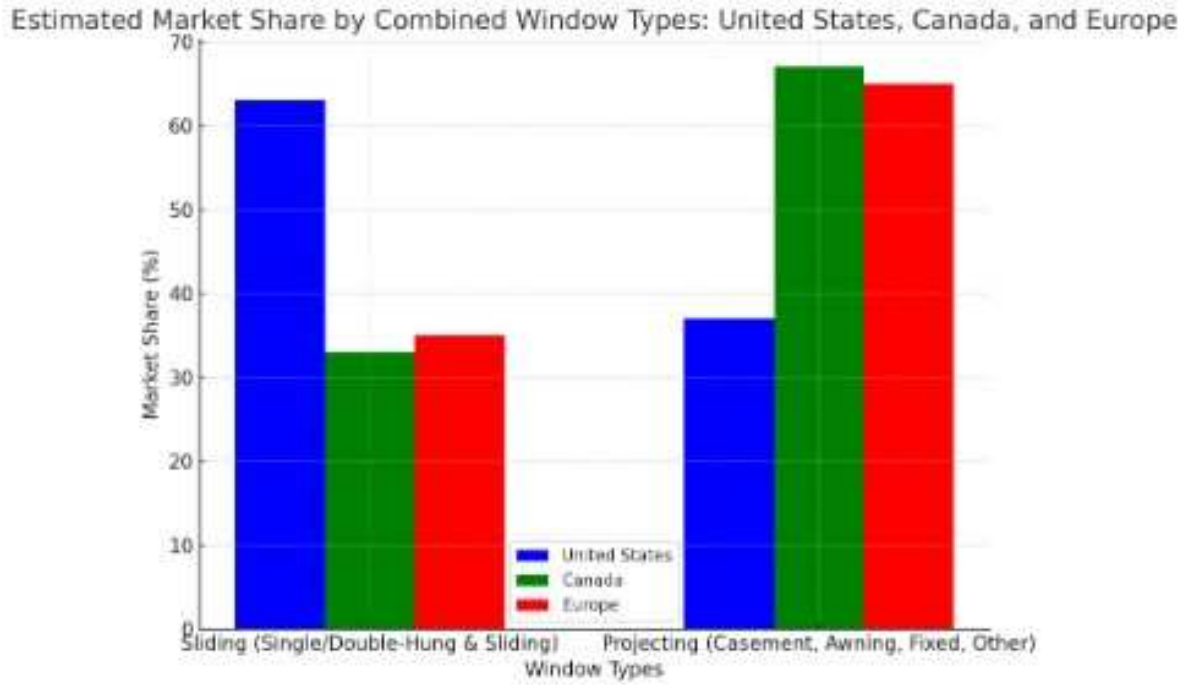
Narrower Frames (and Walls), Sliding Sash Designs, Climate, Energy Costs Have Resulted in a Norm for Narrower Glass Pockets in the U.S.

Window Type	Glass Pocket Depth	Design Characteristics
United States Window	0.75 to 1 inch	Double-pane, thinner frame, cost-efficient
European Window	1.5 to 2 inches	Triple-glazed, deeper frame, tilt-and-turn, energy-efficient
Canadian Window	1.25 to 2 inches	Double/triple-glazed, deeper frame, built for cold climates



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Five Big Important Triggering Events Have Driven Most of the Changes in US Windows Over the Last 50 Years

1.Invention of the float glass process for glass (1959);

2. Arab Oil Embargo (70s);

3. LBNL enabling research on soft coat low-e coatings on glass (early 80s);

4. The arrival of the vinyl window (late 70s);

5. ENERGY STAR labeling for windows, NFRC and LBNL Windows software (90s).

THESE ARE THE EVENTS THAT MORE THAN ANYTHING INFLUENCED THE EVOLUTION OF THE WINDOW IN THE US IN HUNDREDS OF YEARS

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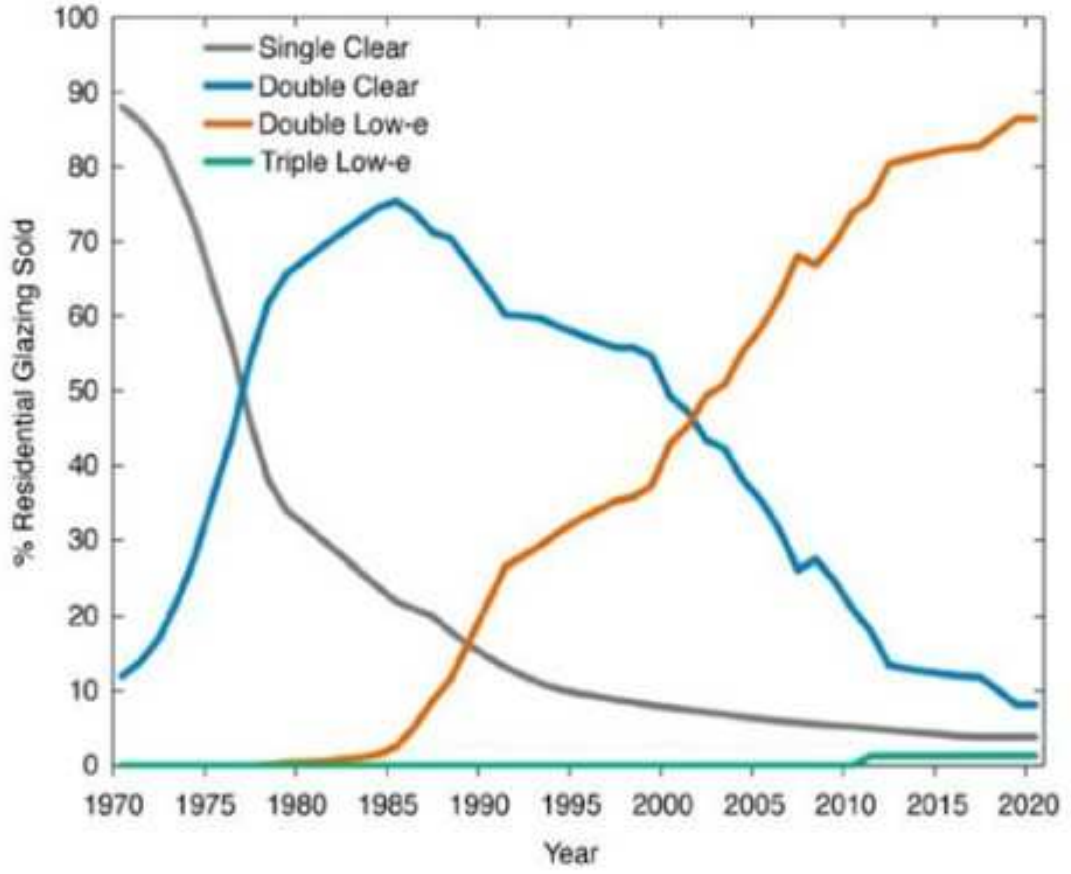
Key Glass Milestones in US Window Industry

Double Pane 50%+ Only in 1977

Low E Glass 50%+ Only in 2003



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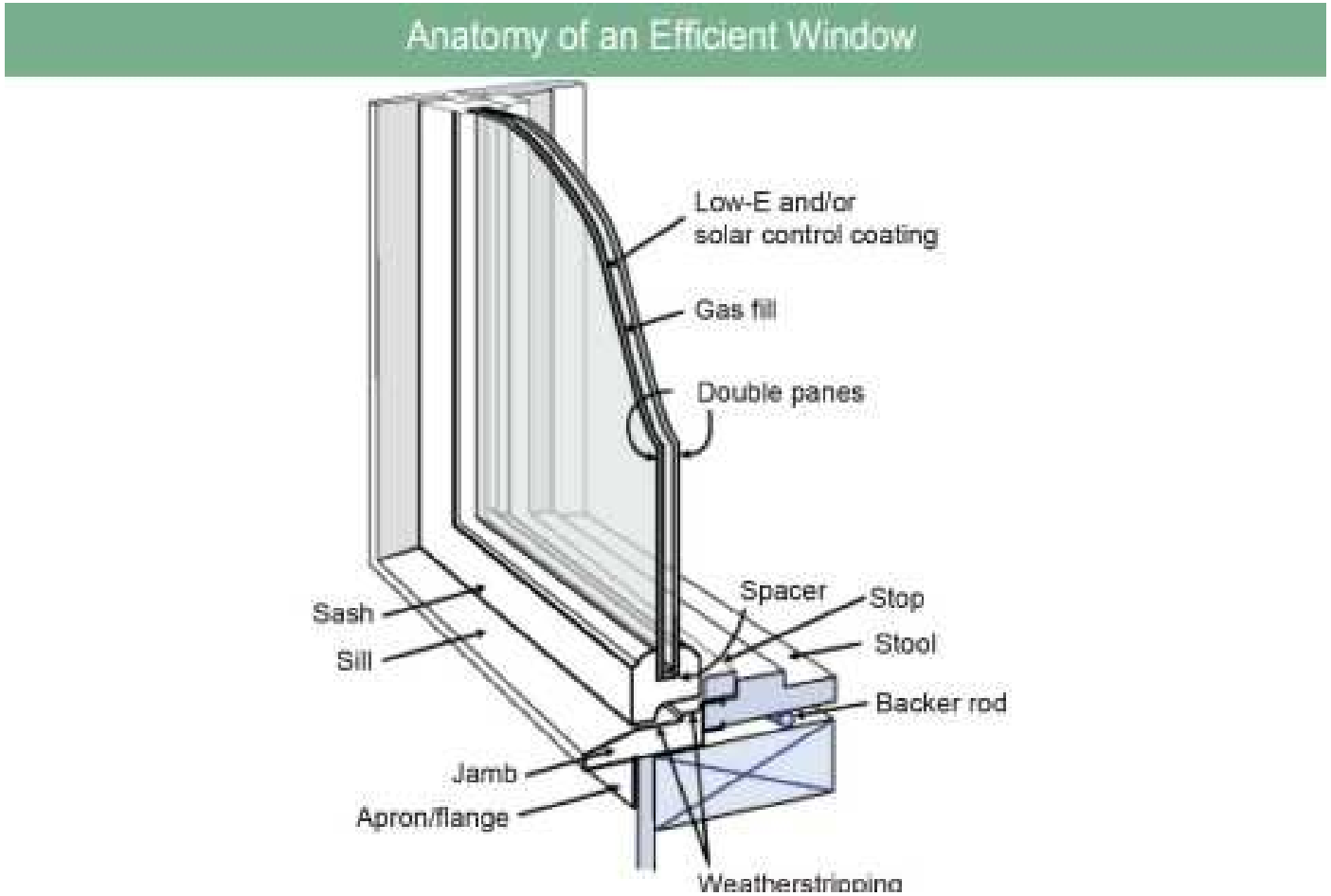
The Prototypical “Energy Efficient” Window Sold in the United States

1995



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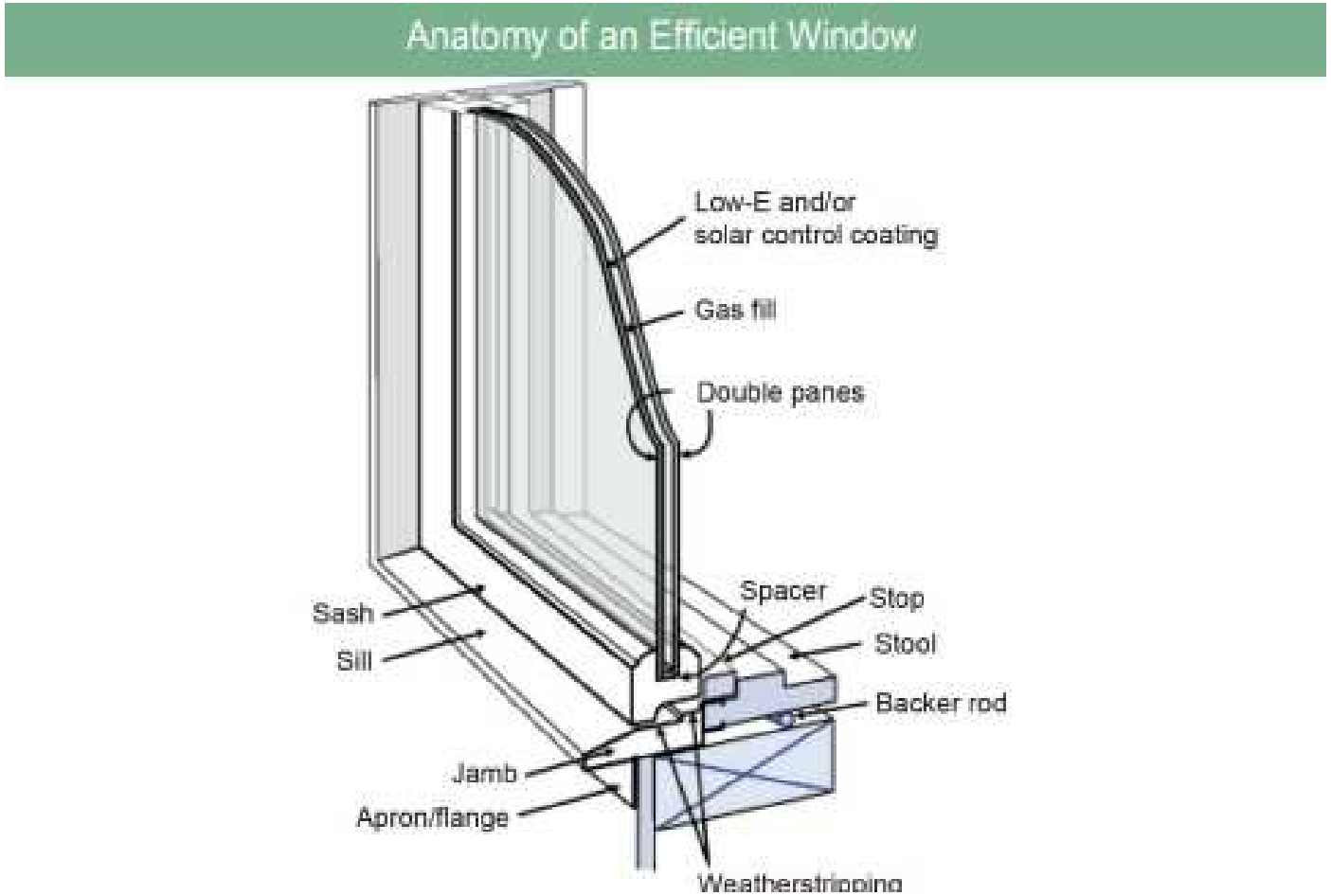
The Prototypical “Energy Efficient” Window Sold in the United States

2024



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History of Last 5 Years in the US Driving Today's Emerging Glass and Window Technology

. . . in 5 Minutes

SO WHY WOULD ANYTHING CHANGE AFTER 30 YEARS?

HINT: SOMETHING VERY UNUSUAL IS HAPPENING

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An Extraordinary Moment in Time for Windows in the US

Historic Intersection of Three Recent Critical Events:

1. Fundamental unprecedented market shifts in market requirements and demands (political will responding to climate crisis anxiety);

2. Largely unprecedented federal government spending to enable new high potential sustainable technologies ***to de-risk early stage private investment*** to allow scaling of high potential technologies (Inflation Reduction Act, Infrastructure Act);

3. The emergence of “new” (but proven) high potential commercializable glass technologies that enable the US window industry meet #1 above.

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UNPRECEDENTED SHIFT IN WINDOW ENERGY STAR CRITERIA REQUIREMENTS

Most Stringent U-Value ENERGY STAR Criteria for ***Windows (in Northern Zone)***

Version(s)	Effective Date	U-valu e	% Change	Enabling ***glass and coating*** technologies
1.0	3-1-98	.35	–	Low-e coatings, argon glass filling, improved spacers
2.0, 3.0, 4.0	1-1-00 to 7-1-02	.35	0%	Most significant changes made to other climate zones and SHGC requirements
5.0	1-4-10	.30	14%	Triple pass low-e; high solar gain low-e
6.0	1-1-15	**.27**	10%	Improved 4th surface low-e coatings
7.0	10-23-23	**.22**	19%	Triple-pane, alternative tech, krypton gas, spacers (some double pane but window dependent)

What's the Big Deal?

ENERGY STAR IS VOLUNTARY

WHO CARES?

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First A Quick Word on Low-e Coatings

From the inception of soft coat low-e coatings on glass emerging in the 1980s, the steady development of advanced low-e coatings has been the most important single enabling technology permitting ever increasing advancements in window performance.

Examples: Single pass, double pass, triple pass, 4th surface low-e

For the first time, however, there is consensus that low-e coating technology is approaching the limits of significant advancements.

New four pass low-e coatings aren't moving the needle and perhaps we are crossing the boundaries of getting "too dark."

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So what are the core challenges of the US window industry?

U.S. CONSUMERS WANT HUNGS AND SLIDER WINDOWS AND NARROW SITELINES

NARROW SITELINES AND SLIDING (Vertical/Horizontal) WINDOWS ARE DESIGNED FOR NARROWER, LIGHTER INSULATED GLASS PRODUCTS

The *challenge* then is to get higher performance cost effective glass solutions that fits into existing high quality U.S. window designs–**not change the U.S. window to look different and behave differently**

How does the industry do that?

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Emerging High Potential Glass and Window Technologies in the US Window Industry

. . . in 5 Minutes

SO WHY WOULD ANYTHING CHANGE AFTER 30 YEARS?

HINT: SOMETHING VERY UNUSUAL IS HAPPENING

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What is the difference between older “emerging” glass technologies that haven’t caught on and new ones?

It goes to the core of what problems or gaps glass technologies are addressing

. . . quite literally

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Introducing Today's New Emerging Glass Technologies

Lighter

Narrower

Higher Performance

They Fit in U.S. Frame Designs

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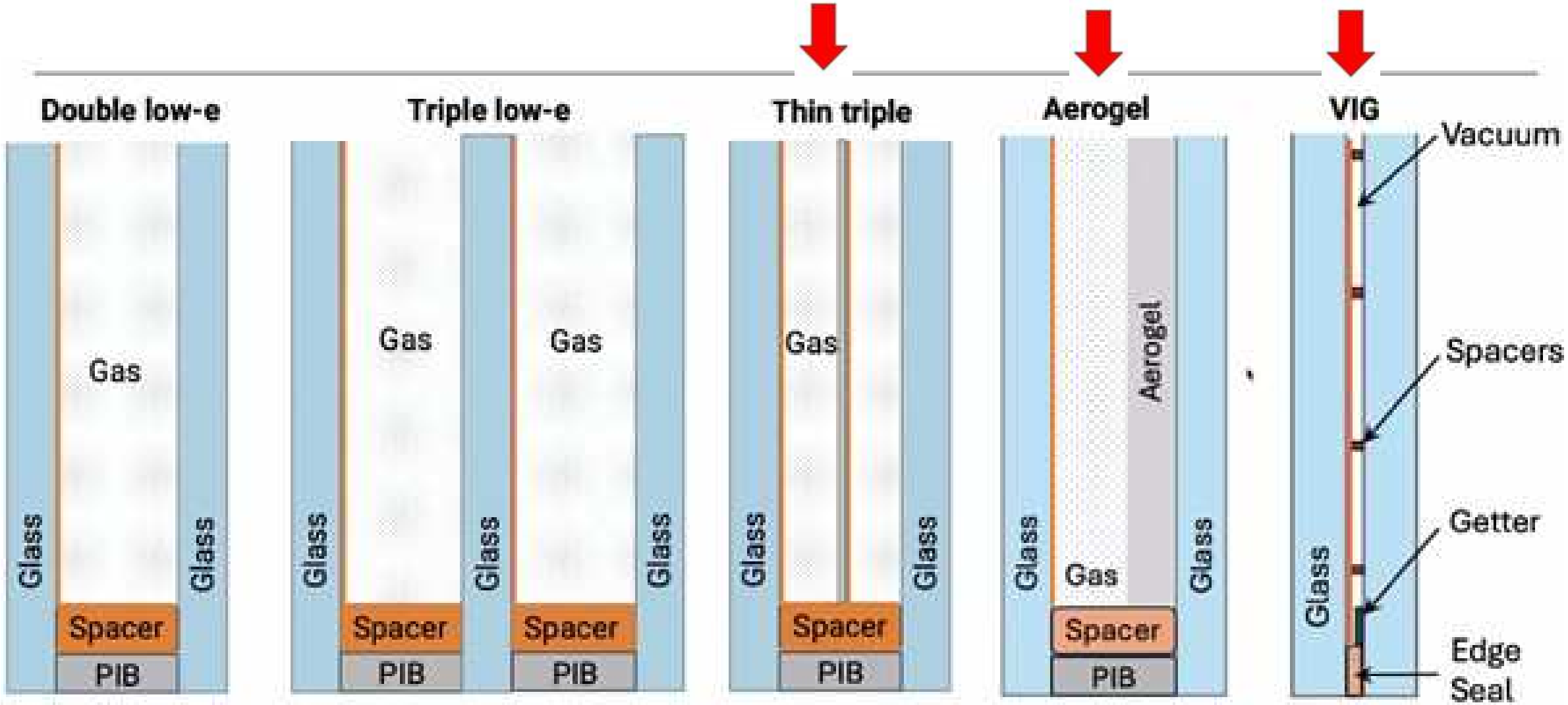
Images of Existing and Emerging High Performance Glass Technolog



Mature “Emerging” Glass Technology?

Vacuum insulated glass units

Original patent 1913

Available in US market since 1996

Thin glass triple-pane units

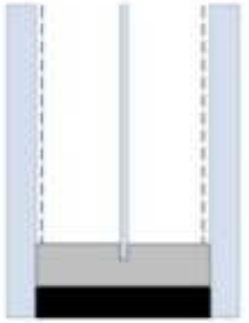
Original patent in 1991

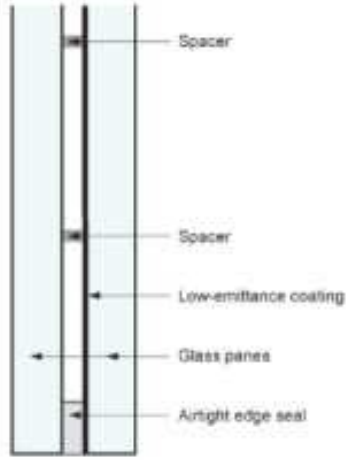
Available in US market since 2019

(Thin glass patented in 1964)

Transparent aerogel technology

Original patent in 1931





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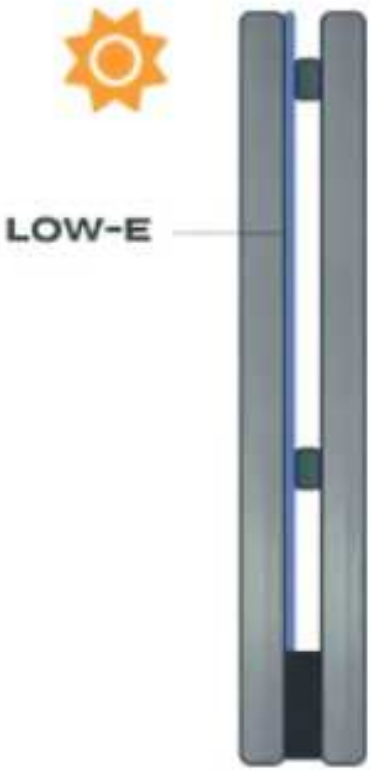
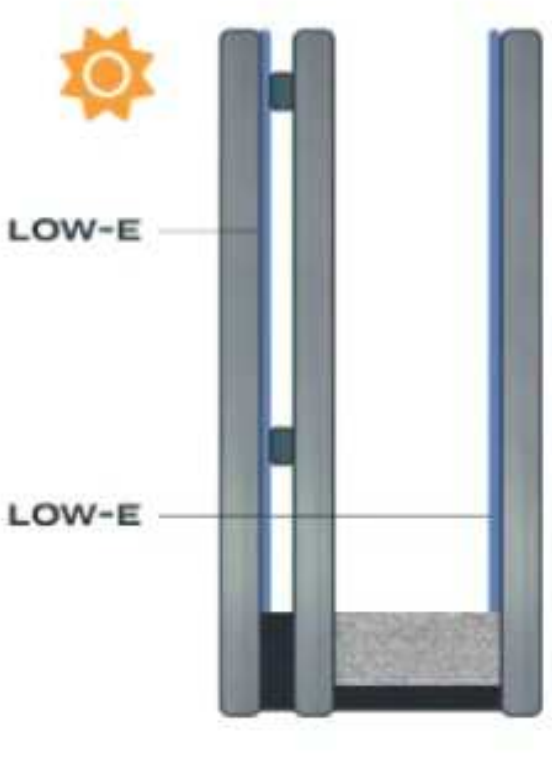
What is VIG? Vacuum Insulated Glass Technology



VIG IG Unit



Hybrid IG Unit

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VIG Commercialization - New US VIG Manufacturing

Alongside Governor Whitmer, LuxWall celebrates opening of new advanced glass production facility, part of $165-million investment in Michigan creating 450+ local jobs

ALMOST ALL OTHER VIG MANUFACTURING IS IN ASIA

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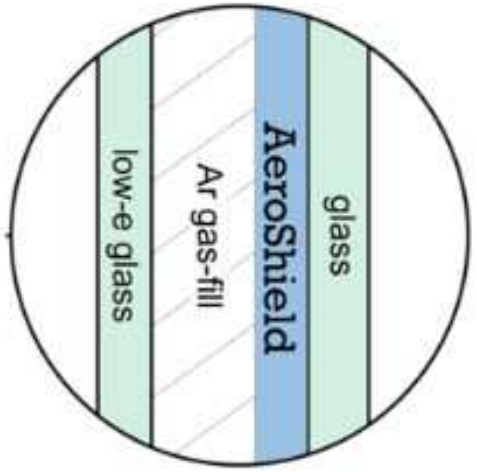
Aerogel Commercialization

$14.5 MILLION DOE GRANT FUELS DEVELOPMENT OF ADVANCED WINDOW AEROGELS



US Glass METAL & GLAZING
THE INFO SOURCE OF RECORD FOR ARCHITECTURAL GLASS LEADERS.

EXPECTED TO PRODUCE SIGNIFICANT COMMERCIAL QUANTITIES IN 2026

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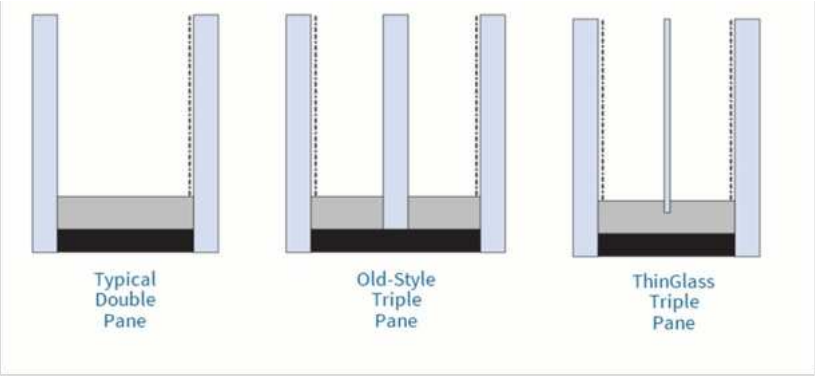
What is Thin Glass Technology?

THIN GLASS TRIPLE

THIN GLASS QUAD



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Thin Glass Commercialization

Two companies with IG manufacturing capabilities with at least 5 high speed thin glass automated lines will be installed and operational by end of 1Q25

Two Years Ago: No thin glass automated IG equipment was available

Today: At least five major equipment manufacturers have solutions

Two million square feet of thin glass installed in hundreds of project to date

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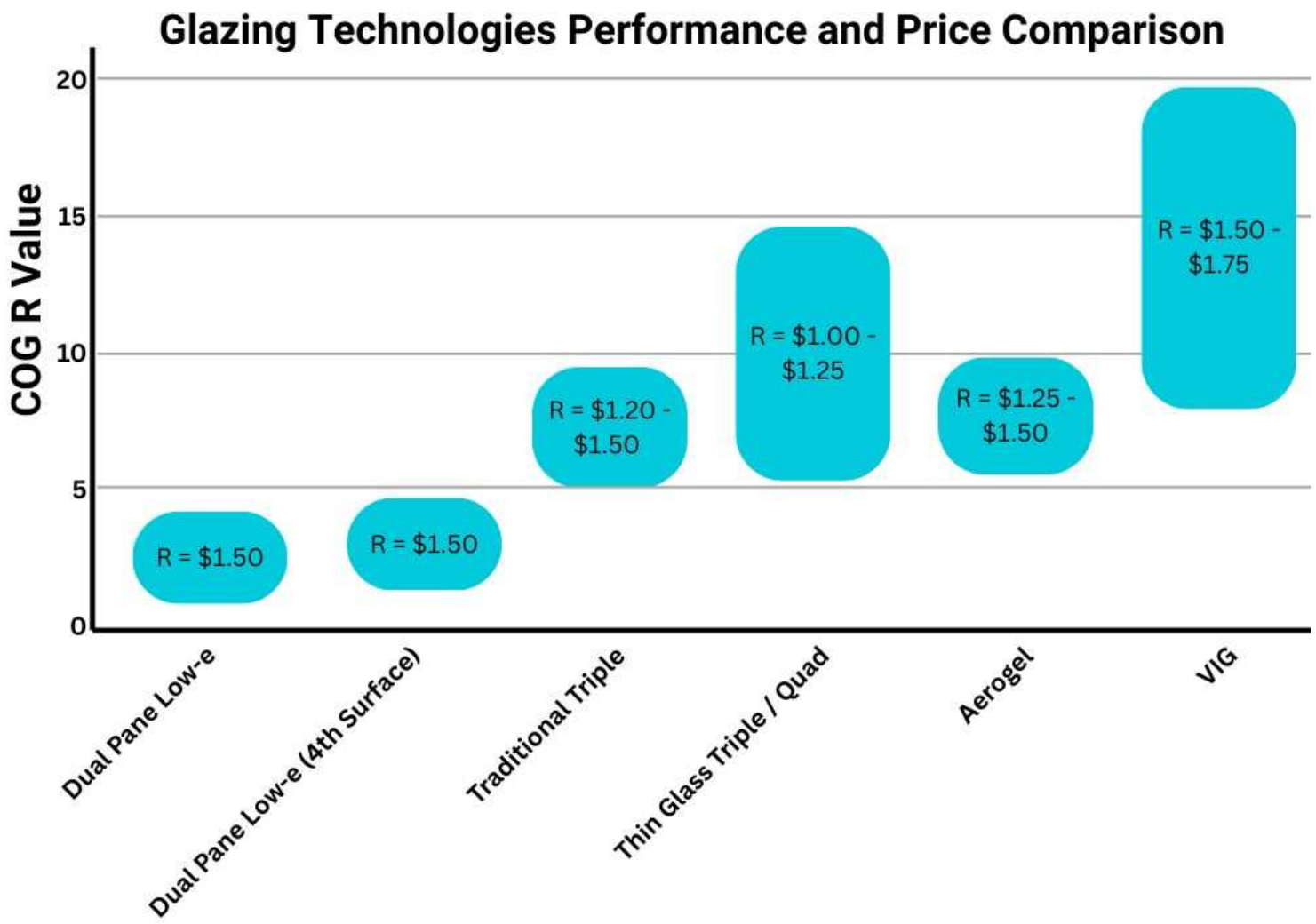
Relative Cost and Performance Ranges - COG



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A Recent Analytical Evaluation of Emerging Technologies Potential to Reach Mass Market Potential*

1. Technical potential to achieve R8 - R10 glazing unit
2. Cost target of < $3/sf manufacturing cost increment
3. Flexibility to address window industry needs- range of product sizes, shapes, etc.
4. Scale up – capital investment to scale to 1%, 10%, 50% market share
5. Technical risk to reach market ready state
6. Market risk to become an affordable, high-volume product
7. Time frame for scaling to get to 1% market share, 10%, 50%

Window Technology	R8-R10 potential	Cost	Market Flexibility	Scale-up potential	Tech Risk	Market Risk	Time	**Weighted Total**
Conventional triple	4	3	3	5	5	2	4	**26**
Thin, lightweight triple/quad	5	5	4	5	4	4	4	**31**
Vacuum glazing	5	3	2	3	3	2	2	**20**
Aerogel glazing	5	2	2	2	1	2	2	**16**

Table 4: Relative Assessment of the Potential of Each Technology to Scale to Mass Market, Affordable Glazing Options in 5-year time frame; (Scale of 1 to 5 for each; 5 is best/highest rank, 1 is lowest/poorest)

*Selkowitz, *State-of-the-Art Review of High-Performance Window Technologies*

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HPW
Case Studies, Incremental Cost, and Value Engineering

Northwest Energy Efficiency Association Builder Pilots

- 2021 to Current: NEEA engaged 7 builders in Pacific NW
- Builders received grants to cover incremental cost of HPW
- 0.22 U-factor maximum
- Goal is to learn about market for High-Performance Windows
  - Ordering/delivery
  - Installation time and cost
  - HPW pricing
  - Builder impression

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Habitat for Humanity, Bend Oregon

Comfortable homes without energy burden

- 12 units, affordable home builder
- Replaced Continuous Insulation with HPW in their scope of work with equivalent energy savings
- **HPWs $4,300 cheaper** per home than CI
- Energy modeling shows the HPWs to be more efficient than the R-5 foam CI
- Same delivery time
- Same install time
- No design considerations swapping double pane windows for HPW

27th Street Townhomes

"…Triple-panes are light, easy to work with, and carried by our normal suppliers" -Grace Weger, Bend/Redmond Habitat for Humanity

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Confederated Tribes of Grand Ronde, Grand Ronde, Oregon

Comfortable homes without energy burden

- 24 homes, tribal elder housing
- HPW part of low load home
- All homes achieved net zero
- third pane of glass added **wildfire resilience**
- ~Half as much sound from busy nearby highway
- Same delivery time
- Same install time
- No design considerations swapping double pane windows for HPW

Creekside Elder Housing

"…I would struggle to understand why builders wouldn't want to install triple pane windows." *–Ryan Webb, CTGR*

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Lennar, Ridgefield, Washington

Flexible Code Compliance

- 100 homes, high production builder
- Novel path to WSEC compliance
- Initial concern for added labor
- Same delivery time
- Same install time
- No design considerations swapping double pane windows for HPW
- **Since beginning Lennar HPW pilot, 3 other high-production builders in area now use triple-pane windows for WSEC compliance**

Ridgefield Heights

"There were no lags or supply issues with triple-pane windows"- Gabs Danese, Lennar

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Window Cost – not linear with energy performance

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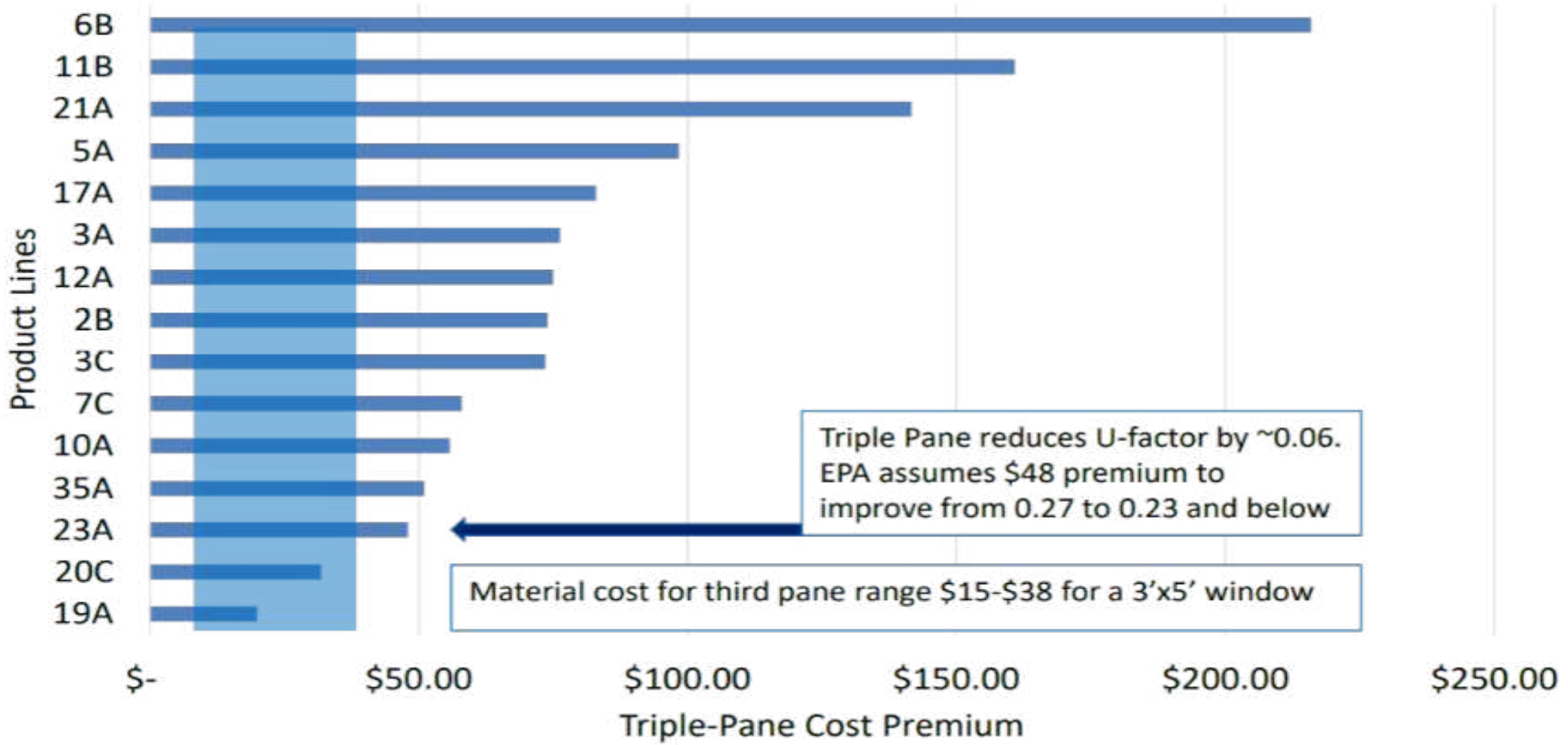
Triple Pane Upgrade Cost



EPA

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Consumers Love Windows

Windows are historically one of the first things customers consider upgrading when assessing their home's energy performance.

The annual survey, "What Homebuyers Really Want" backs this up: ENERGY STAR windows are near the top of home buyers wish list – one of only two efficiency measures to make the top 10.

Windows offer numerous benefits to homeowners and home occupants beyond a reduced energy bill.

Non-Energy Benefits

- Cuts outside noise in half
- Improved comfort for occupants
- Increased resale value

Energy Benefits

- Almost double the insulating power
- Peak demand reduction
- Tighter building envelope
- Lower energy usage

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Selling HPW in New Construction

Bonus or prescriptive rebate for ENERGY STAR windows

- Addressing backup heating peaks

PAWS Tools (in development) –

- Builder benefits
  - Enables smaller HVAC system (1-2 tons)
  - Code and above-code program compliance
- “Why Buy ENERGY STAR Windows” resource

Builder case studies

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Windows Value Engineering

Windows identified as a key way to meet advancing Above Code Programs

- ENERGY STAR Homes v3.2 (modeling by EPA, CEE, and others)
- Zero Energy Ready Homes
- Savings Over Code utility programs

e.g. ENERGY STAR Homes v3.2 ($2500 tax credit)

	% Improvement Over Baseline
Normal Envelope	**0.0%**
All windows to 0.22 U-factor	**6.8%**
All foundation insulation to R-15	**3.7%**
Entire Slab to R-10	**2.1%**
Attic to R-60	**1.7%**
R-5 Exterior insulation on all framed walls	**6.0%**
*Percentages are how much above or below 2021 IECC UA	

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Summary

Where to Learn More?

- PAWS booth at EEBA
- Window Manufacturer booths at EEBA
- Today's speakers can connect you with resources!
- Many resources are available at www.PAWS.energy

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Key Points

- High-performance windows have a proven track record as a key value engineering tool for many types of builders
  - Performance, volume, affordable housing, etc.
  - Incremental cost is typically $50-100 more per window
- High-performance window technology options have grown notably and are on an upward trajectory
- Homeowners value windows highly (including NEBs); they are a daily visible reminder of their home's high performance

Bottom line: High-performance homes require high-performance windows!

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Thank you!
Questions?

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